GUIDANCE MANUAL FOR Sewage Treatment Plant PROCESS AUDITS

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Guidance Manual for **Sewage Treatment Plant** Process Audits

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THE GREAT LAKES 2000 CLEANUP FUND

Environment Canada's Great Lakes 2000 Cleanup Fund supports the development and implementation of cleanup technologies to restore beneficial uses in Canada's 17 Areas of Concern. The Cleanup Fund has provided about $43 million in support of more than 230 projects in the areas of sediment cleanup, stormwater management, municipal wastewater treatment, and habitat rehabilitation. For more information or copies of project reports contact:

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ONTARIO MINISTRY OF ENVIRONMENT AND ENERGY

The Ministry of Environment and Energy supports the development, demonstration, and implementation of innovative and cost-effective technologies which maintain and enhance the natural environment. To date, the Great Lakes 2000 Cleanup Fund and the Municipal Assistance Program have provided $12 million and $350 million respectively in support of more than 350 projects dealing with water and wastewater facility expansion and upgrades, stormwater management, and wetland rehabilitation. For more information regarding the Water and Wastewater Optimization Initiative contact:

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WATER ENVIRONMENT ASSOCIATION OF ONTARIO

The Water Environment Association of Ontario (WEAO) is a non-profit professional organization, dedicated to the transfer of information and concepts regarding all areas of the water environment. The Association serves its membership by publishing bi-monthly newsletter, organizing a number of seminars each year, as well as an annual conference/equipment exhibition. The Association membership comprises scientists, operators, engineers, and academics dedicated to improving the water environment. Members come from consulting firms, industries, equipment manufacturers, municipalities, colleges and universities, and provincial and federal government agencies. WEAO is also an association member of the Water Environment Federation which is an international organization with a vision of "Clean Water Everywhere". For further information regarding WEAO contact:

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EXECUTIVE SUMMARY

This manual describes techniques to assess existing municipal wastewater treatment plants to identify their hydraulic and process bottlenecks, and to establish the plants' actual capacity. Hydraulic modelling, oxygen transfer tests, online data acquisition, digester tracer studies, and dye tests are some of the tools used for evaluation and optimization. These tools assist in the generation of accurate design information for plant expansions, and combine process operating and design information not readily available from traditional evaluation approaches. In conjunction with traditional plant operating information, the results are used to determine a plant's ability to treat future loads while forestalling plant expansion when possible. If the results indicate that a plant expansion is needed, the information gathered will be useful for design.

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CHAPTER 1
INTRODUCTION TO LIQUID TRAIN PROCESS AUDITS

This guidance manual is an information source document for agencies, municipalities, consultants, planners, organizations, and individuals responsible for the assessment, optimization, and upgrading of municipal sewage treatment plants. It focuses on technical methodologies that have been used to examine and assess full scale plants. In particular, conventional and modified activated sludge facilities have been addressed. This manual has evolved from a performance appraisal and energy conservation program initiated by Environment Canada (Speirs and Stephenson, 1985) to a program objective that is directed at identifying ways to maximize the usage of existing facilities while achieving the overall treatment objectives (Daigger, et al., 1992).

1.1 PROCESS AUDITS: GENERAL DESCRIPTION AND PURPOSES

The manual directs the user to specific plant testing methodologies that can be used to define plant capacity and plant optimization approaches. The process audit techniques are specific tools in an overall toolkit for plant optimization.

Wastewater Treatment Plants (WWTPs) represent significant capital investments for most municipalities and industries. Increasingly stringent discharge standards, and the demands for new facilities caused by growth within the areas served by the WWTPs, result in demands for further expansion of existing facilities. In many instances, the most cost-effective approach to facility upgrade and expansion is optimization of an existing facility. Even if treatment units must be added to upgrade and/or expand an existing facility, the magnitude of the upgrade/expansion can be minimized if the existing facility is first optimized.

Achieving enhanced treatment performance is an objective of plant optimization in certain situations. For example, the process audit approach has been used to assist in achieving enhanced treatment goals in existing activated sludge plants for: nitrification, phosphorus removal to less than 0.5 mg TP/L without effluent filtration, improved effluent suspended solids control, and aeration energy savings by dissolved oxygen monitoring and aeration control.

This manual is a companion document to the handbook "*The Ontario Composite Correction Program Manual for Optimization of Sewage Treatment Plants*", which is derived from the U.S. EPA publication *Handbook: Retrofitting POTW's.* The approach in these handbooks is described below.

1.1.1 The Ontario and U.S. EPA Composite Correction Programs

Considerable scope exists to optimize the performance of existing municipal sewage treatment plants (STPs) prior to expansion. One evaluation and optimization approach which has been demonstrated in Ontario is the Composite Correction Program (CCP). The CCP was developed by the U.S. Environmental Protection Agency (EPA) to identify and resolve factors which limit the performance of municipal STPs. The CCP uses a two-step program to identify the unique combination of factors contributing to non-compliance with effluent criteria and to implement onsite technical assistance and training to bring the plant back into compliance.

The first step is called Comprehensive Performance Evaluation (CPE). The CPE evaluates the operation, design, maintenance, and administration of the STP to determine how performance is affected. Activities conducted during a CPE include: assessment of plant performance data, evaluation of major unit processes, identification and prioritization of performance-limiting factors, assessment of the applicability of a follow-up technical assistance or process audit phase, and reporting the results of the evaluation. Based on a major unit process evaluation, the plant is categorized as Type 1 (adequate), Type 2 (marginal) or Type 3 (inadequate).

When a CPE determines that the major unit processes are adequate (Type 1) or marginal (Type 2) and the performance of the STP does not meet the effluent criteria, the second step of the CCP (called Comprehensive Technical Assistance or CTA) is initiated. During a CTA, prioritized factors are systematically addressed and resolved to enable the treatment plant to achieve the desired effluent quality. Maintenance, administrative and minor design related factors are resolved to derive a capable treatment plant. Assistance is provided to operations staff with process control skills to produce an optimum effluent quality from the capable plant. Staff are facilitated so that skills and performance are maintained after the conclusions of the assistance.

The background, rationale, approach and costs of conducting CCPs are documented in *The Ontario Composite Correction Program Manual for Optimization of Sewage Treatment Plants*. A second pertinent reference is the U.S. EPA publication *Handbook: Retrofitting POTWs*.

When the Comprehensive Performance Evaluation determines that the unit processes are inadequate (Type 3), a "process audit" of the liquid train is recommended to estimate the plant capacity and identify bottlenecks which should be resolved to improve performance. The process audit involves an extensive monitoring and analysis program involving the collection of off-line and on-line data to characterize the dynamic performance of the facility. Additional components of a "process audit" include:

- Historical review of plant data
- Flow meter calibration
- Dye tests to characterize internal flow splits and the hydraulic behaviour of secondary clarifiers under high flows
- Oxygen transfer tests
- Evaluation of impact of loads from sludge train recycle streams
- Other techniques including tracer evaluations of digester mixing, jar tests to select optimum chemical dosage and point of addition for phosphorus removal

1.1.2 What is a 'Wastewater Treatment Plant Audit'?

The wastewater treatment plant process audit is a plant performance assessment methodology that has been proven in full-scale applications over the last decade. Microcomputer technology and online monitoring instrumentation are applied to evaluate plant processes. Real-time data are collected to accurately characterize process operating conditions and energy use. Detailed plant design and historical operating data are assessed to supplement the online data collected. After the data are collected, interpretation is made to provide critical process information related to plant design and capacity limitations, plant optimization approaches and energy conservation measures. The potential for energy savings in the aeration system and the advantages of installing online instrumentation for process control can also be identified.

Numerous process audit technologies are used to analyze operating treatment plants. These technologies include the following:

- *Online Monitoring*: use of a computer and online instrumentation to record "real time" data. On-line monitoring is used to identify dynamic interactions between various treatment components. Examples include (1) diurnal variations of biological solids inventory in the aeration tank, (2) instantaneous effects of flow rate changes on clarifier effluent suspended solids, and (3) diurnal loading effects on biological system performance (both organic removal and nitrification).
- *Aeration Efficiency Analysis*: measurement of "dirty water" and "clean water" oxygen transfer efficiencies for aeration systems. Dirty water tests are done

using the off-gas technique for diffused air systems and the hydrogen peroxide technique for diffused air and mechanically-aerated systems. Clean water tests generally use sodium sulfite with re-aeration.

- *Stress Testing*: evaluation of unit process performance during high loading conditions. The actual capacity of processes is determined by inducing high loads (both hydraulic and organic) and measuring system performance.

Systems stress tested include primary clarifiers, aeration basins, secondary clarifiers, and effluent polishing filters.

- *Clarifier Flow Pattern Analysis*: dye tracer analysis to determine flow patterns and short circuiting within a clarifier.
- *Hydraulics Analysis*: evaluation of overall plant hydraulics by field measurements and hydraulic modelling.
- *Digester Residence Time Distribution and Mixing Evaluation*: tracer analysis of digesters. Mixing efficiencies, short circuiting patterns, and digester deadspace are typically identified using this test.
- *General Process Analysis*: review of overall plant processes. This includes a spreadsheet and graphical analysis of historical plant operational data, non-compliance assessment, and general plant operational monitoring and control approaches.

1.1.3 Why Audit?

Analysis of wastewater treatment plant capacity is often done using existing plant loadings and population growth estimates, standard design criteria, and experience gained from other facilities. Use of these criteria introduces uncertainty that must be accounted for by assuming conservative values and allowing a comfortable "factor of safety". Differing opinions may arise when applying these general criteria. To reduce this uncertainty, and to maximize the established plant capacity, the plant in question may be tested. By testing the actual facilities, the evaluator can begin to move from the realm of opinion into the realm of fact.

Plant audits can help to determine actual plant capacity as it relates to the physical plant facilities. In addition, various process control strategies can also be tested. However, operation and maintenance procedures and resources are not typically analyzed. Therefore, audit results should be considered in conjunction with other plant capacity factors when determining overall plant capacity.

There are well documented studies that indicate process failures in wastewater treatment plants. Studies conducted by the U.S. Environmental Protection Agency (EPA) indicate that one third to one half of these facilities do not meet the standards for which they were built. Hegg et al. (1979) found that around 50 to 90 percent of the plants investigated regularly violate treatment standards. Berthouex et al. (1985) selected 15 plants that were operating well within their permitted limits to characterize plant upsets. The most common causes of suspended solids (SS) and biochemical oxygen demand (BOD) excursions were low dissolved oxygen (DO) concentrations in the aeration tanks, low mixed liquor suspended solids (MLSS) concentrations, high influent wastewater flowrates, and solids handling problems. These factors support the use of the process audit approach.

Industrialization and urbanization in Ontario have focussed the public's attention on acceptable effluent quality. The activated sludge process is a cost intensive process that has been generally designed and constructed using traditional design guidelines based on steady state assumptions. This practice does not always permit optimum operation and expenditure minimization. Limited conventional process data are collected at the plant on a discrete basis (grab-samples). Such discrete information is often not sufficient to determine the dynamic operating characteristics and ultimate treatment capacities of these facilities. In some cases, the limited information reduces process control options, leading to plant upsets and excursions from the effluent limits.

Table 1.1 summarizes process audit application and benefits that can be obtained. Several evaluation and optimization techniques can be used to assess the actual condition, capacity and operating status of a wastewater treatment plant. These techniques are grouped under the title "Liquid Train Process Audit". In many cases, the application of recommendations resulting from the audit leads to significant energy savings and postpones or minimizes plant expansion requirements and costs through more effective process optimization and control.

Industrial and residential growth, along with increasingly stringent environmental regulations, often necessitate wastewater treatment plant expansion or upgrading. The rapidly escalating costs of such capital works make it imperative that municipalities make maximum use of the existing facilities. Expansion plans must take into account the full capability of the existing hardware. This capability, in some cases, may be significantly more than the hydraulic rating of the facility because of the design practices which have historically been used. Optimization of the facility can often reduce the extent and cost of expansion through low-cost design modifications, the use of online instrumentation and control techniques, and through elimination of hydraulic and process bottlenecks.

Table 1.1
Process Audit Applications and Benefits

Application of Process Audit Technologies	Benefits of the Process Audit Approach
1. Plant Capacity Evaluation a. As a stand-alone evaluation b. As part of a Master or Facilities Plan 2. Plant Certification (as a part of plant start-up services or of C of A) 3. Energy Audit a. Digester Gas Utilization Study b. Diffused Aeration Efficiency Study 4. Plant Operations Evaluation 5. Plant Management and Operations Audit (also can be implemented with CPE/CTA program) 6. Plant Upgrading Study (new requirements to be imposed) 7. Part of Plant Expansion Project (where it is necessary for the owner to defer some capital improvements or better define needs) 8. Part of an Instrumentation and Control Evaluation	1. Avoid Unnecessary Expansion a. Actual capacity is greater than textbook or design guideline analysis indicates b. Identify remedial improvements rather than full expansion c. Achieve higher quality effluent (e.g., lower effluent TSS, nitrification) through process improvements and optimization 2. Bring Plant into Compliance (Improve Process Performance) a. Eliminate hydraulic disturbances b. Optimize biological treatment performance 3. Reduce Operating Costs a. Reduce blower operating costs b. Reduce chemical dosing rates 4. Obtain Accurate Design Numbers a. Optimize size of expansion 5. Improve Instrumentation and Control a. Obtain improved I & C equipment used during the audit b. Improved information allows better operation or reduced labour costs

The wastewater treatment plant design and process audit can be a valuable tool to assist engineering and operations staff in defining the condition of the existing facility. In addition, the potential exists to realize significant operating cost savings by minimizing power use in energy-intensive aeration processes.

Recent efforts to identify factors limiting treatment plant performance in Ontario concluded that the situation was similar to that in the U.S. (XCG, 1992; Wheeler, 1994). In the Ontario studies, the key and most frequent factors identified were:

- Inadequate sludge wastage and disposal
- A general lack of understanding of the fundamentals of sewage treatment processes and the inadequate application of these concepts to process control
- Policies of the plant administration and lack of support provided to plant operational staff
- Excessive hydraulic loading
- Inadequate instrumentation and control
- Extraneous flow due to infiltration and inflow into the sewage collection system
- Inadequate process monitoring to support process control decisions
- Inadequate oxygen transfer capacity to meet oxygen demand
- Industrial discharge to the STP
- Inadequate O&M manuals

The studies have found that:

- There was a unique combination of design, operational and administrative factors which contributed to poor performance at any specific plant.
- Equipment maintenance was not identified as a factor affecting performance.
- In order to achieve long-term performance improvements, all of the factors which contribute to poor performance at a facility must be addressed.

Many of these factors are investigated in detail in a process audit and, when combined with the CCP investigative approach, are used to address these factors.

Many projects can involve plant analysis and optimization, either as a primary focus or as part of a larger project. Examples include:

- Plant capacity evaluation – either as an evaluation alone or as part of a Master or Facilities Plan
- Plant upgrading study – where new requirements have been imposed
- Part of a plant expansion project – where it is necessary to prioritize some capital improvements
- MOEE plant certification – as part of plant start-up services and compliance with Certificate of Approval (C of A) requirements

- Energy audit – e.g., digester gas utilization study, diffused aeration efficiency study
- Plant operations evaluation
- Plant management and operations audit
- Part of an instrumentation and control evaluation

1.1.4 What are the Benefits?

Process audits conducted to date have demonstrated the utility of the approach for troubleshooting operational and design problems, and for accurately defining the condition and capacity of a facility. In many instances, factors such as hydraulic disturbances, oxygen transfer limitations, biomass inventory imbalances, disinfection limitations, and sludge treatment and disposal problems, which have impaired process performance, were identified. Cost effective remediation approaches were developed to optimize plant operation. The costs of implementing energy-conservation measures and the potential return-on-investment were defined.

Many benefits can result from a plant analysis project. Some of these benefits are described below.

1.1.4.1 Avoid Unnecessary Expansion

Process analysis testing allows unit processes to be "stressed" to their actual limits and record their performance. In reality, some plants may have an actual capacity greater than that predicted by a desk-top analysis. If the actual capacity is higher through optimization, expansion might be avoided or reduced. In other cases, remedial measures are identified during the analysis that are significantly less expensive than full expansion.

A sufficient database must be developed to verify claims regarding actual plant capacity. In all cases, the plant C of A must be recognized as a controlling factor regarding plant capacity. The plant audit or optimization project can be used as an opportunity to work with MOEE to confirm or modify the C of A criteria. This may also involve working with receiving water limitations that must be addressed as part of the work. In the event that a hydraulic capacity increase is identified, regulations such as the approvals programs under the *Environmental Assessment Act* (Class EA) and the *Ontario Water Resources Act* must be recognized.

1.1.4.2 Meet Stricter Standards

Numerous analysis technologies, and in particular on-line monitoring, have been used to achieve higher quality effluent with existing facilities. For example, the City of Windsor faced a possible

derating of the Little River STP to achieve nitrification. But it was shown by a thorough process audit, including on-line monitoring, accurate and consistent biological solids retention time (SRT) control, oxygen transfer testing, and secondary clarifier baffling, that the plant could achieve year-round nitrification at hydraulic loadings higher than the original rating.

Plants with strictly defined effluent criteria must have sufficient redundancy and reliability of key process equipment to ensure that continuous treatment can be provided. However, optimization approaches discussed in this document can enhance the reliability of key components of a plant, e.g. secondary clarifier with baffles.

1.1.4.3 Bring Plant Into Compliance

By improving process performance, treatment plants that are out of conformance with their Certificate of Approval can be brought into conformance. Process performance can be improved in several ways:

- Hydraulic disturbances caused by pump station cycling, can be identified. These disturbances can go undetected by plant personnel, and can be shown through on-line monitoring to directly affect effluent quality. Changes in pump station control can correct the problem.
- The effluent quality of an activated sludge treatment plant was optimized using online monitoring. Dissolved oxygen, RAS and WAS concentrations, and wastewater and sludge flow rates have been monitored and related to effluent quality.
- The effect of sludge train recycle streams on plant performance can be identified. Alternative operational modes can reduce this impact.

1.1.4.4 Reduce Operating Costs

A large part of an activated sludge plant's operating costs are related to energy use in the aeration system. For example, DO and energy use are related to optimum blower or mechanical aerator operations. By pacing blower output or aerator submergence to DO concentration, significant savings have been achieved with a relatively short payback period.

Online monitoring can also be used to optimize chemical usage by monitoring dosing rates and locations, and process performance with online measurements and control.

A process audit tests unit processes using available technologies to "see what they can really do". Then the actual capacities are incorporated into the capacity analysis—if actual capabilities are

larger than those predicted by desk-top assumptions, the owner benefits. In addition, in-plant testing can identify operational improvements that result in improved performance and reduced operating costs. The process audit approach has been used successfully to optimize the existing treatment facilities, to postpone expensive plant expansions, and to revise the priority list of treatment process modifications (Daigger, et al., 1992). For example, a recent project identified remedial improvements that allowed a plant to avoid a multi-million dollar expansion (Newbigging, et al., 1994).

1.2 DURATION AND COST OF A PROCESS AUDIT

Process audit duration and cost are dependent on several variables, including:

- Individual tasks involved (project scope)
- Duration of field work
- Location
- Field staff involvement
- Equipment purchase/rental and supplies
- Sampling and analytical costs
- Miscellaneous items
- Project meetings (number)

All specific projects should be evaluated on a case-by-case basis in advance to determine the project objectives and the level of effort required. The variables identified have a significant bearing on cost. For thirteen plants that have been audited using multiple test technologies identified in this manual, Table 1.2 and Figure 1-1 show the overall weekly cost with plant design flow capacity. These projects varied in duration from six weeks to one year, each with specific tasks. There is significant variability between the projects. The cost trend tends to increase with plant size; however, other combined factors affect cost as much as flow. The costs shown should not be used to estimate budgets for specific projects. These data are shown only to give an idea of the range and variability of costs of historical projects. In most cases, the cost of performing a wastewater treatment plant process audit has been shown to benefit the municipality in terms of total future plant capital and/or operating cost.

1.3 PURPOSE OF THE PROCESS AUDIT MANUAL

The purpose of this manual is to provide WWTP evaluators with a source book to guide them in the application of specific testing approaches for evaluating and optimizing plants.

Table 1.2
Components and Cost of Historical Process Audit and Plant Optimization/Evaluation Projects

Plant	Design Flow (MLD)	Cost ($'000/week)	Historical Data Review	Online Monitoring	O_2 Transfer Testing	Energy Savings Analysis	Flow Metering Assessment	Flow Split Analysis and Hydraulic Modelling	Stress Testing	Clarifier Dye Test	Clarifier Baffle	Digester Tracer Study	Digester Capacity Analysis	Sludge Recycle Streams	Dynamic Modelling	Plant Rating Assessment		Application of Step Feed	SRT Control	Operator Training
																Hydraulic	Nutrient			
1	9	6.5	*	*	HP	*	*	*	A, F					*		*	*		*	*
2	15	6	*	*	HP	*	*		F	*		*			*	*				
3	22.5	10	*	*	HP	*	*									*	*		*	
4	24.5	4	*	*	HP	*	*		F			*	*		*	*	*		*	*
5	36	9		*	HP					*										
6	36.3	3	*	*	P, S, O	*	*		A, F							*	*	*	*	*
7	54.5	6.6	*	*	HP	*	*							*		*	*			
8	75	6	*	*					F							*	*			
9	93	5	*	*	HP	*	*	*		*		*	*		*	*	*			
10	123	12	*	*	HP	*	*	*				*				*	*	*	*	*
11	182	9	*	*	HP					*	*	*	*							
12	281	12	*	*	HP	*										*	*			
13	818	16	*	*	OG	*	*			*				*	*	*	*	*	*	

Notes: **O_2 Transfer Testing**
S - Clean water test using sodium sulfite
HP - Dirty water test using hydrogen peroxide
OG - Off gas approach

Stress Testing
A- Aeration Tank
F - Final clarifier
FF - Final filters
P - Primary clarifier

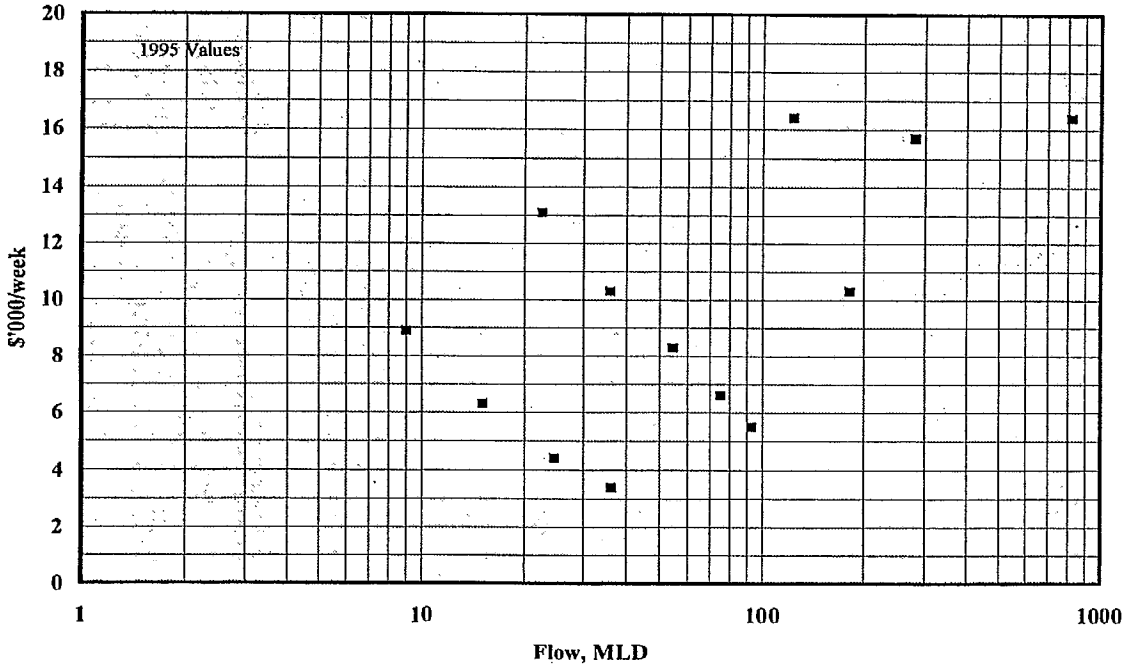


Figure 1-1
Process Audit Costs at Selected
Municipal Wastewater Treatment Plants

The manual describes an extensive monitoring and analysis approach which involves the collection of off-line and on-line data to characterize the dynamic performance of key components of a facility. An understanding of wastewater treatment theory and practice is required for use of the manual and the tools described.

1.4 USING THE MANUAL

The manual is intended for the use of consumers and process audit providers who have an understanding of wastewater treatment and process design. It is an information source document for agencies, municipalities, consultants, planners, and providers of wastewater treatment process audits.

The main use of the manual is to assist with the application of tests for identification of plant bottlenecks and limitations and to define the capacity of an existing facility, while ensuring its ability to continue to meet required effluent non-compliance criteria and design objectives.

Each chapter in this manual indicates an approximate duration and level of effort for each test; however, every project will have a site-specific requirement in this regard and costs shown should *not* be used for direct project cost estimation without examining the specific effort required. Review of the manual will assist with identification of budget for specific projects.

Audit technologies are constantly being developed and improved, and new technologies should be reviewed as they become available. The technologies presented in this manual represent the major tests that are available and frequently used at the time of preparation of this version of the manual. It does not cover all methodologies, e.g. odour control testing, and other specific tests required should be developed based on available literature.

Each chapter of the manual can be used independently or with related chapters. References should be reviewed to clarify or back up each chapter and to obtain more detailed information about each test.

The project kick-off meeting and the plant inspection provide opportunities to obtain information from plant operators and supervisors and to assess the condition of plant facilities and equipment. This preliminary analysis can be qualitative, based on firsthand observations and discussions with plant personnel, and quantitative, such as analysis of plant maintenance and operational records.

Historical data analyses serve a variety of purposes. Data on influent wastewater flows and pollutant concentrations are analyzed to characterize average and peak wastewater flows and constituent loadings; the latter is typically expressed as a daily mass flow. Variability is expressed in several ways. Typical approaches involve probability distributions and/or the description of loadings occurring at various frequencies, i.e. peak month, peak week, and peak day. Field observation of the condition of process units provides qualitative information on plant performance which is useful in interpreting field observations.

Capacity calculations are based on predetermined criteria for the performance of unit processes. These criteria are site-specific and should be determined by the process audit provider.

An operations review involves analysis of: staffing levels, including both numbers and skills, maintenance procedures, operating strategies, and day-to-day operational procedures. A checklist, such as the CPE checklist (U.S. EPA, 1989; WTC et al., 1995), is helpful in gathering information for plant assessments and operations reviews.

The key is to use available information to select test conditions that result in efficient and effective testing. The following criteria should be used to develop a testing program:

- Plant processes should be prioritized for testing based on the results of the initial analysis.
- Each process tested should be loaded to capacity. This may be above or below the original unit process design criteria. These loadings must be sustained long enough to replicate the condition of concern (e.g., peak hour, peak day, maximum month, etc.).
- For unit processes consisting of identical parallel components, it is usually sufficient to test a single component.
- The auditor should consider the effect of the tests on treatment plant constraints. The plant must normally continue to meet its discharge requirements. A plant can often sustain short periods of deteriorated effluent quality and still meet its discharge requirement. A C of A addendum may be required prior to initiating these tests.

1.5 REFERENCES

Berthouex, P.M. and Fan, R. "Evaluation of Treatment Plant Performance: Causes, Frequency, and Duration of Upsets". *IWPCF*. Vol. 58, No. 5. Pp. 368-375. May 1986.

Daigger, G.T.; Buttz, J.A.; and Stephenson, J.P. "Analysis of Techniques for Evaluating and Optimizing Existing Full-Scale Wastewater Treatment Plants". *Wat. Sci. Tech.* Vol. 25, No. 4-5. Pp. 103-118. 1992.

Hegg, B.A.; Rakness, K.L.; and Schultz, J.R. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance. EPA-600/2-79-034, NTIS No. PB-300331. U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory. Cincinnati, OH. 1979.

Newbigging, M.L.; Stephenson, J.P.; Romano, L.S.; Dryman, R.; and Booth, A. Process Evaluation Exceeds Expectations at Windsor's Little River PCP. Presented at the 23rd Annual Technical Symposium and Exhibition of the Water Environment Association of Ontario. Toronto. 1994.

Speirs, G.W. and Stephenson, J.P., "Operational Audit Assists Plant Selection for Demonstration of Energy Savings and Improved Control". Instrumentation and Control for Water and Wastewater Treatment and Transport Systems. Editor R.A.R. Drake. *Proceedings of the 4th IAWPRC Workshop.* Houston, TX and Denver, CO. April 27 to May 4, 1985.

U.S. EPA. Handbook: Retrofitting POTWs. EPA/625/6-89/020. July 1989.

Wastewater Technology Centre and Process Application Inc. The Ontario Composite Correction Program Manual for Optimization of Sewage Treatment Plants (draft). Ontario Ministry of Environment and Energy, Environment Canada and the Municipal Engineers Association. January, 1995.

Wheeler, G. Assessment of the Comprehensive Performance Evaluation Technique for Ontario Sewage Treatment Plants. Prepared for Ontario Ministry of Environment and Energy. January 1994.

XCG Consultants Ltd. Assessment of Factors Affecting the Performance of Ontario Sewage Treatment Facilities. Report for the Ontario Ministry of Environment and Energy, Environment Canada, and the Municipal Engineers Association. March 1992.

CHAPTER 2
PROCESS AUDIT OVERVIEW

This chapter examines the approach to conducting a process audit. It includes guidance for project setup, general staffing, general equipment needs, and overall budgeting.

2.1 DETERMINATION OF PROCESS AUDIT OBJECTIVES

The objectives must be clearly established by the proponents of the work to set a realistic project budget and schedule to ensure that the required work can be completed effectively. If a formal objective and workplan cannot be developed by the proponent alone, then advice should be obtained from the regulatory authority (MOEE) or other funding agency to ensure that test conditions and conclusions will be acceptable to the parties involved.

The reasons for implementing a plant audit are summarized in Chapter 1 and in companion documentation (U.S. EPA, 1989; WTC, 1995). In particular, process audits that are used for planning and regulatory purposes must be budgeted with the overall facility planning concept in mind. Appropriate budgets will allow for the level of effort that is appropriate for adequate testing, interpretation and upgrading analysis. Each project task should be adequately budgeted with this in mind.

2.2 METHODOLOGY

Specific plant testing technologies described in Chapter 1 are available to form the basis for a process audit. An understanding of wastewater treatment theory and applications is required for use of the manual and the tools described.

Figure 2-1 depicts a general task flow sheet for a project making use of each of the audit technologies. Specific projects must be tailored to the needs and will require different grouping of tests, fewer tests or different technologies depending on the scope and budget of the investigation. The scope of the investigation should be clearly identified prior to project bidding, quotation or initiation based on the owner's or regulator's needs. This will help to ensure that the project budget and level of effort matches the scope of work and that surprises are avoided.

Many project tasks will be phased to allow for examination of plants on a step-by-step basis. For example, it is common to complete a review of plant design and historical performance and operational data early in a project to obtain a good understanding of plant operating conditions. This may be completed as part of the process audit or as part of a previous project such as a CPE or CTA.

Proper scheduling is required to phase the process tests, and to meet the needs of the operations and laboratory staff in the plant. An overall approach with all the parties concerned, including the plant operating staff should be agreed upon during project initiation.

2.3 LABOUR AND EQUIPMENT REQUIREMENTS

The project scope determines the level of effort and equipment required. Subsequent chapters in this manual indicate the expected duration and effort for each test; however, projects will have a site-specific requirement in this regard and the costs should not be used for direct project cost estimation without examining the specific effort required. Audit technologies are constantly being developed and improved, and new technologies should be reviewed as they become available. The technologies presented represent the major tests that are available and frequently used at the time of preparation of this version of the manual. It does not cover all methodologies available to the industry, e.g. odour control testing, and other specific tests required should be developed based on available literature and information sources.

In general, the project team will include the plant owner and the process audit provider. Often the MOEE and other regulatory agencies or funding partners are involved on an overall project steering committee. The actual tests require the support of plant operators, technologists and engineers to complete the field work, assess the results, and document the findings. The use of temporary online field instrumentation requires continuing technical support to maintain its calibration and accuracy. This is important when auditing to determine actual capacity, especially with stress testing. A trained and experienced field technologist is required on a full-time basis for audit activities which may extend from a few days for a single short-term test to several months for a complete plant audit involving online instrumentation, and stress testing in different seasons. The duration of the test work has a significant bearing on the level of effort expended and the cost.

Installation of field equipment may require additional staff to assist the field technologist and in-kind assistance from plant staff, including operators and maintenance staff. Often the plant can supply an electrician for the installation of instrumentation power supplies and hook-ups to existing plant instrumentation. Additional plant support may be required during testing, such as:

- General staff assistance during test for installation and startup
- Plant process adjustments during a test
- Laboratory analytical and daily sampling

With online instrumentation, trained staff who are familiar with the instrumentation are essential to ensure that adequate results are obtained. In many cases, plant staff will not have the resources themselves to provide this service on a sustained basis, and external assistance is needed.

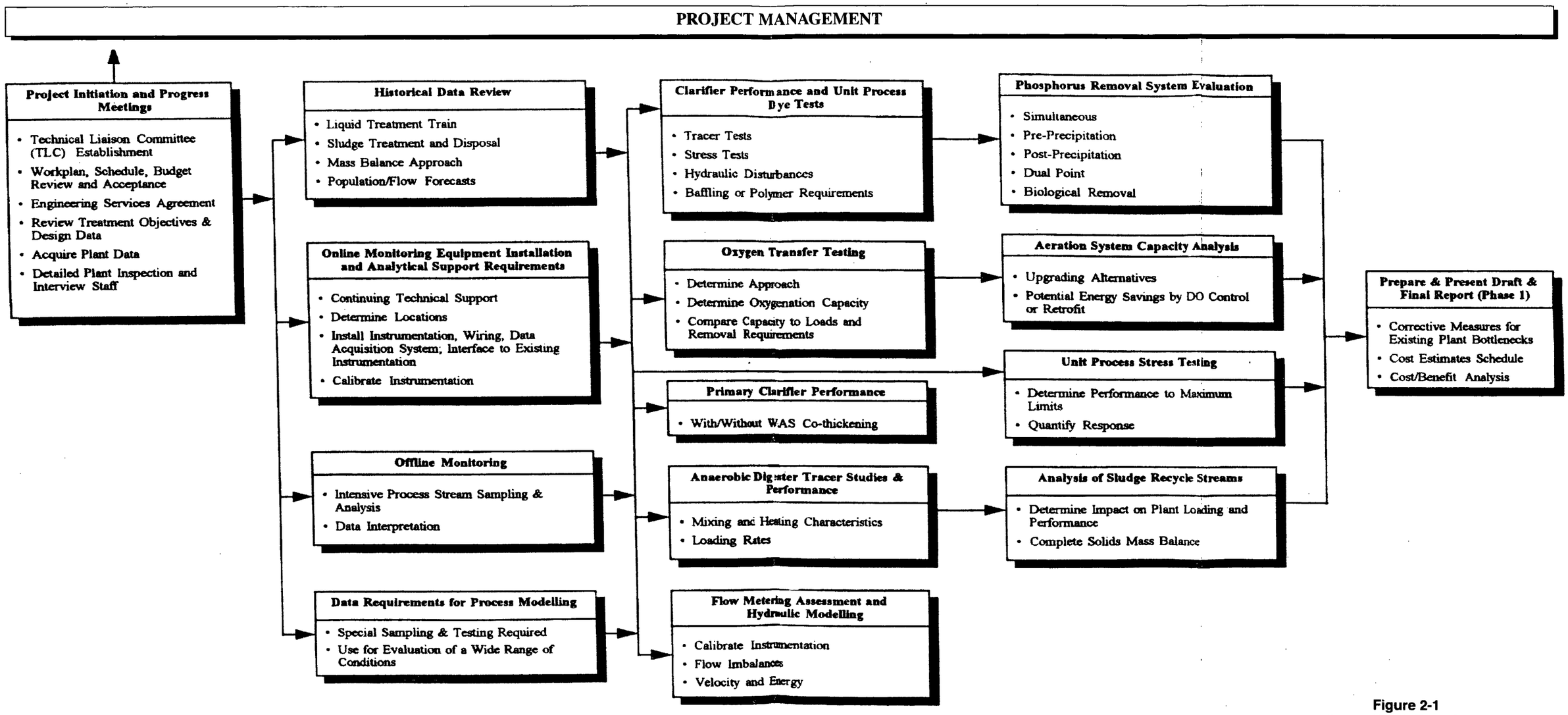


Figure 2-1
General Task Flow Sheet

2.4 PROJECT APPROACH AND SETUP

Before field testing, it is best to conduct a thorough initial analysis of the plant, for several reasons:

- Historical performance and operational data inform the assessment team about the plant capability under the existing conditions.
- Historical plant performance can help establish target loading conditions for the tests.
- Problem processes can be identified, thus allowing the auditor to target the field testing.

Other factors and approaches are identified in the Ontario CCP Manual for Optimization of Sewage Treatment Plants.

Information should be gathered from all persons familiar with the treatment plant, including plant superintendents, plant operators and maintenance staff, design engineers, process experts, and MOEE. With their unique viewpoints and decision-making roles, each of these people has valuable input to the capacity evaluation.

The scope of the initial analysis varies, depending on the processes to be tested. For a small project, such as stress testing of a single clarifier, the analysis may simply entail a visit to the plant to view the process and discuss process performance with plant operators, followed by a review of recent operating data and engineering drawings, and finally establishment of test criteria.

For a large project (e.g., capacity analysis and optimization of an entire plant), a comprehensive analysis is needed, which might consist of the following steps:

- Project kick-off meeting to establish project approach
- Plant inspection to discuss process performance with plant operators
- Review of historical data (preferably two to three years of data)
- Field observation of process units
- Preparation of a solids balance
- Hydraulic analysis
- Capacity calculations
- Project review meetings to establish a consensus on project results

Following the selection of appropriate plant tests, a schedule and level of effort (budget) must be developed for the installation of specific testing equipment. In general, a complete online instrument-based plant audit will require one to three weeks for instrument installation and initial calibration

setup. In large plants, a longer setup time may be required. Testing duration should be sustained long enough to take advantage of the setup effort, and to allow for the evaluation time period required. This may range from several hours for a peak hourly flow stress (e.g. secondary clarifier) to several seasons that include dry and wet weather conditions or seasonal industrial loads.

The installation setup requirements for each test method are summarized in the chapters that follow in this manual.

2.5 INITIAL PLANT INSPECTION AND PROJECT KICK-OFF

The proponent and process audit provider need to plan a kick-off meeting and site inspection at the project outset. Many aspects of the site inspection and kick-off meeting are summarized in the Ontario CCP Manual, and should be reviewed for use in a process audit. Several additional elements are required for a process audit.

The proponent, process audit provider, and plant staff will meet to discuss the scope of work for the process audit. Based on those discussions, the detailed project approach will be finalized. The following items will be discussed:

- Involvement of plant staff and administration
- Location of online field instruments
- Wiring of connections to existing plant signals, especially flowrate
- Location for data acquisition hardware
- Test schedule
- Requirements of plant laboratory

Several key example instruments that should be discussed, include:

- Plant flows (existing plant signal)
- Return activated sludge (RAS) flow (existing)
- Waste activated sludge (WAS) flow (existing)
- Aeration basin air flow (existing), for diffused air
- Power draw for surface aeration
- Aeration basin dissolved oxygen (DO) concentrations
- Mixed liquor suspended solids (MLSS) concentration
- RAS SS concentration
- Secondary effluent SS concentration
- Secondary clarifier sludge blanket level

- Other specialized instruments, if required, including automatic sampler locations and specifications

For a medium-sized activated sludge plant, e.g. 25 MLD, expect a full day to inspect the plant layout with a senior plant operator or superintendent. Plant instrument specifications should be obtained.

2.6 BRIEF DESCRIPTIONS OF PROCESS AUDIT TECHNOLOGIES

The following descriptions introduce the specific technologies discussed in this manual.

2.6.1 Historical Data Review (Chapter 3)

Historical data review provides the opportunity to introduce key project personnel and to become familiar with the operation and performance of the wastewater treatment facility. The general objectives of the historical data review are:

- To determine historical unit process loadings and operating conditions, and performance
- To identify factors which may limit plant performance
- To provide the background required for the refinement and successful completion of other process audit tasks
- To consolidate graphical (e.g. time trends) and tabular data

Generally, the proponent must provide the data for this task in a suitable format.

2.6.2 Flow Metering Assessment (Chapter 4)

Accurate flow measurement is essential for the efficient operation of a wastewater treatment facility. Accurate flow measurement is required by the following:

- Regulatory agencies to evaluate loadings to the receiving waters
- Municipal authorities to determine the capacity status and project future expansion requirements
- Operation staff to control and optimize the treatment processes
- Plant administration for billing purposes

Accurate flow measurement is essential for the control and management of a WWTP. Lack of readily available plant flow metering maintenance and calibration indicates that a flow metering assessment is critical to the success of a process audit and its acceptance. WWTPs often have both open

channel and closed-pipe flow metering equipment. The dynamics of flow and its relevance to sampling and control make it paramount to investigate its accuracy and performance. Overestimating actual flows can lead to premature or unnecessary expansion of a WWTP.

2.6.3 Online Monitoring (Chapter 5)

Conventional manual or automatic data collection at a wastewater treatment plant involves a combination of grab, time or flow-proportioned composite samples. Grab samples represent an instant in time, while composite samples represent an average over a period of time. Unfortunately, these methods often fail to identify dynamic (or "real-time") responses occurring in wastewater treatment facilities.

Online monitoring is a system consisting of field instrumentation interfaced to a computer to collect and record real-time data. Online monitoring is a key component of a process audit, and provides the information on the dynamic behaviour of the treatment processes under typical operating conditions or in association with other process audit tasks. Processes with relatively slow rates of change, such as anaerobic digestion systems, do not typically require online monitoring.

Following are some of the objectives of online monitoring in the context of a process audit:

- To reveal real-time responses by providing an instantaneous display of data
- To determine cause and effect relationships within the treatment plant
- To provide a system for data storage and statistical data analysis
- To support data collection requirements for other process audit technologies or process modelling

Data are typically collected over a period of several weeks to several months to allow process relationships to be quantified for a variety of loading and operating conditions. Online monitoring has been used to detect several hitherto difficult to observe WWTP effects such as: toxic shock impact on aeration basin DO; pump station and/or plant influent screen impacts on hydraulic disturbances; clarifier underflow concentration dynamics due to clarifier mechanism characteristics; and determination of plant flow metering inaccuracies.

2.6.4 Offline Monitoring (Chapter 6)

Representative samples are necessary to measure the performance of a wastewater treatment plant. Manually collected grab samples are adequate for routine monitoring tests, such as MLSS, settleability, and oxygen uptake rate. However, manual grab samples can be misleading when used to measure wastewater streams at various points in the treatment plant where conditions can change

rapidly. In such cases, samples which indicate the average condition of the plant over a specific time period are more meaningful. Because automatic sampling equipment collects small samples at frequent intervals into a container, this equipment is ideal for the collection of daily samples.

The objectives of enhanced offline monitoring as part of a process audit are to:

- Supplement plant historical data in terms of duration, frequency or location of samples
- Obtain specific analyses not conducted historically at the plant
- Provide data to calibrate online instrumentation

The offline sampling program, used in conjunction with online monitoring, can provide a more complete picture of a plant's performance and unit process operations.

Plant historical data often does not fully characterize a wastewater treatment plant, e.g. biological process influent data (i.e. primary effluent) may not be routinely sampled. Diurnal sampling, such as 4-h composites, is not usually part of a plant's normal sampling practice. An offline sampling program can also be used to provide information concerning diurnal variations in a particular parameter.

Plant historical data may not include analyses for parameters that may need to be removed by the plant in the future, for example total ammonia-N. To obtain accurate information from online instrumentation, offline samples will need to be obtained and analyzed.

2.6.5 Aeration System Capacity Analyses (Chapter 7)

Oxygen transfer rate is a key factor in estimating maximum plant capacity for removal of organic matter and for nitrification. Experience has shown that oxygen transfer rate and efficiency is site-specific and can vary significantly from location to location. With mandates such as toxicity reduction pointing toward the need for ammonia reductions in WWTP effluents, and for improved energy efficiency, more precise information is usually required to define plant aeration capacity. Therefore, this technology often forms a critical component of a plant performance audit. The results are used to estimate:

- Plant capacity for BOD_5 removal and nitrification
- Potential for energy savings by aerator retrofits and by DO control

Frequently, plant capacity can be extended without major capital construction, i.e. aeration tankage, after examining the possibility to upgrade existing aeration systems. Furthermore, the potential to modify the aeration influent loading, for example, by enhanced primary treatment can provide for upward plant re-rating. The assessment of denitrification potential using anoxic

zones to reduce oxygen transfer requirements in nitrifying situations is often a consideration, along with the potential for biological phosphorus removal. This can also minimize settleability problems and unintentional denitrification in secondary clarifiers. These considerations require specific investigations which are outside the scope of this manual; however, investigation of plant aeration capacity is essential in all cases.

2.6.6 Hydraulic Modelling (Chapter 8)

The hydraulic capacity, that is the ability to handle the flow adequately, and flow distribution characteristics are key factors in determining the capacity and operational flexibility of a wastewater treatment plant. This capacity can be constrained by pump capacities, pipes, channels, weirs, flumes, and by the elevation of plant structures. The assessment of plant hydraulics requires a complex analysis.

Hydraulic characteristics are modelled using a variety of mathematical techniques. The purpose of this chapter is to present a general approach that can be used to prepare a hydraulic model of an existing wastewater treatment plant.

Hydraulic modelling is used to:

- Determine the hydraulic capacity of an existing facility
- Identify hydraulic bottlenecks and capacity limiting factors and to investigate alternative strategies for reducing the limitations identified
- Determine flow imbalances and investigate methods to improve the flow distribution between parallel unit processes
- Determine velocity and energy gradients and identify optimum locations for chemical addition

Flow imbalances or lack of hydraulic capacity are frequent recurring problems in WWTPs. Correction of these problems can be costly, but may be essential to maximizing the plant capacity.

2.6.7 Analysis of Sludge Recycle Streams (Chapter 9)

Sludge thickening and treatment recycle streams are often responsible for problems in the liquid train of a wastewater treatment plant. These streams can increase the organic loading by 5 to 50 percent, depending on the type and number of solids treatment processes used. Troublesome contributors from a liquid treatment standpoint are anaerobic digester supernatant, dewatering system returns, and thermal treatment liquors. These streams can significantly impact the loading to the liquid train and these streams need to be identified and evaluated.

In some cases, digester supernatant may more closely resemble the digesting sludge, i.e. high solids concentration and, despite their low flow, enhanced liquid train performance may depend on removal of these streams. In addition to solids, such streams also carry significant levels of nutrients and other parameters to the liquid train.

Overloaded or poorly performing sludge thickening facilities can severely impact plant treatment capacity by the generation of a poor quality, high-solids-content recycle that can overload the liquid processing system. Similarly, poor solids capture in sludge dewatering systems will negatively impact liquid train performance. Overall plant capacity and performance will generally be optimized if a high solids capture is maintained across the thickening or dewatering processes. This will improve the viability of the biological treatment system, including secondary clarifier solids loading rate.

Assessment of sludge train recycle streams is essential to complete a plant solids mass balance or sludge accountability analysis. This aspect of plant assessment is also addressed in the Ontario CCP Manual, and is a key consideration in maximizing the capacity and performance of existing WWTPs.

2.6.8 Stress Testing (Chapter 10)

If a treatment unit has historically been loaded beyond its treatment capacity, removal rates may be developed during the historical data analysis. However, if the historical loading rates to specific unit process have been lower than typical design or guideline values, it is difficult to establish the treatment limits using historical data.

Stress testing, normally conducted with online monitoring, is used to increase the loading rates to a unit process beyond normal operations. The objective is to determine the actual treatment capacity of a unit process by increasing the loading to the process. The response of the unit process to variation in the loading rate is quantified and the results are presented as process loading condition versus performance. Stress testing provides a quantitative measure of the impact of loading rates on process performance to determine actual capacities of unit processes.

An alternative to continuous long-term stress testing is the use of a calibrated process model to predict the impact of hydraulic and load variations on process performance. The advantages of using a dynamic process model to assess treatment plant capacity and optimization approaches are discussed in Chapter 12.

Stress testing has been used in practice to determine treatment plant capacities. In Ontario, this has been successfully accomplished at plants such as the Metro Main WWTP, Windsor Little River WWTP, and the Collingwood WWTP. In each case, the work assisted in developing plant capacity.

In performing stress tests, it is important to recognize that future operating conditions, (e.g. settleability changes, and tanks out-of-service), can change beyond those investigated in the stress tests. This must be understood in determining final recommendations for plant capacity. Appropriate process, design, and operational knowledge is required to make these recommendations.

2.6.9 Unit Process Tracer Tests (Chapter 11)

Tracer test techniques evaluate the hydraulic characteristics of unit process tanks. Test results serve to indicate short circuiting, determine existing mixing regimes, locate dead zones within the fluid volume, evaluate baffling arrangements and identify predominant flow patterns within the unit process.

Secondary clarifier dye tests are used to provide a qualitative assessment of flow characteristics and to estimate the effectiveness of various baffle techniques to reduce short-circuiting and suspended solids carryover. A generally accepted method for carrying out this test is described in Chapter 11.

In addition, one- and two-dimensional clarifier models are available to estimate steady-state and dynamic clarifier behaviour with and without baffle modifications.

As secondary clarification effectiveness is a critical process, clarifier dye tests and baffle retrofits can have a significant influence on improving plant capacity. This is especially important in existing facilities that have been designed with shallow sidewater depths and conventional feedwell and effluent weir systems.

In aeration tanks, modifications to plug flow to maximize nitrification or to provide step feed capability may require the use of dye tests to determine the mixing regime.

In an existing full-scale digester, tracer studies provide a quantitative evaluation of mixing. Tracer testing involves the addition of an inert tracer to the digester and measurement of tracer concentration in the digester outlet. Analysis of the tracer data allows identification of such non-ideal behaviour as short-circuiting, dead zones, and deviations from complete mix and plug flow characteristics.

Tracer studies are performed on digesters with suspected mixing problems. Indicators of poor mixing include:

- Grit or scum buildup in the digester
- Low gas production
- Poor volatile solids destruction
- Intermittent raw sludge pumping and digested sludge withdrawal

Proper mixing greatly enhances anaerobic digestion of municipal wastewater treatment plant sludges. Mixing provides uniform environmental conditions such as temperature and substrate concentration, which are critical to optimum performance of high-rate anaerobic digesters. Mixing also serves to prevent short-circuiting, to distribute active biomass within the digester, and to disperse the digester load.

2.6.10 Dynamic Process and Plant Modelling and Simulation (Chapter 12)

Chapter 12 examines requirements for the use of modelling and simulation as a tool in wastewater treatment process liquid train audits. This chapter provides an introduction to the area, discusses commercially available tools that can be used for this purpose, outlines the model development process, and provides details on the tasks and data required if modelling and simulation are used as part of a liquid train process audit.

In wastewater engineering, there has been rapid progress in the development of models for processes used in a typical municipal or industrial treatment plant. Many of the modelling systems available today use the International Association on Water Quality (IAWQ) models which are mechanistic in nature. Mechanistic models are developed from basic principles of physics, chemistry, and biology. This type of "bottom-up" approach results in a robust model that has applicability over a wide range of conditions.

There are many different unit processes and unit process configurations used in wastewater treatment. Each of these is unique, as are the models developed to represent these systems. This chapter stresses the application of modelling and simulation tools to the liquid train of the conventional activated sludge wastewater treatment process.

Although models are not an everyday tool in all treatment plants or designers' tool boxes, their recent advances have significantly increased their acceptance and use. They are especially applicable, after appropriate calibration, to the examination for multiple design and operating scenarios for the upgrade of existing WWTPs. Usually, it is impossible to examine all combinations and permutations of these scenarios by piloting or desktop calculations alone.

2.7 REFERENCES

Wastewater Technology Centre and Process Application Inc. The Ontario Composite Correction Program Manual for Optimization of Sewage Treatment Plants (draft). Ontario Ministry of Environment and Energy, Environment Canada and the Municipal Engineers Association. January, 1995.

U.S. EPA. Handbook: Retrofitting POTWs. EPA/625/6-89/020. July 1989.

CHAPTER 3
HISTORICAL DATA REVIEW

3.1 GENERAL OBJECTIVES

Historical data review is an essential component of a process audit. Generally, the first technical task in a process audit, historical data review provides the opportunity to introduce key project participants and to become familiar with the operation and performance of the wastewater treatment facility. The general objectives of the historical data review are to:

- Determine historical unit process loading condition and performance
- Identify factors which may limit plant performance
- Provide information for planning other process audit tasks

3.2 DATA COLLECTION METHODOLOGY

For a process audit of an entire treatment facility, a comprehensive analysis of historical operating data is conducted, usually consisting of the following steps:

- Project kickoff meeting to establish project approach and to introduce key project participants, including field personnel
- Site visit guided by plant staff for field observation of all unit processes
- Collection and review of historical loading, operating and performance data, relevant reports, and planning information
- Capacity calculations and operations review
- Development of a solids mass balance
- Preparation of summary document and review meeting

Participants in the project kick-off meeting should include a representative for the owner of the facility (i.e. Town Engineer or Utilities Director), the plant supervisor and/or chief operator, the project manager and designated field personnel providing the process audit, representatives from the regulatory agency and representatives from all parties funding the project. Both the project kick-off meeting and plant tour provide opportunities to obtain relevant information from plant staff, including the preliminary identification of possible operational limitations or concerns.

The initial plant tour is conducted to become familiar with and inspect the physical layout of the available facilities. Often, the plant tour will provide a basis for further discussion of the plant performance capabilities and operational flexibility or the identification of instrumentation or support required for subsequent process audit tasks.

Following the plant tour, a major effort is initiated to collect historical plant performance and operational data. Previous reports and planning information may also be collected to provide supporting information on plant performance and possible expansion requirements. Historical data is transferred to an electronic format, if required, to facilitate the statistical analysis of the data, including graphical presentation in terms of probability distributions, time trends or scatter diagrams.

To identify plant flow increases/decreases and to identify possible seasonal flow variations, average and maximum day plant flow records for a 10-year period are reviewed in conjunction with rainfall data, if available. Long-term historical flow records are especially pertinent if the plant is approaching its rated hydraulic capacity or if severe flow impacts have been identified, such as infiltration/inflow or periodic industrial discharges.

Historical plant performance data, including influent, primary effluent and final effluent concentration data is reviewed for a 5-year period to identify recent trends in the influent wastewater characteristics and to assess the recent performance history of the facility in comparison to its effluent objectives and criteria. All available operations data for a 1 to 2-year period is collected and analyzed to provide a complete understanding of the plant performance and condition. The detailed operational information is also used to determine unit process loading rates, operational parameters (i.e. F/M and SRT) and a solids mass balance (refer to Section 3.4). Additional plant visits and discussion with key plant personnel (i.e. plant superintendent or chief operator) will be conducted as required to ensure that all available information is obtained and that the information obtained is accurate.

The data collection methodology used to conduct a Comprehensive Performance Evaluation (CPE) of a non-compliance facility (U.S. EPA, 1989 and Wastewater Technology Centre and Process Applications Inc., 1995) is similar to that used for the process audit of a wastewater treatment facility. It is recommended that these references be consulted to obtain detailed information on the CPE data collection methodology. The methodology includes a number of forms which may assist with the data collection effort.

The scope of a historical data analysis may vary depending on the processes to be studied during the audit. For example, the process audit of an entire treatment facility would require an analysis of all available historical operating and performance data, relevant reports and planning information. If the scope of the process audit was limited to the capacity assessment of a specific unit process, historical data review activities would target the performance and operation of that unit process and associated process interactions.

3.3 DEVELOPMENT OF A DETAILED FLOW SCHEMATIC AND EQUIPMENT DESCRIPTION SUMMARY

The plant information collected must be sufficiently detailed to develop an accurate process flow schematic which identifies the following:

- Unit processes, including number, configuration and operational flexibility
- Sampling locations
- Location of existing instrumentation (i.e. flowmeters)
- Internal recycle streams (i.e. digester supernatant)
- Points of chemical addition (i.e. chlorine for effluent disinfection, metals salts/lime for phosphorus removal)

In addition, key equipment must be itemized, including tank sizes, equipment manufacturer where applicable and the power rating of major equipment such as mechanical surface aerators, aeration blowers and pumps. The CPE checklists (U.S. EPA, 1989 and Wastewater Technology Centre and Process Applications Inc., 1995) may assist with the collection of the required process flow and equipment details.

3.4 DETERMINATION OF UNIT PROCESS LOADING RATES, OPERATIONAL PARAMETERS AND SOLIDS MASS BALANCE

Using the detailed historical data, loading rates and operational parameters for each unit process are determined and compared to typical design and performance criteria. Because of possible impacts of one unit process on the operation and performance of another unit process, all unit processes including sludge handling facilities should be assessed in a process audit of an entire treatment facility. Table 3.1 provides an example of the common unit process loading rates and operational parameters determined in a historical data review of a conventional activated sludge plant. It is recommended that available literature be consulted to obtain reference values for the specific analysis parameters of the unit processes at the facility. Three primary sources of technical information for wastewater treatment unit process operation are described below to provide a starting point for the process audit provider who may wish to use these documents in conjunction with other reference materials.

1) Ministry of the Environment Guidelines for the Design of Sewage Treatment Works, July 1984

These design guidelines were prepared to document desirable ranges including the normal minimum and maximum levels used in the design of municipal wastewater treatment plants

Table 3.1
Example of Common Unit Process Loading Rates and Operational Parameters Determined in Historical Data Review

Unit Process Parameters	Typical Units
Influent	
Average Plant Flow	MLD or m^3/d
Maximum Day	MLD or m^3/d
Plant Bypass Flow	MLD or m^3/d
Per Capita Flowrate	L/capita•day
Parameter[1] Concentrations	mg/L
Parameter[1] Loading Rates	kg/d
Aerated Grit Tank	
Detention Time	minutes
Air Supply	L/m•s
Surface and Tank Floor Velocity	m/s
Quantity of Grit Removed	m^3
Primary Clarification	
Surface Overflow Rate	L/m^2•s
Parameter[1] Removals	percent
Weir Overflow Rate	L/m•s
Tank Depth	m
Aeration	
Hydraulic Retention Time (HRT)	hours
Solids Retention Time (SRT)	days
Organic Loading Rate	kg/m^3•d
Food/Microorganism Ratio	$days^{-1}$
Return Sludge Rate	percent
Power Input of Aeration	W/m^3 or L/m^3s
MLSS/MLVSS Concentration	mg/L
Biological Yield	kg VSS/kg BOD_5
Chemical Addition for P-Removal	
Addition Rate	kg/d
Dosage Rate	mg/L
Metal Ion/P Ratio	kg/kg or mol/mol
Secondary Clarification	
Surface Overflow Rate	L/m^2•s
Solids Loading Rate	kg/m^2•d
Sludge Volume Index (SVI)	mL/g
Tank Depth	m
Weir Loading Rate	L/m•s
RAS/WAS Flowrates	m^3/d

Table 3.1
Example of Common Unit Process Loading Rates and Operational Parameters Determined in Historical Data Review (contd.)

Unit Process Parameters	Typical Units
Final Effluent	
Parameter[1] Concentrations	mg/L
Parameter[1] Loading Rates	kg/d
Parameter[1] Removals	percent
Dissolved Air Flotation	
Solids Loading Rate	$kg/m^2 \cdot d$
Hydraulic Loading Rate	$L/m^2 \cdot s$
Air/Solids Ratio	kg/kg
Chemical Addition	g/kg
Recycle Ratio	percent
Anaerobic Digestion	
Hydraulic Retention Time	days
Volatile Solids Loading Rate	$g/m^3 \cdot d$
Temperature	°C
pH	pH units
Volatile Acid Concentration	mg/L
Alkalinity	mg/L as $CaCO_3$
Power Input	W/m^3
Solids Concentration	percent
Volatile Solids Destruction	percent
Sludge Production (Volume or Mass) Per Unit Flow	L/m^3 or g/m^3
Gas Production Rate	m^3/kg volatile solids
Land Application Parameters	mg/L or kg/kg ratio
Effluent Dissection	
Chlorine Dosage Rate	mg/L
Chlorine Residual Concentration	mg/L
Contact Time @ Peak Flow	minutes
Fecal Coliform or E. coli Concentration	Number/100 mL

Notes: [1] Conventional monitoring parameters include biochemical oxygen demand (BOD_5), total suspended solids (TSS), and total phosphorus (TP). Other available monitoring data, such as nitrogen series data, is also summarized as part of the historical data review.

which require approval by the Ontario Ministry of Environment and Energy. Although a complete documentation of all parameters relating to wastewater treatment plant design is beyond the scope of the guidelines, parameters of greatest importance to the Ministry from a process and reliability standpoint are provided for both liquid stream and sludge handling unit processes.

2) Water Environment Federation Manuals of Practice (MOPs)

Manuals of Practice (MOPs) are publications made available through the Technical Practice Committee of the Water Environment Federation. The manuals provide details of current operating practises and procedures which are developed by consensus of practicing professionals. There are general manuals of practice available which include the most common wastewater treatment unit processes, as well as detailed manuals for specific liquid treatment and sludge handling processes (Appendix 3-A).

3) U.S. Environmental Protection Agency (EPA) Design Manuals

The U.S. Environmental Protection Agency has sponsored the publication of several design manuals for the wastewater treatment industry through the Office of Technology Transfer and Regulatory Support. The manuals (Appendix 3-B) provide process design information for specific topics of interest to the wastewater treatment industry, often including supporting case study examples.

Solids mass balances across unit processes (e.g. clarifiers) and for the activated sludge process are completed as part of the unit process analysis. A solids balance (accumulation = solids in – solids out) is completed to account for solids within the treatment process. Mass balances generally will not close exactly. A discrepancy of less than approximately 10 to 15 percent is considered acceptable. Discrepancies in a solids mass balance of more than 10 to 15 percent indicate further assessment is required to resolve the cause of the inconsistency. Although it is possible to complete mass balances for other parameters (e.g. phosphorus), only solids information is typically available for each process stream.

Accumulation = Solids In – Solids Out

An example of a solids mass balance for a secondary clarifier is provided as follows:
If the accumulation = 0 (assuming there is no increase/decrease in the sludge blanket inventory) then:

Solids In = Solids Out

where:

Solids In = MLSS Concentration • (Flow + Return Flow)

Solids Out = (Effluent SS Concentration • Flow) + [Return Concentration (Return Flow + Waste Flow)]

Some of the most common sources of error in a solids mass balance are listed:

- Non-representative samples (analytical accuracy, sampling techniques)
- Inaccurate flow monitoring
- Impact of periodic recycle streams (the boundaries of the balance must be clearly defined and all inputs/outputs of the defined boundaries must be accounted for in the mass balance)
- Assumptions made concerning accumulations

3.5 IDENTIFICATION OF PROCESS BOTTLENECKS AND REDEFINING PROJECT OBJECTIVES

The detailed historical data review may identify key areas where additional information is required to complete the plant performance assessment, or point to potential process bottlenecks which may be further explored during the process audit. It may be necessary to reassess the project objectives and/or to prioritize subsequent process audit tasks. The findings of a historical data review and the impact on subsequent process audit tasks will be specific to the conditions revealed at each individual treatment facility. However, some examples of the impact of historical data review findings on subsequent process audit tasks is provided in Table 3.2. Detailed case study examples are provided in Section 3.7.

3.6 REPORTING RESULTS: DATA ANALYSIS AND PRESENTATION

A historical data review summary document is prepared to provide direction and for reference through the remainder of the process audit tasks. As outlined in Table 3.3, the summary document provides an introduction to the project and its objectives, a complete facility description and the results of the unit process analysis. The summary document should be reviewed with key project personnel (kick-off meeting participants) before proceeding with subsequent process audit tasks.

Examples of the level of detail required for the process flow schematic and the equipment summary are provided in Figures 3-1 and 3-2, respectively. The process flow schematic shows all major unit processes including the number and operational flexibility of each unit process, sampling and flow monitoring locations, internal recycle streams (e.g. DAF underflow and digester supernatant), and the points of chemical addition (e.g. alum for phosphorus removal and chlorine for effluent disinfection). The equipment summary example shown in Figure 3-2 shows tank sizes throughout the facility

Table 3.2
Examples of Historical Data Review Impacts on Subsequent Process Audit Tasks

Historical Data Review Finding	Impact on Process Audit Tasks
Mass balance cannot be completed	Obtain required information (e.g. flow)
Mass balance does not close within 15 percent	Complete flowmeter assessment and/or review offline 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 offline monitoring program
Clarifier loading rates less than design values	Conduct stress tests to determine capacity limits

Table 3.3
Recommended Content of Historical Data Analysis Summary Document

Introduction • Background to the project • Project objectives
Facility Description • Type of treatment (e.g. activated sludge, RBC) • Design capacity and current flows • Plant effluent performance requirements • Age of plant and facility upgrades • Service population and future capacity requirements • Pertinent flow considerations (infiltration/inflow, industrial discharges) • Detailed unit process flow diagram and description • Unit process/equipment summary (e.g. size, power requirements, etc.)
Unit Process Analysis • Comparison of loading rates/operational parameters for each unit process to typical design/operation values available in the literature • Presentation of solids mass balance • Probability plots, time trends or scatter diagrams to support significant findings • Identification of additional information requirements or potential process bottlenecks

and influent pump capacities. If possible, existing equipment should be itemized in the equipment summary, including tank sizes, equipment manufacturer (e.g. clarifier mechanism, blowers) and power rating/capacity of major equipment.

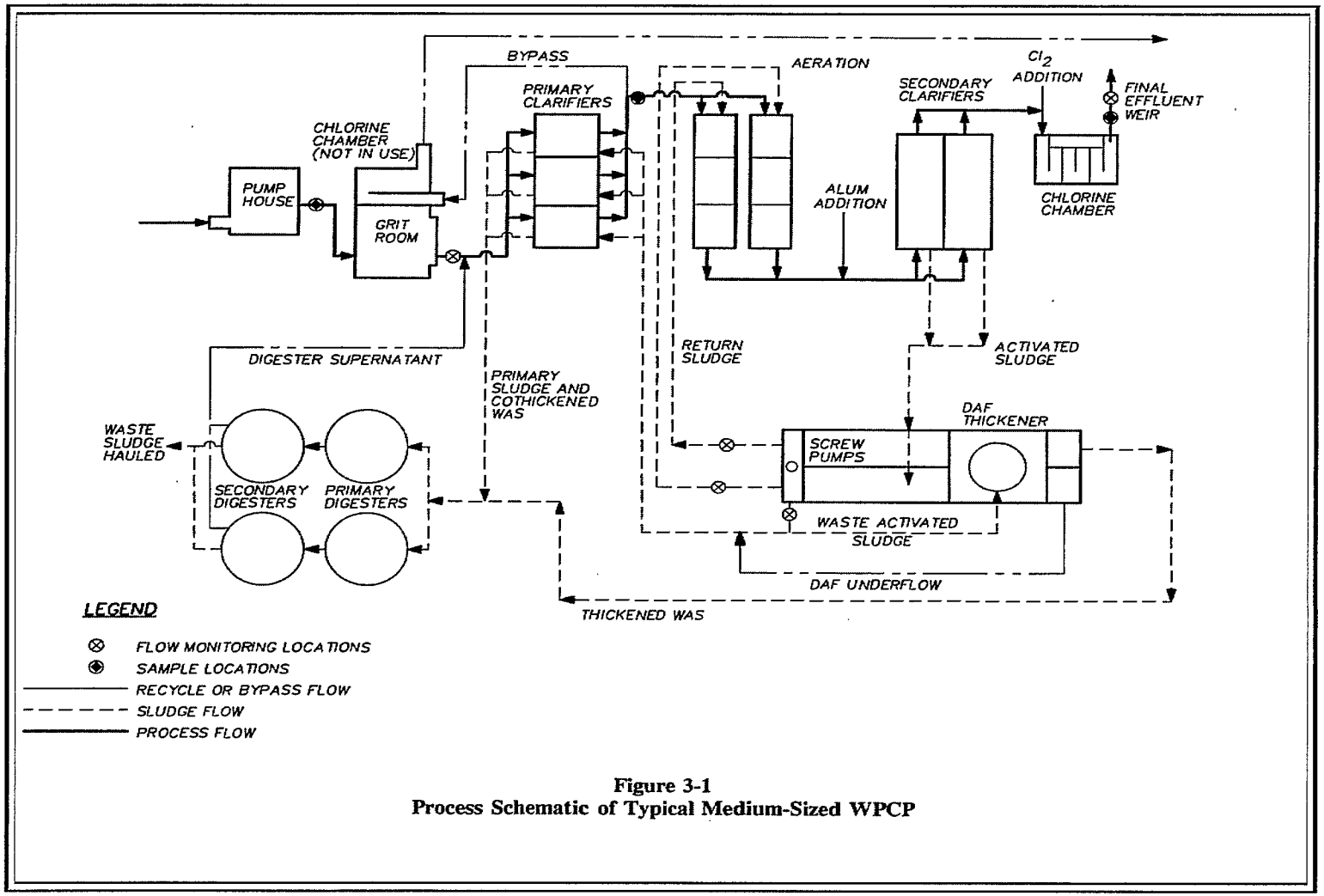


Figure 3-1
Process Schematic of Typical Medium-Sized WPCP

Historical plant performance data may be presented graphically in terms of time trends, scatter diagrams or probability distributions to highlight significant findings. An example of the graphical presentation of the long-term historical flow records is shown in Figure 3-3. Plant performance data, including influent, primary effluent, and final effluent concentrations is usually also presented graphically.

3.7 SELECTED CASE STUDIES

Optimization and Upgrading of the Belleville WPCP

The main objective of the optimization project conducted in 1988 at the Belleville WPCP was to review and document the present condition of the facility and to determine the corrective action required to achieve compliance. Phase 1 of the project consisted of an evaluation of the plant based on 16 months of historical operating data, plant site inspections and discussions of plant operating limitations with operations personnel. Data collection forms similar to the CPE checklists were used. Major concerns addressed by the historical data analysis included chlorination/disinfection, plant hydraulics, solids mass balance and sludge hauling/dewatering and effluent quality. Subsequent process audit tasks were conducted in Phase 2, including online monitoring and an aeration capacity analysis.

The historical data and operations review indicated that the performance of the disinfection system (Figure 3-4) had deteriorated due to sludge accumulation and inadequate chlorine delivery and control capability. A final project recommendation for chlorine control system upgrading was presented, including chlorinator relocation, controller adjustment in response to bypass flows and chlorine diffuser inspection and replacement, if necessary.

Historical waste activated sludge flows recorded from a magnetic flowmeter were substantially higher than expected from theoretical calculations. Subsequent online monitoring identified WAS flow disturbances which contributed to flowmetering inaccuracy. The plant data also indicated that sludge haulage had been less than sludge generation rates, resulting in sludge accumulation throughout the treatment system, including the sludge holding tanks and liquid treatment train (i.e. primary clarifiers). As a result of the solids accumulation, inadequate digested sludge quality with low ammonia concentrations and ammonia/metals ratios was noted as part of the sludge characterization data review. Short-term and long-term options to address the identified sludge disposal deficiencies were developed.

The data collection effort assisted in the identification of several operation and maintenance issues. These deficiencies included items such as upgrade of flow control gates and clarifier mechanisms,

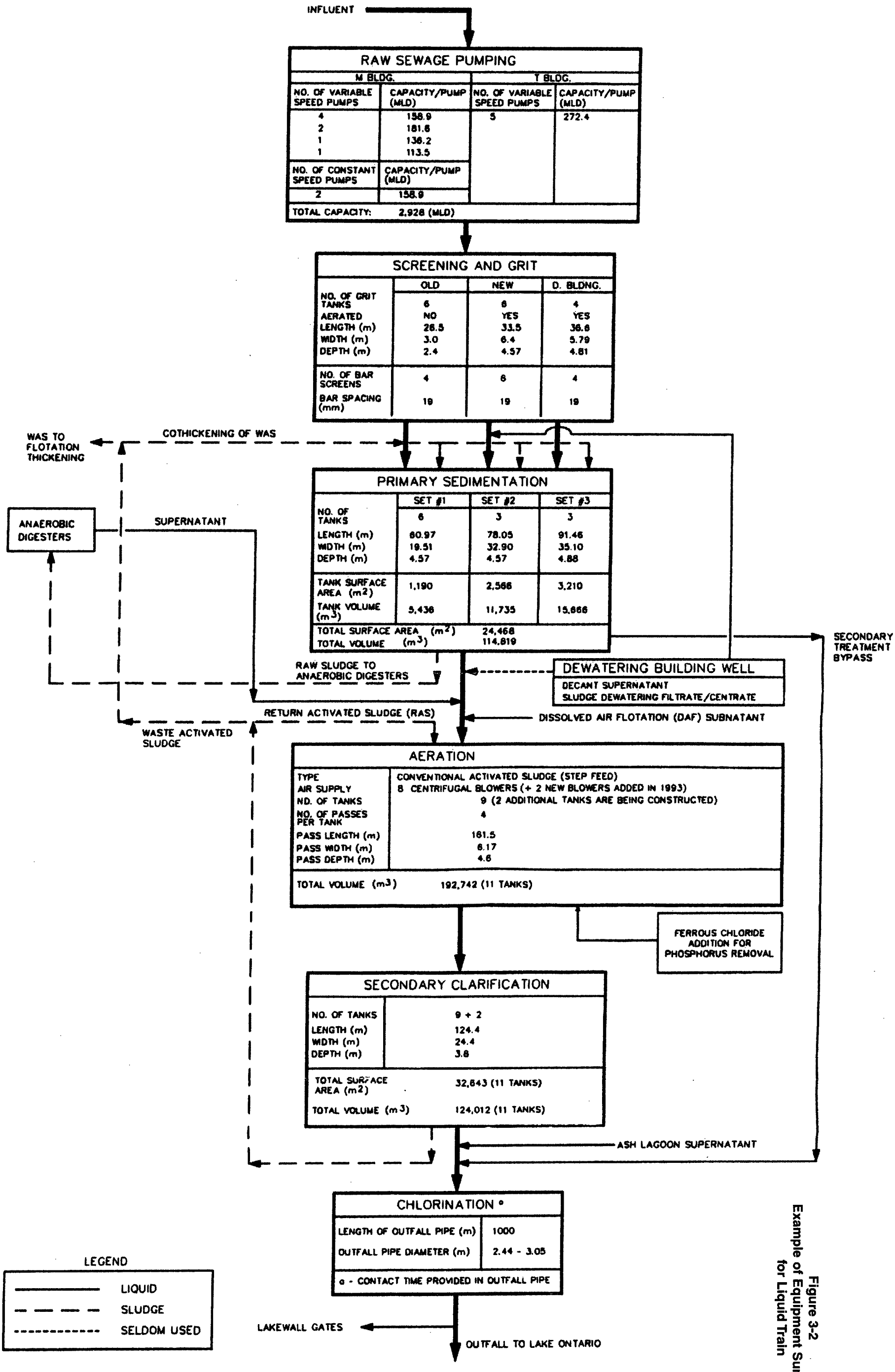


Figure 3-2
Example of Equipment Summary for Liquid Train

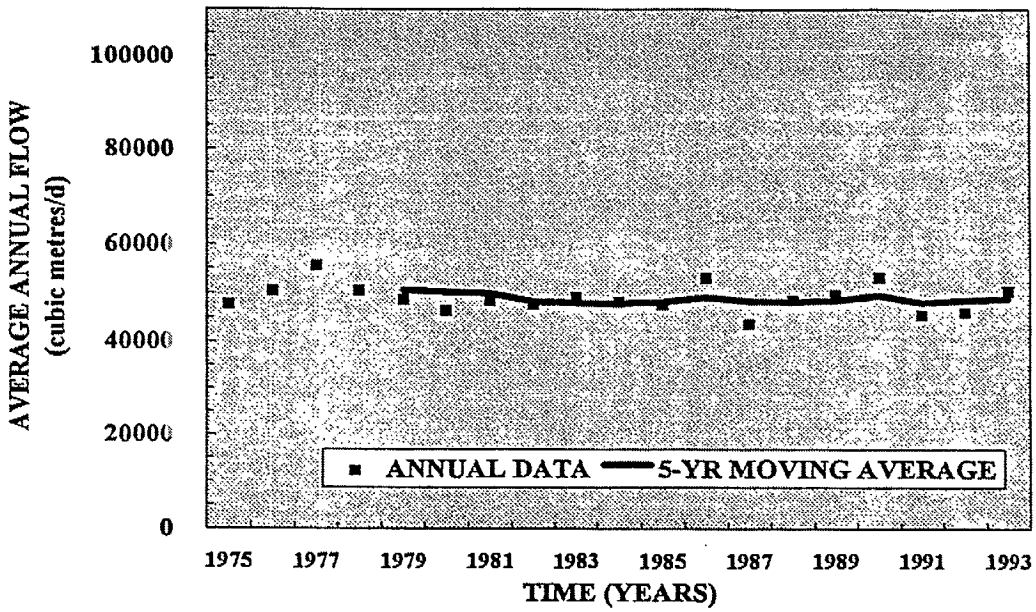


Figure 3-3
Time Trend Analysis of Annual Average Flow Conditions

concrete repair, sludge pump replacement, and the installation of sludge holding tank mixing equipment.

Operational Audit of the Regional Municipality of Halton's Burlington Skyway Water Pollution Control Plant

One component of the operational audit of the Regional Municipality of Halton's Burlington Skyway WPCP was a review of historical operating and performance data to establish and define the performance status of the facility. The analysis included the collection and review of 10-year flow data and 1 1/2 years of detailed operating and performance data. Relevant reports, such as documents prepared by the Remedial Action Plan team for Hamilton Harbour, and future flow forecasts were also considered as part of the historical data review process. Specific improvements addressed in the RAP documents included phosphorus and total ammonia-nitrogen removal.

In general, flows and loadings for unit processes were less than the design criteria of the operating ranges recommended by the Ministry of the Environment Design Guidelines (1984). However, peak surface overflow and solids loading rates for the secondary clarifiers which were approaching or exceeding typical values suggested that the secondary clarifier capacity could restrict the possibility of increasing the solids inventory to maintain a higher SRT for nitrification purposes as required by

the RAP. Final recommendations from the process audit included a staged approach to secondary clarifier improvements.

The biological net yield was estimated to be 1.26 mg VSS/mg BOD_5 based on the available historical data compared to a typical literature value for the activated sludge process with primary clarification of 0.4 to 0.8 kg VSS/kg BOD_5. This yield value suggested an inaccuracy of one or more parameters in the solids mass balance and resulted in a final recommendation for volumetric calibration of the effluent, RAS and WAS flowmeters.

A plot of monthly average sludge volume index (SVI) values was generated as part of the historical data analysis (Figure 3-5). SVI values exceeding the typical range for a well settling sludge as reported in the literature (60-140 mL/g) indicated possible sludge bulking problems. Subsequent microscopic examination of foam and activated sludge indicated the presence of filamentous organisms (*Nocardia sp.* and *Microthrix parivella*). In this case, discussions were initiated with plant personnel concerning RAS chlorination to control the excessive growth of filamentous organisms during subsequent process audit activities.

Process Audit of the Collingwood Water Pollution Control Plant

One component of the process audit of the Collingwood WPCP was a review of historical operating and performance data to establish and define the performance status of the facility. The analysis included the collection and review of 5 years of flow and wastewater characterization data and 2 years of detailed operating and performance data. Relevant reports, such as documents prepared by the Remedial Action Plan team for Collingwood Harbour, industrial discharge records and future flow forecasts were also considered as part of the historical data review process. One of the primary issues of the RAP studies was phosphorus discharged by the Collingwood WPCP.

Over the five-year review period, a reduction of the influent total phosphorus concentration from approximately 13 mg/L to less than 5 mg/L was attributed, at least in part, to the initiation of in-house measures by industry to reduce phosphorus discharges. Approximately 14 percent of the 1989/1990 loading rates (biochemical oxygen demand, suspended solids and total phosphorus) to the plant were attributed to industrial discharges.

A solids mass balance using secondary clarifier historical data revealed a discrepancy of approximately 35 percent. Further investigation during the online monitoring period indicated that the historical RAS flows were only half of the actual total RAS flow. To close the solids mass balance during the online monitoring period, wasting to the primary clarifiers in excess of the DAF capacity was temporarily suspended and a volumetric calibration of the raw sludge pumps was undertaken.

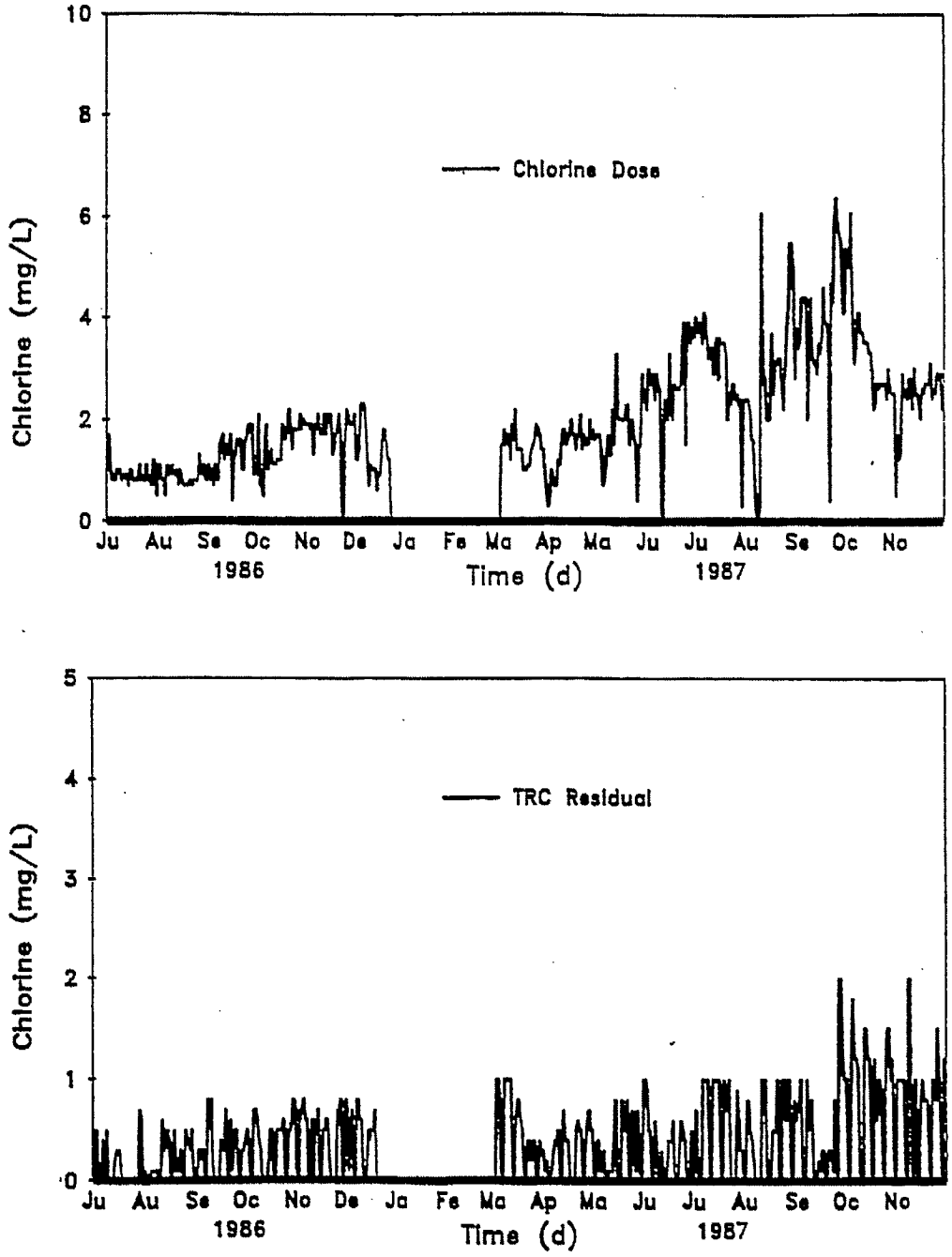


Figure 3-4
Historical Chlorine Dosage and Chlorine Residual for Belleville WPCP

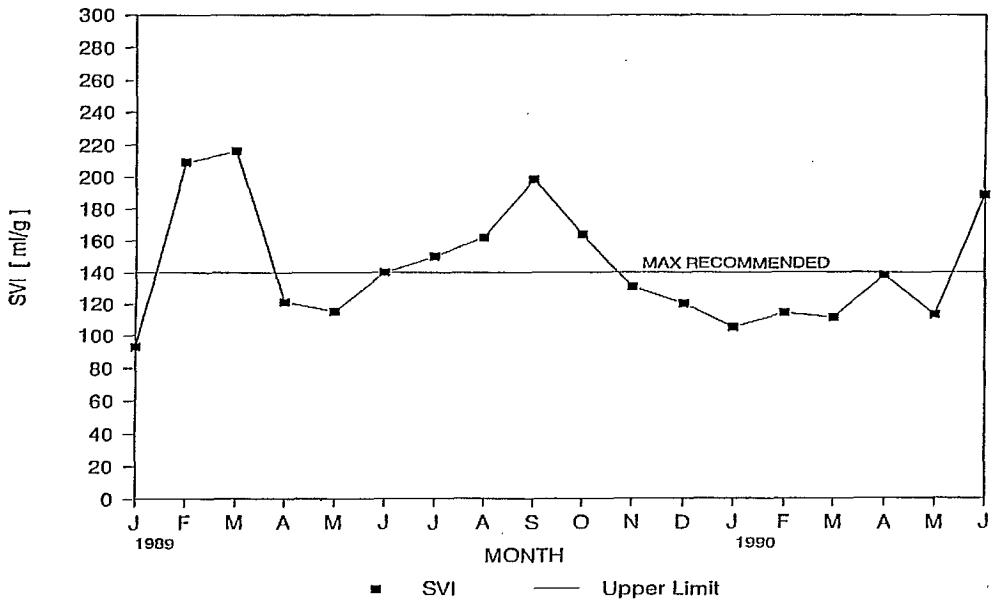


Figure 3-5
Burlington Skyway WPCP Sludge Volume Index (SVI)

A previous assessment of plant capacity indicated that a Class Environmental Assessment should be initiated immediately to ensure that community growth was not restricted by treatment plant capacity limitations. Independent flow projections which were developed as part of the historical data review indicated that the average flow would approach but not exceed the rated hydraulic plant capacity to the year 2001, without an industrial reserve capacity. Uncertainty in future plant capacity requirements was associated with the projected increase in the "recreational" population (Figure 3-6), compared to the historical growth rate of 0.5 percent per annum for the permanent population.

3.8 EXPECTED DURATION AND COSTS

The time period covered by a historical data review may vary according to specific study objectives and availability of information. For a process audit of an entire treatment facility, the historical data which is reviewed includes a 10-year period of flow data, a 5-year period of wastewater characterization data and a 1 to 2 year period of detailed operational data. Historical data collection and review may be modified as appropriate where the process audit scope is limited to the assessment of a single unit process.

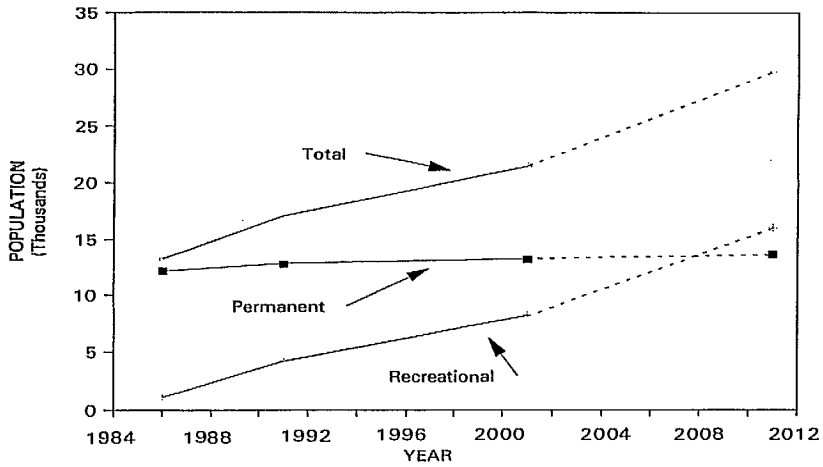


Figure 3-6
Population Projection for the Town of Collingwood

Collecting, compiling, evaluating, and summarizing the historical data is relatively time-consuming. Historical data review, including data collection activities, onsite visits and follow-up discussion with plant staff and preparation of the summary document may require up to 5 to 10 days of effort by two experienced persons to cover an entire treatment facility. Clearly, the level of detail obtained in the historical data review is dependent on the level of effort expended, size and complexity of the facility, knowledge and experience of audit personnel, and the availability of the data to be reviewed. Historical data review expenses include travel to the site for plant tours/meetings, drafting and computer graphics and office support services.

3.9 REFERENCES

Canviro Consultants. Optimization and Upgrading of the Belleville WPCP. October 1988.

CH2M HILL ENGINEERING LTD. Operational Audit of the Regional Municipality of Halton's Burlington Skyway Water Pollution Control Plant. Report prepared for the Regional Municipality of Halton. March 1991.

CH2M HILL ENGINEERING LTD. Process Audit of the Collingwood Water Pollution Control Plant. Report prepared for the Town of Collingwood. December 1991.

CH2M HILL ENGINEERING LTD. The Operational Evaluation of the Main Treatment Plant. Report prepared for the Municipality of Metropolitan Toronto. 1993.

CH2M HILL ENGINEERING LTD. Draft Final Report for Cornwall Pollution Control Plant. Prepared for the City of Cornwall. 1994.

Ministry of the Environment. Guidelines for the Design of Sewage Treatment Works. July 1984.

U.S. Environmental Protection Agency (U.S. EPA). Handbook: Retrofitting POTWs. EPA/625/6-89/020. 1989.

Wastewater Technology Centre and Process Applications Inc. The Ontario Composite Correction Program Manual for Optimization of Sewage Treatment Plants. Prepared for the Ministry of Environment and Energy, Environment Canada and the Municipal Engineers Association. 1995.

CHAPTER 4
FLOW METERING ASSESSMENT

4.1 FLOW METERING

Accurate flow measurement is essential for the efficient operation of a wastewater treatment facility. Accurate flow measurement is required by the following:

- Regulatory agencies to evaluate loadings to the receiving waters
- Municipal authorities to determine the capacity status and project future expansion requirements
- Operation staff to provide the information required to control and optimize the treatment processes
- Plant administration for billing purposes

4.1.1 Types

Flow metering equipment commonly found in wastewater treatment facilities can be divided into two basic categories: open channel flow meters and full pipe flow meters. Table 4.1 summarizes advantages and disadvantages of five types of flow meters commonly found in wastewater treatment plants.

4.1.1.1 Open Channel Meters

The most commonly used open channel flow meters consist of a primary hydraulic structure inserted into the flow stream and a secondary element that measures the water elevation at a known location upstream of the hydraulic structure. The purpose of the hydraulic structure is to produce a flow that is characterised by a known relationship between the liquid level measurement (head) and the flow rate. The head flow relationship, commonly called the rating curve, of the primary device is used to convert the water elevation measured by the secondary element into flow. The overall accuracy of the open channel flow meter is determined by the accuracy of both the primary and secondary elements.

The primary device can be divided into two categories: weirs and flumes. A detailed discussion of different types of weir and flume configurations that are used in North America is presented in the Isco Open Channel Flow Measurement Handbook (Grant, 1989). The performance of the primary device is determined largely by the quality of the installation. Weirs require a uniform velocity profile in the upstream approach channel, free discharge over the weir crest and an aerated nappe to ensure accurate measurement.

Table 4.1
Flow Metering Equipment Commonly Used in Wastewater Treatment Facilities

Type	Accuracy	Advantages	Disadvantages
Open Channel Flume	5-7%	- low head cost - self cleaning	- requires a well developed flow profile - requires careful construction - susceptible flooding
Open Channel Weir	5-7%	- low cost - ease of installation	- high head loss - requires a well developed flow profile - cleaning required
Full Pipe Electromagnetic	1-3%	- no head loss - bi-directional	- minimum conductivity required - expensive - well developed velocity profile required
Full Pipe Doppler	2-5%	- no head loss - low cost - not affected by air bubbles	- not suitable for some pipe material - well developed velocity profile required
Full Pipe Venturi	1-3%	- low head loss - high accuracy	- expensive - well developed velocity profile required

Flumes require a uniform velocity profile in the upstream approach channel, free discharge through the flume throat and accurate conformance to the standard geometry, including location of the secondary element measurement, for the flume type. The standard requirements for common types of flume and weir installations are presented in Grant, 1989; U.S. EPA, 1988; and Kulin, 1984(a).

The secondary element measures the water surface elevation at a specified location within or upstream of the primary element. Common secondary elements include:

- Ultrasonic level measurement
- Bubbler system
- Mechanical float
- Submerged pressure transducer
- Electrical transducer – capacitance or reactance type

Ultrasonic level measurements are commonly used at wastewater treatment plants because of the simplicity of installation, low maintenance requirements and level of accuracy provided.

4.1.1.2 Full Pipe Flow Meters

Full pipe flow measurements commonly used in wastewater treatment facilities include:

- Electromagnetic Flow Meters
- Ultrasonic Flow Meters (Doppler) or transit time
- Venturi
- Flow Tubes

Electromagnetic flow meters are based on Faraday's law of electromagnetic induction. The meter creates a magnetic field perpendicular to the direction of flow, flow through the magnetic field induces a voltage which is proportional to the flow rate. The magnitude of the induced voltage is proportional to the magnetic field strength, distance between electrodes and the velocity of the fluid. The achievable level of accuracy for an electro-magnetic meter is 1 to 3 percent of flow.

Ultrasonic Doppler meters are used in "dirty water" applications. The ultrasonic beam is interrupted by particulate matter in the moving fluid and reflected towards a receiver. The difference between the propagated and reflected frequencies is proportional to the velocity of the particulate matter in the fluid and therefore to the fluid flow rate. Doppler meters require a minimum concentration and size of solids or air bubbles for reliable operation. They also require a minimum velocity through the meter to maintain the particulate matter in suspension. The achievable level of accuracy for a Doppler meter is 2 to 5 percent of flow.

Venturi meters are differential pressure meters. The change in cross-sectional area through the throat constriction of the meter forces a change in the fluid velocity resulting in a change in pressure. The flow rate is a function of the differential pressure. Venturi meters use a gradual change in pipe diameter upstream and downstream of the throat constriction to reduce the headloss through the meter. The achievable level of accuracy for a Venturi meter is 1 to 3 percent of flow.

Flow tubes are modified Venturi meters where the sectional geometry and profile is proprietary to the manufacturer of the meter. Flow tubes are usually shorter than the classical Venturi meter, however they are more sensitive to upstream disturbances.

4.1.2 Common Installation Concerns

The achievable accuracy of the flow metering equipment quoted in the previous section is based on the meter installation conforming to the established standards. Most of the standards are well documented and can be found in the standard reference material (U.S. EPA, 1988; Kulin, 1984[a], [b], and [c]). Unfortunately, in many wastewater treatment plants the meter installation does not meet the recommended standards and therefore the accuracy of the measurement is adversely effected.

Table 4.2 summarizes common installation problems for the flow metering equipment in wastewater treatment plants. Useful checklists and summaries to evaluate the installation of flow measuring equipment are provided in a report on flow meters prepared by the Water and Wastewater Instrumentation Testing Association (W/WW ITA).

4.1.2.1 Open Channel Flow Meters

Accurate and appropriate level measurement is a common installation concern with open channel flow meters. Standard flume and weir equations were developed and calibrated using empirical data based on specified location (distance from the throat) for the level measurement. The open channel flow meters in many installations do not meet the standard configuration and therefore the standard equations converting the level measurement to flow rate are not applicable. Non-standard weir and flume configurations must be calibrated in the field. The secondary element which measures the water surface level requires maintenance and calibration on a regular basis to ensure an accurate level measurement.

Both weir and flume installations require uniform flow upstream and free discharge down-stream of the hydraulic structure. The required straight length of channel upstream of the flow measurement device for each type of hydraulic structure is specified in the published standards. The discharge over a sharp crested weir requires a free fall with an aerated nappe for accurate measurement. The nappe is defined as the section of the flow stream immediately downstream of the weir crest where the flow direction changes from horizontal to vertical and the sides of the flow stream contract. An air vent on both sides of the channel under the downstream edge of a rectangular weir crest will help aerate the nappe under low flow conditions.

4.1.2.2 Full Pipe Flow Meters

The accuracy of most of the full pipe flow meters is affected by meter orientation and the velocity profile in the pipe cross section upstream and downstream of the meter. The installation guidelines for full pipe meters include minimum pipe lengths upstream and downstream, direction of flow, and minimum and maximum velocities.

Table 4.2
Common Installation Concerns for Flow Metering Equipment in Wastewatrer Treatment Facilities

Type	Concerns
Flume	- flooded (discharge not free flow) - flume geometry and location of level measurement not conforming to standard - non-parallel flow stream - level measurement out of calibration
Weir	- minimum/maximum flow exceeded - non-parallel flow profile upstream - level measurement in an appropriate location - level measurement out of calibration
Electromagnetic	- insufficient clear length of straight pipe upstream and downstream of meter - entrained air collecting in meter section
Doppler	- insufficient clear length of straight pipe upstream and downstream of meter - insufficient solids in fluid - sensors mount on the vertical plane - vibration in pipe
Venturi	- insufficient clear length of straight pipe upstream and downstream of meter - pulsating flow - pressure sensor out of calibration

Electromagnetic meters require full pipe flow at all times and a clear length of 5 pipe diameters upstream and downstream. The Doppler meter requires a pipe material which will allow penetration of an ultrasonic signal (concrete pipe is very poor), horizontal installation, a clear length of 10 pipe diameters upstream and 5 diameters downstream. Venturi meters require full pipe flow at all times and a clear length of pipe 20 throat diameters upstream and 10 throat diameters downstream.

4.2 FIELD CALIBRATION OF PLANT FLOW METERING

There are three levels of evaluation for flow metering equipment:

- Record checks to ensure design specifications for the meter are suitable for the application
- Physical inspection of the installation to determine if the device meets the design specifications and recommended standards for installation
- Field calibration to verify the accuracy of the device

Record checks are used to provide initial screening of the flow meter installation. The questions to be addressed during this phase of the evaluation include:

- Is the type of meter suitable for the application?
- Is the expected level of accuracy acceptable?
- Is the meter size appropriate for the expected flow range?

Following the record check, a physical inspection of the meter is required to determine if the installation is appropriate for the type of meter and meets the applicable recommended standards. The physical inspection includes:

Weirs and Flumes

- Physical measurements of the hydraulic structure including the approach channel, throat or weir section, throat or weir elevations, and the location of the level measurement
- Calibration (zero and span) of the secondary device

Full Pipe Meters

- Meter orientation
- Clear length of pipe upstream and downstream of meter

The overall accuracy of the flow metering equipment is evaluated using one or more the field calibration techniques discussed below.

4.2.1 Dye Testing Techniques

The dye dilution technique is non-intrusive and produces absolute measurements to accuracies of 2 percent. The procedure does require considerable care in set up and selection of sampling equipment and materials.

The procedure consists of 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. Complete mixing is required between the injection and sample collection points to ensure accurate results.

Suitable tracer material includes fluorescent dyes such as Rhodamine WT. The accuracy of the calibration is determined by the accuracy and precision of the tracer preparation and injection procedures, the degree of mixing achieved between the injection and sample collection point, and the accuracy of the analytical method used to determine the downstream concentration.

The general procedures for conducting tracer dye studies are discussed in Chapter 12. Crosby (1987) provides detailed instructions for using Rhodamine WT dye dilution to measure flow in open channel sections.

4.2.2 Draw and Fill Test

The simplest and most reliable method of checking flow meter accuracy is a draw-and-fill test. A draw-and-fill test involves simply drawing down the liquid level in a basin or tank and filling it back up while recording the meter reading.

Equipment required for a draw-and-fill test is also quite simple: a method for measuring changes in water surface elevation and a means of recording the flow meter reading during the test. Since the **total** flow over the draw/fill period is desired, it is best to totalize flow meter readings. This can be done by:

- Using the meter totalizer reading if one is provided
- Manually recording meter readings over short intervals and totalizing
- Using a computerized method of recording flow meter output

Measurement can be done either during **draw-down** if the flow meter is on a pipe downstream of the tank, or during **fill** if the flow meter is on a pipe upstream of the tank.

If measurements are taken during filling, draw down the tank level by shutting off influent flow and continuing effluent flow. Sufficient draw-down is required for accuracy (at least one foot is preferred). Fill using only the pipe on which the flow meter in question is installed. If measurements are taken during draw-down, shut off all influent and effluent flow lines except the effluent pipe being tested, and measure water elevation drop.

If possible, repeat the test at several flow rates (preferably three) to check accuracy over the potential operating range. The actual flow rate is calculated by dividing the volume of tank filled or drawn down by the length of the test period. The measured flow is then compared to the flow meter output.

4.2.3 Redundant Instrumentation

Many wastewater treatment facilities measure flow in more than one location. For example many facilities have a raw influent flow meter, plus flow meters on each parallel process stream, and an effluent flow meter. Flow measurement from a redundant meter can be used to calibrate a suspected meter over a range of flow. The procedure involves:

- Obtain a series of measurement over time (time interval of approximately 1 minute) from both of the meters
- Evaluation of the recorded flow from each meter to determine the time required for the hydraulic perturbations to travel between the meters
- Statistical analysis of the time delay corrected flows from the two meters to determine the best fit equation for calibration of the suspected meter

Alternatively, a portable flow meter such as a "strap-on" Doppler meter for full pipe flow measurement and/or a velocity-area meter for open channel flow can be used to calibrate a permanent installation. This method of calibrating a suspect meter relies on the accuracy of the redundant meter. It should be used with caution and only when the other methods described above are not available.

4.2.4 Other Methods

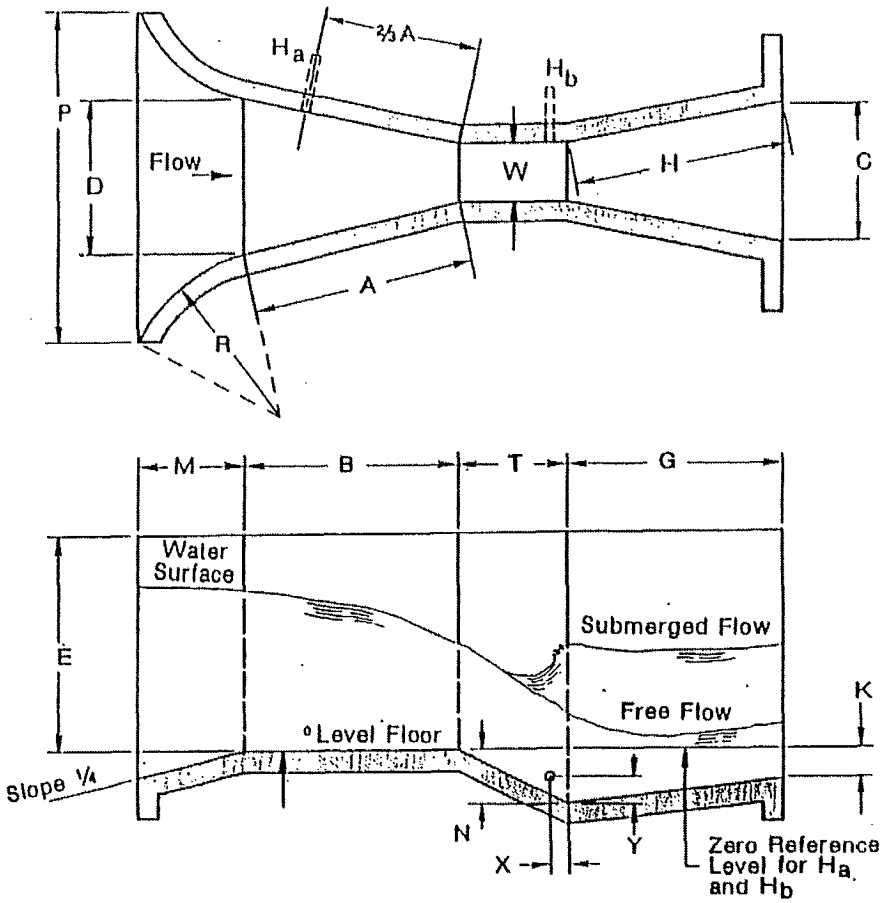
Hydraulic modelling techniques can be used to develop the head versus flow relationship for non standard flume and weir installations. Marsalek (1991) presents a detailed description of the application of hydraulic modelling based on similarity theory and scale model development to the analysis of a non standard flow measurement structure. A thorough understanding of hydraulic principles, and a laboratory scale flume for testing the scale model are required in the application of this calibration technique.

4.3 PRESENTATION AND INTERPRETATION OF RESULTS

The results of the record check and physical inspection are presented in a summary table which compares the installation to recommended standards. Figure 4-1 presents an example of the results of the physical inspection of a Parshall flume installation.

The dye dilution technique for field calibration of flow measuring equipment uses a mass balance procedure to provide an indirect measure of flow:

$$Q \bullet C = c_1 \bullet q_1 + c_2 \bullet q_2$$



Comparison of Field Measurements versus Standard Flume Dimensions				
Parameter*	2-foot Flume		6-foot Flume	
	Standard Dimension**	Field Measurement	Standard Dimension**	Field Measurement
W (inlet)	24	24	72	71.62
W (outlet)	24	24	72	71.25
A	60	60	84	120
2/3A	40	40	54	51.75
B	58.9	58	82.4	76
C	36	36	84	84
D	47.5	48	105	103
E	36	48	36	48
T	24	24.5	24	24
G	36	42	36	36

All values in inches
** From "Isco Open Channel Flow Measurement Handbook".

Figure 4-1
Physical Inspection of a Parshall Flume Installation

where:

c_1 = injection tracer concentration

q_1 = tracer injection flow rate

c_2 = background tracer concentration

q_2 = channel flow rate

C = tracer concentration in collected sample

Q = total flow rate ($q_1 + q_2$)

$$(q_1+q_2)\bullet C = c_1\bullet q_1 + c_2\bullet q_2$$

If

$$q_1 << q_2 \quad \text{and} \quad c_2 \approx 0$$

Then

$$Cq_2 = c_1 \bullet q_1$$

$$q_2 = q_1 \bullet \frac{c_1}{C}$$

The test is conducted at several different flow rates and a plot of the meter reading versus measured flow is prepared. A statistical analysis of the data will determine the best fit calibration equation for the meter installation.

The draw and/or fill approach for field calibration of flow measuring equipment measures the change in volume in a tank located either upstream or downstream of the flow meter. The cumulative volume is measured over the test period and compared to the cumulative volume recorded by the flow meter. Figure 4-2 presents a typical Cumulative Volume versus Time plot for a fill test. The average flow for the test period is obtained from the slope of the line. The test is conducted at several flow rates, and a plot of the meter reading versus measured flow is prepared. A statistical analysis of the data will determine the best fit calibration equation for the meter installation.

The results of the field calibration tests are plotted as meter reading versus measured flow. A statistical analysis of the data will determine the best fit equation for adjusting the meter reading to reflect the actual flow. Figure 4-3 presents an example of the results of the field calibration of an influent flow meter.

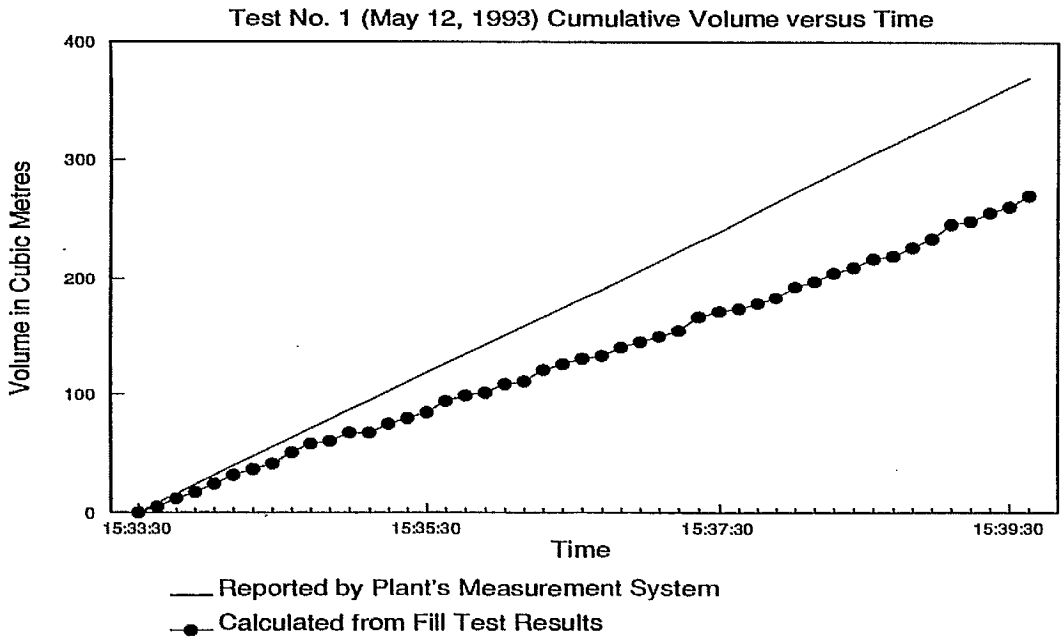


Figure 4-2
Cumulative Volume Versus Time for a Fill Test Calibration

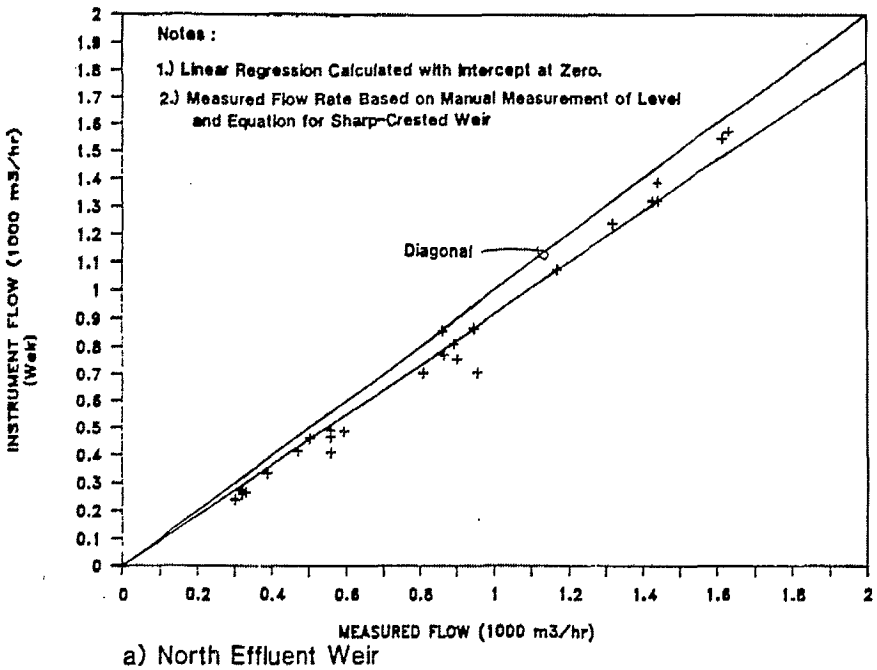
4.4 SELECTED CASE STUDIES

Optimization and Upgrading of the Belleville WPCP

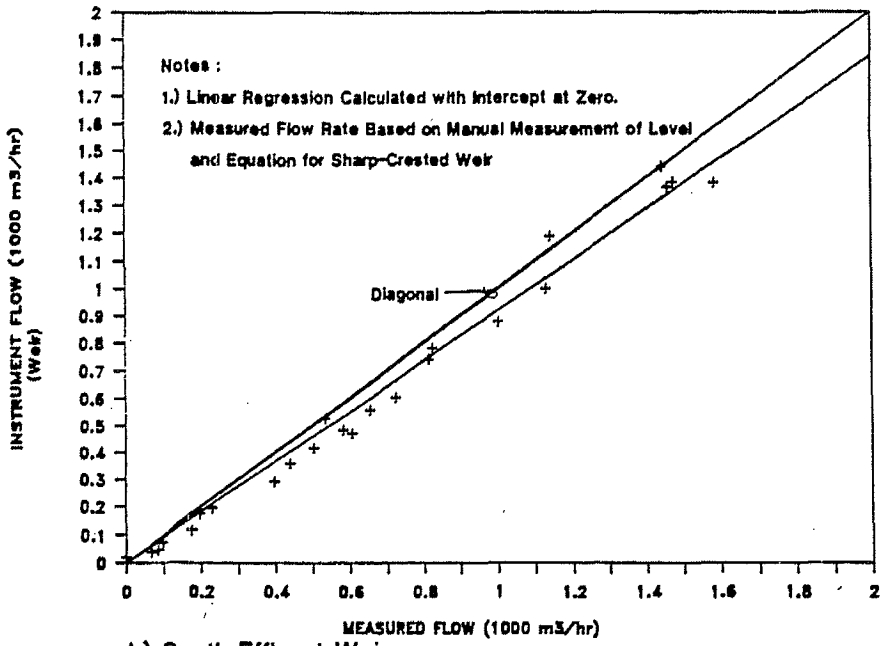
The flow measurement accuracy verified as part of the process audit component of this study included:

- The effluent flow, calculated as the flow summation of two identical rectangular weirs at the chlorine contact chamber
- The secondary effluent flow, determined by summation of two magnetic flow meters
- The Plant 'A' influent flow, determined by a magnetic flow meter
- The RAS flow, determined by a magnetic flow meter
- The WAS flow, determined by a magnetic flow meter

The total effluent flow is calculated using two ultrasonic level detectors located on the two 2100 mm rectangular weirs at the chlorine contact chamber. To verify the accuracy of each of these instruments, manual height measurements were taken above the weir crest. The flow rate was



a) North Effluent Weir



b) South Effluent Weir

Figure 4-3
Field Calibration of an Effluent Weir

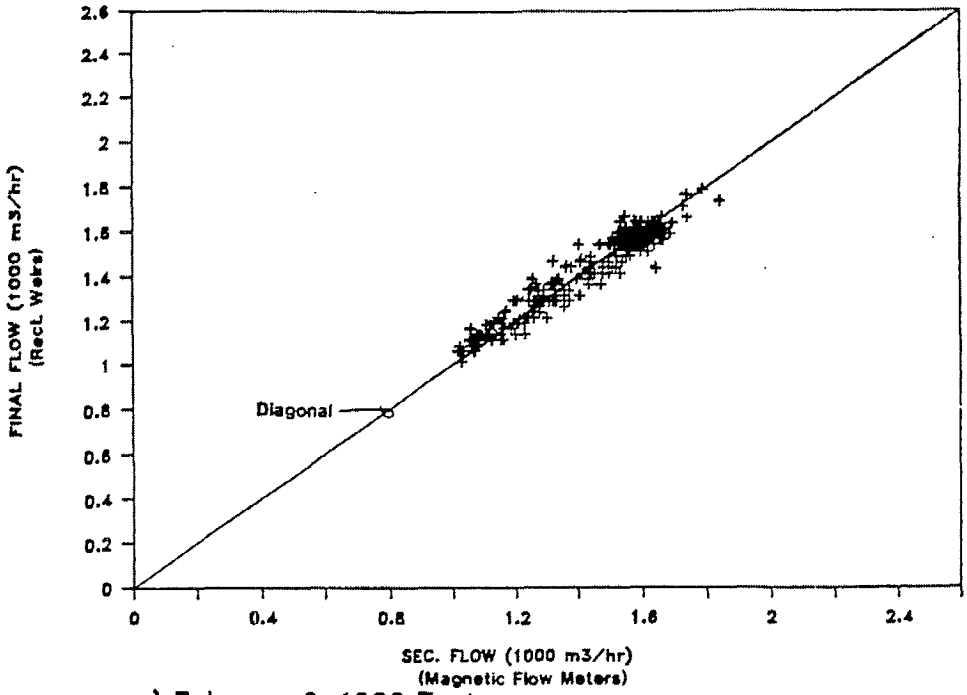
estimated using a standard equation for a sharp-crested weir. To create a variety of flow conditions, the gates at the influent of the chlorine contact chamber were adjusted. In addition, a number of zero points were taken when the water level was flush with the weir crest. The ultrasonic flow instruments provided measurements 8.5 and 8 percent below the manual measurements for the north and south channels, respectively.

The secondary effluent flow is measured by two magnetic flow instruments located at the effluent of the secondary clarifiers. One meter is located in a chamber on the east side of the clarifiers, the other is located on the west side of the clarifiers in the pipe gallery. An attempt was made to verify the accuracy of these instruments by performing a draw and fill test using the chlorine contact chamber. Unfortunately, due to the time involved in manually operating the influent gates and the high flows at the plant, the tank filled before depth measurements could be taken. Therefore, the effluent rectangular weirs were used to verify the conformance of the two magnetic flow instruments.

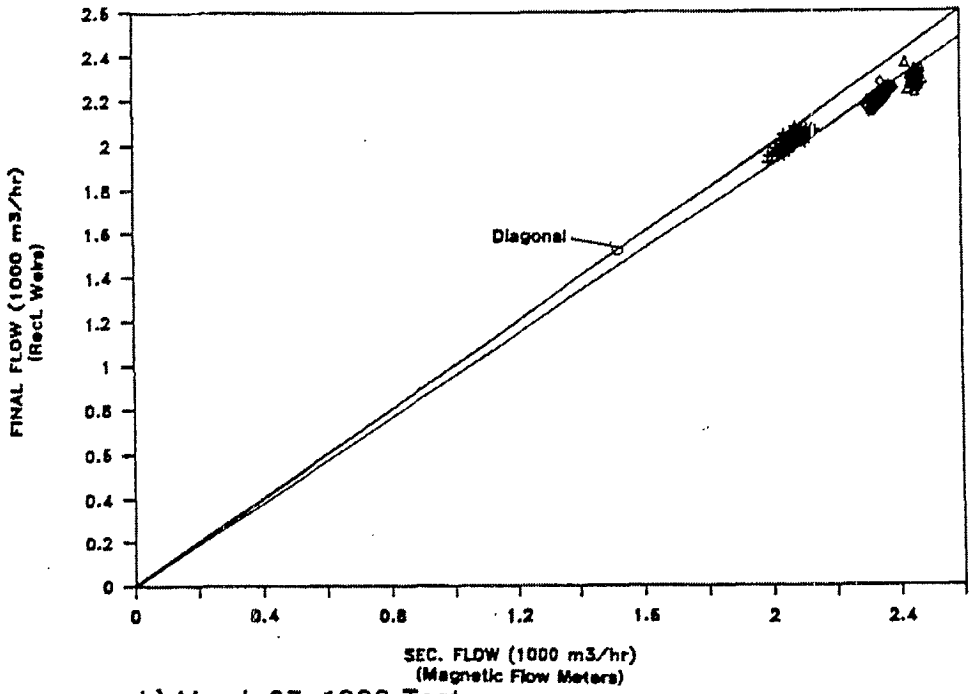
Two sets of tests were completed. The results of the two tests are shown in Figure 4-4. For the first test, the instrument values from both locations were identical (i.e. within 0.5 percent). For the second test during which flows were significantly higher, the magnetic instruments were on average 4.5 percent higher than the effluent rectangular weir flow. Both sets of tests provided results indicating that the magnetic flow meters conformed with the final effluent flow meters within the level of accuracy generally accepted for these types of instruments.

The return activated sludge (RAS) rate is determined by a magnetic flow meter downstream of the return activated sludge pumps. RAS is pumped to a 3-way splitter box from which it flows by gravity to the three aeration tanks. The meter was checked by comparing the average daily return rate, determined using data logged as part of the audit, to the rated capacity of the RAS pumps. For the two-month audit period, the average RAS flow rate was 818 m^3/h. The rated capacity of the RAS pumps is 368 m^3/h each. The plant currently operates two pumps continuously. The approximate capacity is 736 m^3/h.

To more accurately check the RAS flow instrument, an aeration tank solids mass balance was used. Since the primary effluent solids from the Plant 'A' primaries were not measured, it was assumed to equal the Plant 'B' primary effluent solids as measured by an online solids probe. For the 45 days of daily average data used, an error of 5 percent between the flow rate estimated by the mass balance and that measured by the flow instrument resulted. Therefore, the return activated sludge magnetic flow meter provided an accurate estimate of the flow.



a) February 2, 1988 Test



b) March 27, 1988 Test

Figure 4-4
Secondary Flow Meter Verification Using Redundant Instrumentation

Process Audit of the Collingwood Water Pollution Control Plant

The accuracy of the existing plant influent and effluent flow measuring equipment at the Collingwood WPCP was evaluated using a volumetric draw and fill test. On-line monitoring of both the influent and effluent flow signals permitted a real time comparison of the instantaneous flows and the integrated flow over a specific time period.

The influent flow meter consists of a "strap on" Doppler meter, the effluent flow meter consists of a rectangular weir primary hydraulic structure equipped with an ultrasonic level measurement. The chlorine contact chamber was used for the fill test.

Prior to starting the calibration test of the influent meter, the time required for a hydraulic perturbation to travel from the influent meter to the chlorine contact chamber was estimated using on-line data from the influent and effluent meters. Using this data and a cross-correlation function, the hydraulic time lag of the Collingwood WPCP was estimated to be approximately 5 minutes.

The results of the testing are shown in Figure 4-5 and indicate the plant flow metering equipment was operating within the expected accuracy for the meters installed.

Crystal Beach Flow Meter Evaluation

The Crystal Beach effluent meter is a 12-inch Parshall Flume installed in the secondary clarifier discharge channel approximately 1 metre upstream of chlorine injection. The channel is 90 cm wide. The flume appears to be well installed, the grouted joints at the entrance and exit are smooth, nicely tapered, and well sealed. The approach conditions were smooth without standing waves or turbulence.

The secondary element is a Milltronics Multiranger plus with an ultra-sonic level sensor. The level sensor is solidly mounted at the centre of the flume convergence section at the appropriate point specified for Parshall Flumes. The measuring system was calibrated for a flow range of 0 to 40,000 m^3/day.

Application of the dye dilution method of flow meter evaluation at this site involved dye injection in the effluent channel at the point of clarifier discharge. The sample point was located after the flume approximately 1 metre ahead of chlorine injection. Care was required during sampling to ensure that there was no chlorine interference in the test results.

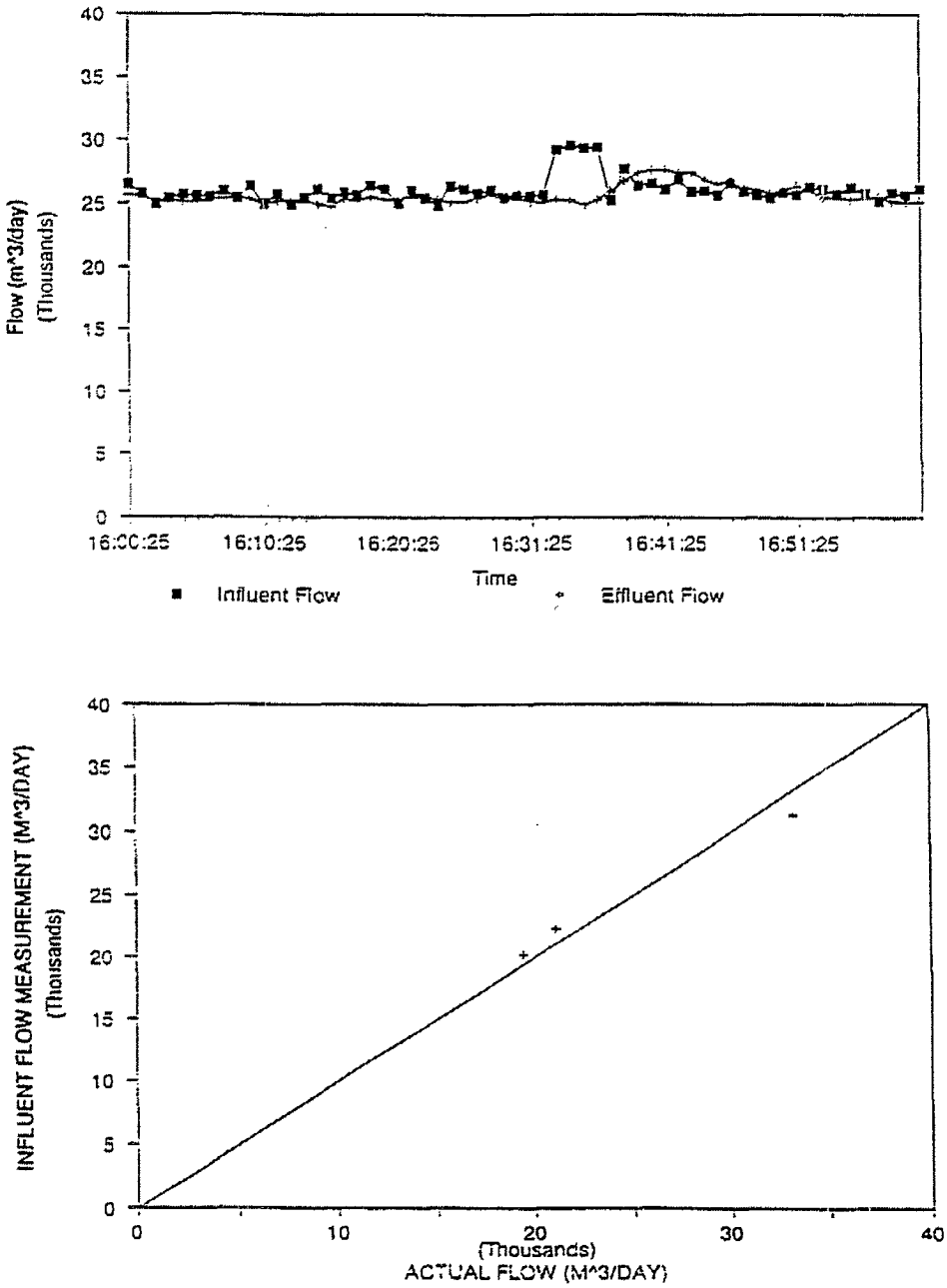


Figure 4-5
Influent Flow Meter Calibration at Collingwood WPCP

The difference between the metered and calculated values for all data was 3 percent of the indicated flow. The meter was accurate to within the estimated +/- 5 percent error of the field test. Flow steadily increased during the test from 4500 m^3/day to 8000 m^3/day. Errors were consistent across the measured range. The meter was in good working order.

Assessment of Seaway Pollution Control Plant Flow Measurement Weir

The effluent from the Seaway Pollution Control Plant (SPCP) in Port Colborne is measured by a suppressed (i.e. full-width) rectangular weir as shown in Figure 4-6. This weir was designed as a sharp-crested weir, but concerns about its measurement accuracy and possible drowning at higher flows were raised during the audit of flow measurement facilities. Because the flows measured by this weir are used for billing purposes, measurement accuracies higher than those required under the MISA regulations are desirable.

The SPCP Flow Measurement Weir in Port Colborne is a non-standard rectangular weir. The main deviation from standard weir specification is the lack of aeration of the downstream weir face, which leads to the attachment of the weir nappe to the weir plate and the supporting concrete structure. This feature increases the discharge through the facility and causes the facility to operate as a short-crested weir rather than a sharp-crested weir. Because the condition is stable, the facility produces a well-defined rating curve which was determined by calibration of a 1 m section of the weir in a hydraulics laboratory.

The investigation was carried out in a full-scale hydraulic model of the weir. The selection of this large scale was deemed necessary in view of the weir operation as a short-crested weir rather than a sharp-crested weir. Short-crested weirs are more difficult to model and modelling results may be affected by scale effects. The testing of the model weir was done by installing a 1-m wide section of the weir in the laboratory 1 metre wide flume. Because the flume is relatively shallow (0.6 m), it was impossible to scale properly the depth of flow in the approach channel. Therefore, it was necessary to correct the model measurements for the shallow depth of water in the approach channel.

To derive rating curves for the weir designs tested, discharges over the model weir were measured for a wide range of flows by means of a laboratory 90° sharp-crested V-notch weir. The accuracy of such measurements was estimated as ±1 percent. The corresponding weir heads were measured directly in the approach channel by a point gauge located 1 metre upstream from the weir. The accuracy of these head measurements was estimated as ±0.3 mm.

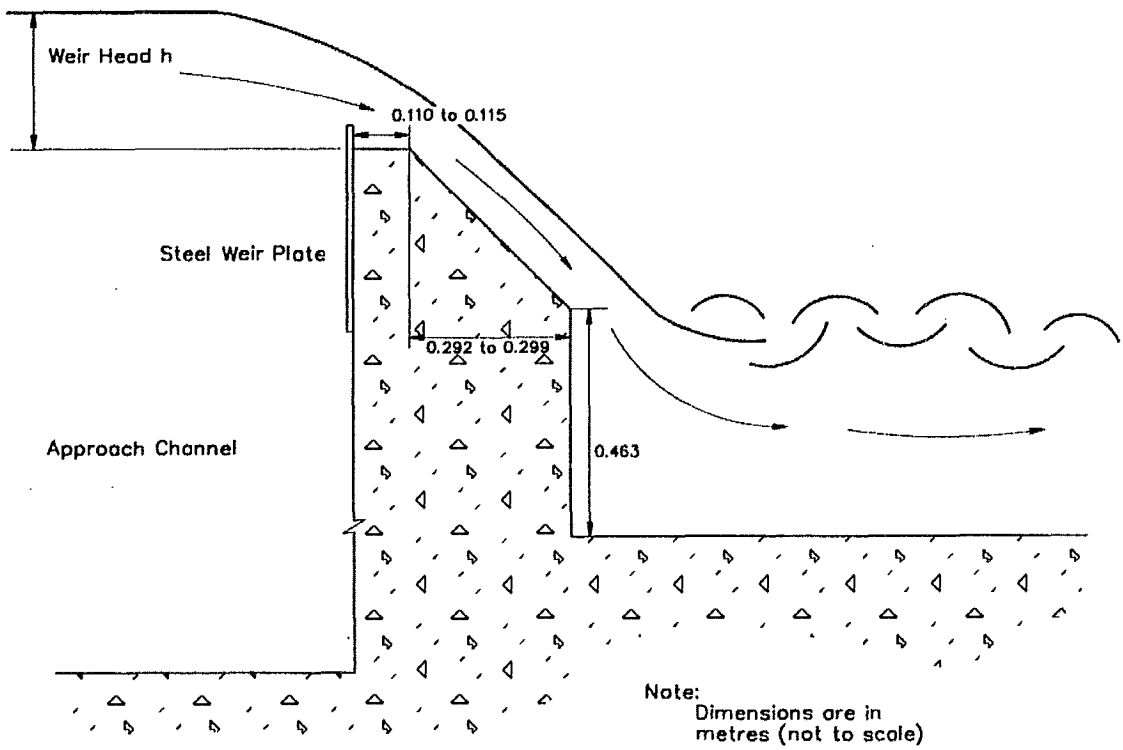


Figure 4-6
Effluent Weir Structure at Seaway WPCP

Modifications of the existing SPCP weir to make it comply with standard weir specifications would be costly. It would require the weir crest to be elevated by at least 0.2 m and to install vents along the downstream weir face, or the concrete supporting wall would have to be removed and replaced by a thin metal structure which would again require venting. In view of the satisfactory results obtained with the existing structure, it is recommended to retain it and use it with the new rating curve produced by this study as shown in Figure 4-7. It also appears feasible to keep the existing slanted, uneven weir crest without causing excessive measurement errors. Such errors can be reduced by using weir heads averaged across the full weir width.

4.5 EXPECTED DURATION AND COSTS

Table 4.3 presents an estimate of the duration and costs for an evaluation of flow metering equipment.

Table 4.3
Expected Duration and Cost for an Evaluation of Existing Flow Metering Equipment

Task	Person Days
Background Information	2 - 5
Physical Inspection	1
Field Calibration	
• Draw/Fill Test	4 - 8
• Dye Dilution	2 - 4
• Hydraulic Modelling	10 - 30
Interpretation	2 - 4
Report	2

Expenses		
Equipment Rental	- Fluorometer	@ $100/day
	- Datalogger	@ $225/wk
Materials	- Rhodamine	@ $60/kg

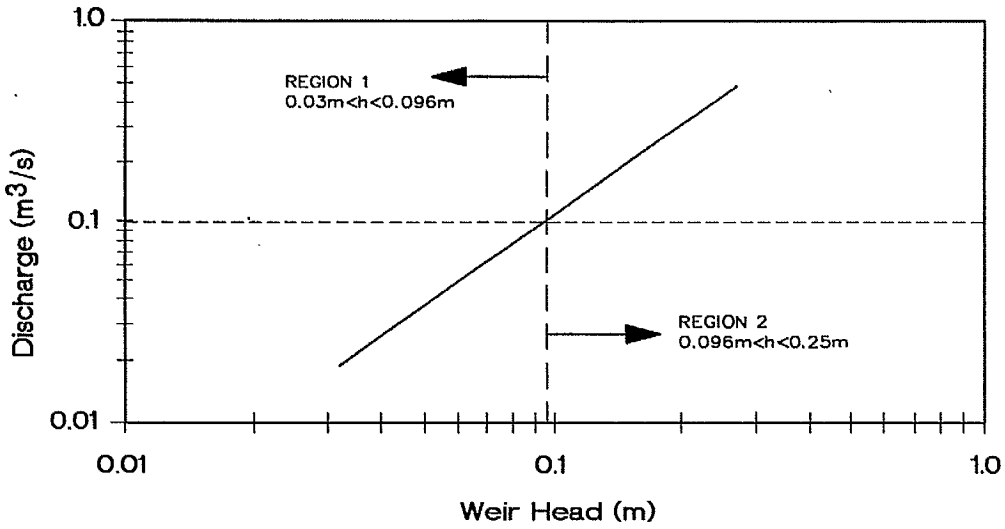


Figure 4-7
Rating Curve Developed for the Seaway WPCP Effluent Weir

4.6 REFERENCES

Crosby, Robert M. *Dye Dilution Flow Measurement Procedure*. Crosby and Associates Inc. Plano, Texas. 1987.

Grant, Douglas M. *Isco Open Channel Flow Measurement Handbook*. 3rd ed. Isco, Inc. Lincoln, Nebraska. 1989.

Kulin, Gershon. Recommended Practice for the use of Parshall Flumes and Palmer-Bowlus Flumes in Wastewater Treatment Plants. Cincinnati: Municipal Environmental Research, Office of Research and Development, U.S. Environmental Protection Agency. 1984(a).

Kulin, Gershon. Recommended Practice for the Use of Electromagnetic Flowmeters in Wastewater Treatment Plants. Cincinnati: Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. 1984(b).

Kulin, Gershon. Recommended Practice for Flow Measurement in Wastewater Treatment Plants with Venturi Tubes and Venturi Nozzles. Cincinnati: Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. 1984(c).

Marsalek, J. Hydraulic Modelling of Flow Measurement Systems. Paper presented at Flow Measurement Workshop. Sacramento, California. May 16, 1991.

U.S. Environmental Protection Agency (U.S. EPA). NPDES Compliance Inspection Manual. Office of Water Enforcement and Permits, U.S. Environmental Protection Agency. 1988.

Water and Wastewater Instrumentation Testing Association (W/WW ITA). Flowmeters. Report DC-1, Designer Checklists, Vol. I. Washington, D.C.

Water Pollution Control Federation (WPCF). Process Instrumentation and Control Systems, Manual of Practice O&M-6. 1984.

CHAPTER 5
ONLINE MONITORING

5.1 GENERAL OBJECTIVES

Typical data collection at a wastewater treatment plant involves a combination of grab and composite samples. Grab samples represent a point of data in time while composite samples represent an average over a period of time. Unfortunately, both of these methods fail to identify dynamic (or "real time") responses occurring in wastewater treatment facilities (Figure 5-1). Online monitoring is a system consisting of field instrumentation and a computer which is used to collect and record real time data.

Online monitoring is a key component of a process audit, providing the tools required to observe the dynamic behaviour of the treatment processes under typical operating conditions or in association with other process audit tasks. Processes with relatively slow rates of change, such as anaerobic digestion systems, do not typically lend themselves to online monitoring techniques.

In the overall context of a process audit, the objectives of online monitoring are to:

- Reveal real time responses by providing an instantaneous display of data
- Determine cause and effect relationships within the treatment plant
- Provide a system for statistical data analysis and data storage
- Support data collection requirements for other process audit technologies or process modelling

Data is typically collected over a period of several weeks to several months to allow process relationships to be quantified for a variety of loading and operating conditions.

5.2 BUILDING A COMPUTERIZED DATA ACQUISITION SYSTEM

The principal components of an online monitoring system (Figure 5-2) are as follows:

- Temporary field instruments and existing plant instrumentation
- Field transmitters
- Data acquisition system, consisting of a signal processor (analog to digital converter), personal computer and printer

The field instrument signals from both temporary field instruments and/or existing plant instrumentation are processed and transmitted to the data acquisition system. The signal processor is used to convert the signals and for temporary data storage. The data, converted to engineering

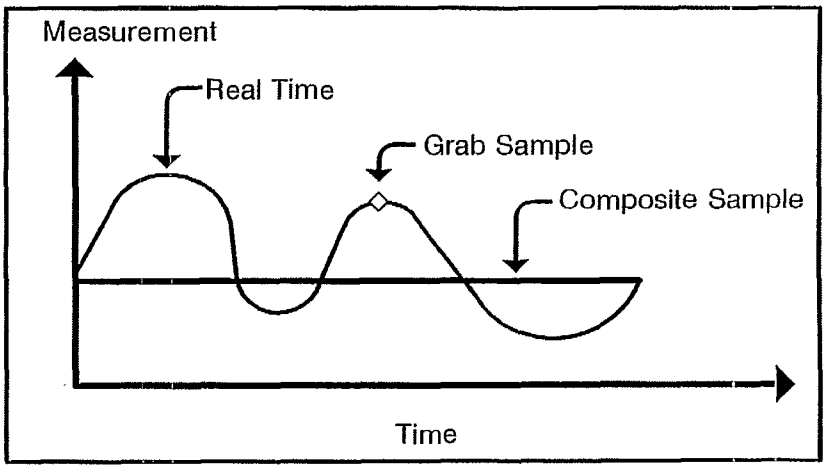


Figure 5-1
Types of Data Sampling

units, is displayed on the personal computer and stored for analysis. A printer is usually included in the data acquisition system to obtain hard copies of daily summaries such as trend plots and average data values.

5.2.1 Software Requirements

The software required for the process audit data acquisition system may be either custom computer programming or one of many commercial software packages available which will fulfil the following minimum requirements:

- Convert raw signals (i.e. 4-20 mA, 0-20 V etc.) to engineering units (i.e. mg/L, m^3/day, etc.)
- Store calibration records and provide input signal control
- Compute statistical data summaries (i.e. daily average, maximum and minimum values) and process loading conditions as appropriate
- Provide graphical displays (trends) of collected data (i.e. daily, weekly)
- Log data in a storage system for analysis
- Provide remote communication capabilities and commercial software links, if appropriate

Custom software may be developed using any of the standard programming languages for engineering applications (i.e. C, Pascal, Basic, etc.). Some examples of prominent commercial

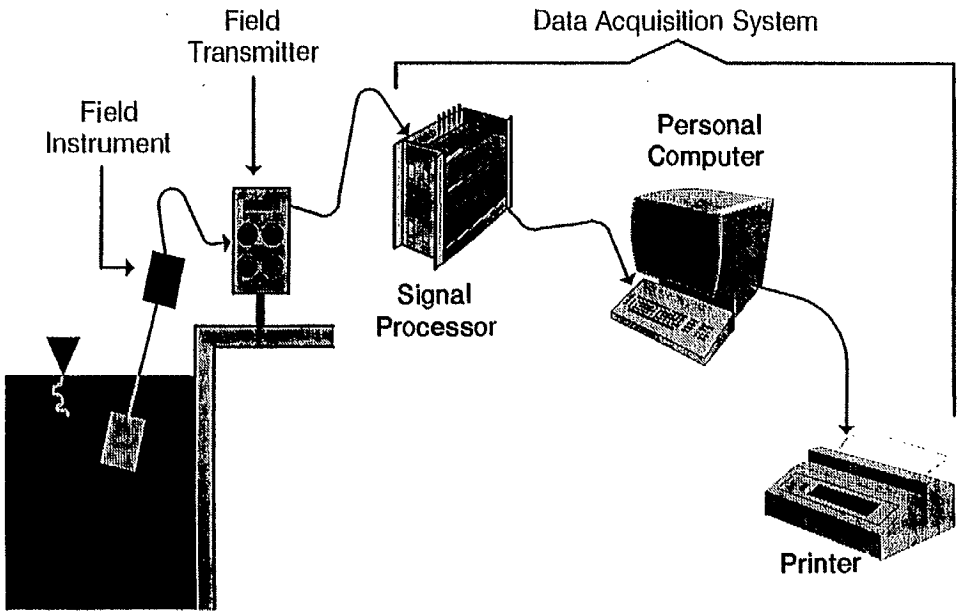


Figure 5-2
Online Monitoring System Schematic

software packages which may fulfil the minimum software requirements of a process audit application are presented in Table 5.1. However, it is recommended that the specific functions and details of any commercial software package for a process audit application be carefully reviewed in conjunction with the supporting data acquisition platform. The listing of commercial software packages provided in Table 5.1 is provided as an example only and does not constitute any recommendation for the applicability of a specific software package.

5.2.2 Hardware Requirements

The hardware required for a process audit typically includes a front-end control device and a personal computer including monitor, keyboard and printer. Minimum specifications for the computer system are as follows:

- An IBM PC-XT or an IBM compatible
- 640 Kb of RAM
- 20 Mb hard disk and one floppy drive
- Colour monitor with graphics capabilities
- Parallel communications port
- Printer

However, selected hardware must support the specific software requirements and provide sufficient memory for data collection and storage during the online monitoring period. Therefore, an IBM or IBM compatible 386/486 platform with up to 8 Mb of RAM may be required for commercial data acquisition software, especially with the current trend toward Windows-based interfaces. The hardware used for a process audit may be exposed to more severe environmental conditions (i.e. moisture, dust, corrosive gases) than the typical office environment for which most computer hardware is designed.

Several process audits have been conducted using a "MiniSAFE", which is a system manufactured by Control Microsystems, Inc., as the front-end control device.

The MiniSAFE is a computer control and data acquisition that may be programmed directly to act as an input/output device for personal computers. The MiniSAFE hardware includes a main panel circuit board, central processing unit (8-bit or 16-bit), input/output boards and power supply. The programming language interpreter for the MiniSAFE is SAFE BASIC which is a copyright product supplied by Control Microsystems. SAFE BASIC also contains standard control functions using a series of control blocks to implement PID loops, ratio control, ratio bias control, alarm scanning, and square root functions.

Table 5.1
Potential Commercial Software for Process Audit Applications

Company and Corporate Location	Telephone	Software Product
Comdale Technologies Inc. 933 The Queensway Toronto, Ontario M8Z 5Z1	(416) 620-1234	Process Vision Comdale/C Expert System
Intellution 315 Norwood Park South Norwood, MA 02062	(617) 769-8878	The FIX/FIX DMACS
National Instruments 6504 Bridge Point Parkway Austin, TX	(512) 794-0100 (800) 433-3488	LabVIEW
US Data 1551 Glenvill Drive Richardson, Texas 75081	(214) 680-9700	Factory Link
Wonderware 16 Technology Drive, Suite 154 Irvine, CA 92718	(714) 727-3200	In Touch

Some earlier process audits used Tecmar boards as the front-end device. More recently, other front-end control devices which have been used successfully in wastewater treatment plant evaluations include process logic controllers (PLC) which are widely available (i.e. Moore Industries, Allen-Bradley, General Electric).

5.2.3 Remote Data Transfer

If a technician is onsite during the online monitoring period, remote data transfer via modem is not normally required. However, in some instances, remote data transfer capabilities may be used to accelerate the data analysis process or the development of dynamic models based on the data collected. Remote control programs such as PC Anywhere, Close-Up, and Co-Session are available to facilitate data transfer activities.

5.3 SELECTION OF INSTRUMENTATION

Process variables which are typically measured with online instrumentation in a process audit are shown in Table 5.2. If a plant consists of more than one treatment train, online monitoring of the process variables in each part of the treatment plant is recommended. An example of the field and plant signals monitored in a wastewater treatment facility to optimize performance of a secondary treatment system is shown in Figure 5-3.

Table 5.2
Online Process Variables Typically Measured in a Process Audit

Process Flowrates	Process Parameters
Influent/effluent wastewater	MLSS concentration
Return activated sludge (RAS)	RAS/WAS suspended solids concentration
Waste activated sludge (WAS)	Dissolved oxygen (DO) concentration
Process air	Effluent suspended solids concentration
	Sludge blanket height
	Process air temperature and pressure
	Aerator power draw

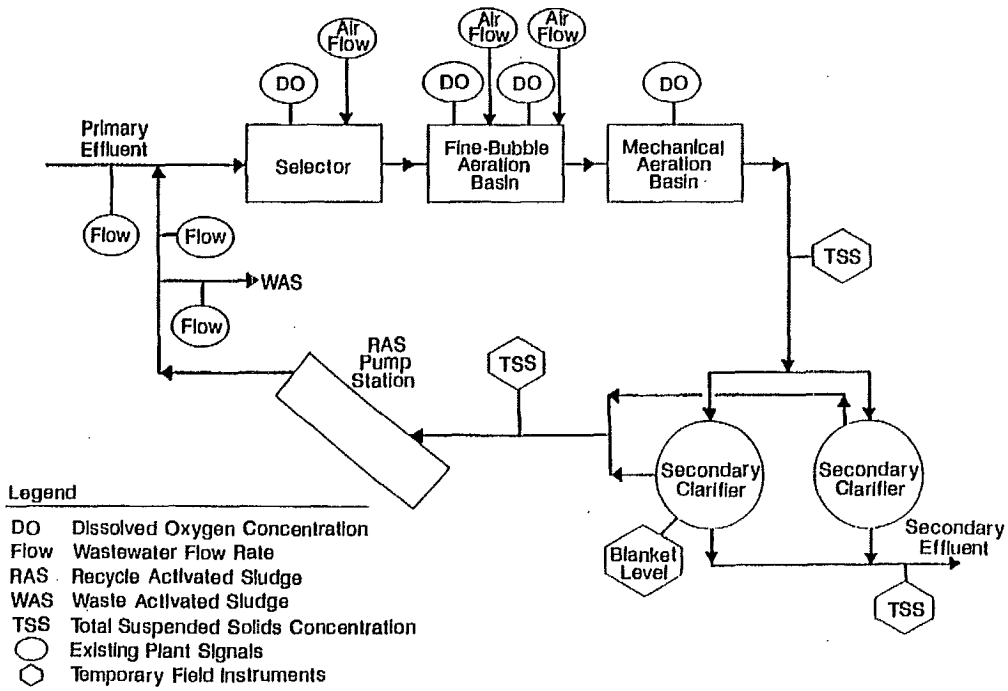


Figure 5-3
Plant Monitoring Schematic

The selection of additional instrumentation for a process audit is related directly to the objectives and scope of the project. For example, it may be appropriate to include nutrient analyzers and/or chemical tank levels for those process audits where the objectives of the project concern the field evaluation of nutrient removal capabilities. Other parameters which should be considered for online monitoring during a process audit are listed below:

- Nutrient concentrations (e.g. phosphorus, total ammonia-nitrogen, nitrate-nitrogen)
- Levels (e.g. chemical tank, wet well)
- Oxidation-reduction potential
- pH and liquid temperature

A task order form and site visit checklist are included in Appendix 5-A and Appendix 5-B as the first step of a project which involves online monitoring. The task order form and site visit checklist present the preliminary information to be collected and serve as a plan for the selection of appropriate process audit instrumentation and the field work set-up process.

5.4 USING EXISTING PLANT INSTRUMENTATION

Some of the process variables to be continuously monitored during a process audit may be permanently installed at the wastewater treatment facility. For example, as a minimum, most wastewater treatment facilities have either influent or effluent wastewater flow recording devices for regulatory reporting purposes. Existing plant instrumentation may be temporarily interfaced to the data acquisition system (with the appropriate signal isolation) during the online monitoring period. **However, it is recommended that the process audit provider assume responsibility to review the installation and calibration of the existing plant instrumentation prior to its use to ensure reliable and accurate data is obtained during the process audit.** If existing plant flow instrumentation is used in the process audit, it is usually necessary to include flow metering assessment (refer to Section 4) when feasible as a process audit task.

At project mobilization, a list of necessary equipment and materials is assembled based on the completed task order form and site visit summary. At this point, the existing plant instrumentation and additional temporary instrumentation to be included in the online monitoring has been defined. An example of an equipment and materials checklist for online monitoring set-up is included in Appendix 5-C.

5.5 RESPONSIBILITIES OF FIELD PERSONNEL

Field personnel act as a direct onsite liaison with the plant staff. In this role, field personnel contribute substantially to the success of the project. To coordinate the activities of the process audit and to ensure the cooperative participation of plant staff, field personnel keep plant staff informed of project progress and activities. Field personnel also assume responsibility for the set-up of all equipment and the ongoing calibration and maintenance required to ensure that the equipment is in working order and yields reliable results. This typically involves an initial calibration of all measuring devices as well as a schedule of routine maintenance and calibration checks and equipment troubleshooting, if required. In some instances, plant staff may be requested to assist with scheduled field maintenance and calibration activities. Field personnel are also generally responsible for the maintenance of the data acquisition system and onsite data management activities (i.e. printing daily summaries and trend plots, making backup copies of saved data, etc.).

5.5.1 Operation and Maintenance Scheduling Checklist

All monitoring equipment must be periodically maintained and its calibration checked to verify that it is in proper working order and yielding reliable data. A realistic maintenance and calibration test schedule

must be developed and implemented. Since each situation is unique, the problems encountered at each treatment facility will be different. For example, a plant with no screening equipment may experience rag buildup on a probe, a condition requiring constant attention. In some plants, an excess of oil and grease can cause fouling of the membranes of DO probes, necessitating frequent cleaning and attention. It is important to establish the frequency of maintenance and calibration checks early in the project to avoid the collection of inaccurate data during the process audit.

Although the frequency of calibration is determined by the application and the instrument quality, an example of a typical operations and maintenance scheduling checklist for a process audit is provided in Table 5.3. Instrument cleaning may range from wiping the cover of an indicator to removing an online probe (i.e. DO, solids or pH) for cleaning. Generally, DO probes and suspended solids probes require frequent attention to keep them in working order because they tend to become easily fouled with hair, algae, rags, etc. For this reason, it is recommended that they be checked often in the early stages of a process audit so that an appropriate maintenance and calibration schedule can be established. Other instrumentation, such as a non-contacting level detector, may not require any cleaning during the course of a process audit.

Maintenance instructions supplied with each instrument should be followed where dismantling of recorders or analytical probes is required. Calibration of online instrumentation is normally completed at project initiation after installation in the field and as required by periodic calibration checks throughout the process audit.

5.5.2 Field Work Record Sheets, Calibration Status Sheets and Solids Lab Sheets

The recommended approach for quality assurance and quality control (QA/QC) during a process audit is the use of field work records, calibration status and solids lab sheets. The following discussion provides a description of each QA/QC measure, with example sheets provided in the Appendices.

Field calibration checks and recalibration of the instrumentation should be recorded on a field work record sheet similar to the one shown in Appendix 5-D. The field work record sheet is customized to identify the specific instrumentation in the process audit, including measurement parameter and instrument location. The field work record sheets are used to ensure that the established operations and maintenance schedule is completed and to report additional field observations/notes regarding the instrument operation and performance.

Table 5.3
Example Operations and Maintenance Scheduling Checklist

Instrument	Cleaning Frequency	Calibration Check Frequency	Complete Calibration
DO Probe	Daily/Weekly	Daily/Weekly	Project initiation and as required
SS Probe	Daily/Weekly	Daily/Weekly	Project initiation and as required
Flow Meter	-	-	Verify at project initiation
Level Detectors	Not required (non-contacting)	Weekly	Project initiation and as required
Sludge Blanket Detector	Weekly	Weekly	Project initiation and as required
Temperature Device	Weekly	Weekly	Project initiation and as required

The deviation that will be tolerated in a calibration check between the instrument reading and the actual value must be established for each instrument in the process audit. Recalibration of the instrument is to be completed if this deviation exceeds the predetermined limit of tolerance for the deviation. Details of the initial calibration and any subsequent recalibration are recorded on calibration status sheets as illustrated in Appendix 5-E. Onsite laboratory-type analyses which are conducted for calibration purposes (i.e. suspended solids concentrations) are also recorded. An example of a solids lab sheet is presented in Appendix 5-F.

5.6 FIELD EQUIPMENT DESCRIPTION/INSTALLATION/CALIBRATION/TROUBLESHOOTING

This section of the manual contains a basic description of the operating principles, installation concerns, generic calibration techniques and troubleshooting approaches for field equipment typically used for online monitoring in a process audit. Although specific equipment is identified for each parameter, this does not constitute any recommendation for the applicability of specific instrumentation. The selection of appropriate instrumentation must be based on a thorough understanding of the fundamental operating principles of the device and the intended application, measurement range, reliability, maintenance requirements, manufacturer reputation and cost. One source of this type of information is the Instrumentation Testing Association (ITA), a not-for-profit organization of instrument users and designers dedicated to improving the reliability and performance of instrumentation used in the water and wastewater treatment industries.

The organization provides rigorous controlled testing of commercially available instrumentation, develops guidelines for the installation and operation of process measuring equipment and provides a base for information transfer throughout the water and wastewater treatment community. A number of technical papers and instrument evaluation reports are available through the association, which may be contacted as follows:

Water and Wastewater
Instrumentation Testing Association
1225 Eye Street, N.W., Suite 300
Washington, D.C. 20005
(202) 682-3760

In general, installation and calibration of field instrumentation must be completed following the detailed procedures provided by the manufacturer, including proper orientation and location in the process. If the equipment is not installed or calibrated properly, inaccurate data may be collected during the process audit or equipment damage may occur, resulting in a possible loss of data during the online monitoring period.

5.6.1 Field Wiring

Field wire carries the instrument signals from the various equipment installed throughout the plant to the data acquisition system. The data acquisition system is typically centrally located to minimize wiring distances (i.e. a control room or administration building), with consideration of environmental conditions in the selected location.

Wherever possible, it is recommended that all signal wires be run along handrails and overhead of walkways. Wire should not be run on the ground where it can be damaged by groundskeeping equipment and/or foot traffic. During installation, wire should not be dragged on concrete structures or roadways as this will result in excessive wear of the protective insulation covering. Wooden strapping poles may be erected from railings to create overhead wire guides. Plant staff should be informed of overhead wire locations and all temporary wiring for the process audit should be clearly marked with caution tape.

Twisted shielded pair (18-24 gauge) wire is generally sufficient for carrying the milliamp outputs of the field instrumentation. Heavier gauge wire may be needed if high voltage is required to power instrumentation.

5.6.2 Dissolved Oxygen (DO) Probes

A DO sensor generally consists of two electrodes immersed in an electrolyte. The oxygen content of the electrolyte reaches equilibrium with the oxygen content of the process fluid (i.e mixed liquor) through a membrane. The rate of reaction induced in the electrolyte creates a current flow between the electrodes which is proportional to the dissolved oxygen concentration in the wastewater.

Some suppliers of online DO instrumentation for wastewater applications are listed as follows:

- Capital Controls Company Inc.
- Danfoss Manufacturing Company Limited (Lisle-Metrix)
- Enterra Instrumentation Technologies
- Fischer and Porter Company
- Bestobell Engineering Products Ltd. (Züllig)
- Rosemount Analytical, Delta Division
- Royce Instrument Corporation

An ITA evaluation report is available (ITA, 1988) for these dissolved oxygen instruments (sensor and transmitters). It is recommended that the specific performance details of any DO instrumentation be carefully reviewed prior to use in a process audit application. Specific installation, calibration and troubleshooting information is usually provided by the manufacturer.

In a process audit application, the DO probe is inserted into an aluminium pole or PVC pipe with a threaded 45° elbow joint. All threaded joints are sealed to prevent leakage into the pole and possible damage to the probe. The wires from the probe are threaded through the pole and attached to the junction box. The top of the pole is plugged with a rubber stopper to prevent rain or snow from entering. The pole is normally mounted to the handrailing around the aeration tank using a mounting bracket. The probe itself may be fitted with a plastic flotation ball to prevent the probe from sinking below the surface during normal operation. The flotation ball may be removed to determine dissolved oxygen profiles or the dissolved oxygen concentration at difference depths in the aeration basin during specific test procedures (refer to Section 7). A schematic of a typical DO sensor installation is shown in Figure 5-4.

DO probes normally installed for a process audit will provide a profile of the DO concentration along the length of the aeration basin (i.e. one DO probe in each cell). The number of DO probes required to accomplish this objective is a function of the size and configuration of the aeration tanks at the facility. Equipment/wiring costs may be reduced using a multiplexer which allows multiple DO probes to be monitored simultaneously by only one transmitter.

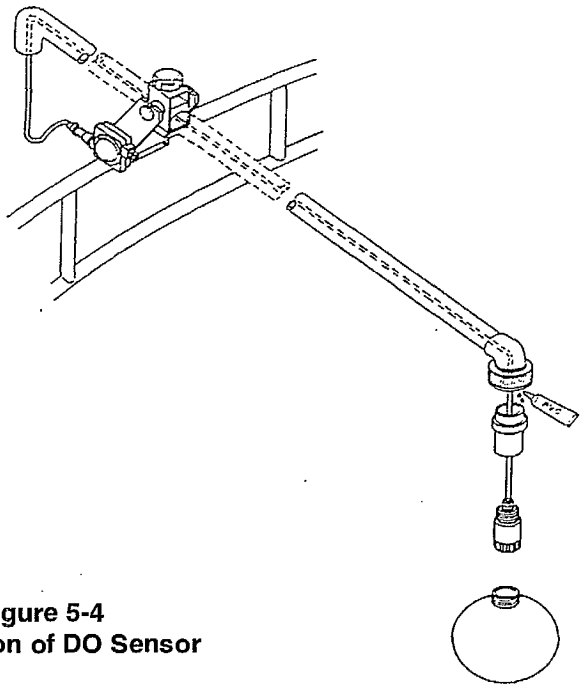


Figure 5-4
Installation of DO Sensor

DO probes are normally cleaned daily as time permits. To clean the probe, the handrail bracket is loosened and the probe is removed from the process location. Slime or dirt deposits may be removed by gently wiping the surface of the membrane with a wet piece of paper towel. Care is recommended in cleaning the membrane to prevent damage. Heavier accumulations may be removed with a squirt bottle. The probe may be placed back in service after cleaning.

A calibration canister (Figure 5-5) is recommended for calibration of DO probes. A wet piece of paper towel or sponge is placed inside the canister. The tubing from the canister is tie-wrapped to the pole to prevent mixed liquor from entering the canister, while allowing the pressure inside the canister to equal atmospheric conditions. The probe is put back into the tank for at least 30 minutes to ensure that the temperature inside the canister is in equilibrium with the wastewater. A reliable thermometer or YSI dissolved oxygen meter with temperature indicator is used to obtain the temperature of the basin, providing a specific saturation value at that temperature. The calibration of the DO probe is then adjusted accordingly using the procedures provided by the manufacturer.

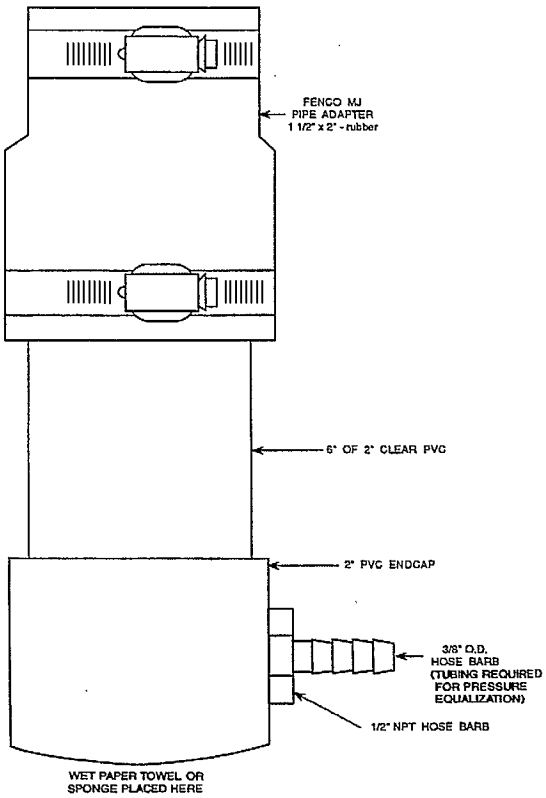


Figure 5-5
DO Calibration Canister

Some common problems associated with the operation of DO probes during a process audit include the following:

- Rain/snow entering electrical components or the probe itself
- Heavy fouling of the DO probe membrane, requiring frequent cleaning
- Tears in the membrane which then requires replacement of the membrane

5.6.3 Suspended Solids (SS) Meters

A suspended solids analyzer most commonly uses the optical properties of solids in wastewater to detect changes in suspended solids concentrations. A beam of visible or infrared light is transmitted through the wastewater, and a detector senses the amount of light that penetrates the sample. Optionally, the detectors may be mounted to measure the amount of light that is absorbed, reflected, or scattered by the solids. During calibration of suspended solids probes, the optical properties are related to the concentration of suspended solids in the wastewater. Other approaches in suspended

solids instrumentation relate the suspended solids concentration to either the acoustical (ultrasonic) or nuclear properties of the wastewater.

Several suppliers of suspended solids instrumentation provide different models, which may operate on variations of the optical measuring principle, for the different applications possible within the wastewater treatment facility (i.e. raw sludge, mixed liquor, return/waste activated sludge and final effluent). Some suppliers of suspended solids instrumentation for wastewater applications are shown in Table 5.4 as a function of the operating range of the application and the principle of operation.

A three-part ITA evaluation report is available (ITA, 1991; ITA, 1993) for these suspended solids instruments (sensors and transmitters). It is recommended that the specific performance details of any suspended solids instrumentation be carefully reviewed prior to use in a process audit application. Specific installation, calibration and troubleshooting information is usually provided by the manufacturer.

For the temporary installation of suspended solids instrumentation during a process audit, one of the most important factors is the installation of the probes in a location that is representative of the process.

The suspended solids instrument selected for a particular location must be appropriate for the range in suspended solids anticipated in the process stream. The range in suspended solids concentrations expected in the process streams of conventional activated sludge process streams are listed in Table 5.5 as a guideline for instrument selection. However, the ranges identified are guidelines only and they are not intended to replace detailed discussion with the plant operations staff or data review of the actual range in suspended solids concentrations experienced at the facility.

Suspended solids probes which operate on optical principles may be susceptible to ambient light conditions. To minimize the possible effects of ambient light, MLSS and RAS probes may be submerged. A final effluent probe is more susceptible to ambient light as a result of the clarity of the effluent. It is possible to use either plywood or black plastic to shield a suspended solids probe in the final effluent. If possible, it is also recommended that the probe be installed in a process stream location with sufficient velocity to minimize the accumulation of deposits on the probe.

Normally, manufacturers supply the suspended solids probe and its transmitter together. The probe is mounted in the process stream according to the specific installation procedures and connected to the transmitter. All electrical connections associated with the instrumentation should be well sealed to prevent the intrusion of moisture and/or gases. If possible, the transmitter should be located indoors or protection from weather conditions (i.e. rain, snow) should be provided.

Table 5.4
Suppliers of Suspended Solids Instrumentation for Wastewater Applications

Supplier	Low Range (4-40 mg/L)	Medium Range (1,500-15,000 mg/L)	High Range (0.8-8.0%)
	Principle of Operation	Principle of Operation	Principle of Operation
BTG Inc.	Optical	Optical	Shear Force Optical
Great Lakes Instruments Inc.	Optical	Optical	
Hach Company	Optical	Optical	
Instrumark Int.	Optical		
Markland Specialty Engineering Ltd.			Ultrasonic
Monitek Technologies Inc.	Ultrasonic	Optical	Optical
Ohmart Corporation			Nuclear
Royce Instrument Corporation	Optical	Optical	Optical

Table 5.5
Range in Suspended Solids (SS) Concentrations in the Process Streams of Conventional Activated Sludge Plants

Process Stream	Typical Range in SS Concentration
Raw Influent	50 – 500 mg/L
Primary Effluent	50 – 500 mg/L
Final Effluent	0 – 100 mg/L
MLSS	1,000 – 8,000 mg/L
RAS/WAS	3,000 – 15,000 mg/L
Primary (Raw) Sludge	0.5 – 5.0 %

Suspended solids probes generally require frequent attention to keep them operational because of the tendency of hair, algae, rags and debris to wrap around the measuring probe. For this reason, suspended solids probes should be checked often in the early stages of a process audit so that an appropriate cleaning and calibration schedule can be established early. For most SS instrumentation, cleaning the probes involves removing the probe from the process stream, removing any accumulated debris, and wiping the sensor head with a rag.

Instrument calibration procedures provided by the manufacturer should be completed following installation, and as required throughout the process audit to maintain instrument accuracy. A three-point calibration at low, medium, and high concentrations spanned over the expected range of concentration is generally recommended. The equipment required to complete a three-point calibration of an insertion-type probe is listed below:

- Suspended solids instrument, including probe, transmitter and power supply
- Suspended solids test equipment and lab sheets (Appendix 5-F)
- Calibration set-up (Figure 5-6), including calibration canister, rubber stopper with probe entry hole, stir plate and bar, and stir stick (magnet retriever)
- Disposable gloves
- Squirt bottle and tissues (paper towels)
- Three or four 20-litre buckets per instrument to be calibrated

A three-point calibration is completed by following the steps listed below:

1. Fill the buckets with samples of the process stream collected from the probe location and determine the suspended solids concentration of the sample. The suspended solids concentration is determined conventionally according to the method described in Standard Methods (1992) for total suspended solids (2540D. Total Suspended Solids Dried at 103-105°C). The tare weight and the weight after drying should be recorded on solids lab sheets as shown in Appendix 5-F. It is generally recommended that suspended solids concentrations be completed in triplicate.

2. Prepare one lower and one higher concentration of the sample in the buckets respectively by adding dilution water or by decanting a settled sample. The amount of dilution water added or decant removed should be predetermined to ensure that the resulting low and high concentrations correspond to the desired span of the instrument. For final effluent, the collected sample is usually first filtered through a glass fibre filter. Medium and high concentrations are then prepared by adding suspended solids to achieve the desired span of the instrument.

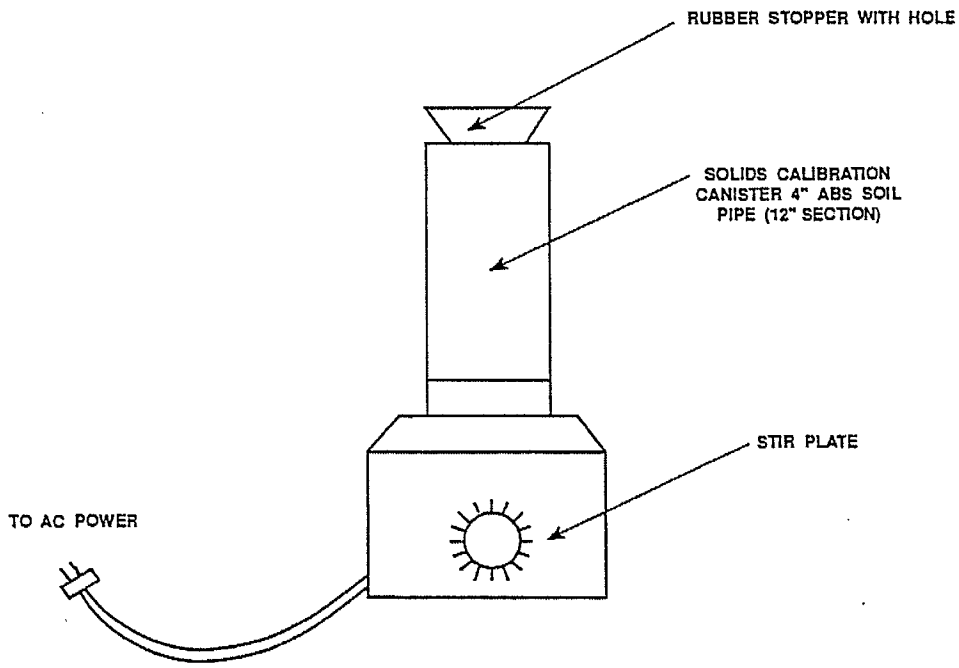


Figure 5-6
Suspended Solids Probe Calibration Canister

3. The calibration canister is filled approximately 3/4 full with sample from the bucket, ensuring that the bucket is well mixed when the sample is taken. The instrument probe is inserted in the calibration canister through the rubber stopper. The sample in the canister is well mixed during the calibration by putting the stir bar in the canister and setting the canister on the stir plate. For each sample (i.e. low, medium and high concentration), the meter reading is allowed to stabilize before adjusting the calibration of the instrument. Although it is difficult to ensure a well-mixed sample, it is possible to submerge the probe in the buckets directly as an alternative for calibration purposes if an experienced technician is conducting the calibration.

4. Suspended solids tests are conducted on representative samples from each bucket to enter the calibration. Some instruments will require this information prior to calibration of the probe signal in the samples. An example of the sheets to be completed for permanent record of the suspended solids test results and the probe calibration are provided in Appendix 5-F and Appendix 5-E, respectively.

5.6.4 Flow Metering Devices

One of the most important parameters measured in a wastewater treatment facility is flowrate. Total plant flowrates may be used to determine process loading rates which may identify capacity limitations or process bottlenecks. In addition, future plant expansions may be linked to the current flow conditions as indicated by the total plant flow measuring device. Other process flowrates, such as return and waste activated sludge quantities are fundamental quantities in the operation of the activated sludge treatment process.

Usually, existing flow instrumentation is interfaced to the data acquisition system during the online monitoring period. **As with any existing instrumentation used during the process audit, it is recommended that the process audit provider assume responsibility to review the installation and calibration of the existing plant instrumentation prior to its use to ensure reliable and accurate data is obtained during the process audit.** If existing plant flow instrumentation is used in the process audit, it is usually necessary to include flow metering assessment as a process audit task when feasible. Detailed information concerning the different types of flow metering devices (including both primary and secondary devices), installation concerns and flow metering assessment techniques are included in Section 4 of this manual.

5.6.5 Sludge Blanket Level Devices

During a process audit, sludge blanket heights are typically measured daily by the onsite technician using a device called a "sludge judge". The device extracts a column of water/ solids from a clarifier to provide a visual profile of the solids in the tank. This approach provides the ability to physically identify the solids/liquid interface in the clarifier. In comparison, sludge blanket devices which are available for online monitoring typically use an ultrasonic or photometric ranging technique to measure the depth of blanket interface. Immediately after generating a narrow beam of ultrasonic energy towards the bottom of the tank, a receiver detects any resulting echoes. The analyzer measures the time delay and the magnitude of these returning signals in the form of a tank profile. Some instruments repeat this procedure several times to build an average profile in memory, thereby minimizing the effects of floating debris or the possible effects of rake passage.

If a sludge blanket height detector is used during a process audit, specific installation, calibration and maintenance procedures provided by the manufacturer should be followed.

5.6.6 Temperature Devices

There are two basic types of temperature sensors for online monitoring: the thermocouple and the resistance temperature detector (RTD). Thermocouples are typically installed in a fixed well, which limits their applicability for temporary installation during a process audit. In an RTD, the resistance of a specific metal wire (i.e. platinum, nickel or copper) to electric current is used for temperature measurement. The resistance of the metal changes predictably over the range of temperatures for which the sensor is designed. Thermistors use a semiconductor, rather than a metal, as the resistance material.

RTDs are used widely in process industries and are therefore widely available from a number of suppliers. It should be confirmed with the manufacturer that the range of temperatures for which the RTD was designed is appropriate for the application. The temperature range for most wastewater applications is from 0 to 30°C. However, waste-water temperatures generally fluctuate according to seasonal changes in ambient temperature. An online temperature device may be used during a process audit to identify unusual temperature fluctuations in wastewater, or to measure process air temperature in connection with the determination of the aeration capacity (refer to Section 7) in which higher temperatures can be experienced.

RTDs are generally easy to install by mounting to a fixed surface. Installation of a floating temperature device in a channel with considerable velocity should be avoided. RTDs are fragile and should be handled carefully during installation. The calibration of the RTD may be checked by comparison to an accurate mercury thermometer in prepared solutions of varying temperature. An RTD should be accurate to within approximately 1°C. Regular cleaning of an RTD is not generally required if the device is located in the final effluent stream. However, the device should be checked regularly in this application to remove algae accumulations and other debris, if observed, which could dampen response.

5.6.7 Nutrient (Phosphorus, Ammonia, Nitrate) Analyzers

The operation of most nutrient analyzers for the wastewater treatment industry are based on one of three principles for the parameter of interest:

- Conventional colorimetric laboratory techniques using wet chemistry
- Absorption of ultraviolet light
- Use of an ion-specific (I/S) electrode

For conventional colorimetric laboratory techniques, the analytical technique is automated through a timed cycle to provide semi-continuous results depending on the length of the analytical cycle. For all principles of operation, the analytical equipment and required chemistry are usually self-contained in an enclosure designed for use in industrial environments.

Although these instruments have been applied successfully at wastewater treatment facilities, these types of instruments have not normally been used in the process audit because of the complexity and cost of these analyzers, ranging from up to as much as $10,000 – $100,000. A sample preconditioning system for the analyzers may also be required depending on the quality of the process stream. If continuous monitoring of nutrients such as phosphorus, ammonia, and nitrate are required to achieve project objectives, an offline sampling program consisting of diurnal grab samples may be developed (refer to Section 6.2) to provide a cost effective alternative to the use of online nutrient analyzers.

Table 5.6 provides a partial listing of specific nutrient analyzers which are currently available worldwide, including the category of the analytical technique used. It is recommended that the specific performance details of nutrient analyzers be carefully reviewed prior to use in any wastewater treatment plant application. Specific installation, calibration and troubleshooting information is provided by the manufacturer. Performance evaluation for this group of instrumentation has not been completed by the ITA.

5.6.8 pH Meters

pH sensors use two electrodes to measure the acidity or alkalinity of a process stream. The measuring electrode is immersed in an electrolyte separated from the process stream by a glass membrane. The reference electrode is mounted outside the membrane. The voltage difference which develops between the electrodes as a result of the difference in hydrogen ion activity is expressed as the pH. pH sensors should be equipped with temperature correction to compensate for the effect of temperature changes on the membrane.

Instrumentation for pH measurement are devices which are used widely in process industries. Therefore, rugged electrode systems and reliable electronic circuits have been developed and are widely available from a number of suppliers. An online pH meter may be used during a process audit to verify suspected pH fluctuations in the influent or effluent flow streams.

The limitations of a pH sensor include the fragility of the glass membrane and the alteration of the pH sensor calibration by membrane fouling.

Table 5.6
Suppliers and Operation Principle of Nutrient Analyzers

Company	Ammonia	Nitrate	Phosphorus
HORIBA, Ltd. (Japan)	UV absorption I/S electrode		Colorimetric (absorbic acid)
Fuji Electric Co. Ltd. (Japan)	UV absorption I/S electrode		Colorimetric
Kimoto Electric Co., Ltd. (Japan)	Gas-sensing electrode		
HACH (USA)			Colorimetric (absorbic acid or molybdovanadate)
Tytronics Incorporated (USA)	Colorimetric (Berthelot or Nessler reagent)	Colorimetric	Colorimetric
ABB Kent-Taylor (Great Britain)	Gas-sensing electrode	I/S electrode	
Capital Controls Company Ltd. (USA)	Gas-sensing electrode	UV absorption	Colorimetric (molybdenum blue)
Scientific Instruments (USA)	Colorimetric (Berthelot)	Colorimetric	Colorimetric (molybdenum blue)
Applikon (The Netherlands)	Colorimetric I/S electrode	Colorimetric I/S electrode	Colorimetric
Bran & Luebbe (Germany)	I/S electrode	I/S electrode	Colorimetric (molybdate)
Skalar (The Netherlands)		I/S electrode	Colorimetric (molybdate)
BTG (USA)	I/S electrode	I/S electrode	
Biotronics (USA)		UV absorption	UV absorption

5.7 USE OF ONLINE MONITORING DATA IN AUDIT TECHNOLOGIES

Online monitoring is a task that is well suited to provide input information and support for other process audit technologies. A graphical representation of these relationships is illustrated in Figure 5-7. The simultaneous collection of real-time process data in association with other process

audit tasks allows identification and quantification of process interactions that could not otherwise be shown.

Online monitoring is a critical support tool for the following process audit tasks:

- Flow metering assessment (Section 4)
- Aeration system capacity analysis (Section 7)
- Hydraulic and/or process modelling (Section 8 and Section 12)
- Unit process stress testing (Section 10)

Further information on the field measurements required to support each of these process audit tasks and specific case study examples are provided in each section respectively.

5.8 PRESENTATION AND INTERPRETATION OF RESULTS

Daily plots and summaries of the collected data are usually generated onsite through the data acquisition system by the field technician. From this database of information, data plots are selected to illustrate significant findings of the process audit and to support the conclusions of specific process audit tasks. Typical trend/graph categories for the presentation of collected online monitoring data are discussed below. Further examples of the interpretation and presentation of online monitoring results are provided in the selected case studies presented in Section 5.9.

5.8.1 Diurnal Variations

The online instrumentation provides an accurate representation of the diurnal variation in the monitored parameters. Often, the diurnal variation in the raw data (i.e. DO concentration or influent/effluent flowrate) will provide valuable data to support the interpretation of impacts on process operation and performance.

At the St. Thomas WPCP (CH2M HILL, November 1992), comparison of the diurnal variation in DO concentration in two parts of the facility (Plant No. 3 and Plant No. 4) indicated that the DO concentration in Plant No. 3 was more variable than the DO concentration in Plant No. 4 (Figure 5-8). Elevated DO concentrations in Plant No. 4 suggested that energy savings could be achieved in this part of the plant by overall reduction in blower output. In comparison, energy savings related to elevated DO concentrations which were observed in Plant No. 3 during unmanned hours of operation (evening) would require automatic adjustment of blower output.

Comparison of the variation in DO concentration at the surface and at mid-depth in an aeration tank may be used to identify mixing limitations. At the Corbett Creek WPCP (CH2M HILL, 1990), two-speed

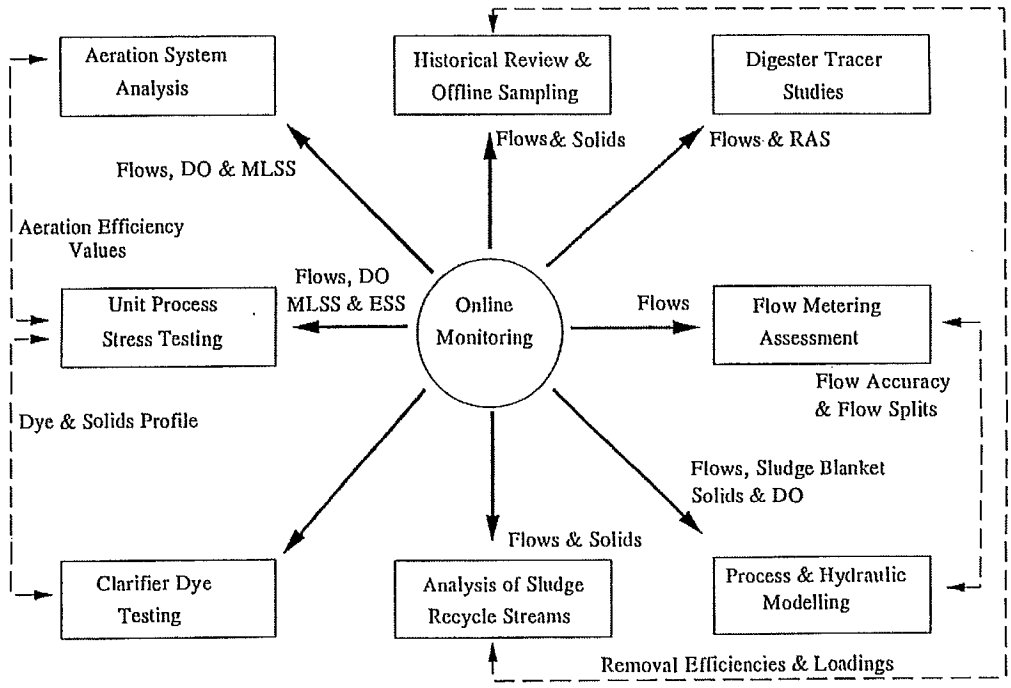


Figure 5-7
Potential Interconnection Between Online Monitoring and Other Audit Technologies

aerator operation effected the DO concentration measured at the surface of the tank as shown in Figure 5-9a. The DO concentration measured at the surface increased by approximately 100 percent under high speed operation, compared to the DO concentration measured at approximately mid-depth which was approximately constant under both high speed and low speed operation. On slow speed operation, the DO concentrations measured on the surface and at mid-depth were approximately equivalent, indicating that the tank was well-mixed. The impact of two-speed operation on the MLSS concentration was also observed (Figure 5-9b).

Influent/effluent flow monitoring will provide a graphical representation of the typical dry weather flow variation. As shown in Figure 5-10a, flow to the Seaway WPCP (CH2M HILL, February, 1992) generally increases through the morning hours. The typical dry weather flow variation provides a basis for comparison when identifying the possible impact of infiltration/inflow on plant operating conditions. At the Seaway WPCP, flows quickly increased up to three times the typical dry weather flow in response to a significant rainfall event (Figure 5-10b). A diurnal flow variation with an elevated minimum flow (i.e. as typically observed during early morning hours) may be an indication of a continuous industrial discharge.

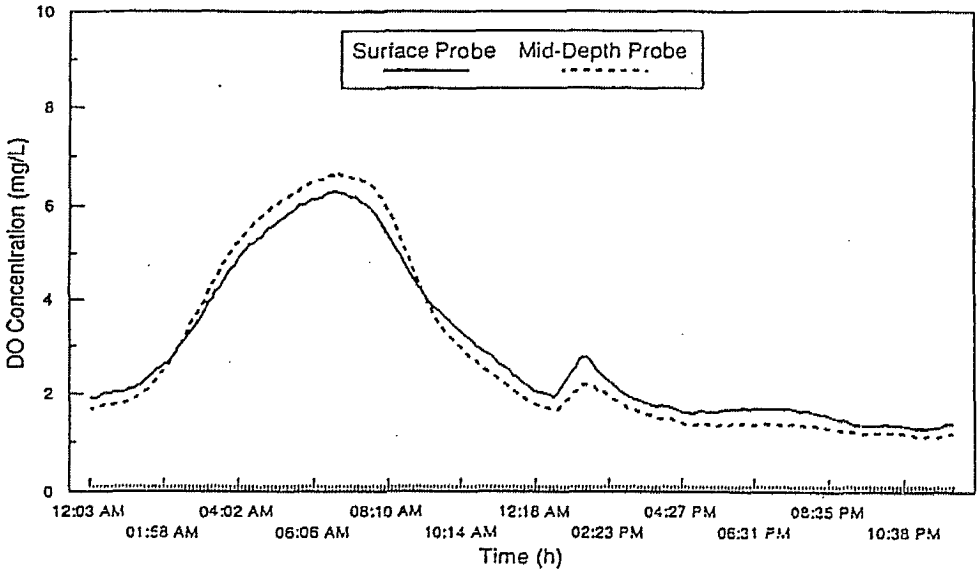


Table 5-8a
Online DO Concentration Time Plot for
Plant No. 3 for June 16, 1992 (St. Thomas WPCP)

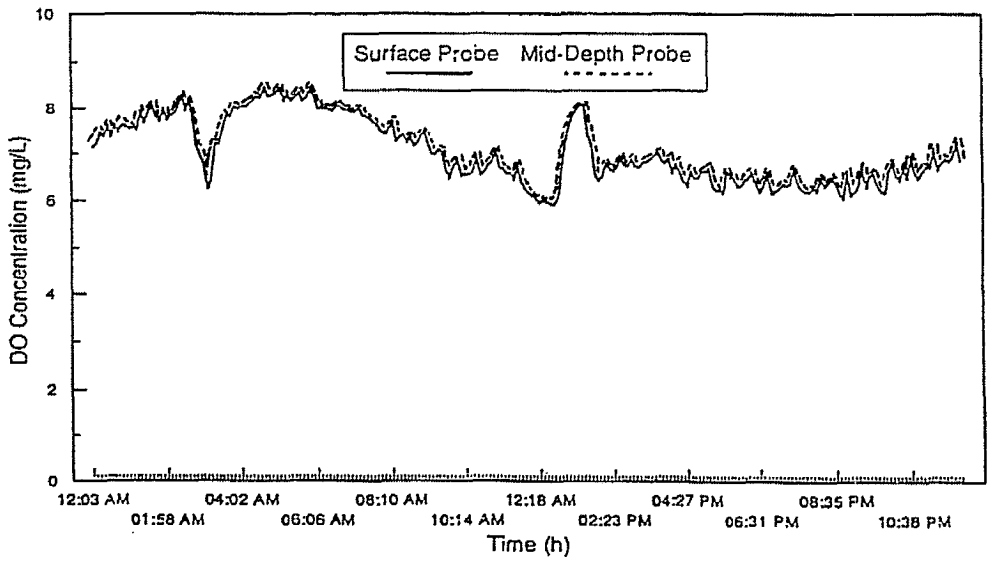


Table 5-8b
Online DO Concentration Time Plot for
Plant No. 4 for June 16, 1992 (St. Thomas WPCP)

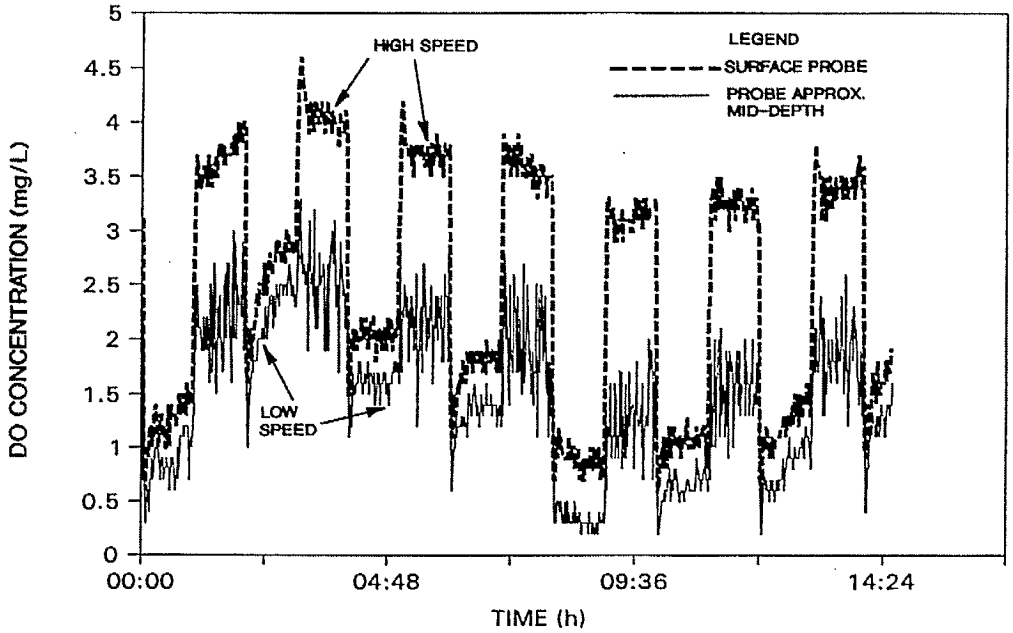


Table 5-9a
Effect of Two-Speed Aerator Operation on Surface and Mid-Depth DO Concentation (Corbett Creek WPCP)

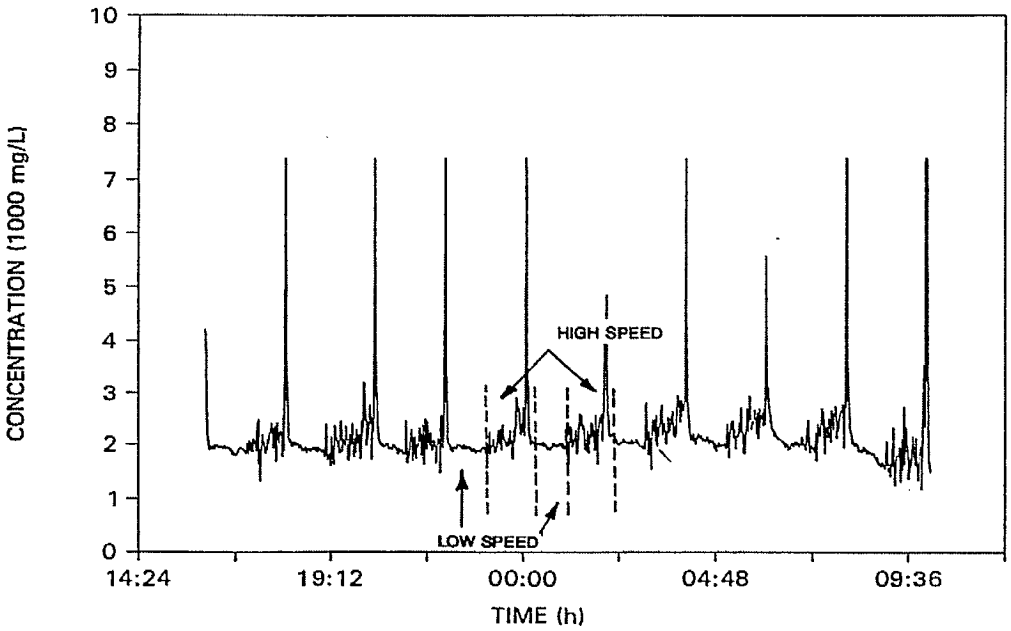


Table 5-9b
Effect of Two-Speed Aerator Operation on MLSS Concentation at Bottom of Aeration Tank (Corbett Creek WPCP)

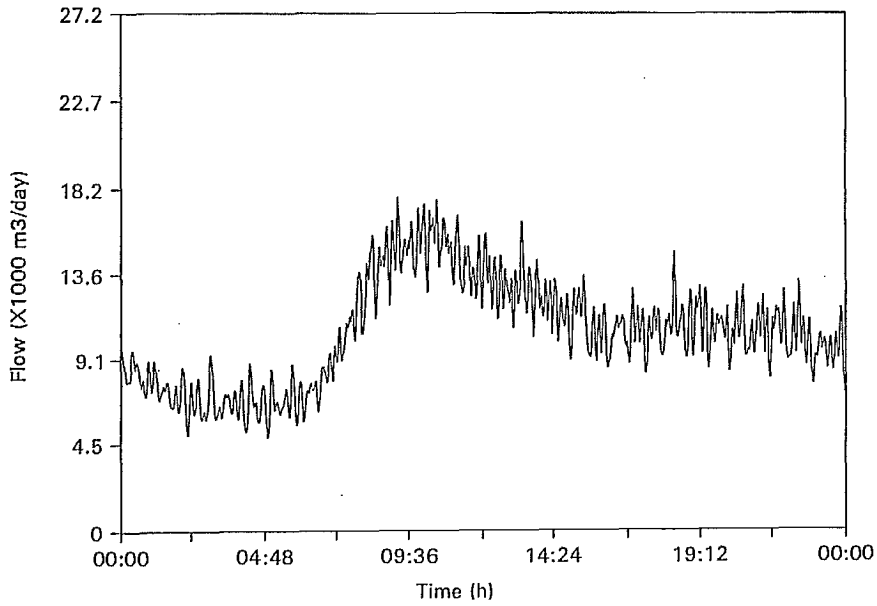


Figure 5-10a
Typical Dry Weather Final Effluent Flow
May 28, 1990 (Seaway WPCP)

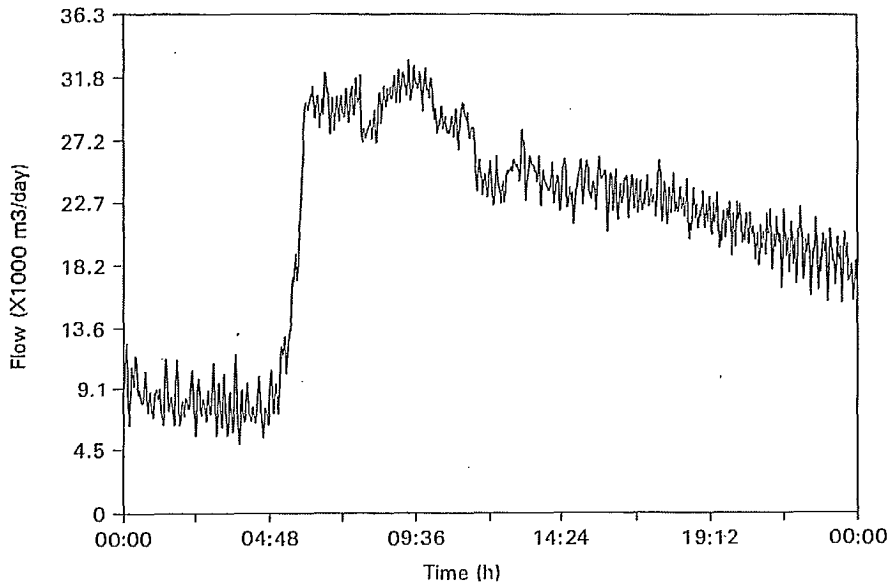


Figure 5-10b
Final Effluent – September 7, 1990 (Seaway WPCP)
During Wet Weather Flow Event

5.8.2 Data Summaries for Entire Monitoring Period

Data summaries are prepared for the entire monitoring period, generally including daily average, maximum and minimum values. This data may be presented as time trends for comparison with offline monitoring results or used for the calculation of key process parameters and process loading rates. As a minimum requirement, average values for all online monitoring data and key process parameters are usually summarized in tabular form.

A trend plot of the daily average, maximum and minimum values was prepared for the DO concentration data obtained at the Woodward Avenue WPCP (CH2M HILL, January 1992). Low DO concentrations generally less than 2 mg/L were observed in the South Plant (Figure 5-11) from the beginning of the monitoring period to April 4, 1991 when the aerator submergence was increased to complete an aeration capacity assessment. The bar chart showing a difference between the daily minimum and maximum values of less than approximately 1 to 2 mg/L emphasizes the consistency of the low DO concentrations measured before increasing the aerator submergence.

At the Oakville South East WPCP, average flow values recorded by the data acquisition system and the plant integrator over the monitoring period for an existing venturi flume with ultrasonic flow transmitter in Plant No. 2 corresponded closely (Canviro Consultants, 1987). However, a discrepancy of approximately 35 percent between the average flow values recorded by the data acquisition system and the plant integrator for the total plant flow as measured by a rectangular weir was observed. Since the total plant flow is directed to Plant No. 2, equivalent flow measurement by the rectangular weir and the venturi flume was expected. The observed discrepancy between the two flow measurements and the impact of the plant hydraulics on the effluent turbidity is shown in Figure 5-12. In the tabular summary of the online monitoring data, the average plant flowrate as measured in Plant No. 2 by the venturi flume was 12,318 m^3/day, compared to an average total plant flowrate of 8,080 m^3/day measured by the rectangular weir. Extensive efforts during the process audit did not resolve the rectangular weir flow discrepancy.

5.8.3 Parameter Correlations

Cause and effect relationships between parameters may be identified from the analysis of the collected online monitoring data. Parameter correlations in the form of trend graphs are developed to support such observations. Common parameter correlations are developed from the impact of diurnal variations (i.e. flow or DO concentration) on effluent quality or the impact of specific operational activities on plant performance. Further discussion with plant staff may be required to identify the cause of specific trends or correlations observed in the online monitoring data.

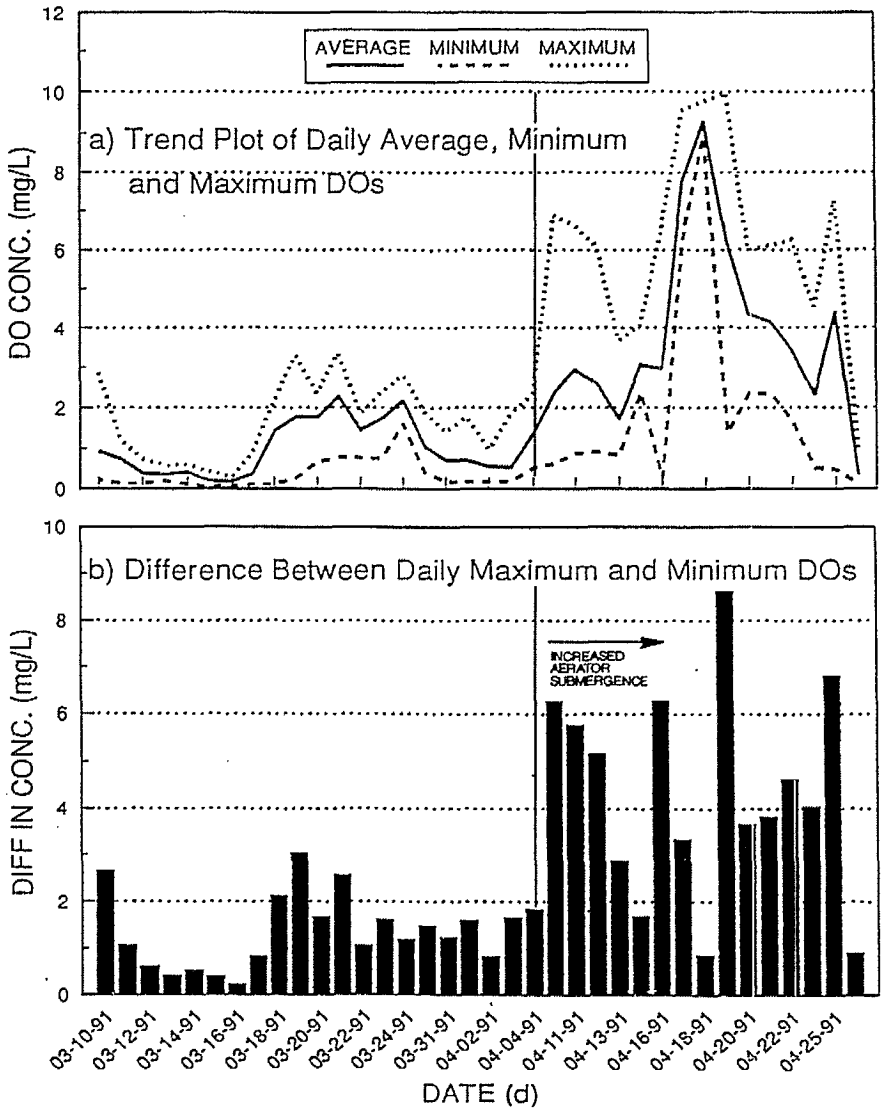


Figure 5-11
South Plant Dissolved Oxygen Concentration Variations (Woodward Avenue WPCP)

As an example, total plant flowrates and flow from Plant No.1 as measured by existing Parshall flumes at the Kitchener WPCP were monitored during a process audit (Stephenson et al., 1987). It was found that significant hydraulic disturbances were created by two automatically raked bar screens in the pretreatment system downstream of the total plant flume (Figure 5-13).

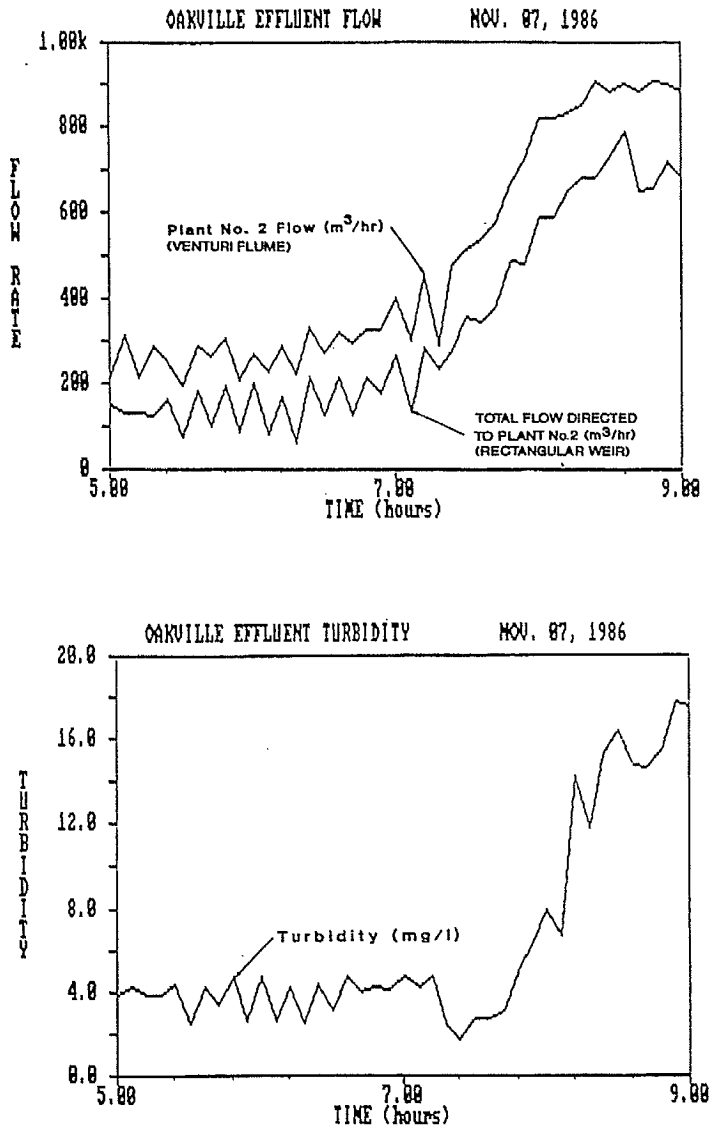


Figure 5-12
Variations in Plant Flow and Turbidity from OnLine Data
(5:00 a.m. – 9:00 a.m., November 7, 1986) (Oakville South East WPCP)

The alternate cleaning of the two screens caused a headloss imbalance which resulted in flow oscillations between the two treatment plants with a periodicity of approximately 60 minutes. Corrective action downstream of the screens eliminated the flow disturbances.

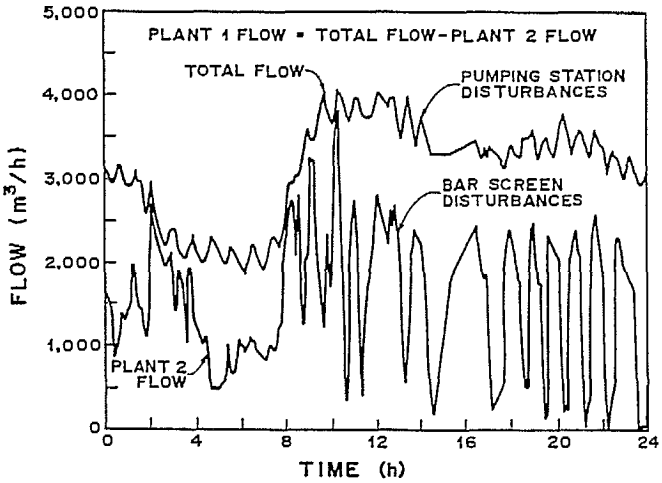


Figure 5-13
Flow Variations to Kitchener WPCP Prior to Elimination of Bar Screen Disturbances

5.9 SELECTED CASE STUDIES

Impact of Pump Cycle and Airflow Distribution Disturbances on Effluent Quality

The Cambridge (Hespeler) Water Pollution Control Plant (WPCP) is a 9,300 m³/d Degremont Oxy-Rapid (high rate) activated sludge plant which was exceeding it's effluent quality requirements at a flow averaging only 60 percent of the rated hydraulic capacity. Temporary online instrumentation including 6 aeration tank DO probes, 2 effluent turbidity probes, 2 aeration tank MLSS probes and existing influent/effluent flow instrumentation was monitored for a one month period as part of the project (Canviro Consultants Ltd., 1986) to evaluate the design and operating deficiencies.

The impact of hydraulic surges on secondary clarifier performance was assessed using the online data acquisition system. The online data showed that hydraulic surges due to cycling of constant speed pumps in an upstream pump station reduced secondary clarifier performance (Figure 5-14). The pump station disturbances were observed to occur approximately once per hour, with the 15 to 30 minute disturbance almost tripling the flow through the plant during this period (Stephenson et al., 1987). In this case example, clarifier efficiency was improved significantly by retrofitting the pumps with variable speed drives to eliminate the hydraulic disturbances induced in the wet well.

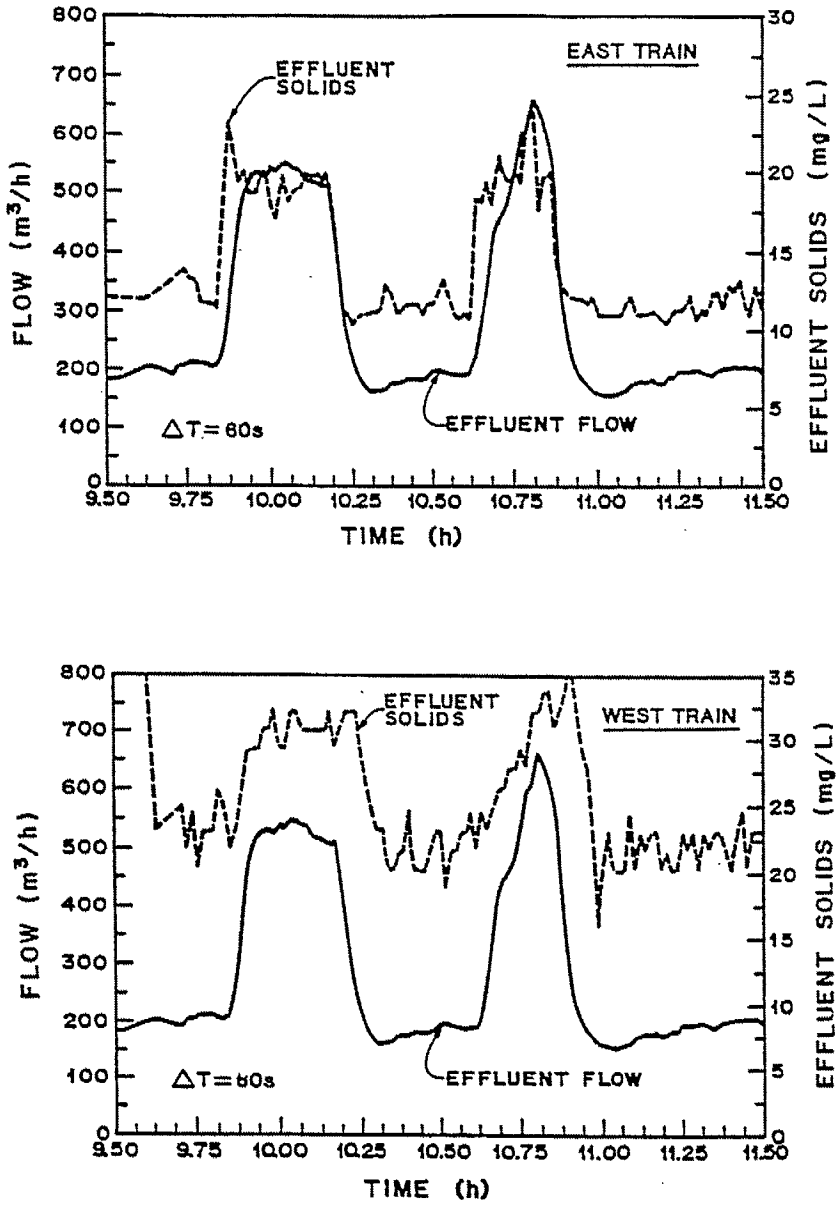


Figure 5-14
Dynamic Effect of Hydraulic Disturbances
(Hespeler WPCP)

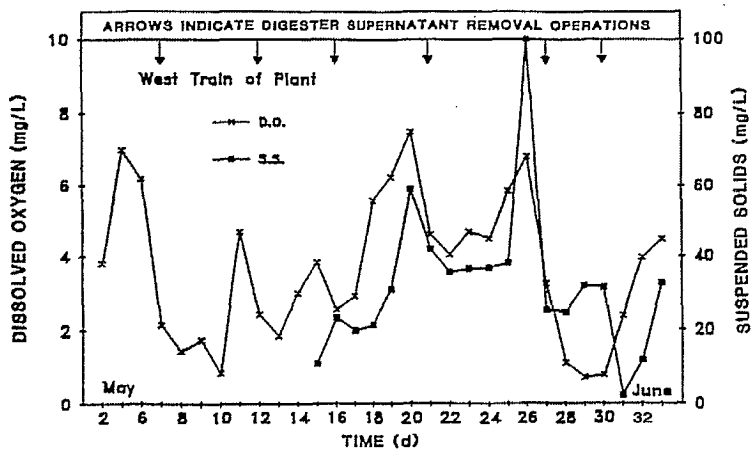


Figure 5-15
Daily Average Dissolved Oxygen and Effluent Suspended Solids Concentration (Hespeler WPCP)

Extreme variation in process airflow to the aeration basin corresponded with effluent suspended solids changes. As shown in Figure 5-15, digester supernatant removal operations were linked to the DO concentration variation from 1 to 7 mg/L over relatively short time periods (i.e. 4-8 hours). Excessive aeration tank shear rate is known to reduce the separation efficiency of the secondary clarification process. Modifications of the airflow control system including separation and isolation of the air supplied to the aeration tanks and to aerobic digestion and the provision of variable speed drives for the aeration blowers significantly improved performance.

Determination of Potential Energy Savings by Automatic DO Control

A project was initiated by Environment Canada's Wastewater Technology Centre (WTC) to demonstrate energy savings possible at full-scale by comparing automated and manual control of the aeration system. Online sensors measuring dissolved oxygen concentration and flowrate were used at the wastewater treatment facility in Tillsonburg, Ontario to demonstrate energy savings achieved by automated DO control ranging from 15 to 35 percent (Speirs and Stephenson, 1985). Subsequently, the use of online monitoring data to provide an indication of potential energy savings in an aeration system has been completed as part of many process audits. The payback period for purchase and installation of DO control equipment can be calculated based on the predicted energy savings.

As one example, the potential for energy cost savings in the aeration system at the Burlington Skyway WPCP was investigated with the assistance of online DO instrumentation and an analysis of the aeration system capacity (CH2M HILL, 1991a). The Skyway WPCP is a conventional activated

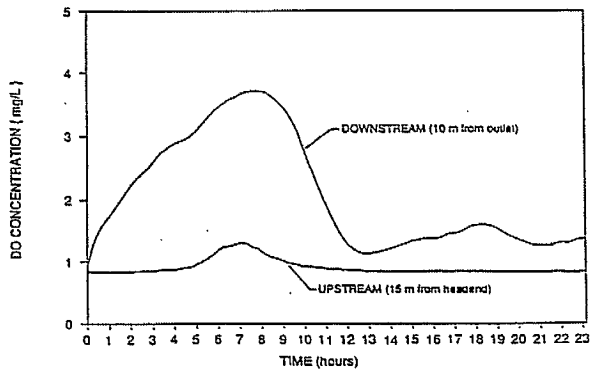


Figure 5-16
Variation in DO Concentration at Two Locations
(Skyway WPCP)

sludge plant with chemical treatment for phosphorus removal, with an average hydraulic design capacity of 93,000 m^3/d. The scope of the online data acquisition included a five-month monitoring period of 6 DO probes, 2 MLSS probes, 1 RAS probe, 1 effluent SS probe and existing plant flow instrumentation.

Using the online DO concentrations recorded over several weeks, the average diurnal variation in DO concentration in the aeration tank was determined (Figure 5-16). Further information for this case study analysis regarding the use of oxygen transfer test results in the determination of potential energy savings is provided in Section 7.8.2.

Biological Response to Toxic Discharges

Process upsets that would be difficult to detect in a timely manner using conventional sampling methods have been detected by online instrumentation during a process audit of the Waterloo wastewater treatment plant (CH2M HILL, 1991b). With an annual average flowrate of 37,000 m^3/d, a process audit and leachate treatability study was conducted to determine the nitrification capability at flowrates up to the rated plant capacity of 72,000 m^3/d. Online instrumentation used during the performance monitoring period included 6 DO probes, 1 MLSS probe, 1 RAS probe, 1 effluent SS probe and existing plant flow instrumentation. The online monitoring period was extended over a one year period as a result of several mixed liquor solids losses which prevented completion of other

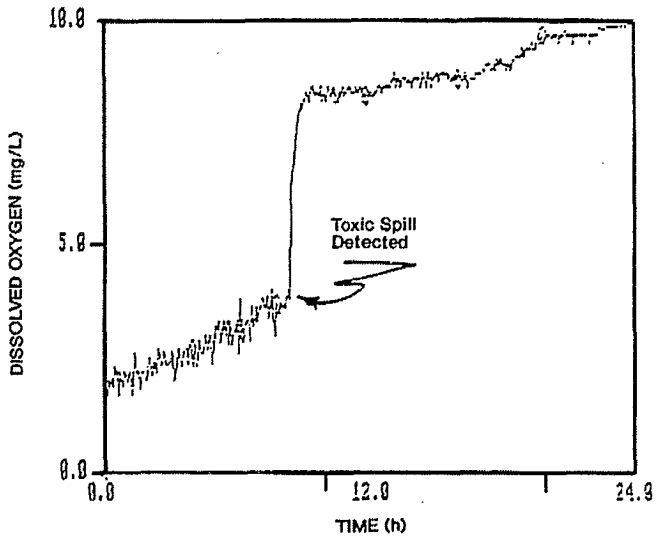


Figure 5-17
Online Illustration of Toxic Spill
(Waterloo WPCP)

process audit tasks. The primary reasons for solids losses which were identified through the online monitoring instrumentation included excessive sludge wastage caused by defective valves, toxic shocks, high flow conditions during periods of poor settling conditions and uneven flow distribution to the secondary clarifiers.

An example of the sudden increase in aeration tank DO concentration that was associated with a toxic discharge to the Waterloo treatment facility is shown in Figure 5-17. Field personnel also reported a pink coloration and hydrocarbon odour in the raw sewage at this time, providing supporting information for the discharge of a toxic substance to the treatment facility.

Influence of Diurnal Flow/Load Variations on Biological System Performance

Online monitoring was conducted at a treatment facility with an average daily wastewater flow capacity of 102,200 m^3/d to optimize the performance of new secondary treatment facilities (Buttz and Daigger, 1990). Online monitoring provided evidence of diurnal increases in effluent total ammonia-nitrogen concentrations in the nitrifying activated sludge system in response to diurnal loading variation.

Low online DO levels were linked to high ammonia concentrations measured in offline sampling of the secondary effluent (Figure 5-18a). It was found that variations in performance were minimized by the following:

- Activating a DO control system to adjust oxygen transfer capabilities in response to the diurnal variation in process load
- Using existing emergency storage ponds for periodic flow equalization during high loading period

Other findings of the online monitoring included the correlation of secondary effluent suspended solids concentrations (Figure 5-18b) with the influent flowrate.

5.10 EXPECTED DURATION AND COSTS

The duration of the online monitoring period of a process audit may range from a minimum of approximately one month to more than a year. The duration of the online monitoring period must be sufficient to complete associated process audit tasks. Longer online monitoring periods provide the opportunity to observe the performance of the facility over a range of operating conditions, such as the possible impact of seasonal flow variations resulting from infiltration/inflow or industrial discharges.

Generally, the minimum amount of time required for initial instrumentation setup and installation may vary from three to ten days for two experienced field personnel, at a cost ranging from approximately $1,000 to $8,000. These set-up/installation costs vary according to the knowledge and experience of field personnel, the size and complexity of the facility, existing instrumentation condition, and the quantity of instrumentation to be used during the online monitoring period. In some instances, it may be possible for plant staff to assist with or complete the initial installation of the instrumentation and/or wiring, thereby reducing project costs accordingly.

An experienced technician is typically assigned to calibrate and maintain the field instrumentation and data acquisition system throughout the online monitoring period on either a full-time or part-time basis, subject to the onsite requirements of other routine process audit tasks (e.g. sample preparation and submission, sampler maintenance). Completion of part of this effort by plant staff will have a significant impact on cost as this is usually a labour intensive component of a process audit. However, experience has shown that it may be difficult for the plant to provide dedicated time and resources for a process audit project given existing responsibilities. Therefore, the responsibility for ensuring that reliable data is obtained from the online monitoring equipment is designated to a field technician experienced with process audit procedures, at a cost of approximately $1,500 to $2,000 per week for the duration of the online monitoring period. However, the onsite technician usually provides

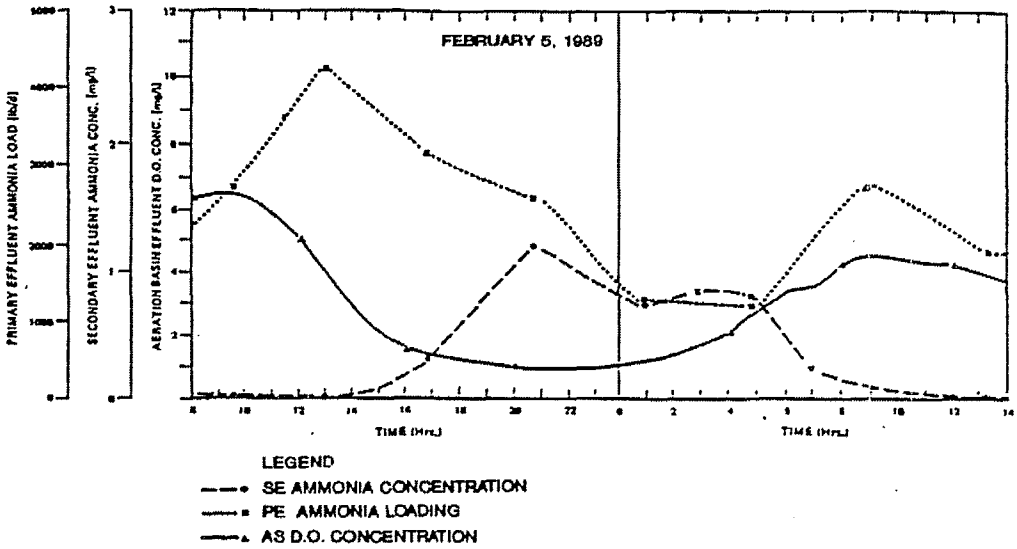


Figure 5-18a
Ammonia Removal Relationship

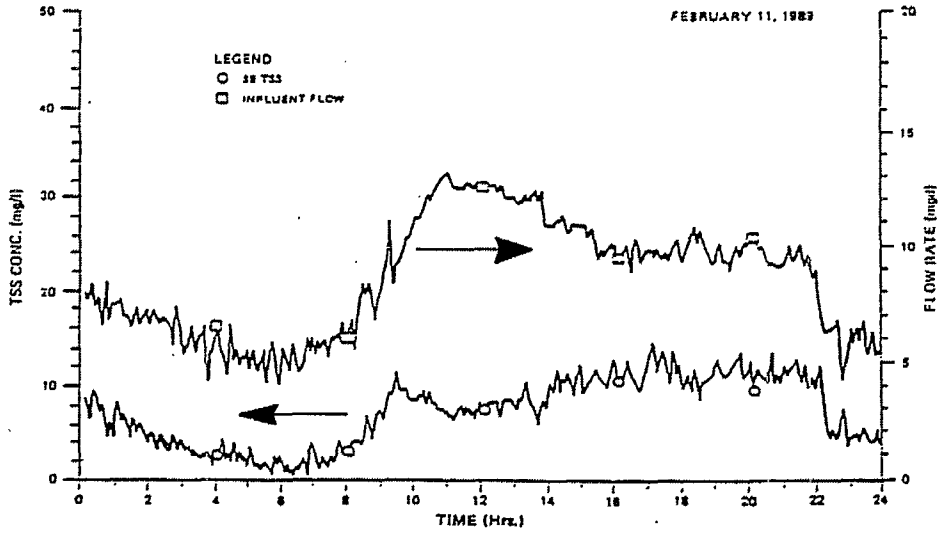


Figure 5-18b
Influent Flow Effect on Effluent Suspended Solids

assistance with onsite components of other process audit tasks during this period. Additional online monitoring costs are associated with the level of effort required for interpretation and presentation of the collected data.

Data acquisition equipment and instrumentation may be rented for the online monitoring period or purchased directly by the plant. It is recommended that price quotations be obtained directly from local equipment/instrumentation suppliers for cost estimating/budget purposes. However, approximate costs for major items required for online monitoring during a process audit are summarized in Table 5.7. If the equipment and instrumentation is to be purchased and installed directly by the plant, detailed system specifications and an equipment delivery and installation schedule should be provided as a minimum to ensure the efficient delivery of reliable process audit results. Typically, however, the equipment and instrumentation is temporarily installed for the online monitoring period, with field responsibilities designated to an onsite technician.

Table 5.7
Approximate Unit Prices for Basic Online Monitoring Equipment/Instrumentation

Equipment/Instrumentation	Unit Price Range
Computer and Accessories	$4,000 - $8,000
386 IBM or compatible complete with memory, hard disk and floppy drive; colour monitor, and printer (excluding software)	
Analog to Digital Converter (Front End Device)	$8,000 - $15,000
Field Wiring and Conduit	
18 or 24 gauge stranded conductor (305 m/1,000-ft spool)	$200 - $300
PVC conduit (30 m/100-ft length)	$50 - $120
Dissolved Oxygen Probe and Transmitter	$4,000 - $8,000
Suspended Solids Probes and Transmitters	
MLSS/RAS applications	$3,500 - $18,000
Effluent SS applications	$3,500 - $15,000

5.11 REFERENCES

American Public Health Association, American Water Works Association and Water Environment Federation. Standard Methods For the Examination of Water and Wastewater, 18th Ed. Pp 2-56. 1992.

Buttz, J.A. and Daigger, G.T. "Real-time Biological Process Optimization Using On-line Monitoring. Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems". *Proceedings of the 5th IAWPRC Workshop held in Yokohama and Kyoto, Japan.* 1990.

Canviro Consultants Ltd. Evaluation and Correction of Design and Operating Deficiencies at the Cambridge (Hespeler) Wastewater Treatment Plant. Report prepared for the Regional Municipality of Waterloo. July, 1986.

Canviro Consultants Ltd. Evaluation of Potential Energy Savings and Plant Capacity at the Region of Halton Oakville South East Water Pollution Control Plant. Report prepared for the Regional Municipality of Halton. January, 1987.

CH2M HILL ENGINEERING LTD. Operational Audit of the Regional Municipality of Halton's Burlington Skyway Water Pollution Control Plant. Report prepared for the Regional Municipality of Halton. March, 1991(a).

CH2M HILL ENGINEERING LTD. Process Audit and Treatability Study at the Waterloo Wastewater Treatment Plant. Report prepared for the Regional Municipality of Waterloo. May, 1991(b).

CH2M HILL ENGINEERING LTD. Woodward Avenue WPCP Pre-Audit Oxygenation Testing and Evaluation. Report prepared for the Regional Municipality of Hamilton-Wentworth. January, 1992(a).

CH2M HILL ENGINEERING LTD. Seaway WPCP Assessment. Report prepared for the Regional Municipality of Niagara. February, 1992(b).

CH2M HILL ENGINEERING LTD. Process Studies at the Corbett Creek WPCP. Report prepared for the Regional Municipality of Durham. March, 1990.

CH2M HILL ENGINEERING LTD. Review of the Aeration System Performance and Energy Usage at the St. Thomas WPCP. Report prepared for the City of St. Thomas. November, 1992.

Daigger, G.T., Buttz, J.A. and Stephenson, J.P. "Analysis of Techniques for Evaluating and Optimizing Existing Full-Scale Wastewater Treatment Plants". *Water Science Technology*. Vol 25, No. 4-5. pp 103-118. 1992.

Instrumentation Testing Association (ITA). Dissolved Oxygen Analyzers Evaluation Report. 1988.

Instrumentation Testing Association (ITA). Performance Evaluation of Low Range Suspended Solids Analyzers for Wastewater Treatment Applications. 1991(a).

Instrumentation Testing Association (ITA). Performance Evaluation of Medium Range Suspended Solids Analyzers for Wastewater Treatment Applications. 1991(b).

Instrumentation Testing Association (ITA). Performance Evaluation of High Range Suspended Solids Analyzers for Wastewater Treatment Applications. 1993.

Nolasco, D. and Stephenson, J.P. Evaluation and Optimization Techniques for Existing Wastewater Treatment Plants. Presented at the 38th Ontario Waste Management Conference. Toronto, Ontario. 1991.

Speirs, G.W, and Stephenson, J.P. "Operational Audit Assists Plant Selection for Demonstration of Energy Savings and Improved Control". Instrumentation and Control of Wastewater Treatment and Transport Systems. *Proceedings of the 4th IAWPRC Workshop*. Houston, TX and Denver, CO. 1985.

Stephenson, J.P.; Nutt, S.G.; and Speirs, G.N. Online Instrument and Microprocessor Based Audit of Activated Sludge Systems. Advances in Instrumentation, 42, pp. 337-350. 1987.

Water Environment Federation. Instrumentation in Wastewater Treatment Facilities MOP 21. 1993.

Water Pollution Control Federation. Process Instrumentation and Control Systems, Manual of Practice OM-6. 1984.

CHAPTER 6
OFFLINE MONITORING

6.1 GENERAL OBJECTIVES

The general objectives of an offline monitoring task as part of a process audit or evaluation program are to:

- Supplement plant historical data in terms of duration, frequency or location of samples
- Obtain specific analyses not conducted historically at the plant
- Provide data to calibrate online instrumentation

The offline sampling program, when used in conjunction with online monitoring, can provide a more complete picture of a plant's performance and unit process operations.

Plant historical data may not include sufficient data to fully characterize a wastewater treatment plant. Biological process influent data (e.g. primary effluent) may not be routinely sampled by plant staff. In addition, diurnal sampling, such as 4-h composites, may not be part of the plant's normal sampling practice. An offline sampling program can also be used in lieu of a particular online instrument which may be unavailable or expensive, to provide the same information concerning diurnal variations in a particular parameter.

A plant may sample its influent and effluent on a particular day (e.g. every Wednesday) or five days per week, and additional sampling can often provide additional information. Plant historical data may not include analysis for parameters that in the future may need to be removed by the plant, for example total ammonia-N for a plant that is expected to be required to nitrify in the future. To obtain accurate information from online instrumentation, frequent offline samples will need to be obtained and analyzed.

6.2 DESCRIPTION OF PARAMETERS MONITORED

Many different parameters may be sampled as part of an offline sampling program. Generally, these parameters can be divided into two groups:

- Automatic composite samples
- Grab or manual composite samples

Composite samples are generally taken using an automatic sampler. These samples are often taken at the influent and effluent of the main liquid train processes in a treatment plant. Common parameters for analysis for an activated sludge plant with primary clarifiers are shown in Table 6.1. A plant's historical records will often include some raw influent and final effluent analysis similar to those shown in Table 6.1. However, the primary effluent may not be sampled and is critical to characterize the biological system (e.g. see Section 6.13). Grab sampling needs are more site specific, but could include:

- pH
- Alkalinity
- Wastewater temperature
- Bacteria analysis (e.g. fecal coliform or *E. coli*)
- Calibration samples

Common calibration samples include suspended solids, phosphorus and nitrogen values. All these samples, except calibration samples, must be grab samples and need to be analyzed immediately, since these parameters may continue to react in the sample container. Calibration samples may be grab samples or composited over a period of time. Since these samples are to be analyzed for conventional parameters, they can be refrigerated prior to analysis (i.e. calibration samples do not need to be analyzed immediately).

Table 6.1
Common Sample Parameters for an Activated Sludge Plant

Location Through Liquid Train		
Raw Influent	**Primary Effluent**	**Final Effluent**
Most Common	Most Common	Most Common
Total BOD_5	Carbonaceous BOD_5	Carbonaceous BOD_5
Carbonaceous BOD_5	Total suspended solids	Total suspended solids
Total suspended solids	Total phosphorus	Total phosphorus
Total phosphorus	Soluble phosphorus	Soluble phosphorus
Soluble phosphorus	Total Kjeldahl nitrogen	Total Kjeldahl nitrogen
Total Kjeldahl nitrogen	Total Ammonia nitrogen	Total Ammonia nitrogen
	Nitrate/Nitrite	Nitrate/Nitrite
Less Common	Less Common	Less Common
Soluble BOD_5	Soluble BOD_5	Soluble BOD_5
Nitrate/Nitrite Nitrogen	Chemical Oxygen Demand	Chemical Oxygen Demand
Chemical Oxygen Demand		

Note: Table is example only and does not include all analysis possible.

Some processes may operate periodically and therefore a grab or manually composite sample will have to be taken. Often sludge handling recycle streams (e.g. see Section 9), raw sludge, and waste activated sludge streams are operated in this manner. These streams are often sampled for solids only, either suspended solids (SS) or total solids (TS) depending on the concentration, although further analysis may be warranted to characterize the strength of these streams. Conventional analysis, such as BOD_5, phosphorus and nitrogen, may provide valuable information as to the strength and therefore the impact of these streams on the liquid train (see Section 9).

6.3 SAMPLING AND LABORATORY WORK SCHEDULE

The preparation of a sampling and laboratory work schedule is critical to the successful completion of an offline sampling project. Whether sampling and laboratory work are being conducted by the auditor or others, it is important to get the main sampling to be conducted and its frequency identified early so the program can proceed as planned. Sample analysis may be done at the plant by the auditing team or plant staff, or the analysis may be conducted at a commercial laboratory. Regardless of who is analyzing the samples, initial planning will assist in scheduling the analysis to be done and estimating analysis turn-around-time. A sampling and laboratory schedule should include:

- Dates for sampling
- Duration and type of analysis to be conducted
- Person responsible for sampling, collection and handling
- Person/firm responsible for analysis
- Date analysis will be complete

Figure 6-1 is an example sampling and laboratory schedule for a two-week offline sampling task combining analysis by the audit team and a commercial laboratory. The schedule provides a "road-map" of the offline sampling program and shows all the information required to successfully complete the task.

6.4 SAMPLE COLLECTION EQUIPMENT

The selection of appropriate sample collection equipment is critical to a sampling program. The type of equipment will vary depending on whether the sampling is to be composited over a period of time or a grab sample. For most conventional parameters sampled in the liquid train, a composited sample will be taken. An automatic sampler is used to take these samples.

There are many automatic samplers available on the market, a commonly used sampler is shown in Figure 6-2. Automatic samplers can take time-proportioned or flow-proportioned samples. Time-proportioned samples are taken based on time (e.g. every hour), with the sampler taking a similar sample volume every time period. Flow-proportioned samples use a flow signal, either continuous or totalizer, to determine when to take a sample. Time-proportioned samples can be flow-weighted by taking twenty-four, hourly, discrete samples and physically proportioning the samples based on a flow profile for the plant. An example of a manual flow-proportioned exercise is outlined in Table 6.2 based on 24-hourly time-proportioned samples and hourly flow records. In this example, the maximum hourly flow uses the entire sample volume and every other hourly period's sample volume is based on a ratio with respect to this volume.

A number of other items are critical to the setup of an automatic sampler, these include:

- **Sampler Location** – Samplers should be located as close as possible to the location to be sampled. Suitable power supply is needed, depending on the location use 110V AC power or 12V DC battery power. The battery should be replaced every 24 hours and left to charge for the next sampling day.

- **Intake Line** – The intake line should be located at a point where a representative sample can be obtained. A strainer can be attached to the end of the sample line to avoid clogging and to weigh down the sample line. The intake line should be clean and of the proper material. Generally, sample lines are made of vinyl or polyvinyl tubing, but other materials such as teflon lined tubing may be required for non-conventional parameters.

- **Sampler Programming** – The sampler must be set up to take the samples based on time or flow and also to take a specific volume of sample. Samplers have to be set up to purge the sample lines before and after the sample is taken.

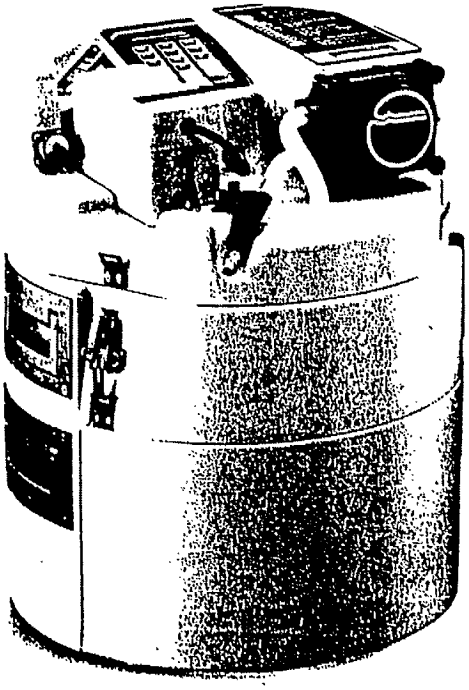
- **Sample Containers** – The sample container must be installed to capture the sample. Sampler containers are generally either polyethylene or glass, multiple bottles or single composite containers.

- **Sample Enclosure** – The sampler should be kept in an enclosure to shelter it from the elements. In climates where the temperatures fall below 0°C, a heated and insulated enclosure may be necessary to prevent the samples from freezing. In addition, consideration should be given to using a refrigerated sampler to ensure the samples are maintained at 4°C to prevent the sample from degrading.

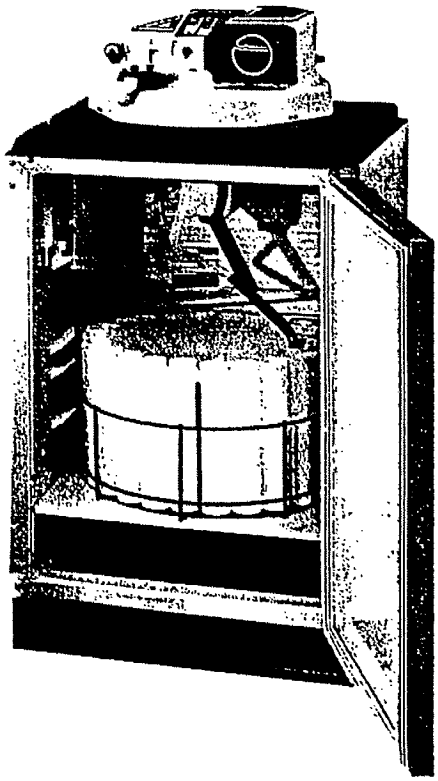
Action	Day of Week						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	6	7	8	9	10	11	12
Notes/Comments	Setup Samplers	First Sampling Day					
Samples Taken		Raw,PE & FE	PE & FE	Raw,PE & FE	PE & FE	Raw,PE & FE	
Analysis In-field		Temp and pH	Temp and pH	Temp and pH	Temp and pH	Temp and pH	
Lab. Samples Sent		Held in Frig	Held in Frig	Send Lot 1	Held in Frig	Held in Frig	
Lab. Sample Results							
	13	14	15	16	17	18	19
Notes/Comments							
Samples Taken	PE & FE	Raw,PE & FE	PE & FE	Raw,PE & FE	PE & FE	Raw,PE & FE	
Analysis In-field	Temp and pH	Temp and pH	Temp and pH	Temp and pH	Temp and pH	Temp and pH	
Lab. Samples Sent	Send Lot 2	Held in Frig	Held in Frig	Send Lot 3	Held in Frig	Held in Frig	
Lab. Sample Results		Results for Lot 1				Results Lot 2	
	20	21	22	23	24	25	26
Notes/Comments	Sampling Complete					Program Complete	
Samples Taken							
Analysis In-field							
Lab. Samples Sent	Send Lot 4						
Lab. Sample Results		Results Lot 3				Results Lot 4	

Note: 1) Sample Locations are: Raw (Raw influent), PE (Primary effluent) and FE (final effluent)
2) Analysis for each stream as follows: Raw($CBOD_5$, TSS, TP, TKN), PE($CBOD_5$, TSS, TP, TKN, total NH_3-N) and FE ($CBOD_5$, TSS, TP, TKN, total NH_3-N, and NO_3-N/NO_2-N)

Figure 6-1
Example Sampling and Laboratory Schedule for a Two-Week Offline Sampling Program



Non-Refrigerated



Refrigerated

Figure 6-2
Refrigerated and Non-Refrigerated Automatic Samplers

A number of different rigs have been made onsite for grab sampling purposes. It is important that the device be able to reach the sample location from an area of safety and that the sample container be clean. An example grab sampler device is shown in Figure 6-3.

6.5 SAMPLE HANDLING, LABELLING AND PRESERVATION

Once a sample has been taken, the next few steps prior to analyzing the sample will ensure the sample results are accurate. Sample handling, labelling and preservation will ensure the sample will be representative of the location being monitored.

After the sampling period has ended or grab sample has been taken, the sample can be transferred from the sampler container to a clean container such as a pail. The pail containing the sample can then be aliquoted at the plant's lab or onsite into the number of sample bottles for the parameters being analyzed. While mixing the sample thoroughly, immerse a clean beaker (i.e. rinsed several

Table 6.2
Example Manual Proportioning of Time-Proportioned Sample

Maximum Sample Volume = 250 mL			
Hour	**Flow Rate (m^3/d)**	**Percent of Daily Q**	**Sample Volume (mL)**
1:00 a.m.	10,500	3.0%	135
2:00 a.m.	8,000	2.3%	103
3:00 a.m.	8,500	2.4%	109
4:00 a.m.	9,000	2.5%	115
5:00 a.m.	10,000	2.8%	128
6:00 a.m.	10,500	3.0%	135
7:00 a.m.	10,000	2.8%	128
8:00 a.m.	13,000	3.7%	167
9:00 a.m.	15,000	4.2%	192
10:00 a.m.	19,500	5.5%	250 Max Period
11:00 a.m.	18,000	5.1%	231
12:00 a.m.	18,500	5.2%	237
1:00 p.m.	18,000	5.1%	231
2:00 p.m.	18,250	5.1%	234
3:00 p.m.	18,500	5.2%	237
4:00 p.m.	18,000	5.1%	231
5:00 p.m.	18,500	5.2%	237
6:00 p.m.	17,000	4.8%	218
7:00 p.m.	17,000	4.8%	218
8:00 p.m.	16,500	4.7%	212
9:00 p.m.	17,000	4.8%	218
10:00 p.m.	16,000	4.5%	205
11:00 p.m.	15,000	4.2%	192
12:00 p.m.	14,500	4.1%	186
Total	354,750	100.0%	4,548

times with the sample) into the pail and aliquot into the sample bottles. It is imperative that the sample be well mixed before sub-sampling from the pail, so that suspended solids do not settle out in the pail, causing the samples to be invalid.

Whether the sample is being analyzed by the auditor, plant staff or a commercial laboratory, accurate and complete sample bottle labelling will ensure the results are not confused. A label should be affixed to the sample bottle indicating the following information:

- Sample Date (Time if appropriate)
- Location (e.g. Raw influent)

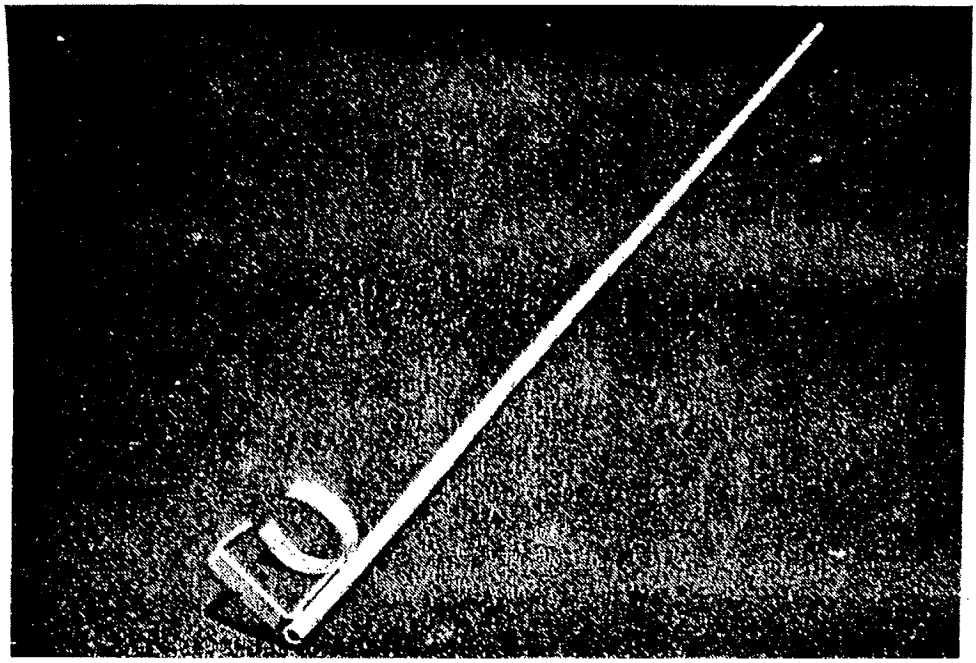


Figure 6-3
Sampling Pole with Bottle Holder for Taking Grab Samples

- Analysis parameter (e.g. total BOD_5)
- Sampler's name (Company as well if appropriate)
- Wastewater Plant Name

Each individual sample must be preserved immediately, and then submitted to the lab for analysis. Table 6.3 lists some sampling parameters and their corresponding methods of preservation, the types of containers to be used, sample volumes required, and recommended maximum storage times. Some samples, such as pH and alkalinity, should be grab sampled and analyzed immediately in the field or at a nearby lab. Bacteria counts and microscopic examination and identification are also grab sampled; however, these analyses are generally done by a laboratory and should be sent by the fastest possible route.

Every sample must be refrigerated at 4°C until the sample is analyzed. Some laboratories freeze BOD_5 samples to avoid further degradation prior to analysis. Concerns with freezing BOD_5 samples include possible cell breakdown from freezing and crystallization of sugars. It is recommended that acidified samples be preserved after the sample has been aliquoted into the sample bottles. Soluble phosphorus samples must be filtered through a 0.45 micron glass fibre filter (membrane filters can also be used) before acidification. If this is not possible in the field, then the sample should be

Table 6.3
Sample Preservation

Parameter	Container	Volume (mL)	Storage	Maximum Storage
BOD	Polyethylene	55	4°C[1]	3 days
COD	Poly/glass	100	Freeze	7 days
Total Phosphorus	Poly/glass	500	H_2SO_4 pH<2	14 days
Soluble	Poly/glass	500	H_2SO_4 pH<2	14 days
Phosphorus				
TKN	Poly/glass	500	H_2SO_4 pH<2	28 days
Ammonia	Poly/glass	500	H_2SO_4 pH<2	28 days
Nitrate	Poly/glass	100	4°C	5 days
Nitrite	Poly/glass	100	4°C	5 days
Suspended Solids	Poly/glass	1,000	4°C	7 days
Total Solids	Poly/glass	1,900	4°C	7 days

Note: [1] Freezing of BOD_5 samples is an alternative method used by some laboratories.

refrigerated, filtered, and acidified as soon as possible off site. If a chemical oxygen demand (COD) is required then the sample should be preserved at a pH of less than 2 with sulphuric acid.

If the auditor is going to conduct conventional analysis of samples, standard methods for conducting these analysis should be followed (Standard Methods, 1992).

6.6 MICROSCOPIC EXAMINATION OF SLUDGE

The activated sludge process is a living biological process. Activated sludge is made up of many different types of micro organisms which are often referred to as a mixed culture. This mixed culture is made up of micro organisms such as:

- Bacteria
- Protozoa
- Rotifers
- Worms and fungi
- Algae

The load to a municipal wastewater plant is rarely at steady state. The relative stability of the system is directly related to the response of the microbial population to the load exerted on the system. The composition of the microbial floc will, within certain limits, continually adjust to changes in the load and to operational procedures, such as the quality of the influent and seasonal influences.

Monitoring the biological system can be used to determine the "health" of the system and provide early identification of potential problems, such as bulking sludge.

Because the activated sludge process depends on microscopic organisms to remove contaminants from the wastewater, microscopic examination of the biological sludge can be useful in evaluating plant conditions. The type and diversity of the microbial population can provide a skilled operator with information regarding the age of the sludge, its activity level, and its general condition. For example, the presence of higher life forms such as protozoa and rotifers usually is indicative of a well-aged sludge and a good quality effluent in a conventional system.

A sample for microscopic examination must be:

- Fresh, that is a grab sample and observed as soon as possible.
- Taken from a place in the aeration tanks where the micro organisms should be "hungry". This location provides information on the health of the organisms prior to being reused in the activated sludge process. For example, from the end of the aeration tank in a conventional system.

To conduct a microscopic examination of an activated sludge, the following equipment is required:

- Phase-contrast microscope with at least 100x magnification
- Flat glass slides and glass covers
- Eye dropper or pipet
- Gram and Neisser Stains
- Cleaning solution and lens cleaning paper

There are many methods of reporting microscopic identification, most are designed to produce some reproducibility on what is a very subjective evaluation. Two methods will be introduced:

The Filamentous Growth Category (Jenkins et al., 1986) – This method can be used to categorize the relative number of filaments in a sludge and provide an early warning of predominance of filamentous bacteria which could cause bulking sludge and could upset adequate solids separation. The Filamentous Growth Category involves the analysis of samples for filamentous bacteria with the help of a microscope. Counting and measuring the filaments is often impossible when they are strongly bent and twisted. Therefore, the extent of filamentous growth is roughly estimated by eye. The activated sludge is categorized on the basis of the extent of filamentous growth as follows:

0 = filamentous organisms almost absent
1 = small number of filamentous organisms
2 = moderate number of filamentous organisms

3 = large number of filamentous organisms
4 = excessive number of filamentous organisms

In arriving at the category, the microscopic inspection is compared with a series of reference images in the form of photographs of the different categories. The Filamentous Growth Category is often observed clearly and can often predict settleability problems prior to increases in the sludge volume index (SVI). Alternatively, this process can be part of a complete evaluation of the sludge. One worksheet format for a complete evaluation is shown in Appendix 6-A.

Micro organism Counting (U.S. EPA, 1989) – An alternate method used to count a variety of micro organisms in a sludge sample is shown in Appendix 6-B. The method involves dividing the square cover glass into fields and counting the micro organisms in a series of representative fields to obtain an average abundance of the organisms present. The counting technique is detailed in Appendix 6-B.

Lastly, stains can be used to preserve samples and to assist in identification of different filamentous bacteria. Staining techniques are time consuming and difficult to master and users should refer to other references for particulars (Jenkins et al., 1986; and U.S. EPA, 1989). Alternatively, a permanent record can be made by using a camera if one is available for the microscope being used.

There are many good references on microscopic examinations that should be referred to for further information (see Reference Section). Alternatively, samples can be sent to a micro-biologist for their examination. This procedure is very cost-effective and provides an expert opinion on the identification and relative frequency of population contained in the sludge. As of the writing of this manual this service is available from at least two sources:

- Dr. Peter Dold, McMaster University, Hamilton, Ontario, Canada
  (905) 525-9140 ext. 27040
- Dr. David Jenkins, University of California at Berkeley, Berkeley, California,
  United States (510) 642-5337

Whether or not the auditor does the bacteria identification, it is recommended that at least two or three samples be sent to an expert for an opinion.

6.7 JAR TESTING – APPLICATION AND LIMITATIONS

Jar testing is generally used to evaluate the benefits of coagulant or chemical addition to a wastewater for improved settleability or precipitation of some element in the wastewater (e.g. phosphorus removal). The tests are usually conducted on raw sewage or activated sludge to simulate primary or secondary settling, respectively. Multiple jars are tested at one time to provide a relative

comparison of the performance of the coagulant or chemical being tested. A common jar testing apparatus is shown in Figure 6-4. This six-jar apparatus allows the tester to evaluate a control and five different dosages. Floc formation and settling can be observed and noted, and the supernatant and settled material sampled and analyzed. Common settings for conducting a jar test are as follows:

- Chemical Addition (e.g. alum) – Rapid mix for 2 minutes at 100 RPM
- Coagulant Addition (e.g. cationic polymer) – Rapid mix for 1 minute at 100 RPM
- Flocculation – Slow mix for 5 minutes at 35 RPM
- Settle Time – No mix for 15 minutes

These settings are examples only and variations in the mixing times, speeds and settling times may be appropriate for different situations. The results of a jar test can be summarized on a data sheet similar to that shown in Table 6.4. These sheets provide for both observations and discrete sampling of the test results to summarize the coagulant or chemical being evaluated.

The jar testing approach is a good procedure for estimating the performance of chemicals and coagulants for improved settling or precipitation; however, care must be exercised in evaluating jar test results. Jar testing cannot simulate the performance of a full-scale settling basin and results in terms of supernatant quality, sludge concentration and settling times should not be considered as being reproducible at full-scale. Jar testing is a useful tool for estimating the performance of various chemicals and coagulants for settling and precipitation and can provide initial information about dosage requirements.

6.8 ADDITIONAL LABORATORY/FIELD TESTS

An offline sampling program can involve numerous additional laboratory/field tests depending on the project objectives. There are numerous standard and customized tests that can be performed at a facility to review the performance of a particular unit process. Some common laboratory/field tests are discussed below.

6.8.1 Grit Removal Efficiency

Grit removal through a grit chamber, aerated grit tank or swirl/vortex grit separator can be evaluated by sampling the influent and effluent from the reactor and determining the grit contents of both. Care must be taken to evaluate the grit removal process for the size of grit it was designed to remove. In addition the following test items should be considered and followed:

- Grit quantities are normally present at concentrations of 5 to 6 ppm and therefore sampling techniques must be accurate enough to establish these levels of grit.

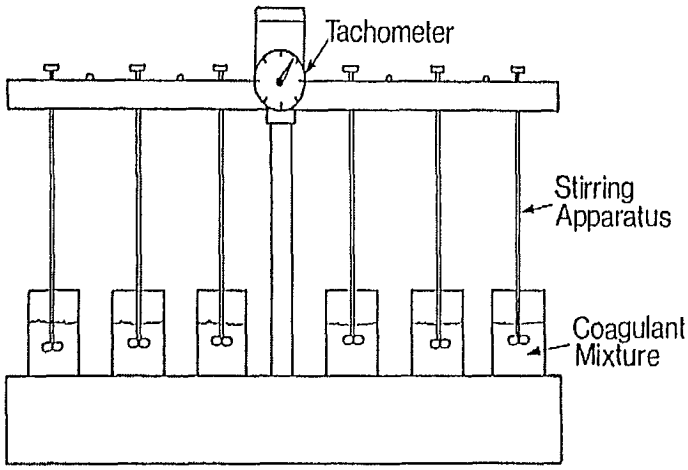


Figure 6-4
Jar Test Apparatus

Therefore, samples should be collected over an extended period at numerous locations.

- Samples must be washed and screened to separate the grit from organic material. Generally samples will be screened through a 100 mesh screen.
- Captured grit needs to be dried and the remaining organic material volatized to establish the actual grit quantities.
- Samples can be further classified by passing the sample through 50, 70 and 100 mesh screens prior to weighing and assessment.

The objective of this test is to assess the grit quantities in the influent and effluent of the grit removal process to establish the removal efficiency of the targeted grit size through the process.

6.8.2 Settling Column Test

To determine the settling characteristics of a suspension of flocculant particles, a settling column test can be used. This test is most applicable for raw sewage or fixed film effluent samples (i.e. trickling filter or rotating biological contactor), since these samples will settle in the flocculent settling range. A variety of column sizes have been used; however, a 150 mm diameter column with column heights varying from 2 to 3 m (Metcalf and Eddy, 1979; U.S. EPA, 1986) is common. Four sampling ports are inserted into the column at equal intervals. Samples are withdrawn at various time intervals and analyzed for suspended solids. The percent removal is calculated for each sample and is plotted

Table 6-4
Example Jar Testing Report

Plant:
Description:
Date:

Chemical Dosage	1	2	3	4	5	6
Raw Sample						
pH						
Alkalinity (mg/L CaCO3)						
Turbidity (NTUs)						
Total P (mg/L)						
Soluble P (mg/L)						
Supernatant						
pH						
Alkalinity (mg/L CaCO3)						
Turbidity (NTUs)						
Total P (mg/L)						
Soluble P (mg/L)						
Settled Solids						
Volume (mL)						
Suspended Solids (mg/L)						

Observations	
Sample 1	
Mix:	
Floc:	
Settle:	
Sample 2	
Mix:	
Floc:	
Settle:	
Sample 3	
Mix:	
Floc:	
Settle:	
Sample 4	
Mix:	
Floc:	
Settle:	
Sample 5	
Mix:	
Floc:	
Settle:	
Sample 6	
Mix:	
Floc:	
Settle:	

against time and depth. An example of a settling column and a settling curve generated from the test are shown in Figure 6-5.

Various other settling column test methods are available for conducting settling tests. One such test apparatus has the advantage of a constant water surface elevation, and smaller sample volume requirements (Tyack, 1993).

6.8.3 Dissolved Oxygen Monitoring and Profiling

Dissolved oxygen (DO) concentration is a key operating parameter in an activated sludge plant and monitoring this parameter can provide useful information as to the operation of a plant. Online DO concentration monitoring can provide continuous and reliable DO concentrations in an aeration basin (e.g. see Section 5 for details). Offline monitoring can be used to:

- Calibrate online DO equipment
- Determine if an aeration basin is well-mixed
- Monitor the DO profile in a plug-flow type reactor to assess complete treatment needs, especially for nitrification

Offline DO concentration monitoring can be conducted using a portable, hand-held unit. Many units are available on the market. A common unit is shown in Figure 6-6.

6.8.4 Oxygen Uptake Rate

This test is used in the determination of the rate of oxygen consumption of the activated sludge. It has been shown that this test can be useful in evaluating the uptake of oxygen by the biomass in an activated sludge system (Standard Methods, 1992). Equipment required to conduct this test includes:

- A DO meter
- A bottle, such as a BOD bottle, into which the DO sensor can be inserted with a tight fit
- Stirring mechanism
- Means of increasing DO concentration to near saturation levels
- Stop watch
- Sample of activated sludge

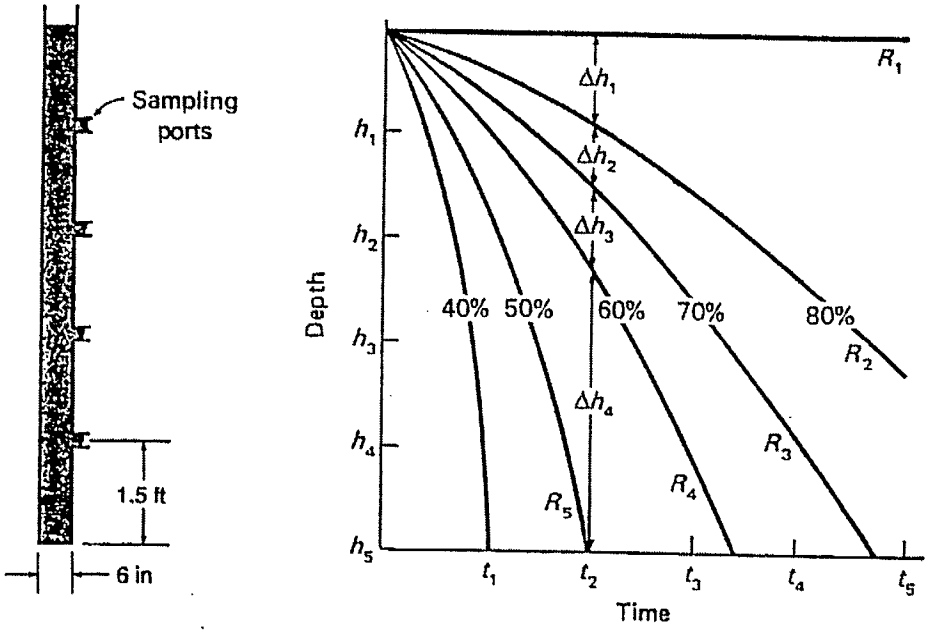


Figure 6-5
Settling Column and Settling Curves for Flocculant Particles

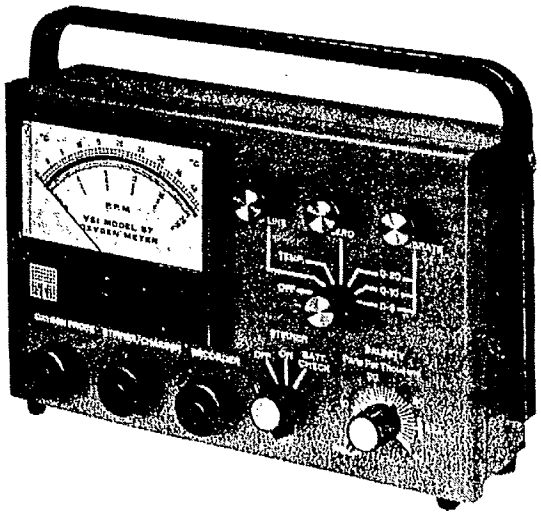


Figure 6-6
Hand Held Dissolved Oxygen Meter

First, fill the test bottle with activated sludge and aerate the sample to elevate the DO concentration to near saturation levels. Insert the DO probe and seal the top of the bottle, the bottle should be full enough that inserting the probe displaces activated sludge to ensure no air is present. Monitor the DO concentration over a 15-minute period while mixing the sample. Plot the DO concentration versus time interval, the slope of the line is the oxygen uptake rate. The oxygen consumption rate is the oxygen uptake rate divided by the volatile suspended solids concentration of the activated sludge. High oxygen uptake rates (OURs) indicate high biological activity, while low OURs indicate low biological activity. OURs can be a useful measurement both for monitoring and controlling the activated sludge process (Metcalf and Eddy, 1991). Typical OURs used for design purposes average from 30 to 50 mg O_2/L • h with peak days from 60 to 80 mg/O_2/L • h (WEF, 1992). In addition, respirometric technology can be used to characterize an activated sludge plant, improve its treatability and provide relevant data for process modelling (see Appendix 6-C for additional data).

6.8.5 Activated Sludge Settling and Sludge Volume Index

The activated sludge settling characteristics are critical to an activated sludge plant's ability to separate the activated biomass for return and wasting from the effluent discharged from the process. A good settling sludge is important if a plant is to produce a good quality effluent. The activated sludge settling rate is generally determined by placing a mixed sample of activated sludge into a 1-litre graduated cylinder and reading the volume of settled sludge after a 30-minute period. The sludge volume index (SVI) is the volume in millilitres occupied by 1 gram of suspended solids after 30 minutes of settling. It is calculated as follows:

$$\text{SVI} = \frac{\text{sludge volume after settling (ml/L)} \cdot 1000}{\text{MLSS (mg/L)}}$$

The SVI is a measure of the activated sludge settleability and can indicate a bulking sludge. In general, a SVI in the range of 50 to 150 mL/g indicates a good settling sludge. To better approximate the settling of a full-scale settler, a stirred sludge volume index (SSVI) test was developed. This test is conducted in a similar fashion, except instead of a graduated cylinder, a column of similar volume with a slow speed mixer is used for the 30-minute settling test. The stirring is used to enhance flocculation and better simulate clarifier performance at full-scale clarifier depth. SSVI values are similar to SVI values for a good settling sludge; for a poor settling sludge, the SSVI values are lower. Another method uses a SSVI determined at various solids concentrations to determine the maximum permissible solids loading rate of a clarifier (White, 1975).

6.8.6 Sludge Blanket Monitoring

The level of sludge in a secondary clarifier is an important operating parameter. High sludge levels in a final clarifier can indicate settling or recycle rate problems, and high sludge blankets can also cause denitrification to occur in a nitrifying plant. The sludge blanket height can be determined by:

- Lowering a density meter into the clarifier and observing the point of large concentration change closest to the clarifier bottom.
- Using an ultrasonic instrument.
- Taking a physical profile of the clarifier contents using a clear, hollow, small diameter (25 to 50 mm diameter) tube with a check valve at the bottom. Generally this apparatus is referred to as a "sludge judge".

The "sludge judge" is the best way to monitor the sludge blanket and conditions in the clarifier on an offline basis. The tube is slowly lowered into the clarifier to avoid disrupting the solids in the clarifier. Once the unit touches the bottom of the tank, the tube is removed from the clarifier and the contents observed and the interface between the concentrated solids and the transition solids (i.e. fluffy area) is assessed to determine the blanket depth. The "sludge judge" should be used to profile the same location(s) so comparisons between the various values are possible. Often, a location one-third of the clarifier radius from the outside wall is used for circular clarifiers.

6.9 CONTROLLING CALIBRATION OF ONLINE INSTRUMENTATION USING OFFLINE DATA

One important use for offline sampling in a complete audit program, is to control or monitor the accuracy of online instrumentation. Online monitoring of an activated sludge process can include the temporary installation of the following online instrumentation:

- Dissolved oxygen probes
- Turbidity or suspended solids probes
- Sludge blanket indicator
- Phosphorus and nitrogen analyzers

It is especially important during online monitoring to maintain the accuracy of the instrumentation since the monitoring period is probably limited and all the monitoring data is required. Offline monitoring of online equipment is generally conducted as part of a routine sampling program during

an audit. Data sheets similar to those shown in Appendix 5D can be used to compare offline, discrete values to online measurements. Some items to consider are:

- Offline monitoring samples should be collected close to the online equipment.
- The timing of sample collection needs to be accurate (i.e. clock used for the discrete sample should correspond to the online monitoring computer clock).
- Taking offline samples at various times of the day to obtain checks at a variety of levels or concentrations. For example, if the DO concentration is high in the morning and low in the afternoon, alternate daily offline monitoring checks between the morning and afternoon to check the online instrument at various concentrations.
- **Offline monitoring checks should never be used to re-calibrate an instrument, only to determine if an online instrument requires re-calibration.** Offline monitoring checks evaluate the instruments accuracy over a tight operating band, which would not be used to recalibrate an instrument over its entire operating range (see example below).

Recalibration of Online Instruments

Offline monitoring checks will most likely evaluate the instrument in a tight band of values, which are probably well within the range of the instrument. If these checks indicate that the online instrument is inaccurate, a recalibration should be conducted. A recalibration will calibrate the online instrument over a wide range of values. If the offline monitoring checks are used for calibration purposes (which are testing accuracy in a tight range) the online instrument's accuracy will not necessarily be accurate over the instrument's entire operating range. This practice should therefore be avoided.

For example, if an online DO instrument is being monitored for accuracy using a hand-held DO instrument and the results are within 0.5 mg/L, the online instrument would be considered well calibrated. However, if the offline monitoring checks indicated that the online DO instrument was inaccurate (i.e. differences greater than 0.5 mg/L) the online instrument should be recalibrated. If the offline checks were incorrectly used to recalibrate the instrument, inaccuracies in the recalibration could occur because the monitoring checks are taken over a small range of DO concentrations (e.g. probably 2 mg/L), and the online instrument's range is much larger (e.g. 0 to 10 mg/L). Figure 6-7 shows the impact this could have on an online DO instrument's accuracy. If the monitoring values were used to recalibrate the entire operating span of the instrument an inaccurate calibration would be generated. When the instrument is recalibrated over its entire operating span, an accurate calibration is generated, which also addresses the inaccuracies noted from the offline monitoring checks.

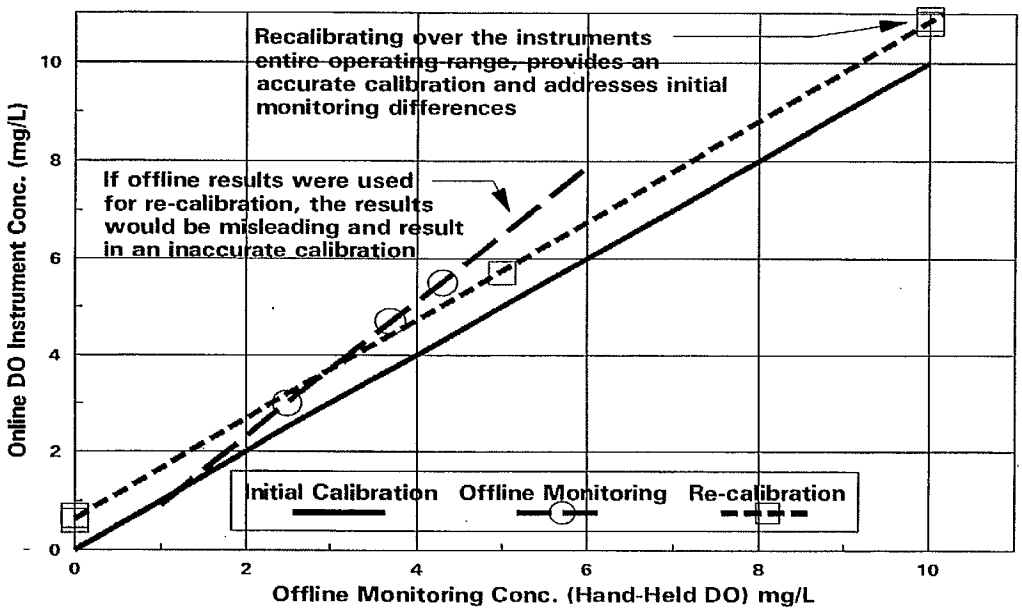


Figure 6-7
Example of Offline Monitoring Checks of an Online DO Instrument

Offline monitoring checks should be done using either a standard device calibrated to manufacturers specifications (i.e. hand-held DO instrument) or grab samples analyzed using standard methods (Standard Methods, 1992). The level of discrepancy between offline monitoring checks and online monitoring values will depend on the accuracy of the monitoring check and online instrument. DO, MLSS, and RAS units currently available should generally be accurate to within about 5 to 10 percent of an offline monitoring check. Generally, if multiple offline monitoring checks (i.e. two or three consecutive) are either consecutively greater or lower than the online instrument's valve by a target difference (i.e. 5 or 10 percent), the instrument should be recalibrated.

6.10 PROCESS MASS BALANCES AND TYPICAL LOADING RATE CALCULATIONS

Offline monitoring and historical data are often used to determine process unit mass balances and typical unit process loading rates. This information is useful for characterizing the performance of a unit process and assists the auditor in determining potential bottlenecks in the system.

The most common mass balance is the solids balance around a unit process. For example, the solids loading entering a clarifier must equal the solids removed following settling plus the solids lost in the effluent. This relationship is visually portrayed in Figure 6-8 for a primary clarifier. With all the parameters known (Case I) the results are within 5 percent, probably indicating that components in and out of this process have been accurately accounted for. Alternatively, if the mass balance did not close (i.e. load in less than load out), some stream may not be accounted for in the mass balance. This condition is shown in Case II, where a digester supernatant stream discharges downstream of the influent sampler but upstream of the primary clarifier, and this stream accounts for the observed difference. Mass balances can also be used to estimate a missing stream's concentration or flow. Case III shows that if the raw sludge concentration was unknown, the unknown value could be determined based on a mass balance around the process. Mass balances can also be determined for other parameters, such as phosphorus, nitrogen or BOD_5.

Typical loading calculations can be determined for all unit processes and offline sampling can assist in providing the appropriate analytical data for the calculation of these loading rates. Some common loading parameters in the liquid train of an activated sludge plant are:

- Primary Clarifier Surface Overflow Rate (SOR) ($L/m^2 \cdot s$)
- Aeration Tank Organic Loading (kg $BOD_5/m^3 \cdot d$)
- Aeration Tank Nitrogen Loading Rate (kg NH_3-$N/m^3 \cdot d$)
- Food-To-Micro organism Ratio (F/M Ratio) (d^{-1})
- Hydraulic Retention Time (h)
- Solids Retention Time or SRT (d)
- Final Clarifier SOR ($L/m^2 \cdot s$)
- Final Clarifier Solids Loading Rate or SLR ($kg/m^2 \cdot d$)

Calculations for these typical activated sludge plant loading rates are presented in a variety of literature sources (Metcalf and Eddy, 1979; WEF, 1992). In addition, loading rates can be compared to typical guideline values to assist in identifying problem areas (MOE, 1984).

6.11 DEVELOPMENT OF A QA/QC PROGRAM

A quality assurance/quality control (QA/QC) program is an essential part of an offline sample program to verify the accuracy of the sampling program with either an outside commercial or provincial/federal laboratory. This task is especially important when the offline analysis is being conducted in the field or by the client's laboratory. By split sampling a number of samples to a independent laboratory for separate analysis, any doubt as to the analytical method or accuracy can be avoided. A QA/QC program should be considered when the results are to be used with the

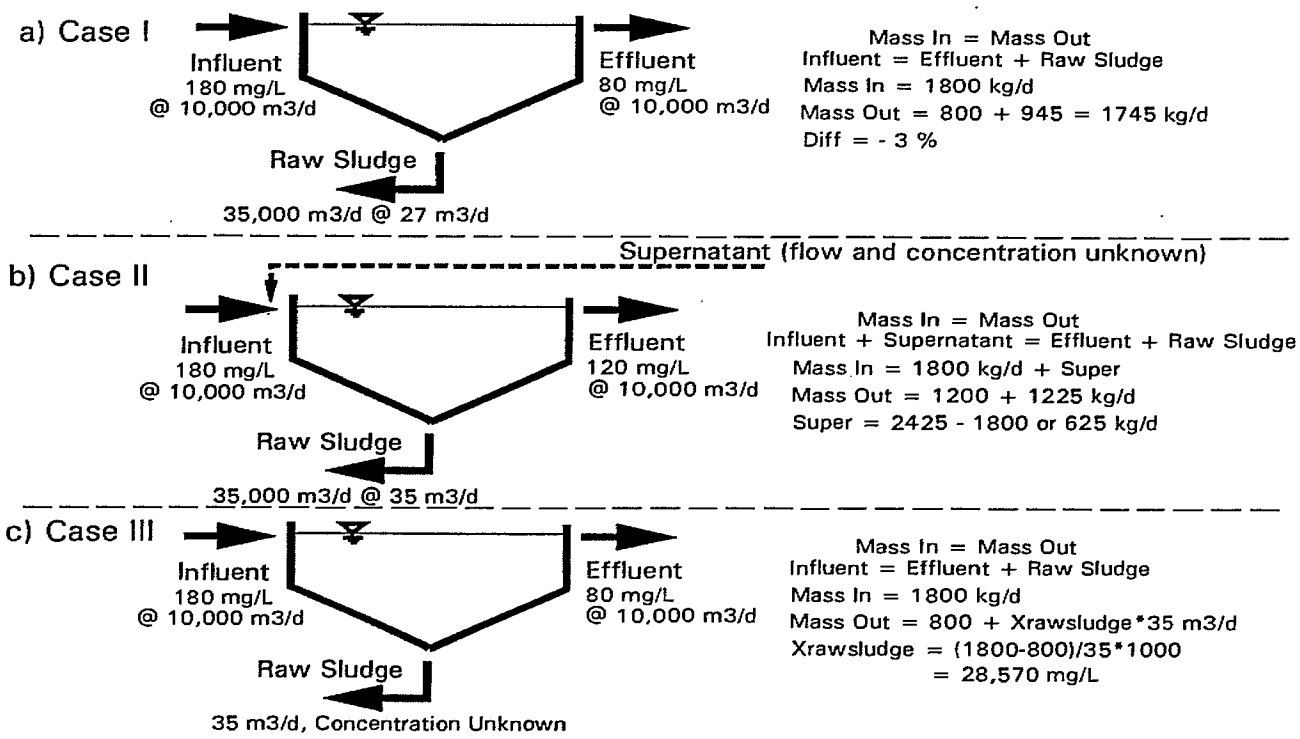


Figure 6-8
Example SS Mass Balances Around Clarifier

intention of establishing plant capacity. In these circumstances the option of a QA/QC program should be discussed with the regulatory agency to determine if such a program would preclude questions of accuracy and analysis methods later in the project. Lastly, a QA/QC program may be warranted if the results of the historical review or initial offline sampling indicates inconsistencies either with respect to mass balances or loading rates.

A QA/QC program may not be required if the offline sampling results are being used to get a better understanding of the process and are being analyzed by a recognized laboratory.

The need for a QA/QC program should be discussed early in an offline sampling task. If QA/QC samples are to be taken, the split samples need to be taken over the length of the program, not just at the end of the project. If QA/QC samples are taken at the end of an offline sampling task and differences are noted, it is too late for corrective action to be taken. For a QA/QC program regular samples need to be split between the two (or more) laboratories. Proper attention to sample handling, labelling and preservation need to be followed. If samples are being transported to a remote laboratory for analysis, provision for maintaining the sample temperature needs to be addressed (e.g. coolers with ice packs).

The amount of QA/QC sampling also needs to be discussed early in the project. Frequency of split sampling can vary depending on the project resources and the objective of the offline sampling program (e.g. plant capacity concerns). On a longer term offline sampling program (i.e. over one month), QA/QC split samples taken once or twice per month should provide a good verification of the offline sampling results (i.e. 5 to 10 percent of total analysis).

QA/QC split sampling results can be displayed in tabular or graphic form depending on the amount of data to be presented. Alternatively, a statistical approach, such as a "t"-test, can be used to determine if the two data sets are statistically different (Box, G. et al., 1978).

6.12 PRESENTATION AND INTERPRETATION OF RESULTS

Offline monitoring results can be presented in many ways depending on the parameter being displayed and the results obtained. Standard presentation methods and examples are listed below:

- *Tabular Results.* For displaying average biological system influent and effluent concentrations or for displaying average loading rates (see Tables 6.5 and 6.6 – Section 6.13 Selected Case Studies).
- *Trend Plots.* For displaying diurnal sampling results (see Figure 6-9) or for daily sampling results for an entire sampling period.

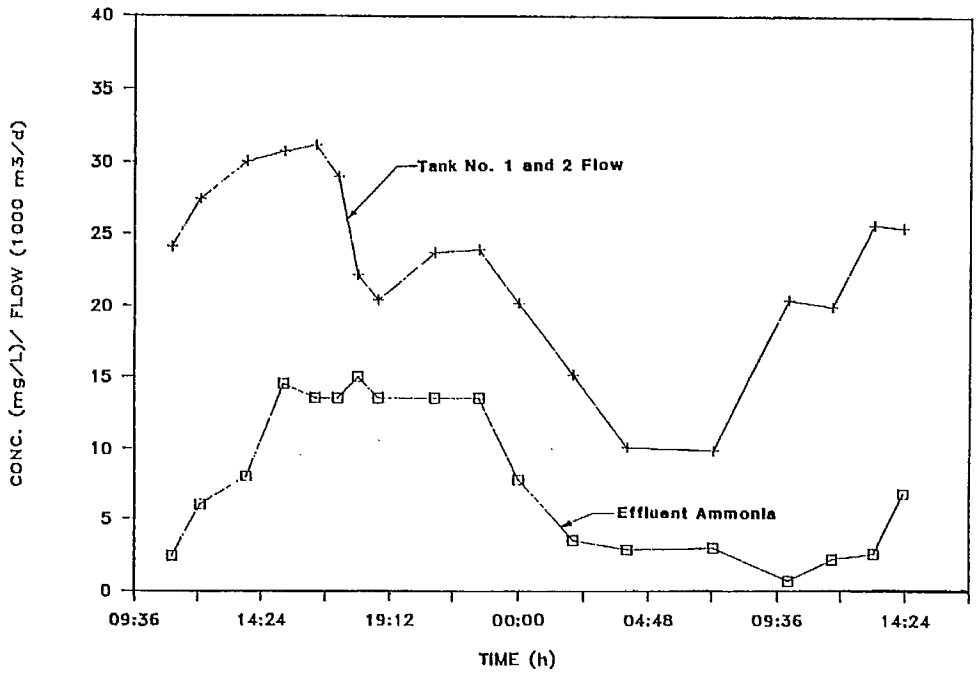


Figure 6-9
Impact of Peak Hydraulic ad Organic Loading on Nitrification at the Little River PCP

- *Probability or Frequency Graphs.* For displaying influent sampling results to show whether the results are distributed in a particular fashion such as normally distributed (see Figure 6-10).
- *Contour Plot.* To show the DO profile through an aeration tank indicating the DO concentration at various locations and depths (see Figure 6-13 – Section 6.13 Selected Case Studies).

Results can be displayed in many formats; however, some general guidelines that should be followed are:

- *Clarity.* The task conclusions should be clear from the results presented.
- *Completeness.* The data should be shown in a consistent manner without selectively summarizing only positive results, without clear discussion and reasons for any manipulation of the data set.
- *Simplicity.* Avoid displaying too much data in a table or graph, since the overall point that the presenter is trying to make can be obscured or lost.

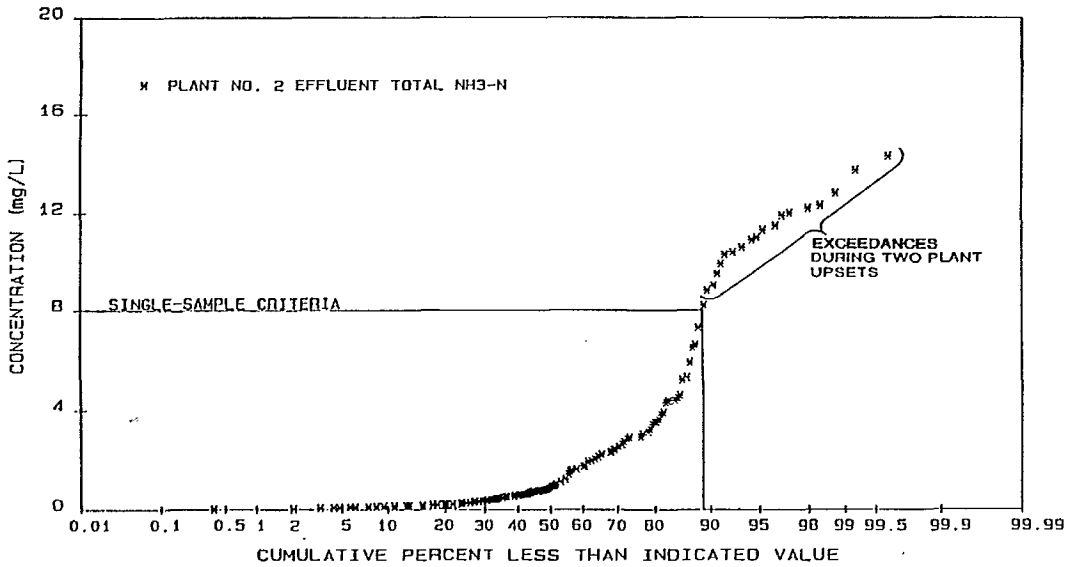


Figure 6-10
Probability Plot of Effluent Total NH_3-N Concentration from the Little River PCP

In conjunction with the presentation of the offline sampling results, interpretation of the results is an important task. The underlying significance of the sampling results should be presented and their implications interpreted. Interpretation of the results will depend on the overall objective of the sampling program. If the objective is to show that a plant can operate at a particular loading and meet effluent criteria values, then the presentation of the data and interpretation should try to address this issue. Interpretation of offline sampling results should be defendable by the sampling results. If the conclusion is that the aeration tank is poorly mixed, then a DO concentration profile covering the entire tank that supports this conclusion is required. If a program is trying to show that a plant can nitrify at a particular loading year round, then the sample results should cover the period of at least one year.

6.13 SELECTED CASE STUDIES

The following case studies and discussion refer to the results associated with actual offline sampling programs.

Little River PCP Process Evaluation

The City of Windsor's Little River Pollution Control Plant (PCP) provides secondary treatment in two separate plants on the same site for a nominal design capacity of 63,700 m^3/d (14 MGD). At the time

of constructing its second plant (Plant No. 2) in 1988, the Ministry of Environment and Energy (MOEE) issued a conditional Certificate of Approval (C of A) which required the facility to provide nitrification and organic carbon removal. This requirement, in addition to the ability to handle peak flows, raised the question of the actual capacity of the existing plant (Plant No. 1) and the proposed new plant (Plant No. 2).

The audit evaluated the performance of each plant at elevated hydraulic, organic and nitrogen loading rates. Loading rates were increased by stressing the plants, by taking some of the existing tankage out-of-service. Stress testing, in addition to conducting other auditing techniques, was used to establish the capacity of each plant. Other tests performed included: offline sampling, aeration system testing, flow metering evaluation, microscopic analysis of microorganisms, implementation of a wasting control strategy and review of the plant's ultra-violet disinfections system.

The audit work showed that the two plants (Plant Nos. 1 and 2) should be rated at 72,000 m^3/d (16 MGD). The results indicated that the two plants could handle this average daily capacity based on average and peak-day (wet weather events) flows, current influent concentration and the plant's current effluent non-compliance values.

Offline sampling was conducted throughout the study to evaluate daily performance and diurnal trends. One important diurnal trend observed during this study is shown in Figure 6-9. This trend plot shows the plant's response to variations in the influent hydraulic loading (and also the nitrogen loading). This trend was observed as the plant was being stressed near its capacity limits and therefore during diurnal peak periods, the effluent ammonia-N concentration increased significantly. On this particular day a peak flow event was simulated by increasing the load to peak-day levels on a dry-weather winter day. The average effluent ammonia-N concentration for this test was 7.7 mg/L, slightly less than the plant's single-sample (daily) effluent requirement concentration of 8 mg/L. The plot shows that as the loading increased, the plant's ability to maintain near complete nitrification (i.e. levels less than 2 mg/L) was affected. One limitation with this test was that it was found to not simulate a real-storm event, since during an actual storm event the influent concentrations (especially total ammonia-N) tend to be lower than on an average day. As a result this simulated test needed to be considered a worst-case scenario, which would not in all likelihood be observed during normal operations of the plant. Care must be taken when setting up such test events that the test method does in fact simulate actual conditions.

Online monitoring was also used extensively during the audit at the Little River PCP. Offline sampling was used on a regular basis to monitor the performance of the online instrumentation. Figure 6-11 compares an online effluent suspended solids instrument with daily grab samples. Results showed a close relationship between the two values, indicating the online equipment was accurately estimating the effluent SS concentration. Grab samples were taken at a variety of concentrations, ranging from

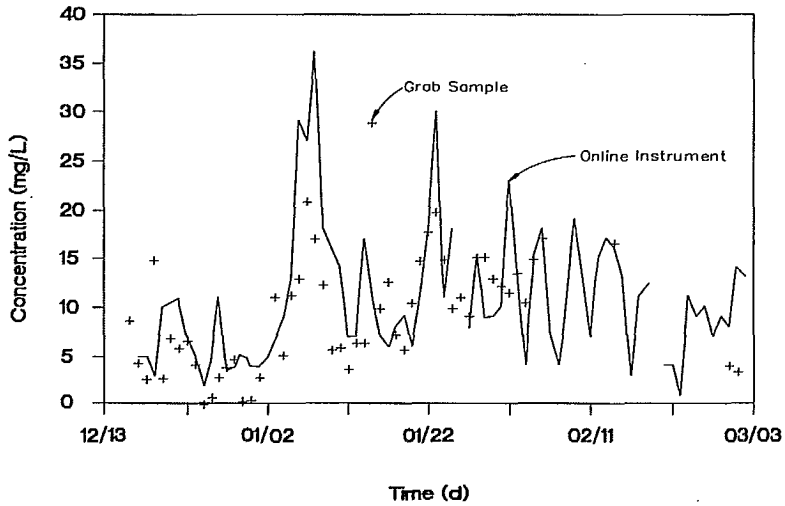


Figure 6-11
Daily Average Online Effluent Suspended Solids and Daily Analytical Effluent Concentration from the Little River PCP

5 to 20 mg/L, and the differences tended to be randomly situated. Initially, small differences resulted in re-calibration of this instrument, but once a longer trend of the instrument's performance was available, it was determined that the instrument was performing well and indicative of the underlying trend. The instrument's values were being affected by many factors including: algae interference, location of the grab sample, timing of samples and the unit's own accuracy limitations.

Since the audit work at this plant was initiated to establish the capacity of the plant, an extensive QA/QC sampling program was set up for the project. This QA/QC program was initiated early in the study and involved twice monthly split sampling with the MOEE. The results of the comparison for the final effluent is shown in Figure 6-12. This figure shows six effluent parameters that were split to ensure that the offline monitoring samples were providing accurate information about the performance of the plant during the audit. Influent and primary effluent samples were also split with the MOEE. The effluent samples compared closely; however, the influent BOD_5 concentrations initially varied considerably between the two labs. The influent samples are important because the MOEE's lower influent BOD_5 results tended to indicate that the audit period might not be a typical period for this plant. Additional split samples, including a three-way split sample with a commercial lab, resulted in confirming the accuracy of the plant's laboratory and the audit results.

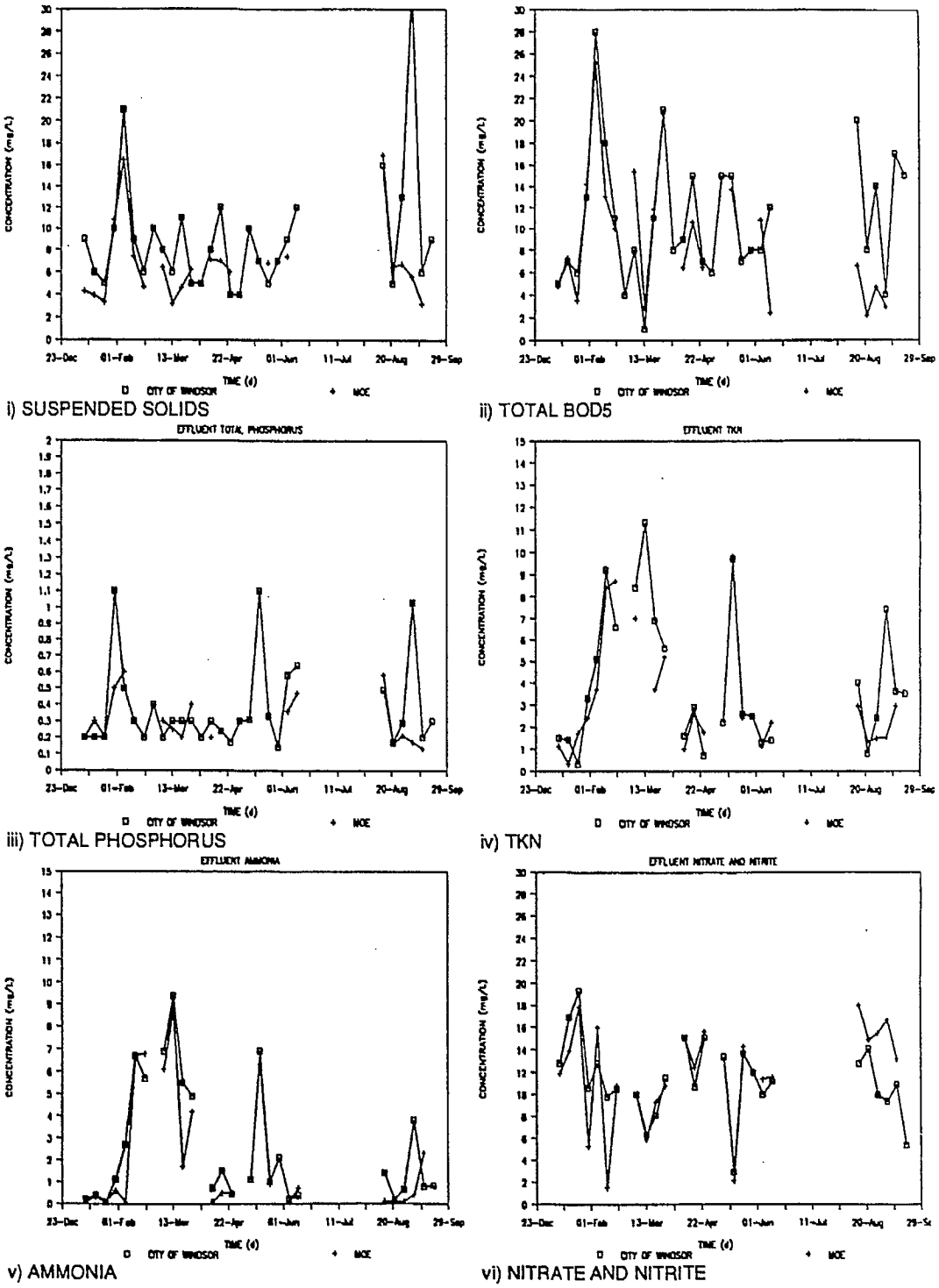


Figure 6-12
Comparison of City of Windsor and MOEE
Final Effluent Analytical Samples

Process Audit and Treatability Study at the Waterloo WWTP

The Waterloo wastewater treatment plant (WWTP) is rated for an average hydraulic capacity of 72,700 m^3/d (16 MGD). The MOEE indicated that advanced treatment will be required at this facility when the flows reach 54,600 m^3/d (12 MGD). At this point and until the current capacity is reached, the plant will need to achieve the following effluent values: 15 mg/L BOD_5, 15 mg/L SS, 0.6 mg/L TP and 1.8 mg/L total ammonia-N.

A full-scale operational audit and stress test was performed to determine the:

- Nitrification capacity of the plant
- Phosphorus removal capacity at future flow rates

The project demonstrated that the plant could nitrify and remove phosphorus and meet the effluent requirements without a major expansion. Some requirements would be needed at the plant to accomplish this goal including additional secondary clarification capacity; however, the need for tertiary treatment was demonstrated to be unnecessary at this time.

As part of the work to determine the ability of the existing plant to nitrify, the oxygenation capacity of the existing aeration system was required. The plant utilizes mechanical aeration, and the approach generally taken to test this type of equipment is to conduct an hydrogen peroxide, desorption test. Prior to conducting this test a DO profile of the aeration system was conducted. A cross section of the aeration tank shows the results of this test (Figure 6-13). One of the main assumptions of the desorption test is that the aeration system is well mixed. The cross section shows that this was not the case and a different method had to be employed to determine the oxygenation capacity of the aeration system at this site. The method used involved evaluating the oxygen demands and residual DO concentrations over a period of time. Had the aeration capacity test been conducted without first conducting the DO profile to ensure that the tank was well mixed, the results would have been incorrect.

South San Francisco WQCP Capacity Evaluation

The City of South San Francisco initiated a plant capacity evaluation study because of service area development plans and indications that the actual plant capacity may be lower than the design plant capacity. The South San Francisco and San Bruno water quality control plant (WQCP) is rated for an average and peak daily flow of 49,200 and 132,500 m^3/d, respectively, based on the plant's original design. The plant is a secondary activated sludge plant that treats a combination of domestic and industrial wastewater.

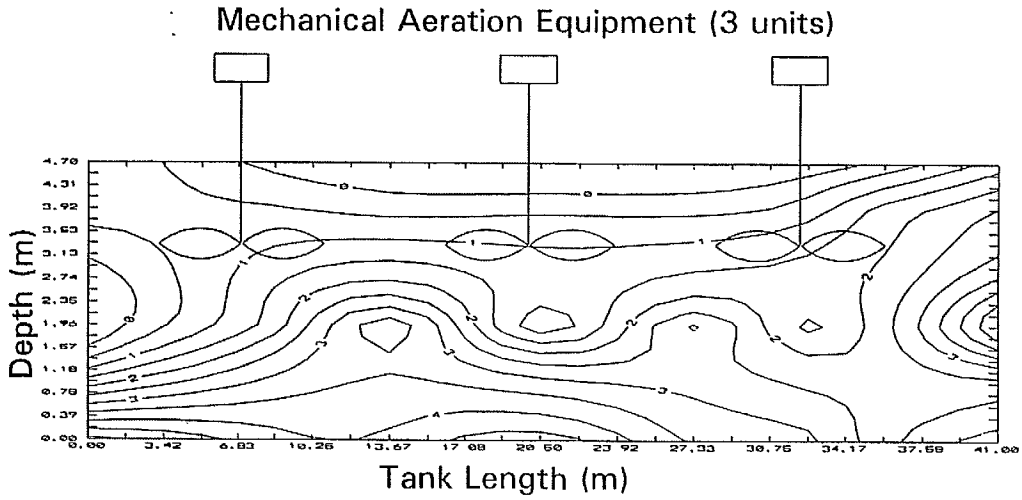


Figure 6-13
DO Profile in Aeration Tank at the Waterloo WWTP

Testing was conducted on the secondary clarifiers and aeration system in an attempt to determine the capacity of the facility. Based on the historical data and the testing conducted on the two main unit processes of the liquid train, it was concluded that the capacity had been reached and, on occasion, the plant will exceed the effluent limits for the plant. The report went on to identify limitations in the existing liquid train.

One unique aspect of this plant was the use of vacuators for primary treatment, instead of conventional clarifiers. The vacuator process uses diffused air to float oil and grease and to remove it from the influent. These vacuators were initially installed to remove high oil and grease in the influent caused by a number of meat packaging and processing plants in the City. These industries are no longer significant contributors and therefore the vacuators are not providing significant pretreatment. An offline sampling program was set-up to sample the vacuator effluent and the results showed that these units were not removing any BOD_5, SS or P as shown in Table 6.5. These results confirmed the plant staff's own understanding that these units were not removing any conventional parameters. In this case offline sampling was able to confirm that a unit process was not beneficial at this site and potentially should be removed and replaced. Slight increases in the vacuator effluent results over the raw influent results were attributed to sample or analysis variations and recycle streams. The report concluded that primary clarifiers in place of the existing vacuators, could provide removal of particulate and associated organics and reduce the loading on the biological section which is currently overloaded.

Table 6.5
Sampling Results from the South San Francisco and San Bruno WQCP

Parameter	Concentration (mg/L)				
	Raw Influent	Final Effluent	Vacuator Effluent	DAF Subnatant	Digester Supernatant
TSS	303	19	349	498	7454
Total BOD_5	278	29	291	314	702
Soluble BOD_5	130	29	150	38	133
Ammonia-N	30	29	31	25	230
Phosphorus	5.6	34.0	5.6	13.0	200

Note: Based on data collected from November 11 to December 2, 1993.

St. Thomas WPCP Aeration System Energy Evaluation

A study was conducted to review the performance and energy usage of the St. Thomas WPCP's aeration system. The study resulted from earlier work at the plant which identified high aeration DO concentrations (i.e. 6 to 8 mg/L) and concluded that changes to the system could reduce energy usage at the plant.

The study recommended a number of options for retrofitting the aeration system which would reduce aeration energy usage and would have a simple payback period of between 2 and 6 years. The City proceeded with one recommendation which provided a common air header and associated air flow measurement and controls between the two aeration systems at the plant. Historically, the plant has used two blowers for most of the years (a 125 kW and a 150 kW blower) and an additional blower during the summer (a 125 kW blower). The benefits of this retrofit have exceeded expectations by not only reducing the seasonal need of using a third 125 kW blower, but also reducing the daily demand by 25 kW by using small blowers at the plant and occasionally operating the entire plant with only one 150 kW blower.

An important part of the work was the determination of the oxygenation capacity of the existing plant. As a result the loading to the biological section was required. Since the plant has historically not sampled the aeration system influent, an offline sampling program was initiated. The results of the two-week sampling program are summarized in Table 6.6. The results indicated that the primary clarifiers removal efficiencies were 59, 41, and 58 percent for SS, $CBOD_5$ and TP, respectively. This sampling program was critical to the determination of the oxygen requirements for this site. Since the sampling program was of limited scope (i.e. two-week duration) it was important to ensure that this sampling period was a typical period for this plant. Therefore, the influent during the sampling period

Table 6.6
Analytical Sampling Results for Period June 16 to June 30, 1991 for the St. Thomas WPCP

Description	Concentration (mg/L)					
	TSS	$CBOD_5$	TKN	NH_3-N	NO_3-N	TP
Raw Influent						
- Entire Period[2]	105[1]	70	25	-	-	3.1
- Plant No. 3[2]	114	76	27	-	-	3.7
- Plant No. 4[2]	94[1]	65	24	-	-	2.6
Primary Effluent						
- Entire Period	43	41	24	20[1]	-	1.7
- Plant No. 3	53	47	26	21[1]	-	1.9
- Plant No. 4	33	34	22	19[1]	-	1.5
Final Effluent						
- Entire Period	2	2	1.8[1]	0.9	16.5	0.9
- Plant No. 3	2	2	2.1[1]	1.3	15.6	0.8
- Plant No. 4	2	2	1.6	0.6	17.4	1.0

Notes: [1] A number of erroneous results have not been included in average.
[2] Titles refer to sample period, entire is all sampling days and sample locations, Plant No. 3 is 5 daily samples taken while monitoring Plant No. 3 (primary and final), and Plant No. 4 is 5 daily samples taken while monitoring Plant No. 4.

was compared to the historical influent concentrations. Overall, the sampling period concentrations were similar to the median average of the historical data. Had this not been the case, the length of the sampling period should have been increased and, if necessary, the discrepancy between the historical period and monitoring period investigated further (e.g. split samples).

6.14 EXPECTED DURATION AND COSTS

The cost of an offline sampling program can vary based on a number of items, including:

- Length of the sampling program
- Number of other auditing tasks being performed (i.e. personnel available onsite for other tasks such as online monitoring)
- Laboratory costs, if the samples are being analyzed by a commercial laboratory
- Assistance from plant staff in terms of collecting samples

The length of the sampling program will have the largest impact on the cost of an offline monitoring program. The length of the program will increase the number of analyses, the labour to collect/ submit/transport samples, and the time needed to present and interpret the results. Sample analysis

costs can be determined once the number and turn around time are known. The required turnaround time can increase the analysis cost by 100 percent if results are required within a short period (1 or 2 days) over the laboratory's regular turnaround time (approximately 7 days). Approximate sample costs for conventional parameters are shown in Table 6.7. If the offline sampling program can be integrated into the performing of other auditing tasks, such as online monitoring or clarifier dye/stress testing, the labour cost associated with taking and collecting the samples can be reduced. Lastly, the use of plant personnel for sample taking/collecting and analysis of conventional parameters can greatly reduce the cost associated with an offline sampling program; however, adequate resources should be maintained to setup, monitor and interpret the testing results.

Table 6.7
Approximate Analytical Pricing for Conventional Parameter
(Based on CANVIRO Analytical Laboratory's Quote of March 27, 1995)

Parameter	Abbrev.	Price range
Total suspended solids	TSS	$9.00 - $15.00
Five-day biochemical oxygen demand	BOD_5	$25.00 - $30.00
Soluble five-day biochemical oxygen demand	$SBOD_5$	$27.00 - $32.00
Total ammonia nitrogen	NH_3-N	$12.00 - $18.00
Total Kjeldahl nitrogen	TKN	$15.00 - $22.00
Total phosphorus	TP	$13.00 - $19.00
Soluble phosphorus	SP	$15.00 - $21.00

Note: Price range is based on quantity submitted and required turnaround.

6.15 REFERENCES

Box, G.; Hunter, W.; and Hunter, J. *Statistics for Experimenters – An Introduction to Design, Data Analysis and Model Building.* John Wiley and Sons. New York. 1978.

CH2M HILL ENGINEERING LTD. Process Audit Technologies. CH2M HILL Internal Document. 1992.

CH2M HILL ENGINEERING LTD. Chlorination of Return Activated Sludge to Control Bulking Sludge. Report prepared for the City of Windsor. 1990.

CH2M HILL ENGINEERING LTD. Process Studies at the Corbett Creek WPCP. Report prepared for the Regional Municipality of Durham. 1990.

CH2M HILL ENGINEERING LTD. Little River Pollution Control Plant Process Evaluation. Report prepared for the City of Windsor. 1990.

CH2M HILL ENGINEERING LTD. Process Audit and Treatability Study at the Waterloo Wastewater Treatment Plant. Report prepared for the Regional Municipality of Waterloo. 1991.

CH2M HILL ENGINEERING LTD. Review of the Aeration System Performance and Energy Usage at the St. Thomas WPCP. Report prepared for the Corporation of the City of St. Thomas. 1992.

CH2M HILL ENGINEERING LTD. Process Evaluation of Plant No. 2 at the Little River Pollution Control Plant. Report prepared for the City of Windsor. 1992.

CH2M HILL ENGINEERING LTD. South San Francisco and San Bruno Water Quality Control Plant – Aeration System and Final Clarifier Evaluation. Report prepared for the City of South San Francisco. 1993.

CH2M HILL ENGINEERING LTD. Little River Pollution Control Plant Process Evaluation (Audit 2B). Report prepared for the City of Windsor. 1995.

Jenkins, D.; Richards, M.; and Daigger, G. *Manual on the Causes and Control of Activated Sludge Bulking and Foaming*. Ridgeline Press. 1986.

Metcalf and Eddy. *Wastewater Engineering : Treatment, Disposal and Reuse 3rd Edition*. McGraw-Hill, New York. 1991.

Ministry of the Environment. Guidelines for the Design of Sewage Treatment Works. MOE, Toronto. 1984.

Standard Methods for the Examination of Water and Wastewater 18th Edition. Prepared and Published jointly by the American Public Health Association, American Water Works Association, and Water Environment Federation. Washington DC. 1992.

Tyack, J.N.; Hedges, P.D.; and Smission, R.P.M. A Device for Determining the Settling Velocity Grading of Storm Sewage. Presented at the Sixth International Conference on Urban Storm Drainage. Niagara Falls Canada. 1993.

U.S. Environmental Protection Agency (U.S. EPA). Operation of Wastewater Treatment Plants, Volume II A Field Training Program. Prepared by California State University. 1989.

Water Environment Federation (WEF). Design of Municipal Wastewater Treatment Plants Volumes 1 and 2, WEF Manual of Practice No. 8. Book Press Inc. Vermont. 1992.

White, M. Instruction Manual for WRC Settling Apparatus for Activated Sludge. British Water Research Centre (WRC) Internal Technical Memorandum (TM103). 1975.

CHAPTER 7
AERATION SYSTEM CAPACITY ANALYSES

7.1 GENERAL OBJECTIVES

The transfer of dissolved oxygen is one of the most fundamental and costly processes in aerobic biological wastewater treatment systems. In North America, there are 0.6 to 0.8 billion dollars of installed aeration systems and approximately 0.6 billion dollars per year is spent on power costs to run these aeration systems (Barnhart, 1985). The size of the investment and the operating costs suggest that optimization of oxygen transfer system will provide a substantial payoff.

A number of procedures have been outlined to evaluate the aeration system capacity at a plant, and are detailed in a number of sources (Section 7.10). This chapter describes the three most common procedures: clean-water testing using sodium sulfite, dirty-water testing using hydrogen peroxide, and off-gas testing. The appropriate methods to be used and the application and interpretation of results are also addressed in this chapter. Potential limitations of each of the methods are also discussed. For instance, when conducting a dirty-water hydrogen peroxide test, the system must provide complete mixing of the hydrogen peroxide and the respiration rate during the test must be constant (Kayser, 1979; CH2M HILL, 1991; ASCE, 1984). Therefore, initial DO/MLSS profiling of the aeration tank to ensure adequate mixing, and isolation of the test tank, is highly recommended to obtain meaningful results. If the tank cannot be isolated, a test can still be conducted if adequate sampling, test replications and oxygen uptake rates are obtained during the test.

Field equipment, in addition to or in place of online monitoring equipment, may also be used for these tests. For example, for the clean-water and dirty-water chemical addition tests, a non-linear regression software package is needed to fit the test data to a model for determining the aeration system efficiency parameters. This section includes the analysis of results, including alternative software aids.

In addition to the field tests mentioned, a procedure for calculation of the aeration capacity, also used to double check field test results, is explained.

One of the objectives of the aeration system capacity evaluation is to compare the existing aeration capacity with current and future (or potential) oxygen demands. This comparison is 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. The procedure used to make this comparison is presented in this chapter and a discussion of possible treatment limitations and energy saving options is included.

Process audit experience with conventional activated sludge plants designed for $CBOD_5$ and TSS removal has shown that:

- Aeration systems often have adequate aeration capacity to provide nitrification without additional aeration tank volume, as demonstrated at the Windsor Little River PCP, Collingwood WPCP, and Metro Main TP (CH2M HILL, 1990; CH2M HILL, 1995; CH2M HILL, 1993; Nolasco et al., 1994a; Nolasco et al., 1994b)
- Energy savings can be obtained by a variety of means including a retrofit of coarse bubble diffusers to fine pore diffusers or by making changes to the aeration system configuration. This was demonstrated at the St. Thomas WPCP, where the interconnection of two separate aeration systems at the plant resulted in an immediate reduction in aeration energy usage and an increase in aeration system flexibility (CH2M HILL, 1992)

In summary, the following topics related to aeration system capacity analysis are addressed in this chapter:

- Determination of the most appropriate methods for assessing the capacity of the aeration system within a process audit.
- Description of the three most commonly used test methods for determination of the oxygenation capacity of an aeration system. A step-by-step guide on how to perform the tests, a description of the equipment required, examples of problems generally found when using these procedures, together with solutions used in previous process audits are presented. Discussion of analysis and verification methods, and presentation of software commonly used in these tests are included.
- Description of instrumentation specifically related to these tests and not addressed in other chapters of this manual.
- Assessment of aeration capacity and equipment efficiency using test results.
- Determination of aeration system requirements to meet potential effluent standards versus the available oxygenation capacity of the aeration system, as obtained from the aeration tests.
- Presentation of two selected case studies covering analysis of present and future oxygenation requirements, potential for energy savings in the aeration system, presentation of results, and common limitations found in the aeration system assessment of process audits.
- Discussion of expected duration and costs of aeration system capacity analysis.
- Extended list of references related to the above topics.

Many factors affect oxygen transfer efficiency of an aeration system. These factors and examples of how they affect oxygen transfer are presented in Table 7.1. Differences between oxygen transfer values for different plants and for the same plant at different times can be caused by one or more of these factors (U.S. EPA, 1989).

7.2 DETERMINING THE MOST APPROPRIATE METHOD FOR ASSESSING THE CAPACITY OF THE AERATION SYSTEM

The determination of the most appropriate method (i.e., oxygen transfer test) for assessing the capacity of the aeration system at a given facility requires previous understanding and knowledge of:

- the objectives of the aeration study (may differ from the standard objectives laid out in section 7.1)
- the available aeration capacity evaluation and testing methods
- the aeration system to be evaluated
- the costs and time involved in completing the analysis and achieving the objectives

Oxygen transfer tests can be used for one or more of the following purposes:

- To troubleshoot aeration systems
- To determine aeration system capacity
- As part of a wastewater treatment plant certification
- For comparing diffuser systems under process conditions
- For determining diffuser cleaning schedules and for evaluating the effectiveness of various diffuser cleaning methods
- To evaluate changes in air flow within the aeration basin and to verify metered air flow readings
- As a tool to gather oxygen transfer information to be used for design of an aeration system

7.2.1 Off-Gas Analysis

Off-gas analysis is one of the testing methods that can be used for evaluation and optimization of oxygen transfer systems. It can be used to evaluate dissolved oxygen transfer in diffused aeration systems, allowing assessment of their efficiencies. Basically, off-gas analysis measures the composition of the air entering and exiting an aeration tank. By comparing the composition of the off-gas (air exiting) to the gas entering an aeration tank, it is possible to calculate the overall process

Table 7.1
Factors Affecting Oxygen Transfer (U.S. EPA, 1989)

Factor	Example of Effect on Oxygen Transfer
Equipment Factors	
Diffuser Type	Generally, fine bubble diffusers have higher oxygen transfer efficiency than coarse bubble diffusers.
Diffuser Density	Under similar installation conditions, tanks with a greater number of fine pore diffusers per unit area have higher oxygen transfer efficiency.
Diffuser Submergence	As submergence increases, the oxygen transfer efficiency (OTE) increases. The mass of oxygen transferred per unit of energy typically remains almost constant with submergence.
Diffuser Layout	Grid patterns produce higher oxygen transfer than spiral rool, mid-width, or cross roll configurations.
Diffuser Age	As diffusers age, loss of plasticity and creep, in addition to other changes in membrane materials may cause a decrease in oxygen transfer.
Flow Regime	Generally, plug flow basins have higher overall oxygen transfer efficiency than completely mixed basins.
Basin Geometry	Tanks that are short and wide have less variation in αF, the overall coefficient a for dirty water to clean water oxygen transfer coefficient (k_La) and diffusers fouling factor (F), throughout the tank than tanks with high length-to-width ratios.
Operation Factors	
Solids Retention Time/Nitrification	Processes with higher solid retention times have higher oxygen transfer. Likewise, processes that are nitrifying have higher oxygen transfer efficiencies than processes that are not.
Food to Microorganism Ratio	Increases in food-to-microorganism ration cause decreases in oxygen transfer efficiency because of potential fouling of diffusers.
Airflow Rate Per Diffuser	As the airflow rate per diffuser increases, the oxygen transfer efficiency of most fine bubble devices decreases. For other devices (e.g. coarse bubble diffusers), oxygen transfer efficiency may increase, remain unchanged, or decrease with increased inflow.
Mixed Liquor Dissolved Oxygen	As dissolved oxygen increases, actual oxygen transfer efficiency decreases.
Diffuser Fouling	Fouling caused by formation of a biofilm on the diffuser surface decreases oxygen transfer efficiency.
Temperature	Increases the oxygen transfer coefficient, but decreases the saturated dissolved oxygen concentration.
Elevation	Affects the horsepower consumption and oxygen saturation concentration.
Wastewater Conditions	
Wastewater Characteristics	Increases in interfering agents, such as surfactants (often associated with increases in BOD), cause a decrease in oxygen transfer.

oxygen mass transfer coefficient (αFk_La) within the tank (Kayser, 1979; Daigger et al., 1992; Groves et al., 1990; Redmon et al., 1983; U.S. EPA, 1989; Nolasco et al., 1994a; Nolasco et al., 1994b).

Off-gas analyses are conducted by collecting gas from under a floating hood and sending it to an analyzer circuit where the air flow rate, oxygen content, and CO_2 content are determined. The off-gas system consists of (Figure 7-1):

- A floating hood
- A hose connecting the hood to an analyzer
- A vacuum source that draws the gas from the hood through the analyzer
- An analyzer that measures gas flow rate and off-gas composition, temperature and pressure

In the analyzer, all of the gas collected from the hood first passes through flow meters. Because gas flow exiting the aeration tank is essentially equal to gas flow entering the tank, the flow meters provide information on air flow entering the aeration basin at each sample location.

After the off-gas passes through the flow meter, a portion is passed through the analyzer circuit. Reference air (which is equivalent to the air entering the aeration basin) and off-gas from under the hood are alternately passed through the analyzer circuit. Comparison of the composition of the gas entering (reference air) and the gas exiting (off-gas) the aeration basin provides data on the changes the gas is undergoing within the basin.

In the analytical circuit, the gas is passed through a drying column, eliminating the need to correct for humidity. Next, the gas is passed by an oxygen probe under controlled pressure and flow rate. CO_2 concentration is determined by drawing a sample of gas into a CO_2 analyzer. The operation of this analyzer is based on the pressure drop caused by the adsorption of CO_2 by an alkaline solution.

The use of a floating roof to collect off-gases, makes off-gas analyses very difficult (almost impossible) to perform on surface aeration systems. Therefore, for surface aeration system tests, the hydrogen peroxide method is recommended.

When troubleshooting diffused aeration systems, off-gas analysis provides localized data on the performance of diffusers. In addition, oxygen transfer throughout the aeration system can be compared to other similar systems, thereby determining its shortcomings (Groves et al., 1990).

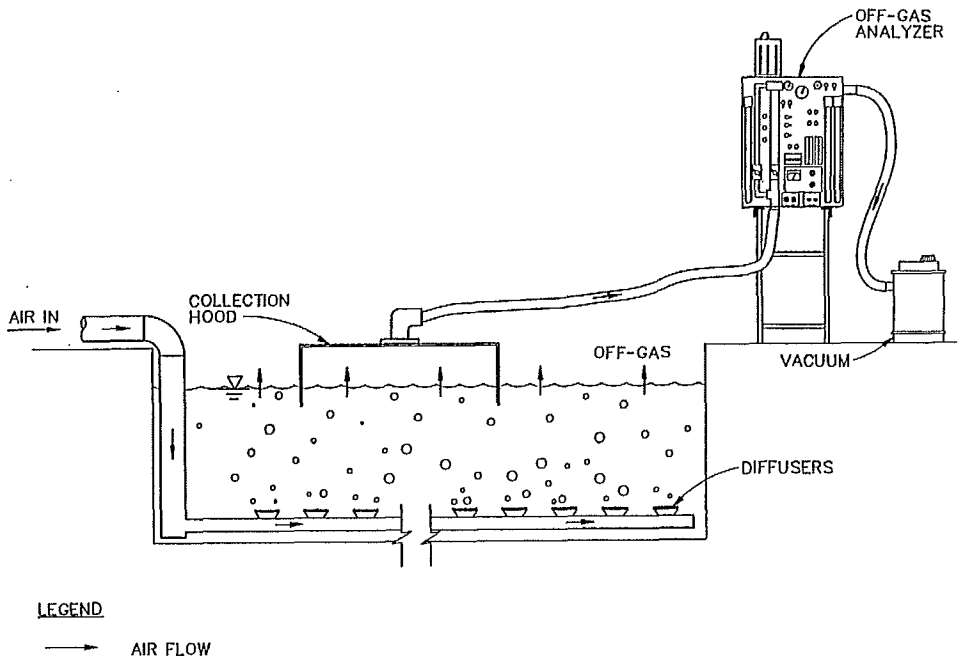


Figure 7-1
Off-Gas System

Off-gas analysis is useful when making choices of costly diffuser systems and their configurations. Full-scale, side-by-side comparisons performed before a major aeration system retrofit provide actual data from which to make decisions.

The off-gas analyzer provides data on air flow at each sample location. This capability can be used for evaluation of long-term changes in air flow at specific locations within the basin. In addition, the total air flow for the basin can also be calculated from the off-gas analysis results. These data can be used to verify the readings from the plant air flow meters.

A diffuser cleaning schedule can be determined with off-gas analysis in conjunction with dynamic wet pressure (DWP) analysis (U.S. EPA, 1989). This is done by performing periodic analysis, and cleaning the diffusers when the oxygen transfer efficiency drops and/or the pressure drop rises to a predetermined point. The most cost-effective cleaning schedule can be calculated by using an energy analysis. The effectiveness of various diffuser cleaning methods can be evaluated by using different cleaning methods on separate parts of the aeration system and comparing oxygen transfer efficiencies and DWP after cleaning (Redmon et al., 1991).

Finally, off-gas analysis provides oxygen transfer data for various systems and conditions. This data can be used as a design aid for new systems or expansion of existing systems.

One of the main advantages of using the off-gas method is that the operation of the aeration basins does not need to be interrupted during the test. This is usually not the case for the hydrogen peroxide desorption method, where the aeration influent is generally interrupted well before the beginning of the test.

A complete description of the off-gas analyzer can be found in the manual for this equipment (Ewing, 1992).

A summary of recommendations for determining if the off-gas test is the most appropriate method to use in a given process audit is shown in Table 7.2.

7.2.2 Hydrogen Peroxide Test

In this test, hydrogen peroxide (H_2O_2) is added to an aeration basin to elevate the DO level to approximately 25 mg/L. The aerators then strip this oxygen from the basin and re-establish an equilibrium DO concentration. By recording the DO concentration over time, a deoxygenation curve is developed, the inverse of which corresponds to the oxygenation potential of the aerators. By fitting a theoretical curve to the field results, the overall process oxygen mass transfer coefficient (αFk_La) can be determined (Kayser, 1979; Speirs and Stephenson, 1985; CH2M HILL, 1991; Daigger et al., 1992). This is discussed in this chapter.

The first step in preparing for the test is to obtain the hydrogen peroxide required. The goal in adding the peroxide is to elevate the DO level in the basin to approximately 25 mg/L. Prior to defining the number of DO probes required and their locations for the test, a DO profile should be constructed to determine the mixing conditions within the tank to be tested. When all equipment is ready, the basin to be tested is taken offline, with the aerators at maximum submergence. The peroxide is then added to the basin and DO readings are recorded. Data recording can occur in several ways: the DO probes can be tied into a online monitoring system, or readings can be recorded manually. Data are typically recorded for at least 2 hours. Finally, a regression is run on the data using a computer program. From this, αFk_La and the oxygen transfer capacity are obtained.

It should be stressed that peroxide at a concentration used for this test is potentially dangerous and must be handled carefully. The H_2O_2 Material Safety Data Sheet should be read prior to designing and conducting the tests.

Table 7.2
Examples of When to Use the Off-Gas Test

Recommended to Use	Not Recommended to Use
• In diffused aeration systems • When the aeration basin to be tested cannot be taken out of service • When the aeration basin does not have proper mixing • To obtain data on aeration system operation under different influent/process conditions (e.g. high/low loads, nitrification, etc.) • To obtain localized data on performance of diffusers • To measure air flow rates in different sections of the same aeration basin (leak detection) • To evaluate long-term changes in air flow and oxygen transfer efficiency at specific locations within one aeration basin • In full-scale side-by-side comparisons of diffusing systems • In large aeration basins where H_2O_2 costs become prohibitive • In side-by-side comparisons of diffuser cleaning methods	• When off-gas collection is not possible due to: - surface aeration systems - covered tanks without access to off-gas - covered tanks with contaminated off-gas (e.g. combined off-gas from various sources) • When costs of purchase/rental, or transportation of the off-gas analyzer makes the test not cost-effective

Proper mixing is one of the key issues to be addressed prior using the hydrogen peroxide method. DO profiles must be performed before an H_2O_2 test is recommended. In the off-gas method, the floating hood can be moved easily to measure at various locations without a time limitation. In the hydrogen peroxide method, all DO readings must be taken at the same time in as many locations as required by the mixing conditions. The poorer the mixing is, the more DO probes will be required. In aeration tanks with very poor mixing, the number of DO probes required to obtain accurate $\alpha F k_L a$ measurements using the H_2O_2 test may be impractical or too expensive. The determination of the number of DO measurement locations required as a function of the mixing conditions within the tank is discussed in Section 7.3.2 (CH2M HILL, 1993; ASCE, 1984).

The other key issue when considering the hydrogen peroxide method is the flexibility of operation of the facility being evaluated. The hydrogen peroxide method requires leaving the tank being tested out of service for a minimum of one hour prior to the beginning of the test, plus two hours or longer during the test. Therefore, if the facility does not have the flexibility to divert the aeration influent to another tank or section of the plant for a minimum of four hours, another method of testing should be considered. If required, an operating tank can be tested with the hydrogen peroxide method, but some corrections are required and the results obtained may not be as accurate as with the tank isolated (i.e. offline).

A summary of recommendations for determining if the hydrogen peroxide test is the most appropriate method to use is shown in Table 7.3.

Table 7.3
Examples of When to Use the Hydrogen Peroxide Test

Recommended to Use	Not Recommended to Use
• In surface aeration systems • In diffused (subsurface) aeration systems, when the off-gas test is not warranted, or not practical	• When the aeration basin to be tested cannot be taken out-of-service for approximately three to four hours per test • When thorough distribution and mixing of H_2O_2 is not possible due to: - covered tanks without appropriate access points - large tanks with difficult access - poor mixing conditions • In a very large tanks where quantity of H_2O_2 required make the test too expensive • When mixing and DO distribution conditions require a very large number of DO probes

7.2.3 Clean Water Tests

The clean water oxygen transfer test measures the rate of oxygen transfer in tap water (ASCE, 1984; U.S. EPA, 1989). Test results provide information on the oxygen transfer system independent of any effects of wastewater since the test is performed with clean water. This test can be used to verify performance claims by aeration system manufacturers, to compare different aeration devices, to observe the effects of specific factors (such as submergence) on aeration system devices and, in conjunction with wastewater tests, to determine alpha factors (CH2M HILL, 1990).

The test is conducted by removing DO from water using sodium sulfite, then reoxygenating. DO concentrations are measured at several points throughout the aeration tank during reoxygenation. Oxygen transfer parameters (Fk_La and C_s) are calculated by performing nonlinear regression on the DO values obtained at each sample location during reoxygenation. The alpha factor, α, is assumed to equal 1.0.

Some of the requirements for this test are similar to those of the hydrogen peroxide test:

- The number of DO measurement locations required increases with decreasing levels of mixing within the tank to be tested (ASCE, 1984)
- The aeration tank to be tested has to be out-of-service.
- The data analysis approach is similar.

In addition to these requirements, clean water (i.e., tap water) is required in the tank. Therefore, this test is usually performed to test new aeration equipment prior to starting the normal operation of the tank.

A summary of recommendations for determining if the clean water test is the most appropriate method to use is shown in Table 7.4.

7.2.4 Other Methods

Calculation-based methods can be used to estimate the oxygenation capacity (OC) of the aeration system (i.e., kg O_2 transferred/unit time). With the calculated OC, and knowing some of the operating characteristics of the aeration system (e.g., air flow rate, water temperature, etc.) certain aeration parameters can be estimated (e.g., $\alpha F k_L a$ and oxygen transfer efficiency).

Two calculation-based methods used in process audits for aeration system capacity analyses are:

- Empirical equation for calculating oxygen demand
- Computer-based mechanistic models of the activated sludge process

Table 7.4
Examples of When to Use the Clean Water Test

Recommended to Use	Not Recommended to Use
• To obtain information on the oxygen transfer efficiency and mass transfer coefficient of an aeration system independently of any effects of wastewater • To combine with a dirty-water test and determine the alpha factor (a) of the system • In mechanical (surface), or diffused air (sub-surface) aeration systems • Prior to startup of newly constructed or retrofitted aeration systems • To compare onsite clean water efficiency results with manufacturers' estimates	• When the aeration basin to be tested does not have clean (tap) water meeting ASCE standards for the tests • When thorough distribution and mixing of the reagents required (e.g., Na_2SO_3 and $CoCl_2$ or $CoSO_4$) is not possible due to: - covered tanks without appropriate access points - large tanks with difficult access - poor mixing conditions • When mixing and DO distribution conditions requlre a very large number of DO probes

Empirical Equation for Calculating Oxygen Demand

The most common calculation method used in process audits (described in Section 7.3.4) uses an equation that determines the oxygen requirements (kg O_2 required/unit time) (Boon and Chambers, 1982). Aeration influent and effluent characteristics (e.g., flow rate, $CBOD_5$, and TKN) are combined to estimate the oxygen demand (OD) for a given period of time (e.g., day or month). Provided an acceptable dissolved oxygen (DO) level has been maintained in the aeration tank evaluated, the OC of the system will be equal to or higher than the OD calculated with the equation. One drawback of this method is that, unless the aeration basin tested is stressed to its maximum oxygenation capacity, an estimation of the maximum oxygenation capacity cannot be obtained.

Assuming that flow-proportionate 24-hour composite automatic samplers are available, the cost of this method is directly related to analytical costs and labour effort involved. Therefore, this is the least expensive method. However, in the best of cases (i.e., aeration basin stressed to its oxygenation limit), the oxygenation capacity values obtained are only an indication of oxygen demand values that can be treated by the system. If the unit cannot be stressed to the limit (i.e. DO deficient), then the maximum OC cannot be estimated. Nevertheless, this desk-top method is practical and has been successfully used in process audits to confirm or double-check results obtained with aeration system capacity field tests.

Computer-Based Mechanistic Models

The other method for analysis of the aeration system is computer modelling (steady-state or dynamic). Dynamic models have been used successfully to confirm and expand the knowledge of the aeration system acquired from field tests. As in the case of empirical equations, the application of models will also depend on the availability of field data for calibration (Takács et al., 1990; Patry and Takács, 1990; Nolasco and Stephenson, 1991; Nolasco et al., 1994b).

A summary of recommendations for determining if using calculation techniques are appropriate in a given process audit is shown in Table 7.5. In general, the use of empirical equations for determining the oxygen demand exerted on a given aeration basin is always recommended. Whether to confirm results from oxygenation tests, or to determine the ultimate oxygenation capacity after a stress test, or to establish current and future oxygen demands for different operating conditions, the use of empirical equations is always useful in process audits.

Table 7.5
Applications of Calculated Aeration Capacity Assessment Techniques

Recommended to Use	Not Recommended to Use
• To estimate the oxygenation capacity of an aeration system without performing aeration system field tests • To confirm results with dirty-water tests (H_2O_2 or off-gas) • Applicable to any type of aeration system	• Its application is always recommended. Caution should be taken in those cases where the aeration influent and effluent characteristics are unknown or not adequately estimated.

7.3 DESCRIPTION OF TEST METHODS, EQUIPMENT, AND POSSIBLE PROBLEMS/SOLUTIONS

7.3.1 Off-Gas Analysis

7.3.1.1 Test Description

A description of the off-gas test is provided in Section 7.2.1.

7.3.1.2 Equipment Needed

The following equipment is needed to run the off-gas analysis:

- Off-gas analyzer for oxygen and CO_2 with stand
- CO_2 scrubbing solution (caustic)
- Miscellaneous spare parts for off-gas analyzer and CO_2 analyzer: extra oxygen analyzer cells, dye for manometers, dye for CO_2 analyzer, pipe attachments to analyzer, Teflon® tape, electrical tape, knife
- Heavy duty waterproof gloves
- Portable dissolved oxygen and temperature probe
- Vacuum source with hose attached. Most domestic vacuum cleaners can be used in this application
- Nitrogen cylinder with regulator
- Hood
- Vacuum hose and pressure hose for hood
- Ropes
- Tool kit with pliers and screwdrivers to repair analyzer and hood on site as needed

7.3.1.3 Test Preparation

Prior to actual performance of the off-gas analysis, the following preparatory steps must be completed:

- Define test objectives and experimental design
- Gather equipment needed
- Obtain background information
- Construct the hood
- Prepare and test the analyzer circuit

This section presents these preparatory steps as well as the actual off-gas analysis procedure.

Define Test Objectives. A clear understanding of the objectives of performing aeration test is required before beginning the preparation of the test. In general, the objectives of the aeration tests are defined in the general objectives of the process audit.

Background Information and Planning. Background information from the plant will be helpful in the interpretation of the data. The primary information that should be obtained includes:

- Diffuser type and pattern (e.g., coarse bubble, cross-roll)
- Number of diffusers
- Typical air flow rate to each basin
- Typical DO concentrations (DO levels less than 1 mg/L levels may make the results of the analysis questionable)
- Aeration basin dimensions
- Aeration basin freeboard
- Description or sketch of the aeration basin (e.g., elevation above grade; handrails, power access)
- Frequency of foaming events in aeration basins
- If the tanks are covered: location of access points (if any), description of off-gas treatment system (if existent for odour control), off-gas flow pattern (e.g., connection to other tanks), and flow metering devices.

Figure 7-2 is a sample information sheet which can be used to obtain background information. After this information is obtained, the off-gas analysis can be planned.

The following information should be provided by a person knowledgeable about the facility to be tested. Please provide whatever information you have available.

Date _____

Name of facility _____

Person responsible _____

Address _____

Phone Number _____

Elevation of plant above sea level _____

Volume of each aeration basin _____ million gallon

Length _____ m, Width _____ m, Depth _____ m

Free Board _____ m, Number of aeration basins _____

Are the aeration basins covered? _____

Mode of operation:
- Completely Mixed _____
- Plug Flow _____
- Contract/Stabilization _____
- Step Feed _____
- Other _____

Type and make of diffusers _____

Age of diffusers _____

Cleaning pattern of diffusers _____

Submergence of diffusers _____

Number of diffusers per basin _____

Number of blowers available _____, kW of each _____

Number typically in operation _____

Typical aeration rate per basin _____ m^3/d/basin

Figure 7-2
Pre-Off Gas Testing Information Sheet
(Page 1 of 3)

Pressure at blower outlet _____ kPa

Current average flow _____ m^3/d

Design average flow _____ m^3/d

Current average $CBOD_5$ concentration influent _____ mg/L
effluent _____ mg/L

Solids retention time (SRT) _____ days

Food to microorganism ratio (F/M) _____

Seasonal nitrification pattern _____

Approximate total dissolved solids _____

Typical range of aeration basin dissolved oxygen (DO) _____ mg/L

Average total ammonia-N (NH_3-N) concentration influent _____
effluent _____

Pattern and magnitude of diurnal DO variations _____

Method of controlling aeration basin DO _____
_____

Is there any foam on the aeration basin? _____

If yes, please describe it. _____

What is the appearance of the surface of the aeration basins (e.g., boiling, small evenly distributed bubbles)? _____

Is there a significant industrial loading on the plant? If so, what type of industry is it?
_____

Was a clean water oxygen transfer test done on this system? _____
If yes, could you please include all of the results of it.

Figure 7-2
Pre-Off Gas Testing Information Sheet
(Page 2 of 3)

Please provide a sketch of your aeration basins. Include the dimensions, walkways, flow pattern, inlet and outlet structures, location of air headers and diffusers or mechanical aerators, and any other unusual features.

Figure 7-2
Pre-Off Gas Testing Information Sheet
(Page 3 of 3)

Planning steps should include sizing of the hood, hood locations during the test (i.e. off-gas sampling points), methods of moving the hood, and manpower requirements.

Hood Construction. Plans for construction of a hood are presented in Figures 7-3 and 7-4. The actual dimensions of the hood will be based on the air flow rate as determined in the planning step. Using the air flow rate information (Q_{air}) and the hood surface area (A_H), the hood should be sized so that less than 900 m^3/d of off-gas are collected under the hood which is the analyzer capacity (i.e., pulled through the analyzer).

The following formula can be used to determine if the proposed hood size is appropriate:

$$\frac{Q_{AIR}\ [m^3/d]}{\text{Aeration Basin Surface Area } [m^2]} \cdot A_H\ [m^2] < 900\ m^3/\text{day}$$

It is usually worthwhile to construct the hood at the facility where the off-gas tests are going to be conducted, and store it there, rather than shipping a pre-constructed hood to the plant. Approximately 2 weeks should be allowed for hood construction. Material costs will be roughly $500 and approximately 20 hours of labour will required.

Hood Placement. Hood placement is critical to obtaining representative samples of off-gas. Off-gas sampling should be conducted at points that are representative of all the air flow conditions. For example, with spiral role flow patterns, off-gas should be collected above the diffusers and at the point the air turns down. For plug flow basins, gas should be collected at a number of points along the length of the tank. Knowing where to collect gas samples takes experience, knowledge of the mixing pattern, and a basic understanding of activated sludge aeration. However, as a general rule-of-thumb, the sampling points (i.e. hood locations) should be selected so as to obtain the most representative set of sample from the basin.

Direction for balancing, calibration and leak testing the analyzer as well as instructions for the off-gas testing procedure are contained in the *Operating Manual for Aerator-Rator Off-gas* (Ewing, 1992).

7.3.1.4 Data Analysis and Presentation

In off-gas analysis, oxygen transfer efficiency is calculated based on the performance of a mass balance on oxygen in the gas phase under process conditions. Oxygen transfer efficiency can be calculated by the following equations (Redmon et al., 1983):
and

$$OTE = \frac{MR_{o/i} - MR_{og/i}}{MR_{o/i}}$$

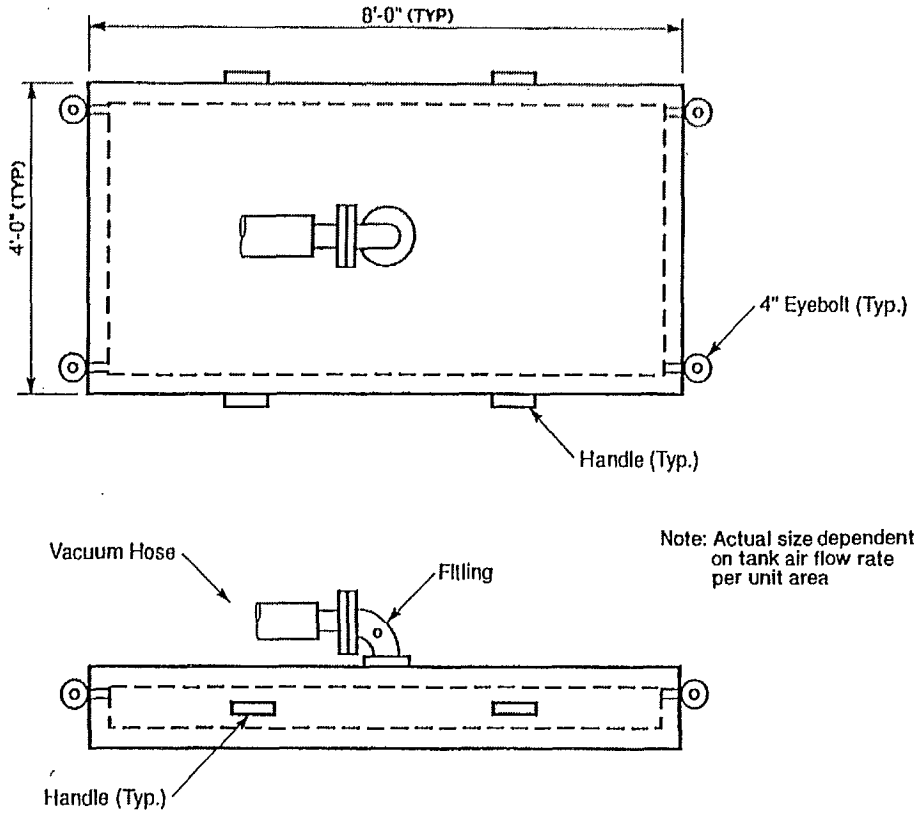


Figure 7-3
Illustrations for Off-Gas Hood Construction – I

where:

G_i = mass rate of inerts [including nitrogen and argon (Mass/time)]

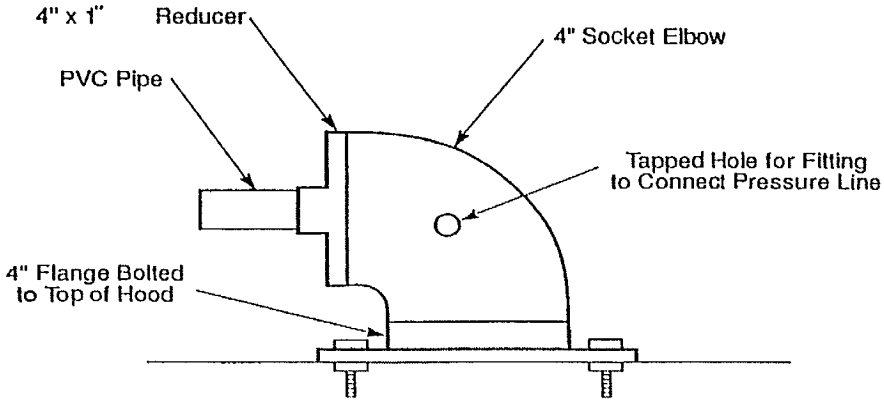
$$OTE = \frac{\text{mass } O_2 \text{ in} - \text{mass } O_2 \text{ out}}{\text{mass } O_2 \text{ in}}$$

$$= \frac{G_i(M_o/M_i)MR_{o/i} - G_i(M_o/M_i)MR_{og/i}}{G_i(M_o/M_i)MR_{o/i}}$$

M_o, M_i = molecular weight of oxygen and inerts

$MR_{o/i}$, $MR_{og/i}$ = mole ratio of oxygen to inerts in inlet and in off-gas

Redmon et al. 1983 should be reviewed for a complete description of this method.



Note: Use PVC cement for fittings

Figure 7-4
Illustrations for Off-Gas Hood Construction – II

The mole ratio of oxygen to inerts can be calculated as:

$$MR_{o/i} = \frac{Y_R}{1 - Y_R - Y_{Co_2(R)} - Y_{W(R)}}$$

and

$$MR_{og/i} = \frac{Y_{og}}{1 - Y_{og} - Y_{Co_2(og)} - Y_{W(og)}}$$

where:

$Y_{CO_2(R)}, Y_{CO_2(og)}$ = mole fractions of CO_2 in inlet gas (R) or off-gas (og)

$Y_{W(R)}, Y_{W(og)}$ = mole fractions of water vapour in inlet gas (R) or off-gas (og)

Y_R = $0.2095\ (1-Y_{W(R)})$

Y_{og} = $(MV_{(og)}/MV_{(R)})Y_R$

$MV_{(og)}$ and $MV_{(R)}$ are the millivolt output readings of the off-gas and reference air oxygen sensor, respectively, which have a linear response of millivolts to partial pressure of oxygen. $Y_{CO_2(og)}$ and $Y_{CO_2(R)}$ are the CO_2 readings taken from the analyzer for off-gas and reference air, respectively. $Y_{W(og)}$ and $Y_{W(R)}$ are both equal to 0 if the analyzer drying column is used during the testing.

Summary Calculations

A weighted bulk average oxygen transfer efficiency for an entire tank is calculated using:

$$OTE_w = \frac{OTE_n q_{an}}{q_{an}}$$

where:

OTE_w = weighted OTE

OTE_n = OTE value at sampling point n

q_{an} = collected gas flow rate per unit surface area at sampling point n

The OTEs presented above are oxygen transfer efficiencies for the temperature and DO of the wastewater during testing. In the off-gas summary spreadsheet, these OTEs are labelled OTE-TF.

Next, the OTE-TF is transformed to a Field OTE (FOTE) for the standard conditions of 20°C, 1 atmosphere, and 0 mg/L DO using a series of calculations. First, OTE-SP20, OTE per mg/L driving force under corrected temperature, pressure, and DO conditions, is calculated using:

$$OTE - SP20 = \frac{OTE - TF}{(C \bullet TF - C)} \times 1.024^{(20-T)}$$

where:

T = wastewater temperature

C•TF = calculated oxygen saturation value in the wastewater

C = wastewater DO

and

C•TF = C•20 x (Pb/Ps) x (C•st/C•s20) x Beta

where:

C•20 = clean water saturation value at standard conditions with same tank geometry usually available from clean water test on the tank (Redmon et al., 1983; Ewing, 1992)

Pb = barometric pressure at time of test (usually available from local airport)

Ps = standard atmospheric pressure (1.0 atm at 100 percent relative humidity)

C•st = surface saturation book value at test conditions

C•s20 = surface saturation book value at 20ºC, always 9.2 mg/L

Beta = ratio of process wastewater saturation value to that of clean water, usually assumed to be 0.95 to 1.00 but can be estimated (Redmon et al., 1983)

Book values may be obtained from WEF (1993).
The standard OTE (FOTE on the off-gas summary spreadsheet) is then:

FOTE = OTE – SP20 x C•20

Another value of interest is the off-gas flux rate (OG Flux on the off-gas summary spreadsheet). This is the air flow per square metre of surface area ($m^3/m^2.d$). This value provides the air flow at each sample location and, when averaged, the air flow for the entire aeration basin. The equation for calculation of off-gas flux is:

off-gas Flux Rate [$m^3/m^2.d$] = $Q_{off\text{-}gas}$

where:

$Q_{off\text{-}gas}$ = $Q_{Rotameter}$(Temperature Correction) • (Pressure Correction)

where:

$Q_{Rotameter}$ = Air flow rate from either Rotameter No. 1 or No. 2 (from chart or equations in (Ewing, 1992)

Temperature Correction = $[(460 + 70^{o}F)/(460 + \text{Rota Temp})]^{0.5}$

= $[530/(460 + \text{Rota Temp})]^{0.5}$

Pressure Correction = $[\text{local barometer in Hg} + \text{Rota Press}/29.92]^{0.5}$

where:

Rota Temp = Off-gas temperature, °F, at rotameter discharge

Rota Press = Off-gas pressure, inches mercury, above or below local barometric pressure

Other off-gas results that are useful in evaluating aeration systems are standard $m^3/d \cdot$diffuser and FOTE at 2 mg/L dissolved oxygen concentration. Design air flow through the diffusers can be compared to actual air flow by determining scfm/diffuser. FOTE at 2 mg/L dissolved oxygen concentration is useful because activated sludge systems are typically designed and operated this concentration.

The data collected during the off-gas analysis are noted in a field data sheet (Figure 7-5). The information from the field data sheets is entered into a off-gas summary spreadsheet. The field oxygen transfer efficiencies and standard oxygen transfer efficiencies are calculated on the spreadsheet for each sample location and for the entire aeration basin. A sample spreadsheet is attached as Figure 7-6.

An example of data analysis for off-gas tests performed at an existing facility as part of a process audit is presented as a case study in Section 7.8.1. Off-gas summary spreadsheets and data presentation techniques are also shown in this case study.

7.3.2 Hydrogen Peroxide Test

7.3.2.1 Test Description

A description of the H_2O_2 test can be found in Section 7.2.2.

7.3.2.2 Equipment Needed

The following equipment is needed for the hydrogen peroxide test:

- Hydrogen peroxide: typically a 50-percent solution is used
- Safety equipment: rubber boots, gloves, and suits; goggles and face shields; safety harness; hard hat; and a person with active freshwater hose (in case of H_2O_2 splash on exposed skin)
- Spigots: required if large drums are used
- Twenty-litre plastic buckets
- DO meters (online meters or YSI-type portable meters)
- Online monitoring equipment (if automatic data acquisition is desired)
- Electrical power measuring hardware
- Stop watches
- Aeration tank temperature measurement device
- Curve fitting program (for data analysis after test)

EXAMPLE OFF-GAS FIELD DATA SHEET

Page _____

Test Site_____ Tank_____ Date_____

Diffuser Water Depth ft._____ Air Rate scfm_____

Mixed Liquor Flow MGD_____ Air Temperature, F_____

Local Barometer, in Mg_____ Mixed Liquor Temp_____

Sludge Age_____

Time	Station	Rot No.	Rotameter Indication (mm)	Hood Pres (in)	Rot T (deg. F)	Rot Pres (in)	Cell Pres (in)	Sensor Out (mv)	Cell T (Deg. F)	DO (mg/L)	CO2 (%)	Comments

Figure 7-5
Off-Gas Field Data Sheet

SITE: Twin Falls
SYSTEM: Sanitaire ceramic disks
BASIN(S): South Aeration Basin
TEST DATE: April 26, 1989

INPUT VALUES

Component	Units	Value
MLSS	mg/l	2619
TDS	mg/l	660
Submergence	ft	14.4
Barometer	in HG	26.64
Hood Area	sq ft	23.4
No. of Diffusers		2268
Basin Area	sq ft	9753
Beta	frac.	0.99
C*s20	mg/l	9.20
C*st	mg/l	9.00
C*20	mg/l	10.20
C*TF	mg/l	8.80

OFF-GAS ANALYSIS SUMMARY TABLE

Station	OTE-TF (%)	FOTE @ D mg/l (%)	Off-Gas Flux (scfm/sq ft)
1	9.8	12.2	0.098
2	11.9	18.3	0.079
3	10.9	16.4	0.587
4	7.6	10.5	0.671
5	8.7	13.1	0.833
6	9.6	14.4	0.670
Flow Wtd. Average	9.2	13.6	

FIELD DATA

Time	Station	Rota1 (mm)	Rota2 (mm)	Rota Temp (oC)	Rota Pres (in WC)	MOG (mV)	MR (mV)	M.L.Temp (oC)	M.L.DO (mg/l)	FCO2 (frac.)
16:00	1	80		66	4.1	917	1000	20.5	2.45	0.004
14:45	2	70		65	2.8	900	1000	20.5	2.2	0.0035
13:40	3		140	67.5	9.4	908	1000	20.5	2.1	0.004
11:30	4		157	66	11.5	935	1000	23	1.9	0.004
10:30	5		190	62	13.8	926	1000	26	2.9	0.004
9:45	6		157	67	10.7	920	1000	26	1.8	0.003

COMPUTATIONS

C*TF-C (mg/l)	Air Flow (acfm)	OG Flux (scfm/sq ft)	OTE-TF (frac.)	OTE-SP20 (1/mg/l)	FOTE @ 0 mg/l (frac.)	TF*OG	SP20*OG	FOTE*OG @ 0 mg/l
8.145	2.40	0.098	0.098	0.012	0.122	0.010	0.001	0.012
6.595	1.95	0.079	0.119	0.018	0.183	0.009	0.001	0.014
6.695	14.35	0.587	0.109	0.016	0.164	0.064	0.009	0.096
6.895	16.35	0.671	0.076	0.010	0.105	0.051	0.007	0.070
5.895	20.15	0.833	0.087	0.013	0.131	0.073	0.011	0.109
5.895	16.35	0.670	0.096	0.014	0.144	0.064	0.009	0.096
SUM		2.937				0.271	0.039	0.399

Figure 7-6
Summary Spreadsheet

Testing is performed on an entire aeration basin as a unit. The basin is usually taken offline during the test, although this is not essential. However, test results may not be as precise if the respiration rate changes during the test. If the aeration basin is left online during the test, different results (lower αFk_La) may also be obtained from the effect of surfactants. These results may be more variable than those obtained when the aeration basin is taken offline during the test. If the test is performed in a plug flow tank under online conditions, organic loadings at the head end may result in low DOs which make parameter estimation difficult (particularly αFk_La).

If the maximum capacity is to be tested, then maximum submergence power draw for the aerators or maximum air flow in a diffused air system should be obtained. The relationship between aerator submergence and power draw should be evaluated and graphed before the test (preferably before installing equipment or ordering H_2O_2; calculations to estimate H_2O_2 requirements are shown below).

For better results, it is recommended to perform multiple tests (at least three). If a DO control study is being conducted, tests will be run at minimum and maximum energy input rates. For the test, the MLVSS concentration should be within the normal operating range.

It is important to inform the plant staff that the peroxide test will not adversely affect plant performance. Die-off of the mixed liquor bacteria is not a concern in H_2O_2 tests due to the rapid mixing, conversion to O_2 and H_2O and the rapid mixing achieved.

7.3.2.3 Test Preparation

Prior to performing an H_2O_2 test, the following preparatory steps must be completed:

- Define objectives and design experiment
- Gather equipment needed
- Obtain background information
- Define power draw-submergence relationship for surface aeration
- Calculate H_2O_2 requirements
- Determine method of adding H_2O_2
- Order H_2O_2
- Determine number and location of DO probes
- Calibrate, test, and install DO probes
- Install electric power metering equipment
- Prepare for data recording
- Prepare aeration basin for test (e.g. take if offline)
- Conduct the tests

The following explains some of the preparatory steps, as well as the actual H_2O_2 test procedure.

Define Test Objectives. A clear understanding of the objectives of performing aeration test is required before beginning the preparation of the test. In general, the objectives of the aeration tests are defined in the general objectives of the process audit.

Background Information and Planning. Background information, similar to the one indicated for off-gas analysis (Section 7.3.1.3), should be collected for the H_2O_2 test. If the aeration system consists of mechanical surface aerators, the following information should then replace the one for diffusers:

- Type and number of mechanical aerators
- Name plate information
- Best location for power draw measurements
- Common operation patterns: aerator submergence, speed (if multiple-speed drives), aerator on/off duration

Define Power Draw-Submergence Relationship. The first step in the test is to define the power draw-submergence relationship of the aeration hardware, using active power (kW) to derive this relationship. In surface aeration systems, excessive submergence may result in ever-increasing power draw, which will ultimately adversely affect oxygenation capacity and efficiency. Therefore, excessive submergence must be avoided.

Field measurements of active power at the motor and submergence of the mixer are required to establish a power draw-submergence relationship. Assistance from plant personnel and the Electrical Power Supplier (e.g., Ontario Hydro) may be required in power measurement of large motors.

Calculate Hydrogen Peroxide Requirements. The next step is to calculate the amount of peroxide required. The sample H_2O_2 quantity calculation below uses the following assumptions:

- Peroxide is added to elevate the DO level in the basin to approximately 25 mg/L
- Initial DO in tank is about 5 mg/L (assuming aeration influent stream is interrupted)
- Fifty-percent (by weight) peroxide (which weighs 1.2 kg/L) is used. Therefore, there is 0.6 kg of H_2O_2/L
- Liquid volume of basin tested is 1,000 m^3
- Molecular weights of oxygen gas and peroxide are 32 and 34, respectively.

- $$\underset{(2x34)}{2H_2O_2} \xrightarrow[\text{(catalase)}]{\text{MLVSS}} \underset{(2x18)}{2H_2O} + \underset{(1x32)}{O_2}$$

O_2 needed = (25 mg/L - 5 mg/L) • 1,000 m^3 • 1,000 L/m^3 • 1 kg/1,000,000 mg = 20 kg

H_2O_2 needed = (20 kg) x (68/32) = 42.5 kg

50 percent H_2O_2 needed = (42.5 kg) / (0.50) = 85 kg

Volume of 50 percent H_2O_2 needed = 85 kg / 1.2 kg/L = 70.8 L

Order Hydrogen Peroxide. After determining the amount needed and method of addition, the peroxide can be ordered in the proper size containers. Peroxide can be delivered in 40-litre buckets, 100- and 200-litre drums and by tanker. Order the peroxide quickly. Depending on the location of the supplier, there may be significant delivery time. If several containers are required, request delivery by a truck with a power gate; the containers are heavy!

Determine Method of Adding the Hydrogen Peroxide. The next step is to determine the method of pouring the hydrogen peroxide into the aeration basin. The goal is to transfer all of the required peroxide into the basin within 4 to 5 minutes. With small aeration basins, the peroxide is often manually transferred from large barrels into 10- to 20-litre buckets which are then placed around the perimeter of the aeration basin. The peroxide is quickly poured into the basin from the buckets. If the basin is large, the number of buckets needed may be prohibitive; in that case, 35-gallon drums have been successfully used. The drums are outfitted with large-diameter spigots and placed on their sides next to the basin. The spigots are then opened quickly and the drums drained into the basin.

Although the actual method used will vary from project to project, safety is always of the utmost importance during peroxide addition.

Determine Location of Dissolved Oxygen Probes. A portable DO probe (e.g., a YSI unit) should be used for a preliminary screening of the DO profile in the tank to determine whether spatial differences in DO exist. Because it is important to avoid any anomalies in the DO concentration distribution, the DO concentration should be checked at least at minimum and maximum power input levels (or airflow rates, in the case of diffused air subsurface systems). The physical orientation of the probe should be such that air is not entrapped on the membrane causing biased or erratic readings.

The hydrogen peroxide test is based on the assumption that the aeration tank is completely mixed. A completely mixed tank ensures that:

- The hydrogen peroxide will be dispersed throughout the tank
- The DO readings taken during the test are representative of the DO desorption trend throughout the basin

To check the aeration tank's mixing, a DO profile should be taken using a hand-held DO probe. The DO concentration should be taken at 0.5 metre (m) intervals from the surface to the bottom. Profiles should be taken along the length of the tanks every 4 m or so and in corners or visible "dead zones" (areas that do not appear to be well mixed). The DO concentration should not vary significantly in the profiles (CH2M HILL, 1991).

The number and location of DO measurement points will be dictated by the size of the test tank, aerator placement (or type of diffuser system), and mixing pattern in the tank. The ASCE standard procedure for measurement of oxygen transfer in clean water dictates the criteria to establish the number and location of DO sampling points (i.e., DO probe locations) (ASCE, 1984). These criteria for clean water testing should be used in the H_2O_2 (dirty water) tests:

- A minimum of four determination points shall be used. One should be at a shallow depth; one should be at a deep location and one should be at mid-depth. The points should be at least 0.6 m from the walls, floor and surface and no closer to the surface than 10 percent of the minimum tank dimension.
- The determination points shall be located in an attempt to have each probe measure an equal portion of the tank volume and shall be distributed vertically and horizontally (or radially) to best represent the tank contents.
- More than four determination points should be used when the tank is large (e.g. >2000 m^3), or when significant spatial k_La variations occur.

Results from the initial DO profile may indicate non-uniform DO conditions in the aeration basin. Non-uniform DO distributions are generally related to inadequate mixing or poor data acquisition. The ASCE standard procedure for clean water tests indicates that non-uniformity does not necessarily invalidate the test. However, it may suggest non-uniform aeration intensity or short circuiting of the flow with some zones of the tank achieving higher oxygen transfer rates than others. Therefore, when non-uniformity is evident, care should be taken to ensure that a sufficient number of determination point locations are adequately placed to correctly sense the changes in DO inventory in the tank. In cases when very poor mixing conditions prevail, the number of DO probes (or sampling points) required, make the H_2O_2 test prohibitive. In these cases, other oxygen capacity evaluation procedures (e.g., off-gas or calculated O_2 mass balances) should be used. Also, the improvement of the mixing conditions in the aeration basin analyzed should be recommended as part of the

process audit recommendations. A detailed discussion of the spatial uniformity of k_La and C_{x20} values related to mixing and oxygen distribution can be found in the ASCE Procedures (ASCE, 1984).

The spatial variation of k_La values computed in each test can be used to judge the adequacy of DO metering point numbers and locations. When a small number of DO probes (e.g. four) are employed, the spatial variation of the average DO values should be limited so that three-fourths of the values are within ±10 percent of the mean value for the tank. When spatial variations greater than this are observed or expected, consideration should be given to using a greater number of determination points (e.g. six to eight), or testing by tank sections.

The ASCE Standard Procedures for Clean Water Test also establishes the criteria of validity based on the reproducibility of functional k_La values (Section 8.2.2). These criteria can also be extrapolated to dirty water tests:

- When a series of at least three replicate tests are conducted, the determination point k_La values in each replicate shall not vary by more than ±15 percent from the mean value for that point.
- Replicate determination point k_La values which exhibit greater variation shall be considered as invalid and shall not be used for calculation of the measured standard oxygen transfer rate (SOTR).
- Deletion of data from a determination point shall invalidate the replicate test unless suitable data from a backup probe are available for that test.

Calibrate and Test Probes. Prior to testing, all DO probes should be calibrated and then placed next to each other in the basin to verify that they all give the same readings. The probe linearity should be verified. The DO probe scale may have to be changed to cover the entire DO range required for the test. For example, the Danfoss probes are usually set at a 0-10 mg/L range for monitoring and must be set at the 0-30 mg/L range for the H_2O_2 test (Danfoss type DO probes are essentially linear).

Prepare for Data Recording. Data can be recorded in two ways:

- automatic online data acquisition
- manual recording

If any of the DO probes are tied into an online monitoring system (discussed in Section 5.3), the computer can record DO readings. This is the case for most process audits. In this case, the system's logging and sampling times should both be set at 60 seconds.

In the second method (i.e., record readings by hand), sufficient data recording sheets should be prepared for each probe. Each person recording should have a stop watch.

7.3.2.4 Conduct the Test

Fifty-percent hydrogen peroxide is an extremely oxidative chemical, and extreme care must be taken in handling it because decomposition liberates oxygen and heat. *The Material Safety Data Sheet (MSDS) for H_2O_2 should be thoroughly read before conducting the test. The safety equipment listed in this manual should be worn at all times while handling shipping containers and during the peroxide addition.* Gloves, goggles, and a face shield should be worn along with protective clothing because peroxide can splash underneath a shield. If the addition of the peroxide requires personnel to work next to an open tank, a safety harness should be worn and staffed by several people. If any person comes in contact with the chemical, i.e., splashes on clothes, the clothing should be removed and the contacted area should be flushed repeatedly with clean water. It is of utmost importance that all team members involved in any way with the test or the handling of H_2O_2 are aware of the hazards related to H_2O_2 use.

If the maximum capacity of mechanical aerators is being measured, then the aerator submergence should be set at its maximum level.

The following steps are used in running the test:

- Calibrate DO probes; set appropriate scale.
- Check DO probes by immersing in 20-litre plastic pail nearly filled with secondary effluent, 1 litre mixed liquor, and H_2O_2 using the addition calculation shown previously. This is done to ensure that the probes will go up to 30 mg/L. If not, the cell may need to be replaced or probe refurbished.
- Position the hydrogen peroxide barrels and DO probes.
- Place stopwatches and data recording sheets at each probe (if needed), or set computer to proper logging rate.
- Take the aeration basin offline and create required submergence for surface aeration.
- Turn on all aerators or appropriate blowers (if a capacity test is being run).
- Record aerator or blower power draw.
- Record MLSS temperature.
- Wait until a stable DO (i.e., steady state oxygen uptake rate) condition is reached in the aeration basin.
- Add the peroxide as quickly as possible (once a stable DO is reached).

- Begin recording data immediately. One person should signal all recorders to start their stop watches. Readings should be taken every 60 seconds at the start of the test (for approximately 30 minutes). Once the tail region of the curve is reached (Figure 7-7), the lead recorder can signal recorders to start taking DO readings at longer intervals (2 or 3 minutes).
- Record data for at least 2 hours. It is *very* important to get a well-defined tail of the curve, so err on the side of recording longer if readings are still dropping. The equilibrium DO must be reestablished.

7.3.2.5 Data Analysis and Presentation

Data Analysis Using a Curve-fitting program. The desorption curve follows a standard equation or model which can be fitted using a non-linear method. The form of the model is (Speirs and Stephenson, 1985; Metcalf and Eddy, 1991):

$$C_t = C_s + (C_o - C_s)^{(-\alpha F k_L a \cdot t)}$$

where;

$\alpha F k_L a$ = process oxygen mass transfer coefficient (h^{-1})
C_t = DO concentration (mg/L) at time, t
C_s = equilibrium DO concentration (mg/L)
C_o = initial DO concentration (mg/L)
t = time (h)

Any non-linear software package can be used for fitting this equation to the data and estimating the parameters ($\alpha F k_L a$, C_o, C_s). Commercially available graphics and statistics packages can also be used to plot the DO curve and perform parameter estimation (e.g., PLOTIT). The estimation procedure for the parameters will vary according to the package used. In general, the following steps will be required:

- Edit the raw data
- Prepare initial model estimates
- Run the non-linear package and estimate the parameters
- Present the data

Organization of Raw Data. Before modelling, the data must be organized into a ASCII or text file. If the data have been collected using online line equipment, a program can construct a test file of the DO concentration data (see Chapter 5 for information on online monitoring). If the DO

concentrations have been recorded by hand, the data can be typed into a spreadsheet software program (e.g., Lotus, Quattro, or Excel).

The data should be arranged in two columns with the first column being the elapsed time in hours and the second column being DO concentration in mg/L. After the data have been entered into a file, the values must be edited to obtain the descending section of the curve. The curve has three sections (Figure 7-7):

- The "increasing" section as the hydrogen peroxide is mixed throughout the tank
- The "peak" section as the last of the peroxide is used to elevate the DO concentration to its maximum
- The "descending" section as the excess oxygen is stripped by the aeration equipment and an equilibrium concentration is re-established

Only the "descending" portion of the curve is used to model the aeration equipment's efficiency. The "increasing" section relates to the reaction rate of hydrogen peroxide being added to the tank. The "peak" section tends to have a number of points which do not relate to the expected desorption curve but rather to mixing limitations in the tank.

Initial Parameter Estimates. To begin the estimation process, initial parameter estimates are required by most non-linear fitting packages. Reasonable estimates can be based on the particular data. "Best-guess" initial estimates for these parameters are:

αFk_La - The αFk_La value will most probably vary from 1 to $5h^{-1}$. For mechanical aeration equipment try $3h^{-1}$. For coarse and fine bubble diffuser systems, use 2 and $4h^{-1}$, respectively.

C_o - The initial DO concentration will be approximately equal to the maximum DO concentration of the data.

C_s - The equilibrium DO concentration will be approximately equal to the final DO concentration of the data.

Final Estimation. The procedure for running the non-linear regression package to estimate the parameters will vary according to the package used. After the model parameters are estimated, the results should be in terms of residual sum of squares and confidence intervals on the parameters. A graphic review of the model's fit to the data is also recommended. A plot of the residuals may also be useful to ensure that the residuals are random. The final estimation run of the model is then plotted as the fitted curve shown in Figure 7-7.

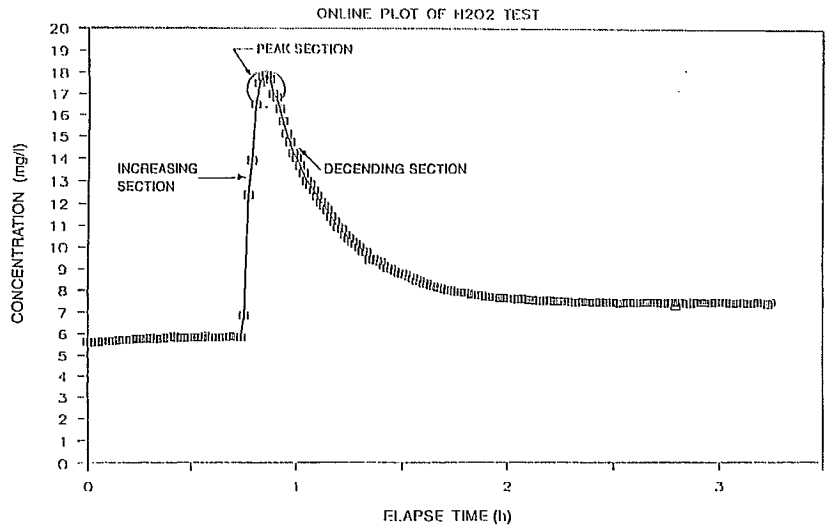


Figure 7-7
Sample Plot of Online Data from a Hydrogen Peroxide Test

The primary result of interest from this test is the $\alpha F k_L a$ and the oxygenation capacity (OC). In addition, the standard aeration (electrical) efficiency of the equipment can be determined. The important calculations are:

1. The oxygen mass transfer coefficient ($k_L a$) varies with temperature as shown in the following equation for a standard temperature of 20°C (Metcalf and Eddy, 1991; U.S. EPA, 1989; WPCF/ASCE, 1988):

$$k_L a_T = k_L a_{20}\ \theta^{(T-20)}$$

where:

T is the actual test liquid temperature (°C) and 20°C is the base temperature. The temperature coefficient, θ, typically has a value of 1.024.

2. The standard oxygen transfer rate (SOTR) or oxygenation capacity (OC) at standard conditions is calculated as follows:

$$SOTR_{20} = \alpha F k_L a_{20} \bullet C_s \bullet V \bullet 24/1000$$

where:

$SOTR_{20}$ = standard oxygen transfer rate at 20°C (kg O_2/day)
C_s = oxygen saturation concentration at 20°C (mg/L)

V = aeration tank volume (m^3)
$\alpha F k_L a_{20}$ = process O_2 mass transfer coefficient at 20°C (h^{-1})

The factor, α, represents the ratio of process water to clean water k_La, and F represents the potential deterioration or fouling that may occur.

3. The standard aeration (electrical) efficiency (SAE) is the oxygen transfer rate per unit of power input, and is calculated as:

where:

SAE = SOTR/(P•24)
SAE = standard aeration efficiency (kg O_2/kW - hr)
P = blower or mechanical aerator active power (kW)

Data Presentation. The primary result of interest from this test is αk_La and the capacity figures that can be calculated from it.

The oxygenation capacity (**OC**) is calculated from the process mass transfer coefficient and the available oxygen for biological activity. The **OC** calculation is temperature-dependent because the oxygen saturation concentration and k_La_T vary with temperature. The **OC** is also dependent on the residual **DO** concentration required. Therefore, the **OC** calculation is similar to the **SOTR** calculation, but with corrections for aeration basin operating temperature and **DO** concentration. The oxygenation capacity (**OC**) is calculated as follows:

$$OC = \alpha F k_L a_T (C_s - C_r) \bullet V \bullet 24/1000$$

where:

OC = oxygenation capacity (kg/day) [at temperature (T) and residual DO concentration (C_r)]
C_r = residual DO required (mg/L)
T = mixed liquor temperature (°C)

The residual DO required (C_r) is usually 0 for maximum capacity or 2 for recommended minimum DO.

Examples of graphical presentation of H_2O_2 test results are shown in a case study in Section 7.8.

7.3.3 ASCE Clean Water Test

7.3.3.1 Test Description

A description of the ASCE Clean Water Test can be found in Section 7.2.3 (ASCE, 1984; U.S. EPA, 1989).

7.3.3.2 Equipment Needed

The following chemicals and equipment are needed for this test:

- Sodium sulfite (Na_2SO_3), reagent or technical grade: approximately 20 mg/L per 1.0 mg/L DO concentration is needed in the tank to be tested. The sodium sulfite will be discharged to the tank in a solution of 0.268 kg/L at 20°C or 0.36 kg/L at 3°C.
- Cobalt chloride ($CoCl_2$) or cobalt sulfate ($CoSO_4$), reagent or technical grade: sufficient cobalt salt should be added to achieve a soluble cobalt concentration in the test tank between 0.10 mg/L and 0.50 mg/L. This is a catalyst for the reaction.
- Two tanks for mixing of sodium sulfite solution and cobalt into solution. The tanks should have spigots on the bottom to facilitate discharging the solution into the aeration basin to be tested. The spigot for the sodium sulfite solution must be large enough to discharge the solution in less than 3 minutes.
- Two mixers for mixing tanks, electrical propeller type mixers or paddles to be used manually.
- DO meters: the number of DO recording locations will be determined following the ASCE Standards (ASCE, 1984).
- Online monitoring equipment can be used to facilitate data acquisition.
- Electrical power measuring hardware.
- Stop watches.
- Nonlinear regression program (e.g., PLOTIT software).
- Temperature measurement device.

7.3.3.3 Test Preparation

Prior to performing a clean water test, the following preparatory steps must be completed:

- Define test objectives
- Gather background information
- Prepare aeration basin for the test

- Define Power draw-submergence relationship
- Calculate chemical requirements
- Determine method for adding chemicals
- Determine location of DO probes
- Prepare for data recording
- Conduct the test

Define Test Objectives. A clear understanding of the objectives of performing aeration test is required before beginning the preparation of the test. In general, the objectives of the aeration tests are defined in the general objectives of the process audit.

Gather Background Information. In addition to the background information required for off-gas and H_2O_2 tests (Sections 7.3.1.3 and 7.3.2.3), information on the water supply source and available water chemistry data should be obtained. Water samples should be made available for laboratory experiments regarding the chemical additions that will be made (ASCE, 1984).

Prepare Aeration Basin for the Test

- The aeration basin installation should be inspected to verify placement and testing conditions.
- Systems employing diffused air aeration should be tested to eliminate leaks.
- Provisions for power and air flow measurement should be verified and modifications made as needed. It may be necessary to install equipment such as meters for power measurement, supplemental air piping, orifice plates and manometers.
- The test tank should be cleaned prior to filling for testing. Once the tank is filled with the test water, chemical and biological contamination should be avoided.
- It may be necessary to dewater and refill the test tank during the testing and adequate pumping and discharge arrangements should be made.
- The water supplied for the initial test shall be equivalent in quality to a potable public water supply. Subsequent tests may be conducted in the same water and, because of the addition of de-oxygenation chemicals, the Total Dissolved Solids concentration (TDS) will increase. Repetitive testing may be conducted in the same water provided that the TDS does not exceed 1500 mg/L (ASCE, 1984).

- When repetitive tests are conducted in the same water, the water should be analyzed for the various constituents and properties.
  - Temperature: every test – beginning and end
  - Total Dissolved Solids: every test series – beginning and end (end value may be calculated by mass balance)
  - Soluble Cobalt: every test series – beginning and end
- The aeration system should be operated to achieve steady state conditions prior to starting the oxygen transfer evaluation. A steady power draw can indicate a steady state hydraulic condition for mechanical aerators. Some mechanical and diffused air systems require 30 to 40 minute to achieve a steady state regime.
- For tests of fixed platform surface aerators and rotors, the water surface elevation shall be held constant so that the power draw is constant during the test. For other systems, the volume of water under aeration shall not vary by more than ±2 percent during any one test.

Define Power Draw-Submergence Relationship. The first step in the test is to define the power draw-submergence relationship of the aeration hardware, using active power (kW) to derive this relationship. In surface aeration systems, excessive submergence may result in ever-increasing power draw, which in the limit will ultimately adversely affect oxygenation capacity due to excessive submergence and efficiency. Therefore, excessive submergence must be avoided.

Field measurements of active power at the motor and submergence of the mixer are required to establish a power draw-submergence relationship. Assistance from plant personnel and the Electrical Power Supplier (e.g., Ontario Hydro) may be required in power measurement of large motors.

Calculate Chemical Requirements. The de-oxygenation chemicals required (i.e., sodium sulphite and cobalt chloride or cobalt sulphate) can be evaluated based on the proportions indicated in Section 7.3.3.2 and following the ASCE Standards (ASCE, 1984).

Determine the Method of Adding Chemicals. Based on experiences from several clean water tests, the easiest way to discharge the sodium sulfite solution into the test basin is by use of a tank with one or more spigots near the bottom.

It is important to keep the sodium sulfite solution mixed while discharging it into the test basin so that is does not clog the spigots.

Determine Location of Dissolved Oxygen Probes. A portable probe should be used for a preliminary screening of the DO profile in the tank to determine whether spatial differences in DO exist. The ASCE standard for clean water tests, described in Section 7.3.2.3 should be used.

Calibrate and Test DO Probes. The same procedure should be used that is identified in Section 7.3.2.3. For de-aeration, the range should be set at 0 to 10 mg/L.

Prepare for Data Recording. Data can be recorded in two ways:

- Automatic online data acquisition
- Manual recording

If any of the DO probes are tied into an online monitoring system (discussed in Section 5.3), the computer can record DO readings. This is the case for most process audits. In this case, the system's logging and sampling times should both be set at 60 seconds.

In the second method (i.e., manual readings), sufficient data recording sheets should be prepared for each probe. Each person recording should have a stop watch.

Conduct the Test. The following steps should be followed when running the test:

- Calibrate DO probes and set appropriate scale.
- Check DO probes by installing them in a 10 L pail with primary effluent (zero DO) and in a pail with stirred tap water (O_2 saturation concentration).
- Position DO probes.
- Create required aeration conditions (i.e., mechanical aerator submergence or air flow rate).
- Place stop watches and data recording sheets at each probe (if manual recording is done), or set computer to proper logging rate.
- Record aeration system power draw.
- Record aeration basin temperature.

- Pour chemicals into aeration basin as quickly as possible allowing for proper mixing.
- Begin recording data immediately. One person should signal all recorders to start their stop watches. Readings should be taken every 60 seconds at the start of the test (for approximately 30 minutes). Once the tail region (steady-stage region) of the curve is reached (Figure 7-8), the lead recorder can signal recorders to start taking DO readings at longer intervals (2 or 3 minutes).
- Record data for at least 2 hours. It is very important to get a well-defined tail of the curve, so err on the side of recording longer if readings are still climbing. The equilibrium DO must be reestablished.

7.3.3.4 Data Analysis and Presentation

For clean water, the rate of oxygen transfer is proportional to the difference between the existing DO concentration and the equilibrium concentration of the oxygen in the water. In other words, the greater the difference between the existing concentration and the equilibrium concentration, the greater the driving force for oxygen transfer through the film. This is expressed by the following equation (Metcalf and Eddy, 1991):

$$dC_t/dt = k_La(C_s - C)$$

where:

dC/dt = rate of change of oxygen concentration, $mg \bullet L^{-1} \bullet H^{-1}$

k_La = mass transfer coefficient, h^{-1}

C_s = dissolved oxygen saturation concentration, mg/L

C_t = dissolved oxygen concentration at time, t, mg/L

$C_t = C_s - (C_s - C_o)^{(k_Lat)}$

When integrated, the above equation becomes:

where:

C_o is the initial DO concentration and t is time.

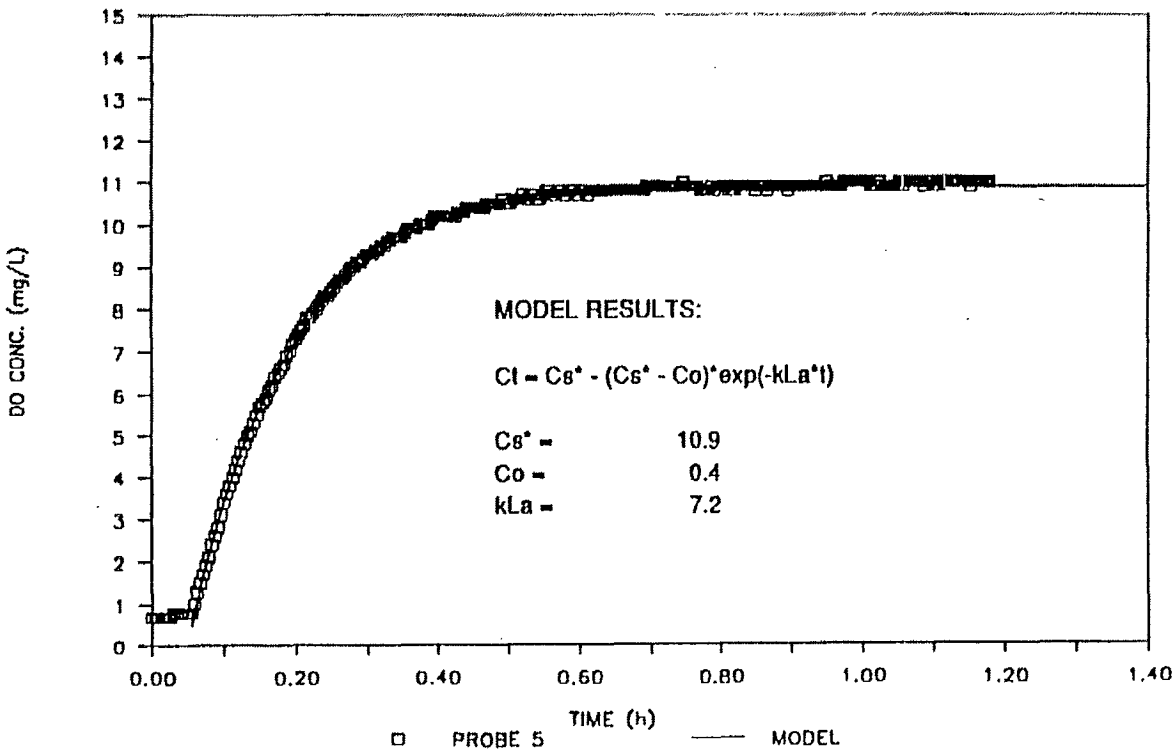


Figure 7-8
Typical Dissolved Oxygen Response Curve and Non-Linear Model Results

A non-linear regression is performed on the test data for DO concentration C, over time, t. The result of the non-linear regression are values for k_La and Cs for each sample point in the test basin. Either a commercially available software program (e.g., PLOTIT) or the program developed specifically for the ASCE standard clean water oxygen transfer test can be used for the non-linear regression (Metcalf and Eddy, 1991).

The non-linear regression produces values for k_La and C_s under the test conditions for the temperature and DO content of the water. Estimates for k_La and C_s are then adjusted to standard conditions using the following equations:

$$k_La_{20} = k_La\theta^{(20-T)}$$

$$C_{s20} = C_s(1/\tau\Omega)$$

where:

k_La_{20} = mass transfer coefficient corrected to 20°C, h^{-1}

θ = temperature correction factor, equal to 1.024 unless proven to have a different value for the aeration system and tank tested

T = water temperature during test, °C

C_{s20} = DO saturation concentration corrected to 20°C and a standard barometric pressure of 1.00 atm, mg/L

t = temperature correction factor, dimension less and equal to C^*_{st}/C^*_{s20}

C^*_{st} = DO surface saturation concentration at the test temperature, a standard total pressure of 1.00 atm and 100 percent relative humidity, mg/L

C^*_{s20} = dissolved oxygen surface saturation concentration at 20°C, a standard total pressure of 1.00 atm and 100 percent relative humidity, mg/L

Ω = pressure correction factor, dimensionless

= P_b/P_s (for tanks under 20 feet, for tanks greater than 20 feet refer to ASCE, 1984)

P_b = barometric pressure during test, kPa

P_s = standard barometric pressure of 1.00 atm, kPa

After adjusting k_La and C_s to standard conditions, the standard oxygen transfer rate (SOTR), or oxygenation capacity (OC), can be obtained using the following formula:

$$SOTR = V \sum (k_La\ C_{s20}) / n$$

where:

Σ = summation sign
V = the volume of water, [length^3]
n = number of determination points

The SOTR is the mass of oxygen dissolved per unit of time at a concentration of zero DO.

Another value which can be calculated from the clean water tests is the standard oxygen transfer efficiency (SOTE), the mass of oxygen transferred per mass of oxygen supplied. The SOTE is calculated as follows:

$$SOTE = SOTR/WO_2$$

where:

WO_2 = mass flow rate of oxygen, [mass/time]

If wastewater tests are also being performed on the basin, the alpha (α) for the wastewater can be determined by using the oxygen transfer values from the clean water test and the wastewater test as follows:

α = K_La of the wastewater/K_La of the clean water, dimensionless

or:

α = Oxygen transfer efficiency (OTE) of the wastewater/OTE of the clean water

Typical values of α are between 0.4 and 1.0.

For both equations it is important that the wastewater oxygen transfer value and the clean water oxygen transfer value are both based on the same airflow, temperature and pressure.

7.3.4 Other Methods

In some cases, the aeration capacity measurement methods described in previous sections (i.e., off-gas, H_2O_2, and clean water tests) cannot be performed. In these cases, or when an oxygen capacity estimate is needed for comparison or confirmation of the results obtained on the field, other methods can be utilized at relatively low cost. Two of the most common analysis techniques used in process audits are: estimation of the oxygen requirements by empirical equations, and modelling (steady-state or dynamic) of the aeration system (Chapter 12).

Calculation methods do not require major equipment preparation (with the exception of special dynamic models, when the cost of training, software, and hardware may be required). The background information required for field tests is also useful for desk-top analysis. In addition to background information, online and offline data from the secondary treatment system are also required.

7.3.4.1 Estimation of Oxygenation Capacity and Oxygen Requirements by Empirical Equations

The carbonaceous biochemical oxygen demand and the carbonaceous and nitrogenous oxygen demand (OD) of the aeration system under analysis can be calculated using a modified version of Boon and Chambers equation (Boon and Chambers, 1982):

$OD = Qraw \bullet (CBOD_{5,IN} - CBOD_{5,FE})$	Carbonaceous BOD_5 Removal
$+ 0.002 \times MLSS \bullet VOL_{TANKS}$	Endogenous Respiration
$+ 4.3 \times QRAW \bullet (TKNIN - TKNFE)$	Nitrification
$- 2.83 \bullet QRAW \bullet [(TKNIN - TKNFE) - (NO^-_3 - N_{FE})]$	Denitrification Credit

where:

Q_{RAW}	= Total Raw Sewage Flow Rate, MLD
$CBOD_{5,IN}$, TKN_{IN}	= Concentrations in Aeration Influent, mg/L
$CBOD_{5,FE}$, TKN_{FE} and $NO_3^- - N_{FE}$	= Concentrations in Final Effluent, mg/L

This is an empirical equation based on observations performed at various treatment plants in the USA and the UK. The original equation uses NH_3-N instead of TKN. The large differences observed at the aeration influent of certain facilities between both parameters (i.e., TKN_{IN} and NH_3-N_{IN}) made the OD (TKN) values considerably larger than the OD (NH_3-N) ones. Because the OD value has a large impact on the oxygenation capacity required, the use of TKN is recommended.

In certain cases and under low DO concentrations, the oxygen bound to nitrate (NO_3) and nitrite (NO_2^-) is used by the microorganisms present in the mixed liquor as an electron acceptor. This process, called denitrification, reduces the overall OD of the system and is shown in the last term of the equation. For estimation of future OD, the denitrification credit should only be used when it has been established that denitrification will occur under future operating conditions.

Using online and offline information retrieved from historical data records or from the process audit data acquisition program, the peak oxygen requirement can be calculated. The peak oxygen requirement calculated with the actual final effluent concentrations obtained during the study period will approximate the maximum rate of oxygen transferred to the mixed liquor (OTmax, kg O_2/day) in that period. If the aeration basins are operated under stressed conditions, the OTmax calculated will

be similar to the oxygenation capacity (OC) of the aeration system. If the aeration basins are not operating under stressed conditions (i.e., the oxygen demand of the aeration influent is under the oxygenation capacity), the OTmax value will be less than the OC of the aeration system, and will only be an indication of the oxygenation requirements that can be met with the existing aeration system.

The nature of this empirical method makes its results only a rough approximation of the OC of the system. However, experience with aeration capacity analyses in process audits indicates that, under normal operating conditions, the values obtained by applying this empirical equation are reasonably close to the actual OC of the aeration systems under study (Boon and Chambers, 1982; CH2M HILL, 1993; Nolasco et al., 1994).

Another application of this empirical equation has been to obtain the oxygenation requirement (OR), or oxygen demand (OD), under various operating conditions (e.g., carbon oxidation, nitrification, and denitrification) including current and future influent flow rates. For example, to obtain the future OD for complete nitrification, Q_{RAW} is set equal to the future flow, the $CBOD_{5,FE}$ and TKN_{FE} values are set close to zero, and the denitrification term is eliminated. It is also used to calculate peak OD using historical plant organic and nitrogeneous loading data.

An example of the application of this equation is discussed in a selected case study (Section 7.8) (CH2M HILL, 1993; Nolasco et al., 1991; Nolasco et al., 1994a; Nolasco et al., 1994b).

7.3.4.2 Modelling of the Aeration System

The use of computer-based mechanistic models of the activated sludge process in process audits is discussed in Section 13 (Takács et al., 1990; Patry and Takács, 1990; Nolasco et al., 1994b). One of the potential uses of these models is in the estimation of the OC of the aeration system (CH2M HILL, 1993; Nolasco et al., 1994b). If a calibrated model of the secondary treatment system is available, the k_La values can be adjusted to match the dissolved oxygen (DO) concentrations recorded with the process audit online data acquisition system. Once the k_La values are determined, the OC and the equipment efficiency for different operating conditions can be calculated using the equations shown in Section 7.3.2.4.

7.4 DESCRIPTION OF ADDITIONAL INSTRUMENTATION

In addition to the off-gas analyzer, described in Section 7.3.1, other instruments generally used in aeration tests are: portable DO meters, air flow meters, and power meters.

7.4.1 Portable DO Meters

Portable dissolved oxygen (DO) meters are used in all of the field tests described. They are used for calibration of the DO online probes (whenever used), determination of DO profiles in the aeration basins tested, and in some cases, for measurement of DO concentrations during the tests.

The calibration of portable DO meters, and the use of these meters for calibration of online DO meters is discussed in Chapter 5: Online Monitoring.

The portable DO meters used in process audits are intended for field or laboratory use for DO and temperature measurement in water and wastewater applications. DO is indicated in mg/L or in percent air saturation. In general, display sensitivity in the mg/L mode may be selected to read in tenths or hundreds of a mg/L (tenths of mg/L are recommended for process audit applications). Temperature is indicated in degrees C from -5°C to +45°C, with 0.5°C resolution.

The mg/L mode is automatically temperature compensated for changes in solubility of oxygen in water and for permeability of the probe membrane.

The DO probes use Clark-type membrane covered polarographic sensors with built-in thermistors for temperature measurement and compensation. A thin, permeable membrane stretched over the sensor isolates the sensor elements from the environment, but allows oxygen and certain gases to enter. When a polarizing voltage is applied across the sensor, oxygen that has passed through the membrane reacts at the cathode, causing a current to flow.

The membrane passes oxygen at a rate proportional to the pressure difference across it. Since oxygen is rapidly consumed at the cathode, it can be assumed that the oxygen pressure inside the membrane is effectively zero. Hence, the force causing the oxygen to diffuse through the membrane is proportional to the absolute pressure of oxygen outside the membrane. If the oxygen pressure increases, more oxygen diffuses through the membrane and more current flows through the sensor. A lower pressure results in less current.

The most common problem in the use of portable DO online meters is the puncture of the probe membrane. To avoid this, it is recommended to protect the membrane area of the probe by covering it with a wet cloth when not in use. Keeping the membrane moist when storing it is recommended to extend its life.

7.4.2 Air Flow Meters

Most aeration systems have air flow meters installed. In general, if the air flow meters at the plant are operational, they are used in the evaluation of the aeration system capacity.

The most common air flow meters found in the aeration systems of wastewater treatment plants are Venturi, flow tubes and orifice plates. A general description of these devices can be found in the literature (WPCF, 1984; WEF, 1993; WPCF/ASCE, 1988).

Selection of the type of meter, sizing, location, installation, troubleshooting, and calibration of these instruments is generally outside of the scope of a process audit. However, their accuracy can be checked by comparing air flow readings with results air flow rates obtained from manufacturer blower curves, and/or by comparison to the air flow rate required to meet the current oxygen demand of the system.

7.4.3 Power Meters

Power meters are used to measure the active power [kW], of motors of mechanical surface aerators or blowers. In the case of mechanical surface aerators, active power is measured at different submergence levels. In diffused aeration systems, the active power of the blowers is measured at different air flow rates and blower configurations. Power factor should also be determined.

The type and size of Watt meter to be used will depend on the power of the equipment to be measured. The plant electricians should always be consulted, and their presence during power measurements should always be required. In large facilities, it is also recommended that the electrical power supplier (e.g., Ontario Hydro) be consulted prior to selecting the type of equipment to be used. (In some process audits, personnel of Ontario Hydro performed the required power measurements.) Only qualified specialists should install this instrumentation, e.g., an electrician, for safety reasons.

7.5 AERATION CAPACITY AND ELECTRICAL EFFICIENCY

The determination of the aeration capacity (i.e., oxygenation capacity, OC) and electrical power consumption have been described for each of the test methods (Sections 7.3.1 through 7.3.4).

7.5.1 Aeration Capacity

The oxygenation capacity (OC) of the aeration system is defined as the mass of oxygen transferred to the mixed liquor per unit time [kg O_2/day].

In a process audit, the oxygenation capacity determined by field tests (i.e., available firm capacity) is generally compared to the oxygenation requirements of the plant at current and future operating conditions (i.e., system needs). Based on this comparison, the following questions can be answered:

- Can the plant meet current oxygenation requirements (i.e., oxygen demand, OD) with the available oxygenation capacity? If not, the results may explain some problems like: low DO conditions leading to filamentous bulking, lack of nitrification (when nitrification is required), carbonaceous removal below required limits, etc.
- Can the plant meet potential effluent requirements (e.g., complete nitrification) at current and future flow rates?
- How much additional oxygenation capacity is required to meet future (or potential) effluent requirements?
- Does the plant have oxygenation capacity in excess of the expected (design) values? How much?
- How much additional treatment capacity does the plant have?
- Can a plant expansion be postponed or minimized? For how long?

7.5.2 Aeration (Electrical) Efficiency

The aeration (electrical) efficiency (AE) is defined as the mass of oxygen (kgO_2)

$$\text{(Electrical) Efficiency} = \frac{\text{Oxygen Transfer [kgO}_2\text{/day]} \bullet \text{1 day}}{\text{Active Power [kW]} \quad \text{24hour}}$$

$$= \left[\frac{\text{kgO}_2\text{ transferred per hour}}{\text{kW}}\right]$$

transferred to the mixed liquor per unit of electrical energy consumed by the system (kWh): where the consumption is expressed as active power.

The aeration (electrical) efficiency value obtained with the selected aeration test can be expressed at standard operating conditions (i.e., T = 20°C and DO = 0 mg/L). The standard aeration (electrical) efficiency (SAE) can be used to compare the aeration system of the plant where the process audit is performed with other aeration systems. Based on this comparison, the following questions can be answered:

- Is the submergence of a surface aerator adequate, and are the aerator blades deteriorated?
- Are the results from the tests within reasonable values? If not, should the tests/calculations be repeated to confirm/reject previous results?

- Is the SAE of the plant under analysis within the expected range of efficiencies for its type?
- If the SAE is on the low end of the range, can the efficiency be improved without major retrofit? For example, in the case of fine pore diffusers: do the diffusers need to be cleaned more often? How often do they need to be cleaned to compensate for energy costs (i.e., where is the economical operation point?)
- How much energy savings can we expect to attain by retrofitting the current aeration system to a more efficient one?
- Knowing the SAE of the current system and the expected efficiency of the potential future system, a cost/benefit analysis can be made to answer the question: is it cost-effective to retrofit on an energy savings basis only? When? (i.e., at what flow rate and under which effluent requirements?)

Answering the types of questions in the above two sections is one of the main objectives of a process audit. Examples of the use of aeration capacity and equipment efficiency values are discussed using selected case studies in Section 7.8.

7.6 DETERMINATION OF SYSTEM NEEDS VERSUS AVAILABLE CAPACITY

The aeration system needs are generally determined by the oxygenation requirements or oxygen demand (OD). The OD can be determined using a modification of the empirical equation proposed by Boon and Chambers (Section 7.3.4.1) (Boon and Chambers, 1982). To apply this equation the following parameters are required:

- Aeration influent characteristics (e.g., $CBOD_{5,IN}$, TKN_{IN})
- Influent flow rates (Q_{raw})
- Effluent requirements (e.g., $CBOD_{5,IN}$, TKN_{FE})
- Aeration basin volume (VOL_{tanks})

When assessing future facility needs, the available oxygenation capacity (OC), determined with the test methods described in Section 7.3, should be compared to the future (potential) OD.

If the future OD cannot be met with the present OC, potential ways of increasing the OC must be analyzed and evaluated. Potential ways of increasing the OC or reducing the OD to meet future effluent requirements are:

- Increase the number of blowers in subsurface aeration systems
- Retrofit from coarse bubble to fine pore diffusers

- Increase power of drives in mechanical aerators
- Reduce the organic loading in the aeration influent by pre-precipitation in the primary clarifiers
- Make the effluent requirements less stringent (e.g., partial instead of complete nitrification)
- Introduce denitrification if aeration basin volume available is sufficient
- Increase the number of aeration basins (plant expansion)
- Reduce the nominal plant capacity (i.e., derate the plant by reducing maximum flow rate allowable)

These are some of the potential alternatives available to make the OD match the OC.

Examples of the application of these alternatives are explained as case studies in Section 7.8.

7.7 EVALUATION OF ENERGY COST SAVING OPTIONS

Several ways of achieving energy savings at the aeration system of an existing facility are available:

- Equipment and diffuser retrofits
- Automatic DO control
- Treatment process modifications

A step-by-step guide on how to analyze the potential to implement equipment and diffuser retrofits, and automatic DO control is presented in the case studies presented in Section 7.8. Several treatment process modifications that may lead to energy savings through reduced oxygen demand in the aeration system without a negative impact on the treatment process are discussed below.

7.7.1 Treatment Process Modifications

Experience in wastewater treatment plant optimization and energy savings using the process audit approach has shown that the aeration influent characteristics and the biological reactor (aeration basin) configuration can be designed to reduce the OD to the aeration system. The following process modifications can potentially reduce the OD to the aeration system:

- **Pre-precipitation in the primary clarifiers**: Metal salts and polymers can be used to improve TSS and BOD removal in the primaries. In this way, the OD to the aeration system can be reduced, thereby leading to energy savings. Moreover, the amount of precipitants to be added to the primary influent can be designed to reduce the BOD loadings to the aeration basins to values such that the resulting

OD matches the available or future OC. This will increase the raw sludge production, but decrease the waste activated sludge production.

- **Retrofitting the primary clarifiers**: In some plants, the inefficient operation of primary clarifiers may lead to higher TSS and BOD loadings to the aeration basins (CH2M HILL, 1993; Nolasco et al., 1994b). Retrofitting these tanks may not be necessary from a strict treatment process stand-point. However, improved BOD removal in the primaries will likely reduce the OD in the aeration system, thereby leading to energy savings and additional oxygenation capacity.
- **Flow equalization**: Reducing the flow rate daily peaks can be used to reduce the OD and energy requirement peaks. Flow equalization will not change the daily average OD or energy requirement values. However, depending on the price of energy at the specific plant, the cost of energy may be reduced by reducing the peaks (CH2M HILL, 1991). In addition to this, a reduction in the daily peak OD may generate an increase in the aeration system treatment capacity.
- **Sludge recycle stream control**: The impact of sludge train streams recycled back to the aeration system has been studied at various facilities (CH2M HILL, 1993; Boyle Gruenwald, 1975; Lawler and Singer, 1984; Lol, 1972; Nolasco et al., 1994a; Nolasco et al., 1994b; Newbigging et al., 1994). In some WWTPs, an increase of the OD of up to 15 percent has been found to be related to sludge recycle streams. The ways in which the impact of recycle stream loadings can be reduced to produce energy savings in the aeration system and an increase in the aeration system treatment capacity vary widely from plant to plant. In some cases, an evaluation and optimization of the sludge train (i.e., a "sludge audit") may be the best way to optimize the overall energy and treatment process requirements at a given facility.
- **Denitrification in the aeration basins**: When the existing aeration basins have enough volume to allow for installation of anoxic zones for denitrification, the oxygen bound in nitrates and nitrites can be used for further oxidation of organic matter. In this way, savings in oxygen requirements (and related aeration energy) of up to 10 to 20 percent can be achieved (CH2M HILL, 1991; CH2M HILL, 1993; Nolasco and Stephenson, 1991; Nolasco et al., 1994b).

In all of these cost saving options discussed, a cost/benefit analysis will be required to determine the viability of using one or more of these process modifications as a means to reduce operating costs at a specific facility without impacting process performance. Examples of the application of some of these alternatives are discussed in detail in a selected case study in the following section.

7.8 SELECTED CASE STUDIES

Matching the Aeration System Capacity with Future Oxygen Demands by Process Improvements and Retrofits

This case study refers to a large facility of a nominal treatment capacity of approximately 800 million litres per day (MLD) (CH2M HILL, 1993; Nolasco et al., 1994a; Nolasco et al., 1994b). The references may be used to get a better understanding of the overall project scope and conditions. More stringent effluent requirements (complete nitrification) were to be imposed on this conventional activated sludge plant originally designed for BOD and SS removal.

One of the main elements needed to evaluate the treatment capacity of this facility was the determination of the oxygenation capacity (OC) of the aeration system. The general objectives of the aeration system efficiency test were to evaluate the aeration system OC and determine the maximum sustainable loadings, as well as to examine the feasibility of upgrading and optimizing the aeration system to achieve complete nitrification at a minimum capital expenditures and operation and maintenance (O&M) costs.

The oxygen transfer efficiency (OTE) and the OC of this plant were evaluated. The specific objectives of this evaluation were to:

- Optimize the performance of the existing aeration system to meet effluent standards on a continuous basis
- Evaluate the current oxygenation (treatment) capacity of the plant to set realistic, attainable effluent standards
- Estimate the maximum organic and nitrogenous loading sustainable by the existing aeration system
- Examine the feasibility of upgrading the aeration system
- Establish additional equipment required to meet future effluent objectives
- Determine imbalances in the oxygen transfer capacity along the aeration tanks

This case study outlines the following items:

- Description and assessment of the existing aeration system
- Presentation of results from aeration tests
- Estimation of future oxygen demands (ODs)
- Assessment of existing and future air flow capacities for various configurations
- Study of alternatives for increasing the OC

- Study of alternatives to reduce future OD with nitrification
- Evaluation of air flow metering accuracy, air flow distribution and dissolved oxygen (DO) control

Description of the Aeration System

The main characteristics of the aeration system at this facility are:

- Nine aeration tanks operating in parallel (two additional aeration tanks were currently under construction). Each tank has four passes in series. Each pass is 161.5 m long, 6.17 m wide and 4.6 m deep (i.e., plug-flow tanks with a length:width ratio of 100:1).
- Each aeration tank operates in a step-feed mode, with a portion of the aeration influent going into each of the passes.
- Total aeration volume: 165,000 m^3 (nine tanks).
- Average hydraulic retention time (HRT): 4.8 h, at a plant average rated capacity of 818 MLD. The HRT observed during the audit (at an average flow rate of 616 MLD) was 6.4 h.
- Subsurface aeration system: Walker coarse bubble sparjers in a "spiral roll" pattern. Each tank contains the same number of sparjers evenly distributed along the pass.

The air supply system consists of eight blowers:

- 5 small blowers (S) with a design capacity of 1.24 X 10^6 m^3/d each at 52 kPa and 20°C, one of which was out of service
- 3 large blowers (L) with a design capacity of 2.65 X 10^6 m^3/d each at 52 kPa and 20°C

These blowers operate in parallel, supplying air to a common underground header.

At the time of the process audit, two new large blowers (N) were being installed. The design capacity of each N blower is 2.65 x 10^{-6} m^3/d at 52 kPa and 20°C. A new common overground header was also being installed at this facility.

Butterfly isolating valves installed on each subheader could be used as throttling devices to adjust air distribution. Each blower is equipped with manually adjusted inlet vanes to control air flow.

All blowers are installed in a blower building with additional space for one small (S) and one large (L) blower.

The existing instrumentation is limited to pressure and temperature gauges on the suction and discharge of each blower. In addition, each blower has a volt meter and ampero-meter, an elapsed time meter, and an inlet vane opening display.

The aeration system can operate with different blower configurations. In general, the system operates with two large blowers and either two or three of the small blowers. The operators decide when to turn on an additional small blower based on the dissolved oxygen (DO) concentrations measured with a portable DO meter at the mixed liquor channel prior to the secondary clarifiers.

Aeration Tests

Method and Equipment Used. The oxygen transfer efficiency (OTE) of the aeration system was measured using the off-gas analysis method. This method was selected for three reasons:

- The large volume of the aeration basins would have required large amounts of H_2O_2, making the aeration test extremely expensive.
- The aeration basins are too long and with limited access points to allow for an even distribution of H_2O_2.
- The aeration basins are completely covered with concrete slabs. Each of the four passes of a tank has independent access hatches that allowed to collect the off-gas from that pass without any contamination from other sources. Therefore, there was no need for using an off-gas collection hood. In addition to this, it was possible to get a representative sample from a complete pass at one spot.

An off-gas analyzer was used to measure the oxygen transfer efficiency (OTE) in each pass of three aeration tanks (i.e., 12 passes in total).

Off-gas analyses were performed without taking the aeration tanks out of service.

Repeated measurements were used to quantify the impact of hydraulic and organic loadings, as well as other dynamic parameters, on the OTE. The equipment used for the off-gas tests at this facility consisted of:

- An off-gas analyzer to measure the difference in mole fraction of oxygen, or mole fraction of oxygen to Inerts, between ambient air and off-gas

- Gas capture hoses connected to the central openings (mid-length) of each of the passes of the tank being analyzed and used to convey the sampled gas to the analytical instrument
- Online and offline DO meters to measure mixed liquor DO concentrations in the vicinity of the off-gas collection points
- Venturi air flow meters, air temperature and pressure meters to determine air mass flow rates
- Electrical gauges (voltage, current and power factor) to measure the standard (electrical) efficiency [SAE, kg O_2/kWh]

Several tests were performed in three aeration tanks at different hydraulic loading conditions and blower configurations. Given that most of the online instrumentation used for the process evaluation was installed in Tanks # 2 and # 3, these tanks were selected for the study. Tank # 8 was chosen as representative of the conditions prevalent in the last tanks. Off-gas analyses were performed in each of the four passes of these tanks.

Presentation of Results. The results of the analyses are summarized in Table 7.6. The nomenclature and complete formulae used for the off-gas tests are explained in Section 7.3.1 and in Ewing (1992).

Oxygen Transfer Efficiencies. The standard oxygen transfer efficiency for process water ($SOTE_{pw}$) was calculated. The $SOTE_{pw}$ is the OTE at zero DO concentration (maximum driving force), standard conditions of ambient pressure (101.3 kPa), and mixed liquor temperature (20ºC).

The average $SOTE_{pw}$ values ranged from:

- 6.4 percent (0.064 kg O_2 transferred/kg O_2 pumped), with two large and two small blowers operating, to
- 7.2 percent (0.072 kg O_2 transferred/kg O_2 pumped), with two large and four small blowers operating.

The increase in SOTE with additional air flow (i.e. more blowers) is typical of coarse bubble diffuser systems (Yunt et al., 1980). The $SOTE_{pw}$ values observed at this facility are in the high end of the range reported in the literature for coarse bubble diffusers (Groves et al., 1990; U.S. EPA, 1989).

Aeration (Electrical) Efficiency. During the tests performed, voltage, current, and power factors of each of the operating blowers were recorded by plant staff. The active power (kW), and the aeration (electrical) efficiency (AE) of the aeration system, expressed as kg O_2 transferred/kWh, were calculated for different blower configurations. The results are summarized in Table 7.7.

Table 7.6
Summary Off-Gas Test Results

Blowers Operating	Tank Tested	Hydraulic Load	MLSS Temp (C)	DO (mg/L)	OTE(f) (%)	SOTEpw (%)	OTEp,o (%)	OTEp,2 (%)	O_2 Pumped to 8 Tanks (tons/day)	Oxygen Transferred to 8 Tanks		
										@OTE(f) (tons/day)	@OTEp,0 (tons/day)	@OTEp,2 (tons/day)
2 L + 2 S	2	Low	24	2.9	4.3	6.3	6.2	5.0				
	2	High	23	1.5	5.4	6.5	5.1	5.1				
S L + 3 S	3	Low	24	2.4	4.5	6.2	4.9	4.9				
	3	High	23.5	1	5.8	6.4	5.1	5.1				
	Average OTEs & O_2 Transfer extrapolated to 8 Tanks					6.4	6.3	5.0	1990	99	125	99
	2	High	23.5	2.9	4.5	6.7	5.3	5.3				
	2	High	22.5	1	6.3	7.0	5.6	5.6				
2 L + 4 S	3	High	23	2.4	5.2	7.1	5.6	5.6				
	3	High	22.5	1.4	5.9	7.0	5.5	5.5				
	8	High	22	2	5.4	7.0	5.6	5.6				
	Average OTEs & O_2 Transfer extrapolated to 8 Tanks					7.0	6.9	5.6	2270	124	156	125
	2	High	22.5	1.3	6.2	7.1	5.7	5.7				
	3	High	22.5	1.6	5.8	6.9	5.6	5.6				
	8	High	22.5	2.4	5.4	7.2	5.8	5.8				
	Average OTEs & O_2 Transfer extrapolated to 8 Tanks					7.2	7.1	5.7	2450	142	174	140

Table 7.7
Aeration (Electrical) Efficiency

Blowers in Operation	Oxygen Transferred [t O_2/day]	Active Power [kW]	Electrical Efficiency [kg O_2/kWh]
2L + 3S	126	4132	1.27
	122	4048	1.25
2L + 4S	140	4649	1.25

Note: Measured at 2 mg/L of DO, local atmospheric pressure (100 kPa), and 20 degrees C of mixed liquor temp.

The average AE for two large and three small blowers or for two large and four small blowers was almost identical at 1.25 kg O_2/kWh. This efficiency falls within the high end of the range measured in coarse bubble aeration systems at other treatment facilities (CH2M HILL, 1991; Groves et al., 1990; Nolasco et al., 1994a; Nolasco et al., 1994b).

Determination of System Needs Versus Available Firm Capacity

Oxygenation Capacity. To obtain the oxygenation capacity (OC) of the aeration system, or oxygen transferred per unit time to the aeration tanks, the oxygen mass flow rates into the aeration tanks were measured for each of the tests performed and multiplied by the corresponding OTE value. The air flow rates were measured using "U tubes". The "U-tubes" were installed during the audit at the existing venturi nozzles in the air headers of each individual tank tested (WPCF, 1984; WEF, 1993; WPCF/ASCE, 1988; U.S. EPA, 1984). The OC was calculated as follows:

$$OC = OTE \cdot O_2 \text{ mass flow}$$

where:

OC = Oxygenation capacity [kg O_2 transferred/day]

OTE = Oxygen transfer efficiency [kg O_2 transferred/kg O_2 pumped]

O_2 mass flow [kg O_2 pumped/day] = air flow rate [kg air/day] • 0.21 kg O_2/kg air

Based on pressure gauge readings, blower curves, physical dimensions of piping, number of air diffusers and their head loss, curves for the air distribution system head loss and air flow curves were developed (Figure 7-9).

Using these curves, the air flow rates achievable for different blower configurations and types of diffusers were obtained. Utilizing the formula described above, the oxygenation capacity (OC) for

each combination was calculated. The maximum OC of the present system is 178 t O_2/d for a combination of two large, four small, and one new blower in operation (2L + 4S + 1N). The various OCs were compared to the predicted oxygen demand (OD) to evaluate any potential limitations in the aeration system to meet future (potential) effluent requirements at present and design flows.

Estimation of Future Oxygen Demands

To determine if the current aeration system would transfer enough oxygen to meet present and future (potential) effluent guidelines, the carbonaceous and nitrogenous oxygen demands were calculated using a modified version of an empirical equation (Section 7.3.4.1) (Boon and Chambers, 1982).

Daily average oxygen demands were calculated using offline ($CBOD_5$ and TKN concentrations in aeration influent) and online (raw sewage flow rate) data. The probability distribution of carbonaceous, and carbonaceous and nitrogenous ODs calculated throughout the process audit period are shown in Figure 7-10. Complete nitrification requirements introduce a large increase in the OD (almost 2.5 times the OD without nitrification). The median and 95 percentile values from both curves (with and without nitrification) were extrapolated to future (design) flows and used to design the aeration system to meet future (potential) effluent requirements with complete nitrification.

The results obtained indicated that to achieve future effluent criteria with nitrification at this facility, the oxygenation capacity (OC) of the aeration system had to be increased.

Oxygenation Capacity Expansion

Three potential ways of increasing the OC to meet present and future ODs with nitrification were evaluated:

- Increase the number of blowers, while maintaining the current coarse-bubble diffusers (i.e. increase maximum air flow capacity at current OTE values)
- Retrofit the existing coarse bubble diffusers to fine pore, while maintaining the existing blowers (i.e. increase the OTE and maintain current maximum air flow capacity)
- Increase the number of blowers and retrofit the existing coarse bubble diffusers to fine pore (i.e. increase both maximum air flow capacity and OTE of the aeration system)

The feasibility of implementing these potential alternatives was analyzed from the technical and economical standpoint.

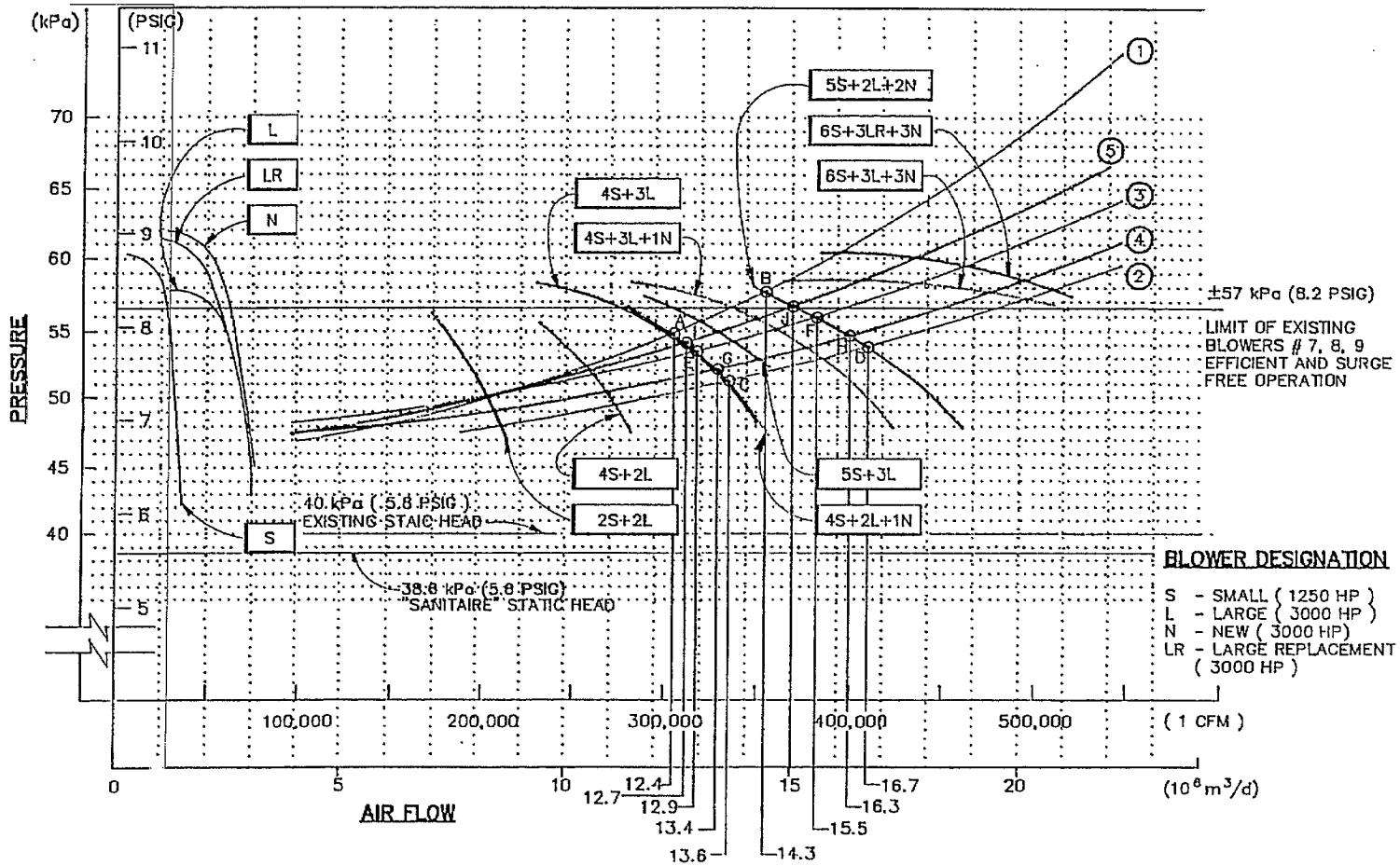


Figure 7-9
Case Study No. 1: Future Aeration System Capacity

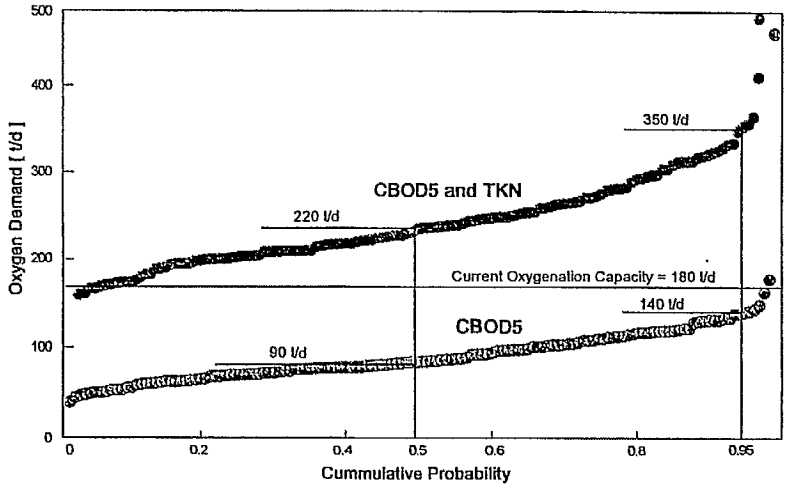


Figure 7-10
Oxygen Demand

Expected ODs and required air flow rates with nitrification at present and design flows for different effluent targets are compared in Table 7.8. The air flow rates required to meet the OD if denitrification is performed (OD credit) are also shown in this table.

Based on the above results, none of the potential alternatives for increasing the oxygenation capacity of the aeration system at this facility would be able to achieve the maximum oxygen demand (95 percentile) with nitrification at design flows (818 MLD); however, the potential capacity does approach this demand.

The results from the oxygenation capacity expansion exercise are summarized in graphic form in Figure 7-11.

Based on the results obtained, the system would need to be retrofitted to fine pore if oxygen demands with nitrification at present and design flows are to be met.

In addition to retrofitting the aeration system to fine pore diffusers, other ways to meet aeration requirements at this facility will have to be implemented. Various alternatives to meet future oxygen demands with nitrification have been investigated during this evaluation and are discussed below.

Table 7.8
Air Flow Requirements

Operating Conditions	MOEE Proposed Effluent Targets (*)				Oxygen Demand (**)		Air Flow Requirements (**)			
							Coarse Bubble		Fine Pore	
	$CBOD_5$ (mg/L)	TSS (mg/L)	TP (mg/L)	Total NH_3-N (mg/L)	Median (tons O_2/d)	95 Percentile (tons O_2/d)	Median (10 m^3/d)	95 Percentile (10 m^3/d)	Median (10 m^3/d)	95 Percentile (10 m^3/d)
Present Flows (616 MLD) (136 MGD)	25	25	1.0	N/A	88	142	6.1	9.9	3.6	5.8
	25	25	1.0	8.0						
	25	25	1.0	3.0						
	25	25	0.3	204	321	14.2	22.3	8.4	13.2	
	with Denitirification:				176	293	12.2	20.3	7.3	12.1
Design Flow (818 MLD) (180 MGD)	25	25	1.0	N/A	117	189	8.1	13.2	4.8	7.7
	25	25	1.0	8.0						
	25	25	1.0	3.0						
	25	25	0.3	271	425	18.8	29.5	11.1	17.4	
	with Denitirification:				234	388	16.2	27.0	9.6	15.9

Notes:
OD values were calculated using TKN.
All oxygen demand values calculated using a modified version of Boon's equation.
(*): MOEE letter dates April 3, 1992.
(**): Oxygen demand values calcuated assuming effluent $CBOD_5$ = 0 mg/l, and TKN = 0 (when nitrification applies) to maintain consistent and reliable operation. Partial nitrification is difficult to control.

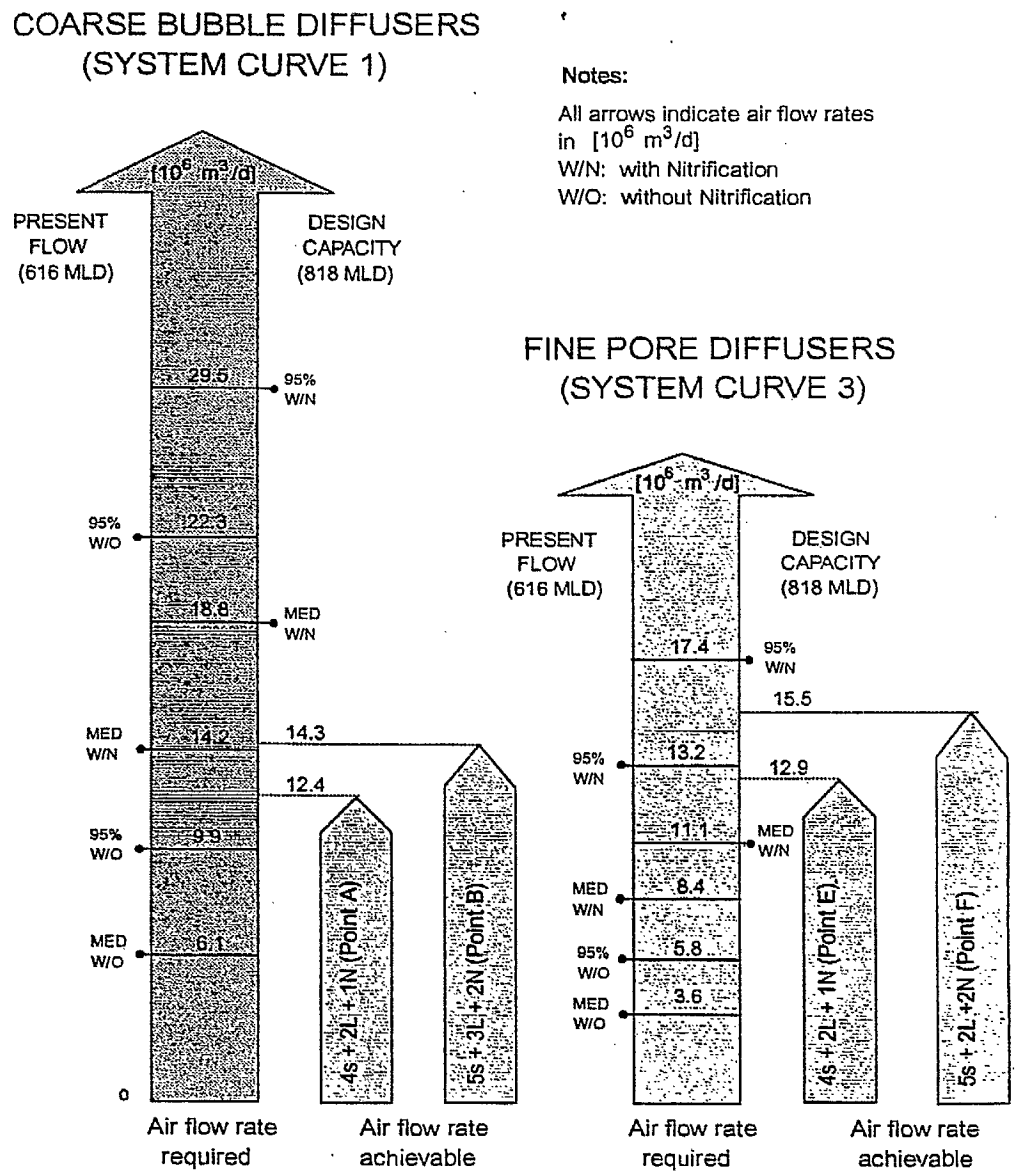


Figure 7-11
Air Flow Rate Requirements

Meeting Future Oxygen Demands with Nitrification by Implementing Process Modifications

In this case study, an example of how to meet OD by implementing process modifications (discussed in 7.7) is presented. Different potential alternatives that may allow to meet future oxygen demands with nitrification without plant expansion were investigated at this facility.

Denitrification in Existing Tanks. At this facility, the first sections of each pass could be retrofitted to anoxic selector zones (i.e. zones without free molecular oxygen (O_2)) where oxygen is available to heterotrophic bacteria in the form of oxidized forms of nitrogen ($NO_3^- + NO_2^-$) (Metcalf and Eddy, 1991).

The hydraulic retention time (HRT) of the anoxic zones could be designed to achieve removal of the readily available BOD (RABOD). In this case study, assuming that the soluble (filtrable) $CBOD_5$ is approximately the same as the RABOD, the credit in the OD would be approximately 10 percent. Selector zones also have the potential to improve biomass settleability and reduce the fouling rate of fine pore diffusers. The reuse of O_2 also provides for energy savings as denitrification reduces the organic load on subsequent aeration tanks.

Pre-Precipitation in Primary Clarifiers. At this facility, the addition of a precipitant (iron salts) in the primaries will reduce the $CBOD_5$ loading to the aeration system, thereby, reducing the carbonaceous OD. To estimate the reduction in the aeration tank influent $CBOD_5$ concentration, bench-scale and full-scale pilot testing were recommended.

For this specific case study and on a preliminary basis, a 30 percent reduction in the $CBOD_5$ concentration in the primary effluent was assumed to estimate the impact of pre-precipitation in the primaries on the total OD. The increased $CBOD_5$ removal in the primaries will reduce the OD by ten percent.

This can be combined with simultaneous precipitation (addition to MLSS) to provide for dual-point addition and optimization of phosphorus removal.

Reduction of Recycle Stream Loadings. Reduction of recycle stream organic loads can result in increased liquid train treatment capacity. Different alternatives for minimizing the impact of the sludge recycle streams on the aeration system have been discussed in Section 7.7 (Boyle and Gruenwald, 1975; Lawler and Singer, 1984; WEF/ASCE, 1991; Newbigging et al., 1994). In this case study, the loading from a Zimpro sludge treatment process, which generates a concentrated recycle stream by heat treatment and resolubilization of organic material, could be reduced to a minimum by process optimization or eventually, discontinuation of the Zimpro units. At this facility, digester supernatant discharges could also be reduced to a minimum by using additional centrifuges to dewater digested sludge. Assuming these modifications to the sludge train were possible, the OD (carbonaceous and nitrogenous) would be reduced by approximately 20 percent.

Install Automatic DO Control System. An automatic DO control system can achieve improved operational control and energy savings. For this system, automatic DO control was not recommended for the existing coarse bubble system due to a lack of diffuser tapering.

Note: Other advantages of minimizing sludge recycle streams is the reduction of the solids and particulate phosphorus loadings to the aeration system. At this specific facility, reduction in the total suspended solids (TSS) loading will be important to maintain a higher and more viable biological solids retention time (SRT) to achieve nitrification, without increasing the MLSS above the secondary clarifier solids loading capacity.

Conclusions and Recommendations

The oxygen transfer efficiency (OTE) of this facility was assessed using the off-gas analysis method. Different OTEs were measured for various blower configurations and operating situations during two days of intensive testing.

Results from the aeration system efficiency tests and an assessment of the installed and future equipment were used to determine air flow capacities for various configurations. The results indicated that the aeration system capacity will have to be increased to meet the oxygen demand (OD) with nitrification at present and design flows.

Based on the oxygenation demand and capacity analysis, and to meet future nitrification requirements at design flows, the following is recommended:

- Retrofit to fine pore diffusers
- Retrofit the first part of each pass to anoxic zones to achieve denitrification, thereby reducing the oxygen demand to the aeration system, maintaining good settling, and reducing the rate of fine pore diffuser fouling
- Perform dual-point chemical addition to reduce the organic, solids and phosphorus loading to the aeration tanks
- Minimize loadings from the sludge recycle streams
- Install an automatic DO control system when a retrofit to fine pore aeration is completed

Note: The estimated capital and operating costs related to implementing these recommendations to achieve complete nitrification at future flows were calculated in this process audit case study. However, these costs are site-specific and for this reason are not presented in this case study. Review the specific report for these details (CH2M HILL, 1993).

Analysis of Aeration System Capacity and Estimation of Energy Savings Using Hydrogen Peroxide Tests and Information from a Process Audit Online Data Acquisition System

The facility where this process audit was performed is a conventional activated sludge plant with chemical treatment for phosphorus removal (CH2M HILL, 1991). The plant average hydraulic design capacity of the plant is 93,000 m^3/d and at the time of the process audit receiving about 75,000 m^3/day. Table 7.9 summarizes pertinent design data for the plant.

Two specific objectives of this project were:

- To identify the potential for energy cost savings in the existing facility, particularly in the energy intensive aeration process.
- To determine the aeration capacity and requirements that would be needed to accommodate future loading increases with nitrification, interim measures required to achieve complete nitrification at current loadings, and the loading at which capital intensive plant expansion would be required.

The process oxygenation capacity and transfer efficiency were evaluated to provide an estimate of the maximum sustainable organic loading rate capability of the facility, to estimate the potential to achieve complete nitrification, and to measure the existing aeration system electrical efficiency.

The aeration system has the following characteristics:

- 6 aeration tanks operating in parallel
- Individual aeration tank dimensions: 80 m long, 8 m wide and 5 m deep
- Total aeration volume: 18,684 m^3
- Average HRT: 4.8 h at plant rated capacity of 93,000 m^3/day
- Subsurface aeration system: course bubble sparjers in a "cross roll" pattern.

Table 7.9
Design Data Overview for Key Processes

Average Hydraulic Capacity (m^3/d)	93,000
Peak Hydraulic Capacity (m^3/d)	186,000
Aeration Tank Volume (m^3)	18,684
Secondary Clarifier Surface Area (m^2)	3,372
Blower Power (kW)	975

Three H_2O_2 tests were conducted (Table 7.10).

Five on-line dissolved oxygen probes were mounted at different locations along the aeration basin under study to measure the DO concentration. The feed and recycle were shut off for one hour prior to the test to achieve a steady respiration rate.

The liquid temperature and the suspended solids concentration (MLSS) in the aeration basins were measured before and after the tests. The airflow rate, air temperature and pressure were recorded from the available plant instrumentation.

Ontario Hydro personnel, with the assistance of the plant electrician, monitored the power draw, power factor, current and voltage for each of the blowers during the tests.

Oxygenation Capacity, Aeration (Electrical) Efficiency and Oxygen Transfer Efficiency

The desorption dissolved oxygen data points and the non-linear estimate of a typical response curve were similar to the ones shown in Figure 7-8. The desorption model followed very closely the DO variation at all sampling locations.

The estimates of the mass transfer coefficient (αFk_La) are summarized in Table 7.10. The data were well behaved within the model parameters. Table 7.10 presents the mixed liquor temperature, MLSS concentration, airflow rate, air temperature and pressure, ambient temperature and pressure, and active power draw of the three blowers under the test conditions.

The temperature corrected mass transfer coefficients are provided in Table 7.10 for the tank average at temperatures at 10ºC and 20ºC to represent winter and summer conditions.

The mass transfer coefficients determined from the data at the five DO probe locations for a single test suggest relatively small spatial variation of the mass transfer capability throughout the aeration tank. For tests 1 and 2, all point mass transfer coefficients are within 10 percent of the tank average mass transfer coefficient. For the third test, 80 percent of the αFk_La values are within 10 percent of the tank average.

The oxygenation capacity (OC) of the aeration basin was determined from the oxygen mass transfer coefficient (αFk_La) and the dissolved oxygen concentration (Section 7.3). Since the mass transfer coefficient and the oxygen (saturation) concentration vary with temperature, the oxygenation capacity of the aeration basin is temperature dependent.

Table 7.10
Summary of Oxygen Transfer Test Results

Data	Test#								
	1			2			3		
Date/Start Time	29-Oct-90/13:40			30-Oct-90/9:00			30-Oct-90/14:10		
Tank #	1			1			3		
Blowers Operating	1,3 & 5 (Config. B)			1,2 & 5 (Config. A)			1,3 & 5 (Config. B)		
% of Installed Power	85			70			85		
Total Active Power Draw (kW)	152 + 320 + 356 = 828			151 + 149 + 356 = 656			151 + 320 + 356 = 827		
Average Airflow Rate (m^3/h)	27,500 + 18,500 = 46,000			18,300 + 18,300 = 36,600			26,500 + 18,200 = 44,700		
Blower Discharge Pressure (kPa)	52			41			52		
Blower Discharge Temperature (°C)	53			52			57		
Ambient Temperature (°C)	6.1			9.8			14.9		
Ambient Pressure (kPa)	99.9			99.2			99.0		
MLSS (mg/L)	1635			1628			1055		
Mixed Liquor Temperature (°C)	18.2	10	20	17.5	10	20	18.7	10	20
Individual Mass Transfer Coefficients*									
DO Probe									
#1	3.81	-	-	3.26	-	-	3.10	-	-
#2	3.65	-	-	3.33	-	-	3.20	-	-
#3	3.51	-	-	3.26	-	-	4.17	-	-
#5	3.27	-	-	2.88	-	-	3.22	-	-
#6	3.63	-	-	3.04	-	-	3.69	-	-
Tank Average αFk_La (h^{-1})	3.57	2.94	3.73	3.15	2.63	3.34	3.48	2.86	3.63
Tank Standard Deviation αFk_La (h^{-1})	0.20			0.19			0.45		

* Individual mass transfer coefficients (αFk_La (h^{-1})) for five tank locations.

An estimate of the αFk_La at maximum power was obtained by extrapolation of the results obtained for tank #1 at two different power draws. With a power draw at maximum capacity of 962 kW, the maximum αFk_La at 20ºC would be 4.04 h^{-1}.

The oxygenation capacities presented in Table 7.11 for all aeration tanks at different operating temperatures and DO concentrations are based on the tank average αFk_La's obtained for each test.

The standard aeration (electrical) efficiencies (SAE) of the aeration system expressed as kg O_2/kWh at a zero mg/L dissolved oxygen residual and a temperature of 20ºC are shown in Table 7.12. The SAEs are based on the calculated oxygenation capacities and the active power draw of the blowers measured during the testing procedure. The average SAE is similar to other coarse bubble systems examined in process audits in Ontario.

Table 7.11
Oxygenation Capacity

Test #	Aeration Power	Tank Average αFk_La (h^{-1})		Oxygen Capacity (kg O_2/d) 2 mg/L residual		Oxygen Capacity (kg O_2/d) 0 mg/L residual	
	(% of total)	10°C	20°C	10°C	20°C	10°C	20°C
1	85	2.94	3.73	12,650	12,320	15,360	15,760
2	70	2.63	3.34	11,320	11,040	13,740	14,120
3	85	2.86	3.63	12,310	11,990	14,940	15,340
Extrapolated from test results	100	3.18	4.04	13,690	13,350	16,620	17,070

Note: For the calculation of the total oxygen capacity, it has been assumed that the OC of the two aeration tanks tested using the hydrogen peroxide desorption testing procedure is representative of the OC of the rest of the aeration tanks.

The SOTE calculated with the air flow rate measured by the plant meters was 3.4 percent. This value is within the expected range of results for this type of aeration system and was used for the blower requirement calculations.

The estimates of the maximum aeration basin oxygenation capacity were used to determine the capability of this facility to treat the current and projected loading rates and to evaluate the potential to achieve nitrification.

The plant's oxygenation capacity (OC) will limit the organic loading that the existing aeration system can handle to allow for complete nitrification at current and future flow rates. The oxygen requirements (oxygen demand, OD) listed in Table 7.13 were estimated applying the empirical equation (described in Section 7.3.4.1) using offline data (influent $CBOD_5$ and TKN), and online data (influent flow rate) (Boon and Chambers, 1982).

Two alternative effluent criteria for $CBOD_5$ and TKN are shown in Table 7.13. Yearly average and 95-percentile loadings are indicated for both effluent criteria. The alternative of adapting the front end of the aeration tanks to an anoxic zone for denitrification was considered. The shaded areas in the table indicate loading conditions that cannot be met by the current oxygenation capacity (OC) of the system, as determined in oxygen transfer tests. To achieve effluent targets at future flows, the aeration system will need to be retrofitted to fine pore diffusers and additional blower power will be required.

For this facility, it was estimated that fine pore diffusers operating under nitrifying conditions will increase the oxygenation capacity by approximately 2.5 times. Therefore, the maximum OC with fine pore will be approximately 34,400 kg O_2/day, which will accommodate most conditions shown

Table 7.12
Standard Aeration (Electrical) Efficiencies

Test #	% of Total Installed Power	Oxygenation Capacity @ 0 mg/L, 20°C (kg/d)	Active Power Draw (kW)	Transfer Efficiency (kg O_2/kWh)
1	85%	15,760	828	0.79
2	70%	14,120	656	0.90
3	85%	15,340	827	0.77
Max.	100%	17,070	975	0.74

in Table 7.13. Installing anoxic basins for denitrification will allow the 95th percentile loadings to be met in the future (see Table 7.13).

Potential for Energy Savings

One objective of this process audit was to identify the potential for energy cost savings in the existing facility, particularly in the energy intensive aeration process. Four alternatives for energy savings were investigated:

- Installing a DO control system
- Upgrading the aeration system from coarse bubble to fine pore diffusers
- Installing anoxic basins and a recirculation system to permit denitrification at the inlet end of the aeration tanks
- Replacing the current blowers with more efficient equipment

DO Control System

The potential energy savings with DO control were analyzed for the following scenarios:

- Present and future (design flow) oxygen demands
- Coarse bubble and fine pore diffusion systems
- With and without pre-denitrification
- Three DO Set Points (DOSP)

Table 7.13
Estimated Oxygen Requirements (kg O_2/d)

Present/Design Flow	Effluent Criteria[1] BOD_5 = 5 mg/L TKN = 6 mg/L		Effluent Criteria[2] BOD_5 = 5 mg/L TKN = 1 mg/L	
	Average	95%ile	Average	95%ile
Present Flows				
BOD_5 removal	5,500	13,300	5,500	13,300
BOD_5 removal + nitrification	12,600	25,900	14,200	28,300
BOD_5 removal + nitrification + denitrification	9,600	20,200	10,000	21,000
Design Flows				
BOD_5 removal	6,800	16,700	6,800	16,700
BOD_5 removal + nitrification	15,700	32,600	17,700	35,400
BOD_5 removal + nitrification + denitrification	10,300	23,000	11,000	23,800

Note: Shaded cells show conditions where OC will be insufficient to satisfy demand at 2 mg/L DO.
Maximum oxygenation capacity of the current aeration system operating at water temperature of 20°C and 2 mg/L of residual DO concentration = 13,350 kg O_2/d.
Effluent criteria are from RAP loadings.

The following relationships and equations (derived by discretizing the reaeration equation) were used to assess energy savings by DO control in this analysis (Speirs and Stephenson, 1985):

$$OUR_{t-1} = \alpha F k_L a\,(C_s - C_{t-1}) - (C_t - C_{t-1}) \bullet 60$$

where:

OUR oxygen uptake rate (mg/L•h)

$\alpha F k_L a$ O_2 mass transfer coefficient (h^{-1})

C_s DO saturation concentration (mg/L)

C DO concentration (mg/L)

t Sample time (Δt = 1/60 hour)

$$\alpha F k_L a_t = OUR_{t-1} / (C_s - DOSP)$$

where:

αFk_La_t required O_2 mass transfer coefficient (h^{-1})

DOSP DO set point (mg/L)

and from linear interpolation of αFk_La results at different powers, the power required is:

$$P_t = 535\ (\alpha Fk_La_t) - 1091.5$$

where:

P_t is the required active power (kW) for blowers to meet the required αFk_La_t with existing coarse bubble, cross-roll spargers

The relationships were based on an average liquid temperature of 17.5ºC during the period examined.

Assuming that fine pore diffusers will increase the specific oxygen transfer efficiency of the aeration system by 2.5 times, a revised relationship between the active power draw of the existing blowers and the mass transfer coefficient was used:

$$P_t = 140\ \alpha Fk_La_t$$

Savings Related to Diurnal Loading Variations

Based on the average DO values obtained from five online DO probes during nine days with a high degree of nitrification (Figure 7-12), the oxygen uptake rate (OUR) variation was calculated at the upstream and downstream ends of the aeration tanks (Figure 7-13). The required process oxygen mass transfer coefficient (αFk_La) was calculated for different DO Set Points (1, 1.5 and 2 mg/L). The results for two tank positions and for a DOSP of 2 mg/L are shown in Figure 7-14. Using the relationship between αFk_La and power draw obtained in the aeration efficiency tests, the power required to meet the fluctuating oxygen demand and the DOSP is shown in Figure 7-15.

To estimate the potential for energy savings it was assumed that each of the DO profiles was representative of the situation in each half of the tank. Assuming no DO control (current situation at the plant), an αFk_La value equal to the maximum value required should be maintained throughout the day to meet the peak OD. Hence, the blowers should be operated to meet the daily peak demand. Ideally, a DO control system will allow variation of the power drawn by the blowers according to the instantaneous demand. The potential energy savings for the average day are represented by the difference between the instantaneous power demand and the maximum power required to meet the daily peak demand (Figure 7-15). The savings in each half of the tank were added to obtain the total potential savings.

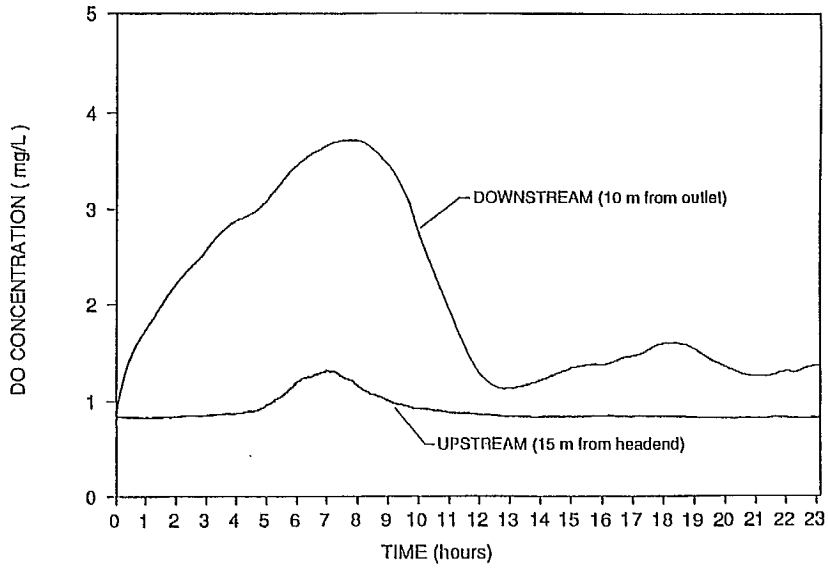


Figure 7-12
DO Concentration at Two Measured Locations

The power draw for fine pore diffusers at a DOSP of 2 mg/L is shown in Figure 7-16. These curves show less variation throughout the day than those for coarse bubble diffusers. Therefore, a DO control system has less potential for energy savings within a day with fine pore diffusers than with coarse bubble diffusers.

The estimated energy savings achievable by an automatic DO control loop (due to the diurnal loading variations in an average loading day) are shown in Table 7.14.

Upgrading the Aeration System to Fine Pore Diffusers

The potential energy savings with fine pore diffusers were estimated for different operation configurations (Table 7.15). It was assumed that fine pore diffusers will increase 2.5 times the specific oxygen transfer efficiency (SOTE) of the coarse bubble aeration system. The potential yearly energy savings listed in Table 7.15 were obtained using the power reduction achieved by retrofitting to fine pore diffusers for the 50 percentile oxygen demand power requirement, and assuming that these savings could be extrapolated for the whole year. For example, the first row of the Table outlines the savings achievable at present flows and with complete nitrification:

Yearly Energy Savings = (Power required by coarse bubble – Power required by fine pore)
• 24 h/day • 365 days/year
= 3.1 • 106 kWh/year

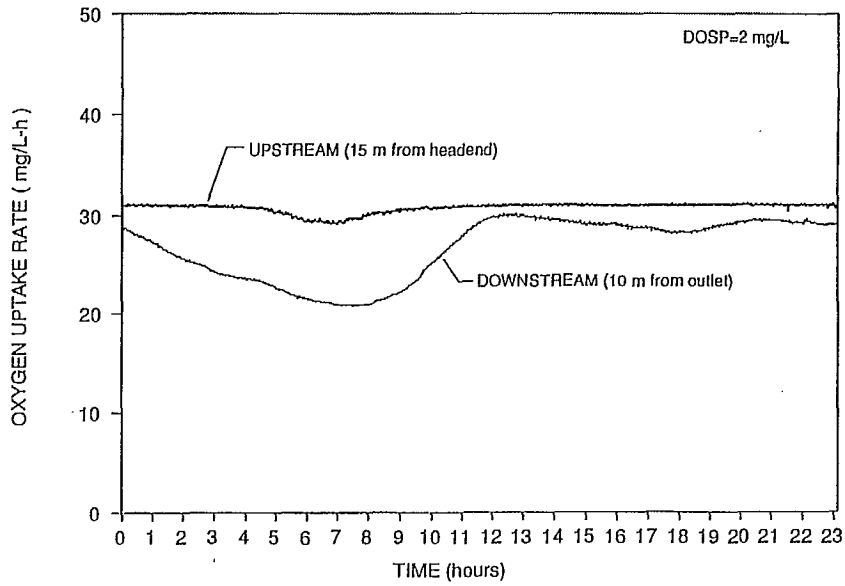


Figure 7-13
Average OUR in Tank 1 at Two Measured Locations

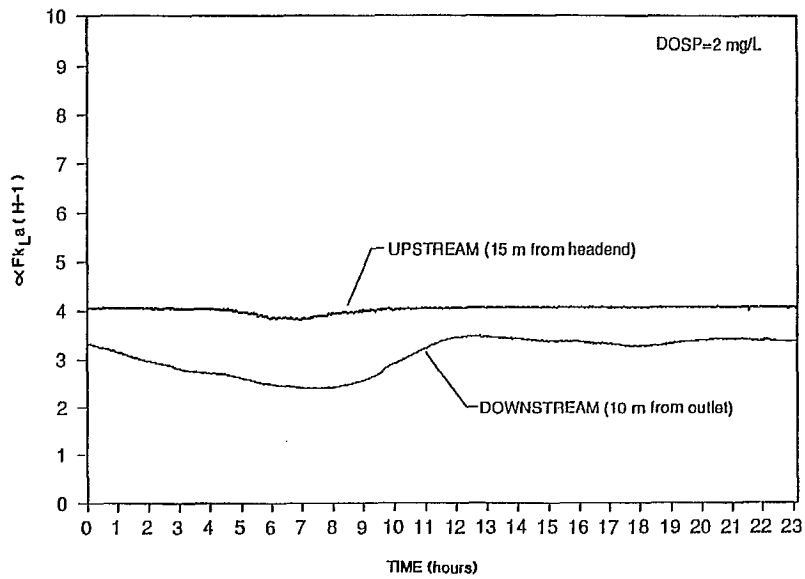


Figure 7-14
Mass Transfer Coefficient Required at Two Measured Locations

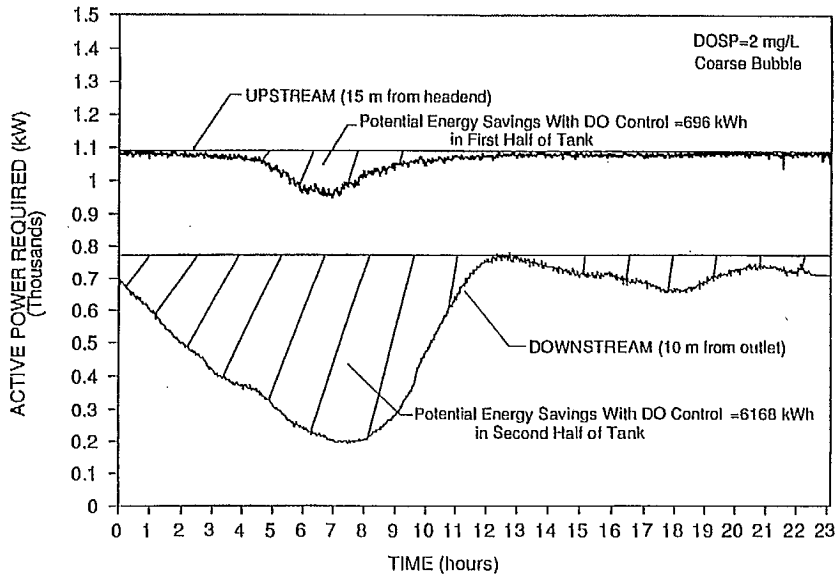


Figure 7-15
Energy Savings at Two Measured Locations

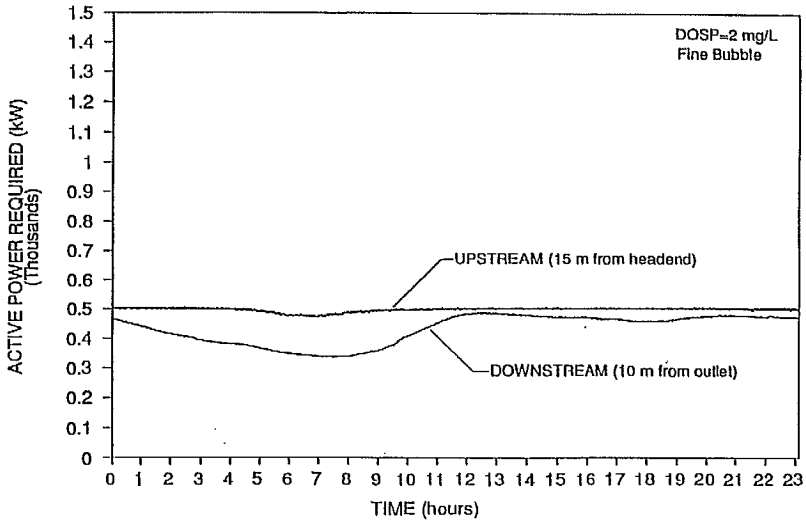


Figure 7-16
Power Required at Two Measured Locations

A tapered fine pore diffuser system will allow this plant to meet the present 95 percentile demand with the current blowers, and will permit a more uniform DO distribution along the aeration tanks. This will help reduce filamentous bulking occurrences by providing sufficient DO in all spatial conditions and provide capacity for effective nitrification.

Conclusions and Recommendations

The current aeration system will not be able to meet the peak OD with complete nitrification at current and future average loading conditions while maintaining a DO concentration of 2 mg/L. Therefore, the aeration system should be retrofitted to fine pore diffusers. Significant energy savings can be achieved with fine pore diffusers.

Installing a DO control system will allow the plant to optimize the treatment process and achieve the required effluent concentrations by maintaining an optimum DO level in the aeration basin. Due to the change in relationship between k_La and power draw between coarse and fine pore aeration systems, the cost-effectiveness must be evaluated on a site-specific basis.

7.9 EXPECTED DURATION AND COSTS

The duration and cost of performing aeration tests vary widely depending on the type of test performed, the size of the aeration basins to be tested, and the number of tests required. The following paragraphs summarize cost estimates and expected test duration of each type of field tests. The cost of performing the required calculations and reporting once the aeration test results (i.e., OTE, k_La, SAE) are obtained, and costs of transportation of equipment are not included in these estimates.

Table 7.14
Daily Average Energy Savings by Automatic DO Control
(Due to Diurnal Loading Fluctuations)

Diffuser Type	DOSP (mg/L)	Daily Average Energy Savings (kWh)
Coarse Bubble	2.0	3432
	1.5	3228
	1.0	3048
Fine Pore	2.0	876
	1.5	828
	1.0	780

7.9.1 Off-Gas Analyses

The cost of performing off-gas analyses can be divided in:

- purchase cost of an off-gas analyzer (if not available)
- construction of off-gas hood
- labour costs

The approximate cost of an off-gas analyzer is $18,000 + tax. Shipping and handling, and customs costs are included in this price. Approximately, two days of training will be required to get acquainted with the apparatus and be able to perform field tests and troubleshooting. The cost of training may vary, but can be estimated in $3,000.

Once the apparatus is purchased, the operation costs are minimal, provided that the unit is adequately maintained. Alternatively, Ewing Engineering Ltd., Milwaukee, can be contacted for support (1-414/461-2205).

Construction of the off-gas hood should take approximately 4 person-days, and material costs should be around $500 + tax.

The labour effort involved in performing three tests in an aeration basin with easy access to the water surface, even air flow distribution (i.e., no major air leaks or diffusers plugged) and a volume of 10,000 m^3 will be approximately 5 person-days. The effort required to evaluate the data can be expected to be 5 to 7 person days.

Table 7.15
Potential Power Reductions and Energy Savings(*) with Fine Pore Diffusers

Condition	Process	Power Required		Power Reduction	Yearly Energy Savings ($x10^6$ kWh/year)
		Coarse Bubble (kW)	Fine Pore (kW)		
Present Flows	Nitrification	870	513	357	3.1
	Pre-denitrification	613	446	167	1.5
Future (Design) Flows	Nitrification	1,668	722	946	8.3
	Pre-denitrification	875	515	360	3.2

Note: (*) At DOSP = 2 mg.L and 50 percentile oxygen demand.

7.9.2 Hydrogen Peroxide Tests

The costs of performing H_2O_2 tests can be divided in:

- cost of H_2O_2
- cost of installing and operating DO meters
- labour costs

The cost of 50 percent H_2O_2 is approximately $1.40/kg. Approximately, 85 kg of 50 percent H_2O_2 will be required to 1000 m^3 of aeration basin (Section 7.3.2.3). Therefore, assuming three tests are performed, the cost of H_2O_2 for a 10,000 m^3 basin will be under $3,000 + tax.

Assuming that online DO meters are being used for the test and are already installed in the aeration basin to be tested, the field labour involved for these three tests will be approximately 8 person-days, in two days of field work. Another one to two person-days will be required to perform desk-top analysis of the raw data to obtain $\alpha F k_L a$, SAE, OTE, OC, and other key aeration parameters.

7.9.3 Clean Water Tests

The costs of performing clean water tests can be divided in:

- cost of chemicals required
- cost of installing and operating DO meters
- labour costs

The cost of sodium sulfite and cobalt chloride is approximately $0.72/kg and $270/kg. Approximately, 160 kg of sodium sulphite will be required per 1000 m^3 of aeration basin per test. Therefore, assuming three tests are performed, the cost of sodium sulfite for a 10,000 m^3 basin will be approximately $1200 + tax. Provided that the tests are all performed in one day, cobalt chloride only needs to added once (before the first test). Approximately, 0.5 kg of cobalt chloride are required per 1000 m^3 for the three tests. Cobalt chloride comes in 2.5 kg buckets, so in this specific case, two buckets will suit the requirements for a 10,000 m^3 basin at an approximate cost of $1,400.

Assuming that online DO meters are being used for the test and are already installed in the aeration basin to be tested, the field labour involved for these three tests will be approximately 8 person-days, in two days of field work. Another one or two person-days will be required to perform analysis of the raw data to obtain $k_L a$, SAE, OTE, OC, and other key aeration parameters.

7.10 REFERENCES

ASCE. ASCE Standard The measurement of Oxygen Transfer in Clean Water. Am. Soc. Civ. Eng. New York, N.Y. 1984.

Barnhart, E.L. "An Overview of Oxygen Transfer Systems". *Proceedings: Seminar Workshop on Aeration Systems: Design, Testing, Operation and Control.* EPA-600/9-85-005. January, 1985.

Boon, A.G. and Chambers, B. "A Design Protocol for Aeration systems - UK Perspective". *Proceedings: Seminar Workshop on Aeration System Design, Testing, Operation and Control.* University of Wisconsin. Madison, Wisconsin. August 2 – 4, 1982.

Boyle, J.D.; and Gruenwald, D.D. "Recycle of Liquor from Heat Treatment of Sludge". *Journal of the Water Pollution Control Federation.* Vol.47, No.10. Pp. 2482-2489. 1975.

Buttz, J.A. and Daigger, G.T. "Real-time biological process optimization using on-line monitoring". Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems. *Proceedings of the 5th IAWPRC Workshop.* Yokohama and Kyoto, Japan. Adv. Water Pollution Control. No. 10 pp. 343-9. 1990.

CH2M HILL ENGINEERING LTD. City of Windsor Little River PCP Process Evaluation. Report prepared for the City of Windsor. 1990.

CH2M HILL ENGINEERING LTD. Operational Audit of the Regional Municipality of Halton's Burlington Skyway Water Pollution Control Plant. Report prepared for Regional Municipality of Halton and Environment Canada. 1991.

CH2M HILL ENGINEERING LTD. Review of the Aeration System Performance and Energy Usage at the St. Thomas WPCP. Report prepared for the City of St. Thomas. 1992.

CH2M HILL ENGINEERING LTD. Operational Evaluation of the Main Treatment Plant. Report prepared for Municipality of Metropolitan Toronto, Ministry of Environment and Energy, and Environment Canada. 1993.

CH2M HILL ENGINEERING LTD. Process Audit of the Collingwood WPCP. Report prepared for the Town of Collingwood. 1995.

Daigger, G.T.; Buttz, J.A.; and Stephenson, J.P. "Analysis of Techniques for Evaluating and Optimizing Existing Full-Scale Wastewater Treatment Plants". *Water Science Technology.* Vol, 25, No. 4-5. Pp. 103-188. 1992.

Ewing Engineering Company. Operating Manual for Aerator-Rator Offgas. Ewing Engineering Company. Milwaukee, Wisconsin.

Groves, K.P.; Simpkin, T.J.; Redmon, D.; Ewing, L.; and Daigger, G.T. Evaluation of oxygen transfer efficiency and alpha-factor for a variety of diffused aeration systems. Presented at the 63rd Annual Conference of the Water Pollution Control Federation, Washington, D.C. and Submitted for Publication, Res. Jour. Water Pollut. Control Fed. 1990.

Kayser, R. "Measurements of Oxygen Transfer in Clean Water and Under Process Conditions." *Prog. Wat. Tech.* Vol. II, No. 3. Pp 23 - 36. Pergamon Press Ltd. 1979.

Lawler, D.F.; and Singer, P.C. "Return Flows from Sludge Treatment". *Journal of the Water Pollution Control Federation.* Vol. 56, No. 2. Pp. 118-126. 1984.

Lol, U. "Treatment of Thermally-Conditioned Sludge Liquors" *Water Research.* Vol. 11, pp. 869-873. 1972.

Metcalf and Eddy. *Wastewater Engineering: Treatment, Disposal and Reuse.* McGraw-Hill. New York. 1991.

Newbigging, M.; Nolasco, D.; DeAngelis, W.; and Dobson, B. "Impact of Solids Handling Recycle Streams on the Liquid Train of the Metropolitan Toronto Main Treatment Plant". Residuals and Biosolids Management. *Proceedings of the WEF 67th Annual Conference and Exposition.* Vol. 3, pp. 441-452. Chicago, IL. October 15-19, 1994.

Nolasco, D. and Stephenson, J.P. "Evaluation and Optimization Techniques for Wastewater Treatment Processes". *Hazardous Materials Management.* Vol. 3, No. 4. August 1991.

Nolasco, D.; Stephenson, J.; and DeAngelis, W. "Maximizing the Use of Existing Facilities at Metro Toronto's Main Treatment Plant Using the Process Audit Approach". *Environmental Science & Engineering.* Vol. 7, No. 3. Pp. 44-46. June/July 1994.

Nolasco, D.; Stephenson, J.; Watson, B.; Takács, I.; and DeAngelis, W. 1994. "Optimization of Nutrient Removal at a Large Facility with Advanced Field Evaluation Tools and Dynamic Modelling". Biological Treatment Systems - Biological Nutrient Removal. Vol. 1, pp. 619-630. *Proceedings of the WEF 67th Annual Conference & Exposition.* Chicago, IL. October 15-19, 1994(b).

Ontario Hydro. Electric Variable Speed Drive. Reference Guide, First Edition. 1988.

Ontario Hydro. Motors. Reference Guide. Second Edition. 1990.

Patry, G.G., and Takács, I. (1990). "Modular/Multi-Purpose Modelling System for the Simulation and Control of Wastewater Treatment Plants". Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems. *Proceedings of the 5th IAWPRC Workshop.* Yokahama and Kyoto, Japan. July 26 to August 3, 1990. Pp. 487-495. Editor: E. Briggs. Pergamon Press. London.

Redmon, D.; Boyle, W.C.; and Ewing, L. "Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Off-gas Techniques". *Journal of the Water Pollution Control Federation.* 55, 1338-1347. 1983.

Redmon, D.T.; Melcer, H.; Ellefson, G.; and Ewing, L. "The Effect of Pore Size in Oxygen Transfer Fouling and Cleaning of Ceramic Diffusers". *Proceedings of the WPCF 64th Annual Conference and Exposition.* Toronto, ON. Oct. 7-10, 1991.

Speirs, G.W. and Stephenson, J.P. "Operational Audit Assists Plant Selection for Demonstration of Energy Savings and Improved Control". Instrumentation and Control for Water and Wastewater Treatment and Transport Systems. *Proceedings of the 4th IAWPRC Workshop.* Houston and Denver, USA. April 27 to May 4, 1985. *Adv. Water Pollution Control.* R.A.R. Drake (Ed.). No. 2, pp 457-465.

Takács, I.; Patry, G.G.; and Nolasco, D. (1990). "A Generalized Dynamic Model of the Thickening/Clarification Process". Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems. *Proceedings of the 5th IAWPRC Workshop.*

Yokohama and Kyoto, Japan. July 26 to August 3, 1990. Editor: R. Briggs. Pergamon Press. City University, London, UK.

U.S. Environmental Protection Agency (U.S. EPA). Recommended Practice for Flow Measurement in WWTPs with Venturi Tubes and Venturi Nozzles. Kulin, G. EPA-600/2-84-185. November 1984.

U.S. Environmental Protection Agency (U.S. EPA). Design Manual – Fine Pore Aeration Systems. EPA/625/1-89/023. 1989.

WEF. Instrumentation in Wastewater Treatment Facilities. MOP No. 21. 1993.

WEF. Basic Maintenance of Diffused Aeration Systems. Problem-Related Operations-Based Education (PROBE).1993.

WEF and ASCE. Design of Municipal Wastewater Treatment Plants. WEF MOP No. 8. ASCE M.&R. No. 76. Volume II. Book Press. Vermont USA. 1991.

WEF/ASCE *Standard Methods for the Examination of Water and Wastewater*, 1991.

WPCF. Process Instrumentation and Control Systems. MOP OM-6. 1984.

WPCF and ASCE. Aeration. WPCF MOP No. FD-13. ASCE M.&.R of Eng. Practice No. 68. 1988.

Yunt, F.; Hancuff, T.; Shell, G.; and Brenner, D. A Summary of Photographic Slides for the Presentation – An Evaluation of Submerged Aeration Equipment. Presented at the Water Pollution Control Federation Conference. Las Vegas, NV. October, 1980.

CHAPTER 8
HYDRAULIC MODELLING

8.1 GENERAL OBJECTIVES

The hydraulic capacity and flow distribution characteristics are major factors determining the capacity and operational flexibility of a wastewater treatment plant. The hydraulic characteristics can be modelled using a variety of mathematical techniques. The purpose of this chapter is to present a general approach that can be used to prepare a hydraulic model of an existing wastewater treatment plant. Detailed descriptions of fluid mechanics theory and hydraulic equations used are available in the literature (Chow, 1959; Streeter, 1981; and Henderson, 1969) and therefore are not included in this section.

Hydraulic modelling is used to:

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

The hydraulic modelling component in a process audit of an existing wastewater treatment plant consists of three steps:

- Development of the mathematical model describing the hydraulic characteristics of the facility
- Calibration of the model using field measurement of the water surface elevation
- Manipulation of the model to predict the performance under various hydraulic loading conditions

The level of detail required in a hydraulic model of an existing wastewater treatment plant is determined by the specific objectives of the study. For example, resolving flow distribution imbalances between parallel unit processes requires a detailed model of all hydraulic elements in each parallel branch since small differences in calculated headloss will result in large differences in calculated flow.

However, simplifying assumptions such as even flow distribution between parallel process tanks, single headloss coefficients between hydraulic control sections and no headloss in process tank

sections can be used in preparing a hydraulic model to determine the hydraulic capacity of an existing facility. Each assumption must be checked to verify whether it is reasonable.

- Single headloss coefficients between hydraulic control sections will give inaccurate modelling results if the cross sectional area (and therefore the velocity) changes significantly between sections.
- At many wastewater treatment plants, the flow distribution between parallel units is not even. The model will produce inaccurate hydraulic capacity estimates if the flow imbalance between parallel unit processes is large.

Irrespective of the level of detail provided in the model, the field calibration procedure is required to ensure the accuracy of the modelling results.

8.2 HYDRAULIC ELEMENTS AND COMMON EQUATIONS USED

Wastewater treatment plants are designed to conserve the available head. They consist of a series of parallel unit processes, gravity flow channels, and pumped recycle flows. The flow through the plant is governed by flow control structures such as overflow weirs, and flow control gates or valves. Open channel flow through channel sections is usually subcritical with the water surface level determined by downstream control sections.

For most applications, hydraulic modelling consists of developing the headloss versus discharge relationships for the hydraulic control sections and performing backwater calculations for the open channel sections between control sections. Calculations begin at the downstream control section and proceed upstream through the plant.

Under normal flow conditions, the total flow to the plant changes relatively slowly and therefore steady-state hydraulic calculations can be used throughout. The assumption of steady-state flow conditions will greatly simplify the calculations required.

Table 8.1 summarizes the hydraulic elements commonly found in wastewater treatment plants and recommended method of approach for modelling each element.

8.3 DESCRIPTION AND USE OF COMMERCIAL SOFTWARE PACKAGES

There are very few commercially available software packages specifically designed for modelling the hydraulic elements commonly found in wastewater treatment plants.

Table 8.1
Common Hydraulic Elements in Wastewater Treatment Plants

Type	Element	Modelling Techniques
Pressure Flow	Pipe	Hazen Williams[1,2,3] Darcy Weisbach[1,2,3] Minor-loss Coefficients[2,3]
Open Channel	Rectangluar Trapezoidal Circular	Gradually varied flow[4,5,6] Manning[4,5,6]
Distribution/Collection	Collection Channel Distribution Channels Launders Diffusers	Gradually varied flow[4,5,6] Modified Manning[5] Orifice Equation[1,2] Minor loss coefficients[2]
Transitional	Abrupt or gradual change in X-section Bends	Gradually varied flow[2,5] Minor Loss Coefficients[2,3]
Obstruction	Bar Screen Trash Rack Control Valves	Manufacturer's Information[2,4] Ratio of Area
Gates	Sluice Gate Submerged Orifice	Sluice Gate Equations[1,4,5] Orifice equation[1,2]
Flumes		Flume equations[1,4,7]
Weirs	Rectangluar or V-Notch Side flow – Bypass Channels	Weir equations[1,4,7] Spatially varied flow[4]

Notes:
1 Streeter, 1981
2 Miller, 1988
3 Ingersoll-Rand, 1984
4 Chow, 1959
5 Henderson, 1969
6 Hwang and Hita, 1987
7 Grant, 1989

However, the theoretical equations and mathematical techniques required are well-documented in the literature and computer tools such as spreadsheet applications, BASIC or FORTRAN computer languages can be used to develop a hydraulic model suitable for a specific application.

Computerized Hydraulic Analysis of Treatment works (CHAT), a commercial software package specifically developed for evaluating flow distribution and the hydraulic and energy grade lines in water and wastewater treatment works, is available through Wallingford Software Ltd., a subsidiary of Hydraulic Research Ltd. in the United Kingdom.

CHAT was originally developed by the University of Loughborough as a mainframe application. It has been revised to operate under a DOS 3.0 or higher environment with a graphical user interface, menu driven data entry and mouse or trackball control.

CHAT performs steady state hydraulic analysis starting at the plant outfall and working upstream through each hydraulic element. Flow distribution between parallel flow routes is calculated using a matrix solution technique and based on headloss through each section. A hydraulic module is used for each control section, channel and transitional section. The program will evaluate open or pressurized flow channels, launders, weirs, flumes, storm overflow structures, filter beds, and screens. The data specification requirements are detailed. "As Constructed" drawings should be used to enter the cross sectional information required for each module.

8.4 FIELD MEASUREMENTS AND MODEL CALIBRATION

The general steps for the preparation and calibration of a hydraulic model are as follows:

1. Prepare a schematic of the flow through the plant including recycle flows, flow splits between parallel tanks, flow control structures and bypass structures.

2. For each path or branch of the schematic, list all hydraulic elements to include in the model. The number of elements included will be determined by the objectives of the study. Hydraulic elements include channels, pipes, weirs, gates, obstructions and flow control structures.

3. Identify the theoretical equation and parameters required to model each hydraulic element including the physical geometry and minor loss coefficients. This information is obtained from the references listed in Table 8.1 or the Users Manual if a commercial software package is used.

4. Starting from the downstream control section (outfall weir or water surface elevation in the receiving water) assemble your model. For backwater calculations, use the Energy Grade Line (EGL) and Hydraulic Grade Line (HGL) at the downstream section, calculate the energy gains and losses through the element and determine the upstream EGL and HGL.

5. The model is constructed in a modular approach using a spreadsheet, computer programming language or commercial software package if available.

6. The model output is compared to field measurements of the water surface level and the model assumptions and loss coefficients adjusted appropriately so that the measured and predicted water surface elevations correspond.

7. Flow through the calibrated model is manipulated to determine the plant performance under various hydraulic loading conditions.

Field verification and calibration of the model is essential to ensure the validity of the modelling results. The model should be calibrated at a minimum of two flow rates:

- Current dry weather flow
- Maximum (attainable) flow

Field verification consists of measuring the flow and water surface level (Hydraulic Grade Line HGL) at key locations in the plant. The number of measurements required for the field verification is determined by the level of detail in the model and the objectives of the study. The requirements for field verification are water surface levels upstream and downstream of key model elements and hydraulic control structures.

Standard survey techniques are used to establish the elevations of key control sections and top of concrete elevations for the hydraulic elements. During the verification survey the water surface level is measured from the reference points established during the standard control survey. Important considerations during the field verification include:

- Calibrate the permanent flow measurement devices prior to the start of the field verification survey.
- Measure all flow including the recycle streams during the survey.
- The flow distribution between parallel units should be measured during the field survey. If the permanent flow measurement equipment does not measure parallel flow streams individually, the following techniques can be used to estimate the flow distribution where appropriate:
  - dye dilution techniques
  - mass balance of a conservative parameter
  - velocity depth profile
- Some of these techniques are discussed in greater detail in Chapter 4.
- Maximum flow can be obtained by conducting the field verification during a storm event. In some circumstances the maximum flow can be simulated using the existing collection system to temporarily store wastewater and manually controlling the operation of upstream pump stations.

- The maximum day flow water surface levels are quite often measured under adverse conditions (during storm events, at night). The equipment must be easy to use under these conditions. An audible level sensor suspended on a tape measure with a hand held level and stick can be used to measure the water surface level in deep tanks and channels. Automatic level measurement equipment such as depth and ultrasonic level meters should be used whenever possible.
- The increase in water surface elevation due to aeration is not a function of flow rate and therefore should be treated as a step-function in the hydraulic model. Shut off the air supply prior to measuring the water surface levels in aerated channels, grit chambers and aeration basins if the effects of aeration are not included in the model.
- The variation in water surface level due to bounce can be large in turbulent channels. An average measurement should be obtained whenever possible. Automatic level measurement equipment with data averaging capabilities should be used whenever possible.

8.5 USING THE HYDRAULIC MODEL

8.5.1 Determination of Hydraulic Capacity

The hydraulic capacity of an existing wastewater treatment plant is defined as the ability of the facility to pass flow through the unit processes in a controlled manner. It is one of the defining factors governing the capacity of the existing facilities and the performance of the treatment works under high loading conditions. Hydraulic capacity is determined by the structure elevations, hydraulic control section elevations, channel arrangements, pump capacity and pipe and fitting sizes.

A hydraulic model is used to determine the hydraulic capacity of an existing wastewater treatment plant. The calibrated model is used to determine the hydraulic and energy grade lines through the plant under high hydraulic loading conditions. The hydraulic load is incrementally increased until the hydraulic capacity of the plant is exceeded.

The first step in performing a hydraulic capacity analysis is to identify the capacity exceedance indicators. Capacity exceedance indicators are site-specific and include one or more of the following items:

- Hydraulic Grade Line (HGL) exceeds the set point elevation in a by-pass structure resulting in unintentional bypass

- The HGL in an open channel section exceeds the minimum allowable freeboard requirements (or top of concrete elevations) resulting in splashing and over flow out of the structure
- The HGL downstream of a flume or weir structure exceeds the critical depth in the throat section resulting in the loss of accurate flow measurement
- The HGL downstream of a flow distribution weir exceeds the weir elevation resulting in a loss of control over the flow distribution between parallel unit processes
- The HGL in the launder sections exceeds the overflow weir elevations resulting in a loss of control over the flow distribution between parallel unit processes

The second step in performing a hydraulic capacity analysis is to incrementally increase the flow through the model until one or more of the hydraulic exceedance indicators have been reached. The results of the hydraulic capacity analysis are presented in a summary table.

8.5.2 Identification of Hydraulic Bottlenecks

A hydraulic bottleneck is defined as a hydraulic element which limits the hydraulic capacity of an existing wastewater treatment plant. Hydraulic bottlenecks are identified during the hydraulic capacity analysis by determining the difference between the upstream and downstream HGL (calculated headloss) for each element. Elements with relatively high headloss will limit the hydraulic capacity of the existing facilities.

The calibrated hydraulic model can be used to investigate methods of reducing the hydraulic bottlenecks identified. The effect of modifications to channel cross-sections, weir elevations, and control sections are evaluated by changing the hydraulic elements in the model and evaluating the performance under high hydraulic loading conditions. Common hydraulic bottlenecks include:

- Process tank inlet structures
- Sudden and multiple changes in channel cross section and direction
- Inappropriately sized flow control structures
- Flow measurement and distribution structures

8.5.3 Optimization of Flow Splitting Imbalances

Most wastewater treatment plants are constructed as a series of parallel unit processes, interconnecting channels and pumped recycle flows. As a method of reducing both operating and capital costs, gravity flow and passive flow splitting techniques are utilised as much as possible.

Flow distribution between parallel unit processes is accomplished through overflow structures, flow control gates and control valves.

Flow distribution between parallel unit processes is often difficult to measure and adequately control over the range of hydraulic loading experienced at a plant. The difficulty in control leads to flow imbalances between parallel unit processes and the inefficient use of available resources. Hydraulic modelling techniques are used to estimate the flow distribution between parallel unit processes under a variety of hydraulic loading conditions. The calibrated model is used to investigate alternative strategies for improving the flow distribution.

8.5.4 Determination of Optimum Mixing Points

A hydraulic model can be used to determine the velocity gradients and contact time through the hydraulic elements of an existing wastewater treatment plant for a variety of hydraulic loading conditions. The velocity gradient is an important parameter in the flocculation process because it influences both the growth rate of the floc particles and the rate of floc destruction caused by shear forces in the fluid in turbulent mixing. The velocity gradient profile is used to determine the optimum mixing location for chemical addition. The calculated velocity gradient and contact times are used in bench tests to determine the optimum chemical dosage required.

The following equations are used to calculate the velocity gradient due to energy dissipation in the hydraulic elements:

Energy Dissipation in Open Channel (Camp and Stein, 1943)

$$G = \left(\frac{W}{\mu}\right)^{1/2}$$

$$= \left(\frac{gh_f}{vt}\right)^{1/2}$$

where:

- G = mean velocity gradient (s^{-1})
- g = force of gravity (m/s^2)
- h_f = headloss along channel calculated by the hydraulic model (m)
- t = retention time in channel (s)
- v = kinematic viscosity (m^2/s)
- W = energy dissipated per unit volume
- μ = absolute viscosity

Energy Dissipation in Weir Splash Pools (Camp, 1955)

$$G = \left(\frac{Qgh}{Vv}\right)^{1/2}$$

where:

G = mean velocity gradient (s^{-1})
Q = flow (m^3/s)
g = force of gravity (m/s^2)
h = upstream minus the downstream hydraulic grade line (HGL) as calculated by the hydraulic model (m)
V = volume of receiving channel (m^3)
v = kinematic viscosity (m^2/s)

For successful flocculation, the velocity gradient profile downstream of the chemical addition point should consist of a short period of high velocity gradients to provide flash mixing of the chemical followed by a longer period of lower velocity gradients to provide for turbulent mixing without the destruction of floc particles due to shear forces.

8.6 SELECTED CASE STUDIES

Burlington Skyway WPCP

Velocity gradient profiles were developed for the Skyway WPCP at three flow rates, corresponding to the minimum flow of 60,000 m^3/d, average flow of 100,000 m^3/d and a peak flow of 180,000 m^3/d. The velocity gradient profiles were used to determine an optimum chemical addition strategy for phosphorus removal.

The hydraulic grade lines established by a hydraulic model were used to calculate velocity and residence time profiles, and the theoretical mean velocity gradients in selected hydraulic elements. The model was also used to investigate and suggest means to improve flow distribution among the secondary clarifiers at the Skyway WPCP.

The modelling procedure involved three steps:

- Input data specification for each element (initial conditions; flow; component dimensions; hydraulic and friction coefficients)
- Model verification and calibration (input data adjustment to meet known conditions)
- Hydraulic projections at desired flows

The hydraulic component dimensions were obtained from "As Constructed" drawings supplied by the Region of Halton. Two field surveys were conducted to verify critical physical elevations and to measure the HGL through the plant at known flow rates. Flow was measured by the plant effluent metering system; corresponding HGL measurements were made using standard surveying techniques.

The survey information was used to adjust the friction and minor loss parameters in the model for each element so that the HGL predicted by the model corresponded to the survey measurements. After calibration the model was used to predict the energy and hydraulic grade lines through the plant at minimum, maximum, and average flow rates.

Figure 8-1 shows the predicted HGL through Skyway WPCP at peak flow conditions. At the peak flow of 180,000 m^3/d, the Skyway WPCP experiences hydraulic difficulties in three areas.

- **Chlorine Contact Chamber Weir.** The overflow weir in the Chlorine Contact Chamber is submerged. This will have minimal effect on the operation of the plant.
- **Primary Tank Weir.** The overflow weirs on the primary tanks become submerged at a flow of approximately 150,000 m^3/d. This condition adversely impacts the flow split between the four primary tanks.
- **Final Settling Tank Influent Channel.** The hydraulic grade line in the influent channels to Secondary Clarifiers 5 to 8 and 9 to 12 is very close to the top of the channel walls. The aeration system in the channel exacerbates this hydraulic situation and will cause mixed liquor to overflow the channel during high flow period.

The positions of the sluice gates at the inlets to the secondary clarifiers are controlling the water level in this channel. At their present position between 390 and 290 mm opening, the free board in these channels at a flow of 180,000 m^3/d is approximately 0.06 metres. With the sluice gates in the fully open position, the freeboard in these channels increases to 0.21 metres. The sluice gates are used to control the flow distribution among the clarifiers.

The hydraulic gradelines were used to determine the near velocity gradient profiles through the plant. The velocity gradient profile is dependent on the flow path, flow rate, and airflow rate in aerated channels.

Figure 8-2 shows the mean velocity gradient plotted as a function of the residence time through a section of the plant. The flow path used in this analysis is Aeration Tank 1, and Secondary Clarifier 8.

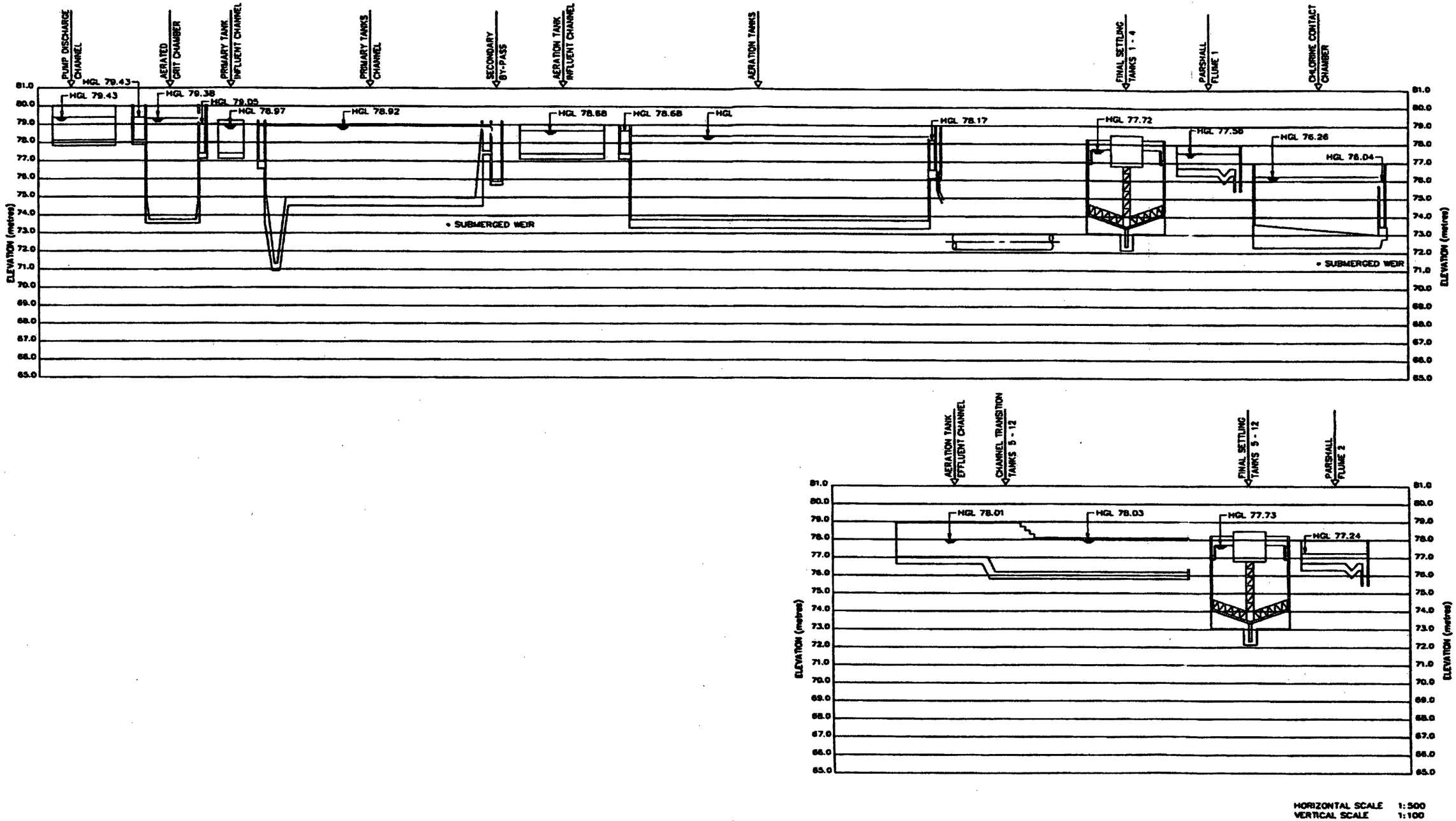


Figure 8-1
Predicted Hydraulic Grade Line at Peak Flow of 180,000 m³/d

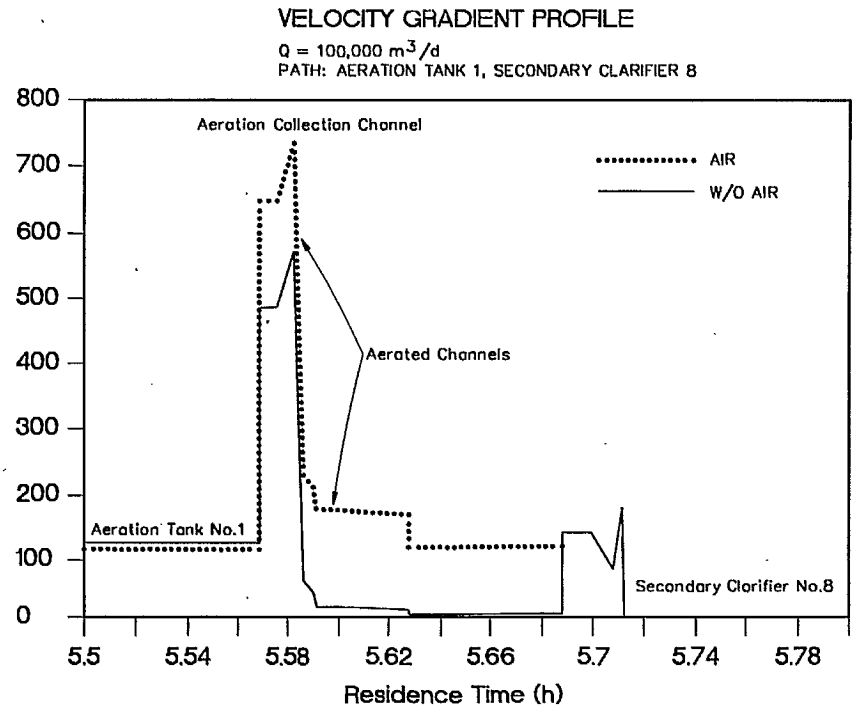


Figure 8-2
Velocity Gradient Profile Between the Aeration Tank and Secondary Clarifier

The plant flow is 100,000 m^3/d and the total air flow is 38,000 m^3/h. The velocity gradient in the aerated channels increased significantly with the addition of air with an average increase of 174 sec^{-1} in each channel.

Gold Bar WWTP, Edmonton, Alberta

A hydraulic model of the Goldbar WWTP was prepared to determine the hydraulic capacity of the existing facilities and suggest methods of improving performance. The calibration of the hydraulic model involved three steps:

- Data specification for each element including invert elevation, element geometry and estimated loss coefficients.
- Surveying the plant hydraulic grade line at three different flow rates.
- Calibrating the hydraulic model using the survey results and the output from the constructed model. The calibration procedure involved adjusting the model to match the actual field conditions.

The model was calibrated at three flow rates. The flow was recorded during the survey period using the existing flow metering equipment. An evaluation of the existing metering equipment indicated that influent flow and bypass meter installation did not meet the required specifications and therefore were not providing accurate measurement. The flows used during the calibration procedures were adjusted accordingly. The recorded flow and the flows used for calibration for each survey are presented in Table 8.2. The results indicated that the model accurately predicted the hydraulic gradline in the plant over the range of flows used to calibrate the model.

Hydraulic Capacity Evaluation

The calibrated model was used to evaluate the hydraulic capacity of the secondary treatment system, the primary treatment system, and the bypass chamber. All hydraulic capacities determined are to failure conditions. Failure was defined as overtopping the existing channels and hydraulic structures. For determining the hydraulic capacity the following was used:

- An average RAS flow of 50 percent of the secondary flow rate
- A river elevation in the North Saskatchewan River of 624.1 m

Figure 8-3 shows the general layout of the Goldbar WWTP. The raw inlet chamber contains two flow control gates which control the flow split between Primary Process 1 and Primary Process 2. Each primary process consists of bar screens, aerated grit chambers and four primary settling tanks. The primary effluent from the two primary processes is combined in the secondary bypass chamber.

The flow distribution to the secondary treatment is controlled by adjusting three butterfly gate valves located on the common primary effluent channel. Valve 1 controls the flow to Aeration Tanks 1, 2, and 3, Valve 2 controls the flow to Aeration Tanks 5 and 6, and Valve 3 controls the flow to Aeration Tanks 6, 7, and 8. The HGL in the common primary effluent channel will determine the HGL in the secondary bypass channel and therefore the hydraulic capacity of the primary settling tanks.

Two modes of operation were modelled. These modes were:

- Maximize the flow through the secondary treatment plant and determine the maximum primary hydraulic loading at this condition.
- Limit the secondary treatment to a maximum of 420 MLD and determine the maximum primary hydraulic capacity at this condition.

Secondary Treatment System

The maximum hydraulic capacity of the secondary treatment system is approximately 550 MLD. At flow rates greater than 550 MLD, the influent Y-channel to the aeration tanks becomes flooded, followed shortly by surcharging in the channel between the aeration basin and the secondary bypass

Table 8.2
Plant Flow During Field Survey

Date	Time	Average Flows (MLD)			Flow Used for Calibration		
		Influent	Effluent	Bypass	Primary	Secondary	Bypass
Aug. 22	16:00-17:30	400	350	0	350	350	0
Oct. 16	12:30-14:50	530	420	30	500	420	80
Oct. 22	11:00-13:30	720	380	200	680	380	300

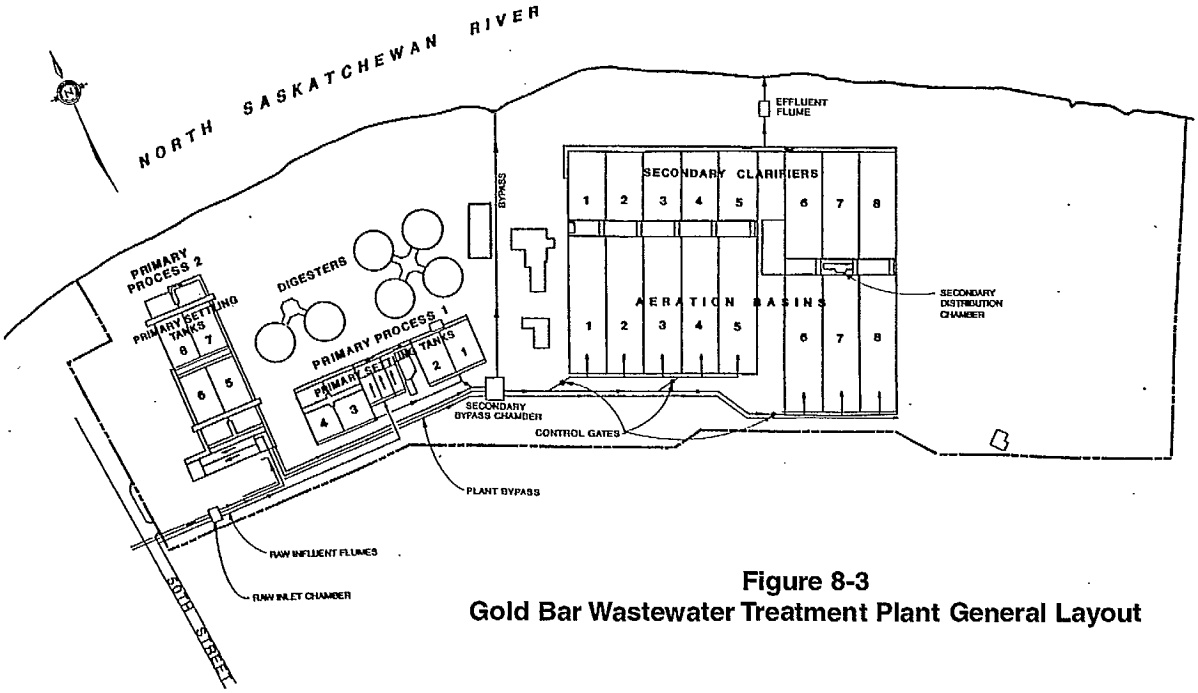
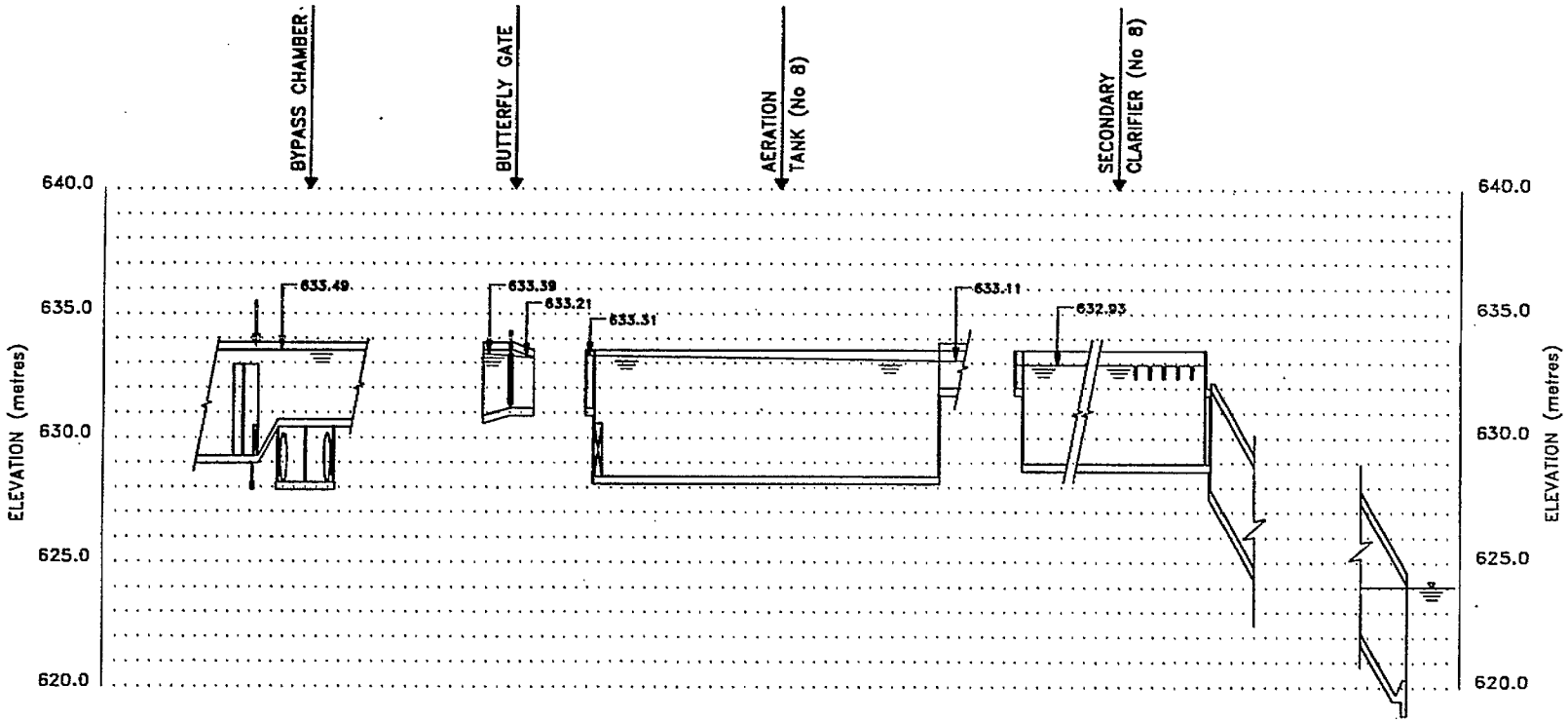


Figure 8-3
Gold Bar Wastewater Treatment Plant General Layout

structure and the mixed liquor channel between the aeration tank and secondary clarifiers. The HGL in these locations is controlled by the secondary clarifier effluent weir elevations.

Figure 8-4 shows the HGL through Secondary Section 8 (i.e. Aeration Tank and Secondary Clarifier 8) at a flow rate of 68.7 MLD (total secondary flow of 550 MLD). Major headlosses in the secondary treatment system occur in the secondary clarifier distribution channel and the aeration tank influent Y-channel.

The HGL developed in the secondary treatment process impacts the hydraulic capacity of the primary system. Assuming a 40/60 flow split between primary treatment Process Systems 1 and 2, primary bypassing to the river will occur at flow rates greater than 650 MLD and flooding will occur in the primary tank influent channel at flow rates of approximately 700 MLD.



NOTE:

SECONDARY SECTION 8, REFERS TO AERATION TANK AND SECONDARY CLARIFIER 8

Figure 8-4
Predicted Hydraulic Grade Line Through the Secondary Treatment Process at Peak Flow of 68.75 MLD (Secondary Flow = 550 MLD)

In summary, for this mode of operation:

- 650 MLD receives primary treatment
- 550 MLD receives secondary treatment
- 100 MLD is bypassed after primary treatment

Primary Treatment System

To determine the maximum hydraulic capacity of the primary treatment system, flow through the secondary treatment system was set at 420 MLD, equal to the current operating practice at the Gold Bar WWTP. The flow distribution between Primary Process 1 and 2 is controlled by adjusting the influent flow control gates.

The maximum hydraulic capacity of primary Process 1 is approximately 300 MLD. At flow rates greater than 300 MLD, flooding will occur in the influent channels to Primary Settling Tanks 3 and 4, followed shortly by flooding in the influent channel to Primary Settling Tanks 1 and 2. The HGL in these channels is controlled by the effluent weir elevations in the primary tanks for flow rates below 250 MLD. At flow rates greater than 250 MLD, the effluent weirs are flooded, and the HGL in these channels is controlled by the HGL in the secondary treatment system.

Figure 8-5 shows the HGL through primary treatment Process 1 at a flow rate of 300 MLD. Major headlosses occur in the grit chamber, bar screen sluice gates, and in the combined channel upstream of the bypass chamber.

The maximum hydraulic capacity of primary Process 2 is approximately 650 MLD; at flow rates greater than this, primary bypassing will occur. Flooding will occur in the primary influent channel to the west of Primary Settling Tank 6 at flow rates of approximately 800 MLD. The HGL in this channel is controlled by the primary effluent weir elevations for flow rates less than 300 MLD. At flow rates greater than 300 MLD, the effluent weirs are flooded; therefore, the HGL in these channels is controlled by the HGL in the secondary treatment system.

Figure 8-6 shows the HGL through primary treatment Process 2 at a flow rate of 650 MLD. Major headloss occurs at the grit chamber influent baffle, the bar screen sluice gates, and the primary tank distribution channels.

In summary, for this mode of operation:

- A maximum 950 MLD receives primary treatment, 300 and 650 MLD for processes 1 and 2, respectively
- A maximum 420 MLD receives secondary treatment
- Potentially 530 MLD is bypassed after primary treatment

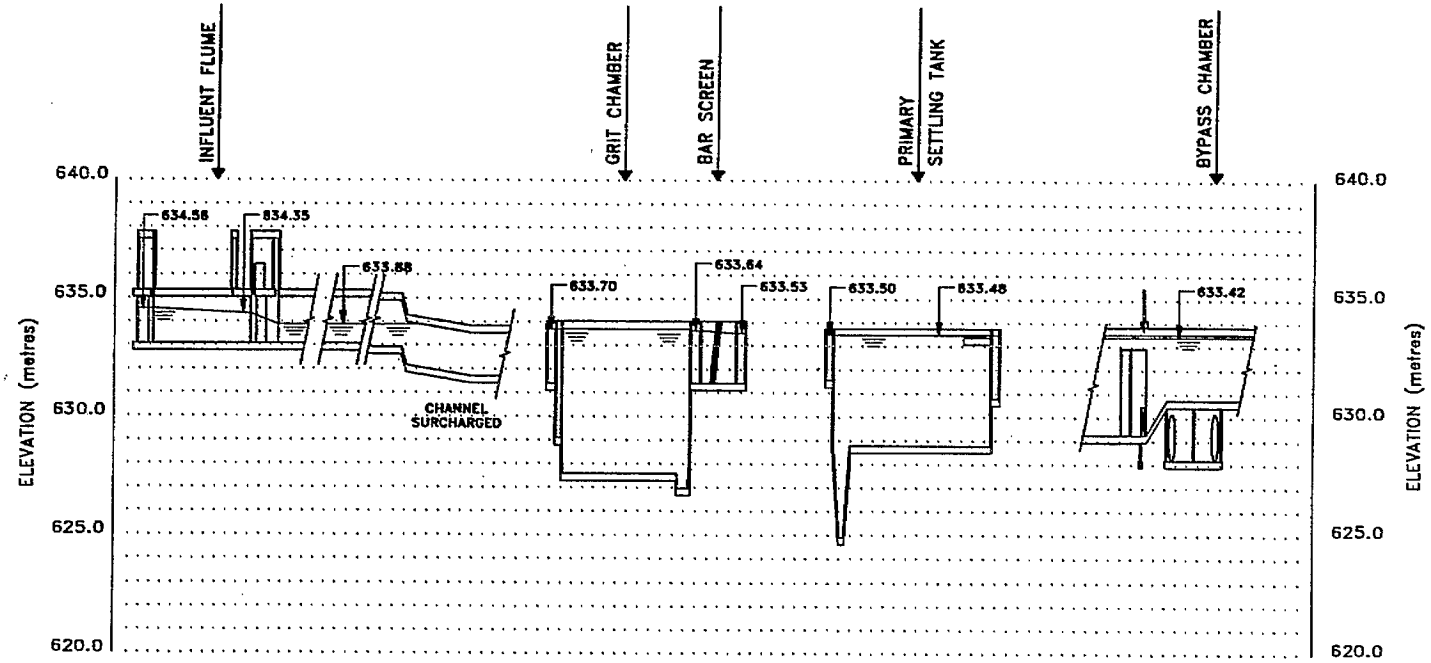


Figure 8-5
Predicted Hydraulic Grade Line Through the Primary Treatment Process 1 at Peak Flow of 300 MLD

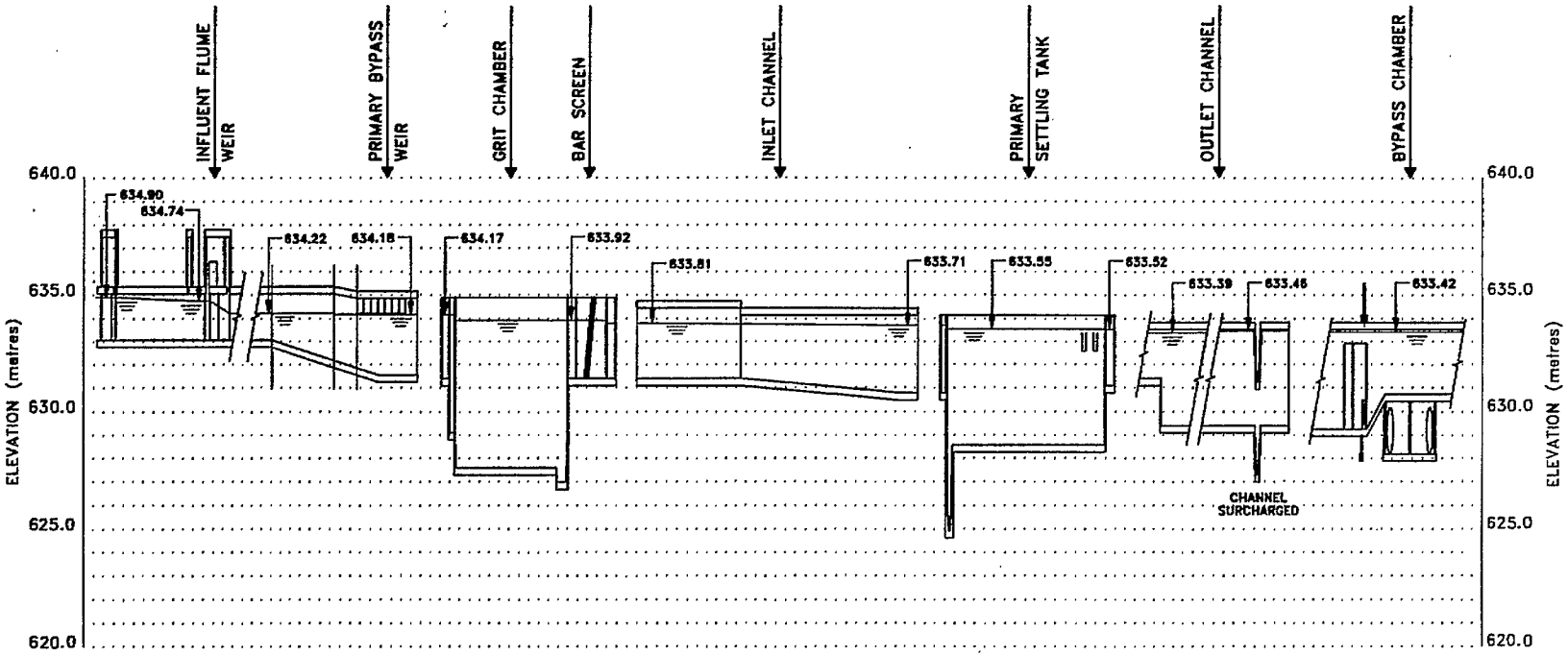


Figure 8-6
Predicted Hydraulic Grade Line Through the Primary Treatment Process 2 at Peak Flow of 650 MLD

Bypass Facilities

The hydraulic capacity of the total bypass facilities is approximately 1150 MLD. The bypass chamber becomes surcharged at flow rates of approximately 1200 MLD. At flow rates greater than 1300 MLD through the bypass facilities, flooding will occur in the roadway upstream of the bypass chamber. A flow rates greater than 1150 MLD, the HGL in the bypass chamber will affect the HGL through the primary treatment facilities and reduce their hydraulic capacity.

Belleville WPCP, Belleville, Ontario

Figure 8-7 shows a plan of the Belleville WPCP and its main components. Maximum flows through the plant and various sections of the plant have been calculated based on the unit dimensions shown on the plant engineering drawings, augmented by field measurements.

Raw Sewage Flow

Raw sewage flows into the plant from two pumping stations and a gravity sewer. The pumping capacity is rated at 114,000 m^3/d (25 MGD) and the capacity of the 1,500 mm diameter sewer is well in excess of that, depending on allowable surcharge. Thus the inflow capacity to the plant is well in excess of the 163,400 m^3/d (36 MGD) overall plant capacity.

The expansion of one of the existing pump stations should not effect the peak flows to the plant.

Grit Tanks

The flow into and out of the grit tanks is through large, rectangular openings, which can pass in excess of 163,400 m^3/d without excessive backup.

Screening

Calculations for the present screen configuration of three barminutors and one manually raked bar screen indicate that the net peak flow velocity through clean screens is about the maximum of 0.9 m/sec. recommended in the MOEE guidelines. However, the present barminutors cannot keep the screens clean. At a site visit on October 19, 1993, the flow was measured at 50,000 m^3/d (11 MGD) total through two barminutors and one manual screen, and the head loss across the screens was measured at 100 mm, indicating that the screens were already more than half clogged. The plant operators have repeatedly experienced screen plugging at approximately 90,000 m^3/d (20 MGD) flow rate, resulting in plant overflow at the bypass chamber.

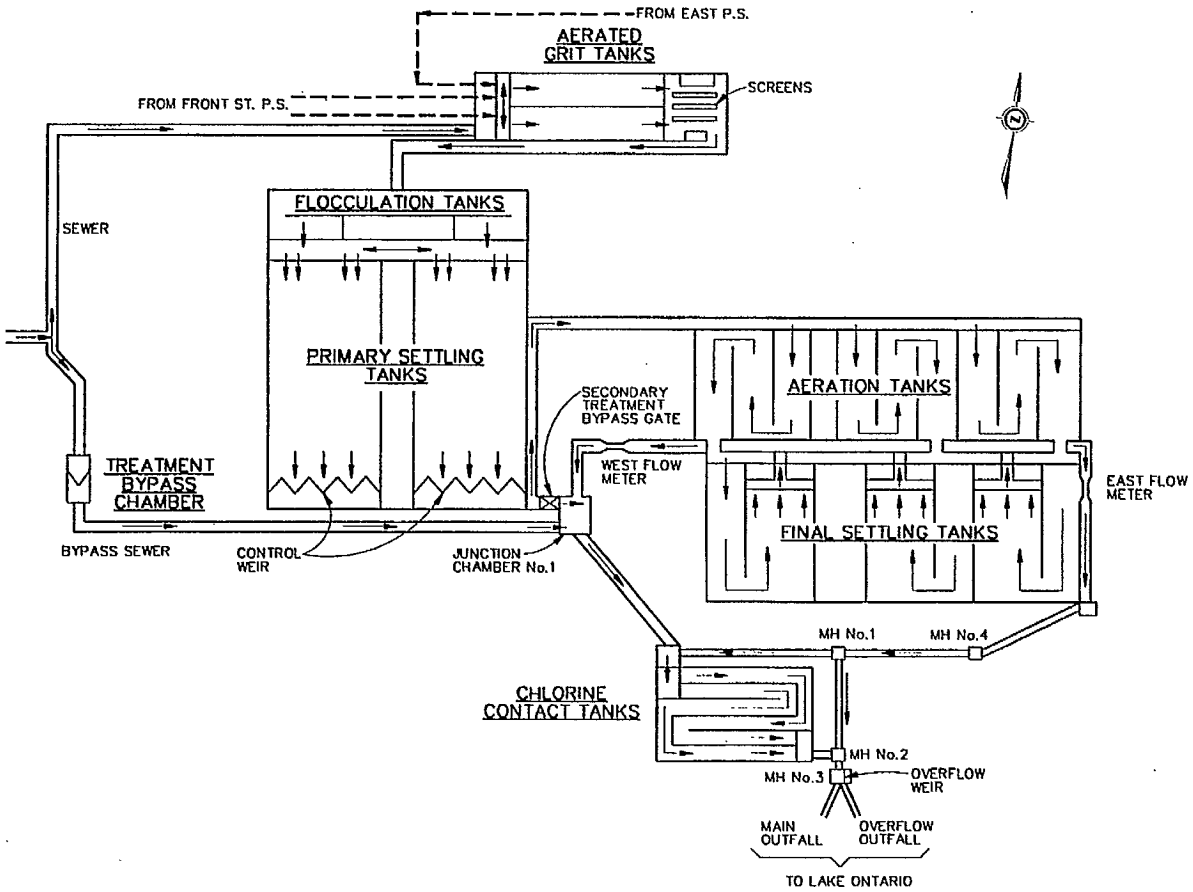


Figure 8-7
Belleville WPCP General Layout

The existing screening system is therefore inadequate for a flow in excess of about 90,000 m³/d (20 MGD). The screen channels and connecting channels would be adequate for 120,000 m³/d (26.5 MGD) for clean or nearly clean screens that have clear openings of about 60 percent of the channel widths, meeting the MOEE guidelines of 0.9 m/s max. flow velocity. Flow in excess of this would be forced through the plant overflow. Better flow through the screen channels and connecting channel to the flocculation tanks would be required to pass the 163,400 m³/d (36 MGD) flow. This would require an improved screening system, with another screen added. Improved screening without that additional filter screen would probably require a raising of the plant bypass overflow weir to prevent unplanned bypass. The minimum would be about 40 mm, but if allowance is to be made for partial screen plugging during such high flows, a raise of about 300 mm would be more realistic. This, of course, assumes that the increased surcharge in the 1,500 mm diameter gravity sewer does not create upstream problems. A review of the upstream sewage collection system was not within the scope of this WPCP evaluation.

Flocculation and Primary Treatment

The primary clarifier system, including the flocculation tanks and connecting channels, is hydraulically capable of passing flows considerably in excess of 163,400 m^3/d (36 MGD). However, since this would cause increased levels at the upstream screens and eventually plant bypass chamber, such an increase is not feasible with the present configuration. The hydraulic capacity of the flocculation and primary tanks is therefore set at 163,440 m^3/d (36 MGD).

Secondary Treatment System

The hydraulic capacity of the secondary system is 54,480 m^3/d (12 MGD) when 163,440 - 54,480 = 108,960 m^3/d (24 MGD) is bypassed directly from the primary clarifiers or plant bypass to the Junction Chamber No. 1, and therefore directly to the Chlorine Contact Tank. In this situation, the flow from the final clarifiers is divided about equally between the east and the west routes. The final clarifier weir overflow is free fall, but with the downstream level at partially weir elevation in the troughs (i.e. without impacting the flow over the weirs and clarifier operation).

The head required in the primary settled sewage conduit downstream of the primary tank weirs is practically at the primary tank weir level in order to convey the 54,480 m^3/d (12 MGD) flow to the aeration tanks. Therefore, the flow through the secondary system is limited to a peak of about 55,000 m^3/d (12 MGD) by the inlet conditions also.

Total flow in excess of 163,400 m^3/d (36 MGD) would result in a higher bypass flow into the Junction Chambers 1 and 2, and thence backup against the final clarifier outlet weirs. As the plant bypass also discharges into Junction Chamber No. 1, any additional plant bypass flow would have a similar effect of causing a reduction in the flow through the secondary system. Thus, the hydraulic capacity of the secondary treatment system is governed by both the inlet and outlet conditions of the secondary system.

The calculation for the flow between the aeration tanks and final settling tanks is based on the 54,480 m^3/d (12 MGD) in-flow plus an equal amount of return sludge. A sludge return flow of 100 percent of the secondary flow has been used in the calculations, but since this has no significant effect on the secondary system feed and discharge channels, it is not of significance in the overall hydraulic performance of the plant. The head loss through the connecting channels is calculated at only 45 mm; a lower sludge return rate will not significantly influence the secondary system capacity.

Chlorine Contact Tank

The chlorine contact tank hydraulic through-flow is limited by the upstream backup into the secondary clarifiers. If the secondary system is bypassed or its through-flow significantly is reduced, more than 163,440 m^3/d (36 MGD) could be passed through the chlorine contact tank. However, based on effluent quality considerations, this does not represent an option.

Outfall

Manhole No. 3 contains two outfall sewers. The main outfall is 1,200 mm in diameter. An overflow weir in Manhole No. 3 directs high flows to the old 900 mm diameter outfall. The outfall combination is calculated to pass about 205,000 m^3/d (45 MGD) at maximum regulated Lake Ontario level of E1.75.591 (248.0 ft) and considerably more at normally lower lake levels.

Plant Bypass

The plant bypass line empties into the Junction Chamber No. 1, which in turn empties into the Junction Chamber No. 2. Since the level in this latter chamber affects the level in the secondary clarifiers in the same way as the secondary system bypass flow, any plant bypass flow cannot add excess to the 163,440 m^3/d (35 MGD) through the Junction Chamber No. 2 without affecting the flow through the secondary system.

If all of the flow is bypassed through the plant bypass chamber, such flow quantity could be about 175,000 m^3/d (38.5 MGD), at which there would begin a backup in the gravity inflow sewer.

8.7 EXPECTED DURATION AND COSTS

The costs of preparing a hydraulic model of a wastewater treatment plant varies considerably. The expected costs and duration are determined by:

- The level of detail required
- Analytical tools available

The personpower requirements for model preparation and specifications will vary between 5 and 30 days.

Model calibration requires 2 people for the control survey plus 1 or 2 people for 2 days to obtain the water surface elevations, and 2 to 5 days for the calibration adjustments. Expenses include survey

Table 8.3
Estimated Duration and Costs for Developing and Calibration of a Hydraulic Model of a WWTP

Task	Person days
Model Specification	5 - 30
Model Calibration	
Field Measurement	4 - 6
Calibration	2 - 5
Model Manipulation	2 - 10
Expenses	
Software (CHAT)	$12,000

equipment rental. Table 8.3 presents an estimate of the duration and costs for the preparation and calibration of a hydraulic model.

8.8 REFERENCES

Camp, T.R. "Flocculation and Flocculation Basins". *American Society of Civil Engineers Transactions.* Vol. 120. 1955.

Camp, T.R. and Stein, P.C. "Velocity Gradients and Internal Work in Fluid Motion". *Journal of the Boston Society of Civil Engineers.* Vol. 30, No. 4. 1943.

Chow, V.T. *Open Channel Hydraulics.* McGraw-Hill. Toronto. 1959.

Grant, D.M. Isco *Open Channel Flow Measurement Handbook.* Isco Inc. 1989.

Henderson, F.M. *Open Channel Flow.* MacMillan Company. 1969.

Hwang, N.H.C. and Hita, C.E. *Fundamentals of hydraulic engineering systems.* Prentice-Hall, Inc. 1987.

Ingersoll-Rand Co. Cameron Hydraulic Data, 1984.

Miller, D.S. Internal Flow Systems, British Hydromechanics Research Association BHRA Fluid Engineering, 1988.

Streeter, V.L. *Fluid Mechanics.* McGraw-Hill Ryerson. 1981.

CHAPTER 9
ANALYSIS OF SLUDGE RECYCLE STREAMS

9.1 GENERAL OBJECTIVES

Sludge treatment recycle streams are often responsible for problems in the liquid train of a wastewater treatment plant. These streams can increase the organic loading by 5 to 50 percent, depending on the type and number of solids treatment processes used (U.S. EPA, 1979). Two of the most troublesome contributors from a liquid treatment standpoint are anaerobic digester supernatant and thermal treatment liquor. Since these stream can have a major impact on the loading in the liquid train of a treatment plant, these streams need to be identified and evaluated. The following discusses some of the main return streams found in wastewater treatment plants.

Anaerobic digestion is used to stabilize the sludge by converting organic matter to carbon dioxide and methane. The net reduction in biological solids accomplished in digestion results in the release of nitrogen and phosphorus in soluble forms (Lawler and Singer, 1984). As a result, supernatant returned to the liquid train can be expected to contain significant concentrations of these nutrients. The characteristics of digester supernatant also vary greatly due to the degree of treatment and solids separation provided. Supernatant solids concentrations can range from 1,000 to 10,000 mg/L (Metcalf and Eddy, 1991). In some cases the supernatant quality is actually the mixed contents of the digester. Results from a study (Lawler and Singer, 1984) indicated that the supernatant TSS loading accounted for 18 to 71 percent of the plant influent loading, while contributing only 0.3 to 1.4 percent of the total plant flow. Separate treatment options considered for digester supernatant include: activated sludge, gravity thickening with and without chemical, and polymer coagulation.

Thermal conditioning reduces the mass of solids that require further processing by solubilizing 30 to 40 percent of the volatile solids and COD in the influent stream, which results in an improvement in the dewatering characteristics of the heat treated sludge. Characteristics of thermal conditioned sludge recycles vary considerably, but BOD_5 concentrations vary from 3,000 to 15,000 mg/L and TSS from 1,000 to 5,000 mg/L (Metcalf and Eddy, 1991). Studies (Lol, 1972; and Boyle and Gruenwald, 1975) indicate that these recycle streams contribute 7 to 21 percent of the total plant BOD_5 loading, while only 0.5 to 1.0 percent of the flow. A variety of separate treatment options have been used on thermal conditioning decant liquors including: anaerobic digestion, anaerobic filters, activated sludge, and rotating biological contactors (WEF, 1991). A U.S. EPA (1980) study found both chemical and biological treatment of thermally conditioned sludge recycle liquors to be potential treatment methods.

Dewatering equipment filtrate and centrate also contribute to the recycle loading exerted on the liquid train, but generally to a lesser extent. Dewatering equipment generally provides greater than

80 percent solids capture (Metcalf and Eddy, 1991) or greater than 90 percent if conditioning chemicals are used. However, depending on the return location of the recycle stream, the impact on the liquid train can be great. This is especially the case if the liquid train is providing nutrient removal, and nutrients are returned to a biological section which should not include this particular nutrient (e.g. recycling nitrate/nitrite nitrogen to an anaerobic zone).

Dissolved air flotation (DAF) units also return a recycle stream to the liquid process. DAFs are often used to thicken WAS prior to further treatment (e.g. digestion). The DAF subnatant is generally a low strength stream if the DAF unit is operating well and is not overloaded.

Since these sludge recycle streams are concentrated, separate treatment options for these streams is often considered. A number of approaches are suggested (U.S. EPA, 1979) to minimize or eliminate the impact of sludge handling recycle streams on the liquid train, including:

- Modifying the solids treatment processes to eliminate recycles
- Modifying the solids handling processes to improve the recycle streams
- Changing the timing, return rate or return point of the recycle streams to minimize the impact on the liquid train
- Modifying the liquid train to handle the recycle streams
- Providing separate treatment for the solids recycle streams

These approaches are all potential solutions, but at a particular site one or more may be more practical than another. The first step in evaluating these stream is to qualify and quantify their impact on the liquid train.

9.2 FIELD SURVEY AND HISTORICAL DATA COLLECTION

Before the impact of sludge handling recycle streams can be evaluated, a number of items need to be identified. These include:

- Number of streams
- Discharge location(s)
- Frequency of discharge
- Historical data availability
- Overall understanding of the solids handling process

These items can often be addressed by having a senior plant operator or superintendent tour the auditor through the solids handling process. If additional items are required this can often be addressed by reviewing the plant drawings, and/or initiating discussions with equipment suppliers and consultants involved with the plant. Once these items have been addressed a solids balance, even if approximate, around the solids handling system can provide a better understanding of the system. An example schematic and solids balance is shown in Figure 9-1 for a major wastewater treatment plant. This schematic outlines the number of recycle streams, their strength (i.e. solids) and flow rates. The next step is to identify the location of the discharge in the liquid train of the recycle streams, and also the location of the plant analytical sampling equipment. An example schematic showing the location of recycle stream discharges for the same plant is shown in Figure 9-2. This schematic indicates that there are four main sludge recycle streams at this plant and that some are returned such that historical analytical sampling results may not represent conditions that these samples were supposed to represent. For instance, the sludge recycle streams are discharged downstream and upstream of the influent and primary effluent samplers and therefore these streams are not accounted for.

Once a good understanding of the sludge recycle streams is known (i.e. discharge location, operation, etc.), a review of available historical data should be initiated. Sludge recycle streams are generally poorly characterized in a plant because they are internal streams. The solids mass balance, shown in Figure 9-1, is usually all that can be created at this initial stage since sampling for SS is often the only analysis done on these streams. Sometimes even SS analysis is not available because there is no location to obtain a representative sample of the recycle stream. Flow metering is also often absent on these streams, and flow/mass balances have to be used to estimate a missing flow value. For instances, the raw sludge pumped is often known at a plant, as is the digested sludge pumped (i.e. either to trucks or influent to dewatering equipment). Therefore, if it is assumed that the plant operates its digesters full (and this assumption is checked), the difference in volume between the raw sludge and the digested sludge pumped is the volume of supernatant produced. Dewatering equipment often have influent flow measurements; however, the centrate or filtrate flow is generally not measured. If the dewatering equipment is producing a concentrated cake (i.e. 20 percent or approximately 20,000 mg/L) and a good quality centrate/filtrate (i.e. less than 1000 mg/L), then the volume associated with the cake will be small and the flow into the unit can be approximated to the centrate/filtrate flow rate.

Once a good understanding of the existing practice and historical data associated with the sludge recycle streams are known, the auditor is in a good position to design a sampling program to compliment the known information.

9.3 DESIGNING A SAMPLING AND ANALYTICAL PROTOCOL

Designing a sampling program to characterize a sludge recycle stream has some unique requirements beyond that of a liquid train offline sampling program (e.g. see Section 6 Offline Monitoring). Some of these requirements/concerns are:

- *Periodic nature of these streams*, often sludge recycle stream operate periodically either during the day shift (e.g. mechanical dewatering equipment), or periodic (e.g. digester supernatant operations, which is dependent on raw sludge pumping, removal rates and initial volume available in the digesters).
- *Difficulty in obtaining a representative sample*, due to the varying strength of the streams and periodic nature of the discharge.
- *High concentration of these streams*, which can make automatic sampling of these streams difficult. For instance, digester supernatant can often be as concentrated as the digester contents with total solids concentrations of between 2 and 4 percent.

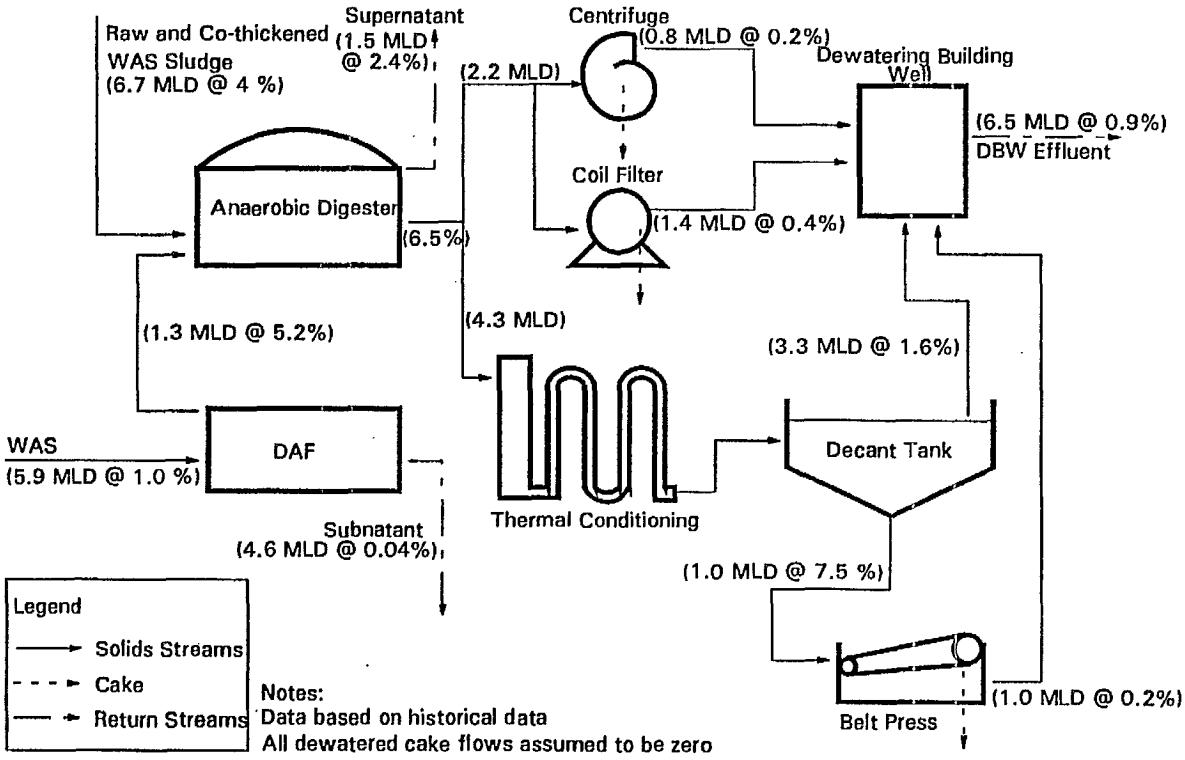


Figure 9-1
Schematic Layout of Solids Handling System

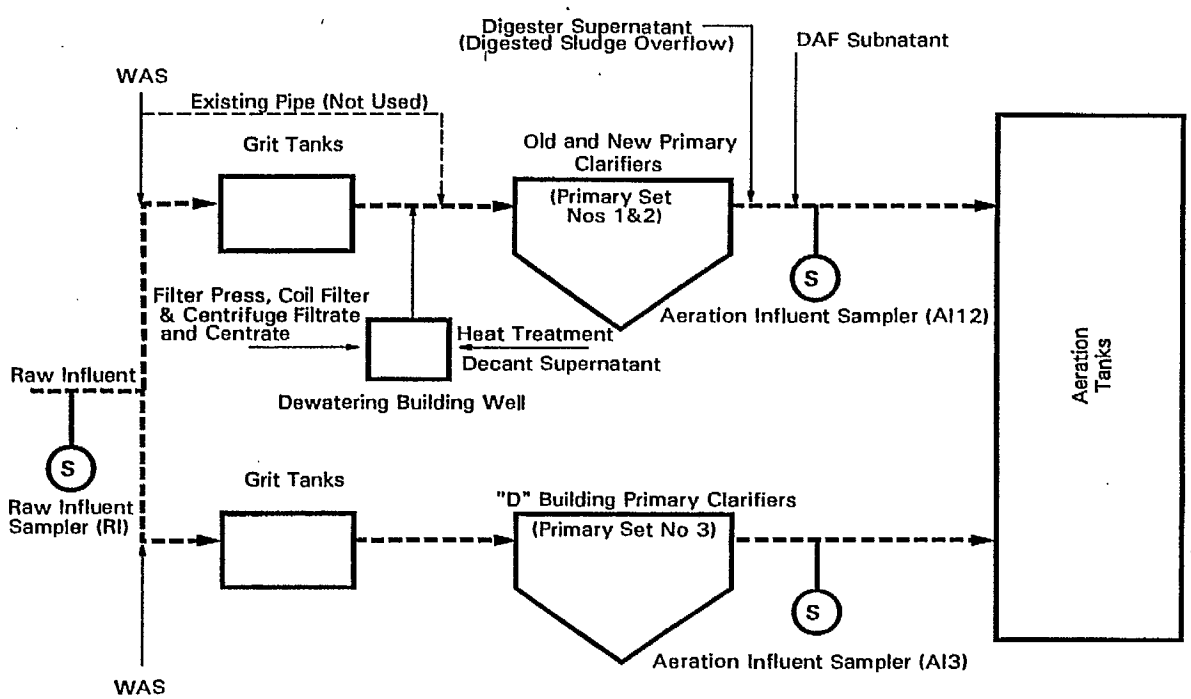


Figure 9-2
Return Stream Discharge Locations

- *Difficulty in obtaining a sample*, sludge recycle streams often discharge through pipes and channels which are not easily accessible.

Therefore, if timing of the recycle, concentration, or sample location make automatic sampling difficult, grab samples can be used to characterize the stream. If grab samples are to be taken, a series of grab samples (e.g. 4 to 8 grabs) should be used to generate a composite sample over a period of time (e.g. 4 to 8 hours). Alternatively, the time of day when the grab sample is taken should be varied, to avoid obtaining erroneous or biased results.

Generally, sludge recycle streams should be analyzed for the same conventional parameters as the liquid train (see Chapter 6). This could include SS, $TBOD_5$, $SBOD_5$, TP, SP, TKN and total ammonia-N. It is a good idea to include some soluble analysis since some solids handling processes (e.g. thermal conditioning) result in a recycle stream that is highly soluble in nature and this information could assist in deciding whether the current discharge location is appropriate. Lastly, additional analysis should be considered if the sludge recycle stream is thought to be toxic or inhibitive to the liquid train. The type of analysis will depend on the stream, but could include pH, alkalinity and hydrogen sulphide.

9.4 PRESENTATION OF RESULTS

Presentation and interpretation of the sludge recycle stream sampling results are interrelated topics. The results need to be presented in a way to assist in the interpretation of the results. Tables and graphs can be used to assist in presenting the results of a sludge recycle characterization program. Some recommended presentation methods include:

- **Mass Balance.** A mass or flow balance around the solids handling system is a good way to present a system and provide an understanding of the recycle streams. Examples of these figures are shown in Figure 9-1 and 9-3.
- **Summary Table or Pie Chart.** A summary table or figure of the recycle streams, often including liquid train concentrations provides an understanding of each stream's relative impact on the liquid train. An example pie chart presentation is shown in Figure 9-4.
- **Solids Handling System Summary.** This summary provides a complete picture of the solids handling process, its current loadings, and recycle streams. This provides information as to the current status of the process and the potential impact of future loadings. For example, see Table 9.1.
- **Simulated Changes to the Process.** If a particular sludge recycle stream is impacting the liquid train, options to correct the problem through changes to the sludge handling system may be proposed. A graphical representation simulating the changes can provide a good understanding of the proposed change. An example of this is shown in Figure 9-5, which simulates an increase in dewatering of digested sludge and a reduction in thermally conditioned sludge generation (i.e. reduction in thermal conditioning return stream flow) and the expected impact on the recycle stream loading.
- **Cumulative Plot of System Operations.** A cumulative plot of either flow or loading can provide a good illustration of typical operations in a solids handling system and the impact of these operations on the sludge recycles. Figure 9-6 shows how the operation of a digester and centrifuge impact the generation of supernatant at a plant.

Presentation of sludge recycle stream results needs to be made in such a manner that the impact of the streams with respect to the liquid train is clearly shown. The magnitude of the recycle streams will dictate whether changes to the system are warranted.

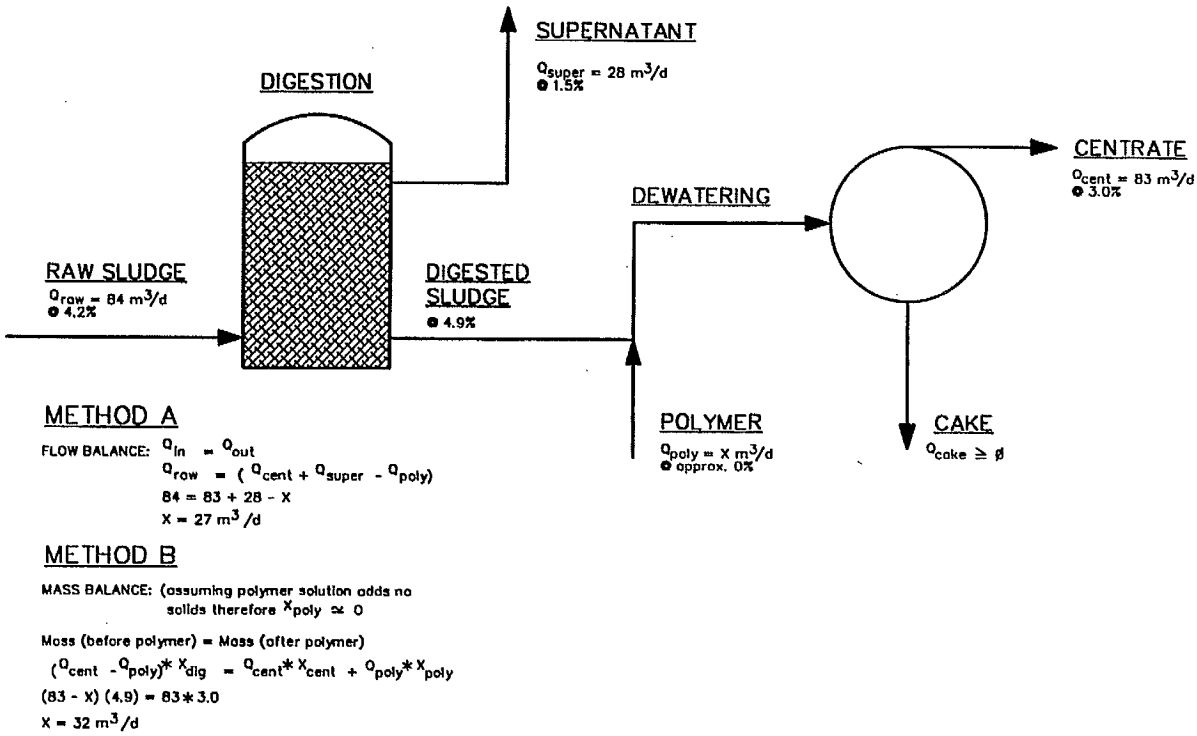


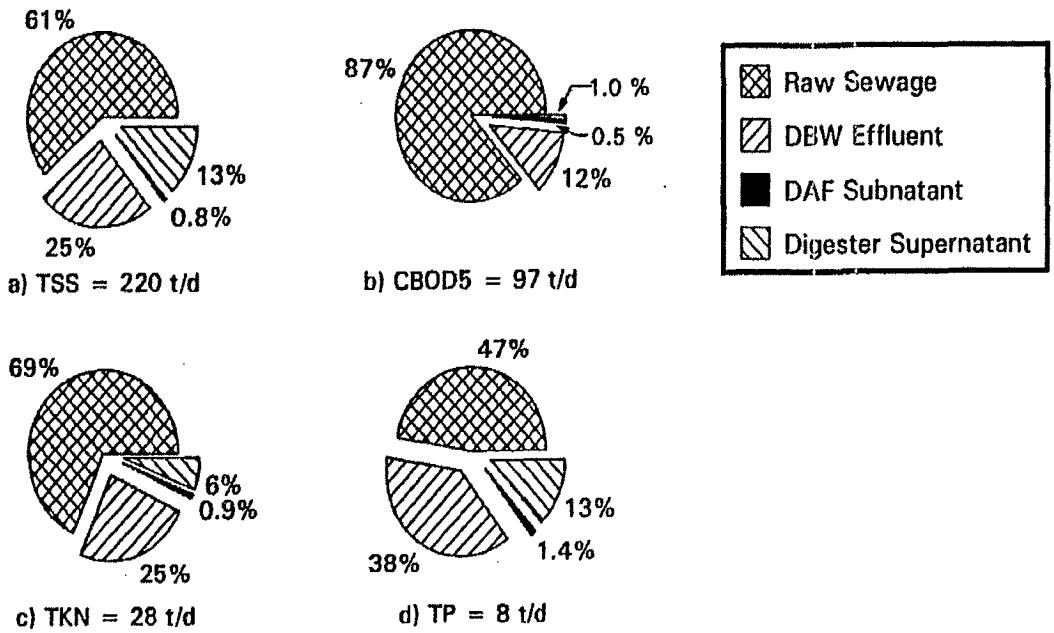
Figure 9-3
Flow and Mass Balance Around Handling System

9.5 INTERPRETATION OF RESULTS

Interpretation of results has been partially covered in the previous section and is further discussed in this section. In particular, the unique impact of sludge handling recycle streams in a nutrient removal facility is discussed.

9.5.1 Conventional Activated Sludge Plants

The presentation of the results will assist in the interpretation of the impact the sludge recycle streams have on the liquid train. Problems in settling, solids handling, having inert solids in the biological section and aeration system oxygen demands are some of the problems associated with these high strength streams. Redirecting the discharge of these streams, revising operations of the sludge handling system, or providing separate treatment of sludge recycle streams are all possible options to reduce the impact on the liquid train.



Note : Total Loading For Each Parameter Does Not Include Contribution From WAS which is co-thickened in the primaries

Figure 9-4
Percentage of Total Influent Loading Associated with Return Streams

All of these scenarios for reducing the impact of sludge handling recycle streams on the liquid process need to be completely evaluated to assess the impacts in terms of:

- Capital costs (new processes)
- Operating costs (energy and chemicals)
- Labour requirements

However, if these streams are significant loadings, these stream are often impacting the performance of the liquid treatment process, and some modifications may be beneficial.

Table 9.1
Solids Handling System Loading Parameters

Parameter	Units	Actual Values	Typical or Guideline	Comments
1. Raw Sludge Volume	m^3/d	9.3	-	Historical average
2. Raw Sludge				
a) TSS	%	3.7	4.0	Historical Average (digester)
	%	4.2	4.0	Monitoring Period
b) VSS		59	60	Monitoring Period
3. Liquid Sludge Generated (raw sewage treated)	L/m^3	5.64	5.00	based on historical average (Q_{raw} = 17,260 m^3/d)
4. Digester Loading				
a) HRT for Primary Digesters	d	8.0	15.0	Primary digester volume = 780 m^3 (27,500 ft^3)
b) Volatile Solids Loading	$g/m^3 \cdot d$	3070	650 - 1600	
c) Volatile Solids Destruction	%	29	40 - 50	Monitoring Period
5. Supernatant				
a) Volume	m^3/d	27.9		Monitoring Period
b) TSS	%	1.6		Monitoring Period
6. Centrifuge				
a) Feed solids	%	3.0	5.0	Monitoring Period; TSS after dilution with polymer
b) Dilution	m^3/d	39.0	-	Based on mass balance
c) Polymer feed solution	%	0.03	0.05 to 0.1	Based on polymer manufacturer
d) Polymer used	kg polymer/ t. dry solids	30	2.5 to 3.0	25lb polymer/day, based on plant experience
e) Hydraulic loading	m^3/h	14.0	18.5	Based on 8h operation
f) Solids Loading	kg/h	423	925	-
g) Centrifuge Cake	%	19	20 to 22	Manufacturers
h) Centrate concentration	mg/L	133	1500	-
i) Solids capture	%	99	97	Manufacturers

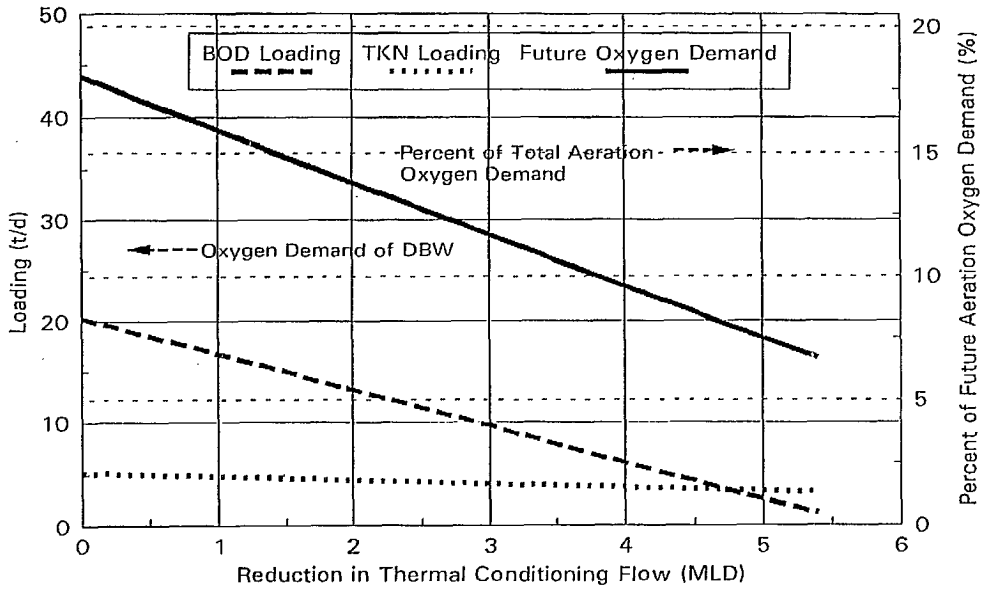


Figure 9-5
Impact on Aeration Loading of Reduced Thermal Conditioning of Sludge

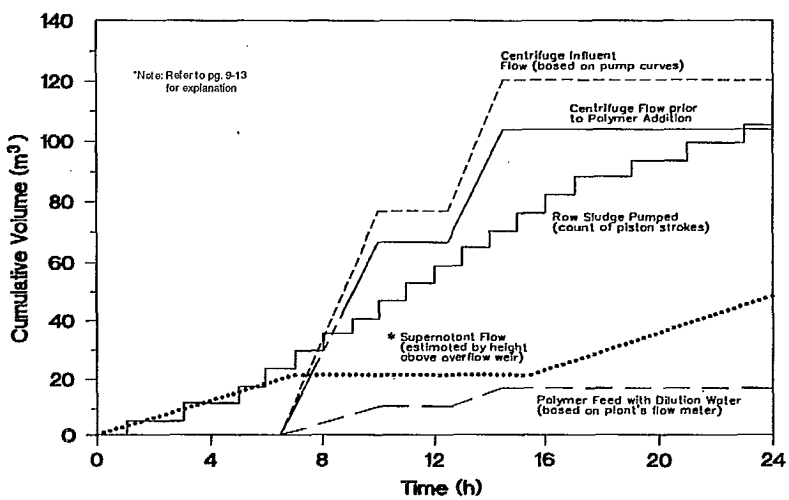


Figure 9-6
Operations of the Solids Handling System at the St. Thomas WPCP

9.5.2 Nutrient Control Facilities

Nutrient control plants have special removal needs including phosphorus, total ammonia-N, and total nitrogen. Since sludge recycle streams are often concentrated phosphorus and nitrogen streams, it is important that this contribution be accounted for in the liquid train design. The following discusses some items for consideration:

- *Nitrification.* The oxygen demand for nitrification can be significantly increased as a result of recycle streams. At one plant (CH2M HILL, 1993) the oxygen demand of the sludge recycle streams increased from 13 percent of the current demand for carbonaceous removal, to 23 percent when the plant was required to nitrify.
- *Chemical Phosphorus Removal.* The chemical requirements for phosphorus removal could be impacted by the phosphorus concentration and discharge location of sludge handling recycle streams. A mass balance with respect to phosphorus should be used to account for chemical removal needs. Conversely, chemicals/polymers used for conditioning sludges prior to dewatering may be returned to the liquid train and reduce chemical needs for phosphorus removal.
- *Biological Nutrient Removal.* A biological nutrient removal plant has special needs and requires good control of nutrients being introduced into each basin of the biological system. As a result, the recycle discharge location and its strength need to be evaluated. For example, if a recycle stream did contain nitrate/nitrite nitrogen and was discharged into an anaerobic cell, which is an essential component in biological phosphorus removal, the performance of the process could be severely affected.

9.6 SELECTED CASE STUDIES

Operational Evaluation of the Toronto Main Treatment Plant

The study conducted at the Metropolitan Toronto (Metro) Main Treatment Plant (Main TP) involved determining the influence the solids recycle streams have on the performance of the plant. The impact of these streams was evaluated in terms of the additional loading on the clarifiers and aeration system. The Main TP has a design capacity of 818 MLD (180 MGD) and is the largest wastewater treatment plant in Canada. The Main TP provides primary treatment, activated sludge secondary treatment with ferrous chloride addition to the activated sludge for phosphorus removal, sludge treatment, incineration, and ash disposal facilities. The treated effluent is discharged to Lake Ontario.

As part of an overall operational evaluation of the plant, the study reviewed the performance of the solids handling facilities and in particular the impact of the recycle streams on the liquid train. The plant is currently required to meet an effluent of 25 mg/L each for SS and total BOD_5 on a yearly basis, and 1.0 mg/L for TP on a monthly basis. These limits are expected to become more stringent in the future and may include the provision to nitrify.

Solids generated by the plant are handled in a variety of ways. A simplified flow schematic is provided in Figure 9-1 and shows the operating layout during the study. Primary sludge and co-thickened waste activated sludge (WAS) can be conveyed to either the anaerobic digesters or the heat treat process. In addition, part of the WAS is thickened using a DAF unit. The DAF thickened WAS can be further treated by either anaerobic digestion or thermal conditioning, prior to dewatering. During the period of the study, all of the primary and co-thickened WAS and the DAF thickened WAS was anaerobically digested prior to thermal conditioning. After anaerobic digestion the digested sludge is either dewatered by centrifuges or coil filters or heat treated, followed by dewatering by belt presses. All thickened sludge are incinerated at the site.

The main sludge return streams and internal recycle streams at the plant include:

- Decant liquor or supernatant from the thermal conditioning or heat treat system
- Centrate or filtrate from the centrifuges, coil filters and filter presses
- Supernatant (digested sludge overflow) from the anaerobic digesters
- Subnatant from the DAF units handling waste activated sludge
- WAS from the biological system which is co-thickened in the primary clarifiers

The dewatering building filtrate and centrate streams and the decant liquor supernatant discharge into a common well, referred as the dewatering building well (DBW), prior to being pumped into the liquid train.

The results of the analysis of the sludge handling recycle streams indicated that these streams were a significant loading to the liquid train at the plant. The results indicate that two of the recycle streams in particular, (i.e. DBW effluent and digester supernatant) were significant loadings to the liquid train, while the loading from the DAF's recycle stream was small in comparison. This is shown in Figure 9-4 by comparing the recycle stream loadings to the total plant loading, assuming all the recycle streams were diverted to the influent of the plant.

Figure 9-4 shows that the DBW effluent and digester supernatant would constitute 38, 13, 31 and 51 percent of the loading to the plant for TSS, carbonaceous BOD_5, TKN and TP, respectively, if both these streams were diverted to the headworks. These recycle streams are highly concentrated but are less than 2 percent of the current influent flow rate. Other work (Lawler and Singer, 1984; Lol, 1972; and Boyle and Gruenwald, 1979) confirms these findings, that recycle streams can greatly affect the loading to the liquid train of a treatment plant especially in terms of SS, nitrogen and TP, although the hydraulic loading from these streams is generally less than 1 to 2 percent of the treated flow. The figure also shows that the DBW, of which the decant liquor is the most significant load, is the largest of the three recycle streams for all four conventional parameters. The digester supernatant is a large SS and TP loading, but not a large BOD_5 and TKN loading when compared to the DBW.

One limitation in the analysis of sludge handling recycle streams is the type and number of samples. For this project grab samples of the recycle stream were taken to characterize each stream. These samples varied greatly in concentration both due to the type of sample and the processes being sampled. The impact this had on the results was minimized by analyzing regular samples (e.g. approximately twice weekly) over a large period (e.g. eight months). As a result about 55 samples from each significant recycle stream was used to characterize its impact on the liquid train.

Since the DBW, and especially the decant liquor, was determined to be a major loading on the liquid train, options to reduce this loading were reviewed. One option included reducing the sludge which was being thermally conditioned at the plant. The result of dewatering additional digested sludge and reducing the sludge which was thermally conditioned is summarized in Figure 9-5. The results show a significant reduction in the organic and nitrogen loading to the liquid train; however, caution is required to ensure all aspects of such a retrofit are addressed.

Review of Solids Handling System at the St. Thomas WPCP

The amount of sludge requiring processing and its adverse impact on the digestion, dewatering, and disposal systems was an ongoing problem at the St. Thomas WPCP. The St. Thomas WPCP is rated for an average daily flow of 27,300 m^3/d (6 MGD) and handles sludge generated at the plant by anaerobic digestion and centrifuge dewatering. As a result of these solids handling operations, two recycle streams are generated at the plant, digester supernatant and centrifuge centrate. The solids handling system is summarized in Table 9.1 in terms of actual and typical or design values. A flow and mass balance around the solids handling system was used to characterize the process. This approach is summarized in Figure 9-3 for this plant.

The results of the sampling program showed that the centrate stream was a small loading on the liquid train; however, the digester supernatant loading was significant. The supernatant loading was large because at the time of this work the plant was hauling dewatered cake to landfill and operating hours of the landfill limited dewatering operations.

Since the plant had no storage capacity for dewatered cake, the centrifuges were only operated such that the plant's single truck would be able to haul dewatered cake during the operating hours of the landfill. Therefore, during the night, once the centrifuges were shutdown, supernatant was returned to the liquid train. This operation is summarized in Figure 9-6, which shows that after the centrifuges are shutdown around 2 p.m. the supernatant is returned to the liquid train.

A number of recommendations were made as a result of the work including:

- Additional storage capacity for dewatered sludge
- Increasing dewatering production
- Increasing primary digester capacity to increase stabilization and improve dewatering characteristics
- Operating the secondary digester as a holding tank
- Providing better monitoring records for the solids handling system

Although the digester supernatant was a large loading on the liquid train, especially in terms of SS, the recommended options reviewed all aspects of the solids handling system. Again, only considering the liquid train would not necessarily provide the most cost-effective or the best operational process.

9.7 EXPECTED DURATION AND COSTS

An analysis of sludge recycle streams, like any offline sampling program, will vary in cost and scope depending on:

- Length of the sampling program
- Number of other auditing tasks being performed (i.e. personnel available onsite for other tasks such as online monitoring)
- Laboratory costs, if the samples are being analyzed by a commercial laboratory
- Assistance from plant staff in terms of taking/collecting/analyzing samples

The length of the analysis period will have the largest impact on the cost of an analysis of sludge recycle streams. The length of the program will increase the number of analysis, the labour to collect/submit/transport samples and the time to interpret and present the results. Sample analysis costs can be determined once the number and turnaround time are known. Approximate sample costs for conventional parameters are shown in Table 6.7 (Chapter 6). If the offline sampling program can be integrated into other auditing tasks, such as online monitoring or clarifier dye/stress testing, the labour cost associated with taking and collecting the samples can be reduced. The use of plant personnel for sample taking/collecting and analysis of conventional parameters can greatly reduce the costs associated with an offline sampling program; however, adequate resources should be maintained to setup, monitor and interpret the program.

It is important to note that if grab samples are being taken, sufficient samples need to be taken to obtain accurate results to account for the differences due to grab sampling and variations in the operation of the solids handling processes. A single grab sample may provide an incorrect evaluation of a recycle stream. Changes in the operation of solids handling processes can cause the stream strength to vary greatly throughout the day.

9.8 REFERENCES

Boyle, J.D., and Gruenwald, D.D. "Recycle of Liquor from Heat Treatment of Sludge". *Journal of the Water Pollution Control Federation.* Vol. 47, No. 10. Pp. 2482-2489. 1975.

CH2M HILL ENGINEERING LTD. Review of Solids Handling System at the St. Thomas WPCP. Report prepared for the Corporation of the City of St. Thomas. 1990.

CH2M HILL ENGINEERING LTD. Operational Evaluation of the Main Treatment Plant. Report prepared for the Regional Municipality of Metropolitan Toronto. 1993.

Lawler, D.F. and Singer P.C. "Return Flows from Sludge Treatment". *Journal of the Water Pollution Control Federation.* Vol. 56, No. 2. Pp. 118-126. 1984.

Lol, U. "Treatment of Thermally-Conditioned Sludge Liquors". *Water Research* Vol. 11. Pp. 869-873. 1972.

Metcalf and Eddy. Wastewater Engineering:Treatment, Disposal and Reuse. McGraw-Hill, New York. 1991.

Newbigging, M.; Nolasco, D.; DeAngelis, B.; Dobson, B. Impact of Solids Handling Recycle Streams on the Liquid Train of the Metropolitan Toronto Main Treatment Plant. Presented at the WEF Annual Conference. Chicago. 1994.

U.S. Environmental Protection Agency (U.S. EPA). Process Design Manual for Sludge Treatment and Disposal. US EPA, EPA 625/1-79-011. 1979.

U.S. Environmental Protection Agency (U.S. EPA). Chemical and Biological Treatment of Thermally Conditioned Sludge Recycle Liquors. US EPA, EPA 600/2-80-020. 1980.

WEF and ASCE. Design of Municipal Wastewater Treatment Plants, Volume II. Book Press, Vermont. 1991.

CHAPTER 10
STRESS TESTING

10.1 GENERAL OBJECTIVES

The general objective of stress testing is to determine the actual treatment capacity of a unit process by increasing the loading to the process. The response of the unit process to variation in the loading rate is quantified by stress testing, with the results presented as process loading performance versus condition. Since stress testing provides a quantitative measure of the impact on process performance, actual capacities of unit processes may be determined.

10.2 PLANNING STRESS TESTS

If a treatment unit has historically been loaded beyond its treatment capacity, process relationships may be developed as part of the historical data analysis (Refer to Section 3). However, if the actual loading rates to specific unit processes have been lower than typical design conditions or guideline values, it is often difficult to establish the treatment limits using historical data.

Stress testing, normally conducted with the support of online monitoring instrumentation, is used to increase the loading rates to a unit process beyond that which has occurred during normal operation. When planning a stress test, there are several alternatives to be considered to increase loading conditions for the test period:

- Use the diurnal flow cycle to provide a steady increase in loading rate over a 24-hour period
- Reduce the number of units in service, thereby increasing the loading rate to the remaining units in service
- Use the existing facilities, if possible, to bias the loading rate to the specific unit under study

Physical limitations, such as the inability to control flow rates in the wastewater treatment plant, must be considered when planning a stress test.

Another alternative for stress testing is the use of a calibrated process model to predict the impact of hydraulic and load variations on process performance. Some of the advantages of using a dynamic process model to assess treatment plant capacity and optimization approaches are discussed in Chapter 12.

10.3 EFFLUENT CRITERIA LIMITATIONS

Stress testing may result in deterioration of the treatment performance as the loading rate is increased beyond the treatment capacity. If the final effluent is treated by the stressed unit process immediately prior to discharge (e.g. secondary clarifiers or effluent filters), the stress testing may result in concentrations exceeding the plant's effluent compliance criteria for a limited time period. **For this reason, potential discharge violations which may occur during stress testing should be discussed with the plant staff and the governing regulatory agency** (i.e. the Ministry of the Environment and Energy). A representative of the regulatory agency should be notified and provided with detailed information on the planned stress testing procedures and action which will be taken in the event of any exceedance of the effluent criteria. For treatment facilities without single sample compliance criteria, deterioration of the effluent quality for a limited period of time during stress testing may not result in exceedance of the average effluent criteria requirements (e.g. an annual average concentration of 25 mg/L).

10.4 INSTRUMENTATION AND EQUIPMENT REQUIRED

Online monitoring equipment and an offline sampling program are two key components of a unit process stress test (Table 10.1). For example, online monitoring parameters of interest for secondary clarifiers usually include total plant flow rate, return/waste activated sludge concentration and flow rates, effluent quality parameters (i.e. suspended solids concentration), and sludge blanket depth. The offline sampling program is designed to collect samples for analysis of the parameters of interest under varying loading rates. A detailed description of the recommended stress testing procedures for each unit process is provided in Section 10.5.

10.5 STRESS TESTING UNIT PROCESSES

10.5.1 Primary and Secondary Clarifiers

Stress testing of primary and secondary clarifiers is conducted over a range of flow rates, such that the initial flows are below and final flows are above the clarifier's design capacity. If possible, other clarifiers are taken out of service to increase flow rates to the online clarifiers. Diurnal and/or wet weather flow increases may be used to stress clarifier performance. If the pumping rate to a clarifier can be varied manually, the stress testing should be conducted at a minimum of five different flow rates over the range of interest. In these circumstances, each flow rate should be maintained for a period of time (e.g. 1 to 2 hours) adequate to allow clarifier performance to stabilize prior to sampling. Sustaining flow rates for extended time periods (e.g. 24 hours or more) increases the level of confidence in performance results.

Table 10.1
Summary of Online Instrumentation and Offline Sampling Requirements for Unit Process Stress Tests

Unit Process	Online Instrumentation	Offline Sampling Parameters and Equipment
Primary Clarifier	• Total plant flow • Sludge blanket height • Raw sludge flow	• Manual sampler and sample bottles • Influent/effluent grab samples • Raw sludge concentration • SS lab analysis equipment • Sludge judge
Secondary Clarifier	• Total plant flow • Sludge blanket height • RAS/WAS flow • RAS/WAS concentration • MLSS concentration • Effluent SS concentration	• Manual sampler and sample bottles • Influent/effluent grab samples • SS lab analysis equipment • Sludge judge
Activated Sludge (including aeration)	• Same as secondary clarifier	• Same as secondary clarifier
Effluent Filter	• Total plant flow • Effluent SS concentration and/or turbidity	• Manual sampler and sample bottles • Influent/effluent grab samples • Headloss • Backwash solids concentration/quantity • SS lab analysis equipment

Plant flow rates are normally recorded by the online data acquisition system throughout the stress testing period. Clarifier influent and effluent grab samples are obtained periodically during the stress testing period to correspond to the variation in flow conditions. For example, in a two day stress test, grab samples may be obtained for offline analysis every 15 minutes during peak flow periods increasing to a 1-hour interval during low flow periods. The samples should be obtained from a location where the flow converges which is representative of overall clarifier performance. If the clarifier has multiple weir channels and it is not possible to obtain a sample from a point of flow convergence, a manual composite sample should be prepared using samples obtained at each weir.

At the time of each sampling, a sludge blanket depth measurement should be obtained manually, or noted from the online measurement of sludge blanket depth. Typically, the sludge blanket depth will increase gradually to a point of stabilization. If the blanket depth continues to increase to the point of solids washout, normal operations should be resumed immediately (i.e. put off-line clarifiers back in service or adjust flow conditions, if possible). It is good practice to obtain sludge blanket depth

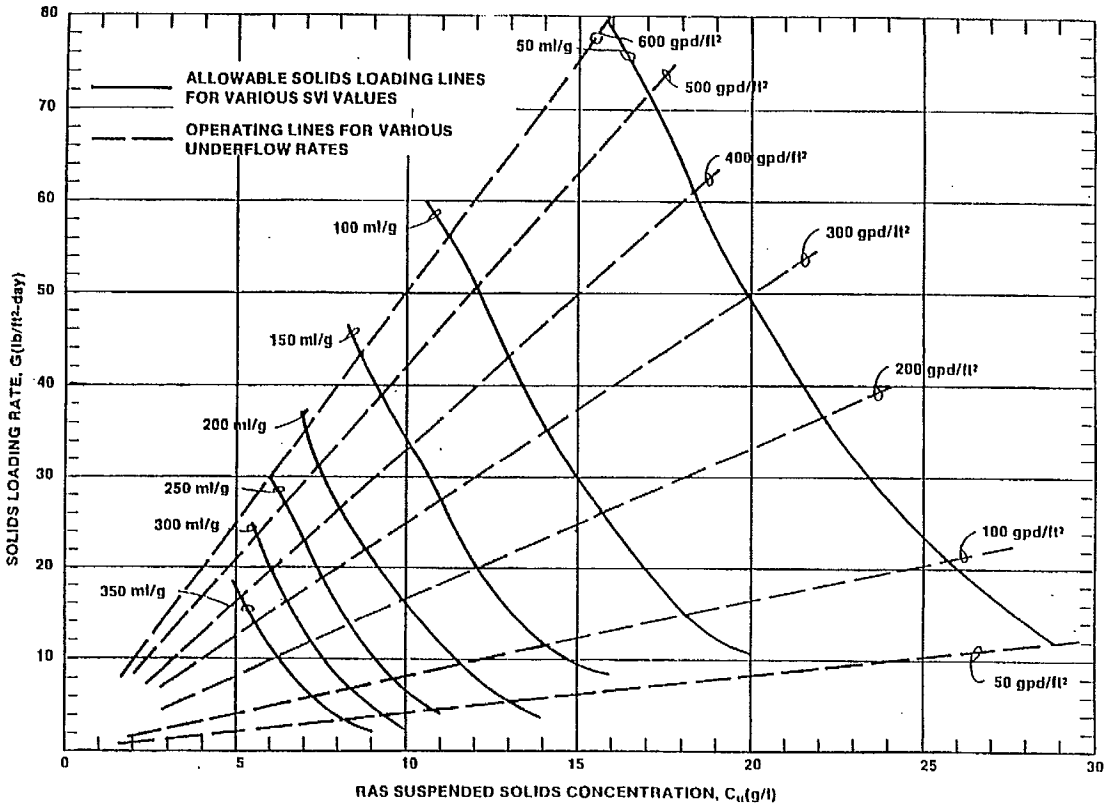
measurements at different locations in the clarifier (i.e. across the clarifier diameter in circular clarifiers or along the clarifier length in rectangular clarifiers) to fully identify sludge blanket characteristics.

In an activated sludge system, the capacity of the secondary clarifiers will be directly affected by the settleability of the sludge as measured by the sludge volume index (SVI). Therefore, the SVI of a mixed liquor composite sample should be determined during the stress testing period. Ideally, a series of tests are done at varying SVI's to develop a family of clarifier performance curves for comparison to typical values (Figure 10-1). RAS and WAS flow rates should also be recorded at the data acquisition system when stress testing secondary clarifiers.

Clarifiers perform two basic functions – clarification and sludge thickening. Clarification capacity is normally quantified by relating the hydraulic surface loading rate to suspended solids removal (for primary clarifiers) or secondary effluent suspended solids concentrations (for secondary clarifiers). Stress testing of primary clarifiers is usually conducted to identify the hydraulic loading rate at which the parameter removal rates (e.g. suspended solids) approaches typical design values as well as the hydraulic loading rate which results in failure of the unit process (e.g. loss of the sludge blanket for secondary clarifiers). For secondary clarifiers, clarification performance is typically linked to achieving effluent criteria under average and peak flow conditions. The thickening capacity of a clarifier is quantified by relating the solids loading rate to the effluent quality. In addition, the variation in sludge blanket depth over time as measured manually or recorded by the data acquisition system is analyzed. A clarifier stress test data sheet (Figure 10-2) provides a record of the data collected during the monitoring period for subsequent analysis and interpretation.

10.5.2 Activated Sludge System (Including Aeration)

Stress testing of an activated sludge system consisting of an aeration system and secondary clarification generally requires an extended period of operation to observe long term performance variations. Characteristics of micro organisms in an activated sludge system (e.g. specific growth rate, settleability) will change under various operating conditions. For this reason, the minimum time required for stress testing of the activated sludge system may be related to the solids residence time (SRT) of the process. In general, specific operating conditions are evaluated over a period of at least approximately 1 to 2 SRTs. A transition period of at least approximately 3-4 SRTs is recommended between different states of operation to allow the impact of operational adjustments to be realized in the biological process. Stress testing over several seasons may be required to demonstrate performance under various operating conditions created by seasonal influences such as temperature variations, seasonal industrial discharges, or infiltration/inflow impacts during wet weather.



SOURCE: Daigger, G. T. and Roper, R. E. Jr. (1984)
"The Relationship Between SVI and Activated Sludge Characterics"
Journal of the Water Pollution Control Federation

Figure 10-1
Theoretical Solids Loading Rate

Hydraulic and organic loading rates to the activated sludge system may be increased by removing one or more units from service. This approach may be used to simulate the full-scale operation of the unit processes at flow rates equivalent to or exceeding the rated treatment capacity. In addition to the parameters of interest to secondary clarifier performance (refer to Section 10.5.1), aeration parameters include organic and nitrogenous loading rate, hydraulic retention time (HRT), solids retention time (SRT), food-to-micro organism ratio (F/M) and recycle ratio. An extended stress testing period of an activated sludge system is normally supported by online instrumentation and an offline sampling program. Aeration system capacity analysis (refer to Chapter 7) may also be conducted to obtain an oxygenation capacity estimate. Stress testing of an activated sludge system at full-scale may be used to verify this treatment capacity estimate.

CLARIFIER STRESS TEST DATA SHEET

Date:_____ Project Location:_____

Clarifier:_____ Time of Test:_____

SVI During Test (mL/g):_____ Average Influent TSS During Test (mg/L):_____

Time	Influent Flow Rate (m^3/d)	RAS Flow Rate (m^3/d)	Blanket Level (m)	Sample Bottle Number	Sample Volume (mL)	Filter Tare Wt. (g)	Final Wt. (g)	Sample TSS (mg/L)

Figure 10-2
Clarifier Stress Test Data Sheet

10.5.3 Other Unit Processes

The procedures used for stress testing of other unit processes should be developed as needed to relate key performance criteria (e.g. effluent quality, removal rates) to defined operating conditions (e.g. loading rates, retention times). Some examples of other unit processes which may be appropriate for stress testing determination of treatment capacity include tertiary treatment (e.g. final effluent filters) and effluent disinfection (e.g. chlorination).

10.6 PRESENTATION AND INTERPRETATION OF RESULTS

A summary of the stress testing conditions and a graphical representation of the results in relation to typical design parameters are used to interpret the unit process capacity. Presentation of stress testing results should include the following as a minimum:

- Unit process tested
- Date and duration of test
- Size and description of unit process
- Unit process design parameters under stress testing conditions
- Evaluation criteria and results during stress testing

Typical unit process design parameters and the evaluation criteria are provided in Table 10.2.

10.7 SELECTED CASE STUDIES

City of Windsor Little River Pollution Control Plant Process Evaluation and Process Evaluation of Plant No. 2 at the Little River Pollution Control Plant

Expansion of the Little River Pollution Control Plant was required to provide adequate capacity for projected increases in flow. Requirements in the conditional Certificate of Approval for the construction of Plant No. 2 concerning nitrification and demonstration of the ability to treat peak flows raised the issue of the actual capacity of both the existing Plant No. 1 and the new Plant No. 2. Process audits including stress testing were conducted in each plant to determine the capacity of the overall facility. Plant No. 2 was to provide a secondary treatment capacity of 27,300 m^3/d (6 MGD) in addition to the original rated capacity of 36,400 m^3/d (8 MGD) for the existing Plant No. 1. Prior to completion of the stress testing evaluations of Plant No 1. and Plant No. 2, there was the potential for a total facility capacity down-rating to 45,500 m^3/d (10 MGD).

Table 10.2
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
Secondary Clarifier	• Surface overflow rate • Solids loading rate	• Conventional effluent quality criteria • Sludge blanket depth • SVI
Activated Sludge (including aeration)	• Same as secondary clarifier • Hydraulic and solids retention time (HRT/SRT) • Organic/nitrogenous loading rate • F/M ratio • Recycle ratio	• Same as secondary clarifier
Effluent Filter	• Hydraulic and solids loading rate	• Effluent quality criteria • Headloss • Backwash solids concentration/quantity
Chlorination	• Detention time	• Bacterial concentrations (total/fecal coliform, E.coli) • Residual chlorine concentration

In Plant No. 1, stress testing was conducted over an eight-month period to illustrate the plant's ability to achieve the effluent discharge criteria during winter, spring and summer/fall. The three operating periods were selected to cover the range of operating conditions experienced at the facility, including cold weather in winter which may impact nitrification, high influent flow rates associated with wet weather in the spring and increased organic loadings associated with late summer and early fall processing at a local cannery.

The stress tests were conducted by dividing Plant No. 1 into two parallel treatment trains and directing between 60 and 70 percent of the total flow to the stressed part of the plant. The stressed part of the plant consisted of two primary clarifiers, two aeration tanks (one mechanical aeration and one fine bubble diffusion) and two secondary clarifiers. A schematic layout of Plant No. 1 and Plant No. 2 at the Little River Pollution Control Plant is shown in Figure 10-3. The performance of the stressed plant was determined using online instrumentation data and the results of an offline sampling program which included the determination of conventional parameter concentrations in the

influent, primary effluent, stressed plant effluent and the combined plant effluent. An example of the impact of intentional increases in the organic and hydraulic loading rate on nitrification during the winter stress test period is shown in Figure 10-4. In Figure 10-5, the online DO concentrations are shown in response to specific periods when the flow to the stressed part of the plant was increased. The stress testing demonstrated that there was no basis for down-rating the existing Plant No. 1 since the plant was capable of achieving all effluent requirements including nitrification at the original rating of 36,400 m^3/d (8 MGD).

A similar approach to stress testing was used in Plant No. 2. Approximately one third of the aeration capacity and one half of the clarifier capacity in Plant No. 2 was in operation for a 13 month period of intensive evaluation of online monitoring and offline analytical data. Seven periods of operation were identified corresponding to seasonal periods (i.e. winter, spring, and summer/fall), modification of the hydraulic loading rate and process upsets. In one of the three winter periods, nitrification was lost due to excessive wasting which occurred in an attempt to lower the SVI (200 mL/g). The cannery discharge during the summer/fall period also resulted in process upset.

Based on the stress testing results, it was recommended that Plant No. 2 be rated at 36,400 m^3/day (8 MGD). The stress testing also identified upgrading alternatives for the overall facility to provide operational flexibility and to further increase total plant capacity.

Stress Testing of the Walnut Creek and South Austin Regional WWTPs

Unit process stress testing was conducted for the City of Austin at the Walnut Creek (WC) and South Austin Regional (SAR) wastewater treatment facilities as part of an overall nutrient removal assessment. To verify the treatment capacity of each plant, stress testing of the primary clarifiers, secondary clarifiers and final effluent filters was conducted in conjunction with dye dispersion tests of several unit processes and off-gas analysis of the aeration system. The rated plant capacities were average daily flows of 283,875 m^3/d (75 MGD) and 189,250 m^3/d (50 MGD) for the WC and SAR treatment facilities respectively, both with a peak factor of 2.

Stress testing of the primary and secondary clarifiers was conducted by increasing the hydraulic and solids loading rate to values approaching and exceeding design values for a 24-hour period. The variation in loading rate was achieved by increasing the flow rate and/or taking units out of service. The number of units in service for each stress test was pre-determined from historical flow conditions to achieve the target peak flow rate. Stress testing of the final effluent filters was conducted by maintaining the target loading rate over a 24-hour period.

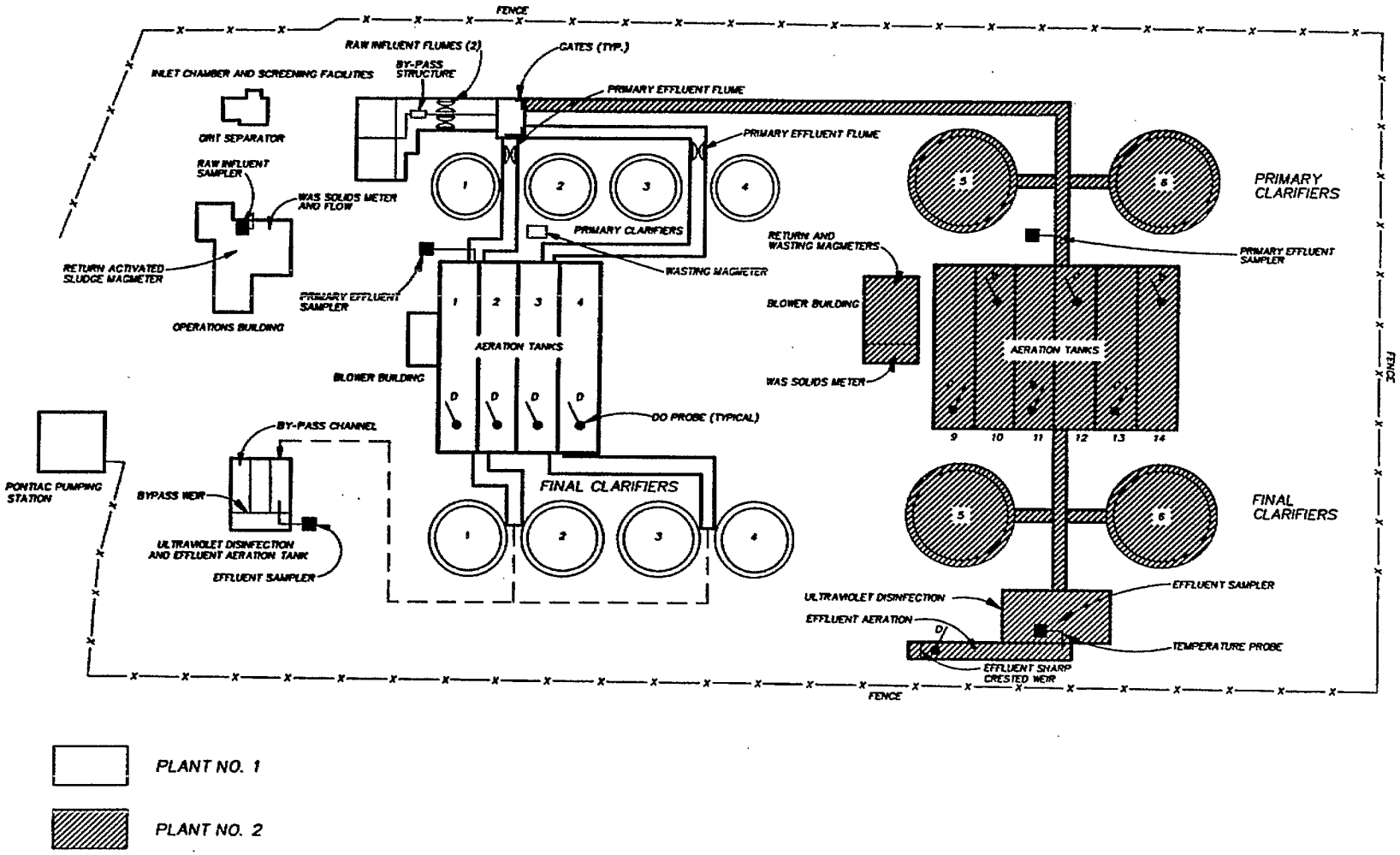


Figure 10-3
Schematic Layout of the Little River Pollution Control Plant

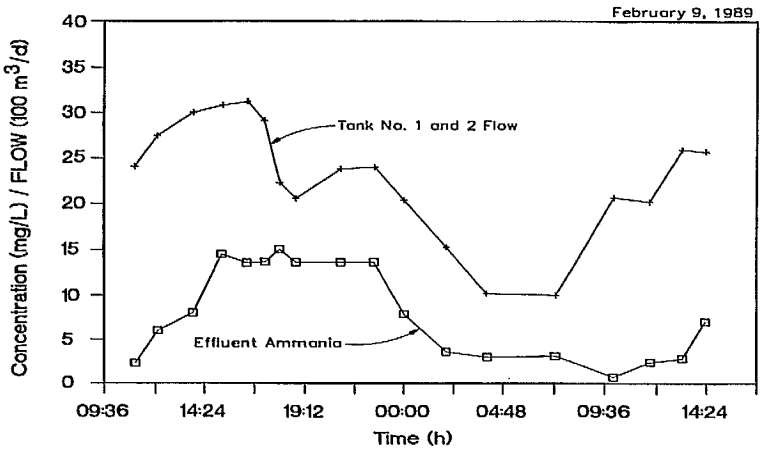


Figure 10-4
Impact Peak Hydraulic and Organic Loading on Tanks No. 1 and 2 Nitrification (Little River PCP)

Graphical representations of the stress testing results were prepared for each unit process. For the primary clarifiers at Walnut Creek WWTP, the suspended solids removal efficiency was to meet or exceed an expected minimum value of 40 percent at the target design loading rate (Figure 10-6). Removal efficiencies were averaged over a surface overflow rate (SOR) interval of 500 gpm/ft² to identify trends. In general, removal efficiency was improved at lower SORs (i.e. less than 1,500 gpd/ft²). An average removal efficiency of less than 40 percent occurred at an SOR of between 2,000 and 2,500 gpd/ft², which may have been affected by influent conditions or raw sludge removal practices. The effluent suspended solids concentration was plotted as a function of increase in loading rate for the secondary clarifiers (Figure 10-7) and final effluent filter at the South Austin Regional WWTP. In general, the final clarifiers maintained effluent SS concentrations of less than the plant's monthly SS requirement of 15 mg/L at SORs up to the target design value of 1,100 gpd/ft².

In general, the stress testing results at both facilities indicated that loading rates approaching peak design target values did not adversely affect the process performance of the primary clarifiers, secondary clarifiers or final effluent filters. The stress testing results were also used to assist in the calibration of a process model for each plant. The process models were developed to assess the applicability of biological nutrient removal using a variety of BNR layouts/processes.

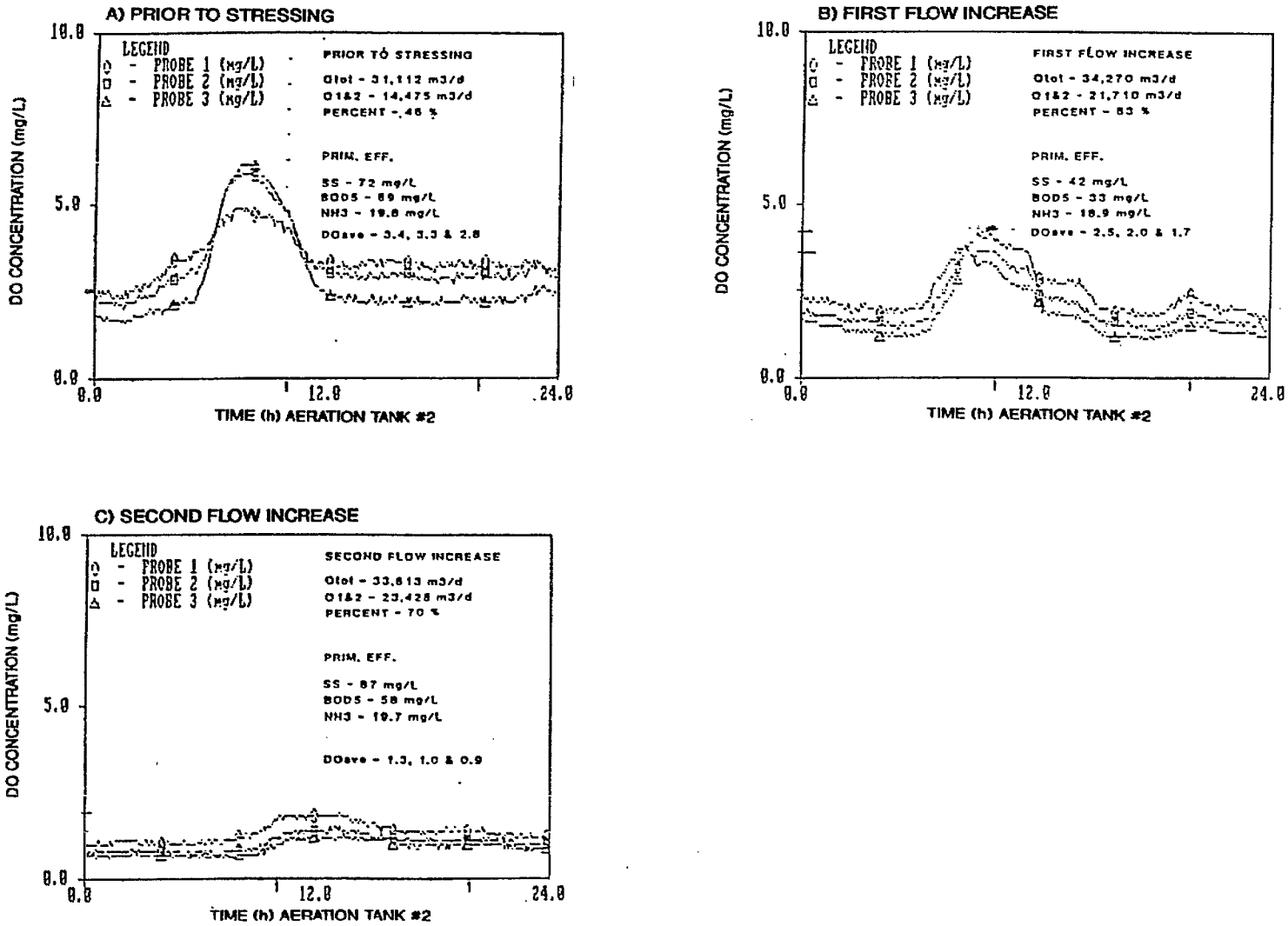


Figure 10-5
Variations of DO Concentration During the Winter Stress Test
(Little River PCP – Plant No. 1)

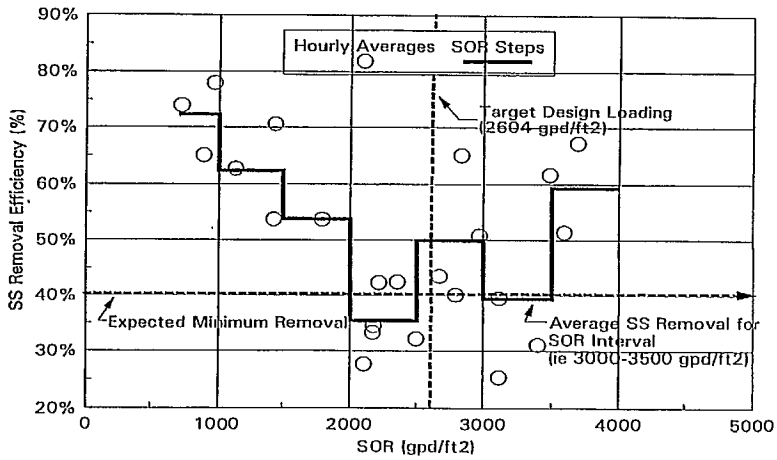


Figure 10-6
Primary Clarifier Removal Efficiency at Various SORs (Walnut Creek WWTP)

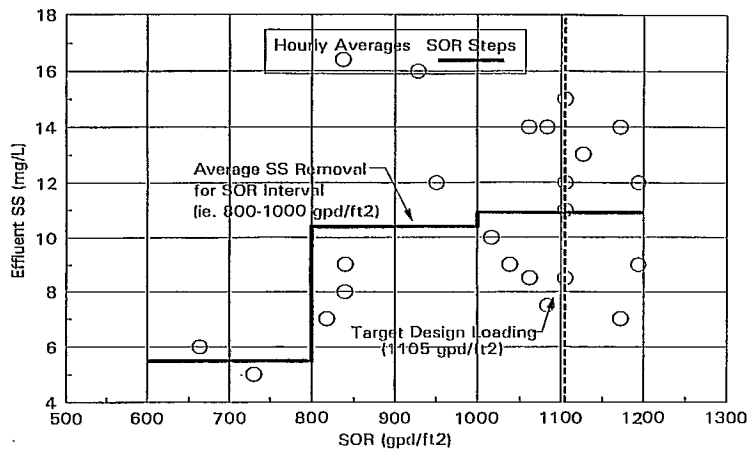


Figure 10-7
Final Clarifier Effluent SS Concentrations at Various SORs
(South Austin Regional WWTP)

Seaway WPCP Assessment

Stress testing of the secondary clarifiers and aeration system was completed at the Seaway WPCP in Port Colborne as part of an assessment to define the plant operating status and to determine the upgrading/expansion requirements of the facility. The assessment was completed in conjunction with an infrastructure needs study of the wastewater collection system as the two main components of a comprehensive program to develop and demonstrate a computer-based expert system for municipal wastewater collection and treatment facilities.

The two-stage stress testing period was supported by online instrumentation and an offline sampling program which was in place for the five-month process audit period. In stage one, one of the secondary clarifiers was removed from service for approximately a two-month period to develop a performance relationship between hydraulic loading rate and the effluent suspended solids concentration. In stage two, one of the four aeration cells was removed from service for approximately one month to define the impact of stress testing on biological treatment and sludge settleability.

Stress testing of the secondary clarifier relied on flow conditions which were experienced during the evaluation period (i.e. naturally occurring) with one clarifier out-of-service. A rainfall event provided the opportunity to examine the clarifier performance under peak hydraulic loading conditions. Instantaneous peak flow experienced during the wet weather event approached approximately 27,000 m^3/d. As shown in Figure 10-8, the secondary clarifier maintained an effluent suspended solids concentration of less than approximately 10 mg/L as measured in offline 2-hour composite samples under conditions approaching the SOR peak flow design value.

Although the hydraulic retention time (HRT) in the aeration system during stage 2 stress testing approached the design value, the impact of stress testing on biological system performance could not be identified since the organic loading rate was lower than typical design values. However, the limit of secondary clarifier performance with a well settling sludge (i.e. SVI = 70) was observed during high peak flows up to approximately 30,000 m^3/d associated with a rainfall event during stage two (Figure 10-9). Confirmation of the secondary clarifier peak flow capacity provided support for one of the conclusions of the program to provide a future increase in the average rated plant capacity with a reduction of the peak flow factor from 3 to 2.5. The data collected during the stress testing period was also used for calibration of the wastewater treatment process model (refer to Chapter 12).

10.8 EXPECTED DURATION AND COSTS

The duration of a stress test may range from one day for a test based on diurnal flow variation to approximately one year where the unit process performance is monitored over a variety of operating conditions. Therefore, costs for stress testing are highly variable, but are generally related to the duration of the stress testing period and the scope of supporting tasks such as online monitoring and the offline sampling program. The variability of process audit project costs is discussed in Chapter 1.

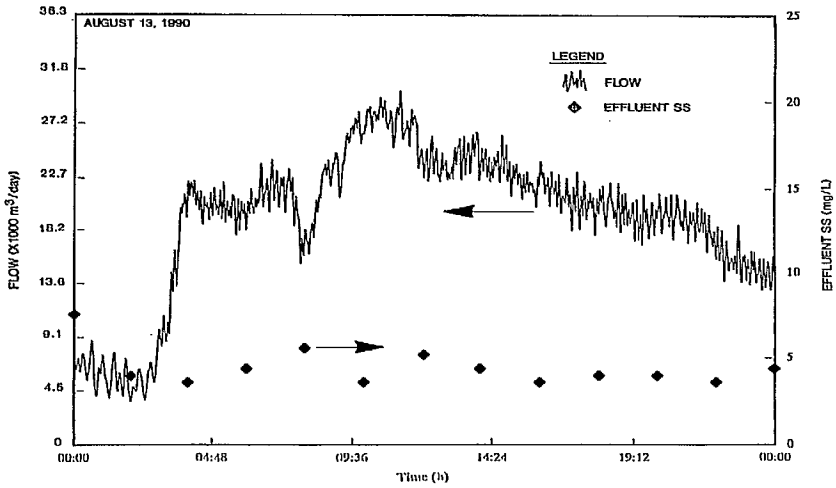


Figure 10-8
Impact of Wet Weather Flow Conditions During Stress Tests on Effluent SS Concentration of Offline Composite Samples (SeawayWPCP)

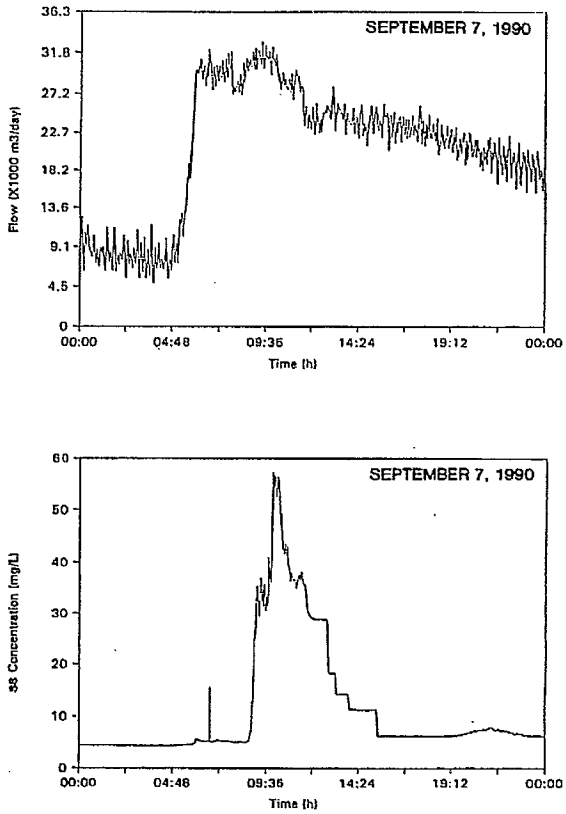


Figure 10-9
Impact of Wet Weather Flow Conditions During Stress Tests on Online Effluent SS Concentration (SeawayWPCP)

10.9 REFERENCES

CH2M HILL ENGINEERING LTD. City of Windsor Little River Pollution Control Plant Process Evaluation. Report prepared for the City of Windsor. January, 1990.

CH2M HILL ENGINEERING LTD. Seaway WPCP Assessment. Report prepared for the Regional Municipality of Niagara. February, 1992.

CH2M HILL ENGINEERING LTD. Process Evaluation of Plant No. 2 at the Little River Pollution Control Plant. Report prepared for the City of Windsor. April, 1992.

CH2M HILL ENGINEERING LTD. Stress Testing of the Walnut Creek and South Austin Regional WWTPs. June, 1994.

Daigger, G.T., and Roper, R.E. Jr. "The Relationship Between SVI and Activated Sludge Settling Characteristics". *Journal of the Water Pollution Control Federation.* Volume 57, Issue 8. Pp 859-866. 1985.

CHAPTER 11
UNIT PROCESS TRACER TESTS

11.1 GENERAL OBJECTIVES

Tracer test techniques evaluate the hydraulic characteristics of unit process tanks. Test results serve to indicate short circuiting, determine existing mixing regimes, locate dead zones within the fluid volume, evaluate baffling arrangements and identify predominant flow patterns within the unit process.

Tracer testing techniques are used to evaluated the following unit processes:

Chlorine Contact Chambers

- determine the disinfection concentration and contact time (CT) parameter
- evaluate baffling arrangements
- identify hydraulic short circuiting and locate dead zones

Aerated Grit Chambers

- identify hydraulic short circuiting and locate dead zones

Aeration Basins

- determine predominant mixing regime (plug flow versus complete mix)
- identify hydraulic short-circuiting and locate dead zones

Settling Tanks

- identify hydraulic short-circuiting and locate dead zones
- identify density currents and sludge blanket carryover problems
- evaluate baffling arrangements

Digester

- identify hydraulic short-circuiting
- evaluate mixing

11.2 PLANNING TRACER TESTS: WHEN AND WHERE TO TEST

Tracer test techniques provide quantitative and qualitative evaluations of the hydraulic characteristics of unit processes. There are two basic test techniques: dispersion tests and flow pattern tests.

Dispersion tests consist of injecting a slug of tracer upstream of the unit process and sampling the effluent over a period of time. The test is used to determine the actual hydraulic residence time (HRT), estimate the degree of hydraulic short circuiting and determine the level of mixing provided. Flow pattern tests consist of injecting the tracer at a constant rate over a period of time upstream of the unit process and collecting samples at different locations and depths through the body of the unit process over a short period of time. Flow pattern tests are used to evaluate the spatial distribution of flow through the unit process including the location of dead zones, density currents, and the effect of baffle arrangements.

General considerations determining when and where to test include:

- For multiple unit processes with similar geometry and hydraulic characteristics, testing is normally limited to one tank. If the tank geometry and hydraulic characteristics are different, one of each type should be tested.
- To evaluate the effectiveness of baffling arrangements, the tests should be conducted before and after installation. Alternatively, testing parallel units with different baffling arrangements can be used to determine the relative performance of the baffling techniques.
- Tests to determine hydraulic short circuiting and evaluate baffling arrangements should be conducted at design flow rates. The high flow rates will be critical in determining the unit performance. Flow to parallel unit processes can be manipulated to achieve the design flow rate in the unit tested. It is crucial to know the flow to the unit at the time of the test to allow accurate interpretation of the test results.
- Tests to determine mixing characteristics and locate dead zones should be conducted at more than one flow rate. The minimum day, average day and maximum month flow are recommended to determine the concentration time (CT) parameter for disinfection.
- Digester tracer studies are performed on digesters with suspected mixing problems. Indicators of poor mixing include:
  - Grit or scum buildup in the digester
  - Low gas production
  - Poor volatile solids destruction

- Digester tracer studies are also used to evaluate mixing equipment, equipment layout and digester geometry. Rectangular and large diameter digesters are more susceptible to mixing problems than standard cylindrical or egg-shaped digesters. Digesters that experience large variations in sludge solids concentration and/or composition may also experience large variation in mixing efficiency. The performance of digesters operating near the design hydraulic residence time (HRT) are more sensitive to poor mixing.

11.3 INSTRUMENTATION AND EQUIPMENT REQUIRED

The equipment needed to conduct tracer tests is described below.

11.3.1 Unit Process Dye Tests

Tracer Dye

Rhodamine WT fluorescent dye is commonly used for hydraulic evaluations in wastewater treatment plants. It was developed specifically for conducting tracer dye tests and has low absorption and adsorption on the particulate matter found in wastewater. It is non toxic and can be detected at low concentrations. However, Rhodamine dye is bleached by free chlorine and therefore the chlorine dosing should be discontinued during testing of a chlorine contact chamber.

Fluorometer

The concentration of Rhodamine WT dye is determined by measuring the fluorescence of the sample with a fluorometer fitted with Rhodamine Optics. The discrete sample (cuvette) attachment is normally used for the analysis of discrete samples collected at different times and/or locations. A flow through analyzer is useful during dye tests which evaluate short-circuiting in tanks with short hydraulic residence times.

Dye Injection Equipment

There are two basic dye injection techniques used in dye tests: the injection of the dye at a constant rate over a period of time and slug injection of the dye at one instant in time. The test objectives determine the most appropriate dye injection technique used for a particular test.

Dye injection equipment required for constant rate addition include:

- Positive displacement chemical feed pump with an adjustable pump rate (0 to 20 mL/min is suitable for most applications)
- Transparent small diameter inlet and outlet hose with water tight connectors. Teflon hose approximately 2 metres long is recommended
- Dye reservoir (5-litre capacity sufficient for most applications)

Dye injection equipment required for slug addition include:

- Glass measuring equipment such as pipettes, graduated cylinders and volumetric flasks
- Suitable mixing container (20 litre polyethylene bucket) for the initial dilution of the dye prior to addition

The dye injection equipment should be arranged so that the dye reservoir is located at the same elevation or below the discharge of the outlet hose to prevent siphoning through the pump during operation. Crosby (1987a) discusses the equipment and set-up required for constant rate injection in more detail.

Sample Collection Equipment

Dye test studies require discrete samples collected at different times and/or location. The samples are collected with manual grab samplers or sample pumps.

The Crosby Clarifier flow pattern test requires a specialised sample collection rig capable of simultaneously collecting five discrete samples at different depths in the clarifier profile. Figures 11-1 and 11-2 present two alternative sample collection rigs. In Figure 11-1, the sample collection rig consists of five self-priming pumps mounted on a 6 x 1 plank so that all pumps are controlled by single ON/OFF switch. The five inlet hoses are 1/2 inch ID reinforced clear PVC tubing cut to appropriate lengths and taped together to form a single bundle. A weight attached to the end of the longest sample tube holds the 5 sampling tubes in a vertical position. The outlet tubes are threaded through a discharge bracket which allows the sample stream to be directed into 5 sample bottles during the test. Crosby (1987b) provides a description of the sample collection equipment.

The sample collection rig shown in Figure 11-2 is constructed from 25.4 mm dia clear PVC with sampling ports located at 0.3 m intervals. The check valve at the foot of the core sampler is open as the sampler is lowered slowly through the tank. The valve is closed and then the sampler is brought to the surface and discrete samples are collected in previously labelled bottles by sequentially

opening the sample port valves, starting at the uppermost valve. Chapman (1989) provides a description of the core sampler.

11.3.2 Digester Tracer Studies

Digester tracer studies measure the response of a mixing system to a step function (slug) of tracer material. The mixing efficiency is determined from the variation in tracer concentration with time either directly or by comparing the observed distribution to predictions from various mixing models. The equipment required to perform a digester mixing study include the equipment to prepare and inject the tracer slug, tracer material and sample collection equipment.

Tracer material which have been used for digester tracer studies include radioactive isotopes such as sodium-24 and tritium, sodium fluoride and lithium. U.S. EPA (1991) presents a discussion of the merits of the different types of tracer material available.

Lithium is currently the tracer of choice for conducting mixing studies in anaerobic digesters. The following sections are based on using Anhydrous Lithium Chloride as the tracer material.

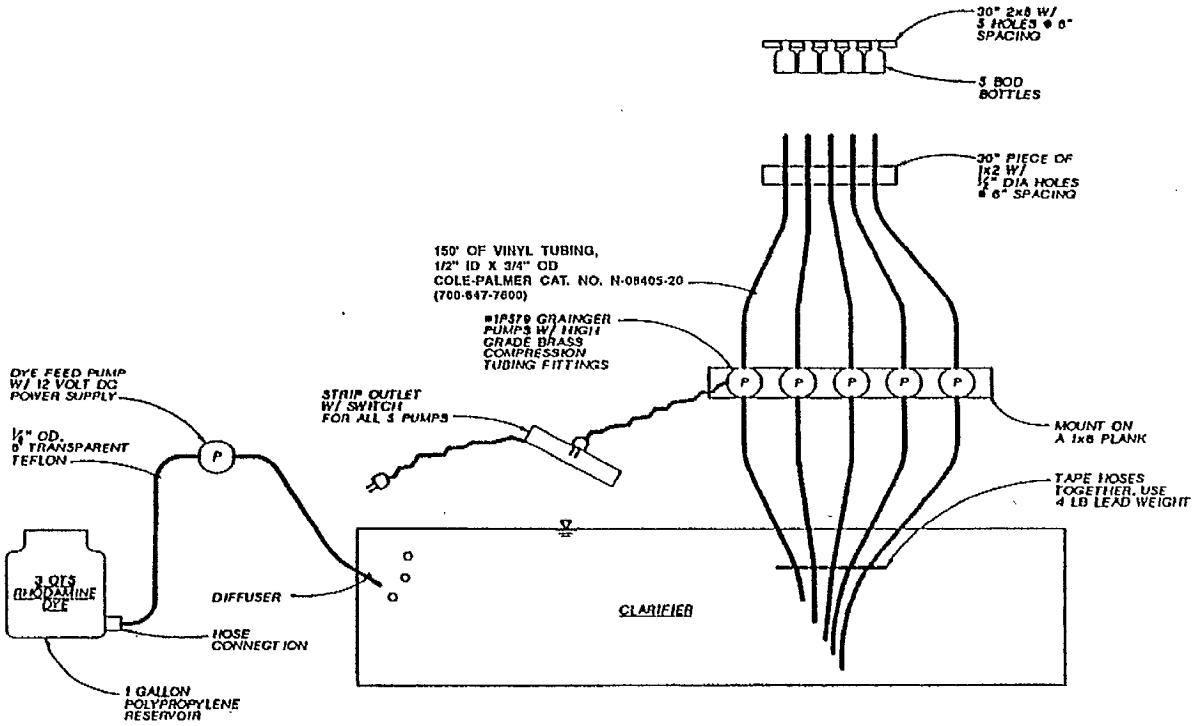


Figure 11-1
Crosby Clarifier Dye Test Sample Collection Equipment

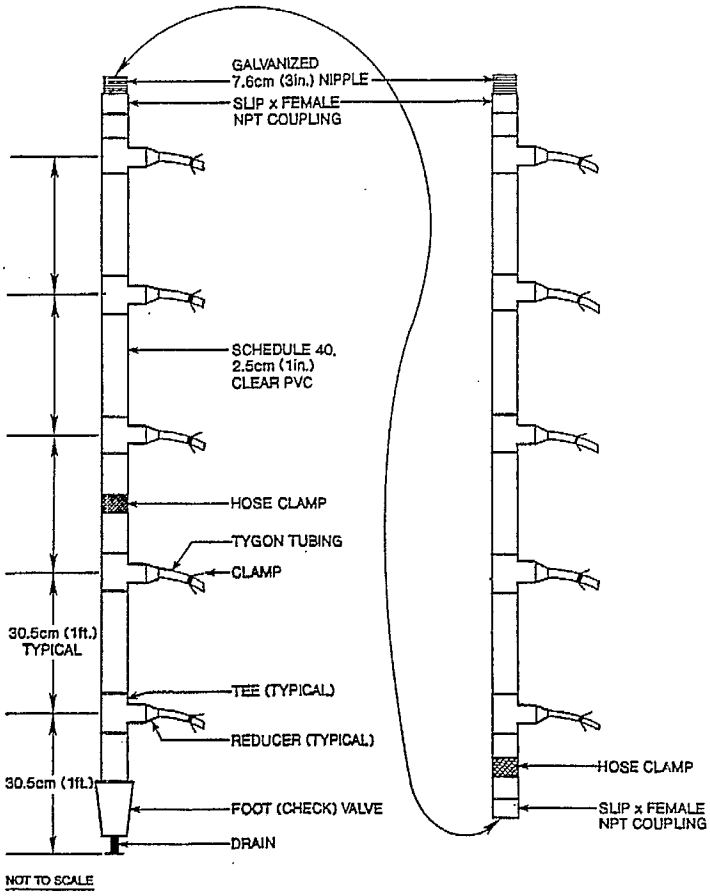


Figure 11-2
Alternative Crosby Clarifier Dye Test Sample Collection Equipment (core sampler)

The following equipment is needed to perform a digester tracer study using lithium chloride:

- Anhydrous lithium chloride (LiCl) – technical grade
- Mixing vessel to prepare LiCl solution
- Mixing paddle or an automatic mixer if a very large quantity of LiCl solution must be prepared
- Approximately 50 sample bottles per digester for lithium analysis, depending on the sampling period
- Curve-fitting program (commercial software) for non-linear parameter estimation

If digester solids and temperature profiles are to be obtained, the following additional equipment is needed:

- Sample pole with attached collection mechanism to sample the digester from sampling ports at varying depths
- Sample bottles for withdrawn sludge samples for total and volatile solids analysis
- Thermometer
- Rainsuit, rubber boots, and gloves (experience has proven that sample withdrawal is a very messy activity)

11.4 TRACER TEST TECHNIQUES/TEST STEPS

Tracer testing of unit processes involves the following steps:

1. Determine the appropriate tracer material and injection method; slug injection or constant rate

2. Calculate the quantity of tracer material required and identify injection location

3. Determine appropriate sample locations, frequency and duration

4. Identify process variables such as flow, RAS, and MLSS which will affect the test results and make arrangements to record the information during the test period

5. Conduct test

The following sections describe four dye test techniques in detail. The principles illustrated in the tests described can be adapted and applied to tracer testing of other unit processes.

11.4.1 The Crosby Dye Test

The Crosby technique is a qualitative test that uses dye to test the hydraulic flow pattern of clarifiers. Test results serve to indicate short circuiting, dead zones, and sludge blanket carry-over problems. This test is often used to measure the effectiveness of various baffling techniques. The Crosby technique is conducted in two stages, the dispersion test and the flow pattern test.

The first step in the Crosby technique is the "dispersion" test, which involves releasing a slug of Rhodamine WT dye into the clarifier influent and sampling at the effluent weirs over a period of time. The dispersion tests gives an indication of horizontal flow distribution, hydraulic short-circuiting and an estimate of when to run the flow pattern test. In the flow pattern test, dye is continuously fed into the influent of the clarifier and samples are then taken simultaneously from five different depths in the clarifier using the specialized sample collection rig as shown in Figures 11-1 and 11-2. These sets of five samples are taken at five or six different stations along the radius of a circular clarifier or along the length of a rectangular clarifier. The samples are taken quite rapidly (over approximately 4 minutes) in such a manner that a "snapshot" of the dye pattern is taken. In other words, the test reveals the dye concentration throughout the clarifier at an instant in time.

The dye concentration of the samples is determined with a fluorometer. The fluorometer readings are then presented graphically and examined to determine the flow characteristics of the clarifier. In addition, suspended solids tests can be run on the samples to determine the distribution of solids within the clarifier.

The general test steps are described below.

Dispersion Test

1. Identify the dye injection point for the test. The dye should be well mixed in the clarifier influent before it reaches the test tank.

2. Identify effluent sample points. These should be spaced to reveal variations in the horizontal flow. For circular clarifiers, four sample locations equidistant around the effluent launder is normally sufficient.

3. Label and place a sufficient number of sample bottles at each sample location. The samples are collected frequently (5 minute interval) for the first half of the test, then more slowly (10 or 20 minute interval) for the remainder. The dispersion test should run for one theoretical detention period.

4. Collect a blank sample of the clarifier effluent before the start of the test.

5. Mix the appropriate quantity of dye with clarifier influent (or water) in a 20 litre bucket. Approximately 50 to 100 mL of dye at 20 percent concentration per MGD flow is sufficient for most applications.

6. At time = 0, add the dye at the injection point and start sampling procedures.

7. After completion of the test, determine the dye concentration in each sample with a fluorometer fitted with the appropriate optical lamps and filters and calibrated according to the manufacturers instructions. Because relative, not absolute readings are required, the calibration procedures can be simplified by using the blank to set the zero reading and the "pinkest" sample to set the span.

The first run of the flow pattern test should correspond with the time of first significant dye arrival in the clarifier effluent observed during the dispersion test.

Flow Pattern Test

The flow pattern test is conducted at least 24 hours after the dispersion test to allow the dye to clear from the system.

1. Identify and mark the sample locations along the clarifier cross section.

2. Set up and test the sample collection rig.

3. Label and place an appropriate number of sample bottles at each sample location. Glass BOD bottles are ideal for this application because of their weight and ruggedness. Perform a "dry-run" of the sampling procedures to identify the most appropriate location for the sample bottles. All the samples should be collected within 3 to 4 minutes.

4. Set up and calibrate the dye injection pump. The dye is added at a rate of approximately 0.5 to 1 mL/min per MGD flow for the duration of the test. Dilute the dye as appropriate for the injection pump capacity and dye reservoir capacity.

5. Collect a blank sample of the clarifier effluent before the start of the test.

6. Start the pump at time = 0 and collect the first set of samples at the time identified by the dispersion test. Collect the second set of samples approximately 15 minutes later.

7. After completion of the test, determine the dye concentration in each sample with a fluorometer fitted with the appropriate optical lamps and filters and calibrated according to the manufacturers instructions. Because relative, not absolute readings are required, the calibration procedures can be simplified by using the blank to set the zero reading and the "pinkest" sample to set the span. One set of samples is reserved for suspended solids analysis to determine the solids profile through the tank cross section.

The Crosby technique is described in Crosby (1987b). Other key points are discussed below:

- Test stations are set up along the bridge of a circular clarifier or along the side of a rectangular unit. Duct tape is typically used on the railings to mark the test stations. At least five horizontal stations are used, with larger clarifiers (greater than approximately 35 m diameter) requiring six stations. The initial and final stations are normally located 1 foot from the "end" conditions (e.g., inlet well skirt and effluent weir) with the rest of the stations equally spaced between.
- Five vertical sampling points are used, numbered 1 to 5 from top to bottom. The bottom sample should be taken approximately 1 foot above the sludge blanket; use the sludge judge to locate this depth. The top sample should be approximately 1 foot below the surface. The other three samples are equally spaced between these two.
- With a rectangular unit, a "boom" is used to extend the sampling reach away from the side wall. With a circular clarifier, the tubes can normally be dropped directly over the edge of the bridge railing.
- Typically, two runs are made during one test (thus the need for approximately 60 BOD bottles). The first run is made at the time determined by the "dispersion" test. The second test is run shortly after. One of these two tests will give the best "snapshot" of the dye pattern. In addition, the tests will reveal the movement of the dye over time.
- Suspended solids tests are normally run on one set of samples for each clarifier (i.e., 25 to 30 samples). These data are graphed similar to the dye test, and illustrate the solids distribution within the clarifier. Because a large set of suspended solids samples must be run, it is important to inform plant staff about these samples in advance.
- Suspended solids tests can be run on one set of dye samples, or separate 1-litre bottles can be filled at the same time as the BOD bottles. The 1-litre bottles provide a larger sample for the suspended solids test; verify that the plant has these sample bottles available.

- Take care not to duplicate numbers on BOD bottles. To avoid confusion, transfer bottles from the clarifier to the lab in the order they are sampled.
- Prime and test the sample collection rig before starting dye injection. It is important to be sure that all pumps are running and pulling water. Shut down the dye feed immediately after collecting the last sample.
- Record the following information at the time of testing (or obtain after the test):
  - Sludge Volume Index (if testing a secondary clarifier)
  - Plant influent and RAS flow
  - Mixed liquor suspended solids concentration
  - Depth to sludge blanket
  - Clarifier dimensions
  - Summary information on process operating conditions and mode (e.g., plug flow vs. complete mix if dealing with an activated sludge system; average F/M)

Because relative, not absolute, readings are needed, the following technique is used to calibrate the fluorometer:

- Use the blank to set the zero.
- Visually choose the pinkest sample.
- Use the sensitivity settings and the span dial to set the pinkest sample at approximately a 90 percent reading.
- Choose the next two or three pinkest samples and verify that they read within the scale.

Read the samples. It is not necessary to shake samples if solids have settled. The solids don't significantly affect the dye concentrations, and it is easier to make readings without the solids. If suspended solids tests are also to be run on the BOD bottle samples, pour the cuvette contents back into the sample bottles after reading. If suspended solids are not to be run on the BOD bottle samples, rinse the cuvette with the sample prior to reading.

11.4.2 CT Tracer Test

A CT tracer test involves determination of CT, the product of the concentration of the disinfectant (C) and the time the disinfectant is in contact with the water (T_{10}). The C value is the required residual disinfectant concentration. T_{10} is the time it takes for 10 percent of the initial tracer concentration to pass through the process unit. The T_{10} value is determined by field tracer tests.

For the tracer test, a tracer is injected adjacent to the plant's disinfectant injection point. Either the tracer is injected at a constant rate throughout the test, or a slug of tracer is introduced at the start of the test.

U.S. EPA (1991) describes the CT Tracer test applied to potable water supply systems in detail. The following sections presents additional considerations:

- The test should be conducted at more than one plant flow rates: one near-average flow, two greater-than-average flows, and one less-than-average flow.
- Because Rhodamine WT dye is bleached by contact with free chlorine an alternative tracer chemical is required. Table 11.1 presents options for tracer materials and the method of analysis for each.
- As a rule of thumb, determine the precision of the analytical method at the sample concentrations to be encountered (including background concentration) and calculate the amount of tracer needed to increase the concentration by about 50 to 100 times the precision. This calculation should give adequate resolution to define the data curve needed for analysis.
- When conductivity probes are used for measurement of the tracer, a big surge in concentration must be created in order to define the curve.

Table 11.1
Tracer Materials and Method of Analysis

Tracer	Method of Analysis
Fluoride (typically hydrofluosilic acid, H_2SiF_6	Ion-specific electrode SPADNS Colorimetric when the fluoride concentration is less than or equal to 2.0 mg/L
Cations (calcium, magnesium, sodium, lithium, etc.)	Atomic absorption
Anions (chloride, sulfate, etc.)	Liquid chromatography Mercuric nitrate titration for chloride Potentiometric analysis using silver/silver chloride electrode for chloride
Rhodamine WT (not recommended for water and wastewater containing free chlorine)	Fluorescence

One method of reducing analytical costs is to analyze every second sample initially, and then any additional samples required to better define the initial breakthrough of tracer or the shape of the curve. Before doing this, however, make sure holding time requirements will be met. It is less expensive to take more samples (than are analyzed) than it is to rerun the test. Table 11.2 provides recommended sampling frequencies and durations when sample analysis is either onsite or delayed.

The general test steps are as follows:

1. Construct a tracer injection feed point adjacent to the section's disinfectant injection point.

2. Calibrate the injection metering pump and set it at the appropriate feed rate.

3. Measure the pH and temperature of the water in the section.

4. At time zero, start feeding the tracer chemical at a constant feed rate and maintain this feed rate for the duration of the test. Alternatively, add a single slug of the tracer material at time zero.

5. Collect samples and, if appropriate, analyze them throughout the duration of the study.

6. Record the following data during the test:
   - Initial effluent flow meter reading
   - Initial volume or mass of tracer in the feed tank
   - Time of collection, sampling site, and tracer concentration of each sample
   - Changes in flow rate or basin volume
   - Final effluent flow metering reading
   - Final volume or mass of tracer in the feed tank

11.4.3 Aeration Tank Mixing Test

The aeration tank mixing test is a dispersion type dye test used to evaluate the mixing regime within an aeration tank. The test results are used to determine if the aeration tank is performing as a continuous flow stirred reactor (CSTR) or a plug flow reactor. Whether a tank is a CSTR or plug flow reactor will determine the type of reactor kinetics that will apply for organic removal and nitrification.

Table 11.2
Recommended Sampling Frequencies and Durations

Timing of Sample Analysis	Frequency			Duration
	Theoretical Detention Time (T)	Initial Sampling Interval	Sampling Interval Following Detection of Tracer	
Onsite (Real-time)	T < 5 mins 5 ≤T < 15 mins 15 ≤T < 30 mins 30 ≤ T 60 mins 1 hr ≤ T < 2 hrs 2 hr ≤ T < 6 hrs T ≥ 6 hrs	30 sec 1 min 2 min 3 min 5 min 10 min 15 min	30 sec 1 min 2 min 3 min 5 min 5 min 5 min	Four consecutive identical sample results if T ≤ 2 hrs. Steady-state for 40 minutes if T > 2 hours (after four consecutive identical sample results frequency may be returned to initial interval)
Delayed	T < 5 mins 5 ≤ T < 15 mins 15 ≤ T < 30 mins 30 ≤ T < 60 mins T ≥ 60 mins	30 sec 1 min 2 min 3 min 5 min		Sample for a period of three times the theoretical detention time

The test results are also used to identify hydraulic short circuiting and to quantify the hydraulic efficiency of the unit process.

The test consists of injecting a slug of tracer material, usually Rhodamine WT dye, upstream of the unit tested and collecting discrete samples at the tank outlet over a period of time. The dye should be well mixed in the influent stream before entering the aeration tank. The quantity of dye added is determined by the influent flow rate including recycles, approximately 3 to 5 mL per L/s flow is usually sufficient.

The general test steps are similar to the test steps given in the dispersion test description for the Crosby Flow Pattern Test.

Samples are collected every 5 minutes for the first hydraulic residence time (HRT) period and then every 15 to 20 minutes for the remainder. Samples are collected for a period of approximately three times the theoretical HRT of the tank tested.

11.4.4 Digester Mixing Test

Digester tracer studies provide a quantitative evaluation of the mixing in an existing full scale digester.

Poorly-mixed digesters tend to suffer from accumulation of grit and solids in the digester, and formation of a scum layer on top of the sludge. These biologically inactive zones reduce the effective hydraulic detention time of the digester. Digesters prone to grit deposition must be taken out of service and cleaned periodically, resulting in significant disruption to plant operations.

Lithium chloride solution is prepared onsite by dissolving technical grade lithium chloride in water. An initial concentration of 3 to 5 mg/L Li in the digester is required for the test. Therefore 3 to 5 grams of Li per cubic metre of digester volume is added. The dissolving of LiCl in water is an exothermic process. Therefore, the mixing container will become warm. The lithium chloride solution is added to the digester as a slug input by adding the solution to the raw sludge feed line or pump. Alternatively, the lithium may be injected by addition to a sump pump well. If a sump pump well is used, the well must be drawn down completely and flushed to ensure that all lithium is injected into the digester as a slug input.

Prior to injecting the lithium chloride, the digester contents should be sampled to determine the background lithium concentration. Immediately following lithium injection, sampling of the digester overflow should commence. On the first day, samples should be taken frequently (i.e. at least once per hour) as experience has shown that any short-circuiting occurs immediately following lithium injection. Thereafter, less frequent sampling (i.e. once per day or once every second day) continues for a period equivalent to approximately three theoretical hydraulic retention times. All digester samples are submitted to a laboratory for lithium analysis.

The analytical method for lithium in sludge involves the acidification of the samples to release the lithium from the solids phase into the liquid phase followed by membrane filtration to remove the suspended solids. Alternatively, digestion with nitric acid can be used for sample pre-treatment. The lithium concentration is determined using flame atomic adsorption. Standard Methods (1992) discusses the analytical methodology for determination of lithium concentration.

If possible, digester sampling to develop solids and temperature profiles may be used to support the results of the digester tracer study. To determine the extent of solids accumulation in the digester, samples are withdrawn from digester sampling ports at several locations and depths. The solids (total and volatile) concentrations and temperature of each sample are used to develop the digester profiles.

11.5 PRESENTATION AND INTERPRETATION OF RESULTS

11.5.1 Crosby Flow Pattern Test

The results from the dispersion test are plotted as relative dye concentration versus time for each sample location. The elapsed time for the dye to reach the clarifier effluent weir is used to determine the timing of the flow pattern test. Differences in the dye concentration and elapsed time of travel between sample locations indicate horizontal imbalances in the flow through the tank.

The results from the flow pattern test present as iso-concentration lines through the clarifier cross section. Figure 11-3 presents a typical flow pattern test result. The location of each sample (X,Y co-ordinates from the bottom of the centre well) and relative dye concentration are used to generate the iso-concentration lines using commercial software for developing contour lines. The iso-concentration plots are superimposed on the clarifier cross-section to determine the influence of the tank geometry and appurtenances on the flow pattern. The flow pattern test results provide a visual representation of the effect of baffling arrangements in the tank.

Dead zones in the clarifier cross section are indicated by areas with zero dye concentration and density currents are indicated by narrow bands of high dye concentrations. A flow pattern profile with widely spaced iso-concentration lines throughout the cross section indicates the efficient use of the clarifier volume.

11.5.2 CT Tracer Test

The results from the CT Tracer Test are plotted as C/Co vs Time graph. The "normalized C/Co" is the tracer concentration (minus the background tracer concentration) divided by the initial tracer concentration (Co). T_{10} is determined from the C/Co versus Time graph by finding the time at which C/Co is equal to 0.10. Figure 11-4 presents a C/Co versus time graph.

The procedure is repeated at four plant flow conditions. The T_{10} values for the four flow conditions are plotted on a Detention Time vs. Flow graph and the T_{10} value that would occur at the plant's peak flow rate is extrapolated. Calculate the CT product by multiplying the disinfection concentration (mg/L) by the T_{10} value (minutes) determined for the peak flow condition.

If a slug dose method of dye injection is used, the data generated must be converted to the equivalent constant-dose data. This is done by summing the area under the concentration C/Co versus time graph.

The incremental area for each sample collected is calculated by multiplying the sample time interval by the tracer concentration at the end of the interval. The incremental areas for each sample point are added to obtain the cumulative area under the C/Co versus time curve in mg-min/L. The data is normalized by dividing the cumulative areas calculated for each sample point by the total cumulative sum for the test period. Figure 11-4 shows a slug dose data series converted into an equivalent constant dose data series.

11.5.3 Aeration Tank Mixing Test

The results from the aeration mixing test are plotted as relative dye concentration versus dimensionless time (time/theoretical HRT). Figure 11-5 shows a typical result from an aeration tank mixing test. The resulting curve is compared to theoretical curves based on mixing regime models. The hydraulic efficiency of the tank is determined as the ratio of the time for 50 percent of the dye to pass through the tank over the theoretical HRT.

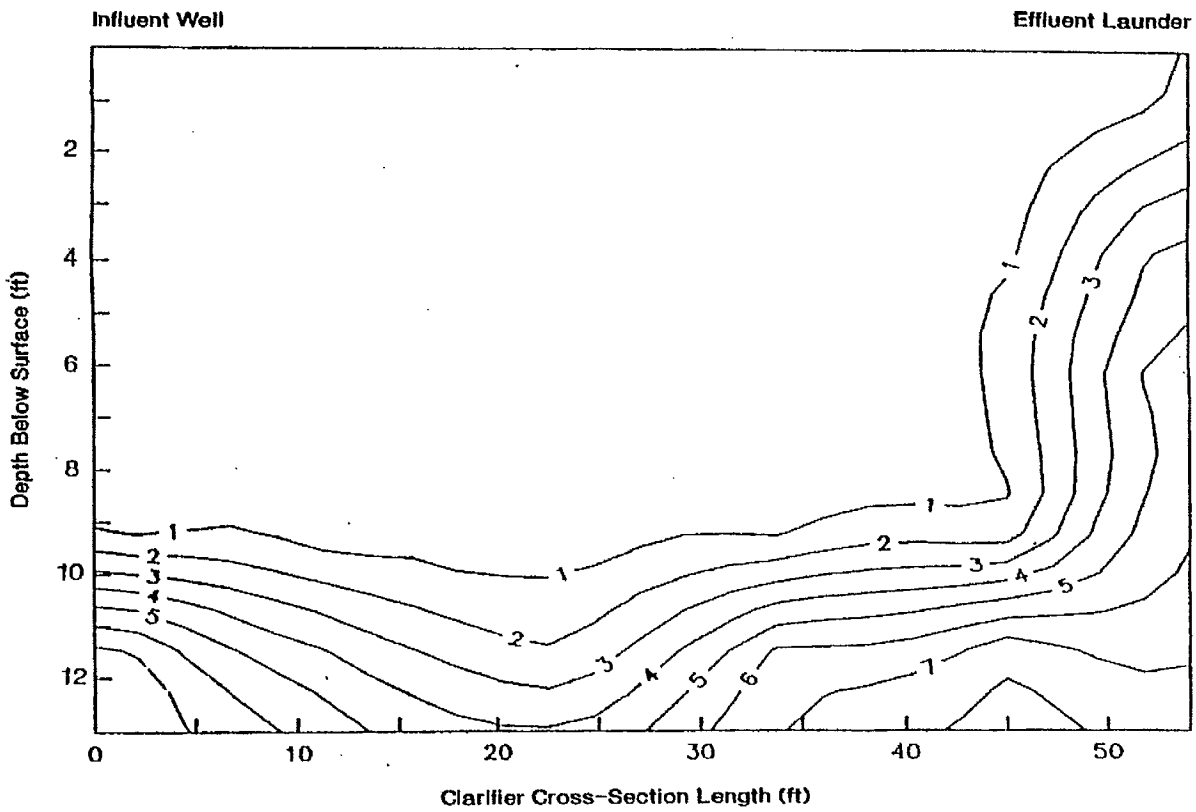


Figure 11-3
Crosby Flow Pattern Test Results for a Circular Secondary Clarifier

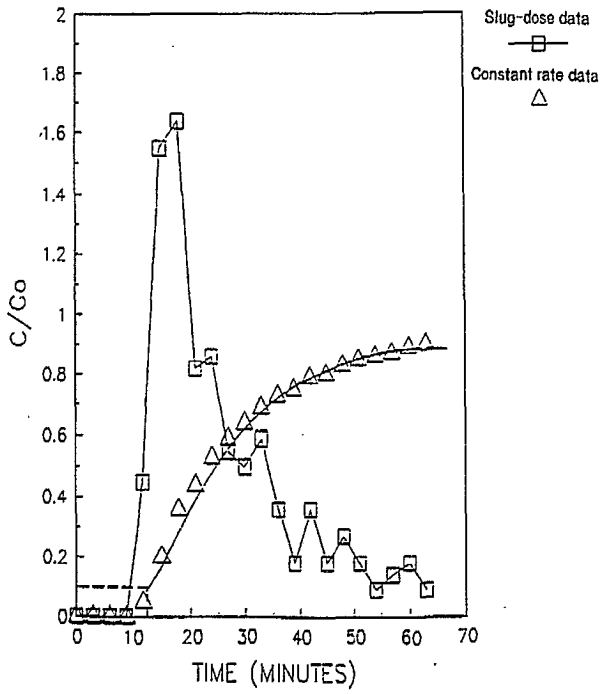


Figure 11-4
Typical C/Co Versus Time Graph for the Evaluation of Chlorine Contact Chambers

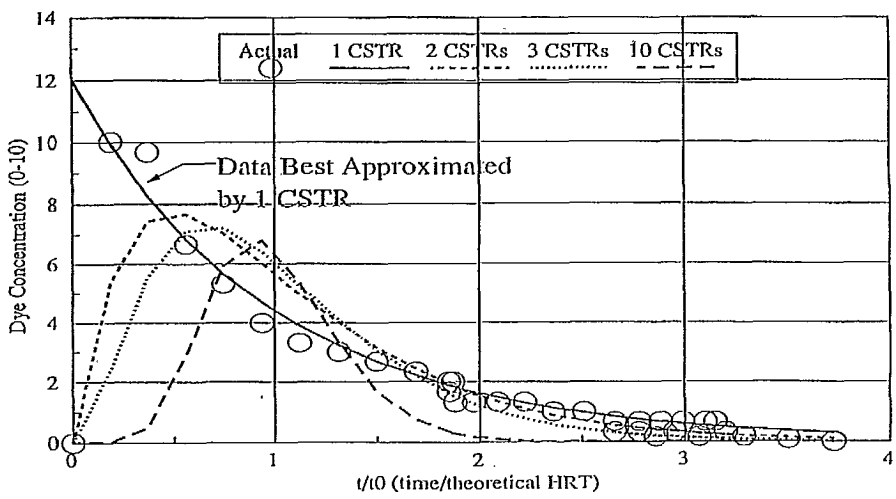


Figure 11-5
Aeration Tank Mixing Test for Evaluating the Characteristics Mixing Regime

11.5.4 Digester Mixing Test

The data collected is plotted as a washout curve of lithium concentration versus time as shown in Figure 11-6. The shape of the washout curve is compared to the predicted washout curve based on a conceptual model of the mixing regime in the digester. The traditional model used to estimate dead space volume and short-circuiting in digesters was developed by Cholette and Cloutier (1959). It is based on two idealized zones in the digester (a completely dead zone and an ideal mix zone) and that a proportion of the flow is short circuiting directly to the digester outlet. Several short comings in this model have been identified recently, and a number of alternative models have been presented in the literature. U.S. EPA (1991) presents a discussion of alternative models. Because of their complexity, some of the alternative models developed require a numerical approach for solution.

The adequacy of the model used is checked by plotting the observed and predicted values together. For the remainder of this section discussion will concentrate on using the Cholette-Cloutier model to estimate the dead zone and short circuiting in the digester. Solids and temperature profiles through the digester volume are used to confirm the tracer study results.

A washout curve is generated from the lithium concentrations of the digester samples. To determine the digester deadspace and short-circuiting, the model for a real continuous stir tank reactor (CSTR) is used:

$$\frac{C}{C_0} = \left(\frac{Q_1}{Q}\right)^2 \frac{V}{V_a} \exp\left(\frac{-Q_1}{Q}\frac{V}{V_a}\theta\right) + \frac{Q_2}{Q} + \delta(\theta = 0) \qquad (1)$$

where:

- C = lithium concentration at time t
- C_0 = theoretical tracer concentration at time t = 0
- Q_1 = flowrate through active volume
- Q_2 = short-circuiting flowrate
- Q = total digester flowrate
- V = total digester volume
- V_a = active digester volume
- V_d = digester deadspace volume
- δ = dirac delta function
- θ = dimensionless time = t/τ
- t = time
- τ = theoretical HRT = V/Q

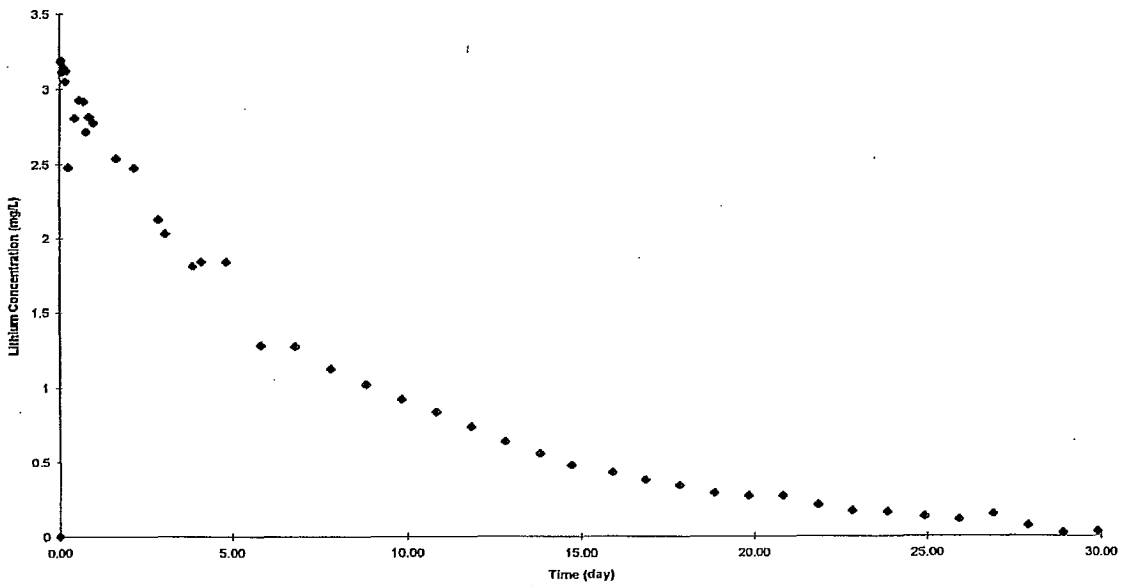


Figure 11-6
Typical Lithium Washout Curve – Lithium Concentration Versus Time

By substituting τ_a (the HRT of the active zone), Equation 1 reduces to the following:

$$\frac{C}{C_0} = \frac{Q_1 V}{Q^2 \tau_a} \exp(-t/\tau_a) + \frac{Q_2}{Q} \delta(t = 0) \qquad (2)$$

From the regression of Ln (C/C_o) against time (t), the slope of the decay portion of the curve provides an estimate of the model parameter τ_a. Using the model parameter τ_a, the intercept provides an estimate of the model parameters Q_1. Since:

$$Q_1 + Q_2 = Q \qquad (3)$$

$$\tau_a = \frac{V_a}{Q_1} \qquad (4)$$

and

$$V_a + V_d = V \qquad (5)$$

The flow short-circuiting (Q_2) and digester deadspace volume (V_d) may be estimated.

For a digester without short-circuiting (i.e. $Q = Q_1$, $Q_2 = 0$), Equation 1 simplifies to the following:

$$\frac{C}{C_0} = \frac{V}{V_a} \exp\left(\frac{-V\theta}{V_a}\right) \qquad (6)$$

or

$$\frac{C}{C_0} = \frac{V}{V_a} \exp\left(\frac{-Qt}{V_a}\right) \qquad (7)$$

For comparison between different tests, and for ease of calculation, the lithium concentration versus time data are presented on a dimensionless semi-logarithmic plot of (C/C_0) versus θ. Lithium concentrations are normalized (after subtracting any background concentration) to the theoretical initial concentration which would result if the lithium added were uniformly dispersed throughout the entire liquid volume of the digester. Sample times are normalized to the nominal hydraulic retention time calculated from the volumetric feed rate and the liquid volume of the digester, as shown in Figure 11-7.

An ideal CSTR response, with C/C_0 plotted on a logarithmic scale, results in $C/C_0 = 1$ at $t = 0$, and a slope equal to -1/(V/Q) or -1/HRT. A reactor in which there is some deadspace will exhibit a response curve with $C/C_0 > 1$ at $t = 0$, because the tracer is initially dispersed in a smaller volume. The tracer will be washed out at a faster rate, resulting in a steeper negative slope than that of an ideal reactor.

Table 11.3 presents additional items which should be recorded during a digester tracer study.

11.6 SELECTED CASE STUDIES

11.6.1 Process Studies at the Corbett Creek WPCP

To enhance the performance of the clarifiers in the activated sludge plant at the Corbett Creek WPCP, the maintenance personnel installed an inlet baffle in secondary clarifier no. 3 (west), and a temporary air curtain in secondary clarifier no. 4 (east). As part of the optimization studies, dye testing techniques were used to evaluate the relative performance of these devices. The objective of the dye test was to determine the hydraulic flow pattern through a secondary clarifier under stress (peak) loading rates.

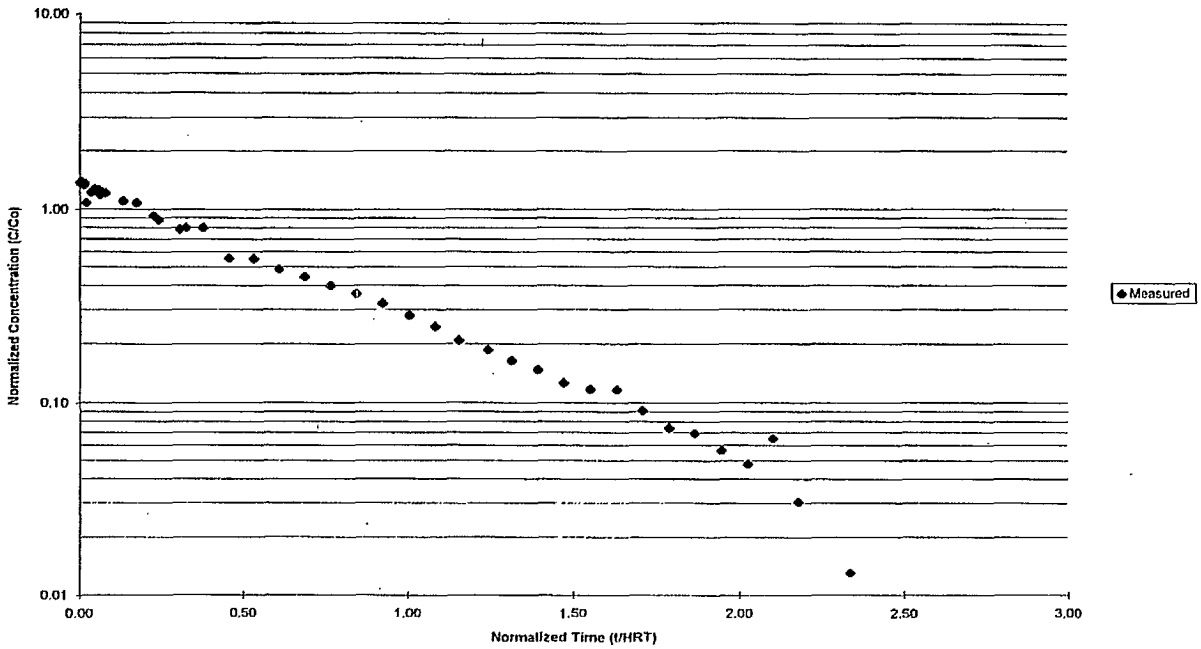


Figure 11-7
Normalized Lithium Washout Curve

To evaluate the relative performance of the inlet baffle and air curtain, three flow pattern tests were conducted at Corbett Creek WPCP. Table 11.4 summarizes the operating conditions for each test. Flow was maintained near the same rate for each test.

Dispersion Test Results

For the dispersion test, a slug of 300 mL of Rhodamine WT was introduced into the clarifier no. 4 influent channel. Four sampling stations were monitored on the effluent launder. The results of the test are presented in Figure 11-8 as fluorometric readings over time at each of the sampling locations.

The dye first appeared at station 4 approximately 15 min after it was introduced into the influent stream. It appeared at station 1 approximately ten minutes later. This time differential indicates the side wall has a significant effect on the horizontal flow pattern in the clarifier. To obtain a representative cross section of the clarifier, the sampling locations used in the flow pattern test were greater than 2.5 metres from the side wall.

Table 11.3
Items to be Reported When Conducting Digester Tracer Studies [1]

Category	Items
Tank configuration	• tank size and shape • location of inlet & outlets • type of cover
Mixing equipment	• type of mixers • number and location of mixers • total mixing HP provided
Mode of operation	• digester feed volumes • date digester previously cleaned • method of feeding - intermittent: frequency - continuous • method of mixing - intermittent: frequency - continuous
Tracer study methods	• type & mass of tracer injected • point of injection • sampling - location - frequency • percent tracer recovery
Tracer performance data	• influent & effluent TSS & VSS • pH & alkalinity of contents • volume and CO_2 content of gas

[1] U.S. EPA (1991)

Table 11.4
Operating Conditions for the Secondary Clarifiers
August 28, 30, and 31, 1989

Test	Flow				
	Raw (m^3/d)	RAS (m^3/d)	Total (m^3/d)	SOR ($m^3/m^2.d$)	SLR ($kg/m^2.d$)
1. Dispersion Test Clarifier 4	6,920	4,480	11,760	12.92	54.9
2. Flow Pattern Test – Control Clarifier	6,570	4,970	11,540	12.27	25.0
3. Flow Pattern Test – Baffle Clarifier 3	6,740	5,040	11,780	12.59	40.4
4. Flow Pattern Test – Curtain Clarifier 4	6,600	4,711	11,310	12.33	30.2
5. MOE Guidelines				< 35.4	< 240

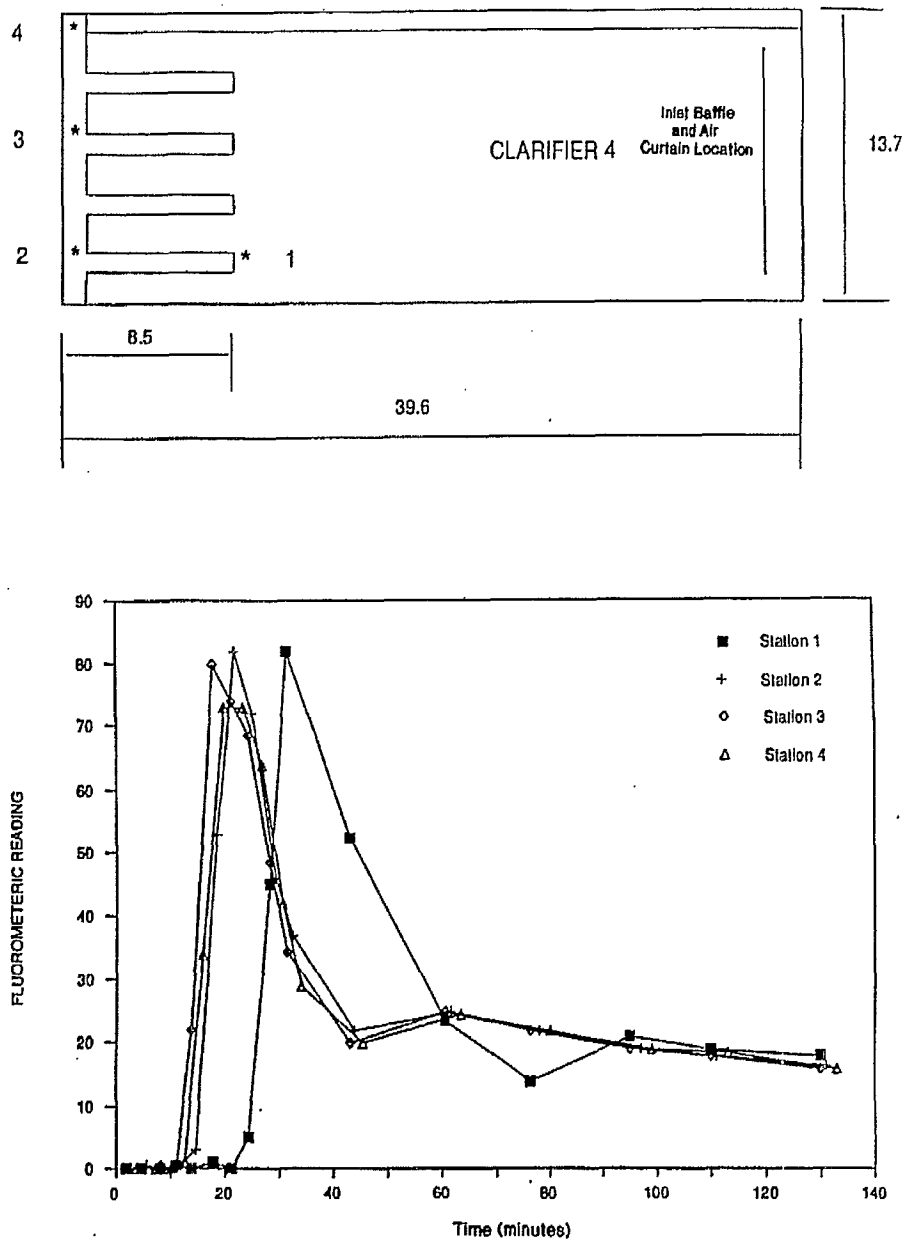


Figure 11-8
Dispersion Test Results for the Corbett Creek WWTP Secondary Clarifier

Flow Pattern Test Results

To evaluate the relative performance of the inlet baffle and the air curtain, three flow pattern tests were conducted. The results from the first test, performed on secondary clarifier no. 4 with the air curtain disconnected, were used as the datum for evaluating the performance of the two

modifications. During each flow pattern test, samples were collected from five depths at six locations along the length of the clarifier approximately 3.6 m away from the side wall, for a total of 30 samples per profile. Two profiles were obtained; one at 15 min, corresponding to the first appearance of Rhodamine WT dye in the dispersion test, and the second at 30 min. The fluorometer readings for each profile were normalized with the highest reading for each set equated to 8. The results are plotted as contour of relative dye concentration along the length of the clarifier and is shown in Figure 11-9.

The results from the dye test show that hydraulic short-circuiting is occurring in the clarifier without baffling. The flow moves downward from the inlet and travels along the bottom of the clarifier directly to the effluent weir. There is little dispersion of dye in the upper half of the clarifier, indicating that the volume is not being used effectively.

The degree of dye dispersion has significantly improved with the installation of the inlet baffle. The inlet baffle, provides a physical barrier to the downward movement of flow at the inlet, forcing the influent to the surface of the clarifier. There is a more even distribution of flow through the clarifier, with the dye front moving horizontally across the clarifier. The average hydraulic retention time for the clarifier has increased so that after 15 min, the dye front has not reached the effluent weir. The effective volume of the clarifier has been increased to include the total volume of the tank.

The air curtain, which consists of a bubbler located below the inlet of the clarifier, provides an upward movement to the influent as it enters the clarifier. Even though the results from the air curtain flow pattern test show improvement over the control flow pattern test, the change in flow pattern is not as dramatic as that seen in the inlet baffle configuration. The flow through the clarifier has improved, but there is still a significant concentration of dye along the bottom of the tank. The effective volume of the clarifier is less than the total volume available in the tank.

11.6.2 Stress Testing of the Walnut Creek and South Austin Regional WWTPs

Walnut Creek WWTP

Dye dispersion tests were conducted on the aeration tanks, final clarifiers and chlorine contact basins. These tests were used to estimate the actual retention in each basin as compared to the theoretical HRT, based on the reactor's volume. The aeration tank HRT is based on the influent flow plus the RAS flow rate of 10.5 mgd. The clarifier hydraulic efficiency is defined as the ratio of the measured to the theoretical HRT. The results are summarized in Table 11.5. Overall, the hydraulic efficiencies are greater than 70 percent for all three processes.

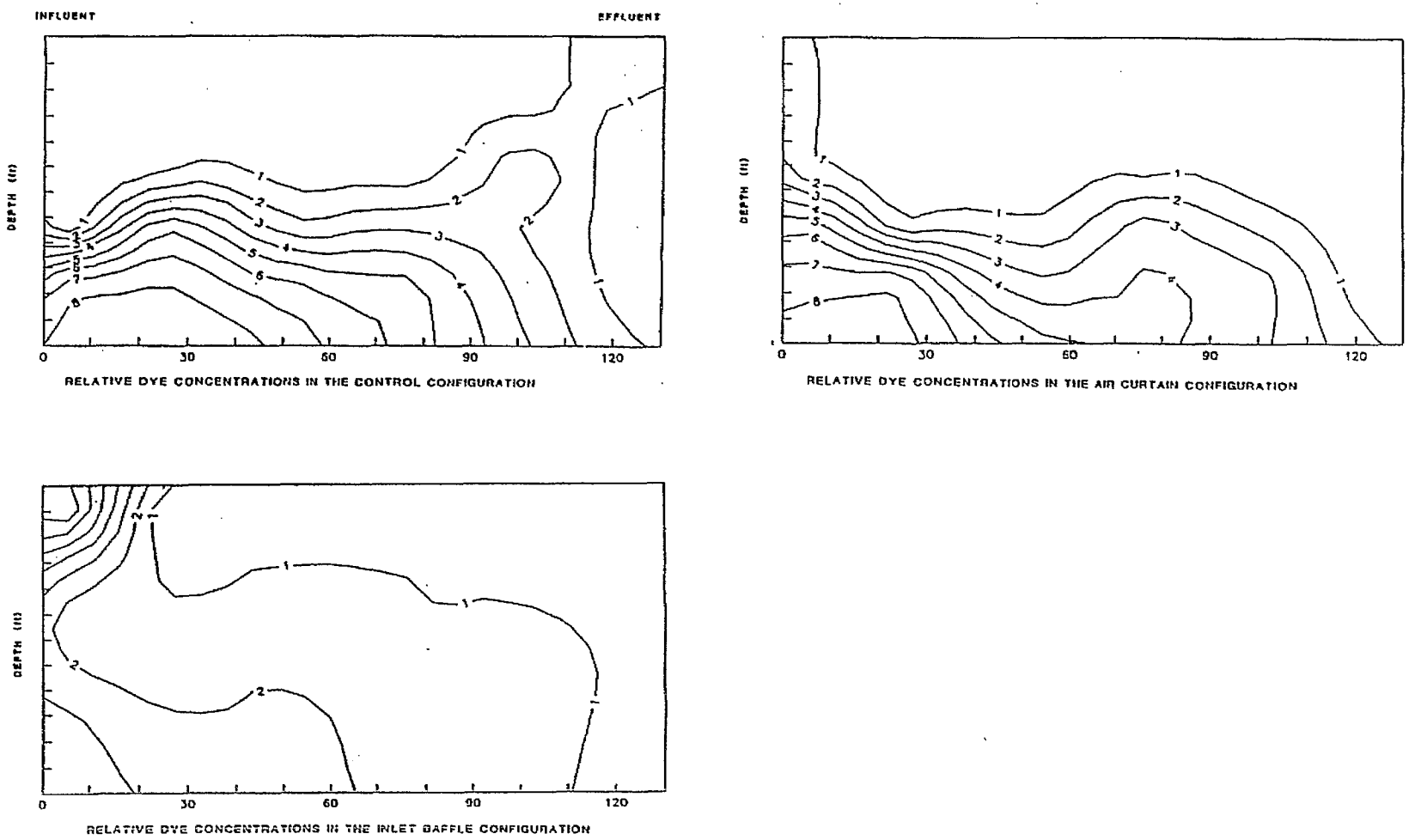


Figure 11-9
Flow Pattern Test Results for the Corbett Creek WWTP Secondary Filter

Table 11.5
Comparison of Theoretical and Actual Reactor HRTs at Walnut Creek

Process	Flow (mgd)	Volume (ft^3)	Theoretical HRT (h)	Actual HRT (h)	Reactor Efficiency (%)
Aeration	37	2,499,000	9.4	8.2	86
Final Clarifiers	20	294,000	2.6	1.9	73
Chlorine Contact Basin	37	162,920	0.8	0.7	78

Notes: 1) During testing, 4 aeration tanks, 2 final clarifiers and 4 chlorine contact basins were in service.

Dispersion test results for the aeration tank were also used to evaluate the hydraulics of the tank, as to whether the tank is performing as a continuous-flow, stirred-tank reactor (CSTR) or a plug-flow (PF) reactor. Given that the length to width ratio is 2 to 1, it was expected that this tank would react as one CSTR. Figure 11-10 is a plot of the test elapse time divided by the theoretical HRT versus dye concentration. The results show that the mass balance equation for a single CSTR closely models the data.

The multi-point dispersion test on the final clarifier was also conducted to evaluate short-circuiting and determine sample timing for the flow pattern test. Figure 11-11 shows the sampling locations and the test results. The dye appeared at the outer weir (Loc #2) 25 to 30 minutes before it appeared at the inner weir (Loc #1). The sample locations in the corner and combined effluent (Loc #3 and #4) also indicate a presence of the dye before the inner weir location (Loc #1). This tends to indicate some short-circuiting through the outer weir. Wall baffling and varying the spacing of the "V"–notchweirs between the inner and outer weirs could improve this situation.

At the location by the clarifier access bridge (Loc #1), the dye was observed in significant quantities after 45 to 50 minutes, peaking at 75 minutes after the slug is added. Therefore, the flow pattern test was conducted after dye was pumped to the clarifier for 45 minutes.

South Austin Regional WWTP

Dye dispersion tests were conducted on the aeration tanks, final clarifiers and chlorine contact basins at the South Austin Regional WWTP. These tests were used to estimate the actual retention in each basin as compared to the theoretical HRT, based on the reactor's volume and flow. The results are summarized in Table 11.6. Overall, the hydraulic efficiencies are low for these reactors, especially the aeration tanks and chlorine contact tank. The retention time in the chlorine contact tank may be a performance limiting factor at target design loadings, since less than the design retention time of 25 minutes will be provided.

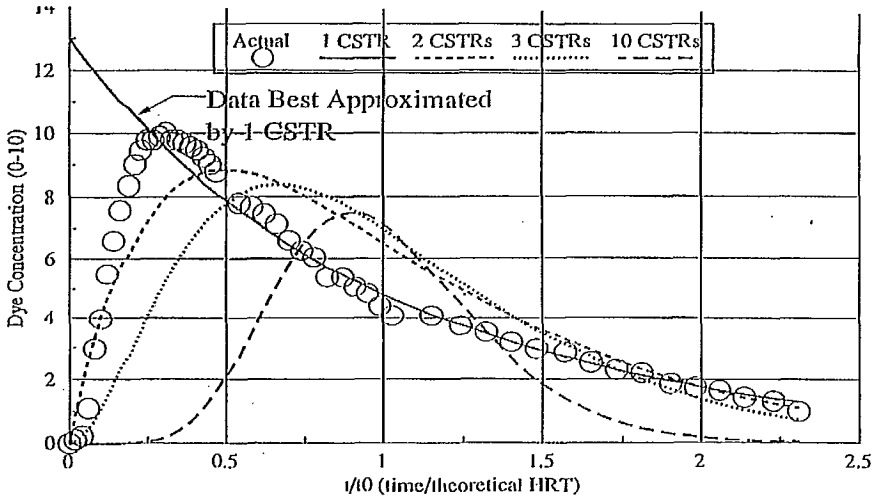


Figure 11-10
Mixing Test Results for the Walnut Creek WWTP Aeration Tanks

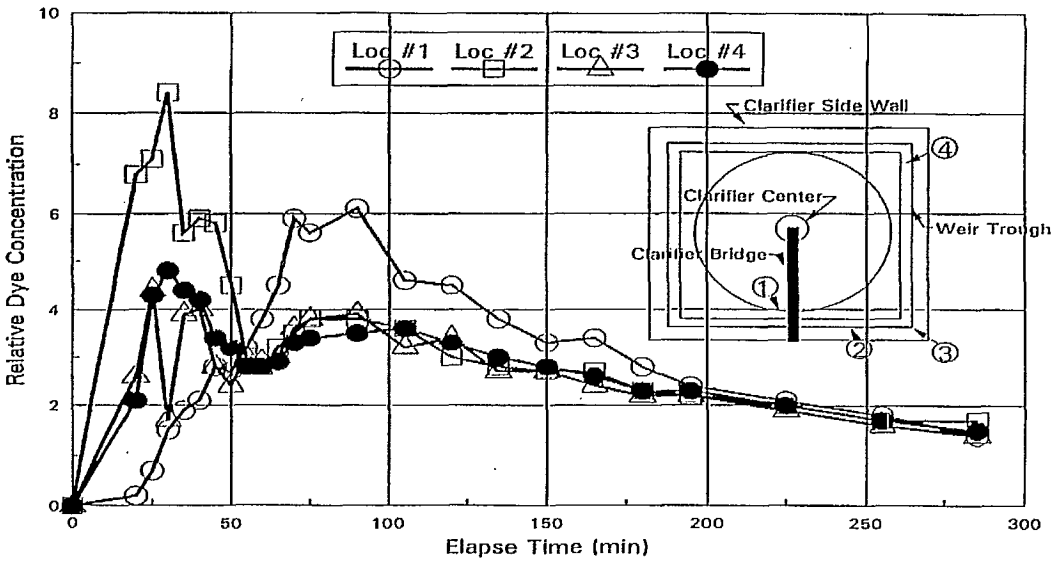


Figure 11-11
Dispersion Test Results for the Walnut Creek WWTP Secondary Tanks

Table 11.6
Comparison of Theoretical and Actual Reactor HRTs at South Austin Regional

Process	Flow (mgd)	Volume (ft^3)	Theoretical HRT (h)	Actual HRT (h)	Reactor Efficiency (%)
Aeration	25	371,720	2.22	1.5	67
Final Clarifiers	25	307,876	2.2	1.3	59
Chlorine Contact Basin	25	57,432	0.41	0.25	61

Notes: 1) During testing, 4 aeration tanks, 2 final clarifiers and 1 chlorine contact basin were in service.

Similar to Walnut Creek, the dispersion test results for the aeration tank were also used to evaluate the hydraulics of the tank. Given that the length to width ratio is 4 to 1, it was expected that this tank would react as one CSTR. The results show, that similar to Walnut Creek's aeration tanks, the mass balance equation for a single CSTR closely models the data.

The multi-point dispersion test on the final clarifier was also conducted to evaluate short-circuiting and determine sample timing for the flow pattern test. The dye was evident at the two outer weirs and the combined sample (Locs #2, #3 and #5) 5 minutes before it was evident at the inner weir (Loc #1). Dye was also evident at significantly higher concentrations at these locations as compared to Loc #1. Visual observations during the test indicated that the dye was evident in the trough between the two outer weirs (Locs #2 and #3) before it was evident in the inner weir area (Loc #1). Wall baffling and varying the spacing of the "V"–notch weirs between the inner and outer weirs could improve this situation.

At the location by the clarifier access bridge (i.e. Loc #1), significant dye concentration is observed after 15 to 20 minutes, peaking at 25 minutes after the slug is added. Therefore, the flow pattern test was conducted after dye was pumped to the clarifier for 20 minutes.

Dye Flow Pattern Testing

Flow pattern tests were conducted on the final clarifiers at both plants, with timing for the sampling based on the results of the multi-point dispersion test discussed above. The conditions during each flow pattern test are summarized in Table 11.7. Contour plots of the dye and SS concentration were used to evaluate each clarifier's performance.

Figures 11-12 and 11-13 show contour plots of the dye concentration through the final clarifiers at Walnut Creek and South Austin Regional WWTP. Figure 11-12 shows the dye is well dispersed throughout the clarifier at the Walnut Creek WWTP. Dye concentrations are lower within 10 feet of

Table 11.7
Plant Conditions During Flow Pattern Test

Plant	Flow (mgd)		Concentration (mg/L)			SVI (mL/g)	Blanket Height (ft)
	Clarifier	RAS	MLSS	RAS	DO		
Walnut Creek	18.0	5.0	1280	4480	5-6	82	0.5
South Austin Regional	12.5	2.5	2690	12,980	5-6	78	1.2

Notes: 1) Clarifier test flow assumes an even flow split to two clarifiers in service during test.

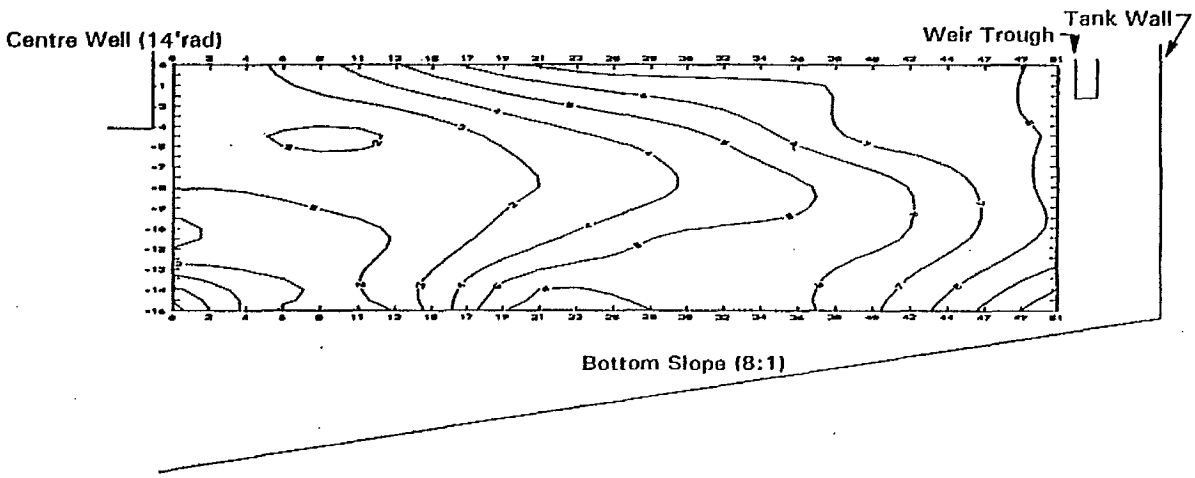


Figure 11-12
Dye Profile for Final Clarifier at Walnut Creek WWTP

the influent well, but beyond this point are well distributed throughout the clarifier. High dye concentrations at the bottom of the tank, one foot from the inner weir edge may be indicating a density current towards the outer weir. This observation is reinforced by the dispersion test results which indicated the dye first appeared at the outer weir.

Overall, these final clarifiers are operating well; although a wall baffle at the clarifier side wall might dissipate any density current being formed along the bottom of the tank and reduce short-circuiting and solids carryover at high flow conditions.

Figure 11-13 shows the dye is poorly dispersed throughout the clarifier at the South Austin Regional WWTP. Dye concentrations are almost non-detectable a third of the way through the clarifier, high concentrations are evident along the bottom of the tank and up the side wall. High dye

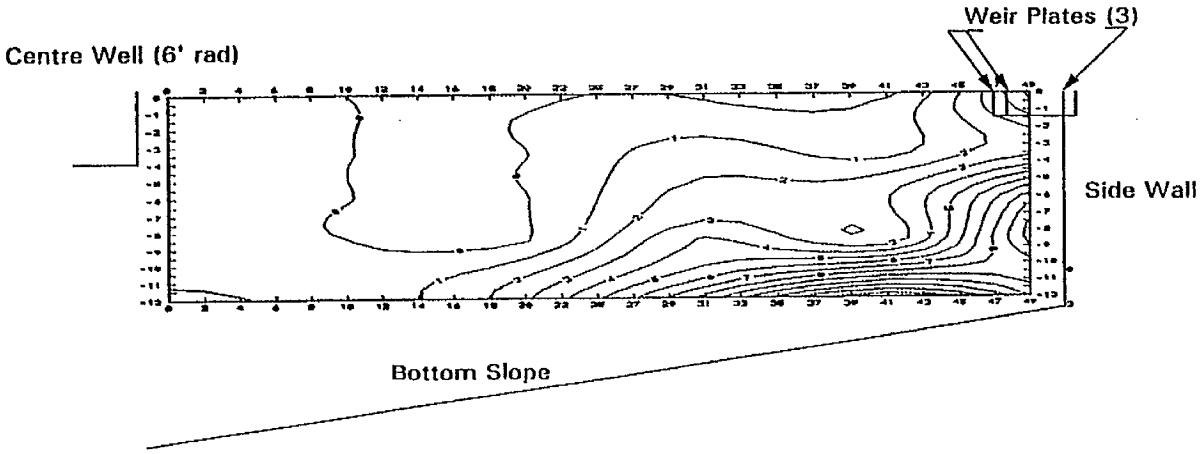


Figure 11-13
Dye Profile for Final Clarifier at South Austin WWTP

concentrations at the bottom of the tank indicate a strong density current towards the outer weir. This observation is reinforced by the dispersion results which indicated the dye first appeared at the outer weirs.

These final clarifiers are shallow (i.e. 10 foot SWD) and are performing similar to other shallow circular clarifiers with small feed wells tested. Recommendations for these clarifiers include a mid-radius ring-baffle and a wall baffle at the clarifier side wall to dissipate the density current formed along the bottom of the tank. This retrofit will reduce short-circuiting and solids carryover at high flow conditions.

11.6.3 Digester Mixing Study of the Collingwood WPCP

Adequate mixing directly affects the degree of raw sludge solids stabilization. At the Collingwood WPCP, a primary digester mixing study was conducted using a tracer response technique. The results were used to identify substrate short-circuiting through the digester and to estimate to active volume available for solids stabilization.

A pulse of anhydrous lithium chloride (LiCl) was introduced to the digester on June 27, 1991. The lithium chloride solution was prepared onsite and was transferred to primary digester #3 (old). A total of 4,090 grams of lithium chloride as lithium (Li) was pumped to the digester.

Samples for lithium analysis were withdrawn at the primary digester overflow. Sampling commenced on the day of lithium injection and continued thereafter for a period of approximately 65 days. Three samples obtained on the day of lithium injection were submitted for analysis. Two samples from the

second day were submitted for analysis. For the following week, samples obtained once per day were analyzed. Thereafter, samples obtained once every second day were submitted up to 40th day following lithium injection. For the remainder of the study period, two samples per week were analyzed for lithium concentration. Prior to the commencement of the lithium chloride tracer study, a blank sample of the primary digester sludge was obtained to determine background lithium levels.

A lithium mass balance was used to determine the lithium recovery of the digester tracer study. The total quantity of lithium recovered, calculated as the area under the washout curve times the sludge flow, was 3,063 grams. This represents a lithium recovery of approximately 75 percent based on the total quantity of lithium chloride injected as lithium (4090 grams).

When short-circuiting occurs, the effluent raw sludge passes almost directly through the digester without sufficient time for adequate sludge digestion and stabilization. During a digester tracer response study, an initial tracer concentration that peaks above the theoretically expected initial concentration is an indication of short-circuiting. Evidence of digester short-circuiting will also impact the lithium recovery. The initial peak concentrations may occur before the first sample is collected.

On the day of lithium injection, three samples were analyzed for lithium concentration. The lithium concentration of these samples is shown in Table 11.8. The expected initial concentration was 3.3 mg/L. The samples obtained on the day of lithium injection did not exceed the expected initial concentration. However, on the second day of the study, the reported lithium concentrations were 3.89 and 3.99 mg/L.

To estimate the fraction of deadspace in the digesters, the lithium results were fitted to a standard wash-out curve by a non-linear regression technique. For a completely mixed tank with no short-circuiting, the theoretical wash-out curve is expressed as follows:

$$C_t = C_o e^{(-kt)}$$

where:

C_t = lithium concentration at time t (mg/L)
C_o = initial lithium concentrations (mg/L)
t = time (days)
k = time contact ($days^{-1}$ = 1/HRT)

The time constant is the inverse of the digester hydraulic retention time (HRT). Figure 11-14 shows the washout curve obtained during the tracer study of primary digester #3. The non-linear regression fitted to the data is also shown on Figure 11-14.

Sludge pumping to the two primary digesters is directed manually on an intermittent basis. During the tracer study, the average sludge pumped to primary digester #1 and primary digester #3 was 28.3 m^3/day and 33.4 m^3/day respectively. The theoretical HRT of primary digester #3 based on the *total* digester volume was 37 days. Based on the non-linear regression of the lithium concentrations, the *effective* HRT was 22 days, or 60 percent of the theoretical HRT. This indicates that some of the digester volume is not actively mixed and available for sludge digestion. This portion of the digester volume is referred to as deadspace. Based on the effective HRT, the deadspace in primary digester #3 was 490 m^3 or 40 percent of the total digester volume.

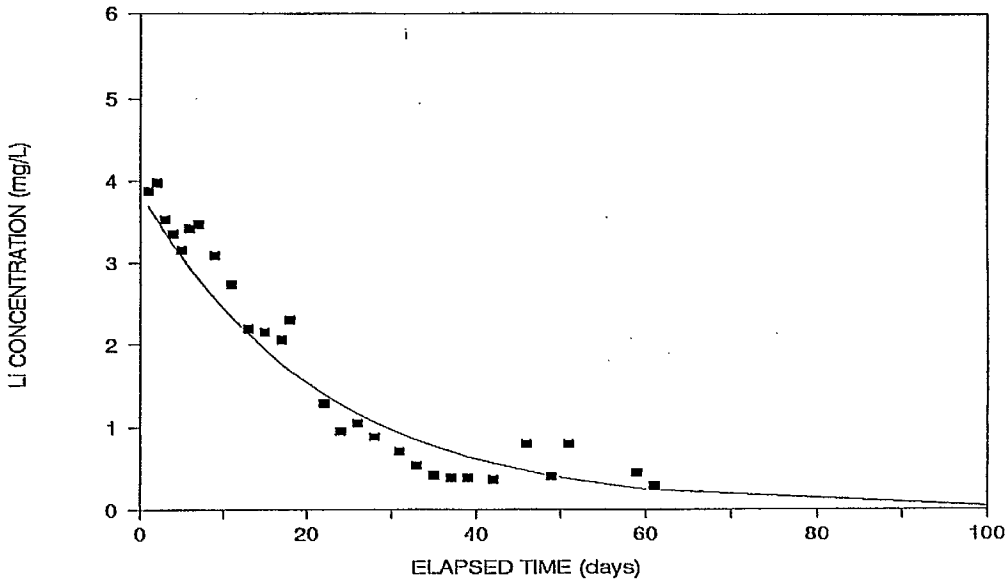


Figure 11-14
Lithium Washout Curve from Collingwood Digester Tracer Study

Table 11.8
Lithium Concentration in Digester Overflow Following Lithium Injection

Day	Time	Lithium Concentration (mg/L)
1	12:45	0.12
1	15:00	0.13
1	17:00	2.96
2	10:00	3.89
2	16:00	3.99
3	-	3.54

11.7 EXPECTED DURATION AND COSTS

The cost of conducting a tracer test depends on site conditions and the scope of work. Several factors that significantly affect cost include:

- The number of flow rates and sample points included in the tracer test
- The amount of help received from plant staff (e.g., setup of equipment, plant operation, samples analyses, sample collection)
- The degree of details needed in the summary report
- Equipment and chemicals available at the plant

Because of the variability in the site conditions and scope of work, the costs of tracer tests may vary considerably.

Table 11.9 presents an estimate of the duration and costs for performing a dye test per tank tested.

11.8 REFERENCES

Chapman, D.T., "Mixing in Anaerobic Digesters: State of the Art". *Encyclopedia of Environmental Control Technology, Vol. 3: Wastewater Treatment Technology*. Gulf Publishing Company. Houston, Texas. 1989.

Cholette, A. and Cloutier, L. "Mixing Efficiency Determinations for Continuous Flow Systems". *Canadian Journal of Civil Engineering*. Vol. 35. Pp. 105-112. 1959.

Table 11.9
Expected Duration and Cost for Conducting Tracer Test, Dispersion Test, Flow Pattern Tests and Digester Mixing Tests

Task	Labour Requirements (person days)	
Project Planning	1 – 3 days	
Dispersion Test	1 – 2 days (2 people for 1/2 to 1 day)	
Flow Pattern Test	2 – 4 days (2 people for 1 to 2 days)	
Digester Mixing Test	5 – 10 days (over a 30 – 45 day period)	
Interpretation of Results	1 – 3 days	
Report	1 – 2 days	
Expenses		
Tracer Material	Rhodamine Dye	$60/kg
	Lithium Chloride	$50/kg
Equipment Rental	Fluorometer	$100/day
Sample Collection Equipment	Crosby Dye Rig	$2,000
Analytical	Lithium Analysis	$15/sample

Crosby, Robert M. Dye Dilution Flow Measurement Procedure. Crosby and Associates Inc. Plano, Texas. July 1987a.

Crosby, Robert M. The Flow Pattern Test for Clarifier Hydraulic Analysis. Crosby and Associates Inc. Plano Texas. July 1987b.

Monteith, H.D. and Stephenson, J.P. "Mixing efficiencies in full scale anaerobic digesters by tracer methods" *Journal of the Water Pollution Control Federation.* S3.1 Pp. 78-84. 1981.

Smart, J. An Assessment of the Mixing Performance of Several Anaerobic Digesters using Tracer Response Techniques. Research Report No. 72. Ontario Ministry of the Environment. 1978.

Standard Methods for the Examination of Water and Wastewater. 18th Edition. Prepared and published by American Public Health Association, American Water Works Association, and Water Environment Federation. 1992.

U.S. Environmental Protection Agency (U.S. EPA). Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Supply Systems using Surface Water Sources. PB93-222933/XAD. EPA/68-01-6989. Prepared by Pirnie (Malcolm), Inc. and HDR Engineering, Inc. March 1991 Edition.

CHAPTER 12
DYNAMIC PROCESS AND PLANT MODELLING AND SIMULATION

12.1 OBJECTIVES OF THIS CHAPTER

This chapter examines the use of modelling and simulation as a tool in wastewater treatment process liquid train audits. The objectives of this chapter are to provide an introduction to the area, discuss commercially available tools that can be used for this purpose, outline the model development process and provide details on the additional tasks and data required if you decide to use these procedures as part of a liquid train process audit. An actual case study is presented which highlights the many ways in which a plant model can be used as a valuable adjunct to the physical experimentation and analysis tasks completed as part of a plant audit.

The role of the simulator model runs parallel to the other technical and onsite processes of data collection, measurement, analysis and interpretation. In many cases of process audit, a comprehensive, robust, calibrated dynamic model can provide a framework against which many of the other process evaluations can be set in order to bring together in a consistent manner, the results of field measurements and ancillary calculations. Typical areas of process audit which can be linked to a model and thus to each other are as follows;

- Checking data consistency
- Estimating plant and individual unit process capacity
- Identification of bottlenecks
- Estimation of benefits of physical plant modifications
- Comparison of operational strategies
- Analysis of alternative automatic control strategies
- Optimization of unit processes
- Evaluation of potential for cost reductions

With a plant or process model, you have a representation of the real system. The model is a valuable tool, but only to the degree that it approximates the real system, thus, the calibration effort is an important aspect of model application.

12.2 AN INTRODUCTION TO TREATMENT PROCESS MODELLING

Modelling and simulation has been practiced by engineers and scientists in the environmental field for many years, however, the models have often been steady-state rather than dynamic. With the advent of powerful, low-cost workstations, numerical solution of dynamic mathematical models has

become practical. In wastewater engineering, there has been rapid progress in the development of models for processes used in a typical municipal or industrial treatment plant. In 1986, the International Association on Water Quality (IAWQ) released a report outlining a general model for the activated sludge process and this has been followed by many modifications and enhancements to allow prediction of other variables and additional physical, chemical and bio-chemical processes (Dold 1990, Wentzel et al. 1992). An updated version of the IAWQ activated sludge model has been announced recently (IAWQ 1994). Sedimentation (Takács et al. 1991), biofilm (Arvin & Harremoës 1990), anaerobic (McCarty and Mosey 1991) and disinfection (Severin et al. 1984) models have also seen gradual improvement. With these developments it has become possible to consider the preparation of models for entire treatment facilities from headworks to effluent disinfection.

Many of the modelling systems available today use the International Association on Water Quality (IAWQ) models which are mechanistic in nature (Henze et al. 1987a). Mechanistic models are developed from basic principles of physics, chemistry and biology. This type of bottom-up approach results in a robust model that has applicability over a wide range of conditions. The mechanistic approach contrasts with the data-driven, regression approach in which large amounts of real data together with selected generic equations are used to develop a model. These model types each have strengths and weaknesses, however, mechanistic models are preferred because of the greater predictive power which derives from process theory. Regression models are best in situations where mechanistic theory fails and when large amounts of real data are available. The models described in this chapter are mechanistic. Some of the software tools that will be described have both mechanistic and regression modelling capabilities.

There are many different unit processes and unit process configurations used in wastewater treatment. Each of these is unique as are the models developed to represent these systems. This chapter will stress the application of modelling and simulation tools to the liquid train of the conventional activated sludge wastewater treatment process. The models employed are the IAWQ Activated Sludge Model 1 (Henze et al. 1987b) and the settler model described by Takács et al. (1991). Extension of the basic principles to other unit processes or plant configurations are straightforward, however, the models may vary significantly, thus, the parameters to be evaluated and the data to collect for these evaluations will differ.

12.3 COMMERCIALLY AVAILABLE SOFTWARE FOR PROCESS AND PLANT MODELLING

Several software packages are now available for building and simulating models of wastewater treatment processes and full plant models. The available software packages include the following:

- General purpose modelling and simulation packages
- Wastewater treatment modelling and simulation packages

Figure 12-1 shows the relationship between these types of tools. While it is possible to program a model in a general-purpose programming language (level 3) or even a specialized simulation language (level 2), it is simpler and more efficient if extensive programming can be avoided in the model building process. Higher-level tools hide lower levels of detail and allow you to concentrate efforts on model understanding rather than low-level code development. This chapter considers only those tools which can be classified as belonging to levels 1 or 2.

Modelling and simulation as a field of study has a broad range of applicability to many different scientific and engineering disciplines. Because of this, several of the available tools are general purpose modelling and simulation packages that provide the essential capabilities for preparing models of real systems. The more advanced of these include development environments that allow you to build models graphically. General purpose modelling and simulation tools provide considerable flexibility at the cost of the additional time required to program the models you need. Proper use of these tools requires expertise in model building as well as familiarity with building and debugging in a lower-level programming language such as FORTRAN or C. Table 12.1 contains a list of some of the available packages.

Software packages designed specifically for wastewater treatment process modelling and simulation are also available (IAWQ 1994). These packages typically include pre-developed models of unit processes or even an entire plant. Software of this type can be further divided into *development* and *run-time* packages. Development packages allow you to build your own models using unit process models as the basic building blocks. Run-time packages do not permit model development and instead incorporate pre-built plant or process models that you configure to model your process or plant. The best packages include graphical user interfaces that make the software easy to use, rich libraries of process models, and other productivity tools such as sensitivity analysis and mathematical optimization

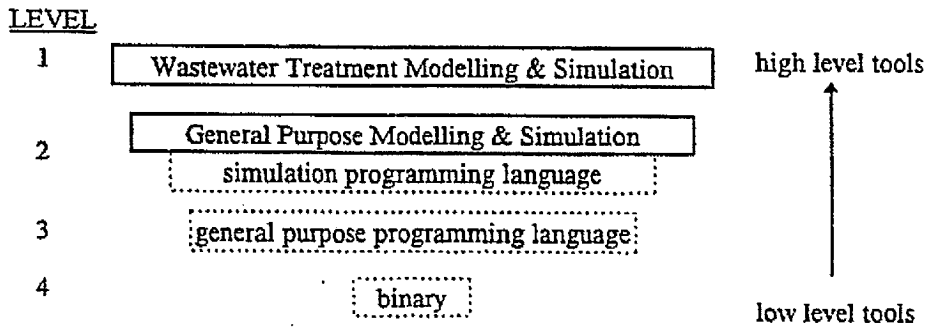


Figure 12-1
Relationship Between Different Types of Modelling and Simulation Tools

Table 12.1
General Purpose Modelling and Simulation Software

Product Name	Supplier
ACSL-GM	MGA 206 Baker Avenue Concord, Massachusetts, U.S.A.
MATLAB-Simulink	MathWorks 24 Prime Park Way Natick, MA 01760-1520
Phoenics	Transoft International 82 Rue de Parie, F-93804 Epinary-sur-Seine Cedex, France
Simnon	SSPA Systems P.O. Box 24001 S-49922 Gothenburg, Sweden
Simplex II	University of Passau Innstrasse 33 D-94032 Passau, Germany
SIMUL_R	SIMUTECH Hadikgasse 150 A-1140 Vienna, Austria
Speedup	Aspen Technology Inc. 251 Vassar Street Cambridge, Massachusetts U.S.A. 02139
Stella	High Performance Systems, Inc. 45 Lyme Road, Suite 300 Hanover, NH 03755
VisSim	Visual Solutions Inc. 487 Groton Road Westford, MA 01886

modules. There are many advantages to using specialized tools including a pre-defined (and debugged!) library of common models and optional modules that are designed to address problems specific to wastewater treatment. Some include the ability to modify or enhance existing models but this capability is usually more restricted than for the general simulation tools. Table 12.2 contains a list of some of the available packages with selected features for each.

Not all of the modelling and simulation tools described in this section have the capability of preparing a model of the full treatment plant including each of the plant unit processes in an integrated model. This type of model development is complicated by the need to track the interactions between unit

Table 12.2
Wastewater Treatment Modelling and Simulation Software

Product Name	Notes	Supplier
AQUASIM	multiple models, incudes open-channel models	EAWAG Ueberlandstrasse 133 CH-8600 Dubendorf, Switzerland
AS40		Aquasystem Habsburgsw. 30 CH-8600 Winterthur, Switzerland
ASIM	user-definition of biokinetic models	EAWAG Ueberlandstrasse 133 CH-8600 Dubendorf, Switzerland
BioWin	basic model library, PC platform	Envirosim Associates Ltd. 482 Anthony Drive Oakville, Ontario L6J 2K5
Crispisim		CEIT P. Manual de Lardizabal 15 P.O. Box 1555, E-20009, San Sebastian, Spain
Daisy		CEIT P. Manual de Lardizabal 15 P.O. Box 1555, E-20009, San Sebastian, Spain
EFOR	basic layout development	EFOR Aps c/o Kruger, 363 Gladsaxevei DK-2860 Soeborg, Denmark
GPS-X	large model library, full-plant models, model development, tools	Hydromantis, Inc. 1685 Main Street West, Suite 302 Hamilton, Ontario L8S 1G5
SIMBA	uses MATLAB-SimuLink, model development, tools in MATLAB	Otterpohl Wasserkonzepte, GbR Kanalstrasse 52 D-23552 Lubeck, Germany
SimWorks	run-time models, standard process/plant layouts, PC platform	Hydromantis, Inc. 1685 Main Street West, Suite 302 Hamilton, Ontario L8S 1G5
SSSP	basic IAWQ biokinetic model	Prof. C.P.L. Grady Clemson University, Clemson Research Park Clemson, SC 29634-0919
STOAT	basic layout development, PC platform, multiple models	WRc plc Frankland Road, Blagrove, Swindon, Wiltshire, 5N5 8YF
UCT		Prof. G. Ekama Dept. of Civil Engineering University of Cape Town 7700 Cape Town, Republic of South Africa
WazuSim	PC platform, single activated sludge model	Van Hall Instituut, Postbus 17, 9700 AB Groningen The Netherlands

processes. For example, all of the tools listed in Table 12.2 consider the recycle of activated sludge from the underflow of a secondary clarifier to the biological reactor. However, not all permit the development of models which include interactions between other unit processes such as cross-flows between parallel treatment trains or the recycle of supernatant flows from sludge treatment processes. When selecting a tool to use for the modelling effort, consider whether it will be necessary to model only a single unit process or the entire treatment facility.

12.4 USING A COMPUTER MODEL FOR PROCESS EVALUATION

Commercially available treatment processes modelling and simulation software packages are comprehensive programs and valuable tools for process audits (Barnett et al. 1995). These tools can be used to prepare models of a wide variety of unit processes and unit operations commonly found in practice. Each unit process/operation is represented by a process model, that is, a mathematical model, that reflects the steady-state or dynamic behaviour of that particular process.

12.5 AN OUTLINE OF THE MODEL DEVELOPMENT PROCESS

Model development here refers to the preparation of a calibrated model of the process or plant using pre-defined models such as those available with software tools listed in Table 12.2. The task of building these pre-defined models is a tedious process and is beyond the scope of this document. In a liquid train process audit the focus is on model application rather than model development, thus, the tools listed in Table 12.2 are most appropriate. While you may find it convenient to use data collected in the plant audit for the purpose of model refinement, in most cases, it will be most efficient to use these data for calibration only. Consult the list of references in Section 12.9 for further information on basic model building.

The model development process is completed in three steps as follows:

1. Preliminary analysis of plant layout and raw data
2. Dynamic model construction
3. Model calibration and verification

The first step involves an analysis of the plant layout and raw data for the treatment facility to be modelled. This information provides the basis for the second step in which the dynamic model is constructed using the unit process building blocks described in Section 12.3. With the model complete, it is necessary to conduct calibration studies to determine proper values for model parameters. Both steady-state and dynamic calibrations can be performed, although the latter are more data intensive. Sensitivity analysis and optimization tools are used in this step. Verification of the calibrated model is achieved by comparison of simulation results with a second data set, i.e. data

which are independent of those used for calibration. Once the model is calibrated and verified, selected simulation scenarios can be prepared to examine the behaviour of the facility under different conditions as required for the process audit. The ways in which a model can be used in the audit are described in Section 12.7.

12.6 DATA REQUIREMENTS FOR MODEL CALIBRATION

The goal of any model calibration is to minimize the difference between model outputs and actual, or target, data. In so doing, it is necessary to close a balance around each unit process for every water quality component of interest. This is an important part of model development since the reliability of a model depends on the quality of the data used in the calibration. Fortunately, many parameters can be measured directly, and some can be obtained from the literature. Parameters that cannot be measured directly or estimated from the literature can often be determined using optimization techniques based on actual plant records and/or experimental tests conducted at the plant (Henze et al. 1994).

Calibration of large-scale wastewater treatment plants requires extensive plant data, with the exact requirements depending on the complexity of the model and whether a *steady-state* or *dynamic* calibration is desired. Steady-state calibrations can use existing daily, weekly or monthly averages that are obtained from grab or composite samples. Dynamic calibrations rely on instantaneous values obtained either on-line or from grab samples. Composite samples should not be used when collecting data for a dynamic calibration. If the plant does not have data sufficient for a detailed dynamic calibration it will be necessary to design a special sampling program in order to obtain dynamic data. The data requirements for each type of calibration are outlined in the following sections. The data collection effort should be conducted in such a way as to ensure that appropriate model parameter estimates can be evaluated. The material provided in the sections below will help you to design the data collection task properly.

When the model is developed as part of a process audit, the measurement of data may form part of the overall data acquisition effort required by the project. Data fall into four categories as described in detail in the following sections. Note that the first three sections (12.6.1-3) describe raw data collected from the plant or simple secondary data calculated from raw data whereas the last section (12.6.4) describes model parameters that must be estimated by calculation procedure (normally mathematical optimization) or obtained by an experimental procedure (respirometry, dye tests, aeration tests, etc.). Each section contains a table which describes the type of parameter to measure, the frequency of measurement required for both steady-state (SS) and dynamic (DYN) calibrations, the relative importance of the measure and the common source for the indicated data. Symbols used in these tables are defined in Table 12.3.

Table 12.3
Variables and Codes Used in Tables 12.4 to 12.7

Variables	Codes
V = volume L = Length N = number of reactors (tanks) D = diameter Q = flow SS = suspended solids $CBOD_5$ = 5-day carbonaceous biochemical oxygen demand COD = chemical oxygen demand	**Frequency** 1 = once SS = steady state s = seasonal DYN = dynamic m = monthly d= daily h = hourly
XCOD = COD of the SS TKN = total Kjeldahl nitrogen TKN_f = filtered TKN NH_3 = ammonia and ammonia nitrogen	**Importance** 1 = required 2 = important 3 = optional
NO_3 = nitrate – nitrogen TP = total phosphorus $CBOD_u$ = ultimate (20-day) BOD, unfiltered, inhibited (no nitrogenous demand)	**Sources** a = automatic m = manual 1 = grab sample 2 = composite sample 3 = special sampling/testing
$CBOD_{uf}$ = ultimate, filtered BOD, inhibited (no nitrogenous demand) VSS = volatile suspended solids k_La = oxygen mass transfer coefficient F = mass flow for chemical dosage MLSS = mixed liquor suspended solids DO = dissolved oxygen OUR = oxygen uptake rate X_{ras} = return activated sludge suspended solids H_f = settler influent sludge feed point height H_s = sludge blanket height in settler	mu = maximum specific growth rate K_a = half saturation constant K_d = decay coefficient Y = yield coefficient X_{min} = minimum SS concentration [1] V_{bnd} = Vesilind settling parameter V_{max} = maximum settling velocity r_{hin} = hindered settling parameter [1] r_{floc} = flocculant settling parameter [1]

Notes: [1] Refer to Takács et al. (1991) for a definition of these terms.

12.6.1 Physical Data

Physical plant data are essential for specifying the configuration of the unit processes in the model as well as their sizes, volumes, etc. The data required for a typical calibration are shown in Table 12.4 and include the following:

- Process flow sheet (flow lines, channels, recycle lines, by-passes, etc.)
- Flow pattern (plug flow, CSTR, etc.)

Table 12.4
Physical Plant Data

	Parameter [1]	Frequency	Importance	Source
Configuration	Layout	1	1	plant drawings
Reactors				
Dimensions	V	1	1	drawings
Hydraulics	N	1	2	dye test
Settlers				
Dimensions	A,H,Hf	1	1	drawings
Pipes, Channels				
Dimensions	L,D	1	2	plant drawings

[1] Parameters, frequency, and importance are defined in Table 12.3.

- Sludge collection and withdrawal details (location, how, when, etc.)
- Dimensions of the various reactors (length, width, depth)

Elements of this data group are generally easy to obtain from plant blueprints and operations manuals. However, note that the physical volume of a reactor is only an approximation of the effective volume of a unit process. In a well designed system the effects of dead-space and hydraulic short-circuiting is normally minimal. However, it may be necessary to determine the true hydraulic characteristics of a particular unit process, as in the case of a quasi-plug flow aeration tank. In this case, a dye test is required to determine the residence time distributions and, from this, the number of tanks-in-series to be used in the model.

12.6.2 Operational Plant Data

Operational data are important because they are a major cause of the steady-state and dynamic behaviours observed in a treatment process. The operational data you will need to complete a calibration are shown in Table 12.5. These data include the following:

- Control variables (independent variables)
- Observed, or response, variables (dependent variables)

Operational data are an important group especially when these data are used as the basis for estimation of model parameters (see section 12.6.4). For example, it is usually necessary to calibrate the model dissolved oxygen (DO) concentration given actual measures of DO. If the aeration capacity is not known or cannot be estimated, then it is possible to match the measured dissolved oxygen (DO)

Table 12.5
Operational Plant Data

	Parameter [1]	Frequency		Importance	Source
Control Variables		SS	DYN		
Flows					
By-passes	Q	m	h	1	a
Recycles	Q	m	h	1	a
Wastages	Q	m	h	1	a
Aeration Capacity	k_La	s,m	s,m	2	m^3
Chemical Dosage	F	m	h	3	a,ml
Observed Variables					
Flows					
Primary Effluent	Q	m	h	2	a
Final Effluent	Q	m	h	2	a
Compositions					
Primary Effluent	SS	m	h	1	a, ml-2
	$CBOD_5$	m	h	1	ml-2
	COD	m	h	2	ml-2
	TKN	m	h	2	ml-2
	NH_3	m	h	1	a,ml-2
	NO_{-3}	m	h	2	ml-2
	TP	m	m,h	3	ml-2
Final Effluent	SS	m	h	1	a,ml-2
	$CBOD_5$	m	h	1	ml-2
	COD	m	h	2	ml-2
	TKN	m	h	2	ml-2
	NH_3	m	h	1	a,ml-2
	NO_{-3}	m	h	2	ml-2
	TP	s,m	s	3	ml-2
	others	s,m	s	3	ml-3
Reactor					
Aeration Tank	MLSS	m	h	1	a,ml-2
	MLVSS	m	h,d	2	ml-2
	COD	m	m,d	2	ml-2
	TKN	m	m,d	2	ml-2
	NH_3		m,d	1	a,ml-2
	TP	m	m,d	3	ml-d
	DO	m	h	1	a
	OUR	m	h,d	2	a,ml
Settler	Xras	m	h	1	a,ml-2
	HS	m	h,d	2	a,m^3

[1] Parameters, frequency, and importance are defined in Table 12.3.

level by changing the oxygen transfer parameter, or one or more stoichiometric and kinetic parameters. Since there are too many degrees of freedom in this estimation problem, the correct evaluation of all parameters is not possible. Similarly, if the wastage rate is not known, then other model parameters which also have a strong effect on the aeration tank mixed liquor suspended solids (MLSS) are impossible to estimate properly.

Mixed liquor suspended solids (MLSS), volatile suspended solids (VSS), chemical oxygen demand (COD) of the mixed liquor, dissolved oxygen (DO), and oxygen utilization rate (OUR) are all required to calibrate the activated sludge process model. These operational data provide the essential information for performing material balances around the system and each unit process. For solids, this requires data on flow rates and solids concentrations at each influent and effluent flow stream. Accordingly, the sludge blanket height and underflow solids concentration are required to calibrate the settler model. Material balances should also be examined for organic material (measured as COD) and, if desired, nitrogen. You can use material balances to check the validity of the data collected.

12.6.3 Influent Wastewater Characteristics

Influent wastewater characteristics together with the plant operational changes are the major causes of dynamic behaviour in a wastewater treatment plant. The data required for calibration are listed in Table 12.6 and include the following:

- Basic water quality parameters
- Influent organic fractions
- Influent nitrogen fractions

Basic influent wastewater characteristics such as $CBOD_5$, $CBOD_u$, COD, SS, VSS, and TKN are important because they allow you to establish mass balances around the system and each unit process. Since CBOD provides only partial information on the influent organic load, COD is the preferred measure. Unfortunately, COD measurements are not readily available in some wastewater treatment plants. In these cases, the $CBOD_5/CBOD_u$ ratio can be used to estimate the influent organic load (substrate). Suspended solids, influent VSS and BOD together, can be used to determine the different influent organic fractions, which are critical for the proper use of the IAWQ activated sludge model. The important stoichiometric relationships are shown in Figure 12-2.

The stoichiometric ratios listed in Table 12.6 are needed to calibrate a model of the influent wastewater which differs from the standard IAWQ model described in the literature. The relationship between this model and the IAWQ model is shown in Figure 12-2. In this figure, items shown in bold text are IAWQ model parameters some of which must be calculated from real data and stoichiometric ratios listed in

Table 12.6. Arrows are interpreted as multiplication with the coefficient shown along the arrow as a multiplicand. Converging arrows are used to indicate a sum. For example, the substrate shown at the top right of Figure 12-2 is calculated as follows:

$$[\text{substrate}] = [CBOD_5] * (CBOD_u/BOD_5) + (-1)*[\text{heterotrophs}] + (-1)*[\text{autotrophs}] ,$$

where each of these variables is given in appropriate concentration units. The same relationships hold between these variables in all other liquid train processes.

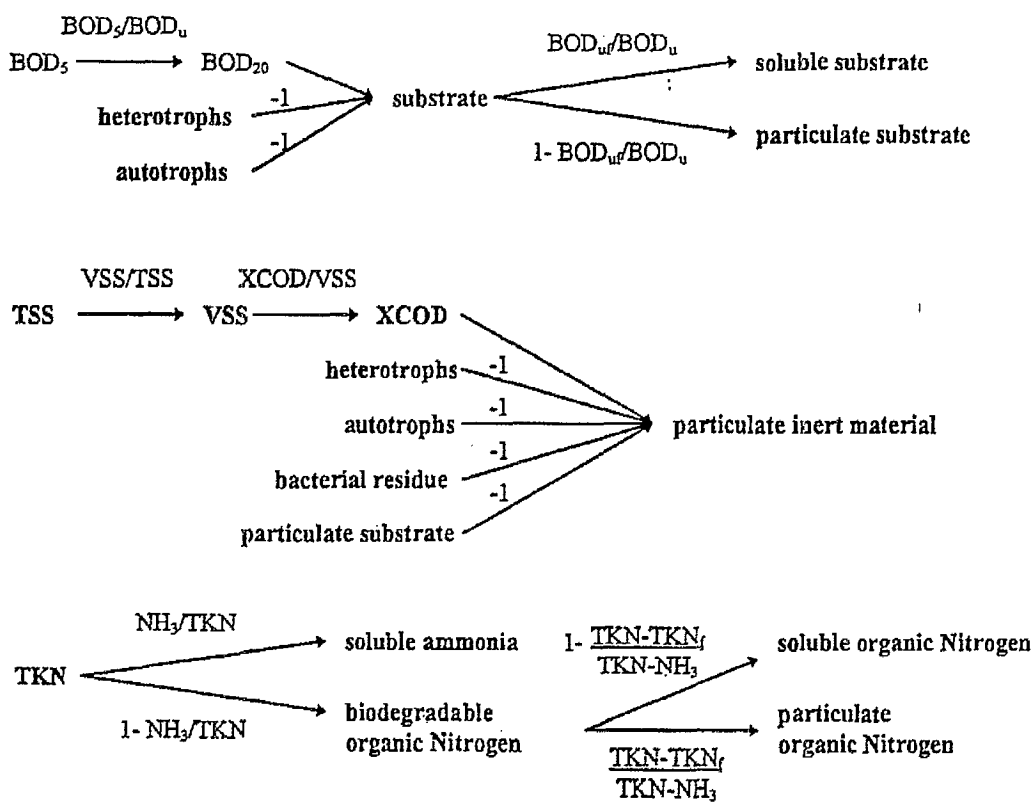


Figure 12-2
Calculating IAWO Model Variables from Influent Data

Table 12.6
Influent Data

Data	Parameter [1]	Frequency		Importance	Source
Main Influent		SS	DYN		
Flow	Q	m	h	1	a
Composition	SS	m	h	1	a,ml-2
	$CBOD_5$	m	h	1	ml-2
	COD	m	h	2	ml-2
	TKN	m	d	2	ml-2
	NH_3	m	h	1	a,ml-2
	NO_3^-	m	d	3	a,ml-2
	TP	s,m	s,m	3	ml-2
Stoichiometry	$CBOD_5/CBOD_u$	s,m	m,d	1	ml-2
	$CBOD_{uf}/CBOD_u$	s,m	m,d	1	ml-2
	VSS/TSS	m	d	1	ml-2
	XCOD/VSS	m	d	1	ml-2
	NH_3/TKN	m	d	1	ml-2
	TKN-TKN_f/ TKN-NH_3	s	s,m	2	ml-2
Secondary Influents					
Flow	Q	m	d	1	a
Composition	SS	m	d	1	a,ml-2
	$CBOD_5$	m	d	1	ml-2
	COD	m	d	1	ml-2
	TKN	m	d	1	ml-2
	NH_3	m	d	1	a,ml-2
	NO_3^-	m	d	3	a,ml-2
	TP	s	m	3	a,ml-2
Stoichiometry	$CBOD_5/CBOD_u$	s	m	1	ml-2
	$CBOD_{uf}/CBOD_u$	s	m	1	ml-2
	VSS/TSS	s	m	1	ml-2
	XCOD/VSS	s	m	1	ml-2
	NH_3/TKN	s	m	1	ml-2
	TKN-TKN_f/ TKN-NH_3	s	m	2	ml-2

[1] Parameters, frequency, and importance are defined in Table 12.3.

Table 12.7
Kinetic and Stoichiometric Data

	Parameter [1]	Frequency		Importance	Source
Organic removal parameters		SS	DYN		
growth rate	mu	s	m,d	2	optimization, respirometry
half saturation construction	K_s	s	m,d	2	optimization, respirometry
decay coefficient	K_d	s	m,d	2	optimization, respirometry
yield coefficient	Y	s	m,d	2	optimization
Nitrogen removal parameters					
growth rate	mu	s	m,d	2	optimization, respirometry
half saturation construction	K_s	s	m,d	2	optimization, respirometry
decay coefficient	b	s	m,d	2	optimization, respirometry
yield coefficient	Y	s	m,d	2	optimization
Settling parameters					
minimum solids	X_{min}	s	m,d	3	optimization, settling tests
maximum settling velocity	V_{bnd}	s	m,d	3	optimization, settling tests
vesilind settling parameter	V_{max}	s	m,d	1	optimization, settling tests
compaction settling parameter	r_{hin}	s	m,d	1	optimization, settling tests
flocculant settling parameter	r_{floc}	s	m,d	1	optimization

[1] Parameters, frequency, and importance are defined in Table 12.3.

12.6.4 Kinetic and Stoichiometric Model Parameters

The IAWQ model for the activated sludge process as well as the sedimentation model contain a number of kinetic and stoichiometric parameters that must be estimated given data described in the previous sections. These parameters are listed in Table 12.7 and include the following:

- Organic removal model parameters
- Nitrogen removal model parameters
- Settling model parameters (primary and secondary)

The organic and nitrogen removal model parameters in Table 12.7 can be obtained from analytical tests as described by Henze et al. (1987). Kinetic (growth rate, half saturation constant and decay coefficient) parameters and settling parameters will vary more than stoichiometric (yields) parameters, however, in most cases constant values can be assumed. Site-specific model parameters include the maximum specific growth rates and yield coefficients. Most of the software tools listed in Table 12.2 contain default values for these parameters which can be used as a starting point in the analysis. If the data described in the previous sections are available then an alternative to analytical determination is mathematical optimization. With the appropriate data and an optimization programs (available with some of the tools listed in Table 12.2) these parameters can be estimated. Settling model parameter values can be obtained using physical experiments and optimization techniques as described by Takács et al. (1991). Clarifier stress test data described in Chapter 10 can be used to establish he hydraulic characteristics of a settler. Mathematical estimation of parameters in wastewater treatment has been described by Beck (1986, 1989) and Jeppsson & Olsson (1993).

12.7 USING THE MODEL TO SUPPLEMENT A PROCESS AUDIT

There are several areas where the treatment process model can be used in a liquid train audit. Since the model is a representation of the real facility, it can be used for experimentation, that is, simulation, to test hypotheses you might have about the plant. Many of these tests will be carried out in conjunction with onsite tests and measurements with one activity complimenting the other as insight to the process is gained from the model and improvement of the model is made possible by physical observation, measurement and experimentation.

The following are typical of the types of investigation which can be addressed:

- **Process capacity estimation.** Based on a calibrated model of the existing facility under current operating conditions, estimate the increase in influent load – either in terms of organic-load or hydraulic load – that is possible with current or future effluent constraints, or improvement which could be achieved with trial modifications to either operating procedures, controls, flowpath modifications or process augmentation.
- **Bottleneck identification.** Use a calibrated model to identify which processes will fail as influent load increases.
- **Hydraulic load change analysis.** Estimate the impact on plant effectiveness and economy of a reduction in hydraulic load through water conservation measures or stormwater separation, etc. Alternatively, analyze the effect of non-uniform hydraulic load distribution over multiple parallel liquid trains.
- **Optimization of the aeration system.** Calculate energy savings which might be achieved by introduction of closed loop control of aeration rate and distribution

(e.g., taper). Simulate equipment upgrades such as the conversion of the aeration system from coarse to fine bubble diffusers.

- **Optimization of sludge recycle and wastage.** Simulate the effect of alternative strategies to control sludge recycle wastage, MLSS or SRT in an activated sludge reactor.
- **Bypass impact reduction.** Simulate alternative bypass strategies to minimize total impact on the receiving waters.
- **Management of wet-weather flow.** Experiment with alternative combinations of bypass fraction and step feed during high runoff events to maintain effectiveness of the activated sludge process and minimize total impact on receiving waters.
- **Sludge production estimation.** Estimate impact of variables such as aeration and recycle rate on MLSS, SRT and hence sludge production rate, for given influent and other operating conditions.
- **Reactor configurations for nutrient removal.** Conduct simulations to determine appropriate flow rates, internal recycles and reactor sizing to meet effluent nutrient effluent criteria.

There are many other areas where a model, especially a dynamic model can be used to augment a liquid train audit. The next section looks at a practical application in which considerable cost savings were realized.

12.8 SELECTED CASE STUDY

City of Toronto Main Treatment Plant

The Main Treatment Plant is the largest activated sludge plant in Canada. At the time of this study, the plant was undergoing a liquid train process audit to identify process bottlenecks, determine actual treatment capacity and examine operational performance. As part of this study, a detailed model of the treatment process was developed to aid in the process audit. In addition, a detailed model of the secondary clarifiers was developed using computational fluid dynamics techniques in order to improve prediction of effluent suspended solids.

The role of the model in this study was to assist in the process audit of the treatment plant. Limited information was available on some aspects of the plant operation that were having a strong impact on treatment. For example, recycle flows from solids handling streams back to the liquid treatment

train were not measured. The impact of these streams was important as they added a heavy load to the liquid treatment train. With the help of a dynamic plant model it was possible to quantify many of the effects of this additional load on total plant performance.

The dynamic process model was also effective in analysis of flow distributions in the plant. Initial attempts at calibrating the model to storm flow data failed. Further investigation showed that the flow through the bypass gate resulted in imbalances in flow through other processes in the plant. After making appropriate changes to the model, this phenomenon could be simulated. Moreover, the model allowed strategies to be identified that could be used to develop improved flow management.

Model calibration also revealed errors in flow rate measurements. Simulations conducted with the recorded flow rates resulted in very low solids retention times (SRT). Since the plant effluent was fully nitrified during this period, it would have been necessary to increase the nitrifier growth rate to an unacceptably large value in order to calibrate the model to actual flow data. Further examination of these data showed that the influent and waste sludge flow rate measurements were higher than actual values resulting in the low SRT values.

The calibrated model developed in this study was delivered to Municipality of Metropolitan Toronto personnel who continue to use it for exploring alternatives in treatment plant process operation. A large part of the project involved transfer of modelling and simulation technology to Metro Toronto staff, including in-office training for a plant engineer. With this training, plant personnel gained the expertise needed to carry out their own studies, including modelling of other treatment plants in the municipality.

The use of dynamic modelling as a tool for assessing operational and capacity issues proved to be an invaluable part of the operational audit. The process of modelling as well as steady-state and dynamic calibration identified various areas where improvements could be made. Results of the study indicated that a projected $220 million expansion thought to be required to achieve nitrification at future flow rates, could be reduced to less than $32 million (Nolasco, et al. 1994).

12.9 EXPECTED DURATION AND COSTS

The costs associated with the use of process modelling in a process audit are subject to the scope of the process modelling tasks and competitive market conditions for commercially available software. In general, the costs of process modelling will include the following two main aspects:

- Development of the simulation model
- Specific investigations conducted using the simulation model

An example of the basic cost estimates provided by one engineering consulting firm specializing in the area of process modelling (Hydromantis, Inc.) is shown in Table 12.8 for the sequential tasks typically involved in the development of a simulation model, exclusive of hardware/software costs. Using a calibrated and verified simulator model, approximate base costs quoted by Hydromantis Inc. to complete some of the typical types of investigations identified in Section 12.7 range from approximately $1,500 to $4,000 (1994 US dollars). However, it is cautioned that more complex cases may be significantly more expensive. As with other process audit tasks, the overall cost of process modelling is highly dependent on project scope and complexity.

Table 12.8
Example of Simulation Model Development Costs
(Hydromantis, Inc., 1994 US Dollars)

Task	Example Task Scope	Cost
Model Layout	• Inspect drawings • Develop and populate layouts • Assign physical properties, parameters • Build and test model execution	From $4,000
Data Collection	• Often available through process audit • Review historical data • Specify required data for calibration • Format data for input to model	From $5,000
Steady-State Calibration	• Compute/check influent stoichiometry • Calibration of unit processes	From $8,000
Dynamic Calibration	• Sensitivity analysis • Optimization of operational parameters • Calibration/verification under dynamic conditions	From $12,000

Note: All prices are approximate but are considered typical for basic projects. All model development costs are exclusive of hardware/software costs.

12.10 REFERENCES

Arvin, E., Harremoës, P. "Concepts and Models for Biofilm Performance". *Water Science Technnology*. 22, 171. 1990.

Barnard J. L. "A review of biological phosphorus removal in the activated sludge process". *Water SA*, 2, 136-144. 1976.

Barnes and Wilson. *Chemistry and unit operations in sewage treatment*. Applied Science Publishers. London. 1978.

Barnett, M. W.; Watson, B. W.; and Gall, R.A.B. "Dynamic Modelling and Simulation of Wastewater Treatment Plants: Applications and State-of-the-Art". *Water Environment & Technology*. December, 1995.

Beck, M.B. "Identification, Estimation and Control of Biological Wastewater Treatment Processes". *IEE Proceedings*. Vol. 133, Pt. D., No. 5. 1986.

Beck, M.B. "System Identification and Control". *Dynamic modelling and expert systems in wastewater engineering*. (G.G. Patry and D. Chapman: eds.). Lewis Publishers. Chelsea, Michigan. 1989.

Dold, P.L. "Incorporation of Biological Excess Phosphorus Removal in a General Activated Sludge Model". *Proceedings of the 13th International Symposium on Wastewater Treatment*. Montreal, Canada. pp. 83-113. 1990.

Dold P. L.; Ekama, G.A.; and Marais, G. v R. "A general model for the activated sludge process". *Prog Water Technol*. Vol. 12, pp. 47-77. 1980.

Grady C.P.L. "Dynamic modelling of suspended growth biological wastewater treatment processes". *Dynamic modelling and expert systems in wastewater engineering*. (G.G. Patry and D. Chapman: eds.). Lewis Publishers. Chelsea, Michigan. 1989.

Grady C.P.L.; Gujer, W.; Henze, M.; Marais, G. v R.; and Matsuo, T. "A model for single-sludge wastewater treatment systems". *Water Science Technology*. Vol. 21, pp. 47-61. 1986.

Grau, P.; Sutton, P.M.; Henze, M.; Elmaleh, S.; Grady, C.P.; Gujer, W.; and Koller, J. "Notation for use in the description of wastewater treatment processes". *Water Research*. Vol. 21, No. 2. pp. 135-140. 1987.

Henze, M.; Grady, C.P.L.; Gujer, W.; Marais, G. v R.; and Matsuo, T. Activated sludge model no. 1. IAWPRC Scientific and Technical Report No. 1. IAWPRC. London. 1987a.

Henze M.; Grady, C.P.L.; Gujer, W.; Marais, G. v R.; and Matsuo, T. "A general model for single sludge wastewater treatment systems". Water Research. Vol. 21, pp. 505-515. 1987b.

Henze M.; Gujer, W.; Takahashi, M.; Matsuo, T.; Wentzel, M.; and Marais G. v R. Activated sludge model no. 2. IAWQ Scientific and Technical Reports, IAWQ Specialized Seminar: Modelling and control of activated sludge processes. Copenhagen, Denmark. August 22-24, 1994.

Herbert, D. "Some principles of continuous culture". Recent Progress in Microbiology. G. Tunevall (Ed.). Almquist and Wiksell, Stockholm, pp. 381-396. 1958.

International Association on Water Quality (IAWQ). *Proceedings of the IAWQ Specialized Seminar: Modelling and Control of Activated Sludge Processes.* Copenhagen, Denmark. August 22-24, 1994.

Jeppsson, U. and Olsson, G. "Reduced order models for on-line parameter identification of the activated sludge process". *Proceedings of the Sixth IAWQ Workshop on Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems.* B. Jank (Ed.). Banff and Hamilton, Canada. 1993.

Marais, G. v R. and Ekama, G.A. "The activated sludge process: part 1 – steady-state behaviour". *Water SA.* Vol. 2, pp. 163-200. 1976.

McCarty, P.L. and Mosey, F.E. "Modelling of anaerobic digestion processes". *Water Science Technology.* Vol. 24, pp. 17-33. 1991.

McKinney, R.E. Mathematics of complete mixing activated sludge. J San Eng Div, ASCE, 88, SA3, Proc Paper 3133, pp. 87-113. 1962.

McKinney, R.E. and Ooten, R.J. Concepts of complete mixing activated sludge. Trans 19th San Eng Conf, University of Kansas, pp. 32-59. 1969.

Metcalf and Eddy. *Wastewater Engineering Treatment, Disposal and Reuse.* 3rd ed., (Tchobanoglous, G. and Burton, F. rev.). McGraw-Hill. 1991.

Nolasco, D.; Stephenson, J.; and DeAngelis, W. "Maximizing the use of existing facilities at Metro Toronto's Main Treatment Plant using the Process Audit Approach". *Environmental Science & Engineering*, Vol. 7, No. 3, pp. 44-46. 1994.

Olsson, G. "Dynamics and Control of the Activated Sludge Process". *Vol. 6, Water Quality Management Library.* Edited by John F. Andrews. Technomic Publishing Co. Inc. Lancaster PA. 1992.

Perry, R.H. and Chilton, C.C. *Chemical Engineer's Handbook.* Fifth edition. McGraw-Hill Book Company. New York. 1973.

Pflanz, P. "Performance of activated sludge secondary sedimentation basins". *4th IAWPRC Conference Proceedings.* Pergamon Press. 1969.

Severin, B.F.; Suiden, M.T.; and Engelbrecht, R.S. "Series-Event Kinetic Model For Chemical Disinfection". *J. of Env. Eng.* Vol. 110, No. 2, pp. 430-439. 1984.

Smith, A.A.; Hinton, E.; and Lewis, R.W. *Civil Engineering Systems Analysis and Design.* Wiley and Sons Ltd. Toronto. 1983.

Stokes, L.; Takács, I.; Watson, B.; and Watts, J.B. "Dynamic Modelling of an Activated Sludge Process Sewage Works – A Case Study". *Proceedings of the Sixth IAWQ Workshop on Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems.* B. Jank (Ed.). Banff and Hamilton, Canada. 1993.

Takács, I.; Patry, G.G.; Nolasco, D. "A dynamic model of the clarification-thickening process". *Water Research.* Vol. 25, No. 10, pp. 1263-1271. 1991.

Van Haandel, A.C.; Ekama, G.A.; and Marais, G. v R. "The activated sludge process: part 3 – single sludge denitrification". *Water Research.* Vol. 15, 1135-1152. 1981.

Vesilind, A.P. Discussion of "Evaluation of activated sludge thickening theories", by R.I. Dick and B.B. Ewing. J. Sanit. Engng Div. Am. Soc. Civ. Engrs 94, pp. 185-191. 1968.

Wasserman, Philip D. *Neural Computing, Theory and Practice.* Van Nostrand Reinhold. New York. 1989.

Wentzel, M.C.; Ekama, G.A.; Marais, G.v.R. "Processes and Modelling of Nitrification-Denitrification Biological Phosphorus Removal Systems – A Review". *Water Science Technology.* Vol. 25, No. 6, pp. 59-82. 1991.

Wentzel, M.C.; Ekama, G.A.; and Marais, G. v R. "Kinetics of nitrification denitrification biological excess phosphorus removal systems – a review". *Water Science Technology.* Vol. 23, pp. 555-565. 1991.

Wentzel, M.C.; Lotter, L.H.; Ekama, G.A.; Loewenthal, R.E.; and Marais, G. v R. Evaluation of biochemical models for biological excess phosphorus removal. *Water Science Technology.* Vol. 23, pp. 567-576. 1991.

CHAPTER 13
REPORTING RESULTS

13.1 THE END PRODUCT: THE PROCESS AUDIT REPORT

The process audit should result in the delivery of a consolidated and comprehensive document to the end user(s). It should detail the work completed, results obtained, conclusions drawn, recommendations for further work, and limitations of the studies conducted. Each chapter in this manual demonstrated technologies that are applicable to process audits and the type of results to be expected. These approaches should not limit the user of the manual from applying other technologies and data analysis procedures that are applicable.

The major elements expected in consolidated reports include:

- Executive summary
- Introduction, including summary of Terms of Reference
- Enumeration of objectives
- Planning requirements
- Current plant status and remediation requirements
- Process audit data presentation and analysis
- Assessment of plant upgrade options
- Cost analysis of recommended upgrade alternatives
- Conclusions
- Recommendations
- References
- Supporting documentation (appendixes)
- Other components, as required

The report should be complete, yet concise, and include other elements such as title sheets; report date; engineer's stamp; firm name; table of contents; lists of tables, figures, and drawings; list of abbreviations; etc. The format of a report should be consistent throughout.

Some elements that may be required to be included in a comprehensive audit include:

- Population and other projections
  - Reasonableness
  - Based on latest published data
- Existing conditions and major assumptions adequately explained

- Proposed improvements and alternatives explained; unproven, or nonstandard solutions pointed out
- Construction (upgrade) feasibility and cost risks identified
- Proposed improvements based on sound judgement, and major criteria set
- Proposed improvements and calculations checked and proofed
- Economics procedures sound and checked
- Inflation effect considered
- Future expansion considered
- Environmental conflicts resolved – air, water, etc.
- Regulatory Agencies Procedures, Codes, Regulations, and Standards reviewed and used

As optimization studies will be required under the Province's Municipal Assistance Program, the process audit documentation must be sound enough to support grant applications when used. The project's terms of reference and scope will provide the relevant instructions for each project, and may require more or less than shown above. Similarly, the approvals process will require documentation of the conclusions and recommendations made from a process audit. A sufficient and satisfactory database must be obtained to support the recommendations made as the Certificate of Approval for a plant may need to be amended as a result.

13.2 THE WORKSHOP APPROACH

The "workshop" approach (Figure 13-1) is a comprehensive way to bring the project stakeholders (plant owner/administrators; plant superintendent; plant staff; MOEE and other regulatory agencies; and the process audit provider) together.

This approach can be used effectively at key points in a project to obtain input on key decision-making criteria (Figure 13-2). It is important to form a consensus of certain project requirements, plant improvement, and outcomes to satisfy the project outcome. This can result in a cost-effective, team-oriented, problem resolution technique that rapidly focuses technical, owner, managerial, and regulatory efforts toward practical and implementable solutions early in a project. Use of the workshop approach must be planned and budgeted at project initiation.

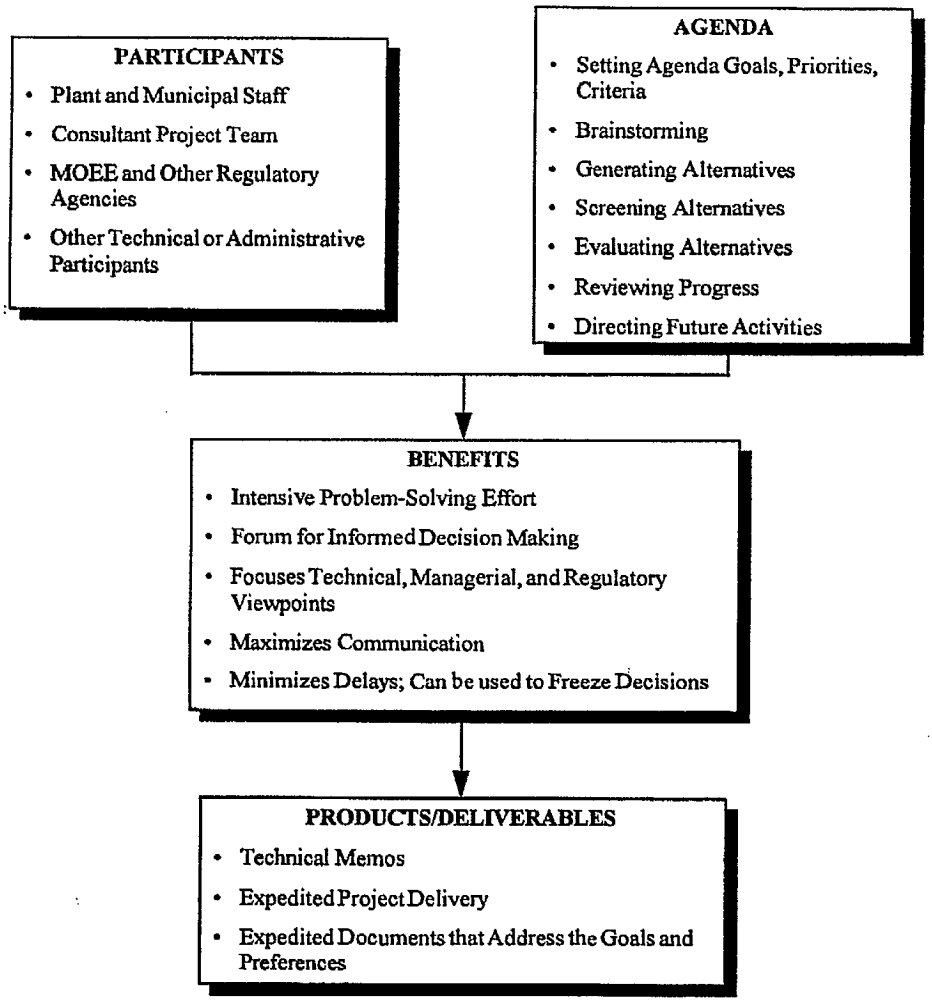


Figure 13-1
Overview of a Workshop Approach

The workshop approach can provide the following benefits:

- It is an interactive approach, which fosters team spirit and cooperation.
- All participants can provide input in the problem-solving effort and the solution.
- It streamlines communication and information exchange among all participants.
- It allows completion of the project more quickly and efficiently than other methods.
- It allows the municipality's management and staff to review progress most effectively, evaluate alternative courses of action, set clear priorities, and provide direction for future activities.

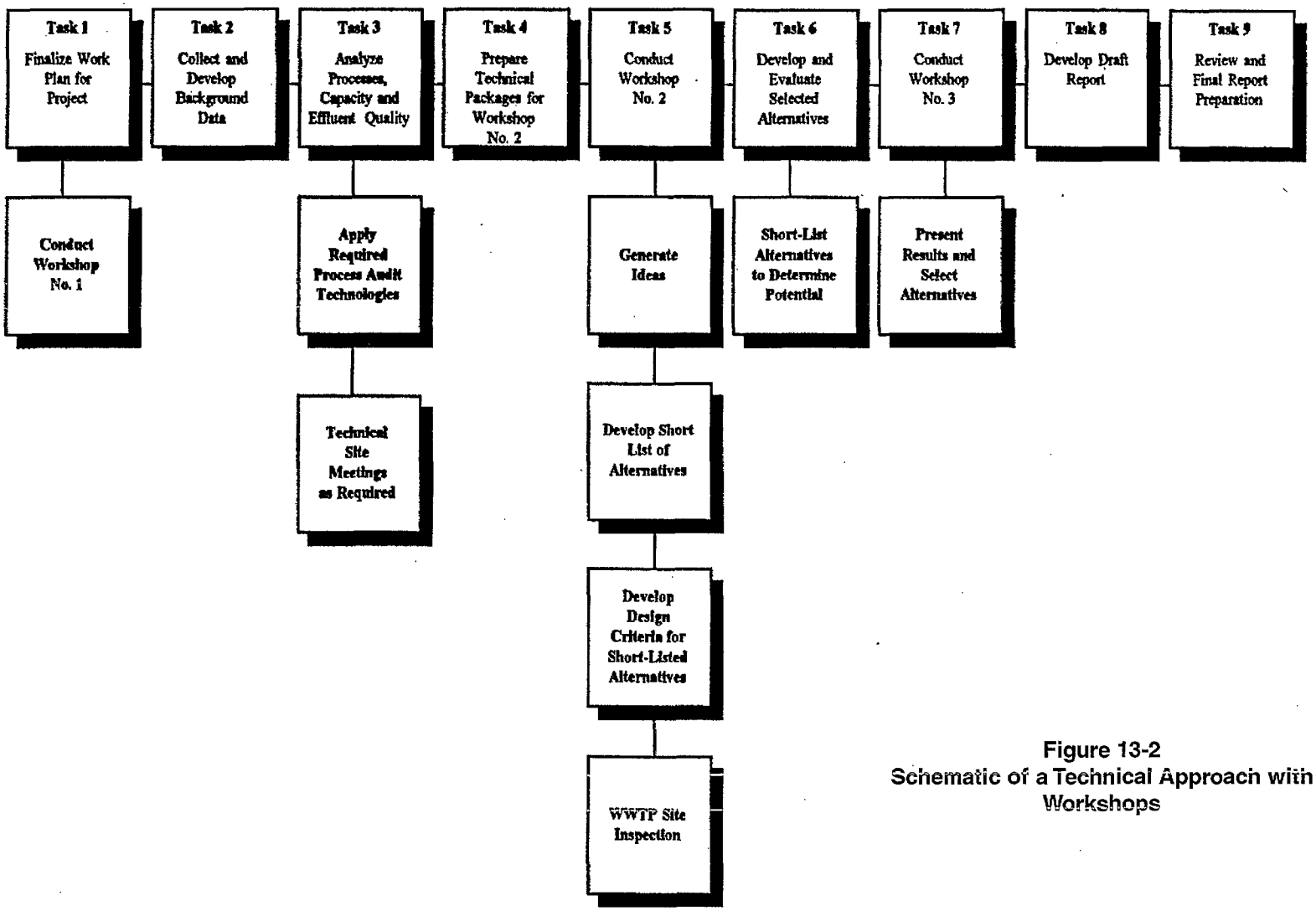


Figure 13-2
Schematic of a Technical Approach with Workshops

- It systematically reduces the number of alternatives being considered and concentrates attention on the most critical aspects of the project.
- It assures management and staff that the goals of the municipality and the regulatory agencies are reflected in the study.

13.3 TECHNICAL MEMORANDA

The project tasks and workshops generate technical memoranda (tech memos) that summarize the assumptions, evaluations, and conclusions of tests in a format that can be reviewed by participants and later can be incorporated in a final conceptual design report.

In addition to the tech memos generated from the decisions made during the workshops, memos are used to document other critical project work, such as the development of screened alternatives and comparison and selection of alternatives.

Technical memoranda should be developed along the following lines:

- Introduction, background and objective
- Presentation and interpretation of information (attach supporting information)
- Comparative analyses where warranted
- Cost estimate
- Conclusions
- Recommendations

These memoranda provide a concise way to present results in a timely fashion as the process audit progresses. It is often advantageous to prepare a tech memo for each test for early presentation to the stakeholders. The tech memos are presented at workshops and used to prepare the project report.

13.4 SELECTED CASE STUDY

Section 7.8 provides an example case study from the largest process audit completed in Ontario at the Metro Toronto Main STP in 1993. The intensive on-line process audit, simulation modelling, and additional performance field tests were carried out between May 1992 and February 1993. The project was focused on assessment of the liquid train together with specific sludge recycle streams and their impact on the liquid train. Independent dynamic modelling was carried out using the GPS-X dynamic model platform.

The overall project extended from early in 1992 to final report submission in September 1993.

This project involved a steering committee composed of the municipality (Metro Toronto) administrators, plant management and operating staff, MOEE, Environment Canada representatives (WTC), and the project consultants. Periodic workshop/steering committee meetings were held at key times (seven) throughout the project. Technical memoranda were prepared usually in advance of the meetings, to apprise the committee of the results. A draft and final report were prepared in consultation with the steering committee.

Although this was the largest process audit carried out, many others have been completed in Ontario and elsewhere in plants ranging in capacity from as low as 9 MLD design to 818 MLD design capacity, in the case of Metro Toronto Main STP (Daigger et al., 1992; Nolasco et al., 1994).

13.5 EXPECTED DURATION AND COST

The duration and cost of reporting on process audits is controlled by several variables, including:

- Project scope and level of effort
- Quality and quantity of information and data collected
- Time and effort required to consolidate report materials, contact suppliers (if required), and develop retrofit options
- Time and effort to prepare technical memoranda, presentation materials for workshops, and draft and final reports

In general, the preparation of technical memoranda takes approximately 3 to 10 person-days after all data are made available in a consolidated format, and depending on the scope of the task. A draft and final report can be expected to require a significant percentage of the project effort to produce a high quality document.

A rule-of-thumb would be for a draft report to require from 20 to 80 mandays to prepare, and additional time for revisions after client review, depending on the project overall scope.

13.6 REFERENCES

Daigger, G.T., Buttz, J.A., and Stephenson, J.P. "Analysis of Techniques for Evaluating and Optimizing Existing Full-Scale Wastewater Treatment Plants". *Wat. Sci. Tech.* Vol. 25, No. 4-5. Pp. 103-188. 1992.

Nolasco, D., Stephenson, J., Watson, B., Takacs, I., and DeAngelis, W. "Optimization of Nutrient Removal at a Large Facility with Advanced Field Evaluation Tools and Dynamic Modelling". In: Biological Treatment Systems - Biological Nutrient Removal, Vol. 1. Pp. 619-630. *Proceedings of the WEF 67th Annual Conference & Exposition.* Chicago, IL. October 15-19, 1994.

Guidance Manual for
Sewage Treatment Plant
Process Audits

APPENDICES

APPENDIX 3-A
MANUALS OF PRACTICE (MOPS) AVAILABLE FROM WATER ENVIRONMENT FEDERATION

1) GENERAL

Design of Municipal Wastewater Treatment Plants MOP 8 (2-volume set), 1992.
Operation of Municipal Wastewater Treatment Plants MOP 11 (3-volume set), 1990.

2) LIQUID TREATMENT

Preliminary Treatment for Wastewater Facilities MOP OM-2, 1980.
Activated Sludge MOP OM-09, 1987.
Aeration MOP FD-13, 1988.
Clarifier Design MOP FD-8, 1985.
Nutrient Control MOP FD-7, 1983.
Operation/Main. of Trickling Filters, RBCs and Related Processes MOP OM-10, 1988.
Operation of Extended Aeration Package Plants MOP OM-7, 1985.
Wastewater Disinfection MOP FD-10, 1986.

3) SLUDGE PROCESSING

Anaerobic Sludge Digestion MOP 16, 1987.
Incineration MOP OM-11, 1988.
Operation and Maintenance of Sludge Dewatering Systems MOP OM-8, 1987.
Sludge Incineration:Thermal Destruction of Residues MFD-19, 1992.
Beneficial Use of Waste Solids MOP FD-15, 1989.
Sludge Conditioning MOP FD-14, 1988.
Sludge Dewatering MOP 20, 1983.
Sludge Stabilization MOP FD-9, 1985.
Sludge Thickening MOP FD-1, 1980.

APPENDIX 3-B
DESIGN MANUALS U.S. ENVIRONMENTAL PROTECTION AGENCY

1) LIQUID TREATMENT

Phosphorus Removal (Sept. 1987). EPA/625/1-87/0001.
Land Treatment of Municipal Wastewater (Oct. 1981). EPA/625/1-81/013.
Municipal Wastewater Disinfection (Oct. 1986) EPA/625/1-86/021.
Fine Pore Aeration Systems (Oct. 1989) EPA/625/1-89/023.
Wastewater Treatment/Disposal for Small Communities (Sept.1992)EPA/625/R-92/0005.
Manual: Nitrogen Control (Sept. 1993) EPA/625/R-93/010.

2) SLUDGE PROCESSING

Dewatering Municipal Wastewater Sludge (Sept. 1987) EPA/625/1-87/014.
Land Application of Municipal Sludge (Oct. 1983) EPA/625/1-83/016.

APPENDIX 5-A
TASK ORDER FORM

Task Order Completed By: _____

Date Completed: _____

Project Number: _____

Project Title: _____

Project Manager: _____

Project Location: _____

GENERAL INFORMATION

When is field work required? Start: _____
Finish: _____

Is field work continuous? _____ or intermittent? _____

Briefly explain the purpose or scope of this project:

Is a site diagram with an **ACCURATE SCALE** attached? _____

Is a site visit planned? Yes _____
No _____

If YES, when? Date: _____
Time: _____

Who will attend the site visit? _____

EQUIPMENT REQUIREMENTS

What temporary instrumentation/equipment will be required for this project?

	YES	NO	Number
DO probes	_____	_____	_____
RAS probes	_____	_____	_____
MLSS probes	_____	_____	_____
ESS probes	_____	_____	_____
Blanket probe	_____	_____	_____
Ultrasonic	_____	_____	_____
Other:			

Number of persons required for installation: _____

Number of persons required for monitoring: _____

Labour: _____ Expenses: _____ Field Days: _____

Labour: Budgeted time for equipment acquisition: _____

Budgeted time for onsite installation: _____

Is overtime expected? _____

Analytical: What is the analytical budget? $ _____

Is a preliminary sampling schedule attached? _____

Which laboratories will be involved? _____

APPENDIX 5-B
SITE VISIT CHECKLIST

Project Number: _____

Project Title: _____

Project Location: _____

Contacts: Phone & Fax No.: _____

Superintendent: _____

Lab Supervisor: _____

Operations Supervisor: _____

Maintenance Supervisor: _____

LOCATION OF TEMPORARY INSTRUMENTATION/EQUIPMENT

1. Return solids probe: _____
2. Mixed liquor solids probe: _____
3. Final effluent solids probe: _____
4. Dissolved oxygen probes: _____
5. Ultrasonic flow meters: _____
6. Sludge blanket monitor: _____
7. Data Acquisition System: _____
8. Others: _____

ESTIMATES OF FIELD WIRING

1 pair	_____m	2 pair	_____m
3 pair	_____m	4 pair	_____m
5 pair	_____m	6 pair	_____m
7 pair	_____m	8 pair	_____m

Overheads: Number of poles?

PLANT ACCESS

When are plant gates open? _____

Who should be contacted during off-hours? _____

LIST EXISTING PLANT EQUIPMENT INTERFACING WITH DATA ACQUISITION SYSTEM

- _____
- _____
- _____
- _____

OTHER TASKS TO BE PERFORMED ONSITE (E.G., H2O2, CROSBY)

- _____
- _____
- _____
- _____

OTHER PERTINENT INFORMATION/COMMENTS

- _____
- _____
- _____
- _____

APPENDIX 5-C
EQUIPMENT AND MATERIALS CHECKLIST FOR ONLINE MONITORING

DATA ACQUISITION SYSTEM

Mini-safe (or other front-end for data acquisition system)
Personal computer
Printer and printer paper
Data acquisition system containment cabinet and lock (if required)
Surge protector
Power supply
Extension cords

FIELD INSTALLATION

Signal isolators
Spools of wire
Wiring junction boxes
Overhead poles for stringing wire
Tie wraps, assorted clamps
Duct tape
Assortment of terminal connectors
Toolkit (general assortment)

INSTRUMENTATION (DEPENDENT ON PROJECT SCOPE)

Field instrument manuals
Probe rods (varies for each instrument)
Rod mounting brackets

DO probes and cells
YSI DO meter
Multiplexer
Ball floats
Calibration canister(s)

Solids transmitters and probes
Sludge blanket monitor (probe, transceiver, transmitter, hardware)
Sludge judge
Flowmeters
Other instrumentation

APPENDIX 5-D
CUSTOMIZED FIELD WORK RECORD SHEET

DESCRIPTION		TIME	FIELD MEAS.	COMPUTER MEAS.	DIFFERENCE	ACTION
DISSOLVED OXYGEN (mg/l)						
TANK #1	PROBE #1 PROBE #2					
TANK #2	PROBE #1 PROBE #2					
TANK #3	PROBE #1 PROBE #2					
TANK #4	PROBE #1 PROBE #2					
SOLIDS CONC. (mg/l)						
	RAS					
	MLSS					
	FINAL SS					
FLOWS (m3/d)						
	FINAL WEIR					
	DEPTH #1					
	DEPTH #2					
OTHERS (SPECIFY)						

APPENDIX 5-E
CALIBRATION STATUS SHEET

Date: _____

Location: _____

Probe: _____

Technician: _____

1. Amount of sample collected (L) _____

2. Average suspended solids concentration _____ mg/L

3. Plant operating range: _____ mg/L to _____ mg/L

4. Desired calibration range: _____ mg/L to _____ mg/L

5. (a) low calibration value: _____ mg/L

   (b) mid calibration value: _____ mg/L

   (c) high calibration value: _____ mg/L

6. Comments:

_____

_____

_____

_____

APPENDIX 5-F
SOLIDS LAB SHEET

Solids Lab Sheet								
Sample	Description/ Date	Tare Wt (mg)	Tare ↓ 106°C Solids (mg)	Tare ↓ 550°C Solids (mg)	Volume (mL)	Residual Suspended Solids (mg/L)	Volatile Solids (mg/L)	% Volatile

APPENDIX 6-A
EXAMPLE FILAMENTOUS ORGANISM IDENTIFICATION WORKSHEET

No._____ Sample _____

SAMPLE DATE ___/___/___ OBSERVATION DATE ___/___/___

FILAMENT ABUNDANCE

0	1	2	3	4	5	6
None	Few	Some	Common	Very Common	Abundant	Excessive

FILAMENT EFFECT ON FLOC STRUCTURE: Little or None Bridging Open Floc Structure

MORPHOLOGY OF FLOC: ☐ Firm ☐ Round, Compact

☐ Weak ☐ Irregular, Diffuse

FLOC DIAMETER (µm)

<150	150 - 500	>500

FEATURES:

Free cells in suspension_____

Zoogloea's _____

Inorganic/Organic Particles_____

FILAMENTOUS MICROORGANISM SUMMARY:

	Rank	Abundance		Rank	Abundance
Nocardia sp.			*M. parvicella*		
type 1701			type 0581		
S. natans			type 0092		
type 021N			type 0803		
Thiothrix sp.			type 1851		
type 0041			type 0961		
H. hydrossis			other		
N. limicola			other		

x = Dominant 0 = Secondary

REMARKS:_____

No._____ Sample _____

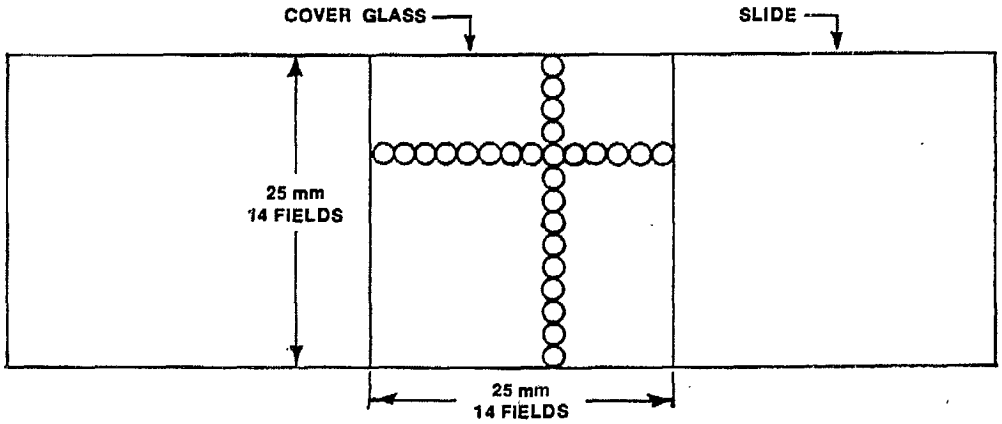
COMMENTS:

OBSERVATION OF:
Protozoa:
Metazoa:

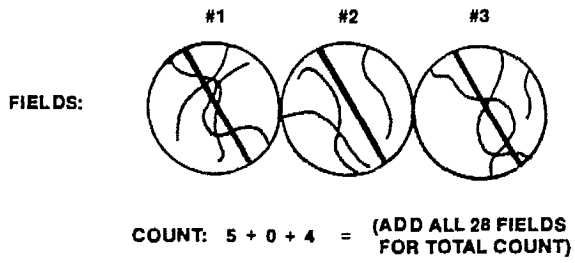
WET MOUNT OBSERVATION, 1000X, PHASE CONTRAST:

FILAMENT #	A	B	C	D	E
BRANCHING					
MOTILITY					
FILAMENT SHAPE					
COLOR					
LOCATION					
ATTACHED UNICELLS					
SHEATH					
CROSSWALLS					
FILAMENT DIAMETER					
LENGTH					
CELL SHAPE					
SIZE					
SULFUR DEPOSITS					
OTHER GRANULES					
COMMONNESS					
RANK					
STAINS, 1000X					
GRAM					
NEISSER					
I.D.					

APPENDIX 6-B
EXAMPLE OF A COUNTING TECHNIQUE FOR DETERMINING NUMBER OF ORGANISMS



TECHNIQUE FOR COUNTING MICROORGANISMS



TECHNIQUE FOR COUNTING FILAMENTS*

NOTE: * TECHNIQUES SHOWN ARE MODIFICATIONS OF ORIGINAL WORK BY R.D. BEEBE, CITY OF SAN JOSE, CALIFORNIA AND D. JENKINS, UNIVERSITY OF CALIFORNIA, BERKELEY (1981) PAPER PRESENTED AT CALIFORNIA WATER POLLUTION CONTROL ASSOCIATION MEETING

DATE _____

TIME _____

WORKSHEET FOR MICROORGANISM COUNTING

ENTER SUM OF ALL 28 FIELDS FOR TOTAL OF EACH TYPE OF BUG

FIELD		AMOEBA		LARGE FLAGELLATES		CILIATES: FREE SWIMMING		CILIATES: STALKED: SINGLES		CILIATES: STALKED: COLONIES		ROTIFIERS		LONG FILAMENTS	
1	15														
2	16														
3	17														
4	18														
5	19														
6	20														
7	21														
8	22														
9	23														
10	24														
11	25														
12	26														
13	27														
14	28														
TOTAL															

HIGH ←	SVI	→ LOW
HIGH ←	F:M	→ LOW
LOW ←	MCRT	→ HIGH

TINY FLAGELLATES _____ NOCARDIA _____

WORMS _____ FLOC CONDITION _____

APPENDIX 6-C
WASTE TREATMENT PERFORMANCE CHARACTERIZED USING RESPIROMETRY ARTICLE PROVIDED BY MR. GARRY PALMATEER SOUTHWESTERN REGIONAL OFFICE MINISTRY OF ENVIRONMENT AND ENERGY

WASTE TREATMENT PERFORMANCE CHARACTERIZED USING RESPIROMETRY

1.1 Introduction

During the 1990's, the major thrust in the management of waste treatment plants in the Province of Ontario has been towards the optimization of their performance. Based on a need to produce higher quality effluents in terms of reduced biochemical oxygen demand (BOD_5) and suspended solids (SS), as well as the necessity to eliminate effluent toxicity, treatment plant operators and the engineers responsible for the management of the waste treatment processes have had to seek new and innovative methods and technologies.

The requirement to address the issue of improving plant performance has developed as a result of two coincident trends. As communities grow, the demand on their pollution control plants to treat elevated loadings of domestic waste increases. Since funding for capital expansion is often limited, the need to optimize the treatment performance of the existing facilities is of the utmost importance.

In addition, as a result of industries that have been established in many communities across Ontario, it is not uncommon for pollution control plants that were originally designed to treat primarily domestic sewage to have to deal with more complex and sometimes inhibitory wastes. In some instances, specific organic or inorganic chemicals inherent to the industrial waste stream may be inhibitory to the biomass comprising the activated sludge. In other circumstances, some of the chemicals may be biodegradable, however, they are frequently mixed with biocides to enhance their shelf life and this also creates a detrimental impact on the biomass of the activated sludge.

1.2 Respirometry Applied

The use of oxygen uptake measurements or respirometry has been employed in the field of sewage treatment for the past fifty years. The method for characterizing biological waste treatment processes using respirometry has been described by Rozich and Gaudy (1992). However, with the advent of the modern day multi-reactor (computerized respirometers that can operate in both aerobic and anaerobic modes), new respirometric procedures can be used to define the treatability of wastes within twenty-four hours (Spanjers and Vanrolleghem, 1995).

Furthermore, the oxygen uptake curves generated during the respirometric run can be converted to biomass growth curves and the biokinetic evaluation of the biomass growth rates can be determined from this information. Using the appropriate biokinetic model, the precise amount of raw sewage (domestic and/or industrial) that can be treated without causing leakage to the final effluent or causing an inhibition of the biomass growth can be determined (D'Adamo et al., 1984).

The biokinetic constants, generated in the biokinetic study, can then be incorporated into standard activated sludge process models to not only predict effluent quality, but also treatment plant size and configuration, flow rates, return sludge rates and the critical loading rates of the exact wastes that require treatment.

1.3 Respirometry Defined

Rozich and Colvin (1991) defined respirometry as the measurement of oxygen uptake exerted by a microbial population contained in a wastewater sample. Under aerobic conditions, the microorganisms exert an oxygen demand proportional to the concentration of organic matter and biomass in the sample. The following expression defines this relationship:

$$\text{Organic Matter} + \text{Biomass} + O_2 \rightarrow CO_2 + H_2O + \text{New Biomass}$$

When this reaction proceeds in the respirometer reaction, the CO_2 produced leaves the well-mixed reaction suspension and collects in the head space of the sample. Since CO_2 is produced proportionally to the amount of oxygen consumed, no pressure change in the reactor is detected.

By adding a strong alkali to the reactor, the CO_2 that is evolved during microbial respiration is absorbed and a pressure differential is created in the respirometer. The differential is corrected by supplying a known quantity of oxygen back to the unit to equilibrate the system. The oxygen supplied to the system is recorded as a function of time and is stored in the computer for plotting purposes depending on the application.

1.4 Respirometric Evaluation – Phase 1

A respirometric evaluation to determine the oxygen uptake when a biomass of activated sludge is fed concentrations of a specific waste is conducted as follows:

- Each reactor is charged with increasing amounts of the feed waste, usually from 10% to 100%. The concentration of feed waste in each reactor should reflect the concentration in the aeration tank of the activated sludge plant being evaluated. In

an eight or twelve reactor respirometer, the feed waste concentrations employed should bracket the concentration typically measured in the aeration tank.

- Each reactor is then charged with one to ten millilitres of biomass. For typical volumes of biomass added to respirometer reactors, see Gaudy et al. (1988).
- If an industrial waste comprises the feed, then the domestic sewage component of feed is simulated by a surrogate synthetic sewage. The synthetic sewage is mixed with the industrial waste in the proportion determined from the raw sewage. This proportion is established by measuring flow rates of the industrial waste and the flow rate of the raw sewage entering the plant. The synthetic sewage formulation from Gaudy et al. (1988) is defined in Table 1.1.
- The synthetic sewage is diluted in the respirometer reactors to the chemical oxygen demand that reflects the concentration of the domestic sewage component of the raw sewage of the plant.
- Once the respirometer reactors have been charged with the appropriate volumes of feed waste and biomass, the reactors should be allowed to equilibrate for one hour before initiating the run.

Following the respirometric run, which in duration represents the detention time of the aeration tank of the plant, the cumulative oxygen uptake curves are plotted as in Figure 1-1.

The above curves represent the cumulative oxygen uptake of biomass in the respective reactors over a period of time. This interval is typical of the retention time of the aeration tank when it is fed raw sewage comprised of representative volumes of domestic and/or industrial waste.

This information may indicate the treatability of an unknown waste in a plant or it may reflect the impact of a specific waste on the biomass of the plant. The family of oxygen uptake curves presents information that exhibits the potential effect of a specific waste on the biomass of the plant being audited.

1.5 Biokinetic Evaluation – Phase 2

Continuous biomass growth is essential to the proper operation of any treatment plant. Biomass growth is dependent on a variety of factors that are controlled by the design and operation of the plant. The most important factor, the wastes received, however, is dependent on the material discharged by the contributors to the sewage system.

All plants operate at different levels of efficiency with regards to substrate removal. The efficiency level is dependent upon the basic plant design and the type of waste received and it is determined

Table 1.1
Synthetic Sewage Formulation

Constituent	Concentration (g/L)
Bacto-peptone	32.0
Beef Extract	22.0
Urea	6.0
Na Cl	1.4
$Ca\ Cl_2, 2H_2O$	0.8
$Mg\ SO_4, 7H_2O$	0.4
$KH_2\ PO_4$	3.5
$K_2H\ PO_4$	4.5
Distilled Water	To Volume

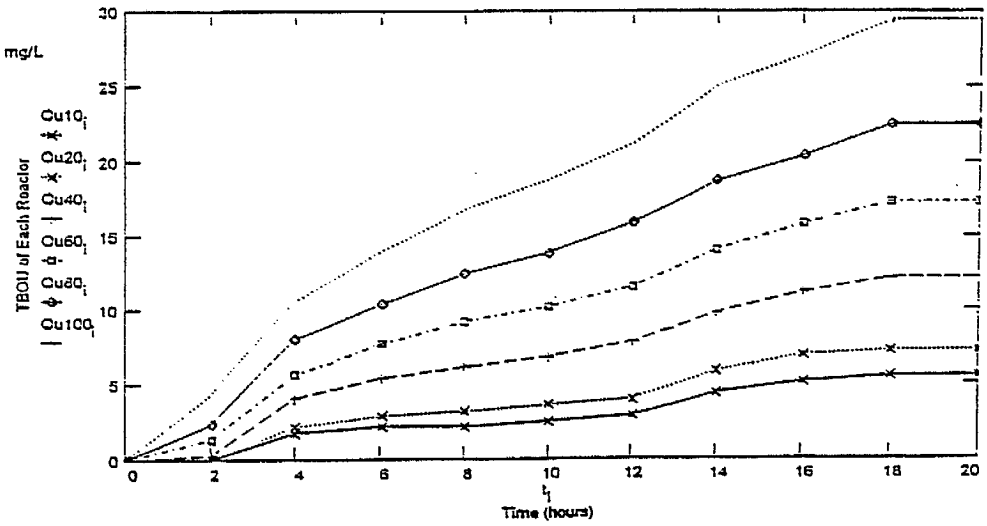


Figure 1-1
Total Biochemical Oxygen Uptake for Reactors Containing 10%, 20%, 40%, 60%, 80% and 100% Feed Waste

by the size, flow, aeration rate, return activated sludge cycle rate, etc. These are some of the variables that contribute to and affect the biomass growth rate.

Sustained reproduction of the biomass microorganisms in a plant receiving domestic waste is relatively simple when compared to that of a plant receiving both domestic and industrial waste. However, one of the major problems experienced in plants receiving domestic waste only is having enough food to maintain a sustained biomass growth.

Continued sustainable biomass growth in any plant receiving an industrial waste, is contingent on the major variable of concern, that is, wastes that have an inhibitory effect on the biomass.

1.6 Continuous Biomass Growth Rate

The continuous growth rate of the biomass on a specific feed or substrate in any treatment plant, domestic or industrial, can be modelled using one of two biokinetic equations.

- The Monod equation for non-inhibitory wastes is defined by:

$$\mu = \frac{\mu Max \cdot S}{K_s + S}$$

where:

μ = specific biomass growth rate per hour
μMax = maximum specific growth rate per hour
S = feed concentration as soluble chemical oxygen demand (COD) in mg/L
K_s = the saturation constant, is the substrate concentration of soluble COD in mg/L that produces one-half the maximum growth rate of the biomass

Figure 1-2 illustrates the biomass growth rate when fed increasing amounts of a non-inhibitory waste.

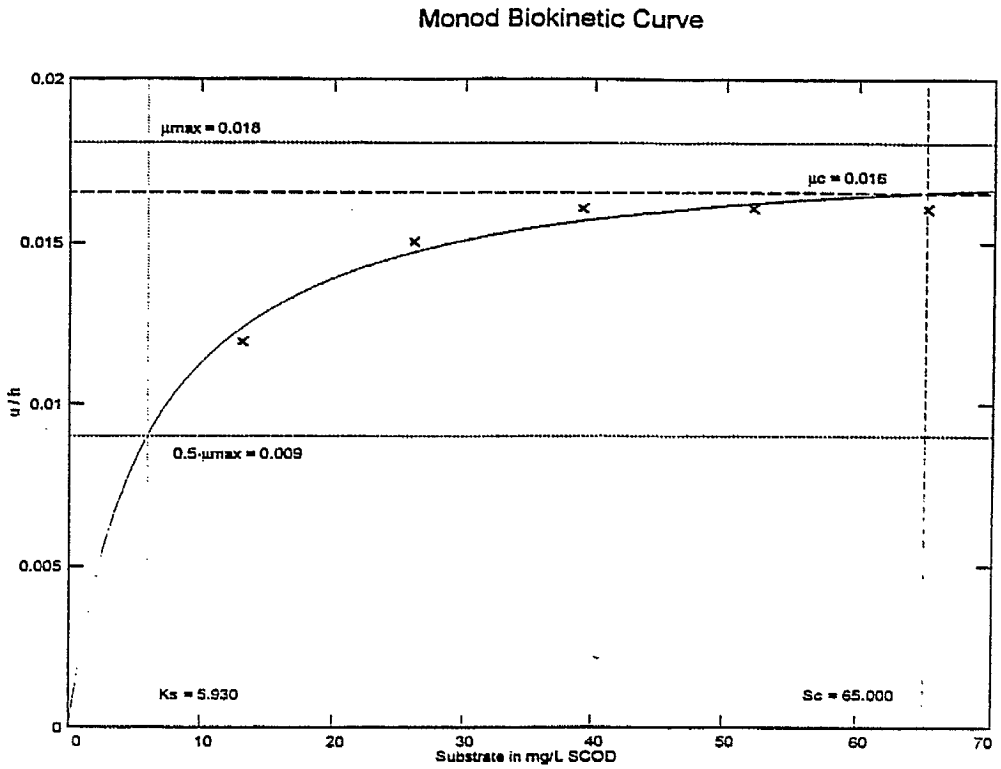


Figure 1-2
Biokinetic Growth Rate Curve for a Biomass Fed a Non-Inhibitory Waste

- The Haldane equation for use with inhibitory wastes is defined by:

$$\mu = \frac{\mu Max \cdot S}{K_s + S + S^2/K_i}$$

where:

K_i = the inhibition constant, is the concentration of inhibitory waste in mg/L

- See Figure 1-3, which illustrates the biomass growth rate when fed increasing concentrations of inhibitory waste.
- In order to generate the preceding biokinetic curves, a non-linear regression analysis using the appropriate model equation was conducted. The data pairs of varying growth rate values with corresponding substrate concentrations (S) were developed from oxygen uptake curves generated by a respirometer.

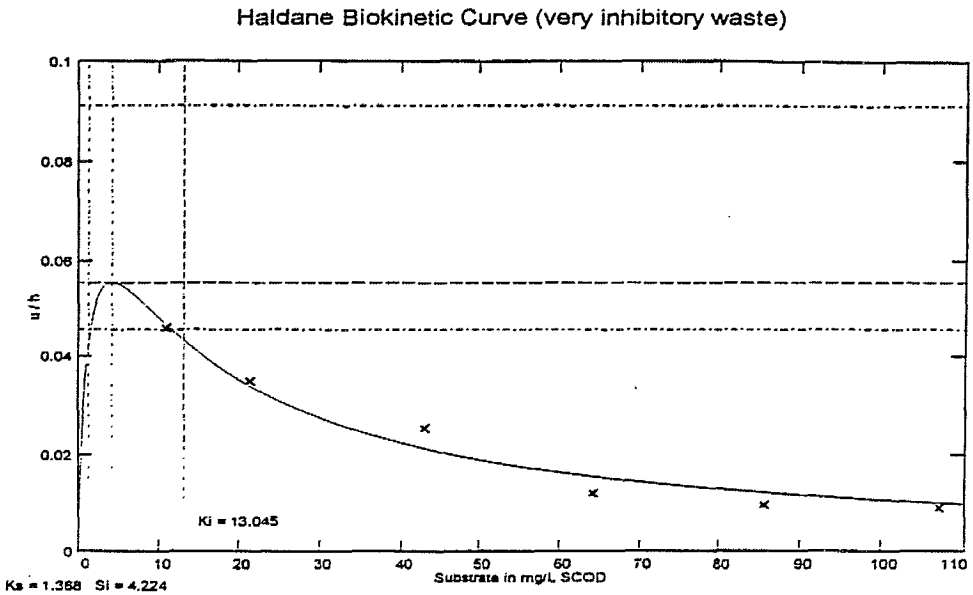


Figure 1-3
Biokinetic Growth Rate Curve of a Biomass Fed an Inhibitory Waste

1.7 Method of Determining the Biomass Growth Rate

The first step in the process of establishing the growth rate relating to a specific feed concentration is to convert the oxygen uptake data from the respirometer to biomass growth in mg/L. The relationship between oxygen uptake and biomass growth is based on the assumption that the soluble COD removed from the solution during metabolism is channelled into varying proportions of the synthesis of new cells and to respiration, which is measured as oxygen uptake. This relationship is shown in Equation 1.

- **Equation 1** $\Delta COD = O_2 \text{ Uptake} + \Delta COD \text{ Cells}$

This simplifies the relationship between the cell mass as suspended solids (SS) in mg/L to oxygen uptake.

- **Equation 2** $X_t = X_o + \dfrac{O_2 \text{ Uptake}}{1/Y - O_x}$

where:

X_o = biomass as SS in mg/L at the beginning of respirometric run
X_t = biomass as SS in mg/L at a specific time in the respirometric run
O_2 = oxygen uptake in mg/L at a specific time in the respirometric run
O_x = COD in mg per mg of biomass
Y = Yield (mg of biomass produced per mg of COD metabolized)

- O_x is calculated as follows: Total COD – COD_s/X_t

The total COD in a reactor is measured during the respirometric run. The soluble COD is also measured at the same time intervals.

The X_t value is a measurement in mg/L of the suspended solids at the same time intervals as the total and soluble COD measurements. This set of values should be measured at least three times during respirometric run in order to calculate an average O_x value.

- Y (Yield Value) is calculated as follows:

$$Y = \frac{SS_t - SS_o}{COD_o - COD_t}$$

The suspended solids are measured at the beginning and at the end of the respirometric run. Similarly, the soluble COD is measured at the beginning and at the end of the respirometric run. The yield value is calculated (in mg/L) as the mg of biomass generated by a reduction in the soluble COD.

- At this point, Y and O_x are entered into Equation 2 with the oxygen uptake measurements acquired during the respirometric run. This calculation is easily computerized.

The new biomass values generated from the oxygen uptake values are plotted over the period of the respirometric run. The resulting graph is a set of growth curves for the biomass in each reactor that contained specific starting concentrations of the feed waste.

- **Equation 3** $\mu = \frac{\ln (X_2/X_1)}{t_2 - t_1}$

The growth rate μ is calculated for every feed waste value in each reactor.

- The data pairs of μ and S for each reactor are then incorporated into one of the models, Monod for non-inhibitory wastes or Haldane for inhibitory wastes. Using a standard non-linear regression analysis, the biokinetic constants μMax, K_s and K_i are computed. The μ and S values are then plotted. The statistical software package, Systat, provided the necessary calculation and plotting capabilities, although many others brands are available.

1.8 Discussion of Biokinetic Curves

Figures 1-2 and 1-3 exemplify the biokinetic curves for both non-inhibitory wastes and inhibitory wastes respectively, along with the biokinetic constants.

It can be easily observed in Figure 1-2 that, as the feed waste increased in concentration, the biomass microorganisms grew rapidly until they reached a critical specific growth rate (μc). If the feed concentration exceeds the critical substrate concentration (Sc) in mg/L, the feed waste begins to leak from the plant and it will be detected in the plant effluent. The K_s constant in mg/L is that amount of substrate that generates one-half the maximum growth rate of the biomass.

The critical substrate concentration (Sc) is determined as follows:

- S_c = initial substrate concentration of soluble COD measured in the 100% reactor

The critical specific growth rate (μ_c) is calculated as follows:

$$\mu = \frac{\ln (X_2/X_1)}{t_1 - t_2}$$

In Figure 1-3, the plot of the growth rate of the biomass in an inhibitory waste was more complex. Initially, the growth rate appeared to be similar to a non-inhibitory growth rate. However, as the feed waste increased as soluble COD in mg/L, a point was reached where the growth began to decline. The maximum critical specific growth rate (μ_{ci}) occurred as a result of a critical substrate (S_i) concentration in mg/L. If the critical substrate concentration increases beyond S_i, then the biomass microorganisms begin to be inhibited. If this feed waste concentration persists, the entire biomass will die and the activated sludge will wash out.

The critical specific growth (μ_{ci}) is calculated as follows:

$$\mu_{ci} = \frac{\mu Max}{1 + 2\sqrt{K_s}/\sqrt{K_i}}$$

The critical substrate concentration (S_i) is calculated as follows:

- $S_i = \sqrt{K_s} \cdot \sqrt{K_i}$

It is readily evident from either of these curves that an optimal feed rate as soluble COD, which can be converted to BOD_5, can be employed in the operation of the plant. This information can be used effectively to determine the loadings of domestic waste and industrial wastes discharging to the sewer. Precise loading rates can be generated for separate industrial wastes discharging to the pollution control plants and surcharges could be developed from this type of data that would reflect the actual treatment required. It would also be an aid in preventing shock loadings of toxic wastes that would affect the plant biomass.

The biokinetic constants generated for specific wastes are subject to some variation based on temperature, consequently, they may have to be recalculated twice a year and based on the temperature differences between summer and winter in Ontario. Rozich and Gaudy (1992) Cht. 6, gives a detailed discussion of the factors affecting biokinetic constants.

The suboptimal performance of an activated sludge plant can often be the result of the inhibitory nature of the raw waste loadings. However, oxygen uptake measurements can easily be generated with a multi-reactor computerized respirometer within twenty-four hours, which will demonstrate the amount of waste which is affecting optimal performance. This process, although simplistic, can inexpensively provide conclusive data that defines the impact that the raw wastes entering the plant have on the biomass.

The second phase of producing the biokinetic constants and growth curve establishes the exact amount of a specific waste that can be treated (Garniewski-Clay et al., 1991).

If a specific discharge from an industry is identified as being inhibitory, the industry can be notified that their waste is reducing the pollution plant's performance and by what amount. This information can provide the impetus for the industry to do further respirometric investigations of their in-plant waste streams to determine what the inhibitory component(s) of their waste is/are.

An obvious benefit of this approach to optimizing plant performance is that expensive and detailed chemical analyses need not be conducted because the respirometric analyses have highlighted the waste(s) that is/are having a negative impact on the plant biomass microorganisms.

1.9 Respirometry Costs

The respirometric analyses as described above can be accomplished with an eight reactor respirometer, which in Canadian dollars in 1995 costs between $25,000 to $35,000. Currently, there are several manufacturers who are producing excellent instruments. The annual savings realized in preventing upset conditions at a plant, optimizing plant performance, reducing in-treatment additives and the potential surcharge revenue makes acquiring a respirometer economically feasible. In addition, several engineering consulting firms in Ontario provide respirometric analyses as described above.

1.10 Case History

The town of Ingersoll has two mechanical activated sludge pollution control plants that treat identical raw sewage comprised of both domestic and industrial wastes. The old plant, which treats 2,270 m^3 per day, has diffused aeration with a ten hour retention time in the aeration tank. The new plant treats 5,448 m^3 per day and has mechanical aeration with a five hour retention time in the aeration tank. The performance of both plants was less than optimal. Frequent loss of solids and extensive foaming was occurring.

A complete biokinetic evaluation was conducted on each plant. Five industrial discharges to the sanitary sewers were continuously sampled with automatic samplers until plant upsets occurred. Using the biomass microorganisms from each plant for the respirometric analyses, the five industrial wastes suspected of contributing to the upset were investigated. Weekend sewage, which was low in industrial wastes, and mid-week sewage, which was high in industrial wastes, were also studied. A control of synthetic sewage was also run to demonstrate the biomass growth potential when growing on a readily degradable substrate.

The oxygen uptake curves by the weekend and mid-week were found to be dramatically different. The mid-week curves were significantly lower than the oxygen uptake curve of the weekend. Further biokinetic evaluations revealed that much more weekend sewage could be treated than the mid-week sewage.

The respirometric investigation elucidated the reasons for these differences when each industrial waste underwent the biokinetic evaluations. The results of the investigation are shown in Table 1.2.

Table 1.2
Summary of Biokinetic Constants from the Performance Evaluation of the Ingersoll Pollution Control Plants

Industrial Waste	Plant Biomass	µMax /h	K_s mg/L	S_c mg/L	K_i mg/L
Weekend	New	0.005	1.80	119.0	-
	Old	0.026	10.99	140.0	-
Weekday	New	0.028	1.60	6.27	24.55
	Old	0.031	2.67	10.36	40.14
B	New	0.357	4.89	10.08	20.76
	Old	0.238	2.73	14.06	72.34
C	New	0.216	3.30	7.92	19.04
	Old	0.387	3.35	7.03	14.72
D	New	0.454	2.42	7.62	23.98
	Old	0.213	1.10	7.72	53.92
E	New	0.233	1.80	4.58	11.68
	Old	0.125	1.18	3.49	10.34
F	New	0.091	1.37	4.22	13.45
	Old	0.155	1.90	7.28	27.87
G	New	0.102	4.87	13.59	37.89
	Old	0.066	3.54	10.40	30.51

It can be observed that the biokinetic constants for the raw sewage treated on the weekend was a Monod or non-inhibitory relationship, however, the evaluation conducted on the mid-week raw sewage displayed a Haldane or inhibitory relationship.

The critical substrate concentrations, that is the maximum concentration of raw sewage treatable without leaking from the plant or causing a die-off of the biomass, were significantly different from the weekend evaluation, when compared to the weekday analyses. The weekend Sc was 119.0 mg/L while the weekday value was 6.3 mg/L.

When the biokinetic constants and the critical specific substrate concentrations were determined for each industrial waste, it was obvious that the industrial wastes were very inhibitory to the biomass microorganisms of each plant.

The precision of biokinetic evaluations provides specific objectives for industry in order to ensure that the pollution control plants produce an acceptable effluent quality on a consistent basis. Significant progress has been achieved with the five industries that ranges from changes in plant production materials, to complete pre-treatment systems.

In conclusion, the use of respirometric technology to characterize an activated sludge pollution control plant can significantly improve its treatability and provide relevant data that can be used in process control models to predict effluent quality. The data can also be used by regulatory control agencies to expedite abatement measures regarding inhibitory loadings to pollution control plants.

2.0 References and Further Reading

D'Adamo, P.D., Rozich, A.F. and Gaudy, Jr., A.F. (1984). Analysis of growth data with inhibitory carbon sources. *Biotechnology and Bioengineering*, 26: 397 - 402.

Garniewski-Clay, S., Gaudy, Jr., A.F., Rozich, A.F. and Moran, N.R. (1991). A practical use for respirometry for assessing industrial discharges to POTWS. *WPCF 64th Annual Conference and Exposition*, Toronto, Canada, Oct. 7 - 10.

Gaudy, Jr., A.F., Rozich, A.F., Garniewski, S., Moran, N.R. and Ekambaram, A. (1988). Methodology for utilizing respirometric data to assess biodegradation kinetics. *42nd Purdue University Industrial Waste Conference Proceedings*, 573 - 584.

Rozich, A.F. and Colvin, R.J. (1990). Formulating Strategies for Activated Sludge Systems. *WATER/Engineering & Management Magazine*, 9: 28 - 31.

Rozich, A.F. and Gaudy, Jr., A.F. (1992). Design and operation of activated sludge processes using respirometry. Lewis Publishers, Chelsea, Michigan, 189 pg.

Spanjers, H. and Vanrolleghem, P. (1995). Respirometry as a tool for rapid characterization of wastewater and activated sludge. *Wat. Sci. Tech.*, 31: 2: 105 - 114.

Extract
Canada Gazette, Part I
December 4, 2004

Extrait
Gazette du Canada, Partie I
Le 4 décembre 2004

DEPARTMENT OF THE ENVIRONMENT

MINISTÈRE DE L'ENVIRONNEMENT

Notice requiring the preparation and implementation of pollution prevention plans for inorganic chloramines and chlorinated wastewater effluents

Avis requérant l'élaboration et l'exécution de plans de prévention de la pollution à l'égard des chloramines inorganiques et des eaux usées chlorées

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Published by the Queen's Printer for Canada, 2004

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Publié par l'Imprimeur de la Reine pour le Canada, 2004

DEPARTMENT OF THE ENVIRONMENT

CANADIAN ENVIRONMENTAL PROTECTION ACT, 1999

Notice requiring the preparation and implementation of pollution prevention plans for inorganic chloramines and chlorinated wastewater effluents

Whereas inorganic chloramines and chlorinated wastewater effluents are substances specified on the List of Toxic Substances in Schedule 1 of the *Canadian Environmental Protection Act, 1999*;

Whereas the Minister of the Environment published a Proposed Notice requiring the preparation and implementation of pollution prevention plans for ammonia dissolved in water, inorganic chloramines and chlorinated wastewater effluents in the *Canada Gazette*, Part I, on June 7, 2003;

Whereas persons were given the opportunity to file comments with respect to the Proposed Notice for a comment period of 60 days;

Whereas the Minister has considered all comments received;

MINISTÈRE DE L'ENVIRONNEMENT

LOI CANADIENNE SUR LA PROTECTION DE L'ENVIRONNEMENT (1999)

Avis requérant l'élaboration et l'exécution de plans de prévention de la pollution à l'égard des chloramines inorganiques et des eaux usées chlorées

Attendu que les chloramines inorganiques et les eaux usées chlorées sont des substances figurant sur la Liste des substances toxiques de l'annexe 1 de la *Loi canadienne sur la protection de l'environnement (1999)*;

Attendu que le ministre de l'Environnement a publié un projet d'avis requérant l'élaboration et l'exécution de plans de prévention de la pollution à l'égard de l'ammoniac dissous dans l'eau, des chloramines inorganiques et des eaux usées chlorées dans la Partie I de la *Gazette du Canada* le 7 juin 2003;

Attendu que toute personne a eu la possibilité d'envoyer des commentaires concernant le projet d'avis pendant une période de commentaires de 60 jours;

Attendu que le ministre a considéré tous les commentaires reçus;

Whereas this Notice is issued as an instrument respecting preventive and control action in relation to inorganic chloramines and chlorinated wastewater effluents in application of section 92 of the Act;

And whereas, the Minister has published a *Guideline for the Release of Ammonia Dissolved in Water Found in Wastewater Effluents*;

The Minister of the Environment hereby requires all persons or class of persons described in section 2 of this Notice to prepare and implement a pollution prevention plan in respect of inorganic chloramines and chlorinated wastewater effluents.

STÉPHANE DION
Minister of the Environment

1. Definitions

"Act" means the *Canadian Environmental Protection Act, 1999*.

"effluent" means untreated or treated wastewater that is released from the outfall(s) of a wastewater system, excluding combined sewer overflows from the wastewater system.

"inorganic chloramines" consists of three chemicals that are formed when chlorine and ammonia are combined in water: monochloramine (NH_2C1), dichloramine ($NHC1_2$) and trichloramine ($NC1_3$).

"representative sampling" means the daily measurement of total residual chlorine concentration in the effluent under normal operating conditions of the wastewater treatment facility.

"surface water" means a lake, pond, marsh, creek, spring, stream, river, estuary or marine body of water, or other surface watercourse.

"total residual chlorine", or TRC, means the concentration of free chlorine and combined chlorine (including inorganic chloramines), expressed as Cl^-.

"wastewater" means a mixture of liquid wastes primarily composed of domestic sewage, that can also include other liquid wastes from industrial, commercial and institutional sources.

"wastewater system" means any works for the collection or treatment and release of wastewater or any part of such works.

2. Person or class of persons required to prepare and implement a pollution prevention plan

This Notice applies to any person who owns a wastewater system at the time of publication of this Notice where the effluent released during either 2004 or 2005 from that system to surface water is greater than or equal to 5 000 m^3 per day, based on an annual average, and where the concentration of total residual chlorine in the effluent released to surface water exceeds 0.02 mg/L in any sample during either 2004 or 2005, based on representative sampling.

3. Activities in relation to which the plan is to be prepared

The Minister requires all persons subject to this Notice to prepare and implement a pollution prevention plan in relation to the use of chlorine or chlorine compounds in wastewater systems and the release of chlorinated effluent to surface water.

Attendu que cet avis est publié comme un instrument concernant les mesures de prévention et de contrôle à l'égard des chloramines inorganiques et des eaux usées chlorées en application de l'article 92 de la Loi;

Et attendu que le ministre a publié une *Ligne directrice sur le rejet de l'ammoniac dissous dans l'eau se trouvant dans les effluents d'eaux usées*;

Le ministre de l'Environnement exige par la présente que toutes personnes ou catégories de personnes, telles qu'elles sont décrites à la section 2 de cet avis, élaborent et exécutent un plan de prévention de la pollution à l'égard des chloramines inorganiques et des eaux usées chlorées.

Le ministre de l'Environnement
STÉPHANE DION

1. Définitions

« chloramines inorganiques » comprend trois substances chimiques formées par la combinaison du chlore et de l'ammoniac dans l'eau : la monochloramine (NH_2C1), la dichloramine ($NHC1_2$) et la trichloramine ($NC1_3$).

« chlore résiduel total », ou CRT, désigne la concentration de chlore libre et de chlore combiné (incluant les chloramines inorganiques), exprimée en Cl^-.

« eau de surface » désigne un lac, un étang, un marais, un ruisseau, une source, un cours d'eau, une rivière, un estuaire ou un plan d'eau marin, ou tout autre cours d'eau de surface.

« eaux usées » désigne un mélange d'eaux usées, composé principalement d'eau d'égout domestique, qui peut aussi contenir d'autres eaux usées de sources industrielles, commerciales et institutionnelles.

« échantillonnage représentatif » désigne la mesure quotidienne de la concentration de chlore résiduel total dans l'effluent, selon les conditions opérationnelles normales de l'installation de traitement des eaux usées.

« effluent » désigne les eaux usées traitées ou non traitées qui sont rejetées à l'exutoire d'un réseau d'assainissement, en excluant les débordements de réseaux d'égouts unitaires du réseau d'assainissement.

« Loi » désigne la *Loi canadienne sur la protection de l'environnement (1999)*.

« réseau d'assainissement » désigne tous les ouvrages servant à la collecte ou au traitement et au rejet des eaux usées, ou toute partie de ces ouvrages.

2. Personne ou catégorie de personnes qui sont tenues d'élaborer et d'exécuter un plan de prévention de la pollution

Cet avis s'applique à toute personne qui, au moment de la publication de cet avis, possède un réseau d'assainissement dont le rejet annuel moyen d'effluent dans les eaux de surface, soit en 2004 ou en 2005, est supérieur ou égal à 5 000 mètres cubes par jour et où la concentration du chlore résiduel total dans cet effluent est supérieur à 0,02 mg/L dans tout échantillon, soit en 2004 ou en 2005, tel qu'elle est déterminée d'après un échantillonnage représentatif.

3. Activités en fonction desquelles le plan devra être élaboré

Le ministre exige que toutes les personnes assujetties à cet avis élaborent et exécutent un plan de prévention de la pollution en ce qui concerne l'usage du chlore ou de composés chlorés dans les réseaux d'assainissement et le rejet d'effluents chlorés dans les eaux de surface.

4. Factors to be considered in preparing the plan

During the preparation of pollution prevention plans, the Minister requires all persons subject to this Notice to consider the following factors:

(1) Following detailed scientific assessments, inorganic chloramines and chlorinated wastewater effluents were found to be toxic under the Act. As such, these substances were added to the List of Toxic Substances in Schedule 1 of the Act. Persons subject to this Notice shall consider that these substances are "toxic" in accordance with the criteria set out in section 64 of the Act. In addition, the deposit of a deleterious substance of any type in water frequented by fish is prohibited by the *Fisheries Act*, under subsection 36(3), unless there is a regulation under subsection 36(5) of the *Fisheries Act* or under another federal law authorizing the deposit. With respect to inorganic chloramines and chlorinated wastewater effluents, there is no federal regulation at time of publication. Refer to section 15 of this Notice for links to the *Fisheries Act* and Compliance and Enforcement Policies of the *Fisheries Act* and the Act.

(2) "Pollution prevention", as defined in section 3 of the Act, means the use of processes, practices, materials, products, substances or energy that avoid or minimize the creation of pollutants and waste and reduce the overall risk to the environment or human health. Pollution prevention planning is a means of addressing the release, to the environment, of toxic substances or other pollutants. The result of pollution prevention planning is the implementation of preventive and/or control actions. In order to achieve the risk management objective set out in subsection 4(3), persons subject to this Notice shall consider the following activities when preparing and implementing their pollution prevention plans:

(*a*) Conducting process audits for chlorine by June 15, 2006, and implementing actions based on the audit findings by December 15, 2008, that minimize the use and release of chlorine or chlorine compounds. Refer to section 15 of this Notice for links to technical guidance.

(*b*) Implementing dechlorination or alternative disinfection technologies. Refer to section 15 of this Notice for links to technical guidance.

(3) The risk management objective for this Notice is to achieve and maintain a concentration of total residual chlorine that is less than or equal to 0.02 mg/L in the effluent released to surface water by December 15, 2009.

(4) The Canadian Council of Ministers of the Environment (CCME) agreed in November 2003 to develop a Canada-wide Strategy for the management of municipal wastewater effluents, which will address specific parameters and governance. The Strategy will be based on the following three cornerstones:

(*a*) harmonization of the regulatory framework;

(*b*) co-ordinated science and research; and

(*c*) an environmental risk management model.

The Strategy is expected to be completed by December 2006, after which it will be implemented by each jurisdiction. Environment Canada intends to use regulations under the *Fisheries Act* as its principal implementation tool to achieve effluent standards for wastewater treatment systems equivalent in performance to conventional secondary treatment, with additional treatment where required. The regulations will also address wastewater systems on federal and aboriginal lands. Refer to section 15 of this Notice for links to the CCME Web site and information on the Canada-wide Strategy.

(5) In order to ensure that the overall risk to the environment or human health is reduced, the pollution prevention plan prepared for this Notice should include, where relevant,

4. Facteurs à considérer lors de l'élaboration du plan

Le ministre exige que toutes les personnes assujetties à cet avis considèrent les facteurs suivants lors de l'élaboration de leur plan de prévention de la pollution :

(1) À la suite d'évaluations scientifiques approfondies, les chloramines inorganiques et les eaux usées chlorées ont été déclarées comme substances toxiques en vertu de la Loi. À ce titre, ces substances ont été ajoutées à la Liste des substances toxiques de l'annexe 1 de la Loi. Les personnes assujetties à cet avis doivent considérer que ces substances sont « toxiques » selon les critères établis à l'article 64 de la Loi. De plus, le dépôt d'une substance nocive dans les eaux où vivent les poissons est interdit par le paragraphe 36(3) de la *Loi sur les pêches* à moins qu'il n'y ait un règlement qui l'autorise, soit en vertu du paragraphe 36(5) de cette même loi ou d'une autre loi fédérale. En ce qui concerne le rejet des chloramines inorganiques et des eaux usées chlorées, il n'existe aucun règlement fédéral au moment de la publication de cet avis. Les adresses Internet des sites d'information sur la *Loi sur les pêches* et les politiques de conformité et d'application des dispositions de cette loi ainsi que de la *Loi canadienne sur la protection de l'environnement (1999)* se trouvent à l'article 15 de cet avis.

(2) La « prévention de la pollution », au sens de l'article 3 de la Loi, désigne l'utilisation de procédés, de pratiques, de matériaux, de produits, de substances ou de formes d'énergie qui, d'une part, empêchent ou réduisent au minimum la création de polluants et de déchets, et d'autre part, réduisent les risques d'atteinte à l'environnement ou à la santé humaine. La planification de la prévention de la pollution constitue un moyen de diminuer le rejet de substances toxiques ou d'autres polluants dans l'environnement. Le résultat de la planification de la prévention de la pollution comporte l'exécution de mesures préventives ou de contrôle. Afin d'atteindre l'objectif de gestion des risques, tel qu'il est décrit au paragraphe 4(3) de cet avis, les personnes assujetties à cet avis doivent considérer les activités suivantes lors de l'élaboration et de l'exécution de leur plan de prévention de la pollution :

a) Entreprendre des vérifications de procédés pour le chlore d'ici le 15 juin 2006 et mettre en œuvre des mesures basées sur les conclusions des vérifications qui minimisent l'utilisation et le rejet de chlore et de composés chlorés d'ici le 15 décembre 2008. Une liste de sites Internet ayant des informations techniques se trouve à l'article 15 de cet avis.

b) Appliquer des techniques de déchloration ou techniques alternatives de désinfection. Se référer à l'article 15 de cet avis pour consulter une liste de sites Internet présentant des documents techniques sur les options de prévention et de contrôle disponibles.

(3) L'objectif de gestion des risques de cet avis est d'atteindre et de maintenir une concentration de chlore résiduel total inférieure ou égale à 0,02 mg/L dans l'effluent rejeté dans les eaux de surface d'ici le 15 décembre 2009.

(4) Le Conseil canadien des ministres de l'environnement (CCME) a convenu en novembre 2003 d'élaborer une stratégie pancanadienne pour la gestion des effluents d'eaux usées municipales qui portera sur l'élaboration de paramètres spécifiques et sur des questions de gouvernance. La stratégie se fondera sur les trois pierres angulaires suivantes :

a) l'harmonisation du cadre réglementaire;

b) la coordination de la science et de la recherche;

c) un modèle de gestion des risques environnementaux.

On prévoit que la stratégie sera complétée d'ici décembre 2006, ce après quoi elle sera mise en œuvre par chaque instance. Environnement Canada a l'intention d'utiliser un

prevention and control actions that address risks posed by other substances that may be found in municipal wastewater effluent, in particular, the following substances which are specified in Schedule 1 of the Act:

(*a*) nonylphenol and its ethoxylates;

(*b*) effluents from textile mills that use wet processing;

(*c*) mercury;

(*d*) lead;

(*e*) hexavalent chromium compounds;

(*f*) inorganic cadmium compounds;

(*g*) inorganic arsenic compounds; and

(*h*) ammonia dissolved in water.

règlement en vertu de la *Loi sur les pêches* comme son principal outil d'exécution afin que les réseaux d'assainissement atteignent des normes qui seront équivalentes, en performance, au rendement du traitement secondaire conventionnel, avec un traitement supplémentaire au besoin. Le règlement tiendra compte des systèmes d'eaux usées se trouvant sur les terres fédérales et autochtones. L'adresse Internet du site d'information sur la stratégie pancanadienne du CCME se trouve à l'article 15 de cet avis.

(5) Pour s'assurer de réduire le risque global pour l'environnement ou la santé humaine, le plan de prévention de la pollution élaboré pour répondre à cet avis devrait comprendre, s'il y a lieu, des mesures de prévention et de contrôle visant les risques posés par d'autres substances qui peuvent se trouver dans les effluents d'eaux usées municipales, en particulier les substances suivantes figurant à l'annexe 1 de la Loi :

a) le nonylphénol et ses dérivés éthoxylés;

b) les effluents des usines de textile qui utilisent des procédés de traitement au mouillé;

c) le mercure;

d) le plomb;

e) les composés de chrome hexavalent;

f) les composés inorganiques de cadmium;

g) les composés inorganiques d'arsenic;

h) l'ammoniac dissous dans l'eau.

5. Period within which the pollution prevention plan is to be prepared

The Minister requires that the pollution prevention plan be prepared and implementation be initiated by June 15, 2007.

5. Délai imparti pour l'élaboration du plan de prévention de la pollution

Le ministre exige que le plan de prévention de la pollution soit élaboré et que l'exécution en soit commencée au plus tard le 15 juin 2007.

6. Period within which the pollution prevention plan is to be implemented

The Minister requires that the pollution prevention plan be implemented by June 15, 2010.

6. Délai imparti pour l'exécution du plan de prévention de la pollution

Le ministre exige que l'exécution du plan de prévention de la pollution soit exécutée au plus tard le 15 juin 2010.

7. Content of the pollution prevention plan

Persons preparing the pollution prevention plan are to determine the appropriate content of their own plan; however, the plan must meet all the requirements of this Notice. It must also contain the information required to file the Declaration of Preparation referred to in section 9 and have the capacity to generate the information required to file the Declaration of Implementation referred to in section 10.

7. Contenu du plan de prévention de la pollution

Les personnes chargées de l'élaboration du plan doivent en déterminer le contenu; toutefois, le plan doit satisfaire à toutes les exigences de cet avis. Il doit également inclure les informations exigées pour déposer la déclaration confirmant l'élaboration à laquelle l'article 9 se réfère et pouvoir générer les informations exigées pour déposer la déclaration confirmant l'exécution à laquelle l'article 10 se réfère.

8. Requirement to keep plan

Under section 59 of the Act, all persons identified in section 2 shall keep a copy of the pollution prevention plan at the place in Canada in relation to which the pollution prevention plan is prepared. Where a single plan is prepared for more than one wastewater system, a copy of that plan must be kept at each location.

8. Obligation de conserver une copie du plan

En vertu de l'article 59 de la Loi, les personnes identifiées à l'article 2 de cet avis doivent conserver une copie du plan de prévention de la pollution au lieu, au Canada, en faisant l'objet. Lorsqu'un seul plan est élaboré pour plusieurs réseaux d'assainissement, une copie de ce plan doit être conservée à l'emplacement de chacun des réseaux d'assainissement en faisant objet.

9. Declaration of Preparation

Under subsection 58(1) of the Act, persons identified in section 2 shall file, within 30 days after the end of the period for the preparation of the pollution prevention plan specified in section 5 or extended under section 13, a written *Declaration That a Pollution Prevention Plan Has Been Prepared and Is Being Implemented — Inorganic Chloramines and Chlorinated Wastewater Effluents*, using the form given in Schedule 1 of this Notice, to the Minister. Where a person has prepared a single plan for more than

9. Déclaration confirmant l'élaboration

En vertu du paragraphe 58(1) de la Loi, les personnes identifiées à l'article 2 doivent déposer par écrit auprès du ministre, dans les 30 jours suivant la fin du délai fixé à l'article 5 pour l'élaboration du plan ou, selon le cas, prorogé en vertu de l'article 13, une *Déclaration confirmant qu'un plan de prévention de la pollution a été élaboré et qu'il est en cours d'exécution — chloramines inorganiques et eaux usées chlorées*, en utilisant le formulaire fourni à l'annexe 1 de cet avis. Dans le cas où une

one wastewater system, a separate Declaration of Preparation must be filed for each of those systems. Section 17 provides further information on completing and filing this form.

personne a élaboré un plan unique pour plus d'un réseau d'assainissement, une déclaration confirmant l'élaboration séparée doit être déposée pour chacun des réseaux. Les détails sur la façon de produire et de déposer ce formulaire se trouvent à l'article 17.

10. Declaration of Implementation

Under subsection 58(2) of the Act, persons identified in section 2 shall file, within 30 days after the completion of the implementation of the plan specified in section 6 or extended under section 13, a written *Declaration That a Pollution Prevention Plan Has Been Implemented — Inorganic Chloramines and Chlorinated Wastewater Effluents*, using the form given in Schedule 5 of this Notice, to the Minister. Where a person has prepared a single plan for more than one wastewater system, a separate Declaration of Implementation must be filed for each of those systems. Section 17 provides further information on completing and filing this form.

10. Déclaration confirmant l'exécution

En vertu du paragraphe 58(2) de la Loi, les personnes identifiées à l'article 2 doivent déposer par écrit auprès du ministre, dans les 30 jours suivant la fin de la période de l'exécution du plan comme prescrit à l'article 6 ou, selon le cas, prorogé en vertu de l'article 13, une *Déclaration confirmant l'exécution d'un plan de prévention de la pollution — chloramines inorganiques et eaux usées chlorées*, en utilisant le formulaire fourni à l'annexe 5 de cet avis. Dans le cas où une personne a élaboré un plan unique pour plus d'un réseau d'assainissement, une déclaration confirmant l'exécution doit être déposée individuellement pour chacun des systèmes. Les détails sur la façon de produire et de déposer ce formulaire se trouvent à l'article 17.

11. Filing of amended declarations

Under subsection 58(3) of the Act, where a person specified in section 2 has filed a declaration under section 9 or 10, and the declaration contains information which, at any time after the filing, has become false or misleading, that person shall file an amended declaration to the Minister within 30 days after the time that the information became false or misleading, using the appropriate form referred to in section 9 or 10.

11. Dépôt d'une déclaration corrective

En vertu du paragraphe 58(3) de la Loi, lorsqu'une personne, telle qu'elle est identifiée à l'article 2 de cet avis, dépose une déclaration confirmant l'élaboration ou l'exécution dont il est question à l'article 9 ou 10, et que la déclaration contient des renseignements qui deviennent faux ou trompeurs à une date ultérieure, cette personne doit déposer auprès du ministre une déclaration corrective dans un délai de 30 jours de la date où les renseignements sont devenus faux ou trompeurs, en utilisant le formulaire approprié mentionné à l'article 9 ou 10, selon le cas.

12. Use of a plan prepared or implemented for another purpose

Under subsection 57(1) of the Act, a person may use an existing pollution prevention plan or other plan in respect of pollution prevention prepared or implemented for another purpose to satisfy the requirements of sections 2 to 8 of this Notice. Under subsection 57(2) of the Act, where a person uses a plan that does not meet all the requirements of this Notice, the person shall amend the plan so that it meets all of those requirements or prepare an additional plan that meets the remainder of those requirements. Persons using existing plans must nonetheless file a Declaration of Preparation under section 9, a Declaration of Implementation under section 10, and any amended declarations under section 11.

12. Utilisation d'un plan élaboré ou exécuté à une autre fin

En vertu du paragraphe 57(1) de la Loi, une personne peut utiliser un plan de prévention de la pollution déjà élaboré ou exécuté à d'autres fins pour satisfaire aux exigences des articles 2 à 8 de cet avis. En vertu du paragraphe 57(2) de la Loi, lorsqu'une personne utilise un plan qui ne répond pas à toutes les exigences de cet avis, cette personne doit modifier le plan afin qu'il réponde à toutes ces exigences ou élaborer un plan complémentaire qui satisfait aux exigences non remplies. Une personne qui utilise un plan existant doit néanmoins déposer une déclaration confirmant l'élaboration conformément à l'article 9, une déclaration confirmant l'exécution conformément à l'article 10 et, le cas échéant, toute déclaration corrective dont il est question à l'article 11.

13. Extension of time

Under subsection 56(3) of the Act, where the Minister is of the opinion that further time is necessary to prepare the plan as specified in section 5 or to implement the plan as specified in section 6, the Minister may extend the period for a person who submits a written *Request for Time Extension — Inorganic Chloramines and Chlorinated Wastewater Effluents*, using the form given in Schedule 3 of this Notice, before the expiry of the date referred to in the applicable section 5 or section 6 or before the expiry of any extended period. Section 17 provides further information on completing and filing this form.

13. Prorogation du délai

En vertu du paragraphe 56(3) de la Loi, lorsque le ministre estime qu'un délai plus long est nécessaire pour l'élaboration du plan, tel qu'il est précisé à l'article 5, ou pour l'exécution du plan, tel qu'il est précisé à l'article 6, le ministre peut proroger le délai pour une personne qui présente par écrit une *Demande de prorogation du délai — chloramines inorganiques et eaux usées chlorées*, en utilisant le formulaire fourni à l'annexe 3 de cet avis, avant la date dont il est question à l'article 5 ou à l'article 6 ou avant l'expiration de toute autre prorogation de délai. Les détails sur la façon de produire et de déposer ce formulaire se trouvent à l'article 17.

14. Application for waiver of factors to consider

Under subsection 56(5) of the Act, the Minister may waive the requirement for a person to consider a factor specified in section 4 where the Minister is of the opinion that it is not reasonable or practicable to consider that factor on the basis of reasons provided by that person when submitting a written *Request for Waiver of the Requirement to Consider a Factor or Factors — Inorganic*

14. Demande de dérogation à l'obligation de prendre en considération certains facteurs

En vertu du paragraphe 56(5) de la Loi, lorsque le ministre estime qu'il est déraisonnable ou impossible de tenir compte d'un facteur précisé à l'article 4, le ministre peut approuver une dérogation à l'obligation de tenir compte de ce facteur pour une personne qui présente par écrit une *Demande de dérogation à l'obligation de prendre en considération certains facteurs —*

Chloramines and Chlorinated Wastewater Effluents, using the form given in Schedule 2 of this Notice. Such a request must be made before June 15, 2007, or before the expiry of any extended period. Section 17 provides further information on completing and filing this form.

15. Additional information

Environment Canada has published a *Guideline for the Release of Ammonia Dissolved in Water Found in Wastewater Effluents*. To obtain a copy of the Guideline, refer to the CEPA Registry Web site at www.ec.gc.ca/ceparegistry.

To obtain a copy of the document *Review of Municipal Sewage Effluent Chlorination/Dechlorination Principles, Technologies and Practices* (November 2003), refer to Environment Canada's Georgia Basin Web site at www.pyr.ec.gc.ca/georgiabasin/reports_e.htm.

To obtain a copy of the document *U.V. Guidance Manual for Municipal Wastewater Treatment Plants in Canada* (October 2003), refer to the Great Lakes Sustainability Fund Web site at http://sustainabilityfund.gc.ca or contact the Manager, Great Lakes Sustainability Fund, 867 Lakeshore Road, Burlington, Ontario L7R 4A6, (905) 336-6273.

To obtain a copy of the document *Guidance Manual for Sewage Treatment Plant Process Audits*, refer to the Great Lakes Sustainability Fund Web site at http://sustainabilityfund.gc.ca or contact the Manager, Great Lakes Sustainability Fund, 867 Lakeshore Road, Burlington, Ontario L7R 4A6, (905) 336-6273.

To obtain a copy of the *Fisheries Act*, refer to the Department of Justice Web site at http://laws.justice.gc.ca/en/f-14. For more information on the compliance and enforcement policies of the *Fisheries Act* and the *Canadian Environmental Protection Act, 1999*, visit the Environmental Law Enforcement Web site at www.ec.gc.ca/ele-ale/policies/policies_e.asp.

Additional information on pollution prevention and preparing pollution prevention plans is available from the National Office of Pollution Prevention Web site at www.ec.gc.ca/nopp, the Canadian Pollution Prevention Information Clearinghouse Web site at www.ec.gc.ca/cppic, and Environment Canada's regional offices.

To obtain information regarding the CCME Canada-wide strategy for the management of municipal wastewater effluents, visit the CCME Web site at www.ccme.ca/initiatives/water.html?category_id=81.

16. Reference code

For administrative purposes, all communication with Environment Canada concerning this Notice shall refer to the following reference code: P2CLMWWE.

17. Declarations and forms

Declarations and forms referred to in this Notice are available from and are to be submitted to

National Office of Pollution Prevention
c/o CEPA Implementation and Innovation Division
Environment Canada
351 Saint-Joseph Boulevard, 13th Floor
Gatineau, Quebec K1A 0H3

Alternatively, the forms can be completed electronically at the Web site listed below.

chloramines inorganiques et eaux usées chlorées, en utilisant le formulaire fourni à l'annexe 2 de cet avis. Une telle demande doit être faite avant le 15 juin 2007 ou avant l'expiration de tout délai prorogé. Les détails sur la façon de produire et de déposer ce formulaire se trouvent à l'article 17.

15. Information supplémentaire

Environnement Canada a publié une *Ligne directrice sur le rejet de l'ammoniac dissous dans l'eau se trouvant dans les effluents d'eaux usées*. Pour obtenir une copie de cette ligne directrice, visitez le site Web du Registre de la LCPE à l'adresse www.ec.gc.ca/RegistreLCPE.

Pour obtenir une copie du document *Examen des principes, des techniques et des procédés de chloration et de déchloration des effluents des eaux usées municipales* (novembre 2003), visitez le site Web du Bassin de Georgia d'Environnement Canada à l'adresse www.pyr.ec.gc.ca/georgiabasin/reports_F.htm.

Pour obtenir une copie du document *Technologie de la désinfection par rayonnement ultraviolet appliquée aux usines de traitement des eaux usées municipales au Canada* (octobre 2003), visitez le site Web du Fonds de durabilité des Grands Lacs à l'adresse http://sustainabilityfund.gc.ca ou communiquez avec le Gestionnaire, Fonds de durabilité des Grands Lacs, 867, chemin Lakeshore, Burlington (Ontario) L7R 4A6, (905) 336-6273.

Pour obtenir une copie du document *Guide relatif aux vérifications des procédés des usines de traitement des eaux usées*, visitez le site Web du Fonds de durabilité des Grands Lacs à l'adresse http://sustainabilityfund.gc.ca ou communiquez avec le Gestionnaire, Fonds de durabilité des Grands Lacs, 867, chemin Lakeshore, Burlington (Ontario) L7R 4A6, (905) 336-6273.

Pour obtenir une copie de la *Loi sur les pêches*, visitez le site Web suivant : http://lois.justice.gc.ca/fr/F-14. Pour obtenir plus d'information sur les politiques de conformité et d'application des dispositions de la *Loi sur les pêches* et de la *Loi canadienne sur la protection de l'environnement (1999)*, visitez le site Web de l'application des lois sur l'environnement à l'adresse www.ec.gc.ca/ele-ale/policies/policies_f.asp.

De l'information supplémentaire sur la prévention de la pollution et la préparation de plans de la prévention de la pollution est disponible sur le site Web du Bureau national de la prévention de la pollution (www.ec.gc.ca/nopp) et sur celui du Centre canadien d'information sur la prévention de la pollution (www.ec.gc.ca/cppic), ainsi qu'aux bureaux régionaux d'Environnement Canada.

Pour obtenir de l'information concernant la stratégie pancanadienne du CCME sur la gestion des effluents d'eaux usées municipales, visitez le site Web du CCME à l'adresse www.ccme.ca/initiatives/water.fr.html?category_id=81.

16. Code de référence

À des fins administratives, toutes les communications adressées à Environnement Canada au sujet de cet avis doivent mentionner le code de référence suivant : P2CLMWWE.

17. Déclarations et formulaires

Les déclarations et les formulaires dont il est question dans cet avis sont disponibles, et devront être soumis, à l'adresse suivante :

Bureau national de la prévention de la pollution
Division de l'innovation et de la mise en œuvre de la LCPE
Environnement Canada
351, boulevard Saint-Joseph, 13e étage
Gatineau (Québec) K1A 0H3

De plus, les formulaires peuvent être remplis électroniquement sur le site Internet mentionné ci-dessous.

Electronic copies of this Notice and the instructions for completing the declarations and forms (Schedules 1 to 5) are available from the National Office of Pollution Prevention Web site, at www.ec.gc.ca/nopp/p2p/en/p2notices.cfm or can be requested by telephone at (819) 994-0186, by facsimile at (819) 953-7970, or by electronic mail at cepap2plans@ec.gc.ca.

The Minister of the Environment intends to publish, in part, the information submitted in response to this Notice on Environment Canada's Green Lane Web site. All persons submitting information to the Minister are entitled to submit a request under section 313 of the Act that specific information be treated as confidential.

18. Environment Canada contact information

For residents of Newfoundland and Labrador

Environmental Protection Branch – Atlantic Region
Environment Canada
6 Bruce Street
Mount Pearl, Newfoundland and Labrador A1N 4T3
Telephone: (709) 772-5491
Facsimile: (709) 772-5097

For residents of Prince Edward Island

Environmental Protection Branch – Atlantic Region
Environment Canada
97 Queen Street, Room 202
Charlottetown, Prince Edward Island C1A 4A9
Telephone: (902) 566-7043
Facsimile: (902) 566-7279

For residents of Nova Scotia

Environmental Protection Branch – Atlantic Region
Environment Canada
Queen Square, 16th Floor
45 Alderney Drive
Dartmouth, Nova Scotia B2Y 2N6
Telephone: (902) 426-8926
Facsimile: (902) 426-3897

For residents of New Brunswick

Environmental Protection Branch – Atlantic Region
Environment Canada
77 Westmorland Street, Suite 450
Fredericton, New Brunswick E3B 6Z3
Telephone: (506) 452-3286
Facsimile: (506) 452-3003

For residents of Quebec

Environmental Protection Branch – Quebec Region
Environment Canada
105 McGill Street, 4th Floor
Montréal, Quebec H2Y 2E7
Telephone: (514) 283-4670
Facsimile: (514) 283-4423

For residents of Ontario

Environmental Protection Branch – Ontario Region
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Telephone: (416) 739-5888
Facsimile: (416) 739-4342

Une copie électronique de cet avis ainsi que les directives nécessaires pour remplir les déclarations et les formulaires (annexes 1 à 5) sont disponibles sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/p2p/FR/p2notices.cfm ou peuvent être obtenues par téléphone au (819) 994-0186, par télécopieur au (819) 953-7970, ou par courriel à l'adresse cepap2plans@ec.gc.ca.

Le ministre de l'Environnement a l'intention de publier, en partie, les informations présentées en réponse à cet avis sur le site Web de la Voie verte d'Environnement Canada. Toute personne présentant des informations au ministre peut soumettre une demande en vertu de l'article 313 de la Loi, afin que certaines informations spécifiques soient traitées de façon confidentielle.

18. Bureaux d'information d'Environnement Canada

Pour les résidents de Terre-Neuve-et-Labrador

Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
6, rue Bruce
Mount Pearl (Terre-Neuve-et-Labrador) A1N 4T3
Téléphone : (709) 772-5491
Télécopieur : (709) 772-5097

Pour les résidents de l'Île-du-Prince-Édouard

Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
97, rue Queen, Pièce 202
Charlottetown (Île-du-Prince-Édouard) C1A 4A9
Téléphone : (902) 566-7043
Télécopieur : (902) 566-7279

Pour les résidents de la Nouvelle-Écosse

Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
Queen Square, 16e étage
45, promenade Alderney
Dartmouth (Nouvelle-Écosse) B2Y 2N6
Téléphone : (902) 426-8926
Télécopieur : (902) 426-3897

Pour les résidents du Nouveau-Brunswick

Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
77, rue Westmorland, Bureau 450
Fredericton (Nouveau-Brunswick) E3B 6Z3
Téléphone : (506) 452-3286
Télécopieur : (506) 452-3003

Pour les résidents du Québec

Direction de la protection de l'environnement — Région du Québec
Environnement Canada
105, rue McGill, 4e étage
Montréal (Québec) H2Y 2E7
Téléphone : (514) 283-4670
Télécopieur : (514) 283-4423

Pour les résidents de l'Ontario

Direction de la protection de l'environnement — Région de l'Ontario
Environnement Canada
4905, rue Dufferin
Downsview (Ontario) M3H 5T4
Téléphone : (416) 739-5888
Télécopieur : (416) 739-4342

For residents of Manitoba

Environmental Protection Branch – Prairie and Northern Region
Environment Canada
123 Main Street
Winnipeg, Manitoba R3C 4W2
Telephone: (204) 983-4811
Facsimile: (204) 983-0960

For residents of Saskatchewan

Environmental Protection Branch – Prairie and Northern Region
Environment Canada
300-2365 Albert Street
Regina, Saskatchewan S4P 4K1
Telephone: (306) 780-6390
Facsimile: (306) 780-6466

For residents of Alberta

Environmental Protection Branch – Prairie and Northern Region
Environment Canada
4999 98th Avenue
Edmonton, Alberta T6B 2X3
Telephone: (780) 951-8860
Facsimile: (780) 495-4099

For residents of the Northwest Territories and Nunavut

Environmental Protection Branch – Prairie and Northern Region
Environment Canada
301-5204 50th Avenue
Yellowknife, Northwest Territories X1A 1E2
Telephone: (867) 669-4725
Facsimile: (867) 873-8185

For residents of British Columbia

Environmental Protection Branch – Pacific and Yukon Region
Environment Canada
201-401 Burrard Street
Vancouver, British Columbia V6C 3S5
Telephone: (604) 666-2799
Facsimile: (604) 666-9107

For residents of Yukon

Environmental Protection Branch – Pacific and Yukon Region
Environment Canada
91782 Alaska Highway
Whitehorse, Yukon Territory Y1A 5B7
Telephone: (867) 667-3401
Facsimile: (867) 667-7962

Environment Canada Headquarters

Environmental Technology Advancement Directorate
Environmental Protection Service
Place Vincent Massey
351 Saint-Joseph Boulevard
Gatineau, Quebec K1A 0H3
Telephone: (819) 953-8074
Facsimile: (819) 953-7253

Pour les résidents du Manitoba

Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
123, rue Main
Winnipeg (Manitoba) R3C 4W2
Téléphone : (204) 983-4811
Télécopieur : (204) 983-0960

Pour les résidents de la Saskatchewan

Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
2365, rue Albert, Bureau 300
Regina (Saskatchewan) S4P 4K1
Téléphone : (306) 780-6390
Télécopieur : (306) 780-6466

Pour les résidents de l'Alberta

Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
4999 98th Avenue
Edmonton (Alberta) T6B 2X3
Téléphone : (780) 951-8860
Télécopieur : (780) 495-4099

Pour les résidents des Territoires du Nord-Ouest et du Nunavut

Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
5204 50th Avenue, Bureau 301
Yellowknife (Territoires du Nord-Ouest) X1A 1E2
Téléphone : (867) 669-4725
Télécopieur : (867) 873-8185

Pour les résidents de la Colombie-Britannique

Direction de la protection de l'environnement — Région du Pacifique et du Yukon
Environnement Canada
401, rue Burrard, Bureau 201
Vancouver (Colombie-Britannique) V6C 3S5
Téléphone : (604) 666-2799
Télécopieur : (604) 666-9107

Pour les résidents du Yukon

Direction de la protection de l'environnement — Région du Pacifique et du Yukon
Environnement Canada
91782, route de l'Alaska
Whitehorse (Territoire du Yukon) Y1A 5B7
Téléphone : (867) 667-3401
Télécopieur : (867) 667-7962

Bureau national d'Environnement Canada

Direction générale pour l'avancement de la technologie environnementale
Service de la protection de l'environnement
Place-Vincent-Massey
351, boulevard Saint-Joseph
Gatineau (Québec) K1A 0H3
Téléphone : (819) 953-8074
Télécopieur : (819) 953-7253

EXPLANATORY NOTE

(*This note is not part of the Notice.*)

Compliance

Compliance with the Act is mandatory under subsection 272(1) of the Act. Subsection 272(2) of the Act defines the penalties for persons who commit offenses under the Act. Subsections 273(1) and 273(2) further outline the terms and penalties of those persons providing false or misleading information. Penalties under subsections 272(2) and 273(2) include fines of not more than $1,000,000, imprisonment for a term of not more than three years, or both.

For additional information on the Act and the *Compliance and Enforcement Policy for the Canadian Environmental Protection Act, 1999* and on applicable penalties, please contact the Enforcement Branch at (819) 953-0331. The Policy is available at www.ec.gc.ca/ceparegistry/enforcement.

NOTE EXPLICATIVE

(*Cette note ne fait pas partie de l'avis.*)

Conformité

En vertu du paragraphe 272(1), la conformité à la Loi est obligatoire. Le paragraphe 272(2) de la Loi détermine les peines applicables pour quiconque commet une infraction en vertu de la Loi. De plus, les paragraphes 273(1) et 273(2) déterminent les peines applicables à quiconque communique des renseignements faux ou trompeurs. Les paragraphes 272(2) et 273(2) édictent qu'une amende maximale d'un million de dollars et un emprisonnement maximal de trois ans, ou que l'une de ces peines, peuvent être imposés.

Pour tout renseignement additionnel sur la LCPE (1999), la *Politique d'application de la Loi canadienne sur la protection de l'environnement (1999)* et les peines applicables, veuillez communiquer avec la Direction de l'application de la loi au (819) 953-0331. La politique est disponible sur Internet à l'adresse suivante : www.ec.gc.ca/RegistreLCPE/enforcement.

Note: Please contact the National Office of Pollution Prevention for more information about electronic reporting or the filing of paper forms.

Schedule 1: Declaration That a Pollution Prevention Plan Has Been Prepared and Is Being Implemented – Inorganic Chloramines and Chlorinated Wastewater Effluents (Subsection 58(1) of CEPA 1999)

Notice Reference Code: P2CLMWWE

Please refer to the instruction booklet "Instructions for Completing the Schedules of the *Canada Gazette* Notice Requiring the Preparation and Implementation of Pollution Prevention Plans for Inorganic Chloramines and Chlorinated Wastewater Effluents" for guidance on how to complete this Declaration.

Electronic copies of the Notice, and the instructions for completing the declarations (Schedules 1 to 5), are available from the National Office of Pollution Prevention Web site at www.ec.gc.ca/nopp/p2p/en/p2notices.cfm or can be requested by telephone at (819) 994-0186, by facsimile at (819) 953-7970, or by e-mail at CEPAP2Plans@ec.gc.ca.

Is this an amendment to a Declaration previously submitted? ☐ Yes ☐ No

If yes, complete Parts 1.0 and 9.0 and any other Parts of this Declaration where previously reported information has become false or misleading. Previously reported information that is unchanged need not be resubmitted.

1.0 Information on the Person or Class of Persons Subject to the Notice

Name of the Person or Class of Persons Subject to the Notice: _____

Facility Name: _____

Street Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

Telephone Number: _____ E-mail (if available): _____
(with area code)

If different from Street Address
Mailing Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

National Pollutant Release Inventory ID (if no ID, leave blank): _____

Six-digit North American Industry Classification System (NAICS) Code: 221320

Facility Technical Contact: _____

E-mail (if available): _____

Telephone Number: _____ Fax Number (if available): _____
(with area code) (with area code)

2.0 Use of Plans Prepared or Implemented for Another Purpose

Is the pollution prevention plan used to fulfill the obligations of the Notice

- a pollution prevention plan that was previously prepared on a voluntary basis? ☐ Yes ☐ No
- a pollution prevention plan that was previously prepared for another government or under another Act of Parliament? ☐ Yes ☐ No

If yes, identify the other government requirement(s) or Act(s) of Parliament.

3.0 Substance and Activity

Substance and Activity for which information is required

Inorganic Chloramines and Chlorinated Wastewater Effluents: Persons identified in section 2 of the Notice who are required to prepare and implement a pollution prevention plan for inorganic chloramines and chlorinated wastewater effluents for the use of chlorine or chlorine compounds in wastewater systems and the release of chlorinated wastewater effluent to surface water.

4.0 Baseline Information Prior to Implementation of the Pollution Prevention (P2) Plan

This Declaration requires reporting of data from the Preparation Year, either **2004** or **2005** (January 1 to December 31).

If the person(s) subject to the Notice has been granted a time extension to prepare a plan that requires reporting for a year other than **2004** or **2005**, all references to **2004** or **2005** in this Declaration are considered to represent the new Preparation Year for which the person(s) is(are) required to report.

If applicable, indicate the new Preparation Year for which the person(s) is(are) reporting: _____

4.1 - 4.4 No information required for Parts 4.1 to 4.4 of this Declaration

4.5 Additional Baseline Information

4.5.1 Wastewater System Information

This section requires reporting of information on the wastewater system in place for 2004 or 2005. Check whichever of the following boxes apply to your system. Note that more than one box in each section may apply.

No Treatment

☐ No Treatment (e.g. collection system with release to surface water)

Preliminary Treatment

☐ None ☐ Skimming
☐ Grit Removal ☐ Other (describe) _____
☐ Screening

Physical/Chemical Primary Treatment

☐ None ☐ Chemical Flocculation
☐ Primary Sedimentation/Clarification ☐ Other (describe) _____

Biological or Secondary Treatment – Mechanical Systems (some systems may have more than one kind of treatment)

☐ None ☐ Oxidation Ditch
☐ Conventional Activated Sludge ☐ Trickling Filter
☐ Extended Aeration Activated Sludge ☐ Rotating Biological Contactor (RBC)
☐ Pure Oxygen Activated Sludge ☐ Sequencing Batch Reactor (SBR)
☐ Other Activated Sludge ☐ Other (describe) _____

Biological or Secondary Treatment – Lagoons or Waste Stabilization Ponds (WSPs) (some systems may have more than one kind of treatment)

☐ None ☐ Storage Ponds
☐ Aerated ☐ Anaerobic
☐ Aerobic ☐ Other (describe) _____
☐ Facultative

Advanced or Tertiary Treatment

☐ None
☐ Polishing Ponds
☐ Ammonia Stripping or Air Stripping
☐ Biological Nutrient Removal (Nitrogen and Phosphorus)
☐ Biological Ammonia Removal – Nitrification Only (NH_3 -> NO_3)
☐ Biological Nitrogen Removal – Nitrification and Denitrification (NH_3 -> N_2)
☐ Biological Phosphorus Removal
☐ Chemical Precipitation (Phosphorus)
☐ Filtration
☐ Other (describe) _____

Effluent Disinfection

☐ None
☐ Disinfection: All Year
☐ Disinfection: Seasonal or intermittent. If seasonal, specify the period of disinfection (which months) or if it is intermittent, specify the frequency: _____
☐ Chlorination Only
☐ Chlorination and Dechlorination
☐ Ozone
☐ Ultraviolet Irradiation
☐ Other (describe) _____

Other Information

Name of the surface water body that effluent is released to _____ ☐ Freshwater ☐ Saltwater

4.5.2 Releases to Surface Water

4.5.2.1 *Inorganic Chloramines and Chlorinated Wastewater Effluents*

Report in the table below the average flow of wastewater effluent and the maximum Total Residual Chlorine (TRC) concentrations. The average monthly flow should be determined on the basis of daily flow measurements. The maximum total residual chlorine concentration should be determined on the basis of representative sampling.

Preparation Year (Month)	Average Flow of Effluent (m^3/day)	Maximum Total Residual Chlorine (TRC) concentration (mg/L as Cl^-)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

5.0 Anticipated Actions and Results

5.1 Anticipated Action(s)

The following section (Parts 5.1.1 through 5.1.6) must be completed separately for each anticipated action in the pollution prevention plan, i.e. this section will be completed as many times as there are anticipated actions to report.

In Part 5.1.1, describe for the activity identified in Part 3.0 of this Declaration the anticipated action to be taken in implementing the Pollution Prevention Plan. In Parts 5.1.2 and 5.1.3, for each anticipated action, identify the type of pollution prevention method(s) or environmental protection method(s), by selecting from the list of options provided below. In Part 5.1.4, report, where possible, the corresponding change to the maximum concentration of total residual chlorine measured in the effluent released to surface water, anticipated to be achieved from implementation of that action, in mg/L. Refer to the instructions for specific information on how to report. Indicate a decrease with a negative sign ("–") and an increase with a positive sign ("+") in front of the reported change. Note that predicting a quantitative change as a result of some anticipated actions, such as training, may not be possible. Finally, in Part 5.1.6, identify the planned completion date for the anticipated action.

5.1.1 Anticipated Action: _____

5.1.2 Type of Pollution Prevention Method(s):

- ☐ Equipment or process modifications
- ☐ Spill and leak prevention
- ☐ On-site reuse, recycling or recovery
- ☐ Good operating practices or training
- ☐ Other: _____

5.1.3 Other Type of Environmental Protection Method(s):

- ☐ Energy recovery
- ☐ Off-site recycling
- ☐ Waste treatment
- ☐ Pollution control
- ☐ Disposal
- ☐ Other: _____

5.1.4 Anticipated Change(s): _____

5.1.5 *No information required for Part 5.1.5 of this Declaration*

5.1.6 Planned Completion Date (year/month/day): _____

This ends the section (Parts 5.1.1 through 5.1.6) that must be completed separately for each anticipated action in the P2 plan.

5.2 No information required for Part 5.2

5.3 Detailed Anticipated Results Information

Total Anticipated Results for Inorganic Chloramines and Chlorinated Wastewater Effluents

The table below summarizes, for the activity identified in Part 3.0 of this Declaration, the anticipated change to the maximum concentration of total residual chlorine (TRC) in the effluent released to surface water, in mg/L and as a percentage relative to the Preparation Year.

Report the total changes anticipated to be achieved from implementing all of the anticipated actions described in Part 5.1 of this Declaration.

Maximum Concentration of TRC in the Preparation Year (mg/L)	Anticipated Maximum Concentration of TRC in the Implementation Year (mg/L)	Anticipated Change* in Maximum Concentration (%)

* Indicate a decrease with a negative sign ("–") and an increase with a positive sign ("+") in front of the reported change.

6.0 Monitoring and Reporting

For the activity identified in Part 3.0 of this Declaration, describe anticipated monitoring and reporting that will be used to track progress in implementing the Pollution Prevention Plan.

7.0 Risk Management Objective

For the activity identified in Part 3.0 of this Declaration, describe how the Pollution Prevention Plan outlined in this Declaration meets the risk management objective identified in subsection 4(3) of the Notice. If this plan does not meet the risk management objective, explain why.

8.0 Factors to Consider

Describe what was done by the person or class of persons subject to the Notice to take into account the other "factors to consider" in subsections 4.2 and 4.5 of the Notice, except those factors for which a waiver has been granted by the Minister.

9.0 Certification

I hereby certify that a Pollution Prevention Plan has been prepared and is being implemented for inorganic chloramines and chlorinated wastewater effluents and that the information provided in this Declaration is true, accurate and complete.

_____ _____

Signature of the Person(s) Subject to the Notice or Duly Authorized Representative — Date

Name: _____

Please Print

Title/Position: _____

Please Print

Note : Veuillez communiquer avec le Bureau national de la prévention de la pollution pour obtenir plus d'information au sujet de la soumission électronique ou du dépôt des formulaires écrits.

Annexe 1 : Déclaration confirmant qu'un plan de prévention de la pollution a été élaboré et qu'il est en cours d'exécution — chloramines inorganiques et eaux usées chlorées [paragraphe 58(1) de la LCPE (1999)]

Code de référence de l'avis : P2CLMWWE

Pour plus d'information sur la façon de remplir cette déclaration, consulter la brochure « Directives pour remplir les annexes de l'avis de la *Gazette du Canada* requérant l'élaboration et l'exécution de plans de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées ».

Une copie électronique de cet avis et les instructions pour remplir les déclarations (annexes 1 à 5) sont disponibles sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/p2p/FR/p2notices.cfm ou peuvent être obtenues par téléphone au (819) 994-0186, par télécopieur au (819) 953-7970, ou par courriel à l'adresse cepap2plans@ec.gc.ca.

La présente déclaration sert-elle à apporter une modification à une déclaration déjà déposée? ☐ Oui ☐ Non

Si vous avez coché « oui », remplissez les parties 1.0 et 9.0, ainsi que toute autre partie de cette déclaration pour laquelle des renseignements déjà déclarés sont maintenant faux ou trompeurs. Il n'est pas nécessaire de répéter les informations inchangées.

1.0 Renseignements sur la(les) personne(s) ou catégorie de personnes visée(s) par l'avis

Nom de la(des) personne(s) ou catégorie de personnes visée(s) par l'avis : _____

Nom de l'installation : _____

Adresse civique de l'installation : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Téléphone : _____ Courriel (si disponible) : _____
(indicatif régional)

Adresse postale de l'installation,
si différente de l'adresse civique : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Numéro d'identité de l'Inventaire national des rejets de polluants (si aucun, laissez en blanc) : _____

Code à six chiffres du Système de classification des industries de l'Amérique du Nord (SCIAN) : 221320

Responsable des renseignements techniques : _____

Courriel (si disponible) : _____

Téléphone : _____ Télécopieur (si disponible) : _____
(y compris l'indicatif régional) (y compris l'indicatif régional)

2.0 Utilisation de plans déjà élaborés ou exécutés à d'autres fins

Le plan de prévention de la pollution utilisé pour satisfaire aux exigences de l'avis a-t-il :

- été préparé à titre volontaire? ☐ Oui ☐ Non
- été préparé pour un autre gouvernement ou en vertu d'une autre loi fédérale? ☐ Oui ☐ Non

Si vous avez coché « oui », indiquez la ou les exigences de cet autre gouvernement ou de cette(ces) autre(s) loi(s) fédérale(s).

3.0 Substance et activité

Substance et activité pour lesquelles des informations sont requises

Chloramines inorganiques et eaux usées chlorées : Personnes identifiées dans l'article 2 de l'avis, qui doivent élaborer et exécuter un plan de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées liées à l'usage du chlore ou de composés chlorés dans les réseaux d'assainissement et le rejet d'eaux usées chlorées dans les eaux de surface.

4.0 Information de base antérieure à l'exécution du plan de prévention de la pollution (P2)

Cette déclaration requiert la présentation des données pour l'année de préparation, soit **2004** ou **2005** (du 1er janvier au 31 décembre).

Si la(les) personne(s) visée(s) par l'avis a(ont) obtenu une prorogation de délai pour préparer un plan qui requiert la présentation de données pour une année autre que **2004** ou **2005**, toutes les références aux années **2004** ou **2005** dans la présente déclaration doivent être considérées comme renvoyant à la nouvelle année de préparation pour laquelle la(les) personne(s) doit(doivent) faire rapport.

Le cas échéant, veuillez indiquer la nouvelle année de préparation pour laquelle la(les) personne(s) visée(s) par l'avis doit(doivent) soumettre un rapport : _____

4.1 - 4.4 Aucune information requise pour les parties 4.1 à 4.4 de cette déclaration

4.5 Information de base additionnelle

4.5.1 Information sur le réseau d'assainissement

Cette section requiert de l'information au sujet du réseau d'assainissement en place pour 2004 ou 2005. Cochez toutes les cases suivantes qui s'appliquent à votre réseau. Notez que plus d'une case par section peuvent s'appliquer.

Aucun traitement

☐ Aucun traitement (par exemple, système de collecte avec déversement dans une eau de surface)

Traitement préliminaire

☐ Aucun
☐ Dessablage
☐ Tamis/grilles à barreaux
☐ Écrémage
☐ Autre (préciser) _____

Traitement primaire physique/chimique

☐ Aucun
☐ Décantation primaire/clarification
☐ Floculation chimique
☐ Autre (préciser) _____

Traitement secondaire ou biologique — systèmes mécaniques (certains systèmes peuvent avoir plus d'un type de traitement)

☐ Aucun
☐ Boues activées conventionnelles
☐ Boues activées par aération prolongée
☐ Boues activées par oxygène pur
☐ Autres boues activées
☐ Fossé d'oxydation
☐ Réacteur à lit fixe ou à lit bactérien aéré
☐ Disques biologiques
☐ Réacteur continu
☐ Autre (préciser) _____

Traitement secondaire ou biologique — étangs ou bassins de stabilisation (certains systèmes peuvent avoir plus d'un type de traitement)

☐ Aucun
☐ Aéré
☐ Aérobique
☐ Facultatif
☐ Étangs de stockage
☐ Anaérobique
☐ Autre (préciser) _____

Traitement tertiaire ou additionnel

☐ Aucun
☐ Bassins ou étangs de polissage
☐ Stripage de l'ammoniac ou stripage à l'air
☐ Élimination biologique des nutriments (azote et phosphore)
☐ Élimination biologique de l'ammoniac — Nitrification seulement (NH_3 -> NO_3)
☐ Élimination biologique de l'azote — Nitrification et dénitrification (NH_3 -> N_2)
☐ Élimination biologique du phosphore
☐ Précipitation chimique (phosphore)
☐ Filtration
☐ Autre (préciser) _____

Désinfection des effluents

☐ Aucun
☐ Désinfection : continue à l'année
☐ Désinfection : saisonnière ou intermittente. Si saisonnière, préciser la période de désinfection (quels mois) ou si intermittente, préciser la fréquence : _____
☐ Chloration seulement
☐ Chloration et déchloration
☐ Ozone
☐ Irradiation par ultraviolets
☐ Autre (préciser) _____

Autre information

Nom du cours d'eau où l'effluent est déversé _____ ☐ Eau douce ☐ Eau salée

4.5.2 Rejets à l'eau de surface

4.5.2.1 *Chloramines inorganiques et eaux usées chlorées*

Déclarez dans le tableau ci-dessous le débit moyen de l'effluent d'eaux usées et les concentrations maximales de chlore résiduel total (CRT). Le débit moyen mensuel devrait être calculé en fonction des mesures du débit quotidien. La concentration maximale de chlore résiduel total devrait être déterminée en fonction d'un échantillon représentatif.

Année de préparation / Mois	Débit moyen de l'effluent (m^3/jour)	Concentration maximale de chlore résiduel total (CRT) (mg/L en CT)
Janvier		
Février		
Mars		
Avril		
Mai		
Juin		
Juillet		
Août		
Septembre		
Octobre		
Novembre		
Décembre		

5.0 **Mesures et résultats prévus**

5.1 ***Mesure(s) prévue(s)***

Les parties suivantes de la présente déclaration (parties 5.1.1 à 5.1.6) doivent être remplies séparément pour chaque mesure prévue indiquée dans le plan de prévention de la pollution, c'est-à-dire que cette section doit être remplie autant de fois qu'il y a de mesures à déclarer.

Dans la partie 5.1.1, décrivez, pour l'activité identifiée à la partie 3.0 de la présente déclaration, la mesure prévue pour l'exécution du plan de prévention de la pollution. Dans les parties 5.1.2 et 5.1.3, identifiez le type de mesures de prévention de la pollution ou de protection de l'environnement, en choisissant l'une des options fournies ci-dessous. Dans la partie 5.1.4, inscrivez, le cas échéant, le changement prévu à la concentration maximale de chlore résiduel total mesurée dans l'effluent rejeté à l'eau de surface, en mg/L, provenant de la mise en œuvre de la mesure. Pour obtenir des informations spécifiques sur la façon de compléter cette section, référez-vous aux instructions. Indiquez une diminution par le signe « – » et une augmentation par le signe « + » devant la quantité indiquée. Notez que dans certains cas, il peut s'avérer impossible de prévoir un changement quantitatif pour certaines mesures prévues, comme dans le cas de la formation du personnel. Enfin, dans la partie 5.1.6, indiquez la date d'achèvement prévue pour chaque mesure prévue.

5.1.1 Mesure prévue : _____

5.1.2 Types de méthodes de prévention de la pollution :

- ☐ Modifications de l'équipement ou du procédé
- ☐ Prévention des fuites ou des déversements
- ☐ Récupération, réutilisation ou recyclage sur place
- ☐ Bonnes pratiques d'exploitation ou formation
- ☐ Autres : _____

5.1.3 Autres types de méthodes de protection de l'environnement :

- ☐ Récupération d'énergie
- ☐ Recyclage hors site
- ☐ Traitement des déchets
- ☐ Contrôle de la pollution
- ☐ Élimination
- ☐ Autres : _____

5.1.4 Changement(s) prévu(s) : _____

5.1.5 *Aucune information n'est requise pour la partie 5.1.5 de cette déclaration*

5.1.6 Date d'achèvement prévue (année/mois/jour) : _____

Ceci termine les parties 5.1.1 à 5.1.6 devant être remplies séparément pour chaque mesure prévue dans le plan de prévention de la pollution.

5.2 ***Aucune information n'est requise pour la partie 5.2 de cette déclaration***

5.3 ***Information détaillée sur les résultats prévus***

Résultats totaux prévus pour les chloramines inorganiques et les eaux usées chlorées

Le tableau ci-dessous résume, pour l'activité identifiée dans la partie 3.0 de cette déclaration, le changement total prévu à la concentration maximale de chlore résiduel total (CRT) dans l'effluent rejeté à l'eau de surface, en mg/L et en pourcentage par rapport à l'année de préparation.

Déclarez le changement total prévu à la suite de la mise en œuvre des mesures prévues décrites dans la partie 5.1 de cette déclaration.

Concentration maximale de CRT dans l'année de préparation (mg/L)	Concentration maximale de CRT prévue dans l'année de la mise en œuvre (mg/L)	Changement* prévu à la concentration maximale (%)

* Indiquez une diminution avec un signe négatif (« – ») et une augmentation avec un signe positif (« + ») devant la quantité déclarée.

6.0 Surveillance et rapport

Pour l'activité identifiée à la partie 3.0 de cette déclaration, décrivez les méthodes de surveillance et de compte rendu qui seront utilisées pour suivre les progrès de l'exécution du plan de prévention de la pollution.

7.0 Objectif de gestion du risque

Décrivez comment le plan de prévention de la pollution, tel qu'il est décrit dans cette déclaration, répond à l'objectif de gestion du risque décrit au paragraphe 4(3) de l'avis pour l'activité identifiée à la partie 3.0 de cette déclaration. Si ce plan ne répond pas à l'objectif de gestion du risque, expliquez pourquoi.

8.0 Facteurs à prendre en considération

Décrivez les mesures prises par les personnes ou catégories de personnes assujetties à l'avis pour tenir compte des « facteurs à prendre en considération » des paragraphes 4.2 et 4.5 de l'avis, sauf pour les facteurs pour lesquels une demande de dérogation a été accordée par le ministre.

9.0 Certification

J'atteste qu'un plan de prévention de la pollution a été élaboré pour les chloramines inorganiques et les eaux usées chlorées et qu'il est en cours d'exécution, et que les renseignements soumis dans la présente déclaration sont véridiques, exacts et complets.

_____ _____

Signature de la(des) personne(s) visée(s) par l'avis ou représentant(e) autorisé(e) — Date

Nom : _____

En lettres moulées s.v.p.

Titre/Poste : _____

En lettres moulées s.v.p.

Note: Please contact the National Office of Pollution Prevention for more information about electronic reporting or the filing of paper forms.

Schedule 2: Request for Waiver of the Requirement to Consider a Factor or Factors – Inorganic Chloramines and Chlorinated Wastewater Effluents (Subsection 56(5) of CEPA 1999)

Notice Reference Code: P2CLMWWE

Please refer to the instruction booklet "Instructions for Completing the Schedules of the *Canada Gazette* Notice Requiring the Preparation and Implementation of Pollution Prevention Plans for Inorganic Chloramines and Chlorinated Wastewater Effluents" for guidance on how to complete this Request.

Electronic copies of the Notice, and the instructions for completing the declarations (Schedules 1 to 5), are available from the National Office of Pollution Prevention Web site at www.ec.gc.ca/nopp/p2p/en/p2notices.cfm or can be requested by telephone at (819) 994-0186, by facsimile at (819) 953-7970 or by e-mail at CEPAP2Plans@ec.gc.ca.

1.0 Information on the Person or Class of Persons Subject to the Notice

Name of the Person or Class of Persons Subject to the Notice: _____

Facility Name: _____

Street Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

Telephone Number: _____ E-mail (if available): _____
(with area code)

If different from Street Address
Mailing Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

National Pollutant Release Inventory ID (if no ID, leave blank): _____

Six-digit North American Industry Classification System (NAICS) Code: 221320

Facility Technical Contact: _____

E-mail (if available): _____

Telephone Number: _____ Fax Number (if available): _____
(with area code) (with area code)

2.0 Factor(s) for which a Waiver is Requested

Identify exactly for which factor(s) listed in the Notice a waiver is requested.

3.0 Rationale for Request

Explain why it would not be reasonable or practicable to consider each factor for which a waiver is requested.

Explain how the outcome of the P2 plan will be affected if this(these) "factor to consider" is(are) not taken into account.

Explain which, if any, additional factor(s) you propose to consider in preparing the pollution prevention plan (optional).

4.0 Certification

I hereby certify that the information provided in this Request is true, accurate and complete.

_____ _____
Signature of the Person(s) Subject to the Notice or Duly Authorized Representative — Date

Name: _____
Please Print

Title/Position: _____
Please Print

Note : Veuillez communiquer avec le Bureau national de la prévention de la pollution pour obtenir plus d'information au sujet de la soumission électronique ou du dépôt des formulaires écrits.

Annexe 2 : Demande de dérogation à l'obligation de prendre en considération certains facteurs — Chloramines inorganiques et eaux usées chlorées [paragraphe 56(5) de la LCPE (1999)]

Code de référence de l'avis : P2CLMWWE

Pour plus d'information sur la façon de remplir cette déclaration, consulter la brochure « Directives pour remplir les annexes de l'avis de la *Gazette du Canada* requérant l'élaboration et l'exécution de plans de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées ».

Une copie électronique de cet avis et les instructions pour remplir les déclarations (annexes 1 à 5) sont disponibles sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/p2p/FR/p2notices.cfm ou peuvent être obtenues par téléphone au (819) 994-0186, par télécopieur au (819) 953-7970 ou par courriel à l'adresse cepap2plans@ec.gc.ca.

1.0 Renseignements sur la(les) personne(s) ou catégorie de personnes visée(s) par l'avis

Nom de la(des) personne(s) ou catégorie de personnes visée(s) par l'avis : _____

Nom de l'installation : _____

Adresse civique de l'installation : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Téléphone : _____ Courriel (si disponible) : _____
(y compris l'indicatif régional)

Adresse postale de l'installation, si différente de l'adresse civique : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Numéro d'identité de l'Inventaire national des rejets de polluants (si aucun, laissez en blanc) : _____

Code à six chiffres du Système de classification des industries de l'Amérique du Nord (SCIAN) : 221320

Responsable des renseignements techniques : _____

Courriel (si disponible) : _____

Téléphone : _____ Télécopieur (si disponible) : _____
(y compris l'indicatif régional) (y compris l'indicatif régional)

2.0 Facteur(s) faisant l'objet d'une demande de dérogation

Indiquez de façon précise pour quel(s) facteur(s) énuméré(s) dans cet avis une dérogation est demandée.

3.0 Justification de la demande

Expliquez pourquoi il serait déraisonnable ou impossible de prendre en considération chacun des facteurs pour lesquels une dérogation est demandée.

Expliquez comment les résultats du plan de prévention de la pollution seront affectés si ce(ces) « facteur(s) à prendre en considération » n'est(ne sont) pas considéré(s).

Si vous proposez d'utiliser un ou des facteurs additionnels lors de l'élaboration du plan de prévention de la pollution, expliquez lequel ou lesquels (optionnel).

4.0 Certification

Par la présente, j'atteste que l'information dans cette demande est véridique, exacte et complète.

_____ _____
Signature de la(des) personne(s) visée(s) par l'avis ou représentant(e) autorisé(e) Date

Nom : _____
En lettres moulées s.v.p.

Titre/Poste : _____
En lettres moulées s.v.p.

Note: Please contact the National Office of Pollution Prevention for more information about electronic reporting or the filing of paper forms.

Schedule 3: Request for Time Extension – Inorganic Chloramines and Chlorinated Wastewater Effluents (Subsection 56(3) of CEPA 1999)

Notice Reference Code: P2CLMWWE

Please refer to the instruction booklet "Instructions for Completing the Schedules of the *Canada Gazette* Notice Requiring the Preparation and Implementation of Pollution Prevention Plans for Inorganic Chloramines and Chlorinated Wastewater Effluents" for guidance on how to complete this Request.

Electronic copies of the Notice, and the instructions for completing the declarations (Schedules 1 to 5), are available from the National Office of Pollution Prevention Web site at www.ec.gc.ca/nopp/p2p/en/p2notices.cfm or can be requested by telephone at (819) 994-0186, by facsimile at (819) 953-7970 or by e-mail at CEPAP2Plans@ec.gc.ca.

1.0 Information on the Person or Class of Persons Subject to the Notice

Name of the Person or Class of Persons Subject to the Notice: _____

Facility Name: _____

Street Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

Telephone Number: _____ E-mail (if available): _____
(with area code)

If different from Street Address
Mailing Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

National Pollutant Release Inventory ID (if no ID, leave blank): _____

Six-digit North American Industry Classification System (NAICS) Code: 221320

Facility Technical Contact: _____

E-mail (if available): _____

Telephone Number: _____ Fax Number (if available): _____
(with area code) (with area code)

2.0 Request for Time Extension

Identify for which of the following a time extension is requested (choose one):

☐ to prepare a pollution prevention plan

☐ to submit an Interim Progress Report — Interim Progress Report No. _____ ***(not applicable for this Notice)***

☐ to implement a pollution prevention plan

For the person(s) identified in Part 1.0, it is requested that the date be extended to _____ (specify exact date – year/month/day)

3.0 Rationale for Request

Explain why further time is necessary to prepare or implement a pollution prevention plan.

4.0 Certification

I hereby certify that the information provided in this Request is true, accurate and complete.

_____ _____
Signature of the Person(s) Subject to the Notice or Duly Authorized Representative — Date

Name: _____
Please Print

Title/Position: _____
Please Print

Schedule 4: Interim Progress Report – NOT APPLICABLE FOR THIS NOTICE

Note : Veuillez communiquer avec le Bureau national de la prévention de la pollution pour obtenir plus d'information au sujet de la soumission électronique ou du dépôt des formulaires écrits.

Annexe 3 : Demande de prorogation du délai — Chloramines inorganiques et eaux usées chlorées [paragraphe 56(3) de la LCPE (1999)]

Code de référence de l'avis : P2CLMWWE

Pour plus d'information sur la façon de remplir cette déclaration, veuillez consulter la brochure « Directives pour remplir les annexes de l'avis de la *Gazette du Canada* requérant l'élaboration et l'exécution de plans de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées ».

Une copie électronique de cet avis et les instructions pour remplir les déclarations (annexes 1 à 5) sont disponibles sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/p2p/FR/p2notices.cfm ou peuvent être obtenues par téléphone au (819) 994-0186, par télécopieur au (819) 953-7970 ou par courriel à l'adresse cepap2plans@ec.gc.ca.

1.0 Renseignements sur la(les) personne(s) ou catégorie de personnes visée(s) par l'avis

Nom de la(des) personne(s) ou catégorie de personnes visée(s) par l'avis : _____

Nom de l'installation : _____

Adresse civique de l'installation : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Téléphone : _____ Courriel (si disponible) : _____
(y compris l'indicatif régional)

Adresse postale de l'installation, si différente de l'adresse civique : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Numéro d'identité de l'Inventaire national des rejets de polluants (si aucun, laissez en blanc) : _____

Code à six chiffres du Système de classification des industries de l'Amérique du Nord (SCIAN) : 221320

Responsable des renseignements techniques : _____

Courriel (si disponible) : _____

Téléphone : _____ Télécopieur (si disponible) : _____
(y compris l'indicatif régional) (y compris l'indicatif régional)

2.0 Demande de prorogation du délai

Indiquez pour laquelle des raisons suivantes une prorogation du délai est demandée (cochez une case seulement) :

☐ pour l'élaboration du plan de prévention de la pollution

☐ pour la présentation d'un rapport provisoire — rapport provisoire n° _____ ***(ne s'applique pas à cet avis)***

☐ pour l'exécution du plan de prévention de la pollution

Pour la(les) personne(s) désignée(s) dans la partie 1.0, il est demandé que le délai soit reporté au : _____ (indiquez la date exacte — année/mois/jour).

3.0 Justification de la demande

Expliquez pourquoi une prorogation de délai est nécessaire pour élaborer ou mettre en œuvre le plan de prévention de la pollution.

4.0 Certification

Par la présente, j'atteste que l'information dans cette demande est véridique, exacte et complète.

_____ _____
Signature de la(des) personne(s) visée(s) par l'avis ou représentant(e) autorisé(e) Date

Nom : _____
En lettres moulées s.v.p.

Titre/Poste : _____
En lettres moulées s.v.p.

Annexe 4 : Rapport d'étape provisoire — NE S'APPLIQUE PAS À CET AVIS

Note: Please contact the National Office of Pollution Prevention for more information about electronic reporting or the filing of paper forms.

Schedule 5: Declaration That a Pollution Prevention Plan Has Been Implemented – Inorganic Chloramines and Chlorinated Wastewater Effluents (Subsection 58(2) of CEPA 1999)

Notice Reference Code: P2CLMWWE

Please refer to the instruction booklet "Instructions for Completing the Schedules of the *Canada Gazette* Notice Requiring the Preparation and Implementation of Pollution Prevention Plans for Inorganic Chloramines and Chlorinated Wastewater Effluents" for guidance on how to complete this Declaration.

Electronic copies of the Notice, and the instructions for completing the declarations (Schedules 1 to 5), are available from the National Office of Pollution Prevention Web site at www.ec.gc.ca/nopp/p2p/en/p2notices.cfm or can be requested by telephone at (819) 994-0186, by facsimile at (819) 953-7970, or by e-mail at CEPAP2Plans@ec.gc.ca.

Is this an amendment to a Declaration previously submitted? ☐ Yes ☐ No

If yes, complete Parts 1.0 and 9.0 and any other Parts of this Declaration where previously reported information has become false or misleading. Previously reported information that is unchanged need not be resubmitted.

1.0 Information on the Person or Class of Persons Subject to the Notice

Name of the Person or Class of Persons Subject to the Notice: _____

Facility Name: _____

Street Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

Telephone number: _____ E-mail (if available): _____
(with area code)

If different from Street Address
Mailing Address of Facility: _____

City: _____ Province/Territory: _____ Postal Code: _____

National Pollutant Release Inventory ID (if no ID, leave blank): _____

Six-digit North American Industry Classification System (NAICS) Code: 221320

Facility Technical Contact: _____

E-mail (if available): _____

Telephone Number: _____ Fax Number (if available): _____
(with area code) (with area code)

2.0 No data are required for Part 2.0 of this Declaration

3.0 Substance and Activity

Substance and Activity for which information is required

Inorganic Chloramines and Chlorinated Wastewater Effluents: Persons identified in section 2 of the Notice who are required to prepare and implement a pollution prevention plan for inorganic chloramines and chlorinated wastewater effluents for the use of chlorine or chlorine compounds in wastewater systems and the release of chlorinated effluent to surface water.

4.0 Baseline Information after Implementation of the Pollution Prevention (P2) Plan

This Declaration requires reporting of data for the year of implementation (January 1 to December 31) of the pollution prevention plan, but no later than for the year 2009 (as specified in the Notice or any other year specified to a person who has been granted an extension of time to implement a plan).

Indicate the year of implementation for which the person(s) is(are) reporting: _____ (This will be the Reporting Year throughout this Declaration.)

4.1 - 4.4 No information is required for Parts 4.1 to 4.4 of this Declaration

4.5 Additional Baseline Information

4.5.1 Wastewater System Information

Describe the changes to your wastewater system since **2004** or **2005**, compared to the information provided in Schedule 1: Declaration that a pollution prevention plan has been prepared and is being implemented.

4.5.2 Releases to Surface Water

4.5.2.1 Inorganic Chloramines and Chlorinated Wastewater Effluents

Report in the table below the average flow of wastewater effluent and the maximum Total Residual Chlorine (TRC) concentrations. The average monthly flow should be determined on the basis of daily flow measurements. The maximum total residual chlorine concentration should be determined on the basis of representative sampling.

Implementation Year _____ (Month)	Average Flow of Effluent (m^3/day)	Maximum Total Residual Chlorine (TRC) Concentration (mg/L as Cl^-)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

5.0 Action(s) Taken and Results Achieved

5.1 Action(s) Taken

The following section (Parts 5.1.1 through 5.1.6) must be completed separately for each action taken in the P2 plan, i.e. this section will be completed as many times as there are actions taken to report.

In Part 5.1.1, describe, for the activity identified in Part 3.0 of this Declaration, the action taken in implementing the Pollution Prevention Plan. In Parts 5.1.2 and 5.1.3, identify whether the action represents pollution prevention method(s) or other environmental protection method(s) by selecting from the list of options provided below. In Part 5.1.4, report, where possible, the corresponding change to the maximum concentration of total residual chlorine measured in the effluent released to surface water achieved from implementation of that action, in mg/L. Refer to the instructions for specific information on how to report. Indicate a decrease with a negative sign ("–") and an increase with a positive sign ("+") in front of the reported change. Note that estimating a quantitative change for some actions taken, such as training, may not be possible. Finally, in Part 5.1.6, identify the completion date for each action taken.

5.1.1 Action Taken: _____

5.1.2 Type of Pollution Prevention Method(s):

- ☐ Equipment or process modifications
- ☐ Spill and leak prevention
- ☐ On-site reuse, recycling or recovery
- ☐ Good operating practices or training
- ☐ Other: _____

5.1.3 Other Type of Environmental Protection Method(s):

- ☐ Energy recovery
- ☐ Off-site recycling
- ☐ Waste treatment
- ☐ Pollution control
- ☐ Disposal
- ☐ Other: _____

5.1.4 Results of Actions Taken in 5.1.1: _____

5.1.5 No information is required for Part 5.1.5 of this Declaration

5.1.6 Completion Date (year/month/day): _____

This ends the section (Parts 5.1.1 through 5.1.6) that must be completed separately for each action taken in the P2 plan.

5.2 No information is required for Part 5.2 of this Declaration

5.3 Detailed Results Achieved Information

Total Results Achieved for Inorganic Chloramines and Chlorinated Wastewater Effluents

The table below summarizes, for the activity identified in Part 3.0 of this Declaration, the achieved change to the maximum concentration of total residual chlorine (TRC) in the effluent released to surface water, in mg/L, and as a percentage relative to the preparation year.

Report the change achieved from all actions taken as a result of implementing the pollution prevention plan.

Maximum Concentration of TRC in the Preparation Year (mg/L)	Achieved Maximum Concentration of TRC in the Implementation Year (mg/L)	Achieved change* in Maximum Concentration (%)

* Indicate a decrease with a negative sign ("–") and an increase with a positive sign ("+") in front of the reported change.

6.0 Monitoring and Reporting

For the activity identified in Part 3.0 of this Declaration, describe the monitoring and reporting used to track progress in implementing the Pollution Prevention Plan.

7.0 Risk Management Objective

For the activity identified in Part 3.0 of this Declaration, describe how the Pollution Prevention Plan outlined in this Declaration met the risk management objective identified in subsection 4(3) of the Notice. If this plan did not meet the risk management objective, explain why.

8.0 No information is required for Part 8.0 of this Declaration

9.0 Certification

I hereby certify that a pollution prevention plan has been implemented for inorganic chloramines and chlorinated wastewater effluents and that the information provided in this Declaration is true, accurate and complete.

Signature of the Person(s) Subject to the Notice or Duly Authorized Representative — Date

Name: _____
Please Print

Title/Position: _____
Please Print

[49-1-o]

Note : Veuillez communiquer avec le Bureau national de la prévention de la pollution pour obtenir plus d'information au sujet de la soumission électronique ou du dépôt des formulaires écrits.

Annexe 5 : Déclaration confirmant l'exécution d'un plan de prévention de la pollution — Chloramines inorganiques et eaux usées chlorées [paragraphe 58(2) de la LCPE (1999)]

Code de référence de l'avis : P2CLMWWE

Pour plus d'information sur la façon de remplir cette déclaration, consulter la brochure « Directives pour remplir les annexes de l'avis de la *Gazette du Canada* requérant l'élaboration et l'exécution de plans de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées ».

Une copie électronique de cet avis et les instructions pour remplir les déclarations (annexes 1 à 5) sont disponibles sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/p2p/FR/p2notices.cfm ou peuvent être obtenues par téléphone au (819) 994-0186, par télécopieur au (819) 953-7970, ou par courriel à l'adresse cepap2plans@ec.gc.ca.

La présente déclaration apporte-t-elle une modification à une déclaration déjà présentée? ☐ Oui ☐ Non

Si vous avez coché « oui », remplissez les parties 1.0 et 9.0, et toute autre partie de cette déclaration pour laquelle des renseignements déjà déclarés sont maintenant faux ou trompeurs. Il n'est pas nécessaire de soumettre les informations inchangées se trouvant dans des déclarations précédentes.

1.0 Renseignements sur la(les) personne(s) ou catégorie de personnes visée(s) par l'avis

Nom de la(des) personne(s) ou catégorie de personnes visée(s) par l'avis : _____

Nom de l'installation : _____

Adresse civique de l'installation : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Téléphone : _____ Courriel (si disponible) : _____
(y compris l'indicatif régional)

Adresse postale de l'installation, si différente de l'adresse civique : _____

Ville : _____ Province/Territoire : _____ Code postal : _____

Numéro d'identité de l'Inventaire national des rejets de polluants (si aucun, laissez en blanc) : _____

Code à six chiffres du Système de classification des industries de l'Amérique du Nord (SCIAN) : 221320

Responsable des renseignements techniques : _____

Courriel (si disponible) : _____

Téléphone : _____ Télécopieur (si disponible) : _____
(y compris l'indicatif régional) (y compris l'indicatif régional)

2.0 Il n'est pas nécessaire de fournir de données pour la partie 2.0 de cette déclaration

3.0 Substance et activité

Substance et activité pour lesquels certaines informations sont requises

Chloramines inorganiques et eaux usées chlorées : Personnes identifiées dans l'article 2 de l'avis, qui doivent élaborer et exécuter un plan de prévention de la pollution pour les chloramines inorganiques et les eaux usées chlorées liées à l'usage du chlore ou de composés chlorés dans les réseaux d'assainissement et le rejet d'eaux usées chlorées dans les eaux de surface.

4.0 Information de base suivant l'exécution du plan de prévention de la pollution (P2)

Cette déclaration requiert la présentation des données pour l'année d'exécution (du 1er janvier au 31 décembre) du plan de prévention de la pollution, qui se trouve au plus tard pour l'année 2009 (tel qu'il est précisé dans l'avis, ou toute autre année spécifiée à une personne qui a obtenu une prorogation du délai pour l'exécution d'un plan).

Indiquez l'année d'exécution pour laquelle la(les) personne(s) doit(doivent) soumettre son(leur) rapport : _____ (Cette nouvelle année sera considérée comme l'année pour laquelle le rapport doit être fait, aux fins de cette déclaration.)

4.1 - 4.4 Aucune information n'est requise pour les parties 4.1 à 4.4 de cette déclaration

4.5 Information de base additionnelle

4.5.1 Information sur le réseau d'assainissement

Décrivez les changements à votre réseau d'assainissement depuis **2004** ou **2005**, en comparaison à l'information fournie à l'annexe 1 : Déclaration confirmant qu'un plan de prévention de la pollution a été élaboré et qu'il est en cours d'exécution.

4.5.2 Rejets dans un plan d'eau de surface

4.5.2.1 *Chloramines inorganiques et eaux usées chlorées*

Déclarez dans le tableau ci-dessous le débit moyen de l'effluent d'eaux usées et les concentrations maximales de chlore résiduel total (CRT). Le débit moyen mensuel devrait être calculé en fonction des mesures du débit quotidien. La concentration maximale de chlore résiduel total devrait être déterminée en fonction d'un échantillon représentatif.

Année d'exécution (mois)	Débit moyen de l'effluent (m^3/jour)	Concentration maximale de chlore résiduel total (CRT) (mg/L en Cl^-)
Janvier		
Février		
Mars		
Avril		
Mai		
Juin		
Juillet		
Août		
Septembre		
Octobre		
Novembre		
Décembre		

5.0 **Mesure(s) mise(s) en œuvre et résultat(s) obtenu(s)**

5.1 ***Mesure(s) mise(s) en œuvre***

Les parties suivantes de la présente déclaration (parties 5.1.1 à 5.1.6) doivent être remplies séparément pour chaque mesure prévue indiquée dans le plan de prévention de la pollution, c'est-à-dire que cette section doit être remplie autant de fois qu'il y a de mesures à déclarer.

Dans la partie 5.1.1, décrivez pour l'activité identifiée à la partie 3.0 de la présente déclaration la mesure mise en œuvre pour exécuter le plan de prévention de la pollution. Dans les parties 5.1.2 et 5.1.3, indiquez si cette mesure représente une mesure de prévention de la pollution ou toute autre mesure de protection de l'environnement, en choisissant l'une des options fournies ci-dessous. Dans la partie 5.1.4, inscrivez, le cas échéant, le changement à la concentration maximale de chlore résiduel total mesuré dans l'effluent rejeté à l'eau de surface, en mg/L, résultant de la mise en œuvre de la mesure. Pour obtenir des informations spécifiques sur la façon de compléter cette section, référez-vous aux instructions. Indiquez une diminution par le signe « – » et une augmentation par le signe « + » devant la quantité indiquée. Notez que dans certains cas il peut s'avérer impossible d'estimer un changement quantitatif pour certaines mesures mises en œuvre, par exemple la formation du personnel. Enfin, dans la partie 5.1.6, indiquez la date d'achèvement prévue pour chaque mesure prévue.

5.1.1 Mesure mise en œuvre : _____

5.1.2 Types de méthodes de prévention de la pollution :

- ☐ Modifications de l'équipement ou du procédé
- ☐ Prévention des fuites ou des déversements
- ☐ Récupération, réutilisation ou recyclage sur place
- ☐ Bonnes pratiques d'exploitation ou formation
- ☐ Autres : _____

5.1.3 Autres types de méthodes de protection de l'environnement :

- ☐ Récupération d'énergie
- ☐ Recyclage hors site
- ☐ Traitement des déchets
- ☐ Contrôle de la pollution
- ☐ Élimination
- ☐ Autres : _____

5.1.4 Résultats des mesures mises en œuvre en 5.1.1 : _____

5.1.5 Aucune information n'est requise pour la partie 5.1.5 de cette déclaration

5.1.6 Date d'achèvement (année/mois/jour) : _____

Ici se termine la section (parties 5.1.1 à 5.1.6) devant être remplie séparément pour chaque mesure mise en œuvre dans le plan de prévention de la pollution.

5.2 ***Aucune information n'est requise pour la partie 5.2 de cette déclaration***

5.3 Information détaillée sur les résultats obtenus

Résultats totaux obtenus pour les chloramines inorganiques et les eaux usées chlorées

Le tableau ci-dessous résume, pour l'activité identifiée dans la partie 3.0 de cette déclaration, le changement obtenu à la concentration maximale du chlore résiduel total (CRT) dans l'effluent rejeté dans l'eau de surface, en mg/L, et en pourcentage par rapport à l'année de préparation.

Déclarez le changement obtenu à la suite de toutes les mesures mises en œuvre découlant de l'exécution du plan de prévention de la pollution.

Concentration maximale de CRT dans l'année de préparation (mg/L)	Concentration maximale de CRT atteinte dans l'année de la mise en œuvre (mg/L)	Changement* obtenu à la concentration maximale (%)

* Indiquez une diminution avec un signe négatif (« – ») et une augmentation avec un signe positif (« + ») devant la quantité déclarée.

6.0 Surveillance et rapport

Pour l'activité identifiée à la partie 3.0 de cette déclaration, décrivez les méthodes de surveillance et de compte rendu utilisées pour suivre les progrès de l'exécution du plan de prévention de la pollution.

7.0 Objectif de gestion du risque

Pour l'activité identifiée à la partie 3.0 de cette déclaration, décrivez comment le plan de prévention de la pollution, tel qu'il est décrit dans cette déclaration, a répondu à l'objectif de gestion du risque décrit au paragraphe 4(3) de l'avis. Si ce plan n'a pas répondu à l'objectif de gestion du risque, expliquez pourquoi.

8.0 Aucune information n'est requise pour la partie 8.0 de cette déclaration

9.0 Certification

J'atteste qu'un plan de prévention de la pollution a été exécuté pour les chloramines inorganiques et les eaux usées chlorées et que les renseignements soumis dans la présente déclaration sont véridiques, exacts et complets.

_____ _____

Signature de la(des) personne(s) visée(s) par l'avis ou représentant(e) autorisé(e) — Date

Nom : _____

En lettres moulées s.v.p.

Titre/Poste : _____

En lettres moulées s.v.p.

[49-1-o]

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Canada Gazette, Part I
December 4, 2004

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Gazette du Canada, Partie I
Le 4 décembre 2004

DEPARTMENT OF THE ENVIRONMENT

MINISTÈRE DE L'ENVIRONNEMENT

Guideline for the release of ammonia dissolved in water found in wastewater effluents

Ligne directrice sur le rejet de l'ammoniac dissous dans l'eau se trouvant dans les effluents d'eaux usées

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DEPARTMENT OF THE ENVIRONMENT

CANADIAN ENVIRONMENTAL PROTECTION ACT, 1999

Guideline for the release of ammonia dissolved in water found in wastewater effluents

Whereas ammonia dissolved in water is a substance specified on the List of Toxic Substances in Schedule 1 of the *Canadian Environmental Protection Act, 1999*;

Whereas the Minister of the Environment published a Proposed Notice requiring the preparation and implementation of pollution prevention plans for ammonia dissolved in water, inorganic chloramines and chlorinated wastewater effluents in the *Canada Gazette*, Part I, on June 7, 2003;

Whereas persons were given the opportunity to file comments with respect to the Proposed Notice for a comment period of 60 days;

Whereas the Minister has considered all comments received;

Whereas this Guideline is issued as an instrument respecting preventive and control actions in relation to ammonia dissolved in water found in wastewater effluents in application of section 92 of the Act;

MINISTÈRE DE L'ENVIRONNEMENT

LOI CANADIENNE SUR LA PROTECTION DE L'ENVIRONNEMENT (1999)

Ligne directrice sur le rejet de l'ammoniac dissous dans l'eau se trouvant dans les effluents d'eaux usées

Attendu que l'ammoniac dissous dans l'eau est une substance figurant sur la Liste des substances toxiques de l'annexe 1 de la *Loi canadienne sur la protection de l'environnement (1999)*;

Attendu que le ministre de l'Environnement a publié un projet d'avis requérant l'élaboration et l'exécution de plans de prévention de la pollution à l'égard de l'ammoniac dissous dans l'eau, les chloramines inorganiques et les eaux usées chlorées dans la Partie I de la *Gazette du Canada*, le 7 juin 2003;

Attendu que toute personne a eu la possibilité d'envoyer des commentaires concernant le projet d'avis pendant une période de commentaires de 60 jours;

Attendu que le ministre a considéré tous les commentaires reçus;

Attendu que cette ligne directrice est publiée comme un instrument concernant les mesures de prévention et de contrôle à l'égard de l'ammoniac dissous dans l'eau se trouvant dans les effluents d'eaux usées, en application de l'article 92 de la Loi;

And whereas the Minister of the Environment has published a Notice requiring the preparation and implementation of pollution prevention plans for inorganic chloramines and chlorinated wastewater effluents;

Therefore, the Minister of the Environment, pursuant to subsection 54(1) of the *Canadian Environmental Protection Act, 1999*, has decided to issue a Guideline as a means to reduce the impact of releases of ammonia dissolved in water to surface water, and pursuant to subsection 54(4) directs that it be published in the *Canada Gazette*, Part I.

STÉPHANE DION
Minister of the Environment

1. Interpretation

"Act" means the *Canadian Environmental Protection Act, 1999*.

"acutely lethal concentration of ammonia" means a level of ammonia in an effluent at 100 percent concentration that kills more than 50 percent of the rainbow trout subjected to it over a 96-hour period when tested in accordance with the acute lethality test set out in Reference Method EPS 1/RM/13. For the purpose of this Guideline, this is represented by a concentration of ammonia that is on or above the curve when plotted versus the effluent pH as shown in Figure 1 of Appendix A. Owners must measure the pH and concentration of ammonia in the effluent and use the curve (Figure 1).

"ammonia" means total ammonia expressed as nitrogen. Total ammonia means the sum of the unionized ammonia (NH_3) and ionized ammonia (NH_4^+) species which exist in equilibrium in water. Analytical methods measure and typically report on ammonia nitrogen as opposed to total ammonia.

"chronic toxicity" means the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually upon repeated or continuous exposure sometimes lasting for the entire life of the exposed organism. For the purpose of this Guideline, chronic toxicity results in reduced reproductive capacity and reduced growth of young in fish and benthic invertebrate populations.

"effluent" means untreated or treated wastewater that is released from the outfall(s) of a wastewater system, excluding combined sewer overflows from the wastewater system.

"fresh water" means water that generally contains less than 1 000 milligrams per litre of dissolved solids.

"representative sampling" means the weekly measurement of ammonia and pH in the effluent under normal operating conditions of the wastewater treatment facility.

"surface water" means a lake, pond, marsh, creek, spring, stream, river, estuary or marine body of water, or other surface watercourse.

"wastewater" means a mixture of liquid wastes primarily composed of domestic sewage, that can also include other liquid wastes from industrial, commercial and institutional sources.

"wastewater system" means any works for the collection or treatment and release of wastewater or any part of such works.

2. Application

This Guideline applies to any person who owns a wastewater system at the time of publication of this Guideline that has an

Et attendu que le ministre a publié un Avis requérant l'élaboration et l'exécution de plans de prévention de la pollution à l'égard des chloramines inorganiques et des eaux usées chlorées;

Le ministre de l'Environnement, en vertu du paragraphe 54(1) de la *Loi canadienne sur la protection de l'environnement (1999)*, a décidé d'établir cette ligne directrice comme moyen de réduire l'impact des rejets d'ammoniac dissous dans l'eau dans les eaux de surface et en vertu du paragraphe 54(4), donne avis de sa publication dans la Partie I de la *Gazette du Canada*.

Le ministre de l'Environnement
STÉPHANE DION

1. Définitions

« ammoniac » désigne l'ammoniac total exprimé en azote. L'ammoniac total désigne la somme des espèces d'ammoniac non ionisé (en NH_3) et d'ammoniac ionisé (NH_4^+) qui existent en équilibre dans l'eau. Les méthodes d'analyse mesurent et présentent généralement leurs résultats en azote ammoniacal, et non en ammoniac total.

« concentration létale aiguë de l'ammoniac » désigne une teneur en ammoniac dans un effluent concentré à 100 p. 100, qui tue plus de 50 p. 100 de truites arc-en-ciel exposées sur une période de 96 heures, lorsque le test est effectué selon la Méthode de référence SPE 1/RM/13. Aux fins de cette ligne directrice, cette concentration létale est représentée par les valeurs se trouvant sur ou au-dessus de la courbe lorsque ces valeurs d'ammoniac sont tracées en fonction du pH de l'effluent, tel qu'il est démontré à la figure 1 de l'annexe A. Les propriétaires doivent mesurer le pH et la concentration en ammoniac de l'effluent et utiliser la courbe (figure1).

« eau de surface » désigne un lac, un étang, un marais, un ruisseau, une source, un cours d'eau, une rivière, un estuaire ou un plan d'eau marin, ou tout autre cours d'eau de surface.

« eau douce » désigne des eaux qui contiennent généralement moins de 1 000 milligrammes par litre de solides dissous.

« eaux usées » désigne un mélange d'eaux usées, composé principalement d'eau d'égout domestique, qui peut aussi contenir d'autres eaux usées de sources industrielles, commerciales et institutionnelles.

« échantillonnage représentatif » désigne la mesure hebdomadaire d'ammoniac et du pH dans l'effluent selon les conditions opérationnelles normales de l'installation de traitement des eaux usées.

« effluent » désigne les eaux usées traitées ou non traitées qui sont rejetées à l'exutoire d'un réseau d'assainissement, en excluant les débordements de réseaux d'égouts unitaires.

« Loi » désigne la *Loi canadienne sur la protection de l'environnement (1999)*.

« réseau d'assainissement » désigne tous les ouvrages servant à la collecte ou au traitement et au rejet des eaux usées, ou toute partie de ces ouvrages.

« toxicité chronique » désigne la capacité d'une substance ou d'un mélange de substances de causer des effets nuisibles sur une période prolongée, habituellement par exposition répétée ou continue, se répétant parfois durant la vie entière de l'organisme exposé. Aux fins de cette ligne directrice, la toxicité chronique donne lieu à une réduction de la capacité de reproduction et à un ralentissement de la croissance des jeunes dans les populations de poisson et d'invertébrés benthiques.

2. Application

Cette ligne directrice s'applique à toute personne qui possède un réseau d'assainissement, au moment de la publication de cette

effluent discharge flow to surface water that is greater than or equal to 5 000 m^3 per day, based on an annual average.

3. Standards

The available scientific literature indicates that the environmental risks associated with ammonia are related to both its acute and chronic toxicity to freshwater organisms. The 2001 Priority Substances List (PSL) Assessment Report that led to the addition of "Ammonia dissolved in water" to the List of Toxic Substances in Schedule 1 of the CEPA 1999 and the CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life provide an overview of the factors known to affect the toxicity of ammonia. Any person who meets the criteria in section 2 of this guideline should take measures to meet the following standards.

Acute toxicity

The concentration of ammonia deposited to surface water frequented by fish should not be acutely lethal. Refer to Appendix A, which describes the procedure for determining whether the effluent is acutely lethal to fish due to ammonia.

- An objective for ammonia releases to surface water is to achieve and maintain a concentration of ammonia in the effluent that is not acutely lethal to fish due to ammonia.

Chronic toxicity

The chronic toxicity of ammonia to fish and benthic invertebrate populations is likely to result in reduced reproductive capacity and reduced growth of young. The zone of impact of non-treated or inadequately treated effluents varies greatly with discharge conditions, mixing capacity of the receiving water, temperature and pH. Potentially toxic conditions resulting from municipal wastewater-related ammonia typically start in May and continue into October in receiving waters that are routinely basic in pH, relatively warm in temperature, and have a low flow. Further guidance to ascertain how site-specific conditions may impact on the chronic toxicity of ammonia can be found in the PSL Assessment Report. Refer to section 5 of this Guideline for links to information on the PSL Assessment Report.

- An objective for ammonia releases to surface water is to achieve and maintain a concentration of ammonia in the effluent that will ensure the protection of freshwater life. Wastewater systems should not release ammonia in quantities or concentrations resulting in a concentration of unionized ammonia greater than 0.019 mg/L in the aquatic environment.

Further information on the chronic toxicity of ammonia can be found in the CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life for ammonia. Canadian water quality guidelines are intended to provide protection of freshwater and marine life from anthropogenic stressors such as chemical inputs or changes to physical components.

ligne directrice, qui rejette dans les eaux de surface un débit d'effluent supérieur ou égal à 5 000 m^3 par jour, selon une moyenne annuelle.

3. Normes

La littérature scientifique disponible indique que les risques environnementaux associés à l'ammoniac sont reliés à la toxicité aiguë et à la toxicité chronique de celui-ci envers les organismes vivant en eau douce. Le Rapport d'évaluation de la Liste des substances d'intérêt prioritaire de 2001, qui a mené à l'ajout de « l'ammoniac dissous dans l'eau » à la Liste des substances toxiques de l'annexe 1 de la LCPE (1999) ainsi que les Recommandations canadiennes pour la qualité des eaux — protection de la vie aquatique du CCME présentent un résumé des facteurs connus affectant la toxicité de l'ammoniac. Toute personne rencontrant les critères tels qu'ils sont définis dans l'article 2 de cette ligne directrice devrait prendre des mesures afin d'atteindre les normes suivantes.

Toxicité aiguë

La concentration d'ammoniac rejeté dans les eaux de surface où vivent les poissons ne devrait pas être létale, à la suite d'une intoxication aiguë d'ammoniac. L'annexe A décrit la méthode afin de déterminer si un effluent contient une concentration d'ammoniac qui s'avère de létalité aiguë pour les poissons.

- Un objectif pour les rejets d'ammoniac dans les eaux de surfaces est d'atteindre et de maintenir une concentration en ammoniac dans l'effluent qui ne s'avère pas de létalité aiguë pour les poissons.

Toxicité chronique

La toxicité chronique de l'ammoniac envers les poissons et les populations d'invertébrés benthiques peut donner lieu à une réduction de la capacité de reproduction et à un ralentissement de la croissance des jeunes. La zone d'impact des effluents non traités, ou traités de façon inadéquate, varie grandement selon les conditions de rejets, la capacité de mélange des eaux réceptrices, la température et le pH. Les conditions potentiellement toxiques reliées à l'ammoniac se trouvant dans les eaux usées municipales débutent généralement en mai et se poursuivent jusqu'en octobre dans les eaux réceptrices, qui se caractérisent par un pH régulièrement basique, par une température relativement chaude et par un faible débit. Plus de détails sur la façon de déterminer comment les conditions propres à un site peuvent avoir un effet sur la toxicité chronique de l'ammoniac se trouvent dans le Rapport d'évaluation de la Liste des substances d'intérêt prioritaire. La section 5 de cette ligne directrice contient l'adresse du site Internet présentant plus d'information sur le Rapport d'évaluation de la Liste des substances d'intérêt prioritaire.

- Un objectif pour les rejets d'ammoniac dans les eaux de surface est d'atteindre et de maintenir une concentration d'ammoniac dans l'effluent qui assurera la protection des organismes vivant en eau douce. Les réseaux d'assainissement ne devraient pas rejeter d'ammoniac en quantité ou en concentration menant à une concentration d'ammoniac non ionisé supérieure à 0,019 mg/L dans l'environnement aquatique.

Les Recommandations canadiennes pour la qualité des eaux — protection de la vie aquatique du CCME pour l'ammoniac contiennent plus d'information sur la toxicité chronique de l'ammoniac. Les recommandations canadiennes pour la qualité des eaux visent à assurer la protection de la vie en eau douce et en eau marine contre des agents anthropogènes qui sont facteurs de stress, tels que des rejets de produits chimiques ou des changements à certaines composantes physiques.

4. Factors to consider

Any person who owns a wastewater system as defined in section 2 above should consider the following factors while developing plans and actions to meet the standards outlined in section 3:

(1) Following detailed scientific assessments, ammonia dissolved in water was found to be toxic in accordance with the criteria set out in section 64 of the Act. As such, it was added to the List of Toxic Substances in Schedule 1 of the Act. In addition, the deposit of a deleterious substance of any type in water frequented by fish is prohibited by the *Fisheries Act*, under subsection 36(3), unless there is a regulation under subsection 36(5) of the *Fisheries Act* or under another federal law authorizing the deposit. With respect to the release of ammonia through municipal wastewater effluents, there is no federal regulation at the time of publication of this Guideline. Refer to section 5 of this Guideline for links to information on the *Fisheries Act*, and the compliance and enforcement policies of the *Fisheries Act* and the Act.

(2) The Canadian Council of Ministers of the Environment (CCME) agreed in November 2003 to develop a Canada-wide Strategy for the management of municipal wastewater effluents, which will address specific parameters and governance. The Strategy will be based on the following three cornerstones:

(*a*) harmonization of the regulatory framework;

(*b*) coordinated science and research; and

(*c*) an environmental risk management model.

The Strategy is expected to be completed by December 2006, after which it will be implemented by each jurisdiction. Environment Canada intends to use a regulation under the *Fisheries Act* as its principal implementation tool to achieve effluent standards for wastewater treatment systems equivalent in performance to conventional secondary treatment, with additional treatment where required. The regulation will also address wastewater systems on federal and aboriginal lands. Refer to section 5 of this Guideline for links to the CCME Canada-wide Strategy.

(3) To ensure that the overall risk to the environment or human health is reduced, owners of wastewater systems should consider actions that reduce or eliminate risks posed by other substances that may be found in municipal wastewater effluent, in particular the following substances which are specified in Schedule 1 of the Act:

(*a*) nonylphenol and its ethoxylates,

(*b*) effluents from textile mills that use wet processing,

(*c*) mercury,

(*d*) lead,

(*e*) hexavalent chromium compounds,

(*f*) inorganic cadmium compounds,

(*g*) inorganic arsenic compounds,

(*h*) inorganic chloramines,

(*i*) chlorinated wastewater effluents.

(4) Nitrogen in ammonia, along with phosphorus, is a nutrient responsible for stimulating plant and algal growth in the aquatic environment. However, excessive amounts of ammonia and phosphorus can cause over-fertilization or eutrophication, resulting in excessive growth of algae. Eutrophication reduces available dissolved oxygen, can have toxic effects on aquatic organisms, harm spawning grounds, alter habitat, lead to a decline in certain species, and impair the aesthetic enjoyment of water. Municipal wastewater is the largest point source of nitrogen and phosphorus released to the Canadian environment, although non-point sources may also be significant. The occurrence of eutrophication depends on a number of site-specific

4. Facteurs à considérer

Toute personne qui possède un réseau d'assainissement, tel qu'il est défini à l'article 2 ci-dessus, devrait considérer les facteurs suivants lors de l'élaboration des plans et des mesures visant à satisfaire aux normes présentées à l'article 3 :

(1) À la suite d'évaluations scientifiques approfondies, l'ammoniac dissous dans l'eau a été déclaré comme substance toxique en vertu de la Loi. À ce titre, cette substance a été ajoutée à la Liste des substances toxiques de l'annexe 1 de la Loi. Les personnes assujetties à cette ligne directrice doivent considérer que cette substance est « toxique » selon les critères établis à l'article 64 de la Loi. De plus, le dépôt d'une substance nocive dans les eaux où vivent les poissons est interdit par le paragraphe 36(3) de la *Loi sur les pêches* à moins qu'il n'y ait un règlement qui l'autorise, soit en vertu du paragraphe 36(5) de cette même loi, ou d'une autre loi fédérale. En ce qui concerne le rejet de l'ammoniac, il n'existe aucun règlement fédéral au moment de la publication de cette ligne directrice. Les adresses Internet des sites d'information sur la *Loi sur les pêches* et les politiques de conformité et d'application des dispositions de cette loi ainsi que de la *Loi canadienne sur la protection de l'environnement (1999)* se trouvent à l'article 5 de cette ligne directrice.

(2) Le Conseil canadien des ministres de l'environnement (CCME) a convenu en novembre 2003 d'élaborer une stratégie pancanadienne pour la gestion des effluents d'eaux usées municipales qui portera sur des paramètres spécifiques et sur des questions de gouvernance. La stratégie se fondera sur les trois pierres angulaires suivantes :

a) harmonisation du cadre réglementaire;

b) coordination de la science et de la recherche;

c) modèle de gestion des risques environnementaux.

On prévoit que la stratégie sera complétée d'ici décembre 2006, ce après quoi elle sera mise en œuvre par chaque instance. Environnement Canada a l'intention d'utiliser un règlement en vertu de la *Loi sur les pêches* comme son principal outil d'exécution afin que les réseaux d'assainissement atteignent des normes qui seront équivalentes, en performance, au rendement du traitement secondaire conventionnel, avec un traitement supplémentaire au besoin. Le règlement tiendra compte des systèmes d'eaux usées se trouvant sur les terres fédérales et autochtones. L'adresse Internet du site d'information sur la stratégie pancanadienne du CCME se trouve à l'article 5 de cette ligne directrice.

(3) Pour s'assurer de réduire le risque global pour l'environnement ou la santé humaine, les propriétaires de réseau d'assainissement devraient considérer de mettre en œuvre des mesures qui réduisent ou éliminent les risques causés par d'autres substances qui peuvent se trouver dans les effluents d'eaux usées municipales, en particulier les substances suivantes figurant à Liste des substances toxiques de l'annexe 1 de la Loi :

a) nonylphénol et ses dérivés éthoxylés,

b) effluents des usines de textile qui utilisent des procédés de traitement au mouillé,

c) mercure,

d) plomb,

e) composés de chrome hexavalent,

f) composés inorganiques de cadmium,

g) composés inorganiques d'arsenic,

h) chloramines inorganiques,

i) eaux usées chlorées.

(4) L'azote dans l'ammoniac ainsi que le phosphore constituent des éléments nutritifs stimulant la croissance des plantes et des

factors and is not generally a problem associated with every municipal wastewater discharge. Excessive loadings of nitrogen and phosphorus are usually best managed on a watershed basis, where loadings from all sources can be identified and the appropriate ones reduced to minimize eutrophication.

(5) A process audit should be conducted and may be useful in identifying the sources and quantities of ammonia discharged to the wastewater collection system from industrial, commercial, and institutional facilities. These facilities may be amenable to pollution prevention or control options that minimize the introduction of ammonia into the wastewater system. Refer to section 5 of this Guideline for links to technical guidance on system and process audits.

(6) Many wastewater treatment facilities are not operated with ammonia reduction as a primary objective. Optimization of the wastewater treatment facility may reduce the concentration of ammonia released to surface water and, where chlorination is practiced, the creation of inorganic chloramines without impairing the attainment of other treatment objectives. A process audit of the wastewater treatment facility should be conducted specifically looking for means to reduce the release of ammonia to surface water. Refer to section 5 of this Guideline for links to technical guidance for process audits.

algues dans l'environnement aquatique. Toutefois, des quantités excessives d'ammoniac et de phosphore peuvent causer une surfertilisation ou une eutrophisation, donnant lieu à la croissance excessive d'algues. L'eutrophisation réduit l'oxygène dissous disponible, ce qui peut avoir des effets toxiques sur les organismes aquatiques, nuire aux frayères, modifier l'habitat, conduire au déclin de certaines espèces et entraver la jouissance esthétique de l'eau. Les eaux usées municipales sont la plus grande source ponctuelle d'azote et de phosphore rejetés dans l'environnement canadien, bien que les rejets de sources diffuses puissent également être importants. L'eutrophisation dépend d'un certain nombre de facteurs propres à un site spécifique, et généralement n'est pas un problème associé à tous les rejets d'eaux usées municipales. Les charges excessives d'azote et de phosphore sont habituellement mieux gérées en tenant compte des bassins versants, où les charges de toutes les sources peuvent être identifiées et où certaines d'entre elles peuvent réduirent leur apport afin de minimiser l'eutrophisation.

(5) Une vérification des procédés devrait être entreprise. Ceci pourrait s'avérer utile afin de déterminer les sources et les quantités d'ammoniac qui sont rejetées dans le système de collecte des eaux usées provenant des installations industrielles, commerciales et institutionnelles. Ces installations peuvent être disposées à considérer certaines options de prévention de la pollution ou de contrôle de la pollution à la source, afin de minimiser l'introduction d'ammoniac dans les réseaux d'assainissement. Une liste de sites Internet ayant des informations techniques sur les vérifications des systèmes et des procédés se trouve à l'article 5 de cette ligne directrice.

(6) De nombreuses installations de traitement des eaux usées ne sont pas exploitées en ayant comme objectif premier la réduction de l'ammoniac. L'optimisation de l'installation de traitement des eaux usées peut réduire la concentration d'ammoniac rejeté dans les eaux de surface et, là où la déchloration est pratiquée, la création de chloramines inorganiques peut aussi être réduite sans entraver la réalisation des autres objectifs de traitement. Une vérification des procédés de l'installation de traitement des eaux usées devrait être entreprise en examinant spécifiquement les moyens de réduire le rejet de l'ammoniac dans les eaux de surface. Une liste de sites Internet ayant des informations techniques sur les vérifications des systèmes et des procédés se trouve à l'article 5 de cette ligne directrice.

5. Additional information

To obtain a copy of the Priority Substances List Assessment Report *Ammonia in the Aquatic Environment*, refer to the Existing Substances Evaluation Web site at www.ec.gc.ca/substances/ese/eng/psap/final/ammonia.cfm or contact the Inquiry Centre, 70 Crémazie Street, 7th Floor, Gatineau, Quebec K1A 0H3, 1-800-668-6767.

To obtain a copy of the report *Treatment Processes for the Removal of Ammonia from Municipal Wastewater* (Environment Canada, 2003, ISBN 0-662-33551-1), contact Environment Canada's Inquiry Centre at 1-800-668-6767.

To obtain a copy of the following documents: *Wastewater Source Control — A Best Practice By The National Guide to Sustainable Municipal Infrastructure* (March 2003), *Wastewater Treatment Plant Optimization* (November 2003), and *Optimization of Lagoon Operation* (March 2004), refer to the National Research Council — National Guide to Sustainable Municipal Infrastructure's Web site at www.infraguide.gc.ca/bestPractices/default_e.asp or contact the Council at 1-866-330-3350.

5. Information supplémentaire

Pour obtenir une copie du rapport d'évaluation de la Liste des substances d'intérêt prioritaire intitulé *L'ammoniac dans l'environnement aquatique*, visitez le site Web sur l'évaluation des substances existantes à l'adresse www.ec.gc.ca/substances/ese/fre/pesip/final/ammonia.cfm ou communiquez avec le Centre de renseignements, 70, rue Crémazie, 7e étage, Gatineau (Québec) K1A 0H3, 1 800 668-6767.

Pour obtenir une copie du rapport intitulé *Procédés de traitement pour l'enlèvement de l'ammoniac des eaux usées municipales* (Environnement Canada, 2003, ISBN 0-662-33551-1), communiquez avec le Centre de renseignements d'Environnement Canada au 1 800 668-6767.

Pour obtenir une copie des documents suivants : *Contrôle à la source des eaux usées, Innovations et règles de l'art par le Guide national pour des infrastructures municipales durables* (mars 2003), *Optimisation d'une station d'épuration des eaux usées* (novembre 2003) et *Optimisation du lagunage* (mars 2004), visitez le site Web du Conseil national de recherches — Guide national de l'infrastructure municipale durable à l'adresse www.infraguide.gc.ca/bestPractices/default_f.asp ou appelez au 1 866 330-3350.

To obtain information regarding the CCME Canada-wide strategy for the management of municipal wastewater effluents, visit the CCME Web site at www.ccme.ca/initiatives/water.html?category_id=81.

To obtain further information regarding the Canadian Water Quality Guidelines, refer to the CCME Web site at www.ccme.ca/initiatives/water.html?category_id=41 or contact the CCME by telephone at (204) 948-2090.

To obtain a copy of the document *Guidance Manual for Sewage Treatment Plant Process Audits*, refer to the Great Lakes Sustainability Fund Web site at http://sustainabilityfund.gc.ca or contact: Manager, Great Lakes Sustainability Fund, 867 Lakeshore Road, Burlington, Ontario L7R 4A6, (905) 336-6273.

To obtain a copy of the *Fisheries Act*, refer to http://laws.justice.gc.ca/en/F-14. For more information on the compliance and enforcement policies of the *Fisheries Act* and the *Canadian Environmental Protection Act, 1999*, visit the Environmental Law Enforcement Web site at www.ec.gc.ca/ele-ale/policies/policies_e.asp.

Additional information on pollution prevention is available from the National Office of Pollution Prevention Web site (www.ec.gc.ca/nopp), the Canadian Pollution Prevention Information Clearinghouse (www.ec.gc.ca/cppic), and Environment Canada's regional offices.

Electronic copies of this Guideline are available from the CEPA Registry Web site at www.ec.gc.ca/CEPARegistry/default.cfm or can be requested by contacting one of the regional offices listed in section 6.

6. Environment Canada contact information

For questions about this notice, or for more information about pollution prevention planning, contact Environment Canada's regional offices:

For residents of Newfoundland and Labrador
Environmental Protection Branch – Atlantic Region
Environment Canada
6 Bruce Street
Mount Pearl, Newfoundland and Labrador A1N 4T3
Telephone: (709) 772-5491
Facsimile: (709) 772-5097

For residents of Prince Edward Island
Environmental Protection Branch – Atlantic Region
Environment Canada
97 Queen Street, Room 202
Charlottetown, Prince Edward Island C1A 4A9
Telephone: (902) 566-7043
Facsimile: (902) 566-7279

For residents of Nova Scotia
Environmental Protection Branch – Atlantic Region
Environment Canada
Queen Square, 16th Floor
45 Alderney Drive
Dartmouth, Nova Scotia B2Y 2N6
Telephone: (902) 426-8926
Facsimile: (902) 426-3897

Pour obtenir de l'information concernant la stratégie pancanadienne du CCME sur la gestion des effluents d'eaux usées municipales, visitez le site Web du CCME à l'adresse www.ccme.ca/initiatives/water.fr.html?category_id=81.

Pour obtenir plus d'information concernant les Recommandations canadiennes pour la qualité des eaux, visitez le site Web du CCME à l'adresse www.ccme.ca/initiatives/water.fr.html?category_id=41 ou communiquez avec le CCME par téléphone au (204) 948-2090.

Pour obtenir une copie du document *Guide relatif aux vérifications des procédés des usines de traitement des eaux usées*, visitez le site Web du Fonds de durabilité des Grands Lacs à l'adresse http://sustainabilityfund.gc.ca ou communiquez avec le Gestionnaire, Fonds de durabilité des Grands Lacs, 867, chemin Lakeshore, Burlington (Ontario) L7R 4A6, (905) 336-6273.

Pour obtenir une copie de la *Loi sur les pêches*, visitez le site Web suivant : http://lois.justice.gc.ca/fr/F-14/index.html. Pour obtenir plus d'information sur les politiques de conformité et d'application des dispositions de la *Loi sur les pêches* et de la *Loi canadienne sur la protection de l'environnement (1999)*, visitez le site Web du Programme de l'application de la loi environnementale à l'adresse www.ec.gc.ca/ele-ale/policies/policies_f.asp.

De l'information supplémentaire sur la prévention de la pollution et la préparation de plans de la prévention de la pollution est disponible sur le site Web du Bureau national de la prévention de la pollution à l'adresse www.ec.gc.ca/nopp/FR/index.cfm et au Centre canadien d'information sur la prévention de la pollution (www.ec.gc.ca/cppic), ainsi qu'aux bureaux régionaux d'Environnement Canada.

On peut obtenir une copie électronique de cette ligne directrice sur le site Web du Registre de la LCPE à l'adresse www.ec.gc.ca/RegistreLCPE/default.cfm ou en contactant un des bureaux régionaux indiqués à l'article 6.

6. Bureaux d'information d'Environnement Canada

Pour toute question concernant cet avis ou pour obtenir des renseignements additionnels sur la planification de la prévention de la pollution, veuillez communiquer avec les bureaux régionaux d'Environnement Canada :

Pour les résidents de Terre-Neuve-et-Labrador
Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
6, rue Bruce
Mount Pearl (Terre-Neuve-et-Labrador) A1N 4T3
Téléphone : (709) 772-5491
Télécopieur : (709) 772-5097

Pour les résidents de l'Île-du-Prince-Édouard
Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
97, rue Queen, Pièce 202
Charlottetown (Île-du-Prince-Édouard) C1A 4A9
Téléphone : (902) 566-7043
Télécopieur : (902) 566-7279

Pour les résidents de la Nouvelle-Écosse
Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
Queen Square, 16e étage
45, promenade Alderney
Dartmouth (Nouvelle-Écosse) B2Y 2N6
Téléphone : (902) 426-8926
Télécopieur : (902) 426-3897

For residents of New Brunswick
Environmental Protection Branch – Atlantic Region
Environment Canada
77 Westmorland Street, Suite 450
Fredericton, New Brunswick E3B 6Z3
Telephone: (506) 452-3286
Facsimile: (506) 452-3003

For residents of Quebec
Environmental Protection Branch – Quebec Region
Environment Canada
105 McGill Street, 4th Floor
Montréal, Quebec H2Y 2E7
Telephone: (514) 283-4670
Facsimile: (514) 283-4423

For residents of Ontario
Environmental Protection Branch – Ontario Region
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Telephone: (416) 739-5888
Facsimile: (416) 739-4342

For residents of Manitoba
Environmental Protection Branch – Prairie and Northern Region
Environment Canada
123 Main Street
Winnipeg, Manitoba R3C 4W2
Telephone: (204) 983-4811
Facsimile: (204) 983-0960

For residents of Saskatchewan
Environmental Protection Branch – Prairie and Northern Region
Environment Canada
2365 Albert Street, Suite 300
Regina, Saskatchewan S4P 4K1
Telephone: (306) 780-6390
Facsimile: (306) 780-6466

For residents of Alberta
Environmental Protection Branch – Prairie and Northern Region
Environment Canada
4999 98th Avenue
Edmonton, Alberta T6B 2X3
Telephone: (780) 951-8860
Facsimile: (780) 495-4099

For residents of the Northwest Territories and Nunavut
Environmental Protection Branch – Prairie and Northern Region
Environment Canada
5204 50th Avenue, Suite 301
Yellowknife, Northwest Territories X1A 1E2
Telephone: (867) 669-4725
Facsimile: (867) 873-8185

For residents of British Columbia
Environmental Protection Branch – Pacific and Yukon Region
Environment Canada
401 Burrard Street, Suite 201
Vancouver, British Columbia V6C 3S5
Telephone: (604) 666-2799
Facsimile: (604) 666-9107

Pour les résidents du Nouveau-Brunswick
Direction de la protection de l'environnement — Région de l'Atlantique
Environnement Canada
77, rue Westmorland, Bureau 450
Fredericton (Nouveau-Brunswick) E3B 6Z3
Téléphone : (506) 452-3286
Télécopieur : (506) 452-3003

Pour les résidents du Québec
Direction de la protection de l'environnement — Région du Québec
Environnement Canada
105, rue McGill, 4e étage
Montréal (Québec) H2Y 2E7
Téléphone : (514) 283-4670
Télécopieur : (514) 283-4423

Pour les résidents de l'Ontario
Direction de la protection de l'environnement — Région de l'Ontario
Environnement Canada
4905, rue Dufferin
Downsview (Ontario) M3H 5T4
Téléphone : (416) 739-5888
Télécopieur : (416) 739-4342

Pour les résidents du Manitoba
Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
123, rue Main
Winnipeg (Manitoba) R3C 4W2
Téléphone : (204) 983-4811
Télécopieur : (204) 983-0960

Pour les résidents de la Saskatchewan
Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
2365, rue Albert, Bureau 300
Regina (Saskatchewan) S4P 4K1
Téléphone : (306) 780-6390
Télécopieur : (306) 780-6466

Pour les résidents de l'Alberta
Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
4999 98th Avenue
Edmonton (Alberta) T6B 2X3
Téléphone : (780) 951-8860
Télécopieur : (780) 495-4099

Pour les résidents des Territoires du Nord-Ouest et du Nunavut
Direction de la protection de l'environnement — Région des Prairies et du Nord
Environnement Canada
5204 50th Avenue, Bureau 301
Yellowknife (Territoires du Nord-Ouest) X1A 1E2
Téléphone : (867) 669-4725
Télécopieur : (867) 873-8185

Pour les résidents de la Colombie-Britannique
Direction de la protection de l'environnement — Région du Pacifique et du Yukon
Environnement Canada
401, rue Burrard, Bureau 201
Vancouver (Colombie-Britannique) V6C 3S5
Téléphone : (604) 666-2799
Télécopieur : (604) 666-9107

For residents of Yukon
Environmental Protection Branch – Pacific and Yukon Region
Environment Canada
91782 Alaska Highway
Whitehorse, Yukon Y1A 5B7
Telephone: (867) 667-3401
Facsimile: (867) 667-7962

Environment Canada Headquarters
Environmental Technology Advancement Directorate
Environmental Protection Service
Place Vincent Massey
351 Saint-Joseph Boulevard
Gatineau, Quebec K1A 0H3
Telephone: (819) 953-8074
Facsimile: (819) 953-7253

Pour les résidents du Yukon
Direction de la protection de l'environnement — Région du Pacifique et du Yukon
Environnement Canada
91782, route de l'Alaska
Whitehorse (Yukon) Y1A 5B7
Téléphone : (867) 667-3401
Télécopieur : (867) 667-7962

Bureau national d'Environnement Canada
Direction générale pour l'avancement de la technologie environnementale
Service de la protection de l'environnement
Place-Vincent-Massey
351, boulevard Saint-Joseph
Gatineau (Québec) K1A 0H3
Téléphone : (819) 953-8074
Télécopieur : (819) 953-7253

Appendix A — Acute Ammonia Toxicity

This appendix describes the method for determining whether or not an effluent contains an acutely lethal concentration of ammonia based on the curve of Figure 1.

Step 1. Take a weekly sample of the effluent released to surface water and analyze the sample for ammonia concentration and pH.

Step 2. Plot the ammonia concentration vs. pH on Figure 1 below.

Step 3. If the data point falls below the curve in the shaded area, your effluent does not contain an acutely lethal concentration of ammonia. If the data point falls on or above the curve, the effluent contains an acutely lethal concentration of ammonia.

Annexe A — Toxicité aiguë à l'ammoniac

Cette annexe décrit la méthode pour déterminer si un effluent contient une concentration d'ammoniac qui s'avère de létalité aiguë, d'après la courbe de la figure 1.

Étape 1. Prélever un échantillon hebdomadaire de l'effluent rejeté dans l'eau de surface et l'analyser quant à la concentration d'ammoniac et au pH.

Étape 2. Tracer les points correspondant aux valeurs des concentrations d'ammoniac en fonction du pH sur la figure 1.

Étape 3. Si les données se trouvent sous la courbe (dans la zone ombrée) votre effluent ne contient pas une concentration d'ammoniac qui s'avère de létalité aiguë. Si les données se trouvent sur ou au-dessus de la courbe, l'effluent contient une concentration d'ammoniac qui s'avère de létalité aiguë.

Figure 1 - Threshold Acute Concentration of Ammonia versus pH

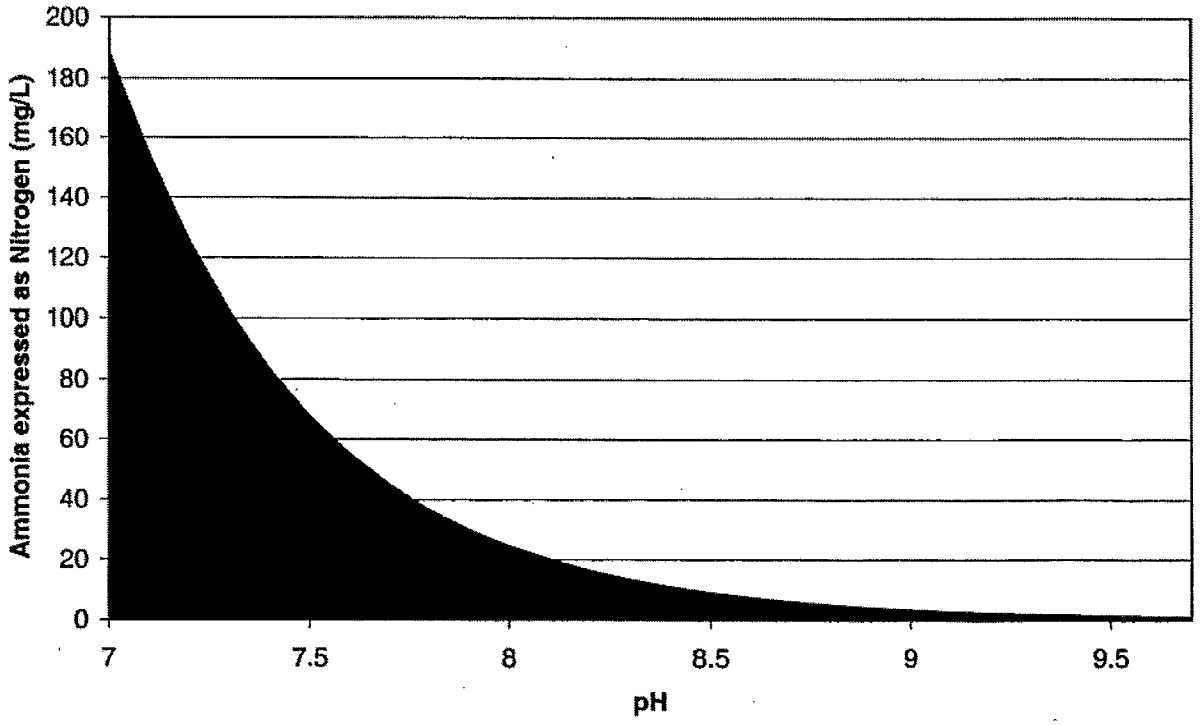
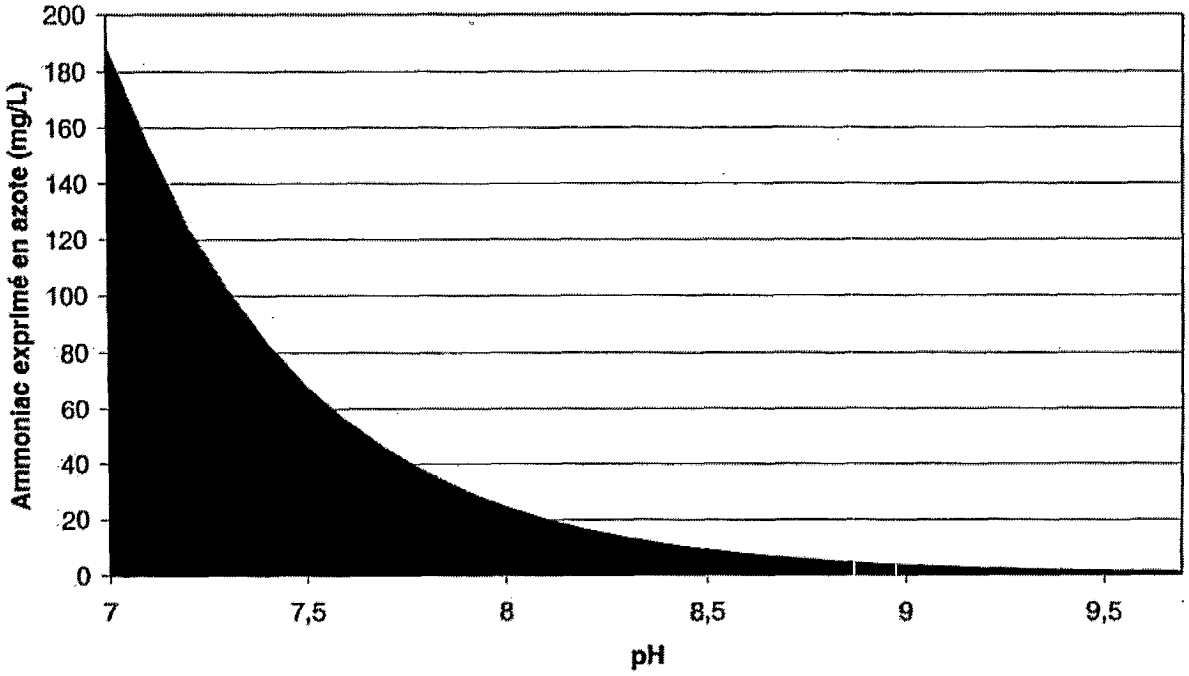


Figure 1 - Seuil de concentration de létalité aiguë de l'ammoniac en fonction du pH



Maximum allowable ammonia concentration (y) at the measured pH of the effluent can be calculated using the following equation:

$$y = 306132466.34 \times (2.7183^{(-2.0437 \times pH)})$$

[49-1-o]

La concentration d'ammoniac maximale admissible (y), en fonction du pH mesuré de l'effluent, peut être calculée à l'aide de l'équation suivante :

$$y = 306132466,34 \times (2,7183^{(-2,0437 \times pH)})$$

[49-1-o]

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For more information about the *Environmental Choice*[M] *Program*, please visit the ECP website at **www.environmentalchoice.com** or telephone (613) 247-1900.

Environment Canada's Technology Outreach Section is proud to support environmental and quality performance standards, and the use of Environmental Choice[M] certified papers and environmentally responsible products and printing processes, throughout its development and distribution of information products. To obtain a copy of the catalogue Environment Canada: Selected Publications and Websites, please contact us toll-free at 1 800 734-3232, or (819) 953-5750; by facsimile at (819) 994-5629; or by e-mail at epspubs@ec.gc.ca.

For additional information on Environment Canada, visit the departmental website at **www.ec.gc.ca**.