OPTIMIZATION OF LAGOON OPERATION

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide to Sustainable Municipal Infrastructure

Guide national pour des infrastructures municipales durables

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Federation of Canadian Municipalities

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INFRAGUIDE – INNOVATIONS AND BEST PRACTICES

WHY CANADA NEEDS INFRAGUIDE

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

This is what the National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices (InfraGuide) seeks to accomplish.

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

A Knowledge Network of Excellence

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

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

Please join us.

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

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

John Hodgson, Chair	City of Edmonton, Alberta
André Aubin	City of Montreal, Quebec
Richard Bonin	City of Quebec, Quebec
David Calam	City of Regina, Saskatchewan
Kulvinder Dhillon	Province of Nova Scotia, Halifax, Nova Scotia
Tom Field	Delcan Corporation, Vancouver, British Columbia
Wayne Green	City of Toronto, Ontario
Claude Ouimette	OMI Canada Inc., Fort Saskatchewan, Alberta
Peter Seto	National Water Research Institute, Environment Canada, Burlington, Ontario
Timothy A. Toole	Town of Midland, Ontario
Bilgin Buberoglu	Technical Advisor, NRC, Ottawa, Ontario

In addition, the Storm and Wastewater Technical Committee would like to express its sincere appreciation to the following individuals for their participation in working groups.

Susheel K. Arora	Municipality of Colchester County, Nova Scotia
Vince Corkery	City of Edmonton, Alberta
André Marsan	Centre d'épuration Rive-Sud de Longueuil, Quebec
Gaétan Morin	Roche Ltée, Groupe-Conseil, Ste-Foy, Quebec
Mark Rupke	City of Toronto, Ontario
Peter Seto	National Water Research Institute, Environment Canada, Burlington, Ontario

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Richard Bonin	City of Québec, Quebec
Howard Brown	SNC Lavalin, Montréal, Quebec
Greg Bull	G. J. Bull & Associates, Whitehorse, Yukon
Don Ford	County of Oxford, Ontario
John Hodgson	City of Edmonton, Alberta
Mano Manoharan	Ontario Ministry of Environment, Toronto, Ontario
Jim McLeod	City of Whitehorse, Yukon
Rick Turnbull	Ontario Clean Water Agency, London, Ontario

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Governing Council:

Joe Augé	Government of the Northwest Territories, Yellowknife, Northwest Territories
Mike Badham	City of Regina, Saskatchewan
Sherif Barakat	National Research Council Canada, Ottawa, Ontario
Brock Carlton	Federation of Canadian Municipalities, Ottawa, Ontario
Jim D'Orazio	Greater Toronto Sewer and Watermain Contractors Association, Toronto, Ontario
Douglas P. Floyd	Delcan Corporation, Toronto, Ontario
Derm Flynn	Town of Appleton, Newfoundland and Labrador
John Hodgson	City of Edmonton, Alberta
Joan Lougheed	Councillor, City of Burlington, Ontario
Saeed Mirza	McGill University, Montréal, Quebec
Umendra Mital	City of Surrey, British Columbia
René Morency	Régie des installations olympiques Montréal, Quebec
Vaughn Paul	First Nations (Alberta) Technical Services Advisory Group Edmonton, Alberta
Ric Robertshaw	Public Works, Region of Peel, Brampton, Ontario
Dave Rudberg	City of Vancouver, British Columbia
Van Simonson	City of Saskatoon, Saskatchewan
Basil Stewart, Mayor	City of Summerside, Prince Edward Island

Serge Theriault	Government of New Brunswick, Fredericton, New Brunswick
Tony Varriano	Infrastructure Canada, Ottawa, Ontario
Alec Waters	Alberta Infrastructure Department, Edmonton,
Alberta	
Wally Wells	The Wells Infrastructure Group Inc. Toronto, Ontario

Municipal Infrastructure Committee:

Al Cepas,	City of Edmonton, Alberta
Wayne Green	City of Toronto, Ontario
Haseen Khan	Government of Newfoundland and Labrador St. John's, Newfoundland and Labrador
Ed S. Kovacs	City of Cambridge, Ontario
Saeed Mirza	McGill University, Montréal, Quebec
Umendra Mital	City of Surrey, British Columbia
Carl Yates	Halifax Regional Water Commission, Nova Scotia

Relationship Infrastructure Committee:

Geoff Greenough	City of Moncton, New Brunswick
Joan Lougheed	City Councillor, Burlington, Ontario
Osama Moselhi	Concordia University, Montréal, Quebec
Anne-Marie Parent	Parent Latreille and Associates Montréal, Quebec
Konrad Siu	City of Edmonton, Alberta
Wally Wells	The Wells Infrastructure Group Inc. Toronto, Ontario

Founding Member:

Canadian Public Works Association (CPWA)

EXECUTIVE SUMMARY

Treatment of municipal wastewater in lagoon-based wastewater treatment plants (WWTPs) is common in Canada and very cost effective for smaller communities where land is available and inexpensive. Lagoons are generally inexpensive to build, simple to operate and, when properly designed and maintained, produce a treated effluent that can be discharged to the environment with minimal impact.

Community growth and increasingly stringent environmental regulations can necessitate expansion or replacement of lagoon-based systems with more costly mechanical treatment plants unless improved performance or increased capacity can be realized through optimization approaches.

This best practice provides owners and operators of lagoon-based WWTPs with information to optimize the performance and capacity of their facilities. Through optimization of lagoon operations, the owner can potentially:

- realize additional capacity;
- meet more stringent discharge requirements through improved effluent quality;
- reduce energy use and cost;
- reduce chemical use and cost; and
- reduce odour emissions.

Lagoon-based WWTPs can be designed in a variety of configurations but all depend largely on natural physical and biological processes to achieve treatment. Improvements in the performance of lagoons can be achieved through:

- operational and minor design changes that may improve the flow patterns and mixing in the lagoon;
- modifying the flow scheme in multi-cell lagoon systems;
- adding mechanical aeration equipment to augment the natural oxygenation of the lagoon;
- adding chemicals to the lagoon to enhance settling and remove phosphorus; and
- adding pre- or post-treatment processes to reduce lagoon loading or improve the effluent quality.

A significant challenge facing owners and operators of lagoon-based systems in Canada will be achieving consistent year-round ammonia removal to ensure effluents are non-toxic. Demonstrated, cost-effective ways to enhance ammonia removal in winter months are needed.

1. GENERAL

1.1 INTRODUCTION

Treatment of sewage in lagoon-based systems is one of the earliest forms of wastewater treatment and is still used extensively to service small communities in Canada. In 1985, it was estimated that there were 868 lagoon-based wastewater treatment systems in Canada, representing almost half of the total number of treatment plants (Smith and Finch, 1985). In some areas of Canada where land is available and inexpensive, lagoons are the predominant type of wastewater treatment plant (WWTP).

Lagoons are generally inexpensive to build, simple to operate and, when properly designed, operated, and maintained, can produce a treated effluent that can be discharged to the environment without adverse effect. However, as communities grow and environmental regulations become more stringent, there is often a need to increase capacity or improve performance. This best practice provides guidance on how to operate these systems effectively, prevent problems, and generally improve performance.

1.2 PURPOSE AND SCOPE

This best practice has been developed by the *National Guide to Sustainable Municipal Infrastructure: Innovation and Best Practices (InfraGuide)*. It is one of more than 50 aspects identified by the Storm and Wastewater Technical Committee relating to linear infrastructure, wastewater treatment, customer interaction, and receiving water issues. The more general topic of wastewater treatment plant optimization is covered in another *InfraGuide* best practice entitled *Wastewater Treatment Plant Optimization*.

This best practice applies to the operation of lagoon-based wastewater treatment plants of various designs and configurations. It is intended to help optimize the capacity or performance of these facilities by providing basic information on the treatment processes that occur in a lagoon, describing different types of lagoons, and summarizing typical design guidelines and performance expectations. It also gives suggestions for enhancing the performance or capacity of an existing lagoon. It is intended as a supplement to more comprehensive design and operating manuals for lagoons, some of which are referenced in this best practice.

1.3 HOW TO USE THIS DOCUMENT

Section 3.1 of this best practice provides an overview of the processes that occur in a lagoon (settling, biochemical oxidation, etc.). A general description of different lagoon configurations along with some advantages and disadvantages of different types of lagoons and the performance that should be expected from a lagoon-based system is provided in Section 3.2. Typical design ranges for various types of lagoons are also summarized, along with information on the optimum physical configuration of lagoons. The type of monitoring and maintenance that should be applied to lagoons is discussed in Section 3.3. Section 3.4 deals specifically with desludging practices.

Suggested approaches to optimize lagoon operations to improve performance or reduce cost are presented in sections 3.5 and 3.6, respectively.

1.4 GLOSSARY

Aerobic degradation — The breakdown of organic matter by bacteria in the presence of dissolved molecular oxygen.

Algae — Primitive one or many celled plants, usually aquatic, that produce their food by photosynthesis.

Anaerobic degradation — The breakdown of complex organic matter by bacteria in the absence of dissolved molecular oxygen.

Anoxic — A condition where free molecular oxygen is absent. Commonly, an anoxic condition is differentiated from an anaerobic condition by the presence of bound oxygen, normally in the form of nitrate.

Biochemical oxygen demand (BOD) — For the purpose of this Best Practice, BOD will mean carbonaceous BOD (CBOD). This is the quantity of oxygen consumed, usually expressed in mg/L, during biochemical oxidation of organic matter over a specified time period (e.g., five day BOD or BOD_5) at a temperature of 20^oC.

Composite sample — A sample comprising multiple grab samples over a specified time period (e.g., 24 hours) that represents average conditions at the sampling location over the period that the grab samples were collected.

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

Facultative bacteria — Those bacteria that can adapt to aerobic or anaerobic conditions and, as a result, can perform either aerobic or anaerobic degradation.

Grab sample — A single sample representative of conditions at the sampling location at a fixed point in time.

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

Lagoon – (Also known as waste stabilization pond) An in-ground earthen basin used for the treatment of wastewater by natural process involving the use of algae and bacteria. They can be classified as aerobic, aerated, facultative and anaerobic. Natural aeration process is enhanced by mechanical devices in aerated lagoons.

Photosynthesis — A process in which chlorophyll-containing plants produce complex organic (living) materials from carbon dioxide, water, and inorganic salts with sunlight as the source of energy. Oxygen is produced in this process as a waste product.

Short-circuiting — Non-ideal mixing conditions in a tank or basin that results in the actual retention time of the liquid being less than the theoretical retention time calculated by dividing the tank or basin volume by the flow rate into the tank or basin.

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

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

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

Volatile suspended solids (VSS) — The amount of total suspended solids burned off at $550 \pm 50^{o}C$ expressed normally as mg/L.

Note: For more definitions on related terms, please refer to "Standards Methods for the Examination of Water and Wastewater" by WEF, AWWA and APHA, 20th edition,

2. RATIONALE

2.1 BACKGROUND

Lagoon-based wastewater treatment plants are one of the oldest forms of wastewater treatment and are in common use in Canada today. Smith and Finch (1985) estimated that lagoon treatment systems represent about half of the total wastewater treatment plants in Canada, distributed as shown in Table 2–1.

Table 2–1: Lagoon Use In Canada

Location	Number of Lagoons	As a Percent of Treatment Facilities
Alberta	278	84
British Columbia	34	31
Manitoba	127	85
New Brunswick	58	63
Newfoundland	1	2
Northwest Territories	15	71
Nova Scotia	14	16
Ontario	128	33
Prince Edward Island	17	9
Quebec	59	21
Saskatchewan	129	92
Yukon Territory	8	70
Canada	**868**	**48**

Although it appears that half of all treatment plants are lagoons, they represent a smaller portion in terms of volumes treated. For example, according to "Report on the 1991 Discharges from Municipal Sewage Treatment Plants in Ontario", Ontario Ministry of the Environment, September 1993, the proportion of sewage flow (ADF) treated by different treatment types (1991) in Ontario are as follows: primary 18.0%, secondary 72%, tertiary 4.3% and lagoon 5.7%

A voluntary survey in 1999 (Environment Canada, 1999) identified 504 waste stabilization ponds in Canadian municipalities with populations higher than 1,000. The lower number in the Environment Canada database may reflect the exclusion of many small systems and conversion of some systems to mechanical plants in the intervening years although, since 1985, a number of lagoons have been constructed in several Canadian provinces to serve small communities

Lagoon systems are simple and inexpensive to operate and maintain. Several treatment processes occur simultaneously in a lagoon including sedimentation, bioflocculation, chemical precipitation, biochemical oxidation, fermentation, and disinfection. Lagoons are often considered to be passive treatment processes over which the operator has limited control; however, the operator can take measures to improve performance, reduce cost, and generally optimize operation.

2.2 EXPECTED BENEFITS

Improvements in lagoon operations could potentially:

- realize additional capacity in the plant;
- improve effluent quality to reduce the impact on the natural environment and meet more stringent permit requirements;
- reduce energy use and costs;
- reduce chemical use and costs; and
- reduce odour emissions.

2.3 RISKS

A lagoon-based wastewater treatment plant can produce a good quality effluent that will have minimal impact on the environment if properly designed, operated, and maintained. This performance can be realized at relatively low cost compared to conventional mechanical treatment systems that have significantly higher energy, maintenance, and operational requirements. Conversely, a poorly operated lagoon can create objectionable odours and result in the discharge of poorly treated effluent that can adversely affect the aquatic life in the receiving stream.

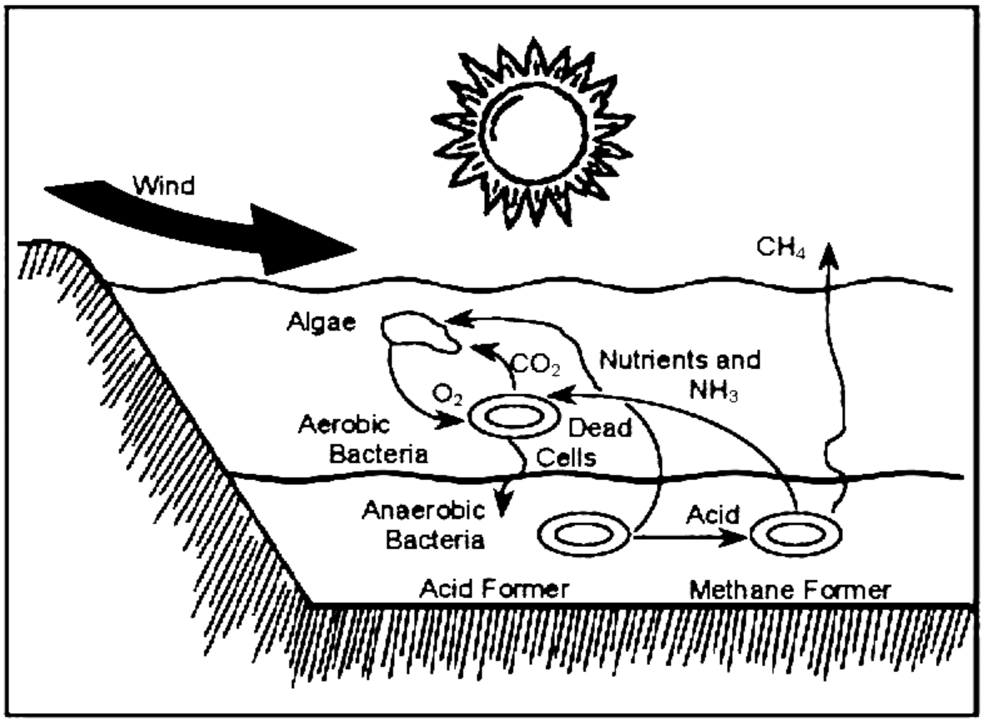
As a community served by a lagoon-based wastewater treatment system grows or regulatory agencies impose more stringent effluent requirements, it may be necessary to consider upgrading the lagoon to a mechanical treatment plant if improved performance or increased capacity cannot be achieved through optimization approaches or expansion. This will result in significant capital investment and higher operation and maintenance costs for the community.

3. WORK DESCRIPTION

3.1 PROCESSES OCCURRING IN A WASTEWATER LAGOON

Wastewater treatment in a lagoon results from a complex combination of physical, chemical, and biological processes that are influenced by weather conditions, lagoon type and configuration, and system design. Figure 3–1 provides a simplified diagram of the major processes that occur in a lagoon.

Figure 3–1: Treatment Processes Occurring in a Lagoon



Source: Adapted from EPA (1977).

When wastewater enters a lagoon, heavier solids settle to the bottom and form a sludge layer. In lagoons in which chemicals, such as alum, are added to precipitate phosphorus, the precipitated phosphorus and aluminum hydroxide floc will also accumulate in the sludge layer. The sludge layer is anaerobic and contains bacteria that ferment the organic matter in the settled solids, solubilizing the organics to organic acids and producing methane. These anaerobic bacteria also produce hydrogen sulphide from the reduction of sulphate. This is the most common source of odours in lagoons (Heinke et al., 1988). Anaerobic activity in the sludge layer is very sensitive to temperature, almost ceasing at cold temperatures in the winter months. Under these conditions, there is very little decomposition of the organic matter. When temperatures increase in the spring, anaerobic activity also increases, releasing soluble organic matter and, potentially, hydrogen sulphide into the water column above the sludge layer.

The water column above the sludge layer generally contains oxygen due to wind motion on the water surface and the photosynthetic activity of algae present in the lagoon. Aerobic bacteria in the lagoon use the oxygen present in the aerobic layer to oxidize the organic matter present in the wastewater or released by the anaerobic bacteria from the sludge layer. Some literature (EPA, 2002) refers to an intermediate anoxic layer between the aerobic and anaerobic zones, called the facultative zone, where facultative bacteria consume the organic matter in the absence of molecular oxygen. The bacteria and algae that grow as a result of the degradation of organic matter and photosynthetic activity flocculate naturally or in conjunction with any chemicals added to achieve phosphorus removal and settle into the sludge layer where they are an additional source of food for the anaerobic bacteria. In winter months, if the surface of the lagoon is ice covered, there is no oxygen transferred into the lagoon from wind motion and photosynthetic activity is significantly reduced. Hence, aerobic biological activity in the lagoon in the winter is minimal.

Lagoon-based treatment systems also achieve natural disinfection. *E. Coli* destruction efficiencies of 99.99 percent have been reported in lagoons (Feachem et al., 1983). Disinfection is achieved through a combination of natural ultraviolet irradiation, temperature, adsorption to solids, settling, and predatory organisms.

3.2 Lagoon Types, Design, and Performance

Lagoons can be classified in terms of the predominant biological environment that exists.

3.2.1 Facultative Lagoons

This is the most common type of lagoon (EPA, 1983), and is usually 1.2 m to 1.5 m deep with an aerobic water layer overlying an anaerobic layer, which contains the settled sludge.

3.2.2 Aerated Lagoons

These lagoons have a mechanical method of aeration, such as surface aerators or diffusers with blowers, to augment the oxygen supplied from natural means, such as surface re-aeration or photosynthesis. Aerated lagoons are typically 2 m to 6 m deep and are generally followed by a facultative lagoon in which the suspended particulate matter that does not settle in the mixed or partially mixed aerated lagoon will settle and anaerobically degrade.

3.2.3 Aerobic Lagoons

These lagoons are typically very shallow, between 0.30 m. and 0.45 m. The shallowness allows sunlight to penetrate the entire depth, and dissolved oxygen is present throughout the water column. Aerobic lagoons are typically limited to sunny, warm climates where there is no risk of ice cover.

3.2.4 ANAEROBIC LAGOONS

These lagoons are most commonly used for treatment of industrial wastewater or mixed domestic and industrial wastewater with a high BOD_5 concentration (EPA, 1983). Anaerobic lagoons are normally 2.5 m to 5 m deep. Due to the depth and high organic load, there is no aerobic layer, and all biological activity is anaerobic. A thick scum layer normally forms on an anaerobic lagoon, which helps reduce odour emissions. These lagoons are normally used for pre-treatment and are followed by a facultative or aerobic lagoon to remove the soluble BOD_5 produced by the anaerobic activity. Anaerobic lagoons are not commonly used for treatment in domestic wastewater treatment. However, in Alberta, anaerobic cells with two day retention times are used for pre-treatment prior to discharging to facultative lagoons (Alberta Environmental Protection, 1997).

Table 3–1 (EPA, 1983) summarizes some of the key design parameters for the four types of lagoons described above. Lagoons can also be classified according to the discharge mode.

Table 3–1: Typical Design Parameters for Lagoons

Pond Type	Application	Typical Loading Parameters	Typical Detention Times	Typical Dimensions	Comments
Facultative	Raw municipal wastewater Effluent from primary treatment, trickling filters, aerated ponds, or anaerobic ponds	BOD_5 of 22-67 kg/ (ha.d)	25-180 d	1.2-2.5m. deep 4-60 ha.	Most commonly used waste stabilization pond type May be aerobic through entire depth if lightly loaded
Aerated	Industrial wastes Overloaded facultative ponds Situations where limited land area is available	BOD_5 of 8-320 kg/ 1000 m^3.d	7-20 d	2-6m. deep	Use may range from a supplement of photosynthesis to an extended aeration activated sludge process Requires less land area than facultative
Aerobic	Generally used to treat effluent from other processes, produces effluent low in soluble BOD_5 and high in algae solids	BOD_5 of 85-170 kg/ (ha.d)	10-40 d	0.30-0.45m.	Application limited because of effluent quality Maximizes algae production and (if algae is harvested) nutrient removal High loadings reduce land requirements
Anaerobic	Industrial wastes	BOD_5 160-800 kg/ 1000 m^3.d	20-50 d	2.5-5 m. deep	Odour production usually a problem Subsequent treatment normally required

3.2.5 Complete Retention Lagoons

These lagoons are designed to depend on evaporation or exfiltration, and there is no net discharge of treated wastewater to the surface water environment. Dry climatic conditions or favourable geologic conditions are required for the operation of complete retention lagoons.

3.2.6 Controlled Discharge Lagoons

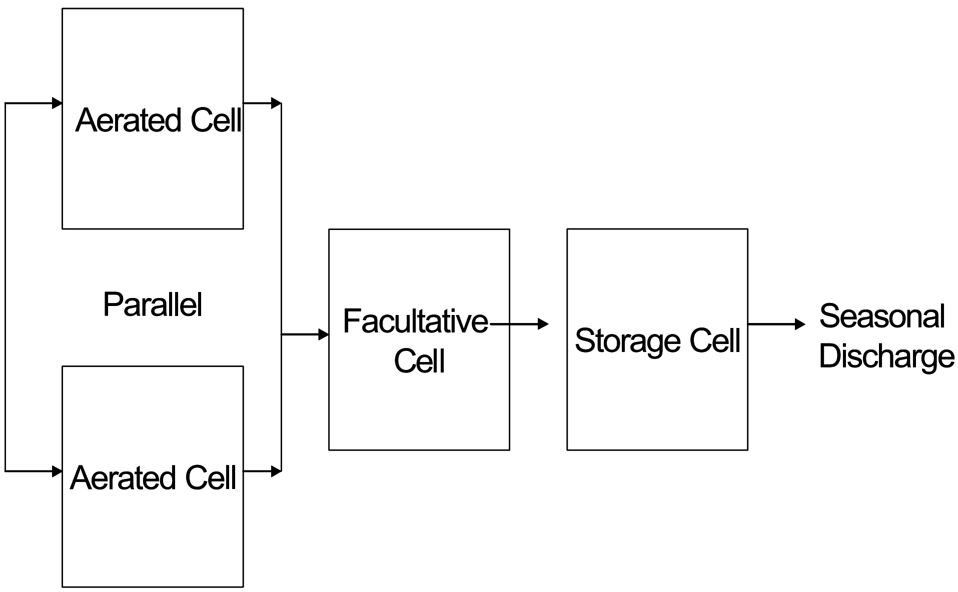
These lagoons treat and store wastewater until the effect of the discharge on the receiving stream is minimal and they are often referred to as Storage Cells. Generally, the discharge of the lagoon will occur when flows are higher in the receiving stream (spring or fall) or when the temperature of the receiving stream is low and biological activity in the stream is minimal (winter). Controlled discharge lagoons may have one period of discharge per year (annual discharge) or several periods (seasonal discharge). Adequate storage volume must be provided to prevent discharge of treated wastewater outside of the allowable periods.

3.2.7 Continuous Discharge Lagoons

These lagoons operate like conventional treatment plants in that the volume of flow that enters the lagoon is discharged to the receiving stream. There is no provision to store flow in the lagoon or regulate the discharge volumes.

A wide range of combinations of lagoon types and configurations are possible depending on the site-specific conditions. Figure 3–2 illustrates a lagoon configuration that includes aerated ponds and a facultative pond, with a storage pond to allow controlled discharge. The multiple cells can be combined in a "parallel" operation in which the flow is divided equally among the lagoons or in a "series" operation, in which the discharge from one lagoon is directed into the next downstream lagoon. In the illustration in Figure 3–2, the aerated lagoons are operated in parallel and the aerated cells, facultative cell and storage cell operate in series.

Figure 3–2: Hypothetical Lagoon Configuration



Note: In some provinces, such as Alberta, an anaerobic cell will precede the facultative cell rather than an aerobic cell.

The optimum lagoon configuration depends largely on the discharge requirements that must be met. This determines the required level of treatment and the amount of storage needed to minimize the impact on the receiving stream. In some cases, retrofitting existing lagoon-based systems can increase capacity and produce a better quality effluent. Table 3–2 presents the typical quality of effluent that can be achieved with different types of lagoons. A detailed assessment of lagoon system performance in Alberta conducted by Smith and Finch (1985) indicated that these performance expectations can be easily met by a properly designed and well operated lagoon system.

Table 3–2: Typical Effluent Quality from Lagoon Systems

Process	Effluent Parameters (mg/L)		
	BOD_5	SS	Total Phosphorus (as P)
Continuous Discharge Facultative Lagoon			
• Without P removal	25	30	6
• With P removal	25	30	6
Controlled Discharge Facultative Lagoon			
• Without P removal	25	30	-
• With P removal by batch chemical dosage	15	20	0.5 to 1.0
• With P removal by continuous chemical dosage	25	30	1.0
Aerated lagoon Prior to Facultative Cell			
• Without P removal with 4-5 days retention time	60	100	-

Source: Adapted from MOE (1994).

3.3 Monitoring Lagoons

Two types of monitoring of lagoon-based systems are recommended:

- process control monitoring provides information to the operating staff on the condition and performance of the system and allows for early warning of possible upsets or operational problems; and,

- compliance monitoring is required under the operating permit or certificate of approval and reported to the regulatory agency.

Different levels of accuracy are needed for these two types of monitoring. Process control testing is intended to be used by the operating staff to make operational decisions. These tests can be done in-house using more rapid, easier test methods that do not necessarily comply with standard methods (APHA, 1998), but which provide dependable results to the operators. Compliance tests should always be done by a certified laboratory using standard methods or equivalent. Less rigorous sampling methods, such as grab samples rather than composite samples, are often appropriate for process control measurements than are needed for compliance monitoring. The results of process control tests not conducted by a certified laboratory using standard methods, should not be reported for compliance purposes to the regulatory authorities.

Table 3–3 presents a recommended sampling program for lagoon-based systems. For compliance monitoring, the operating permit or certificate of approval should be consulted to ensure that the monitoring program meets the requirements. Seasonal variations in loads should also be considered in the design of the monitoring program. Regular site inspections should be conducted and the findings included in the facility operating logs and records.

3.3.1 Sampling Locations, Types, and Frequencies

Sampling locations for compliance testing are normally specified in the operating permit or certificate of approval and usually include only the raw sewage influent to the lagoon and the effluent discharged from the lagoon. These sampling and flow monitoring stations should be included as part of the design process. Intermediary samples collected within the lagoon cells or between the cells of multi-cell lagoon systems are not normally required by the permit. The type of sample to be collected (grab sample or composite sample) and the frequency of sampling may also be specified. If not specified, 24-hour composite samples of raw sewage and final effluent should be collected using automatic, refrigerated samplers. Because of the long retention times provided by lagoons, collection of flow-proportional composite samples is not strictly necessary unless specified in the operating permit or certificate of approval.

The samples should be collected at a location that is representative of the sampled stream. Raw sewage samples can be collected at the overflow from an inlet box, in an inlet channel, or from the raw sewage pump station discharge in a turbulent, well-mixed area. Sampling from wet wells and within inlet or diversion boxes should be avoided unless the area is well mixed because solids can settle in these non-turbulent areas, affecting the result. Similarly, effluent samples should be collected from the overflow of the outlet control structure or at a well-mixed, turbulent location in the effluent channel. The frequency of effluent sampling will depend on the discharge mode.

Table 3–3: Lagoon Sampling Locations and Analyses

Sampling Location	Analysis	Use [1]	Frequency	Type
Raw influent	BOD_5	C	1/week	24 h composite
	TSS	C	1/week	24 h composite
	TKN	C	1/week	24 h composite
	TP	C	1/week	24 h composite
	pH	PC	Daily	Grab
	Temperature	PC	1/week	Grab
Lagoon cell	DO	PC	1/week	Grab
	TSS	PC	1/week	Grab
	VSS	PC	1/week	Grab
	pH	PC	1/week	Grab
	Temperature	PC	1/week	Grab
Lagoon effluent (if different from final effluent)	BOD_5	PC	1/week	Grab
	TSS	PC	3/week	Grab
	NH_3-N	PC	1/week	Grab
	TP	PC	1/week	Grab
	pH	PC	1/week	Grab
	Temperature	PC	1/week	Grab
Final effluent (during discharge period)	BOD_5	PC, C	1/week	24 h composite
	TSS	PC, C	1/week	24 h composite
	NH_3-N	PC, C	1/week	24 h composite
	TP	PC, C	1/week	24 h composite
	Ortho-P	PC	3/week	24 h composite
	pH	PC, C	3/week	Grab
	$NO2^-/NO3^-$ - N	C	1/week	24 h composite
	FC/EC	PC, C	1/week	Grab
	Temperature	PC	1/week	Grab

Notes:

1. C – Compliance
   PC – Process Control
2. TSS – Total suspended solids
   TKN – Total Kjeldahl nitrogen
   TP – Total phosphorus
   DO – Dissolved oxygen
   VSS – Volatile suspended solids
   NH_3-N – Total ammonia nitrogen
   Ortho-P – Orthophosphate as phosphorus
   $NO2^-/NO3^-$ - N– Nitrite/nitrate nitrogen
   FC/EC – Fecal coliform/*E.coli*
3. These represent the minimum recommended sampling frequency. Monitoring at a particular lagoon will depend on the requirements in the operating permit or certificate of approval and must consider the size and configuration of the plant and the resources, and staffing available.

For process control purposes, additional samples from within the lagoons and from the discharges of the individual cells should also be collected on a routine basis to assess the condition of the ponds. In well-mixed lagoon cells, samples from within the cells should be collected in four to six locations around the cell depending on the size of the cell and composited into one sample for analysis. In cells that are not well mixed, it can be useful to collect samples individually along the length of the cell between the inlet and outlet to determine the change in water quality as the wastewater passes through the cell. This information can be helpful in assessing the amount of mixing occurring and the possible benefits of adding mixing into the cell. Depending on cell depth, the sample should be collected from 0.3 to 0.6 metres below the water surface, above the sludge layer, and at sufficient distance from the side of the lagoon to avoid the effects of the berm. This distance will depend on the water depth and the berm slope. At the same time, dissolved oxygen, temperature, and pH should be measured at each location using portable equipment. These lagoon samples should not be collected during or immediately after periods of high winds. Because sunlight will have an impact on dissolved oxygen (DO) concentrations in facultative cells, it is recommended that DO be measured twice during the day (early morning and late afternoon) or that the time of the measurement be alternated between sampling events. Observations of the colour of the lagoon should also be made and recorded since this can provide the operator with an indication of the condition of the lagoon, as summarized in Table 3–4.

Table 3–4: Colour Characteristics in Lagoons

Colour	Interpretation
Dark sparkling green	Good conditions. Generally occurs with high pH and DO.
Dull green to yellow	Not so good; pH and DO generally dropping. Blue-green algae beginning to predominate.
Tan to brown	May relate to brown algae, which is OK. If related to silt or bank erosion, can indicate physical problems in lagoon or collection system.
Gray to black	Very bad. Pond is septic, virtually zero DO.

Source: Adapted from EPA (1977).

Samples of the discharge of individual cells within a lagoon system should also be collected at representative locations; however, grab samples can be used in these locations instead of composite samples.

3.3.2 Flow Measurement

Measurement of flows into the lagoon is essential to determine hydraulic and organic loadings and to compare the loads with system design. Influent flows are also needed to determine and adjust dosage rates of chemicals used for continuous phosphorus removal. Measurement of flows out of the lagoon is essential to ensure compliance with the discharge requirements specified in the operating permit or certificate of approval. It is best practice to measure flows in to and out of lagoons. In continuous discharge lagoons, comparison of influent and effluent flows can be used to assess flow metering accuracy.

A number of methods can be used to measure or estimate flows, including:

- run time meters and pump capacities on raw sewage pump stations;
- magnetic flow meters on pump station discharges;
- velocity/area meters in channels;
- various open channel flow meters such as weirs or flumes; and
- changes in water level in lagoons during periods of discharge or fill.

A variety of references are available such as Grant and Dawson (1995) on flow meter installation and calibration. Flow meters should be electronically calibrated (secondary flow element) annually and physically calibrated (primary element) at least once, or more often if physical changes are made to a meter that might affect its accuracy.

3.4 Desludging Lagoons

Facultative and aerobic lagoons are intended to accumulate sludge, because part of the treatment process involves the biological decay of the settled material, either anaerobically in facultative systems or aerobically in aerobic systems. The rate of sludge accumulation will depend on the design of the lagoon, the strength of the wastewater, and the climatic conditions. In colder climates, sludge will accumulate more rapidly, because the rate of degradation of the settled organic matter is significantly reduced. Facultative lagoons generally accumulate solids more quickly than aerobic lagoons as they depend on anaerobic degradation for breakdown of the settled matter, which occurs slower than aerobic degradation, the predominant biological process in aerobic lagoons. Because facultative lagoons are generally deeper than aerobic lagoons, there is more volume available for sludge storage. The location and invert level of the discharge piping should be verified however, to ensure that settled sludge is not being inadvertently discharged with the lagoon effluent.

Generally, desludging of a lagoon is required infrequently. Heinke and Smith (1988) suggested that 5 to 10 years may be the typical frequency for desludging short detention-time lagoon cells, while long detention-time lagoons with seasonal or annual discharges may not need to be desludged for even longer periods. Early in 2003, *InfraGuide* conducted a scan of current wastewater treatment plant optimization practices and trends in Canada. Of 25 respondents who operated lagoons, 32 percent reported they had never desludged their lagoon, and 40 percent reported they desludged every 10 to 20 years. A desludging frequency of every five years or less was reported by 20 percent of respondents operating lagoon-based systems.

The amount of sludge accumulated in the lagoon should be measured every year or so to determine the volume and to plan effectively for the desludging operation. Sophisticated equipment, such as depth samplers, ultrasonic or optical sludge blanket detectors, or transits, can be used to determine the amount of sludge accumulated in a lagoon. A Sludge Judge, which is a clear plastic tube commonly used to measure sludge blanket levels in a clarifier, is also an effective and economical tool for estimating the amount of settled sludge in a lagoon. The "white towel" method described by Malan (1964) is also simple and effective. A white towelling material is wrapped around the bottom third of a long pole, which is slowly lowered vertically into the lagoon until it reaches the bottom. It is then slowly withdrawn. The depth of the sludge layer is visible at the point where the white towel is discoloured by the sludge particles that have been entrapped. Sludge depth should be measured at five or six points in the lagoon remote from the base of the berm.

There are two common methods for sludge removal from a lagoon:

- pumping after mixing the sludge with the remaining liquid lagoon contents following discharge of the bulk of the lagoon; and
- draining the lagoon and removing the settled sludge using a front-end loader or similar equipment.

Sludge that has accumulated for many years in a lagoon may be too concentrated to pump directly. In these cases, it may be necessary to mix the sludge with the lagoon water after discharging the bulk of the lagoon contents. Commercially available raft-mounted dredges equipped with pumps can be effectively used to desludge lagoons.

In single cell lagoons, removal of sludge will have to be carefully performed using methods like the employment of specialized equipment that floats on the surface, sucks up the sludge and directs it to equipment on the shoreline so that lagoon operation can be maintained. If the lagoon system includes several cells, the individual cells can be taken out of service and drained in the fall. Leaving the sludge in the cell over the winter will allow it to freeze and concentrate for easier handling in the spring. Care must be exercised to ensure the lagoon bottom and the berms are not damaged during this operation. Liquid sludge from the lagoon can be dewatered using portable dewatering equipment to reduce the costs of transporting dilute sludges.

Sludge that has accumulated at the bottom of a lagoon for several years generally has microbiological quality similar to, or better than, stabilized sludge from a mechanical treatment works. In most jurisdictions, this material can be land applied or disposed of in the same fashion as other stabilized biosolids. For example, in Ontario, solids removed from a lagoon system can be land applied if the lagoon cell has not received raw sewage for three months or longer and the lagoon has been designed and operated according to MOE guidelines (OMAF, 2003). In Quebec, solids removed from lagoons are commonly dewatered (Morin, 2003). Information obtained from the 2003 *InfraGuide* scan indicated that half of the respondents who had desludged their lagoons applied the material to agricultural lands, one third discharged it into sludge holding ponds, and the remainder put the material in landfills. Local regulations should be consulted before disposing of this material.

Owners of lagoon-based systems should ensure that the costs of desludging the lagoon and managing the resultant solids are included in their operating budgets. Sewer rates for these systems should reflect these occasional costs.

3.5 Optimizing for Improved Effluent Quality

While lagoon-based WWTPs have been shown to be very effective for removal of the BOD_5 and suspended solids present in the raw sewage, they are less effective for removal of nutrients such as nitrogen and phosphorus, and can release high concentrations of particulate matter in the form of algae in the late summer and fall. Because of the simplicity of operation of lagoons, there is limited opportunity for the operator to modify the operation to improve performance; however, some optimization techniques have proven to be effective in improving the operation of lagoon-based systems.

3.5.1 Operational and Minor Design Changes

Short circuiting in lagoons due to the poor configuration of inlets and outlets is the most common cause of poor performance. Improvements in the flow distribution within the lagoon can improve performance significantly in these cases. This can be achieved through:

- installing baffles around the lagoon inlet and/or outlet;
- relocating the inlet and/or outlet to minimize short circuiting and dead space;
- adding recirculation from the outlet of the lagoon to the inlet to improve mixing;
- adding additional inlets and/or outlets;
- changing from series to parallel operation;
- cleaning out weeds or accumulated solids if they affect the flow patterns; and
- locating or relocating mixers or aerators in a cell to promote improved flow distribution.
- discharging from a water depth below the algae bloom to reduce the concentration of solids in the effluent (care must be shown not to discharge sludge)

A simple tracer test using a visible dye or a fluorescent dye such as Rhodamine WT can be used to evaluate the degree of short circuiting in a lagoon cell. Low-cost textile or plastic baffles can be effective in lagoons to improve flow distribution. Solar-powered and wind-driven mixers and aeration systems are available to reduce operation and maintenance costs. These are particularly cost effective at remote sites where suitable power may not be readily available.

3.5.2 Modifying the Flow Scheme

Studies have shown that lagoon effluent quality is poorest in the winter months, particularly if the pond is ice covered, and during spring and fall overturn periods

(EPA, 1983). Discharging during the summer or early fall, and particularly during periods that coincide with low algae levels in the pond, will produce the highest quality effluent in terms of BOD_5, TSS, and ammonia. In many cases, the allowable periods of discharge are specified in the operating permit or certificate of approval and may coincide with high flow seasons in the receiving stream (spring and fall). In such cases, there may be limited capability to change the discharge period, although implementing a discharge scheme that is proportional to the flow in the receiving stream can often extend the discharge period without adversely affecting receiving water quality.

Operation of ponds in series will produce a better quality effluent than operation in parallel, but care must be taken not to overload the first cell of a series operation organically. If operation in series is not possible due to the configuration of the lagoon system, adding baffles to an existing pond to promote plug flow through the pond can also be effective (Prince et al., 1994).

3.5.3 Addition of Aeration

The capacity of a facultative lagoon can be increased and its performance improved by adding mechanical aeration to the influent area of the cell or by building an aerated cell upstream to pretreat the raw sewage. Mechanical aerators significantly increase the oxygen transfer into the liquid compared to natural re-aeration and photosynthesis. Furthermore, mechanical aerators prevent surface icing in cold climates, allowing aerobic conditions to be maintained year round. As noted previously, solar-powered and wind-driven aeration equipment is available for use in lagoon systems.

Aerated lagoons can be operated at BOD_5 loading rates, an order of magnitude higher than facultative lagoons (MOE, 1984). A properly designed aerated cell will remove the bulk of the dissolved BOD_5 upstream of the facultative cell, increasing the capacity of the system and allowing for improved ammonia removal in summer months.

3.5.4 Addition of Chemicals

Research work in Ontario in the 1970s and almost 30 years of full-scale operation has shown that the addition of metal salts, particularly alum, is effective in removing phosphorus from the lagoon effluent and can be used to settle suspended algae before the discharge of seasonal discharge lagoons (Pollutech, 1975). The addition of chemicals to the lagoon for phosphorus removal will increase the amount of sludge that is accumulated in the lagoon and increase the frequency of desludging. For intermittent discharge lagoons, treatment is normally done by batch immediately before the start of the discharge period. Jar testing can prove useful in selecting the optimum chemical and the required dosage. Chemical addition is usually done from a motorboat, although more sophisticated and costly recirculation pumping systems have been used.
For continuous discharge lagoons, chemical addition into the raw sewage at a raw sewage pumping station if available or to the influent distribution box is the

common practice (Graham and Hunsinger, 1977). In this situation, accumulation of sludge at the point where the raw sewage enters the lagoon can be significant, and more frequent desludging may be necessary. In multi-cell systems, chemicals can be added at the inlet to the final cell. This approach reduces chemical use and sludge production.

3.5.5 PRE-TREATMENT TO REDUCE LAGOON LOADINGS

Installation of processes, such as fine screens or clarifiers upstream of lagoons, can reduce the loadings on the lagoon, increasing capacity and/or improving performance. Consideration must be given to the management of the solids removed by this equipment, particularly at remote sites that are largely unmanned. Screening of the raw sewage can also remove flotable material that can be a nuisance in lagoons and can be discharged with the effluent if the discharge structure is not properly designed.

3.5.6 POST-TREATMENT TO IMPROVE EFFLUENT QUALITY

Achieving substantial improvements in effluent quality from lagoon-based systems, particularly in terms of effluent ammonia, phosphorus, or TSS concentrations, sometimes requires the addition of post-treatment processes to polish the lagoon effluent.

Polishing for removal of suspended solids related to algal blooms or to improve phosphorus removal to levels substantially below 1.0 mg/L can be achieved by using any of the conventional solid–liquid separation processes including microstrainers, conventional rapid sand or multi-media filtration, coagulation–clarification, or dissolved air flotation (EPA, 1983). Natural wetlands have also been shown to be effective for BOD_5 and suspended solids removal (Longmuir and Langcake, 2000), but less effective for phosphorus or ammonia removal in cold climates.

Based on a review conducted on behalf of MOE (R.V. Anderson Associates and XCG, 1992), intermittent sand filtration represents the best available technology for upgrading lagoon effluents for ammonia removal to produce a non-toxic effluent. A number of these systems are operating in Ontario, but operation is generally limited to warmer months, requiring significant storage during the winter. Intermittent sand filters are typically operated from about August to November in southern Ontario to prevent freezing of the liquid on the filter surface.

Enhanced disinfection beyond that accomplished by natural means can be provided by any of the conventional disinfection processes, although the presence of high concentrations of algae can reduce the efficiency of ultraviolet irradiation (Prince et al.,1994).

3.5.7 Minimizing Odours

Odours in lagoon-based systems generally result from overloading, long periods of cloudy weather that reduce the oxygen supply from photosynthesis, ice covering, and short circuiting. Low-cost ways to improve the circulation patterns in lagoons were described in Section 3.5.1. If odours are caused by other factors, the following steps can be taken:

- install mechanical aeration (surface aerators, diffused aeration systems) in the first cell to increase oxygen transfer;
- if accumulated sludge is contributing to odours, desludge the lagoon;
- if floating mats of sludge, algae or vegetation are apparent, remove the mats or break them up with a motorboat and allow them to sink into the sludge layer;
- change to parallel operation to distribute the organic load over an additional lagoon volume;
- recirculate lagoon effluent containing high concentrations of dissolved oxygen to the lagoon cell subject to overloading;
- add chemicals, such as hydrogen peroxide or sodium nitrate , as a source of oxygen;
- if the high loading is created by industrial discharges, implement a sewer use control program to minimize the loading (see InfraGuide best practice on “Wastewater Source Control”); and
- install wind-driven or solar-powered aerators to increase oxygen supply and prevent extended periods of ice or snow cover.

3.6 Optimizing to Reduce Costs

Although lagoon-based systems represent the lowest capital and operating cost treatment processes, some opportunities exist to reduce costs associated with energy use or chemical use, including:

- automatic on/off control of mechanical aeration equipment based on dissolved oxygen sensors to prevent unnecessary aeration during periods of high DO;
- timer activation of mechanical aeration equipment based on diurnal loading and dissolved oxygen concentrations patterns in the lagoon;
- jar testing to establish the optimum chemical dosage to achieve the required level of phosphorus removal (alum or similar chemicals) or disinfection (chlorine, where permitted);
- proportioning chemical feed rates to flow to prevent overdosing during low or no flow periods; and
- on-site analysis of process control parameters such as ortho-phosphorus, suspended solids, ammonia, and residual chlorine (if chlorine is permitted) to reduce contract laboratory costs.
- monitor ortho-phosphorus concentrations near the point of chemical addition for phosphorus removal to determine and adjust the chemical dosage rate.

3.7 EMERGING TRENDS AND RESEARCH NEEDS

The need to control the concentration of ammonia in municipal WWTP effluents to ensure the discharge is non-toxic will place an added burden on lagoon-based systems. Although up to 80 percent removal of ammonia can be achieved in lagoons in the summer months, this cannot be sustained in winter (EPA, 2002). Achieving a consistent high level of ammonia removal year round has often required post-treatment with intermittent sand filters or upgrading of the lagoon to a mechanical treatment plant. Installing media in biological treatment systems to increase the inventory of biomass and achieve cost-effective nitrification has been shown to be effective in activated sludge and similar mechanical WWTPs. This approach may also be applicable to lagoon-based systems, but needs to be demonstrated on a large scale in Canadian climatic conditions.

Some operators have reported successful usage of enzymes to reduce odours and volume of sludge in lagoon systems. Further research and monitoring of full scale applications are necessary support the use of specific additives (e.g. enzymes) for particular operating conditions and wastewater characteristics.

Use of chlorine as a disinfectant is not permitted in some provinces, and it is being discouraged across Canada by the new regulations. If disinfection is required at specific sites, other alternatives such as U.V. radiation have to be explored.

4. APPLICATIONS AND LIMITATIONS

4.1 APPLICATIONS

Lagoon-based treatment systems are very prevalent in Canada, particularly in smaller communities where land is readily available and relatively inexpensive. These systems are economical to build and operate. However, as the community grows and more stringent environmental regulations are applied to treated effluent discharges, many lagoon owners must consider upgrading and expanding their systems. Conversion to a full mechanical treatment plant can require a substantial capital expenditure and a significant increase in operation and maintenance costs over the lagoon system that it would replace. This best practice presents cost-effective approaches to improve the performance of lagoon-based systems and to reduce the costs of operation.

4.2 LIMITATIONS

This best practice focuses on lagoon-based WWTPs, but there is minimal discussion of anaerobic lagoons as these are not commonly used as a primary method for municipal wastewater treatment applications.

Because lagoon systems generally are operated with limited staff due to the relatively low operational requirements, safety around lagoons is a particular concern. Sufficient numbers of trained staff must always be available with proper safety equipment whenever hazardous work is to be performed. In winter, when berms can be ice or snow covered, operators should not work alone even for simple tasks, such as sampling. This best practice is not intended to provide direction on health and safety during lagoon operation. Operating manuals and other training material should be referred to for more detailed information related to this issue.

Berm integrity and leakage should be assessed on a regular basis by a qualified professional to avoid failure. This is not addressed in this Best Practice.

This best practice is not intended to replace the operations manual that should be available at the WWTP.

5. EVALUATION

A well-designed and operated lagoon can produce a treated effluent quality comparable to that produced by a mechanical secondary treatment plant, but at lower cost if land is available economically. A high-quality effluent that has minimal impact on the receiving water and a lagoon system that does not produce objectionable odours or otherwise impact on the environment are indications that best practice has been achieved.

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