Final Report

Sewage Treatment Best Available Technology

Prepared for

**Indian and Northern Affairs Canada
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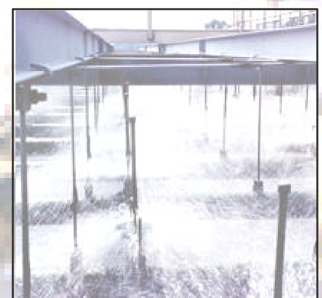

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1. Executive Summary

Indian and Northern Affairs Canada contracted Ferguson Simek Clark to discuss Best Available Treatment Technology (BATT) for recommended for municipal sewage treatment in the North.

Eight BATT processes for domestic sewage have been discussed including:

1. Activated Sludge – Extended Aeration;
2. Sequencing Batch Reactors;
3. Lagoons;
4. Wetlands and Overland Flow;
5. Membranes;
6. Physical-Chemical Treatment;
7. Biofilters; and
8. Rotating Biological Contactors.

Each of these eight processes has been used successfully in the North.

Each process has its advantages and disadvantages ranging from the cost to build and operate the process, to the amount of land used.

The application of a process to a particular situation is an engineering judgement based on:

- The effluent quality required for the receiving environment;
- The availability of land and future land use;
- Sustained access to trained operators; and
- The cost to build and operate the process.

The generation of treatment process residuals (sludge) are as important a consideration as the treatment process itself. Sludge treatment can account for up to 50% of the cost of sewage treatment. Sewage treatment processes and their liquid discharges must not be considered in isolation from their sludge, or the potential for and impact of contaminated sludge.

2. Introduction

Indian and Northern Affairs Canada contracted Ferguson Simek Clark to discuss Best Available Treatment Technology (BATT) for municipal sewage treatment in the North.

In order to get the whole picture behind BATT for municipal sewage treatment in the North, several items are considered before examining individual treatment processes. The first items of discussion are reviews of government legislation and regulations that affect wastewater systems as a whole. Reviews are done on the *NWT Waters Act and Regulations, the Northern Inland Waters Regulations, the Fisheries Act* and the *NWT Public Health Act*.

There are eight (8) sewage treatment processes examined. For each process the background, general description, flow sheet, performance expectations, and advantages and disadvantages are presented. The eight BATT processes are:

1. Activated Sludge – Extended Aeration;
2. Sequencing Batch Reactors;
3. Lagoons;
4. Wetlands and Overland Flow;
5. Membranes;
6. Physical-Chemical Treatment;
7. Biofilters; and
8. Rotating Biological Contactors.

A discussion on sludge treatment and handling is also presented.

Applicable legislation is discussed in sections 3, 4, 5, and 6. Section 7 outlines two example water licences. Section 8 discusses the eight BATT processes. Section 9 discusses the treatment, handling, and disposal of sludge Section 10 provides a summary.

3. Review of the NWT Waters Act

The *Northwest Territories Waters Act*[1] establishes the NWT Water Board and describes its objectives:

> 12. The objects of the Board are to provide for the conservation, development and utilization of waters, in a manner that will provide optimum benefit therefrom for all Canadians and for the residents of the Northwest Territories in particular.

In accordance with the objectives, the Board is able to issue water licences, have public hearings, and keep a public register. These actions are normally done in conjunction with the Mackenzie Valley Land and Water Board, and Fisheries and Oceans.

3.1 Review of the Northwest Territories Waters Regulations

The *Northwest Territories Waters Act* describes what water-involved activities are allowable without the need of a water licence, criteria for Class A and Class B licences and the application process for receiving, renewing or cancelling a water licence.

[1] http://canada.justice.gc.ca/en/laws/N-27.3/73719.html

4. Review of the Mackenzie Valley Resource Management Act

The *Mackenzie Valley Resource Management Act* (MVRMA) cites the mandate of the Mackenzie Valley Land and Water Board to be:

> 102. (1) The Board has jurisdiction in respect of all uses of land or water or deposits of waste in the Mackenzie Valley for which a permit is required under the *Northwest Territories Waters Act*, and for that purpose the Board has the powers and duties of a board established under Part 3, other than powers under sections 78 and 79, as if a reference in that Part to a settlement area were a reference to the Mackenzie Valley.
>
> (2) the regional panel of the Board for a settlement area shall exercise
>
> (a) the powers and duties referred to in subsection (1) in respect of a use of land or waters or a deposit of waste that is to take place, and that is likely to have an impact, wholly within the settlement area.
>
> (b) the powers conferred by section 78 to 80 on the board established under Part 3 for the settlement area.

The three main functions of the Mackenzie Valley Land and Water Board are:

1) To process transboundary land use and water use applications in the Mackenzie Valley;
2) To ensure consistency in the application of the legislation throughout the Mackenzie Valley; and
3) To issue land use permits and water licences outside settled land claim areas in the Mackenzie Valley.

The MVRMA also asserts the existence of the Sahtu and Gwich'in Land and Water Boards that are responsible for the areas as outlined in their respective land claims. These boards act in accordance to:

> 58. A board shall regulate the use of land and waters and waste so as to provide for the conservation, development and utilization of land and water resources in a manner that will provide the optimum benefit to the residents of the settlement area and the Mackenzie Valley and to all Canadians.

The act covers the issues of water licensing, land use permits, environmental impact review, and environmental monitoring and auditing.

5. Review of the Fisheries Act

The Fisheries Act (1985), amended, prohibits persons from depositing or permitting the deposit of "deleterious substances" into "waters frequented by fish," unless the deposits are of a type, quality, or concentration authorized by regulation. Deleterious substances can include industrial effluent and municipal sewage discharges, as well as bunker oil, ammonia, sewage, gravel, wood preservatives (such as tetrachlorophenol and pentachlorophenol), and diesel fuel. The Act also imposes a duty to report any deposit of a deleterious substance, or any serious and imminent danger of such a deposit.

Beginning in the 1970's, several effluent regulations were adopted under the Fisheries Act. These impose limits on the contents of discharges from pulp and paper mills, petroleum refineries, chlor-alkali plants, meat and poultry plants, metal mining operations, and potato-processing plants. The regulations allow deposits that otherwise would have been prohibited under the general offence provisions of the Act. In 1992, the federal government tightened the pollution standards in the Pulp and Paper Effluent Regulations under the Fisheries Act, and added an important new set of regulations, the Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations under the Canadian Environmental Protection Act (CEPA) , prohibiting dioxins and furans in pulp mill effluent by January 1994. Also under CEPA are the Phosphorous Concentration Control Regulations.

Fisheries and Oceans Canada provide Fish Habitat Management through activities, legislative responsibilities and policies that conserve, restore and develop productive capacity of habitats for the fisheries resources. The federal *Fisheries Act* defines fish habitat as any part of the environment “on which fish depend, directly or indirectly, in order to carry out their life processes.” The definition of fish includes all stages of “fish, shellfish, crustaceans, marine animals and marine plants.” Thus, all activities in or near water that could have any impact on fish habitat are considered under the act.

Section 35 of the act defines *deleterious substances* as:

> (a) any substance that, if added to any water, would degrade or alter or form part of process of degradation or alteration of the quality of water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent the water, or
>
> (b) any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water,

> and without limiting the generality of the foregoing includes
>
> (c) any substance or class of substances prescribed pursuant to paragraph (2) (a),
>
> (d) any water that contains any substance or class of substances in a quantity or concentration that is equal to or in the excess of a quantity or concentration prescribed in respect of that substance or class of substances pursuant to paragraph (2) (b), and
>
> (e) any water that has been subject to a treatment, process or change prescribed pursuant to paragraph (2) (c);

It also defines *deposit* as " any discharging, spraying, releasing, spilling, leaking, seeping, pouring and emitting, emptying, throwing, dumping or placing." See the *Fisheries Act* for additional detail

Section 36 states:

> (3) Subject to subsection (4), no person shall deposit or permit the deposit of deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.
>
> (4) No person contravenes subsection (3) by depositing or permitting the deposit in any water or place of
>
> (a) waste or pollutant of a type, in a quantity and under conditions authorized by regulations applicable to that water or place made by the Governor in Council under any Act other than this Act; or
>
> (b) a deleterious substance of a class, in a quantity or concentration and under conditions authorized by or pursuant to regulations applicable to that water or place or to any work or undertaking or class thereof, made my the Governor in Council under subsection (5).
>
> (5) The Governor in Council may make regulations for the purpose of paragraph (4) (b) prescribing
>
> (a) the deleterious substances or classes thereof authorized to be deposited notwithstanding subsection (3);
>
> (b) the waters or places or classes thereof where any deleterious substances or classes thereof referred to in paragraph (a) are authorized to be deposited;

> (c) the works are undertakings or classes thereof in the course or conduct of which any deleterious substances or classes thereof referred to in paragraph (a) are authorized to be deposited;
>
> (d) the quantities or concentrations of any deleterious substances or classes thereof referred to in paragraph (a) that are authorized to be deposited;
>
> (e) the conditions or circumstances under which and the requirements subject to which deleterious substances or classes thereof referred to in paragraph (a) or any quantities or concentrations of those deleterious substances or classes thereof are authorized to be deposited in any waters or places or classes thereof referred to in paragraph (b) or in the course or conduct of any works or undertakings or classes thereof referred to in paragraph (c);
>
> (f) the person who may authorize the deposit of any deleterious substances or classes thereof in the absence of any other authority, and the conditions or circumstances under which and requirements subject to those persons may grant the authorization.
>
> (6) A person authorized to deposit a deleterious substance by or under regulations made pursuant to subsection (5) shall, when directed in writing by the Minister, notwithstanding any regulations made pursuant to paragraph (5) (e) or any condition set out in an authorization made pursuant to paragraph (5) (f), conduct such sampling, analyses, tests, measurements or monitoring, install or operate such equipment comply with such procedures, and report such information, as may be required by the Minister in order to determine whether the person is depositing the deleterious substance in the manner authorized.

The *Fisheries Act* generally prevents the polluting of any fish habitat or any area that may have an effect on fish habitat. Polluting in this Act is generalized into anything that can cause a change to the habitat, thus it is not necessarily what is considered to be a “harmful” substance.

Licences may be granted that allow substances to be released into areas that are considered to be fish habitat. Fisheries and Oceans are involved in water licensing.

6. Review of the NWT Public Health Act

The Public Health Act is the legislation responsible for maintaining and promoting good health. The Act is instituted by the GNWT Department of Health and Social Services in the Northwest Territories.

6.1 GNWT Department of Health and Social Services

The GNWT Department of Health and Social Services supplies a broad range of health and social programs and services to all residents of the Northwest Territories. The Departments goal is to promote, protect and provide for the health and well being of these residents.

6.2 General Sanitation Regulations

The Act describes *General Sanitation Regulations* that prevent such issues as water born disease from spreading to the general public. All of the following issues are in reference to legislation that deals with sewage.

> 15. The inlet of any pipe to withdraw water for human consumption or ablution from any stream, river or channel shall be located at least 30 m upstream from any sewage outfall or from any other source of pollution unless a Health Officer shall otherwise direct.
>
> 16. Ice cut for use as water for human consumption or ablution shall be
>
> (a) obtained from source located at least 150 m from any sewage outfall or from any other source of pollution, unless a Health Officer directs otherwise; and
>
> (b) stored in such a manner as to be protected from contamination.
>
> 17. Every incorporated municipality shall provide for the use of the inhabitants a system for the collection and disposal of human excreta and shall operate the system in a manner as will prevent the spread of disease.
>
> 20. No sewerage system, septic tank or cesspool shall be so constructed, operated or maintained that the effluent from it discharges
>
> (a) in a location or in a manner likely to be injurious to health;
>
> (b) into any stream, river, channel, water course or lake, unless the written permission of a Medical Health Officer has been obtained; or

(c) less than 30 m downstream from the inlet of any pipe withdrawing water for human consumption or ablution.

This last section refers to all waste, which includes such issues as sludge management and honeybags.

> 27. Every incorporated municipality shall provide adequate waste disposal grounds for the disposal of all garbage, refuse, excreta and other waste matter and shall cause such waste materials to be burned, buried or covered with a layer of earth or other innocuous material as necessary to deodorize the matter or thing deposited on the grounds to prevent the breeding of flies.
>
> 28. Every waste disposal ground shall be
>
> (a) located at least 90 m from any public road allowance, railway, right-of–way, cemetery, highway or thoroughfare;
>
> (b) located at least 450 m from any building used for human occupancy or for the storage of food; and
>
> (c) situated at such a distance from any source of water or ice for human consumption or ablution that no pollution shall take place.

6.3 Public Sewerage Systems Regulations

These regulations apply to all public sewerage system, except those that have been constructed before the *Public Health Act* was instated. This exemption can be revoked if there is concern that the sewerage system may be a health hazard changes are made to the system.

Operation of a sewerage system must be under these regulations and any alteration of the system must be approved. A Health Officer is allowed to enter a premise at any time to ensure compliance. He/she can make recommendations to the operator or send a report to the Chief Medical Officer.

> 5. (1) Where the Chief Medical Health Officer is satisfied that the disposal of sewage or effluent creates a health hazard, he or she may order closure of the public sewerage system.
>
> (2) An operator may appeal in writing to the Commissioner within 48 hours after receiving a closure order under subsection (1) and the Commissioner shall either revoke or confirm the order.

These are the general principles for the operation of sewerage or sewage pumping stations:

> 6. (1) No final disposal of effluent from a sewerage system shall be carried out in a manner that creates
>
> (a) a health hazard with respect to water supplies, swimming beaches or any body of water in that area; or
>
> (b) aesthetically unacceptable conditions with respect to temperature, turbidity, colour, taste or odour of any stream or body flowing water in the area.
>
> (2) The buildings and grounds of a sewage treatment system shall be kept neat, tidy and attractive in appearance and no offensive odour shall be allowed to emanate from the building and grounds that is noticeable to persons residing in or occupying buildings situated nearby.
>
> (3) Industrial waste that are, in the opinion of a Medical Health Officer or a Health Officer, of a nature that will adversely affect the sewers, sewerage treatment system or final effluent shall be either pretreated to render them harmless or excluded from the sewerage system.

The design of the sewerage system is also under the authority of the Public Health Act. It is necessary that the design does not create health hazards. All sewage must go through the sewage system unless it is disposed of in a manner that will not create a health hazard.

There are also special regulations regarding the design of sewer system that run in close proximity to streams or other water sources. This is also true of systems that pass below railroad crossings. The storage of electrical equipment must be stored in accordance to the National Board of Fire Underwriters' specifications for hazardous conditions.

Construction plans are to be maintained. If there are additions, extensions or alterations done to the system, the plans must be amended.

Protection of water supplies is of utmost importance.

> 8. (1) There shall be no physical connection between any potable water supply and a sewer or appurtenance to a sewer, which would permit the passage of any sewage or polluted water into the potable water supply.
>
> (2) No sewer shall be so located as to be a contamination hazard to water wells or other water supply sources.
>
> (3) Subject to subsection (4), no water main shall be laid within 3 m of a sewer.

(4) Where a water main must cross a sewer or it is clearly impracticable to comply with subsection (3), then, at any point within 3 m of the sewer

(a) the bottom of the water main shall be not less than 450 mm above the top of the sewer; and

(b) the water main shall not rest on the undisturbed soil.

(5) Where a sewer is laid closer than 3 m to a water main, the sewer shall be of an approved type of water-tight construction and shall be constructed as follows:

(a) there shall be a 150 mm bed of well-tamped granular soil below the pipes, and any over-excavation shall be replaced by granular fill which shall be tamped in layers no less than 150 mm thick to 90% by the standard Proctor test;

(b) where the pipes are laid parallel, there shall be a minimum horizontal distance of 230 mm space between the outsides of the pipe barrels and 150 mm space between the walls of the trench and the outside of the pipe barrels;

(c) where the pipes are laid parallel, water mains shall be routed around sewage manholes so that there is a 150 mm minimum space between the outside of the pipe barrel and the outside of the manhole;

(d) where pipes cross there shall be adequate support on each side of the crossing for both pipes so that there will be stresses in either pipe caused by one pipe settling on the other. Pipe sections shall be centered at the crossing so that there is a maximum distance from the crossing to all joints. Both pipes shall be pressure tested to assure that there are no leaks;

(e) bright coloured plastic ribbon of no less than 150 mm width shall be laid in strips 150 mm above the pipes and parallel to them to serve as a warning to the operator of a digging machine to avoid damage to the pipes.

(6) Where water and sewer pipes are contained in a utilidor, there shall be adequate provision for drainage in order to prevent contamination of the water supply during repairs and breakdowns.

Sewage treatment systems must be designed to ensure protection of the receiving water when the possible use of the receiving water is considered.

There are several safety issues that must be followed. There should be a fence that allows access to only authorized personel. Handrails and guards must be installed where necessary. First-aid equipment as well as protective clothing must be supplied.

7. Sample Municipal Water Licences

Two sample municipal water licences are shown in the appendix. The licences are for the City of Yellowknife and the Incorporated Hamlet of Rae-Edzo.

Issued under the Northwest Territories Waters Act, these licences prescribe conditions for the taking of water and deposit of waste. In years past, drinking water quality criteria and sampling requirements were included in water licences. That practice was stopped in stopped in the mid-1980's when it was determined that prescribing drinking water quality was not in the Water Board's mandate.

When looking at issues related to sewage, Part D: CONDITIONS APPLYING TO WASTE DISPOSAL is the principal section of the licence. Part D describes conditions for sewage quality, location of discharge, sampling requirements, compliance schedules, special studies, and reporting as deemed necessary.

8. BATT Processes

8.1 Activated Sludge

8.1.1 Nomenclature

The activated sludge process is the most efficient biological wastewater treatment process. Because of its widely respected use, the process configuration provides the basis for the nomenclature used in naming the various unit processes. The system may consist of some or all of the processes. For example:

Pre-treatment	Removes large and/or inorganic materials that are incompatible or would otherwise damage following processes.
Primary Treatment	Is the first process. It consists of removing large settleable solids that can be better treated in a sludge process.
Secondary Treatment	Is the second process. It provides for carbon removal.
Tertiary Treatment	Is the third process. It provides for the removal of nutrients

Advances in treatment using activated sludge have combined these unit processes, however, the names remain

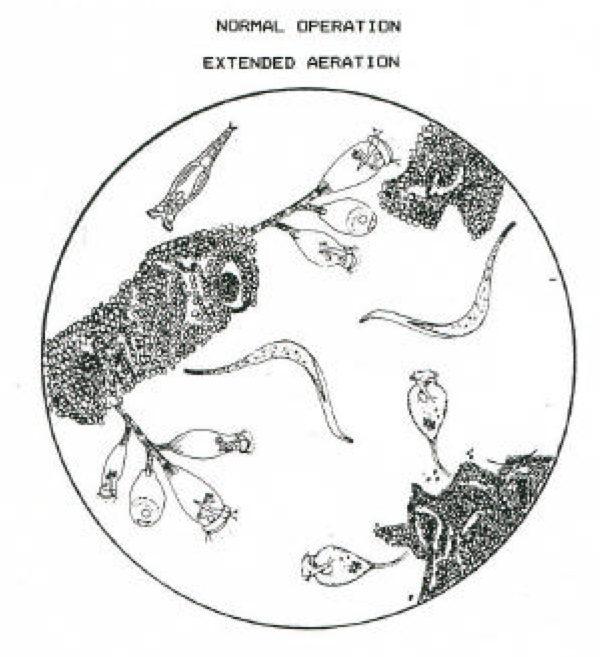
8.1.2 History of Activated Sludge

Dr. H. W. Clark performed the original experimentation in 1912. He determined that sewage could be clarified by mixing it with sewage sludge, agitating it by bubbling air through the mixture for approximately 25 hours, then allowing the resultant liquor to settle under quiescent conditions.

The activated sludge process is a biological wastewater treatment process that uses acclimatized microorganisms to speed up decomposition of wastes. When activated sludge is added to wastewater, the microorganisms feed and grow on waste particles in the wastewater. As the organisms grow and reproduce, more and more waste is removed, leaving the wastewater partially cleaned.

To function efficiently, the mass of organisms (solids concentration) needs a steady balance of food (food/microorganism ratio) and oxygen.

These quantitative relationships were first determined experimentally by I. E. Ardern and W. T. Lockett. Their initial design, which employed long narrow aeration tanks, has become the standard from 1914 to today (Cramer, 1931). Ardern and Lockett are best remembered for their coining of the term “activated sludge”. The term ‘activated’ comes from the fact that the zoogleal sludge particles are teeming with bacteria, fungi, and protozoa.



The first changes to the activated sludge process came when McKinney (1956) recommended the complete mix aeration tank. His studies showed that the conventional plug flow process was not properly designed from a biological treatment standpoint. It was found that the bacteria were in a feed/starve cycle; one in which the bacteria are alternately fed in the aeration tank, and then starved in the clarifier. This cycle made the process susceptible to upset, as it was never in equilibrium.

The next adaptations to the process came in the 1970’s when Dr. Barnard of South Africa used bacterial stress to biologically denitrify and sequester phosphorus. Named the Bardenpho process, Barnard introduced an anoxic zone into the aeration train. In this zone, nitrate/nitrite compounds would provide oxygen for bacteria, reducing these compounds to nitrogen ions. The nitrogen ions would combine to form nitrogen gas, which liberated itself from the liquid.

The stress caused by the anoxic zone also caused the bacteria to sequester phosphorus. This phenomenon is called “luxury uptake”, although the mechanism is not well understood. Once the bacteria are returned to a favourable environment, they will release the phosphorus. As a result, the bacteria must be removed from the process in order to remove the phosphorus.

8.1.3 General Discussion

Shown in Figure 8.1.1, the activated sludge process is a form of secondary treatment. Solids and other debris must be removed before this process can be used. This process’ goals are oxidation and removal of soluble or fine suspended materials within the wastewater. While in the aeration tank, aerobic organisms stabilize these materials by partial oxidation forming carbon dioxide, water, and sulfate and nitrate compounds. All other materials are settled out and removed as sludge during sedimentation.

Wastewater is sent to a settling tank after aeration to separate liquid from organisms (solids). The settled organisms are sent back to the aeration tank as activated sludge. Where required, the liquid or effluent is chlorinated prior to discharge. There are both high-rate and low-rate processes. The high-rate is concerned with the ability of dissolved and suspended particles to settle out of solution. The low-rate is concerned with chemical or biological oxidation with biological being stressed.

Wastewater enters the aeration tanks to mix with the activated sludge which gives a combination of sludge, carrier water and influent solids. The organisms in the activated sludge use the wastewater as food source providing them with energy required to live and reproduce. The bacteria forms floc masses, known as a zoogleal mass, that traps and holds materials that cannot be used as food.

Different organisms require varied time frames to use the available food and some will compete with one another for the food supply. The ratio of food to organisms is of great importance in the activated sludge process. Organisms generally increase with the availability of food (waste load) and the amount of time spent in the aeration tank. When necessary, excess organisms will be removed (sludge wasting) in order to maintain effective waste treatment.

In order for the organisms to oxidize waste, oxygen is required. If the oxygen supply is low, aerobic organisms will slow and facultative ones will be less efficient. This could produce a pungent odour resulting from decomposition and incomplete reactions.

8.1.4 BATT for the North - Extended Aeration

In this process, secondary treatment is combined with primary treatment. Shown in Figure 8.1.2, extended aeration is just that, the organisms and the wastewater are kept in the aeration tank for a longer period of time, typically 24 hours. The organisms get less food since there are more of them to feed. They will also feed off of the stored food in dead organisms. This produces carbon dioxide, water, and a relatively biologically inert residue.

This process is relatively simple to operate, is not subject to rapid upset due to its buffering capacity and does not create as much waste sludge as does the conventional process. Sludge wasting is still required to maintain proper control of the process.

8.1.4.1 Performance Expectations of Extended Aeration

Characteristics	**Range**
Hydraulic Retention Time	24 hours (typical, based on 250 mg/l BOD)
BOD_5 Removal	up to 95%
Effluent BOD_5 Soluble	< 10 – 15 mg/l
Effluent BOD_5 Total	< 40 mg/l
Suspended Solids Carry-over	can reach 50 mg/l
Nitrification	can reach 100%
Sludge Generation	0.15 kg/kg of BOD_5 removed
Minimum air requirement	1.8 kg O_2 / kg of BOD_5 removed

8.1.4.2 Advantages vs. Disadvantages of Extended Aeration

Advantages

- No expensive equipment required.
- Minimum training required by operators.
- Provides equal or superior treatment to the conventional activated sludge process.
- Adaptable to changing loads.
- Most trouble-free activated sludge treatment process.
- Creates little waste sludge.

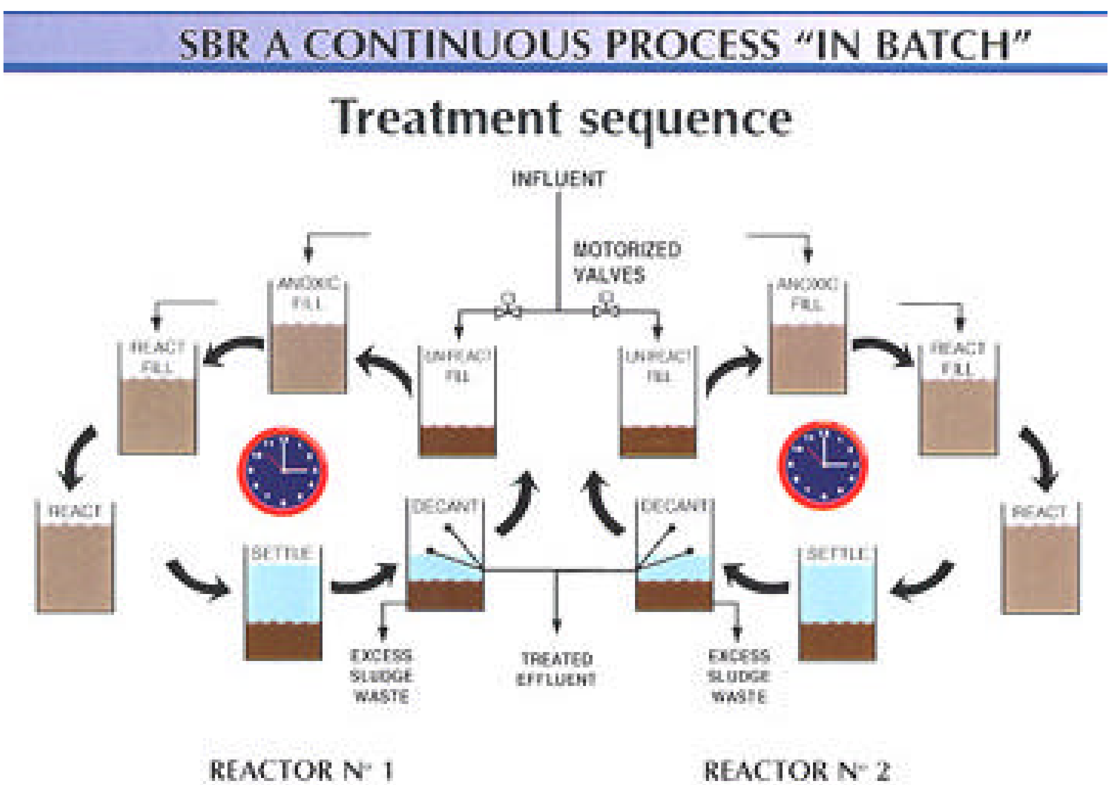
Disadvantages

- Requires a heated building for winter operation.
- Can have high suspended solids in the effluent.
- Requires constant monitoring by operators.
- Energy intensive.

8.2 Sequencing Batch Reactors

A sequencing batch reactor is a further adaptation of the activated sludge process described by Clark's original design. With the advent of modern control systems and microprocessors in the early 1970's, came the emergence of batch treatment technology as a viable alternative to conventional continuous flow systems. One of the most successful and innovative of these technologies was the Sequencing Batch Reactor (SBR), a fill and draw suspended growth activated sludge system, originally developed by Dr. Robert L. Irvine.

Dr. Irvine and his colleagues conducted the first full scale demonstration of the SBR at Culver, Indiana between 1970 and 1983. The study was funded by the United States Environmental Protection Agency (U.S. EPA) as part of the EPA's innovative and emerging technology program. A conventional activated sludge system owned and operated by the town of Culver was converted to a 1400 m^3/d, two tank SBR treatment plant. The conversion was based on results obtained from extensive theoretical analyses and numerous bench scale studies carried out at the University of Notre Dame.



SBR's work as a fill-and-draw process (batch feed, batch discharge). The process is similar in its operational dynamics to a Bardenpho process, with the exception that it is done in a single vessel, rather than plug-flow. This process is well suited for the treatment of:

- industrial waste with priority pollutants, high organic load or flow transients;
- plants with nitrogen and phosphorous removal requirements;
- smaller domestic plants; and
- plants in the North where clarifier operation and effluent quality problems are frequent.

Shown in Figure 8.2.1, fill, react, settle and decant are the four process steps. These are all completed in a single tank. The influent feeds continuously, but batch-wise to each process tank. The influent goes through a sequence of dedicated process periods and discharges periodically.

At the onset of the batch process, the reactor is at a minimum liquid fill level and influent flows to *fill* the reactor. In the *Anoxic Fill* period, jet aerators initiate the operation. The jets initially operate in the "unaerated mix" mode, thus no oxygen is being added and a blending of the influent and mixed liquor solid is being achieved. At a certain point, aeration is begun and oxidation begins.

Once the preset liquid level or time frame is achieved, the aerators are shut off and the s*ettle* period begins. At this time the reactor acts as a clarifier with no internal movement or fluid flow.

After settling, decant begins. A discharge valve opens and the supernatant effluent is collected by an effluent withdrawl mechanism. The discharge valve closes as a minimum water level is achieved. The reactor remains *idle* until influent is added and the process starts anew.

Generally, an operating schedule consists of four complete six hour process cycles per day. A cycle can consist of a four hour fill/mix/aerate process, a forty-five minute settling, a forty-five minute withdrawl and a half hour idle phase. The reactors are designed to meet effluent requirements. The system should be able to determine the influent flow rate, calculate and predict necessary cycle times and adjust operations to maintain effluent quality by monitoring liquid level sensors.

This system is resistant to shock organic loads. The feed cycles can be easily extended if there were a surge of BOD. A control system can automatically change the cycle times for such variabilities as the time of the day.

The process's flexibility is advantageous and is rooted in the fact that treatment is based on time and not the size of the unit. An operator can change the required time for cycles quickly to effect a desired process modification.

8.2.1.1 Performance Expectations of Sequencing Batch Reactors

Characteristics	Range
BOD_5 Removal	can exceed 95%
Effluent BOD_5 Soluble	can reach < 2 – 5 mg/l
Effluent BOD_5 Total	can reach < 5 – 10 mg/l
Ammonia	can reach < 2 mg/l
Phosphorus	can reach < 1 mg/l

8.2.1.2 Advantages vs. Disadvantages of Sequencing Batch Reactors

Advantages

- Provides equal or superior treatment to the conventional activated sludge process.
- Adaptable to changing loads.
- Can be automated and operated remotely.
- Effluent quality can meet general conditions of the Fisheries Act.

Disadvantages

- Requires a heated building for winter operation.
- Requires constant monitoring by trained operators.
- Energy intensive.

8.3 Lagoons

Shallow lagoons or lagoons with a depth of 1 to 1.5 metres can be used to treat wastewater or other wastes by natural processes. The wastewater is stored in artificial lagoons where sedimentation and oxidation take place. This system is generally referred to as a sewage lagoon or an oxidation lagoon.

Shown in Figure 8.3.1, treatment of the wastewater is dependent on the interactions of bacteria and algae. The decomposable organic matter is converted into more stable products by the bacteria, thus liberating nutrient elements that are essential for algal growth. The algae uses these nutrients to produce a surplus of oxygen through photosynthesis. This supplies aerobic conditions for the bacteria.

These lagoons are generally used in small communities. They can operate as a single unit or in a series. The three (3) classifications of lagoons are the aerobic, the anaerobic and the facultative lagoons.

Aerobic lagoons have a constant supply of dissolved oxygen throughout the water column. It is usually necessary to provide these lagoons with an additional source of oxygen. This can be done by algae during sunlight hours, mechanical agitation of the surface and/or compressors throughout the lagoon.

Anaerobic lagoons do not have any dissolved oxygen. Treatment is based on the fermentation of the sludge that has settled to the bottom of the lagoon. This lagoon is highly efficient especially for treating industrial waste, but odour issues are a problem.

Facultative lagoons are the most prominent type. They have both aerobic and anaerobic processes. Algae supplies oxygen to the supernatant which is the upper portion of the lagoon. The lower portion has no supply of oxygen.

Facultative lagoons are common in the North because they have a long detention time for the waste. Effluent can be discharged once or twice a year. If discharging only once, it will happen in the fall. If discharging twice per year, there will be a discharge in both the spring and the fall.

A sewage lagoon functions through the symbiotic relationship of algae and bacteria which feed from the wastewater. Through photosynthesis, algae use carbon dioxide to produce free oxygen that is needed by the aerobic bacteria. On a sunny day, each kilogram of algae is capable of producing 1.6 kilograms of oxygen. During non-daylight hours, the algae use the oxygen through respiration and thus produce more $C0_2$. Algae occur naturally in a lagoon and increase under the right conditions of food, sunlight and warm water.

The organic matter of the anaerobic (bottom) layer of a facultative lagoon is converted to carbon dioxide, nitrogen and organic acids by a group of organisms known as the "acid producers." At the same time, the "methane fermenters" group break down the products from the first group to form methane gas and alkalinity. Another product of organic decomposition is water.

At times, sludge decomposition is interrupted and the sludge begins to accumulate. Sludge accumulation is continuous with small amounts being stored in warm weather and larger quantities stored over the winter.

Cold temperatures and ice cover conditions interfere with the bacteria's ability to multiply at a fast enough rate to handle the waste. During warmer weather, "acid producers" begin to decompose the sludge build-up. Hydrogen sulfide odours may develop if organic acid production is too great for the lagoon. These odours are generally a problem in the North after winter thaw.

8.3.1 Performance

A lagoon's performance is dependent upon its design. The design is based on waste discharge requirements or water quality standards. Depending on the design, the lagoon may provide basic treatment which is primarily settling of solids or it can provide secondary treatment and some tertiary treatment.

BOD removal rates of 50 to 90 percent can be achieved depending on design. The chart below gives more information about facultative lagoons.

Approximately 90% of suspended solids are removed in three days by physical sedimentation alone. Within ten days, dissolved organic solids can be removed by about 80% through biological activity. A healthy lagoon may cause the organic particles to clump together as a result of the action of algae and bacteria. This is called bioflocculation and can remove about 85% of both suspended and dissolved solids within hours. This rate of bioflocculation can increase with optimum conditions, such as increase temperature, wave action and a high dissolved oxygen content.

Lagoons operated in series will provide an improved performance over a single lagoon. The best design is a two short retention lagoons for primary settling operated in parallel, followed by one or two long retention lagoons operated in series.

Secondary treatment is only achieved when the water temperature exceeds 5^{o}C. For lagoons that experience ice cover, wastewater must be stored during this period and then long enough to allow treatment to occur. Generally, storage lagoons are designed for annual retention.

8.3.1.1 Performance Expectations of Lagoons

Lagoon's Detention Time	Percent Removal of Coliform	Percent Removal of BOD	Total Suspended Solids	Percentage of Time Expected for Maximum Removal Rates
50 – 60 days	90 – 95%	70 – 80 %	-	80%
180-day	Up to 99%	85 - 95%	85 - 95%	-

8.3.1.2 Advantages vs. Disadvantages of Lagoons

Advantages

- No expensive equipment required.
- Minimum training required by operators.
- Provides equal or superior treatment to some conventional processes.
- Economical Construction.
- Adaptable to changing loads.
- Consumes little energy.
- Serves as a wildlife habitat.
- Increased potential design life.
- Few sludge handling and disposal problems.
- High levels of microorganism reduction.
- Most trouble-free treatment process.

Disadvantages

- Can emit odours.
- Large land requirement.
- Waste treatment efficiency based on weather.
- Can possibly contaminate groundwater.
- Can have high suspended solids in the effluent.

8.4 Wetlands and Overland Flow

Wetlands sewage treatment is a web of complex physical and biological processes. Sedimentation, absorption of pollutants in the surface soils, nutrient uptake by plants, and the oxidation of compounds by micro-organisms are some of the processes which affect the treatment.

Wetlands are transition zones between terrestrial (land) and aquatic (water) environments as shown in Figure 8.4.1. The word, "wetland", is relatively new terminology which refers to all types of wetland areas. For sewage treatment purposes vegetated areas that are normally dry ground can be converted to a "wetland". Proper technological terminology would call such a system, "overland flow", but the treatment mechanisms are the same.

The plants within a wetland act as natural purifiers trapping and binding pollutants in the mud and roots. The plants also provide a media to which bacteria can cling as it grows. These bacteria, many identical to those present in a mechanical sewage treatment plant, remove carbon and nutrients from the water.

Finally, the thin layer of now clean water allows sunlight to penetrate deeply, thus, killing pathogenic organisms and disinfecting the water. There are many positive aspects to using wetlands for sewage treatment including:

- by enhancing wetlands with nutrients and liquid, the ecology of the area is improved. This, in turn, attracts birds and mammals with a rich productive food source;
- using - in man's terms - an otherwise "unusable" area; and, in doing so
- preserving other areas for other uses.

Wetlands nurture biodiversity. In fact, wetlands are said to rival tropical rainforests in productivity. They provide: feeding, spawning, and nursery grounds for fish and other aquatic life; sanctuary and food for millions of insects and birds; and the only environment in which certain plants can live. Wetlands are the earth's kidneys - they absorb and filter out pollutants that would otherwise end up in our receiving waters, and they protect shorelines and riverbanks from erosion.

8.4.1 History of Wetlands in the North

The use of wetlands to treat municipal wastewater in the NWT probably originated in Hay River almost 30 years ago. Hartland - Rowe (1973) reported on the treatment efficiencies of a wetland area which had been receiving raw and primary treated effluent since 1968. His study found that removal efficiencies for the common parameters of concern ranged from between 70 to 90% over the entire wetland, a distance of 6,200 metres from the discharge to the mouth of the wetland at Great Slave Lake.

More recently Grainger and Yaworsky (1992) reported that several communities in the Yukon presently used, or were planning to use, wetlands as part of their municipal wastewater treatment system. Wetland treatment in many of these systems was informally incorporated, viewed as an added treatment opportunity, into the municipal treatment system. However, as the benefits of wetlands treatment were observed several communities included wetland treatment as an important part of their treatment system.

The communities of Haines Junction, Ross River, and Teslin have received licences from the Yukon Water Board for wastewater treatment incorporating wetlands. In all communities where wetlands are used wastewater is first subjected to long term storage in a lagoon and decanted only during the summer months.

Dillon (1994) reported on the use of wetlands for the treatment of wastewater at Chesterfield Inlet, NWT. Raw wastewater was discharged onto the ground and collected in a natural lagoon before draining through a natural wetland system to the ocean. Analysis of water samples collected in 1993 illustrated compliance with the Guidelines for the Discharge of Treated Municipal Wastewater in the NWT at sampling points within the wetlands system. Improvements to the system in terms of providing sufficient winter storage capacity within the existing lagoon were planned prior to submission of an application for a licence to include wetlands treatment.

With the apparent success of wetlands treatment in Yukon and other jurisdictions, the Government of the Northwest Territories commissioned a study of the potential use of wetlands for the treatment of municipal wastewater in the NWT. Doku and Heinke's (1993) study reviewed the use of natural and constructed wetlands in northern and southern wetlands and identified preliminary design considerations. They concluded that, because wetlands in the NWT generally have nutrient deficiencies, the planned and controlled discharge of partially treated wastewater will enrich the wetlands by providing the essential nutrients required for plant growth. They outlined five basic functions which make wetlands attractive for wastewater treatment:

1. Dispersion of surface waters over a large area through intricate channelization of flow;
2. Physical entrapment of pollutants through sorption in the surface soils and organic litter;
3. Uptake and metabolic use by plants;
4. Use and transformation of elements by microorganisms.
5. Low energy and low maintenance requirements to attain consistent treatment levels.

8.4.2 Potential Effluent Quality

Doku and Heinke also reported removal efficiencies for BOD_5 from natural and constructed wetlands from between 49% to 96%. Suspended solid removal rates was shown to range between 29% and 98% with removal rates generally being more efficient for primary or preliminary treated wastewater than for secondary treated effluent. Highest removal efficiencies occurred where the influent suspended solids concentration was more than 150 mg/l.

Nitrogen removal (inorganic nitrogen only) efficiency in natural wetlands receiving secondary wastewater effluent ranged from 36% to 96% whereas the efficiency in constructed wetlands ranged between 25% to 85%. Generally it was observed that the nitrogen removal efficiency decreases as the hydraulic loading rate increases.

Phosphorus removal efficiencies ranged from 13% to 97% in natural wetland systems and 0% to 90% in constructed wetlands. Removal efficiencies are highest in spring and summer when plant growth and nutrient uptake are highest. Pathogens are removed in wetlands by both physical-chemical processes and biological inactivation and predation by zooplankton. Removal efficiencies for coliforms in constructed wetlands range from 82 to nearly 100%, however, it is difficult to determine removal rates in natural systems using coliforms as the measure as birds and other mammals may be contributing coliforms.

Doku and Heinke also included the Hay River Wastewater treatment facility in their review. This system consists of a three celled lagoon which discharges into a creek which flows into swampland before entering Great Slave Lake. Reports indicate that the 32 hectares affected by the wastewater flow during the summer months effectively removes 141 kg BOD_5/day and 13.1 kg/day of phosphate.

8.4.3 Loading Rates

The hydraulic loading rate is approximately 62.5m^3/hectare each day. With a BOD_5 value of 117 mg/l (as measured in 05/19/92) the BOD_5 loading was 7.09 kg BOD_5/ha/day. Considering the fact that the influent raw wastewater has received only primary level treatment in the anaerobic lagoons, the quality of the effluent affirms the observation that northern wetlands, if properly managed have the potential of removing organic pollutants, nutrients and faecal coliforms from pre-treated wastewater, producing a high quality effluent which can be safely discharged into the receiving water.

Both Dillon (1994) and Doku and Heinke (1993) suggest that discharge of wastewater to wetlands should only occur during the summer months when effective treatment can occur. As such, some method of storage, such as a long term storage lagoon, should be included prior to discharge to the wetland.

In addition to the recommendation to discharge to wetlands only during the summer Doku and Heinke also recommend that some form of pre-treatment of wastewater occur prior to its discharge into the wetlands to reduce the suspended solid load. This could be achieved with a lagoon system which is required for winter storage or some other mechanical means.

While performance data on existing wetland systems are limited, hence , there is little information from which to develop design criteria, Doku and Heinke state that the critically used design parameter is the hydraulic loading rate, while the organic loading rate is used as a check to ensure that the aerobic conditions necessary for microbial activity, prevail in a wetland system.

They suggest that a rate of 100-200m^3/ha/day be used as a guide until more performance data is available. Doku and Heinke also state that a conservative upper limit of 4 kg BOD_5/ha/day has been suggested in other literature for the organic loading rate. The wetland system in Hay River has been subjected to an estimated hydraulic loading of 62.5 m^3/ha/day and an organic loading rate of 7.3 kg BOD_5/ha/day for 20 years and the system continues to remove wastewater contaminants. They suggest a minimum hydraulic retention time of 14 days.

Other design considerations include the configuration of the wetland. Maximum treatment efficiencies will be realized with maximum contact of the wastewater with vegetation and the substrate. Doku and Heinke suggest a high length to width ratio (at least 10:1) of the wetlands is required to prevent short circuiting and decreased performance.

8.4.4 Vegetation Types

Vegetation types and substrates necessary for effective treatment are poorly documented. Hartland- Rowe (1973), in his investigation of the Hay River wetland system with a view to determining design requirements for other systems in the Mackenzie Valley, recommended that primary treated effluent be released into wetlands only in locations where such wetlands include an existing creek watershed supporting a substantial growth of *Carex* species[2].

[2] Also known as a sedge -- a family of glass-like and rush-like herbs found worldwide but especially in subarctic and temperate marshes.

Doku and Heinke found that the plants most frequently found in wetland systems used for wastewater treatment in various locations include cattails, reeds, rushes, bulrushes, sedges, duckweed and water hyacinth. Some of the wetland plant species tested for wastewater treatment in southern Canada and the US are also present in wetlands north of the 60th parallel.

Environment Canada looked into municipal wastewater treatment technologies capable of achieving compliance with the *Fisheries Act* in the Northwest Territories. UMA (1993) determined that four technologies were potentially capable: storage lagoons; zero discharge lagoons; sequencing batch reactors; and wetlands treatment. Of the alternatives, wetlands treatment had the lowest net present value costs for a generic design.

Municipal and Community Affairs, along with funding partners including: Indian and Northern Affairs, the Nunavut Water Board, Environment Canada, and the Department of Health, commissioned a study of three wetlands in the Keewatin region including Chesterfield Inlet. The purpose of the study was to assist in the development of planning and design guidelines for tundra wetlands.

The paper given by Dillon at the 1996 NTWWA conference has shed some light on the process, at least in the Baker Lake situation. The fact that treatment occurred with native species, and that the spring freshet passed before the sewage stored as ice began to melt was particularly interesting, and useful information for this project. The latter result means that sewage is not diluted and discharged during the spring freshet as might have been thought. Instead, the sewage is slowly released to the wetland as the ice melts, thus, receiving full treatment.

8.4.5 DEW Line Experience

Many of the DEW Line sites used overland flow for sewage treatment. A site-by-site review of Royal Roads' extensive report described lush vegetative growth and apparently no impact on the environment as a result of the sewage. Royal Roads reported that, in almost every case, the soil and vegetation exceeded background but was less than the DEW Line Clean up Criteria (DCC) shown in Table 8.4.1.

The DCC are a combination of the CCME R/P[3] and Quebec B[4] criteria and were determined, on the basis of site-specific investigations, to be protective of the Arctic Ecosystem. According to the strategy, soils containing contaminants above the DCC Tier II level should be excavated, secured in containers, and removed to a Northern Disposal Facility. Soils

[3] Interim Canadian Environmental Quality Criteria for Contaminated Sites (1991)
[4] Quebec Soil Contamination Guidelines (1991)

containing PCB's and lead between the DCC Tier I and DCC Tier II levels may be placed in an on-site engineered landfill.

Table 8.4.1 -- DEW Line Cleanup Criteria

Substance	Units	DCC Tier I	DCC Tier II	Toxic Threshold
Arsenic	ppm		30	10
Cadmium	ppm		5.0	
Chromium	ppm		250	
Cobalt	ppm		50	
Copper	ppm		100	25
Lead	ppm	200	500	5
Mercury	ppm		2.0	
Nickel	ppm		100	25
Zinc	ppm		500	
PCB's	ppm	1.0	5.0	200

In their evaluation of the DCC based on contaminant burdens in arctic plants and toxicity, Royal Roads found that the results for the inorganic elements cadmium, chromium, and cobalt were inconclusive due to an insufficient number of quantifiable concentration values available for comparisons. Indications were, however, that the DCC levels for these particular elements were appropriate; in addition, these substances rarely serve as independent triggers for remediation.

In contrast, the DCC values for arsenic, copper, nickel, lead, and PCB's were found to be reliable indicators of ecosystem impact and triggers for soil remediation. The values of threshold toxicity (Royal Roads, 1995e) for these contaminants shown Table 8.4.1, those above which the plants growing in such concentrations could be toxic to grazing animals.

More research needs to be conducted in this area to understand the implications of the Royal Roads conclusion.

8.4.6 Wetlands & Overland Flow Summary

In summary, the literature on the use of wetlands for wastewater treatment is presently limited to a description of existing systems and identification of some of the most important factors to be assessed during site specific designs. The limited design criteria contained in the literature is prefaced by conditions regarding the limited data on which the recommendations are based and that site specific studies are required before design and operation can be implemented.

In their review of the wetland treatment system in Chesterfield Inlet, Dillon (1994) recommended, that prior to final design or during initial operation, a program of geotechnical investigation and ecological study be undertaken addressing: collection of soil and vegetation samples; identification and mapping of soil profile throughout the wetland area; identification of plant species; evaluation of nutrient and pollution removal capabilities of vegetation; and evaluation of soil properties with respect to drainage ability to support plant life.

Doku and Heinke (1993) concur with the need for site-specific studies and limited testing prior to full implementation. "Few if any, design criteria are available that can be used to predict reliably the performance of or to determine the required size of natural wetland treatment systems...". Thus, in principle, for each location there is a need to conduct limited pilot testing to establish the proper design criteria and procedures before the application of wastewater.

Doku and Heinke conclude, " ... wetlands, if properly managed and operated can be used as a wastewater treatment system or incorporated into one for the purpose of enhancing the quality of effluent". The NWT Water Board's (1992) " Guidelines for the Discharge of Treated Municipal Wastewater in the Northwest Territories" allow for disposal of municipal wastewater into swamps and wetlands, however, they may require site-specific studies before they licence such systems.

8.4.6.1 Performance Expectations of Wetlands & Overland Flow

Characteristics	**Range**
BOD Removal	97% to 99%
Effluent Total BOD	2 – 5 mg/L
Effluent Soluble BOD	2 – 5 mg/L
Effluent NH_3-N	less than 1 mg/L
Nitrification to NO_3-N	can reach 100%

8.4.6.2 Advantages vs. Disadvantages of Wetlands & Overland Flow

Advantages

- No expensive equipment required.
- Minimum training required by operators.
- Provides equal or superior treatment to some conventional processes.
- Economical Construction.
- Adaptable to changing loads.
- Consumes no energy.
- Serves as a wildlife habitat.
- Increased potential design life.
- Few sludge handling and disposal problems.
- High levels of microorganism reduction.
- Can meet general conditions of the Fisheries Act.

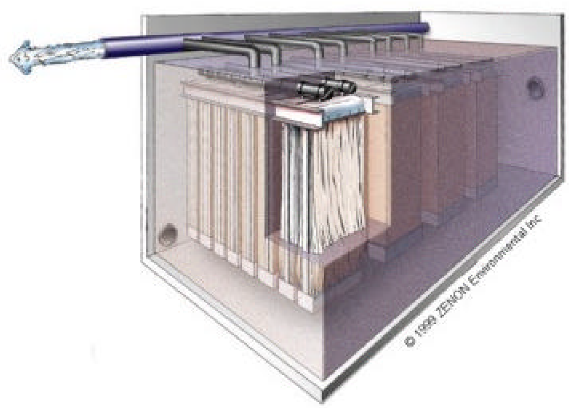
Disadvantages

- Can emit odours.
- Large land requirement.
- Waste treatment efficiency based on weather.
- Spring discharges may exceed effluent criteria.
- Can contaminate groundwater.
- Can have high suspended solids in the effluent.

8.5 Membranes

There is a growing need to reuse processed wastewater because of such factors as limited supplies of potable water to support communities and industries and the focus on the protection of natural resources. Integrated membrane bioreactor systems are able to accomplish this goal.

Membrane bioreactor technology began in the mid 1960's by Dorr-Oliver of Stanford, Connecticut. The work was based on membrane ultrafiltration coupled with an aerated suspended growth reactor. The "Membrane Sewage Treatment" (MST) system treated raw sewage in an aerated suspended growth reactor. The reactor's mixed liquor was pumped through a rotating screen prefilter to eliminate the larger solids before it was sent to the membrane system. The concentrate returned to the reactor and the filtered water, or permeate, left the system.



The system had membranes operating at pressures above 60 psig. It also controlled the concentration of the concentrate and allowed high velocity flow across the membrane surface to reduce surface fouling of the membrane.

Only a few MST systems were installed on sewage applications and Dorr-Oliver did not pursue commercialization. In the early 70's, Sanki Engineering Company Ltd. of Tokyo, Japan and Dorr-Oliver entered into a licensing agreement that allowed the installation of about twenty (20) membrane bioreactor systems at office and apartment buildings between 1974 and 1990.

Thetford Systems, Inc. of Ann Arbor, Michigan began developing a membrane bioreactor system in the early 70's. The system consisted of a two-stage single sludge biological process of anoxic and aerobic digestion. These systems incorporated tubular ultrafilter membranes and two-pump feed and bleed system to provide pressure and velocity to drive the membrane system. A stationary screen was used to filter the process fluid from the aeration process. The screen itself was constantly cleaned by the aeration process. Twenty-seven (27) of these systems were installed from 1974 to 1982 to treat and recycle flushwater from small commercial facilities.

In the 1980's, Membrane technology was being applied to larger facilities such as office buildings, shopping centers, industrial parks and sports facilities. In these areas, the ability to recycle flushwater could have a high impact on reducing wastewater discharge flows. Zenon Environmental Inc. acquired Thetford Systems, Inc. in 1994 while membrane technology was being commercialized for sanitary wastewater applications. Now membrane bioreactor technology for both sanitary and industrial wastewater applications is varied and includes the beverage, pharmaceutical, automotive, and food industries.

8.5.1 Membranes for Sanitary Wastewater Applications

There are four types of membranes available :

- Microfiltration;
- Ultrafiltration;
- Nanofiltration; and
- Reverse Osmosis

Shown in Figure 8.5.1, microfiltration is the largest of the membrane technologies having the ability to separate molecules above 100,000 molecular weight (0.5 to 20 microns). The second largest is Ultrafiltration which separates molecules above 1000 molecular weight (0.0015 to 0.2 microns). Nanofiltration's cut off is less than 300 molecular weight (0.0011 to 0.0015 microns). Reverse Osmosis has the smallest pore size and separates less than 0.0015 microns.

Most systems use the Ultrafiltration or low end Microfiltration. The first is capable of dividing both insoluble solids in the process fluid (bacteria, virus, colloids and suspended solids) and higher molecular weight soluble organics. Smaller organic weight organics are taken up in the aerobic process where the membrane is a barrier to larger more complex organics. The success of the integrated membrane system is dependent on the ability of the physical barrier.

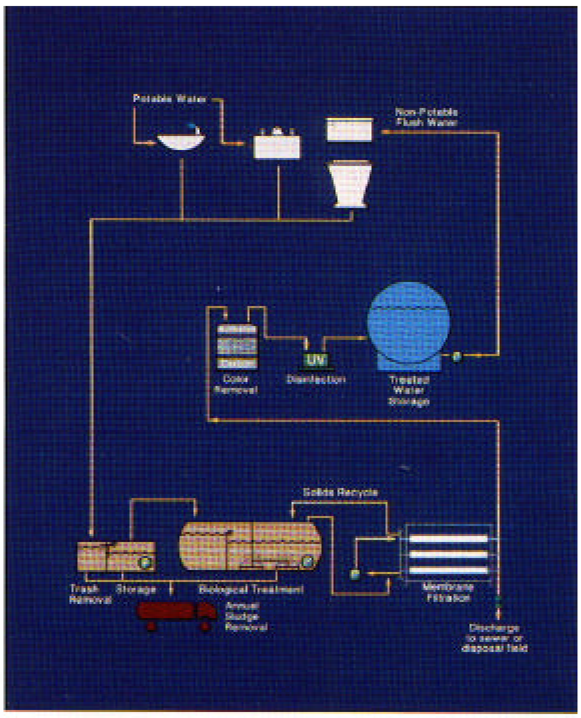
Ultrafiltration and Microfiltration require less energy to operate than Nanofiltration and Reverse Osmosis because they run on relatively low transmembrane pressures. This lower pressure also extends the life of the membrane system since the membrane compaction is reduced. Generally, Ultrafiltration membranes can operate for eight to ten years. The higher pressures reduce the operating life to approximately 4 to 5 years.

8.5.2 Impact of Ultrafiltration Membranes on Reactor Kinetics

A high level of biological treatment is necessary to treat and recycle water that has large concentrations of organic materials. In either suspended or support growth systems, efficiency can be affected by clarifier performance. Upsets in the clarifier can occur which produce "filamentous" or "pin" floc. If this happens, the biological reactor solids can be lost resulting in poor performance. Activated sludge processes normally have mixed liquor concentrations of less than 3000 mg/l to provide sufficient settling.

Membrane separation provides a simple, reliable positive barrier to soluble organics and microorganisms and eliminates passive clarification. The quality of the biological process fluid does not effect the separation performance. The membranes do not have the same maintenance and process limitations as the passive clarifier.

Shown in Figure 8.5.2, membrane filtration is simple treatment process that eliminates routine process adjustments such as chemical additions for enhancing settling, regular sludge management and clarifier maintenance. A stable, efficient biological process is maintained since there are no process upset associated with sludge bulking and difficult mixed liquor floc. It can also be highly automated with industry standard programmable controllers.



Biological Process

Membrane technology is a closed system which eliminates the problems of odours, insects and aesthetics that are common with open tanks and clarifiers. They are generally found within buildings and factories close to the wastewater source. This reduces the installation costs for both treatment and recycling.

The greatest benefits of the system are based on the biological reactor kinetics. The reactor can be operated in the range of 20,000 to 30,000 mg/l mixed liquor suspended solids (MLSS) which is higher than clarifier technology. The separation allows a long Solids Retention Time (SRT) while operating at a short, independently set Hydraulic Retention Time (HRT).

These are excellent processes for treating high strength, difficult to settle biological wastes. Since they operate with a higher concentration of biomass efficiency is increased and sludge production is reduced. A high biomass is effective at consuming organics, nitrifying and denitrifying. Thus, HRT can be low and low volume reactors are possible. The process for destroying complex organics is more efficient because of the combination of a long SRT with a high biomass. This reduces sludge yield and gives a well stabilized sludge.

8.5.2.1 Performance Expectations of Membranes

Characteristics	**Range**
BOD Removal	80-95%
Effluent Total BOD	2 – 5 mg/L
Effluent Soluble BOD	2 – 5 mg/L
Effluent NH_3-N	less than 1 mg/L
Nitrification to NO_3-N	95% - 97%

8.5.2.2 Advantages vs. Disadvantages of Membranes

Advantages

- Minimum training required by operators.
- Adaptable to changing loads.
- Not susceptible to process upsets.
- Few sludge handling and disposal problems.
- Can meet general conditions of the Fisheries Act.
- Can be automated and operated remotely.
- High levels of microorganism reduction.

Disadvantages

- Requires a heated building for winter operation.
- Requires constant monitoring by operators
- Energy intensive.

8.6 Physical-Chemical Treatment

8.6.1 General

Shown in Figure 8.6.1, physical-chemical treatment is used to remove particles from the water through a process involving coagulation, flocculation and sedimentation. In doing so, BOD is removed. If aluminum sulphate is used as a coagulation chemical, phosphorus is also removed. Additional processes are required if dissolved BOD and/or ammonia is to be removed.

8.6.2 Coagulation

In the coagulation process, coagulant chemicals are added to the water. Primary coagulants are chemicals which are responsible for the main coagulation reactions, that is the formation of floc and the neutralization of particle charges. Of all the coagulant aids, aluminium sulphate (alum) is the most commonly used. It is relatively inexpensive; easy to handle, store, and apply; and when used properly, very effective.

All particles carry an electrical charge on their surface which is usually negative, and thus, the particles tend to repel each other. Coagulation chemicals neutralize this charge so the particles can combine into large accumulations if they touch each other.

The chemistry of alum flocculation is complex and can be simplified to the equations which follow. The pH of the water is very important as it determines the charge of the chemicals in the reaction, and determines the solubility of aluminium. The greater the solubility of aluminium, the higher the amount of aluminium in the finished water.

$$Al^{3+} + H_2O <=> Al(OH)^{2+} + H^+ \qquad (8.6.1)$$

$$Al(OH)^{2+} + H_2O <=> Al(OH)_2^+ + H^+ \qquad (8.6.2)$$

$$Al(OH)_2^+ + H_2O <=> Al(OH)_3 \ (s) + H^+ \qquad (8.6.3)$$

$$Al(OH)_3 + H_2O <=> Al(OH)_4^- + H^+ \qquad (8.6.4)$$

These equations are written in "chemical shorthand" and show the progressive reaction of the aluminium ion to produce a species with a negative charge. An important reaction is 8.6.4, which yields aluminium hydroxide which forms as a precipitate and is the aluminium floc that is seen.

Note how in each of the reactions a H^+ ion is formed. If the water has a high alkalinity it will tend to resist pH changes when hydrogen ions are added or removed. The effect of adding aluminium will depend on the properties of the water, but alum will always decrease the pH, the alkalinity, or both.

With most waters the best pH for coagulation and flocculation is between 5 and 7. Usually, the natural alkalinity in the water is such that typical alum dosages will produce a pH close to the desired value. However, in some waters the alkalinity is unusually high or low, or very large doses of alum are necessary. The latter case may be during spring freshet on a river source when the turbidity is very high. In such cases, it may be necessary to adjust the pH and alkalinity.

Coagulant aids (also called flocculant aids) are used to increase the density of slow settling floc particles, or to strengthen them so they do not break up during settling and filtration.

Table 8.6.1 - Coagulant Chemicals Used in Wastewater Treatment

Chemical Name	Chemical Formula	Primary Coagulant	Coagulant Aid
Aluminium sulphate	$Al_2(SO_4) \cdot 14\ H_20$	✓	
Ferrous Sulphate	$FeSO_4 \cdot 7\ H_20$	✓	
Ferric Sulphate	$Fe_2(SO_4)_3 \cdot 9\ H_20$	✓	
Ferric chloride	$FeCl_3 \cdot 6\ H_20$	✓	
Cationic polymer	various	✓	✓
Calcium hydroxide	$Ca(OH)_2$	✓	✓
Calcium oxide	CaO	✓	✓
Sodium Aluminate	$Na_2Al_2O_4$		✓
Bentonite	clay		✓
Sodium silicate	Na_2SiO_3		✓
Anionic polymer	various		✓
Non-ionic polymer	various		✓

There are many different polymers on the market classified into three groups:

1. cationic -- having a negative charge
2. anionic -- having a positive charge
3. non-ionic -- having no charge

While manufacturers and even other operators may claim that the polymer they use is the best, the only way to determine if a polymer should be used is by jar testing, experimentation and observation, and laboratory testing. Each water treats differently and some polymers will have little or no effect, or may even make conditions worse. But the right polymer used under the right conditions, can make a very dramatic improvement.

The way in which a polymer works is complex and not well understood. Interaction of electrical charges on the polymer molecules and on the turbidity particles may be one important factor. The binding or bridging effect of the long polymer molecules may be another factor. But for simplicity, the mechanism is not really important -- either a polymer works or it doesn't.

8.6.3 Flocculation

Following the flash mixer, flocculation is the slow stirring process which causes the flocs to grow and to come in contact with particles of turbidity to form larger, settleable particles. The purpose is to produce a floc of the proper size, density, and toughness for effective removal by sedimentation and filtration. Floc formation depends on the rate at which collisions between flocs and particles occurs, and how the flocs stick together after collision.

In a conventional system which uses separate tanks for flocculation and sedimentation, detention time is usually about 30 minutes. Longer detention times usually do no harm, except that it may break up large floc particles, and result additional wasted tank capacity. Detention times shorter than 20 minutes may result in incomplete floc formation especially during cold water conditions.

Mixing intensity is very important. If it is too low, there will be relatively few collisions between particles, too high and flocs could be broken up. Flocs are very delicate. It takes very little excessive mixing intensity to cause floc break up. A variable speed motor on the flocculator is a must.

Unfortunately, there are no simple tests to see if the coagulation/flocculation process is working well and it is impossible to provide guidelines or instructions. Experience, careful observation, proper records, and good judgement are the only ways to determine the best operating conditions.

8.6.4 Sedimentation Principles

Sedimentation is the separation of suspended material from the water by gravity. The settling of particles in water follows a fundamental theoretical equation known as Stokes Law where:

$$V_{at} = \frac{g}{18} * \frac{D^2}{v} * (S_s - S_W) \qquad (8.6.5)$$

where V_{at} = Settling velocity of the particle
g = gravitational constant
D = diameter of the particle
v = viscosity of water
S_s = specific gravity of the particle
S_W = specific gravity of water (= 1)

The effect of temperature on water is important. First, temperature affects the density of water. Density is the amount of mass contained in a unit volume. As temperature decreases through its normal surface temperatures from 25^o to 4^o, water increases in density. At 4^o, water is at it greatest density. From 4^o to 0^o, water decreases in density. From Stokes Law as the difference between the density of the particle and the density of water increases, the settling velocity of the particle increases.

Second, temperature affects viscosity. Viscosity is a measure of the ability of a liquid to flow. From Stokes Law, the velocity at which a particle settles is inversely proportional to the viscosity, that is, a particle settles faster in a less viscous fluid. Viscosity of water increases as the temperature decreases.

Thus, as water decreases in temperature, the twin effects of increased density and increased viscosity reduce the settling velocity of particles. While the effect of temperature on density and viscosity is not very great (a modest increase of between 1% and 5 %), neither is the difference in specific gravity between particles and water.

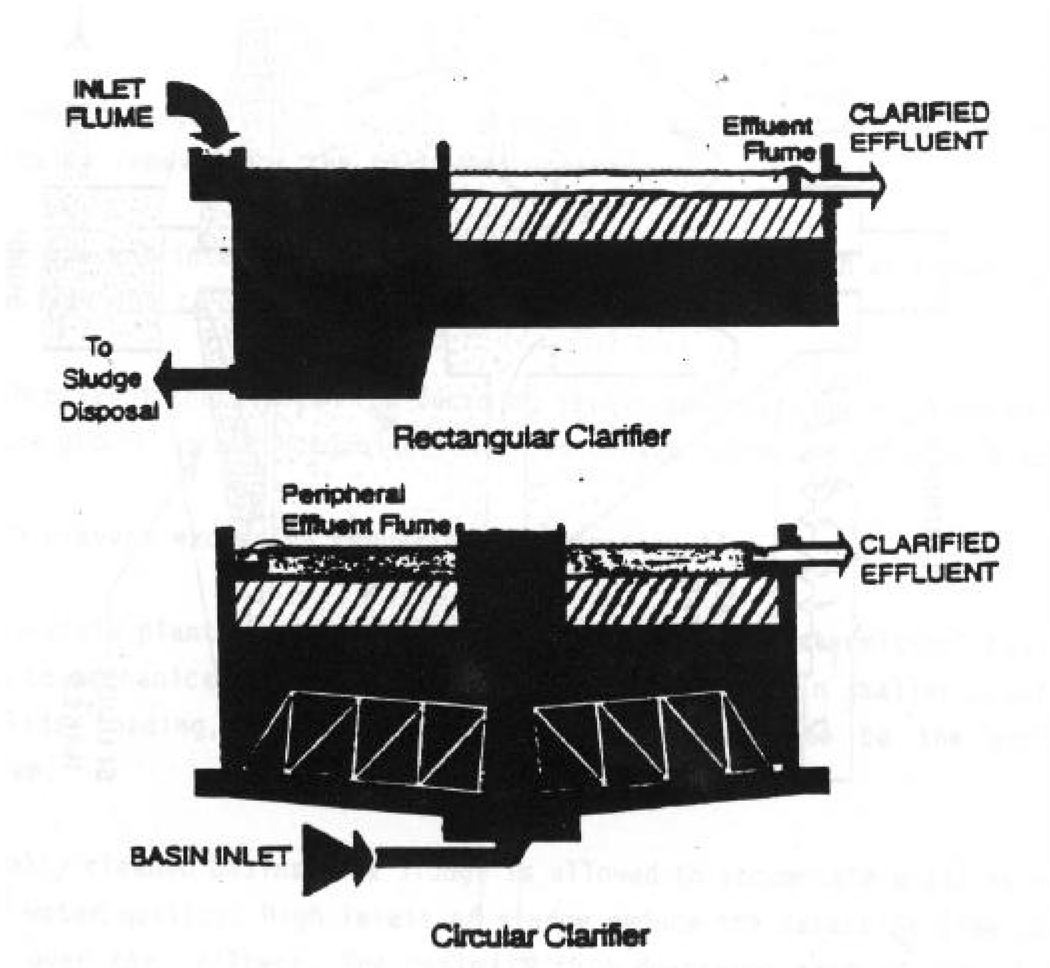
The specific gravity of sewage ranges from 1.03 to 1.05 for particles of organic matter. Floc particles resulting from alum may have a specific gravity of 1.05 to 1.10.

Therefore, cold water will have a noticeable effect on the settleability of particles. Add to this the effects of turbulence, flow currents, edge effects, and sludge build up in a settling tank; the potential for floc carryover increases greatly.

8.6.5 Clarifiers

Most clarifiers are either circular or rectangular. Beyond that, there is often little difference between the clarifiers of different manufacturers. The choice depends on the design engineer, and the internal mechanical equipment depends on the manufacturer. Figure 8.2 shows the two basic types.

FIGURE 8.2 - CLARIFIERS



8.6.6 Summary

Physical-chemical treatment is a viable method for removing suspended and colloidal particles, as well as phosphorus. If the dissolved fraction of BOD and/or ammonia is to be removed, a fix film process such as a biofilter often follows physical-chemical treatment.

8.6.6.1 Performance Expectations of Physical Chemical Treatment

Characteristics	**Range**
BOD Removal	40 – 60 %%
Effluent PO_4	less than 1 mg/L

8.6.6.2 Advantages vs. Disadvantages of Physical Chemical Treatment

Advantages

- Training required by operators.
- Adaptable to changing loads.
- Not susceptible to process upsets.
- Can be automated and operated remotely.
- Removes phosphorus.

Disadvantages

- Requires a heated building for winter operation.
- Requires constant monitoring by operators.
- Energy intensive.
- Only removes settleable material.

8.7 Biofilters

Biofilters have been used for more than 150 years to treat wastewater. They are a fixed film process that using a biological slime layer to treat wastewater. Such reactors have a long history. The earliest beginnings are traced to England where, in the 1850's, efforts toward sewage disposal, let alone treatment, were virtually non-existent.

In 1858 the Nuisance Removal Act was promulgated to control sewage discharge, primarily to safeguard aesthetics. This emphasis quickly shifted towards disease control, however, following Dr. John Snow's landmark publication on epidemiology the same year. As a result, England organized a series of Royal Committees charged with the study of problems relating to sewage disposal and treatment.

In 1868, Sir Edward Frankland, studied filtration performance on raw London sewage in laboratory columns packed with media ranging from coarse gravel to peaty soil (Kiersted, W., 1984). Although the biofilter's treatment capability was solely credited to physical-chemical means, the associated establishment of the intermittent filtration concept had notably introduced a necessity for resting or aeration periods between sewage applications.

Based on these results, the Royal Commission began to place considerable emphasis on the use of intermittent land filtration. (Buswell, A. M, 1928) In 1871, J. Bailey-Denton initiated the first full-scale operation at Merthyr Tydvil, Wales.

The coarse gravel process was later named a trickling filter. Experimentation continued both in England and in Europe to verify, and to improve, the trickling filter process. In addition to aeration techniques, researched focused on media types as new materials became available.

Biofilters take two forms:

1. A true filter form in which solids are removed from the wastewater mechanically. The filtration media in this case is sand or a similar material with small pores; or

2. A form in which course gravel, or a plastic media supports the biological growth. While particles become imbedded in the biological growth, the media itself provides little mechanical removal of solids. Such a process is also known as a bioreactor.

As a filter, the biofilter is used as a tertiary treatment process to move excess solids, to remove alum floc resulting from chemical phosphorus removal, and/or improve nitrification. Some filters incorporate a granular carbon media to assist in removing dissolved carbon. These filters are generally operated in a downflow mode, and can be maintained either aerobically, or anaerobically. Such filters require periodic backwashing and/or media removal and replacement to maintain flow rates through the filter.

Figure 8.7.1 shows a biofilter operating in a downflow mode.

As a bioreactor, the biofilter is either used as a secondary treatment process (such as a trickling filter) or follows a treatment process as tertiary process. Operated in either an upflow or a downflow mode, the process may be used to remove additional dissolved carbon, and/or perform nitrification/denitrification. During operation, biomass sloughs from the process to settle at the bottom of the reactor vessel. This material must be removed periodically.

Figure 8.7.2 shows a bioreactor operating in an upflow mode. In this example, methanol is used as carbon source to cause the consumption of dissolved oxygen and begin the denitrification process.

8.7.1 Summary

Bioreactors are a recommended technology for the North to provide tertiary treatment where required. They are simple and generally inexpensive to operate.

8.7.1.1 Performance Expectations of Biofilters

Characteristics	**Range**
BOD Removal	80-95%
Effluent Total BOD	10-30 mg/L
Effluent Soluble BOD	5-15 mg/L
Effluent NH_3-N	1-10 mg/L
Effluent NO_3-N	2-7 mg/L

8.7.1.2 Advantages vs. Disadvantages of Biofilters

Advantages

- Little training required by operators.
- Not susceptible to process upsets.
- Can be automated and operated remotely.
- Removes ammonia.

Disadvantages

- Requires a heated building for winter operation.
- Cannot adapt quickly to changing loads.

8.8 Rotating Biological Contactors

The Rotating Biological Contactor is fixed film, support growth system; a modern adaptation of a trickling filter. However, as shown in Figure 8.8.1, instead of wastewater being trickled over media, the media is rotated through the wastewater, thus, exposing the biofilm (slime layer) to oxygen to maintain aerobic conditions.

During the early 1960's, the research division of Allis Chalmers Corporation also investigated the use of rotating discs in various chemical processing applications (Antonie, 1976). Their disc was called a two-phase contactor (TPC), and was tested for applications of gas absorption and stripping, liquid-liquid extraction, liquid-liquid heat transfer, and other mass and energy transfer applications. Eventually, the device was considered for oxygen transfer.

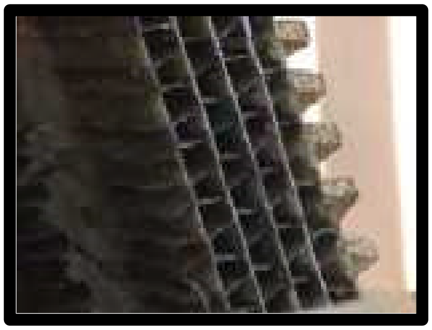
In the summer of 1965, three-foot diameter metal discs were evaluated at the Jones Island treatment plant in Milwaukee, Wisconsin. These units were initially employed for oxygen transfer in an extended aeration process, and then tested without sludge recycle and with an attached biomass (i.e. as a biological contactor).

To confirm the favourable results of these initial tests and to learn more about the treatment process, laboratory tests were subsequently conducted using a synthetic dairy waste and 3-foot diameter aluminum discs.

After learning of the European activities, Allis-Chalmers reached a licensing agreement in 1968 with the German manufacturer for production and sales distribution in the U. S. The treatment process was marketed under the trade name Bio-Disc. The first commercial installation in the U. S. went into operation at a small cheese factory in 1969. (Birks and Hynek, 1971).

In 1970, Allis-Chalmers sold its rotating biological contactor technology to Autotrol Corporation. At that time, polystyrene discs were not competitive with the activated sludge process, due to the high capital cost of plastic. However, in 1972, Autotrol developed new rotating contactor media constructed from corrugated sheets of polyethylene.

Until then, (Smith and Bandy, 1980) the RBC unit consisted of a series of parallel, flat 0.5 inch thick expanded polystyrene sheets, each separated by a 0.75 inch space. The new arrangement used 1/16 inch thick polyethylene sheets with a 1.2 inch space.



At much the same time (i.e. early 1950's) that the West German researchers began exploring plastic RBC's, American investigators at Dow Chemical Company were initiating their experiments with the production and use of plastic packing media. (Bryan, E. H, 1955)

Two initial plastic units were devised at Dow including a modified 'berl-saddle' (trademarked as Dowpac FN-90) and bundled arrays of nested, corrugated sheets (trademarked as Dowpac HCS). Dow subsequently reassigned the Dowpac term, substituting it with 'Surfpac', now a well known product.

Now the RBC is well known and manufactured in various forms by different companies. The basic principals of the process remain the same.

In the North, RBC's were tested at Little Chicago in the early 1970's and at the Yellowknife Airport in 1979. Since that time RBC's have found application at exploration and work camps for mines, and for oil and gas.

8.8.1 Discussion

Rotating Biological Contactors (RBCs) can be used for domestic and biodegradable industrial wastes. They are a secondary biological treatment process that use a rotating shaft surrounded by plastic disks or "media". The shaft and media together are considered the "drum". Biological slime grows on the surface of the media under suitable conditions. It is rotated into the settled wastewater and then the atmosphere to provide essential oxygen for the organisms. The wastewater flows parallel or perpendicular to the shaft.

The media are constructed of high-density plastic circular sheets that are usually 3.6 metres in diameter. The sheets are bonded and compiled onto horizontal shafts up to 7.5 metres in length. The spacing between the sheets provides the gap for distribution of wastewater and air.

The RBC process uses several media drums. The wastewater is held in concrete or coated-steel tanks that are generally shaped to match the shape of the media. The shape prevents dead spots where solids could settle out and cause odours and septic conditions. The media rotate at approximately 1.5 RPM with two-fifths being constantly submerged in the wastewater.

The media pick up a thin layer of wastewater as it rotates. The wastewater flows over the slimes on the discs which feeds the organisms that live on the discs. The organisms use the organic matter from the wastewater and dissolved oxygen from the air. This removes wastes from the water being treated.

Some of the slimes are sloughed from the media as they rotate downward into the wastewater. The effluent and the sloughed slimes travel to the secondary clarifier where settling removes the slime.

Usually the RBC process is divided into four stages. A removable baffle, concrete wall or cross-tank bulkhead separate each stage. As previously mentioned, wastewater flow is either parallel or perpendicular to the shaft.

This is dependent on whether there are less or more than four shafts required, respectively. Wastewater flows between stages through a hole or orifice in each bulkhead or baffle. Every section of media between bulkheads acts as a separate stage of treatment.

The effectiveness of a given amount of media surface area is maximized through staging. The first stage media's organisms are introduced to high levels of BOD and thus reduce it at a high rate. From stage to stage, the BOD decreases and so does the rate at which the organisms work. This is where nitrification starts.

Even when installed in a building, RBCs are covered. They generally have a fiberglass cover that is shaped like the media and can be removed for maintenance. The reasons for having the cover are:

- To keep additional heat in the wastewater to improve the removal efficiency of the biological slime; and
- To reduce the humidity in the building.

8.8.1.1 Performance Expectations of RBC's

Characteristics	**Range**
Hydraulic Loading	
BOD Removal	1.5-6 GPD/sq ft
Nitrogen Removal	1.5-1.8 GPD/sq ft
Organic Loading	
Soluble BOD	25-4 lbs BOD/day/1000 sq ft
BOD Removal	80-95%
Effluent Total BOD	10-30 mg/L
Effluent Soluble BOD	5-15 mg/L
Effluent NH_3-N	1-10 mg/L
Effluent NO_3-N	2-7 mg/L

8.8.1.2 Advantages vs. Disadvantages of RBC's

Advantages

- Little training required by operators.
- Adaptable to changing loads.
- Not susceptible to process upsets.
- Can be automated and operated remotely.
- Can be designed as a mobile package treatment system.

Disadvantages

- Requires a heated building for winter operation.
- Requires constant monitoring by operators.
- Cannot adapt quickly to changing loads.
- Energy intensive.

9. Treatment, Handling, and Disposal of Sludge

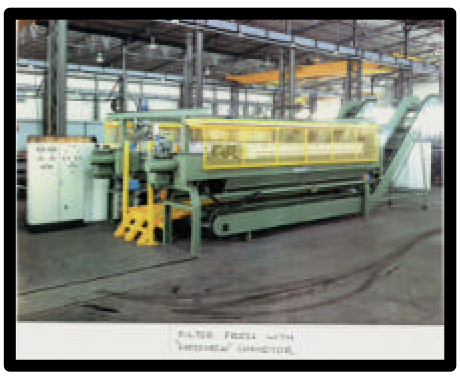
9.1 Background and Terminology

The term sludge is used to designate the solids within a sewage treatment process.

The *HarperCollins Dictionary of Environmental Science* defines sludge as a "viscous, semisolid mixture of bacteria- and virus-laden organic matter, toxic metals, synthetic organic chemicals, and settled solids removed from domestic and industrial waste water at a sewage treatment plant." Over 60,000 toxic substances and chemical compounds can be found in sewage sludge, and scientists are developing 700 to 1,000 new chemicals per year.

World-wide, the treatment and disposal of sewage sludge is a very large problem with millions of tonnes generated each year. Microbes and viruses are the biggest concern. As discussed in a following section, one of the most economical ways to dispose of sludge is to incorporate it into the land. This has been done for millennia in other countries. However, in industrialized countries, industrial waste is also mixed with domestic sewage. Household hazardous waste also contributes to the contaminant loading. Such a mixture concentrates contaminants in the sewage treatment process.

To improve the public acceptability of this economical form of disposal, in North America sewage sludge has been more recently renamed as, “biosolids” or, “bioresiduals”.



This report does not adopt this new terminology. The acceptance of sewage disposed on the land should be a result of its merits and not as a result of sanitized terminology.

Proponents and the public should always be aware of the product and the potential with which they deal.

Generally in the North, the small amount of industrial waste and largely domestic use of sewage treatment processes means that many of the synthetic contaminants are not present in the waste stream. However, sludge cannot be considered pathogen free unless a proven pathogen destruction process is applied.

9.2 Sludge Nomenclature

Sludge is the general term to describe the solid materials remaining and/or developed during solids separation in the treatment of liquids. With respect to sludge treatment, the following terms apply:

Raw or Primary Sludge is sludge from primary clarification, primary lagoons, and septic systems. It is a mixture of faecal material, and other organic and inorganic solids that have settled from the sewage. In this form it is generally considered to be untreated.

Activated Sludge is a growth of microorganisms, also known as mixed liquor, which has developed during biological treatment in a mechanical process. Such processes are described in a following section of this report.

Secondary Sludge (also called waste activated sludge) is activated sludge withdrawn from the treatment process in secondary settling tanks for disposal.

Chemical Sludge is raw or secondary sludge that has been treated with chemicals to improve settling and/or to improve the removal of a parameter of concern typically phosphorus.

Digested Sludge is raw and/or secondary and/or chemical sludge that has been treated in an aerobic or anaerobic digester to reduce its organic carbon content to below 60%, and is now prepared for disposal.

Lagoon Sludge is the sludge removed from the bottom of a lagoon (generally single cell or a secondary lagoon). Such sludge requires additional treatment.

Thickened Sludge is sludge that has been processed either mechanically or chemically to reduce its water volume (typically to about 10% solids or greater)

Dewatered Sludge or **Sludge Cake** is sludge that has been processed to remove the majority of the water.

9.3 Sludge Treatment

Three treatment methods exist:

- Aerobic
- Anaerobic; and
- Landfarming.

Aerobic treatment is generally associated small amounts of the sludge from mechanical treatment. Sludge is held in a warm vessel where it is aerated to ensure mixing and oxygenation. Generally, aerobic sludge digestion takes from 30 to 60 days.

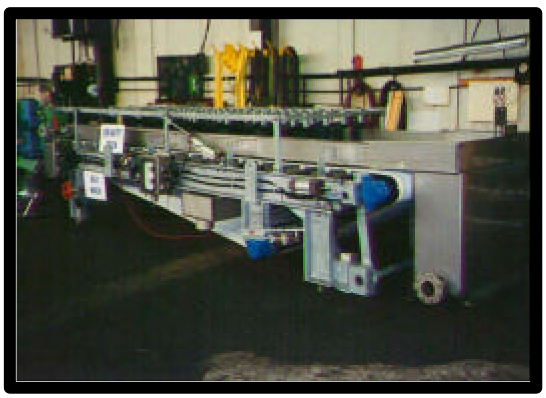
Anaerobic treatment is generally associated with large amounts of the sludge from mechanical treatment plants. Sludge is held in an enclosed vessel which is heated to increase the rate of decomposition. Generally, anaerobic sludge digestion takes from 10 to 14 days.

Landfarming is a form of composting where sludge is discharged to a land area where it is tilled into the soil. The soil may require additional tilling to speed and/or encourage treatment. Landfarming is also often used as a disposal method. This cannot be done on land that may be used for food crops.

Natural Biological Degradation occurs when sludge is left in a lagoon for extended periods of time. The process is temperature dependant, however, and takes a very long time.

Freeze Thaw Conditioning is a process used to dewater volumes of sludge, thus reducing the volume to be disposed. Freeze-concentration is the primary process mechanism. Sludges can be placed in thickness of one metre and left to freeze. Once thawed it will dewater and once de-watered to a large extent will not absorb additional water. The water discharged from the sludge should be collected and retreated prior to disposal.

9.4 Sludge Handling



Sludge is a noxious and odorous material. Most handling involves maintaining the sludge in closed vessels while it is moved from the process to a sludge treatment unit. Any sludge spill must be dealt with immediately. Public health and damage to watercourses are the primary consideration.

All sludge processes require specialized training for operators. All operators must be properly immunized.

Anaerobic treatment processes are regulated by NWT & Nunavut Workers Compensation Board and require a qualified stationary engineer to oversee the operation.

9.5 Sludge Disposal

Disposal options include:

- Disposal on land;
- Landfill in sludge cells at the solid waste management site; and
- Incineration.

The sewage treatment process removes contaminants from the liquid and incorporates them into the sludge. Sludge treatment further concentrates the contaminants. Depending on the amount of a contaminant entering the waste stream, the contaminant may reach a concentration so that the sludge must be treated prior to disposal.

The Guidelines for the Abandonment and Reclamation of Sewage Lagoons in the Northwest Territories, prepared by MACA, Government of the Northwest Territories, in 1999 outlines various treatment options for contaminated lagoon sludges. Depending on the sludge, process methods could be extended to sludges from mechanical systems.

9.5.1.1 Summary of Disposal Methods

Method	Characteristics	Limitations	CCME Application
Landfarming	**Location:** on-site or off site **Function:** Treatment of soils for organic carbon, some hydrocarbons. Sludge stabilization. Plant uptake will reduce nutrient concentrations. **Possible Residuals/ Transformation Products:** none	Temperature dependant. Highly permeable soils may be subject to groundwater contamination. pH, metals and organic compounds are considerations.	Generic, Background, Risk Management
Landfilling in Sludge Cells	**Location:** On-site **Function:** Storage of sludge **Possible Residuals/ Transformation Products:** None	Results of Leachate Testing	Risk Management
Incineration	**Location:** off-site (in plant) **Function:** sludge treatment and volume reduction **Possible Residuals/ Transformation Products:** toxic metals in clinker, fly ash and stack gas	Access to an incinerator, fuel costs, stack gas emissions, clinker disposal. Water in matrix raises costs.	Generic, Background.

9.6 Minimization and Prevention of Sludge Contamination in Design

The design of a new sewage treatment facility should incorporate an environmental assessment to compliment the implementation of good engineering practice. Such a procedure can prevent sludge contamination and in the future, site remediation. Following is a list of items to be considered which may prove to be a useful checklist in proposed designs.

- Implementation of raw sewage quality bylaws to prevent accumulation of metals, hydrocarbons, and other contaminants that would render the sludge toxic;
- Separation of storm and sanitary sewers;
- Where groundwater or surface water influence is a concern, low permeability soils or liners, cut-off ditches or diversion channels to prevent contamination by the lagoon seepage or contamination of the lagoon with surface or groundwater;
- Recognition of potential area sources of pollution, the surface or groundwater discharge from which may bring contaminated wastes and agricultural residues;
- Recognition of former waste disposal sites which may contribute contaminated groundwater to the lagoon;
- Recognition of potential aerial deposition from adjacent land uses;
- Isolation of the lagoon from surface runoff to prevent flooding and wide spreading of contaminants; and
- The use of primary lagoons to minimize the spread of raw sewage solids and reduce bioaccumulation potentials.

9.7 Minimization and Prevention of Sludge Contamination in Operation

Good practice in design is only the first step in prevention of sludge contamination. Sewage sludges can become contaminated despite the best design. Following is a list of items to be considered for operation that should be incorporated into any maintenance management system.

- Continuing enforcement of raw sewage quality bylaws;
- Identification and mitigation of new contaminant sources;
- Good operating and maintenance procedures including procedure measures for loss prevention;
- Groundwater monitoring;
- Emergency planning for accidental discharges to, or from, the lagoon;
- A lagoon sludge quality monitoring program to predict when sludge may become unsuitable and should be removed before further bioaccumulation takes place; and
- A continuing public education program to minimize the disposal of contaminants to the sewage lagoon.

9.8 Sludge Accumulation

Lagoons accumulate deposits of sludge from primary sedimentation of settleable solids and from the settling of bacterial and algae cell mass. In warm temperate climates nearly all the organic fraction of the sludge is converted to gaseous products through both aerobic and anaerobic processes. In contrast, in the north sludge tends to accumulate. The accumulation rate appears to be a function of latitude (average ambient temperature). The rate can actually exceed the rate of solids input. This is because the lagoons are generally operated in a fill-and-draw mode and discharged in the fall. As a result algae and bacteria die in the cold water, settle and are retained.

Higo[5] (1965) observed a rate of 0.08 m^3/person/year in four lagoons in Alberta.

Grainge *et al*[6] (1973) reported accumulation of 0.10 m^3/person/year after five years of operation in Hay River.

Dawson[7] reported sludge accumulation of 0.13 m^3/person/year in Niven Lake in Yellowknife.

Clark *et al*[8] (1970) reported that rates in Alaska varied from 0.09 to 0.14 m^3/person/year.

9.9 Sewage Sludge Quality

Prior to the twentieth century, indoor plumbing was an almost unheard-of luxury. Common people used outhouses, while the wealthy used a primitive indoor system -- bedpans, which were carried away by servants. In either case, the waste ultimately returned to the soil near its point of origin. In traditional, agricultural societies, human waste was prized as a prime ingredient in what the Chinese called "night soil" -- artfully composted, high-grade fertilizer.

Things changed with the industrial revolution, which brought people together in congested cities, far away from farmlands, where composting and recycling were no longer practical. Open ditches and gutters were dug to carry sewage from city streets into nearby bodies of water. When populations were small and water supplies seemed unlimited, the wisdom of using fresh water as a vehicle and receptacle for human waste was not questioned. By the 1920s and 1930s, large cities were piping large quantities of untreated sewage into rivers and

[5] Higo, T. T. A study of the operation of sewage lagoons in the province of Alberta. Division of Sanitary Engineering, Department of Public Works, Government of Alberta, 1965.
[6] Grainge, J. W., R. Edwards, K. R. Heuchart, and J. W. Shaw. Management of Waste from Arctic and Sub-arctic Work Areas. Task Force on Northern Oil Development. Report No. 73-19, Environment Canada, 1973.
[7] Dawson, R. N. Lagoon Treatment in the Mackenzie District, Northwest Territories. Division of Public Health Engineering, Department of National Health and Welfare, Canada, 1967.
[8] Clark, S. E., H. J. Coutts, and R. Jackson. Alaska Sewage Lagoons. Federal Water Quality Administration, Alaska Water Laboratory, College, Alaska, 1970.

oceans, creating serious pollution problems. Thousands of industries were also producing chemical wastes which required disposal.

In hindsight, the environmentally sound approach would have been to develop separate treatment systems for human and industrial waste. Biological wastes could have been recycled through a system that returned their nutrients to the soil, and businesses could have been required to separately treat their chemical wastes on-site so that they could be contained and re-used within the industries from which they came. At the time, however, it seemed easier and cheaper to simply dump everything into a single common sewer system.

For businesses, the system provided tax-based aid to help them dispose of their toxic byproducts. The problem with this system, however, is that, where industrial/commercial waste or irresponsible practices exist, the system collects, mixes, a wide range of toxic materials which are then very difficult, to re-separate and detoxify. In the sewage lagoon, heavy metals and other compounds accumulate in the sludge, a result of sedimentation and bioaccumulation by bacteria and algae. Sludge can become contaminated to such an extent that the sludge becomes toxic.

Ontario recognized this problem more than twenty years ago as larger cities struggled with their ability to dispose of their ever-increasing and increasingly more toxic sludge. Ontario's MISA (Municipal-Industrial Strategy for Abatement) Program targeted wastewater discharges from industry to reduce the volume of contaminants in the waste stream.

In the North, a reduced level of secondary and tertiary industry will result in sludge that is potentially not as contaminated. However, contamination can occur from spills, irresponsible activities, and ignorance. In Yellowknife, mercury and arsenic contamination of the Niven Lake sewage lagoon sludge also occurred from aerial deposition from the local mines.

A study of the Edzo lagoon showed the following results based on CCME and RWED Guidelines in 1994:

Parameter* * 1994 Levels	**Edzo Sludge Conc. (ppm)**	**Agricultural**	**Residential / Parkland**	**Commercial/ Industrial**
Mercury	1.85	0.8	2	10
Copper	337	150	100	500
Acetone	1.28			
Methylene Chloride	5.12	0.1	5	50
2-Butanone (MEK)	0.44			
1,3 Dichlorobenzene	1.72	0.1	1	10
Total Petroleum Hydrocarbons	6590			2500
Ethylbenzene	0.04	0.1	5	50
Toluene	99.2	0.1	3	30
Xylenes	0.24	0.1	5	50

In Edzo, commercial/industrial sources were limited to two sources, the DOT maintenance yard and the DPW maintenance shop. The sludge was contaminated with heavy metals, solvents, and petroleum products. Household hazardous wastes may have an influence.

In addition to engine and oil wastes, copper results may be linked to corrosive water affecting plumbing fixtures. There, however, were no readily identifiable sources of mercury in Edzo.

1,3 Dichlorobenzene is a constituent in commercial disinfectants and cleaners used in schools and hospitals.

Despite the development of sewage quality guidelines by RWED[9] and the development of a model bylaw adopting these guidelines by MACA, no community in the NWT has adopted sewage quality guidelines[10].

Under a land use permit, MACA did impose these guidelines upon a tannery operation to protect a municipal sewage lagoon. However, the frequency with which sewage quality guidelines are used in the North is low and highlights a continuing concern.

[9] Guideline for Industrial Waste Discharges

[10] The Town of Hay River planned to adopt sewage quality guidelines to deal with wastewater from an abattoir, however, the abattoir failed in the concept stage and the guidelines were not adopted.

10. Summary

Eight BATT processes for domestic sewage have been discussed including:

1. Activated Sludge – Extended Aeration;
2. Sequencing Batch Reactors;
3. Lagoons;
4. Wetlands and Overland Flow;
5. Membranes;
6. Physical-Chemical Treatment;
7. Biofilters; and
8. Rotating Biological Contactors.

Each process has its advantages and disadvantages ranging from the cost to build and operate the process, to the amount of land used. Table 10.1a and 10.1b summarize these advantages and disadvantages.

The application of a process to a particular situation is an engineering judgement based on:

- The effluent quality required for the receiving environment;
- The availability of land and future land use;
- Sustained access to trained operators; and
- The cost to build and operate the process.

Table 10.2 follows which summarizes performance expectations.

The generation of treatment process residuals (sludge) are important a consideration as the treatment process itself. Sludge treatment can account for up to 50% of the cost of sewage treatment. Sewage treatment processes and their liquid discharges must not be considered in isolation from their sludge, or the potential for and impact of contaminated sludge.

Table 10.1a --Advantages vs. Disadvantages

	Advantages	Disadvantages
Activated sludge-Extended Aeration	❑ No expensive equipment required. ❑ Minimum training required by operators. ❑ Provides equal or superior treatment to the conventional activated sludge process. ❑ Adaptable to changing loads. ❑ Most trouble-free activated sludge treatment process. ❑ Creates little waste sludge	❑ Requires a heated building for winter operation. ❑ Can have high suspended solids in the effluent. ❑ Requires constant monitoring by operators. ❑ Energy intensive.
Sequencing Batch Reactors	❑ Provides equal or superior treatment to the conventional activated sludge process. ❑ Adaptable to changing loads. ❑ Can be automated and operated remotely. ❑ Effluent quality can meet general conditions of the Fisheries Act	❑ Requires a heated building for winter operation. ❑ Requires constant monitoring by trained operators. ❑ Energy intensive.
Lagoons	❑ No expensive equipment required. ❑ Minimum training required by operators. ❑ Provides equal or superior treatment to some conventional processes. ❑ Economical Construction. ❑ Adaptable to changing loads. ❑ Consumes little energy. ❑ Serves as a wildlife habitat. ❑ Increased potential design life. ❑ Few sludge handling and disposal problems. ❑ High levels of microorganism reduction. ❑ Most trouble-free treatment process	❑ Can emit odours. ❑ Large land requirement. ❑ Waste treatment efficiency based on weather. ❑ Can possibly contaminate groundwater. ❑ Can have high suspended solids in the effluent
Wetlands & Overland flow	❑ No expensive equipment required. ❑ Minimum training required by operators. ❑ Provides equal or superior treatment to some conventional processes. ❑ Economical Construction. ❑ Adaptable to changing loads. ❑ Consumes no energy. ❑ Serves as a wildlife habitat. ❑ Increased potential design life. ❑ Few sludge handling and disposal problems. ❑ High levels of microorganism reduction. ❑ Can meet general conditions of the Fisheries Act.	❑ Can emit odours. ❑ Large land requirement. ❑ Waste treatment efficiency based on weather. ❑ Spring discharges may exceed effluent criteria. ❑ Can contaminate groundwater. ❑ Can have high suspended solids in the effluent

Table 10.1b -- Advantages vs. Disadvantages

	Advantages	**Disadvantages**
10.1 Membranes	❑ Minimum training required by operators. ❑ Adaptable to changing loads. ❑ Not susceptible to process upsets. ❑ Few sludge handling and disposal problems. ❑ Can meet general conditions of the Fisheries Act. ❑ Can be automated and operated remotely. ❑ High levels of microorganism reduction.	❑ Requires a heated building for winter operation. ❑ Requires constant monitoring by operators ❑ Energy intensive.
Physical-Chemical Treatment	❑ Training required by operators. ❑ Adaptable to changing loads. ❑ Not susceptible to process upsets. ❑ Can be automated and operated remotely. ❑ Removes phosphorus.	❑ Requires a heated building for winter operation. ❑ Requires constant monitoring by operators. ❑ Energy intensive. ❑ Only removes settleable material
Biofilters	❑ Little training required by operators. ❑ Not susceptible to process upsets. ❑ Can be automated and operated remotely. ❑ Removes ammonia	❑ Requires a heated building for winter operation. ❑ Cannot adapt quickly to changing loads.
Rotating Biological Contactors	❑ Little training required by operators. ❑ Adaptable to changing loads. ❑ Not susceptible to process upsets. ❑ Can be automated and operated remotely. ❑ Can be designed as a mobile package treatment system	❑ Requires a heated building for winter operation. ❑ Requires constant monitoring by operators. ❑ Cannot adapt quickly to changing loads. ❑ Energy intensive

Table 10.2 -- Performance Expectations

	BOD_5 removal	Effluent BOD_5 Soluble	Effluent BOD_5 Total	Ammonia	Phosphorus	Nitrifiction to NO_3-N	Percent Removal of Coliforms	Total Suspended Solids
Extended Aeration	Up to 95%	< 10-15 mg/L	< 40 mg/L	Can reach < 2 mg/L	some	Can reach 100%	90-95%	Up to 90%
Sequencing Batch Reactors	Can exceed 95%	Can reach <2-5 mg/L	Can reach <5-10 mg/L	Can reach < 2 mg/L	Can reach <1 mg/L	> 90%	> 99%	Can exceed 95%
Lagoon 50-60 days	70-80%				some	some	90-95%	----
Lagoon 180 days	85-95%			Can reach < 2 mg/L	some	85-95%	Up to 99%	85 –95%
Wetlands and Overland Flow	97% to 99%	2-5 mg/L	2-5 mg/L	Less than 1 mg/L	>90%	Can reach 100%	> 99%	97% to 99%
Membranes	80-95%	2-5 mg/L	2-5 mg/L	Less than 1 mg/L	>90%	95%-97%	> 99%	80-95%
Physical-Chemical treatment	40-60%				<1 mg/L		90-95%	40-60%
Biofilters	80-95%	10-30 mg/L	5-15 mg/L	1-10 mg/L	some	2-7 mg/L	> 99%	80-95%
Rotating Biological Contactors	80-95%	5-15 mg/L	10-30 mg/L	1-10 mg/L	some	2-7 mg/	> 99%	80-95%