SECTION 3.0
EXPERIENCE ELSEWHERE

3.1 PREAMBLE

This section provides an overview of the application of nitrification and nutrient removal technology in municipal wastewater treatment plants and the regulatory background for the application of these technologies in Canada, the USA and elsewhere in the world.

3.2 NITRIFICATION TECHNOLOGY REVIEW

3.2.1 Canada

In general terms, nitrification technology has not been widely applied across Canada. Nitrification is not required for discharges to the marine environment. The most powerful piece of legislation requiring the nitrification of municipal wastewaters is the Fisheries Act (1985), which prohibits the discharge of "deterious substances" in fish bearing waters. Environment Canada chooses to define deleterious substances in large part by means of the whole effluent test, i.e., without dilution by the receiving water. However, most municipal wastewater treatment plants operate under discharge permits issued by the Environment Department of the provincial government. Many of these plants have not been required to remove ammonia because the regulatory body allows the determination of toxicity of treated wastewater to be made at the boundary of the initial mixing zone (i.e., after dilution) rather than in the undiluted effluent. However, in recent years, several provincial Environment Departments have become increasingly concerned about ammonia toxicity and the additional nutrient (primarily nitrogen and phosphorus) loading associated with treated municipal effluent discharged to surface waters. In several large population centres, the cost of nitrification is prohibitive, and thought to outweigh the benefits to the receiving environment. For these reasons, it is useful to examine the current application of nitrification and nutrient removal technologies in a number of Canadian provinces.

British Columbia

Approximately 70 percent of the population of British Columbia live in two population centres – the Lower Mainland and Greater Victoria. Municipal wastewater from the City of Victoria receives medium screening only prior to being discharged through ocean outfalls to the Juan De Fuca Strait. The Greater Vancouver Regional District (GVRD) operates four large wastewater treatment plants and one smaller plant. Two of the larger plants, the Annacis Island WWTP and the Lulu Island WWTP, discharge into the lower reaches of the Fraser River and were recently upgraded to secondary treatment using the trickling filter/solids contact (TF/SC) process. At this time, neither of these plants is required to nitrify although provision was made at both sites for the installation of tertiary nitrifying trickling filters (NTFs) should nitrification be required at some future date. The cost of upgrading the Annacis Island WWTP in the future to nitrification has been estimated at $100 million. The other two large GVRD plants, the Iona Island WWTP and Lions Gate WWTP, provide primary treatment only prior to discharge of the effluent through ocean outfalls to the Georgia Strait. The North West Langley WWTP consists of aerobic lagoon pretreatment followed by rotating biological contactors (RBCs), and discharges a non-nitrified effluent to the Fraser River. There are a number of smaller secondary wastewater treatment plants serving Vancouver's satellite communities (Abbotsford, Aldergrove, Chilliwack), but these are not designed for nitrification. The Agassis WWTP is a sequencing batch reactor (SBR) process designed for biological nutrient removal (BNR). The Whistler, James (Abbotsford-Matsqui) and Prince George WWTPs are TF/SC processes that are not designed for nitrification.

Medium sized communities on Vancouver Island (Courtney-Comox and Campbell River have activated sludge plants that are not designed for year round nitrification. The Nanaimo WWTP provides only primary treatment prior to discharge to the Georgia Strait.

The plants serving communities in the Okanagan Valley of Central British Columbia which discharge directly into the Okanagan Lake System (Kelowna, Westbank, Penticton, Summerland, Lake Country) are required to meet extremely stringent effluent standards with regard to BOD, TSS, total nitrogen and total phosphorus concentrations, and faecal/total coliforms. These plants are BNR activated sludge plants designed for year-round nitrification, denitrification, biological phosphorus removal and effluent disinfection. The Vernon WWTP is a non-nitrifying trickling filter plant, and Oliver has a series of aerated lagoons designed for BOD and TSS removal only. Effluent from these plants is spray irrigated on agricultural land under controlled conditions. The Salmon Arm WWTP is a modified TF/SC process designed for nitrification and biological phosphorus removal.

Alberta

The four largest cities in Alberta (Calgary, Edmonton, Red Deer and Lethbridge) are all in the process of upgrading their activated sludge wastewater treatment plants for nitrification (effluent ammonia limit of 5/10 mg N/L in summer/winter), phosphorus removal, and effluent disinfection.

In Calgary, the Bonnybrook (air activated sludge) and Fish Creek (HPO activated sludge) WWTPs have been required to remove phosphorus to below 1.0 mg/L since the early 1980's. This limit was initially met using chemical phosphorus removal with alum addition. In the late 1980's, the City was required to meet seasonal nitrification at the Bonnybrook WWTP, and embarked on a program to retrofit the entire plant to biological nutrient removal in three stages. This program is in its final stages of completion. At this time, the smaller Fish Creek WWTP is not required to be upgraded for nitrification.

The City of Edmonton has a program in place to achieve the future effluent requirements by 2005 using BNR technology. Pilot and demonstration scale testing was carried out in 1995/96, and two new BNR modules and a primary sludge fermenter were recently constructed at the Gold Bar WWTP. The existing eight activated sludge modules will be retrofitted to BNR in the next three years. The Capital Region Sewage Commission is about to initiate a program to upgrade its activated sludge plant to BNR to meet the new requirements for nitrification, phosphorus removal and effluent disinfection by 2005.

The Red Deer and Lethbridge WWTPs have recently been retrofitted to BNR to meet the meet the requirements for nitrification, phosphorus removal and effluent disinfection.

The Medicine Hat WWTP is a TF/SC process with chemical phosphorus removal. There is no established plan for upgrading the plant for nitrification.

Saskatchewan

The plants in Saskatoon and Regina are required to achieve phosphorus removal to an effluent concentration below 1.0 mg/L, but not nitrification. The Saskatoon WWTP is a BNR process. It is now operated in a nitrifying mode because the operators have found that this mode is more stable than when the plant is operated for biological phosphorus removal without nitrification. The Regina WWTP consists of a series of aerated lagoons followed by tertiary chemical phosphorus removal.

The recently commissioned Prince Albert WWTP is an activated sludge plant designed for BOD and TSS removal only. Moose Jaw has a series of lagoons with chemical phosphorus removal and effluent spray irrigation. The Yorkton WWTP is a conventional activated sludge process that achieves nitrification. There are also several smaller communities that are served by large lagoon systems in which the treated wastewater is stored and discharged at non-critical times.

Manitoba

Outside of the City of Winnipeg, Brandon has a sequencing batch reactor process (SBR) process designed for nitrification. Maple Leaf Foods in Brandon has a new anaerobic process followed by an activated sludge process designed for nitrification and denitrification. The Portage la Prairie WWTP is an SBR process designed for nitrification. The Brandon and Portage la Prairie plants discharge into the environmentally sensitive Assiniboine River and may be required to achieve phosphorus removal in the future. There are also several smaller communities that are served by large lagoon systems in which the treated wastewater is stored and discharged at non-critical times, e.g. end of May and early November.

Ontario

Metropolitan Toronto operates three large conventional activated sludge plants – the Humber WWTP, the Main WWTP and the Highland Creek WWTP. In-plant chemical addition is used to meet an effluent total P limit of <1.0 mg/L. At this time, none of these plants are required to nitrify as it is believed that the effluent is rapidly dispersed in Lake Ontario. Further, the cost of upgrading the three Toronto plants for nitrification is extremely high, in the order of $500 million.

The four activated sludge plants operated by the Regional Municipality of Waterloo and the Brantford WWTP discharge into the Grand River system and are designed for year round nitrification as a result of concerns about ammonia toxicity in the river.

The activated sludge plant in London discharges into the Thames River and is designed for year-round nitrification.

The Thunder Bay WWTP is in the process of being upgraded, but the new plant upgrade will not include nitrification. The Guelph WWTP is a high rate activated sludge process followed by RBCs for nitrification.

The Green River WWTP in Ottawa is a conventional activated sludge process that is designed and operated for BOD and TSS removal only.

There are several other secondary wastewater treatment plants in Ontario that are designed to meet site specific effluent ammonia and/or total N and total P limits.

3.2.2 USA

Nitrification has been required at various locations throughout the United States over the past 20 to 30 years. During that period discharge regulations have changed, sources of funding for these facilities have changed, and treatment technologies have evolved to respond to these changes. In the early 1970's when nitrification was required primarily to protect minimum dissolved oxygen concentrations in receiving streams, funding was available from the federal government resulting in little pressure to truly optimize treatment facilities. Consequently, nitrification facilities were normally implemented as suspended growth, activated sludge systems, often as a two-stage system. Essentially all nitrifying high purity oxygen activated sludge (HPOAS) plants constructed during the U.S. EPA Construction Grants program were developed in the two-stage configuration.

As the U.S. EPA Construction Grants program monies became unavailable and plant owners were faced with supporting the entire initial cost of treatment facilities, pressures heightened to push processes harder and downsize facilities required to implement nitrification. In addition, more pressure to nitrify was experienced as the U.S. EPA attention turned from implementing secondary treatment across the nation to truly assessing site-specific needs to protect the local receiving stream. Resulting from that change in focus was a broader application of nitrification to avoid in-stream biota toxicity resulting from high unionized ammonia concentrations. During this period, which spanned most of the 1980's and into the early 1990's, many existing plants were faced with requirements to incorporate nitrification into their existing treatment facilities. In an effort to take advantage of the treatment tankage existing at plants faced with such a challenge, designers began to consider higher rate systems for nitrification. More and more single-stage activated sludge systems were built, thereby avoiding the duplication of clarifiers that is an inherent part of a two-stage system. In addition, more focus was centered on utilizing fixed-film systems as a second stage nitrification system. Biotowers and RBCs have been used for this purpose. Their operating simplicity and relative low cost contributed to their popularity, but with simplicity came limited operational control. This technology is still considered today given favorable circumstances, and biotowers are occasionally used today in warmer climates as a second stage nitrification process, particularly where no final clarifiers are required following them. RBCs are not widely applied as they have experienced significant structural and operational problems.

Over the past decade, particularly the past five years, economic pressures and the need to incorporate nitrification, and many times denitrification and phosphorus removal, into plants with extreme site constraints have led to detailed investigation of alternative processes. Recognizing that the key issue for reliable nitrification is achieving the correct minimum sludge age, several activated sludge modifications and combination fixed-film and suspended growth systems have been investigated. The general objective has been to find ways in which additional sludge age can be attained while not dramatically increasing aeration basin volume. These have included the following:

- Step feed, suspended growth activated sludge – step feeding increases the effective sludge age and enables nitrification in a smaller aeration volume.
- Simultaneous suspended and attached growth using a material suspended in the reactor, such as Ringlace, Captor, or Linpor – the suspended material provides a fixed site for biological growth thereby increasing the effective sludge age for a given tankage and enables, allegedly, nitrification in less tankage.
- Tertiary (or second stage) nitrification with attached growth whereby a portion, if not all, of the carbonaceous effluent, prior to solids separation, is passed through a combination suspended and attached growth basin where nitrification takes place.
- Tertiary (or second stage) nitrifying biotowers – traditional biotower technology applied in a nitrification mode operating on clarified effluent from the carbonaceous treatment step. These may be operated without additional clarifiers following them depending upon the quality of the carbonaceous effluent and the final discharge quality objectives.
- Tertiary (or second stage) nitrifying biological aerated filters (BAF) – similar to the trickling filter option above except that BAF technology is used.
- Membrane bioreactor – a process that allows increased sludge age necessary to achieve single stage carbonaceous treatment and nitrification in a relatively small aeration tankage. Microfilter membranes are immersed into the mixed liquor, the process is operated at very high mixed liquor concentrations (up to 15,000 mg/L), and the treated liquid is pulled through the microfilters by pump suction. The membranes effectively replace final clarifiers, filters, and reduces disinfection requirements.

Many of the options listed above are now being designed or constructed for full-scale application. The most traditional approach until the past few years has been to install single-stage nitrifying activated sludge with aeration tankage adequate to achieve the sludge age necessary for nitrifying. There is, presently, a strong move away from this traditional approach toward those processes listed above, with the incentives being primarily cost and plant site constraints.

Typical nitrification technologies applied in the USA include the following:

- New York City is currently upgrading its twelve large wastewater treatment plants for nitrification or biological nitrogen removal using a combination of step-feed nitrifying activated sludge process, tertiary BAFs, and sludge handling return liquor treatment.

- The Blue Plains WWTP in Washington, D.C. uses a 2-Stage activated sludge process designed for nitrification and denitrification with methanol addition.
- The Metropolitan WWTP in Minneapolis/St. Paul is a step-feed nitrifying activated sludge process that is currently being upgraded to biological nutrient removal.
- The three wastewater treatment plants serving the City of Atlanta have recently been upgraded to biological nutrient removal.
- In Florida, extensive use is made of activated sludge processes designed to meet stringent effluent total N and total P standards by biological means.
- The Reno Sparks WWTP uses a Phostrip process followed by NTFs, followed by attached growth denitrification with methanol addition.
- Phoenix has two large single sludge activated sludge plants designed for nitrification and denitrification.
- At the Lake Tahoe WWTP, the original ammonia stripping process proved to be ineffective and was subsequently replaced by a biological nitrogen removal process.
- The Denver WWTP has a nitrifying activated sludge process and a non-nitrifying HPOAS process which are operated in parallel.
- The Boulder WWTP is a TF/SC process followed by NTFs.

3.2.3 Europe

The trend in the United Kingdom (UK) is towards energy efficient, robust processes, which require very little operator attention. The following technologies are commonly used to meet the requirements for nitrification:

Activated Sludge Process

Large works in the United Kingdom with ammonia limits are usually plug flow activated sludge plants. Most of these works have been modified to include anoxic selectors or zones. The aerobic F/M of these works is typically between 0.12 and 0.10. Thames Water has standardised on the 3-stage Bardenpho process while Severn Trent uses a nitrifying activated sludge process with anoxic selectors. There are very few, if any, plants in the UK that are required to meet a total nitrogen limit.

Both surface and fine bubble aeration systems are used. Most new activated sludge plants use fine bubble aeration. There is concern over falling alpha factors because of the use of biodegradable soaps and trade wastes. In these cases, jet aeration and surface aeration are also considered. The depth of aeration tanks has increased significantly. The new aeration tank at Bran Sands is 10 m deep. This works uses jet aeration. Fine bubble aeration has been used at other sites.

Yorkshire Water and North of Scotland Water have relied more on SBRs. These works can be less costly to build because of the simpler civil structures. In some cases, oxygen injection is used to increase the oxygen supply in an activated sludge works. Many small works are oxidation ditches. However, very few new ditches are being built. North West Water has a few Orbal ditches, one of which is at Warrington in the Midlands. Anglian Water operates a few triple ditches which are batch displacement systems. The industry perception is that a flow through process can better satisfy a lower effluent ammonia "never to be exceeded" grab sample requirement than a batch reactor activated sludge works.

Rock Media Trickling Filters

Rock media trickling filters are the predominant form of secondary treatment in the UK. They are robust and require very little operator intervention. The principal disadvantage of rock filters is their large footprint. Combined BOD removal and nitrification is achieved in either filtration or double filtration. The size of the media is graded to 50 mm. Recirculation may be used during the night to keep the filter wet. These filters typically satisfy a seasonal ammonia limit of 5 mg/L in the summer, and 10 mg/L in the winter.

Tertiary nitrifying trickling filters consist of 28 mm mineral media. The BOD concentration of the feed to the filter must be less than 30 mg/L. These filters produce a well nitrified effluent.

Plastic Media Trickling Filters

Plastic media filters are also used for both combined BOD removal and nitrification, and tertiary nitrification processes. Most structured plastic media and some random media is made from PVC. There is concern in the European Union over the manufacture and disposal of PVC. Structured and some types of plastic media filters with recirculation can meet a 5 mg/L effluent ammonia limit. Both splash and curtain wall distributors have been used on these filters.

Random and structured plastic media has been used in nitrifying trickling filters. Yorkshire Water always pilots these filters first because of problems with establishing a stable biofilm with low alkalinity wastewater.

Biological Aerated Filters (BAFs)

Nitrifying Biological Aerated Filters are often added on to the end of carbonaceous removal biofilters or high rate activated sludge processes. Although a reliable process, it has a high capital cost and is more operator intensive than other competing processes.

Other Processes

- Submerged aerated flooded filters (SAFFs) are used for small works (less than 2,000 population equivalent). They consist of flooded, fixed, or random media. The media is scoured by coarse bubble aeration. SAFFs are often used to replace small rock trickling filter works.
- Moving bed reactors use plastic media (e.g. Kaldnes, Captor) that is trapped in a cell of an activated sludge plant.
- Membrane bioreactors are capable of complete nitrification in a relatively small bioreactor without secondary clarifiers. They also produce a disinfected effluent.
- Severn Trent has standardised on the use of RBCs for small works. These are usually followed by reed beds. RBCs can be operated either in parallel or in series.
- Vertical reed beds have been used to nitrify septic effluent at small sites.
- Deep shaft is used at one site where the wastewater is very strong.

Typical nitrification technologies applied in major European cities include the following:

- The large plants serving London are nitrifying activated sludge processes.
- Birmingham has large nitrifying trickling filters.
- Manchester has 2-Stage biological aerated filters.
- Reading has a 2-Stage system consisting of an HPO activated sludge process followed by a nitrifying air activated sludge process.
- A large SBR system designed for nitrification and denitrification is currently under construction in Dublin.
- Paris has 2-Stage biological aerated filters.
- Frankfurt has two large 2-Stage systems consisting of a high rate activated sludge process followed by a nitrifying activated sludge process.
- Copenhagen has a Biodenitro activated sludge process design for nitrification and denitrification.

- Oslo has chemically enhanced primary treatment (CEPT) followed by 2-Stage system consisting of nitrification and denitrification fixed film processes with methanol addition to the denitrification stage.
- Stockholm has SBRs designed for nitrification and denitrification.
- Malmo has a high rate activated sludge process followed by a 2-Stage fixed film system consisting of nitrification and denitrification processes.
- Gotenburg has a high rate activated sludge process with anoxic and aerobic zones followed by NTFs with recycle to the anoxic zone for denitrification.
- Vienna has an activated sludge process designed for nitrification and denitrification.

3.2.4 Asia

Many of the large population centres in Asia are concentrating on the use of compact activated sludge processes designed for nitrification and denitrification. These processes are both continuous flow processes (e.g. Hong Kong, Singapore, Beijing, Shanghai, etc.), stacked sequencing batch reactor processes (e.g. Bangkok), or hybrid attached growth-suspended growth processes (e.g. Japan).

3.2.5 Australia

Many of the larger cities in Australia (Sydney, Melbourne, Brisbane) are using BNR activated sludge plants designed for nitrification, denitrification and biological phosphorus removal.

3.3 REGULATORY TRENDS TOWARDS NITRIFICATION AND NUTRIENT REMOVAL

3.3.1 Preamble

This sub-section summarizes the regulatory environment in various jurisdictions concerning ammonia as a potential toxicant to aquatic life, and nitrogen and phosphorus as growth limiting nutrients that may be responsible for eutrophication in the receiving waters. The current regulatory situation in several jurisdictions is discussed to view how some of them deal with nitrification and nutrient removal requirements. Current regulatory limits for various jurisdictions are included in the summary tables at the end of this section.

3.3.2 Canada

Environment Canada's position on ammonia toxicity is based on Section 36(3) of the Fisheries Act (1985), which states: "No person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish". Environment Canada chooses to define deleterious substances in large part by means of the whole effluent test, i.e. without dilution by the receiving water. Therefore, the need for nitrification is mandated by the Federal Government's stance that compliance of a wastewater treatment plant is based on whether it passes a static bioassay test conducted with whole effluent samples. The criteria is that at least 50 percent of the fish in a static bioassay survive for 96 hours in an undiluted effluent sample. This is termed to be an LC50 of 100 percent. Ammonia in a secondary effluent can cause failure in such a test, often due to the anomalies of the test procedure, in which the effects of pH and temperature on ammonia toxicity are often disregarded.

British Columbia

The new Waste Management Act Municipal Sewage Regulation was published in British Columbia in April 1999. The new Regulation stipulates that the maximum allowable effluent ammonia concentration at the "end of pipe" must be determined from a back calculation from the edge of the initial dilution zone. The back calculation must consider the ambient temperature and pH characteristics of the receiving water and known water quality guidelines.

Furthermore, the new Municipal Sewage Regulation stipulates that a person must not discharge effluent, unless "…the discharge passes a 96 hour LC50 bioassay test defined by the Environment Canada's Biological Test Method, Reference for Determining Acute Lethality of Effects of Rainbow Trout (Reference Method EPS 1/RM/13)". This stipulation does not apply if:

> *"…the discharge is diluted such that at the outside boundary of the initial dilution zone the dilution ratio exceeds 100:1 and the discharger demonstrates to the satisfaction of the manager that the discharge does not adversely affect the receiving environment."*

Further, these requirements do not apply if the discharge is to ground or open marine waters, for maximum daily flows less than 5,000 m^3/d, and for plants achieving an effluent BOD/TSS below 10/10 mg/L.

In other words, in BC, the Ministry of Environment is largely concerned about the toxicity of the treated effluent after initial dilution in the receiving water, rather than the effluent itself. These regulations are therefore less stringent than those of the Federal Government, and several plants in the province are exempt from a requirement to nitrify.

For example, the issue of nitrification was discussed at length during the recent upgrade of the Annacis Island and Lulu Island WWTPs by the Greater Vancouver Regional District. These plants discharge into the lower reaches of the Fraser River, an important fisheries resource. The plants are TF/SC processes designed for BOD and TSS removal only. While the “end of pipe” effluent does not meet the Federal toxicity requirements, its is generally believed that the effluent is non toxic after initial dilution in the receiving water. Because this issue was not fully resolved during the detailed design stage, a compromise solution was reached in which provision was made to include tertiary NTFs at both plants should it become necessary at some future date.

The only plants in British Columbia that are required to achieve a total nitrogen standard for discharge to surface waters are those in the Okanagan Valley, which are required to meet an effluent total N of < 6.0 mg/L. These plants are also required to meet a total P of < 0.25 mg/L on an annual average basis. These requirements have been proven to be technically achievable, and are based on the need to prevent eutrophication in the Okanagan Valley lake system.

Alberta

Alberta Environment is empowered under the Clean Water Act (1980) to prescribe the water contaminants and the maximum concentrations which may be allowed either in a watercourse, or in a discharge to a watercourse, and is required under the Act to control dischargers that might release effluent to a watercourse via permits to construct, licences to operate, and control orders. Regulations pertaining specifically to the permitting and licensing of municipal wastewater treatment facilities also have been promulgated as the Clean Water (Municipal Plants) Regulations (1985). Alberta Environment has issued “Standard Guidelines for Municipal Water Supply, Wastewater and Storm Drainage Facilities”, in which sewage treatment plant standards are listed. The minimum treatment required is based on the environmental impact and economics, as explained in the following document:

> *“The minimum standard for municipal wastewater treatment in Alberta is the provision of best practicable technology (BPT). While consideration is given to surface water quality in the province, the major factor used to establish wastewater treatment levels is the provision of affordable and demonstrated technologies, i.e., BPT. It is recognized, however, that the population and geographic location of a municipality are also significant factors in determining the wastewater treatment requirements, and therefore the definition of BPT must reflect both economics and environmental impact.”*

BPT is defined for communities with populations exceeding 20,000 persons as stabilization lagoons with 12 months storage, aerated lagoons capable of achieving an effluent BOD less than 20 mg/L, or mechanical treatment capable of an effluent BOD and TSS less than 20 mg/L. In addition, Alberta Environment reserves the right to impose requirements for nutrient control and effluent disinfection. Plant operating permits typically define maximum monthly discharge concentrations for prescribed contaminants, and in some cases, maximum loads in terms of mass loads per day, month, or year. Toxicity related criteria have not been applied directly to any municipal wastewater discharges. Effluent total phosphorus and ammonia criteria were first applied at the Bonnybrook Wastewater Treatment Plant in Calgary, although several other municipalities will also be required to control phosphorus and ammonia discharges in the near future.

The Bonnybrook WWTP discharges into the Bow River, which is considered to be one of the best trout fishing streams in North America as well as an important source of potable water for several downstream communities. To protect the Bow River from eutrophication, the plant received the first effluent total phosphorus limit in the Province of Alberta in 1982, which required phosphorus removal to less than 1.0/1.25 mg/L (summer/winter). This limit was eventually tightened to 1.0 mg/L year-round on a monthly mean basis. Almost a decade later, there was concern about ammonia toxicity in the Bow River and nitrification was made a requirement. Requirements for nitrification at the Bonnybrook WWTP were based on negotiations between the City of Calgary and Alberta Environment to develop an acceptable approach to the impact of the treated effluent on the Bow River.

The approach which was utilized in Calgary allowed a mixing zone in the river of 30 percent of the seven day low flow with a ten year recurrence interval (7Q10). Modelling was undertaken to determine the effluent ammonia levels which could be discharged under these conditions and still satisfy the Canadian Water Quality Guidelines at the edge of the mixing zone. In addition to this dilution modelling, dissolved oxygen modelling was undertaken to determine the impact of ammonia discharges in the winter. The oxygen demand associated with in-stream nitrification can cause oxygen depletion in the water course. The current permit for the Bonnybrook WWTP includes limits of 5/10 mg/L (summer/winter) for ammonia nitrogen, on a monthly mean basis. No ammonia limits have been imposed at the City of Calgary's smaller wastewater treatment, the Fish Creek WWTP, which is a high purity oxygen activated sludge process.

The effluent total P limit of 1.0 mg/L, and effluent ammonia nitrogen limit of 5/10 mg/L in summer/winter will be applied in permit renewals at the Edmonton Gold

Bar WWTP, Capital Region Sewage Commission WWTP, Red Deer WWTP, Medicine Hat WWTP and the Lethbridge WWTP by 2005. The result is that by 2010, all communities >20,000, and some communities <20,000 if they are discharging to the Bow River watershed, will be required to meet a total P <1.0 mg/L, an ammonia nitrogen limit <5/10 mg/L, and a $cBOD_5$/TSS limit <20 mg/L in their permits. In the foreseeable future, the effluent limits are not likely to go much below 1.0 mg/L for total P because of the relatively large phosphorus load from agriculture and/or silt in many areas of the province. However with regard to ammonia, Alberta Environment will begin looking at best practicable technologies and is aware that it is possible to do better than 5/10 mg/L ammonia (summer/winter). Therefore, it is possible that the effluent ammonia limits will be lowered to 3/5 mg/L or 3/7 mg/L (summer/winter) in the next round of permit renewals in about 2010. As yet there has been no imposition of effluent total N limits, but this is likely to be considered in the coming decade.

Wastewater discharge permits issued in Alberta are normally based on a monthly average arithmetic mean for all parameters with the exception of faecal and total coliforms, which are based on the use of a geometric monthly mean.

Environment Canada has not played an active role in the development of a regulatory framework to control municipal discharges in Alberta. Alberta Environment regularly corresponds with the federal agency, but does not involve it in the permitting of new or operating wastewater treatment facilities.

Saskatchewan

Regulators in Saskatchewan rely on two documents to set discharges standards for municipal wastewater treatment facilities: The Saskatchewan Surface Water Quality Objectives; and a report published in the late 1970's report by the Canadian Council of Resource and Environment Ministers (CCRME) [Nowadays, it is named the CCME - Canadian Council of Ministers of the Environment]. The original CCRME report recommended a province wide effluent quality standard for total P <1.0 mg/L.

There are no specific ammonia limits in discharge permits for any of the larger wastewater treatment facilities, including those in Saskatoon, Regina, Prince Albert and Moose Jaw. However, because of a fish toxicity concern, Saskatchewan Environment directs owners of the numerous municipal seasonal retention lagoons to refrain from discharging at certain times of the year, i.e., during the fish spawning season, and during period of minimal or no flow in the receiving streams. The Saskatchewan Water Quality Objectives are based on a general objective that discharges should be free from substances which are toxic or may be harmful to aquatic life. However, the concentration of the pollutant is not considered in the effluent itself, but rather can be considered in light of the dilution and assimilation which occurs in the receiving water course.

With regard to effluent total P limits, Saskatchewan Environment sets site-specific limits. For example in the Qu'Appelle watershed which is highly sensitive to phosphorus loading, there is a limit of 1.0 mg P/L on an average annual basis. This is a technology-based requirement because it is believed that current technology is readily capable of achieving 1.0 mg/L. Saskatoon has a 1.0 mg/L total P limit because Saskatchewan Environment believes that the North Saskatchewan River downstream of the City must be protected from eutrophication. Prince Albert, which recently finished an upgrade to secondary treatment, only has to remove $cBOD_5$ and TSS now but may require phosphorus removal in the future.

In the future, the smaller communities that have the seasonal retention lagoons are unlikely to be faced with more stringent discharge standards. However, for larger communities, and particularly for those with mechanical plants, the approach of Best Available Technology (BAT) must be applied. In some cases this may include biological nutrient removal.

Manitoba

In 1988, Manitoba introduced the new Environment Act, which consolidated several existing pieces of environmental legislation. The Act formed two quasi-government bodies responsible to advise the Minister on environmental matters (Manitoba Environment Council) and to solicit public input and recommend appropriate control action to the Minister (Clean Environment Commission). Manitoba Environment and Workplace Safety was empowered by the legislation to act on behalf of the two bodies and to support the Minister in environmental control measures.

Depending on the scope of the project, the environmental impact and licensing criteria for wastewater treatment facilities are established either through an in-house or a public participation process. The Manitoba Surface Water Quality Objectives were developed to provide a baseline with which to evaluate discharges to natural water courses, as summarized in the following quote:

> *"Paramount among the above applications is the utilization of the objectives to develop effluent discharge limitations necessary to make discharge compatible with specific water uses. Many other additional factors are also simultaneously considered while developing effluent discharge limitations. These include, for example, administrative and technological practicalities, allocation of assimilative capacity between existing dischargers, and allocation of a proportion of assimilative capacity*

> *for future growth and development……The water quality objectives should not be construed as permitting any waste amenable to treatment or control to be discharged into any surface water without treatment that can be reasonably be expected."*

Thus, the application of these guidelines are tempered by practicalities, but not to the degree that certain minimum standards for treatment are not satisfied. The limits for municipal effluent discharges typically are assumed to be secondary treatment or its equivalent. The Surface Water Quality Objectives are very specific with regard to ammonia discharges to water courses which sustain aquatic life. Specific ammonia concentrations are allowed at different ambient water temperatures and pH values, in accordance with the approach adopted by the U.S. EPA. In applying these criteria to a water course, a mixing zone concept is allowed. Mixing zone guidelines suggest that it should not exceed 25 percent of the 7Q10 flow, and that no acutely toxic conditions should prevail within the mixing zone.

Ontario

In Ontario there are several items of legislation which govern the discharge of treated wastewater to surface waters. However, only two objectives/guidelines deal specifically with ammonia; the MISA Program and the Ontario Water Resources Act (1990).

The Municipal Industrial Strategy for Abatement (MISA) Program has required a non-toxic effluent at the "end of pipe". This is defined by a 96 hour LC50 for rainbow trout of 100 percent. The MISA Program also defines a 48 hour LC50 for daphnia magna as being acceptable. The MISA program has not been widely followed, principally because of the high cost of retrofitting a large number of high rate plants that were not designed for nitrification.

The Ontario Water Resources Act states that all discharges must be controlled to protect natural water resources and sets out the responsibilities and powers of the Ontario Ministry of Environment in its administration and enforcement of the Act's requirements. A companion document to the Act is Water Management – Goals, Policies and Implementation Procedures of the Ministry of Environment (1984). This document establishes the ambient water quality goals for surface water courses and sets out methods to use in the evaluation of whether the stated objectives can and will be met. The approach to effluent requirements set out in this document is summarized in the following quote:

> *"Every river or lake has a definable dilution, dispersion or assimilation (self purification) capacity for receiving waste discharges. Efficient use of*

this capacity is the key to optimizing water pollution control programs. The emphasis of the Ministry's water quality management program is to set up effluent requirements based on the waste receiving capacity of a waterbody and the Provincial Water Quality Objectives, with consideration also given to the federal or provincial effluent regulations or guidelines and control on non-point sources of pollution."

The Provincial Water Quality Objectives recognize the mixing zone concept, and specify that there be no acute toxicity in the mixing zone. Further, the size of the mixing zone is to be minimized, and in no case is it to replace treatment. The test to be used is the 96-hour static bioassay. However, failure of a bioassay is not taken to mean failure of a discharger to meet its obligations, but rather as an indication that the discharges "may require more rigorous biological testing to determine if additional treatment is required to afford adequate protection of the environment".

With regard to ammonia, the Surface Water Quality Objectives state that the unionized ammonia concentration should not exceed 0.02 mg/L in the mixing zone. The Ontario design standard is based on achieving an effluent un-ionized ammonia concentration of 0.1 mg/L. At the pH and temperature conditions normal for wastewater treatment plants, this translates to an effluent ammonia concentration of 8 to 10 mg/L. Because the daily average is usually about double the monthly average, an effluent ammonia concentration of 4 to 5 mg/L is required. Plants designed to nitrify normally achieve lower effluent ammonia concentrations in the summer. As a result, the design standard is 2 or 3 mg/L in summer, and 4 or 5 mg/L in the winter.

The Ontario Ministry of Environment administers the guidelines through a number of regions. Each region issues a Certificate of Authorization (C of A) for each facility. The C of A is a legally enforceable instrument that the MOE uses to determine compliance. However, there is some degree of inconsistency in the way each region interprets and enforces the guidelines.

The Southwest Region (Thames River and tributaries, plus some others) has been the most stringent in interpreting the guidelines and using them to prepare C of A's. For the past five years or so, they have been using a design objective of 2/3 mg/L (summer/winter) of ammonia nitrogen, with a compliance limit of 3/5 mg/L (summer/winter) at the end of pipe. There is now some consideration being given to a requirement of 0.02 mg/L unionized ammonia concentration.

The Central Region claims to have adopted the same approach in principle but the actual ammonia limit stated in the C of A varies. The East Region also appears to be inconsistent in its approach. The Northern Region claims to take the mixing zone approach, but does not appear to have stringent effluent ammonia standards.

The Federal Government under CEPA has recently listed ammonia as a toxic substance in its assessments. For water quality and acute toxicity purposes, the Federal Government will allow a mixing zone.

It appears as if there will not be significant changes on the part of the Ontario Ministry of Environment with regard to ammonia limits over the next two or three years. The regional districts will have significant independent say in what happens with no common approach among them. However, it may be that the Federal concept of a mixing zone will gain acceptance and be applied across Ontario on a consistent basis.

The three major plants in Metropolitan Toronto discharge into Lake Ontario are not required to nitrify the effluent. The attitude of the Metropolitan government is that it is extremely reluctant to upgrade these plants for nitrification at an estimated capital cost of $500 million until it can be proved that their effluents have a toxic effect on the receiving water.

With regard to effluent phosphorus limits, the typical limit specified in a C of A is 1.0 mg/L for discharge anywhere in the Great Lakes Basin with some local water quality based limits down to as low as 0.15 to 0.3 mg/L. This approach is not likely to change in the foreseeable future. However, in one watershed in the Eastern Region, MOE is "pilot testing" a concept of loading limit trading on a watershed basis. This would include looking at all sources of phosphorus in the watershed including agricultural, storm runoff and municipal wastewater treatment plants.

3.3.3 USA

Section 303 (d) of the Clean Water Act and its accompanying regulations (CFR Part 130 Section 7) requires each state to identify water bodies (i.e., lakes reservoirs, rivers and streams) which are considered to be water quality limited requiring waste load allocations or total maximum daily loads.

After implementing secondary treatment throughout the US, the Federal EPA has turned its attention toward “water quality standards”. Some individual states within the US have responsibility to carry out the Federal legislation, and some do not. In either case, uniform requirements for setting in-stream water quality standards for each stream based on uses for that stream are being pursued. Once the desired water quality is set, total maximum daily loads of various key pollutants are set, and then the dischargers to that stream are assigned an allotment from that allowable load quantity. In this manner, a treatment facility discharge permit is determined.

Although this program is not at the same stage in all states throughout the US, the trend over the past five years has been issuance of discharge permits which have reduced allowable BOD_5 and TSS effluent concentrations, and have led to limitations being placed on ammonia and, in more sensitive locations, total nitrogen and total phosphorus. Limitation of ammonia has been linked to prevention of in-stream toxicity, and the limiting concentration is often based on whole effluent toxicity results. Total nitrogen limitations are based on the need to limit nutrients available to algae in downstream reservoirs or impoundments thereby reducing tendencies toward eutrophication in those water bodies. Another reason total nitrogen is often limited is to protect downstream water users from high concentrations of nitrates in drinking water supplies. The US secondary drinking water standard for nitrates is 10 mg/L. Finally, the phosphorus limitations are related to prevention of stream or impoundment eutrophication.

Although many exceptions exist throughout the US, most plants required to nitrify are now also required to denitrify. Control of phosphorus discharges is a separate issue as discussed above and is related to prevention of eutrophication. Considering that most of the receiving streams are also potable water supplies for downstream users, it is anticipated that the control of nitrogen will continue to find more and more wide application in discharge permits for both existing and new wastewater treatment plants throughout the US.

3.3.4 Europe

In Europe the requirement for nitrification of wastewater is determined by two tiers of "legislation". Firstly there is European legislation, covered mainly by the Urban Wastewater Treatment Directive (UWWTD) and, secondly, there are additional standards set by the governments of individual countries.

One of the goals of the UWWTD was to reduce the incidence of eutrophication of inland waters and enclosed seas. As part of the directive individual governments identified watercourses that receive treated effluents that were at risk of eutrophication and set effluent standards for nitrogen and phosphorus. Typically these are watercourses where there is sufficient retention time for algal growth to become a problem, typically more than five days. Sensitive water status is therefore not usually attributed to short rivers and are not effective in watercourses where the pollution levels are so high to prevent macrophyte and algal growth.

The UWWTD standards were set depending upon the population equivalent of the wastewater treatment works. For works receiving wastewater from a population of greater than 100,000, the standards are 1 mg/L for total phosphorus and 10 mg/L for total nitrogen. For works receiving wastewater from a population between 20,000 and

100,000, the standards are more relaxed, 2 mg/L for phosphorus and 15 mg/L for nitrogen. These standards are annual averages.

To achieve a standard of 10 or 15 mg/L total nitrogen, it is necessary for the wastewater treatment plant to nitrify almost all of the ammonia nitrogen in the wastewater to nitrate. Normally this would require that the ammonia nitrogen concentration in the effluent to be 2 mg/L or less. In order to meet a total nitrogen standard, almost full nitrification is required and as much denitrification as is necessary.

Individual countries may set additional standards that are more stringent than those specified in the UWWTD. For example, in Germany it is common for the total nitrogen standards to be set irrespective of population size. Effluent standards are based on an 80 percentile value instead of annual averages. An 80 percentile standard is more stringent than an annual average, and requires four out of five samples of the effluent comply with the standard.

In the United Kingdom, total nitrogen standards are not common. Normally, standards are set for ammonia nitrogen. Historically, these have been set on watercourses of reasonable standard where a substantial part of the oxygen demand is due to the oxidation of ammonia. In recent years, as river quality has improved, ammonia standards have been set to enhance the possibility of Salmonid (salmon and trout) fish growth.

In the United Kingdom, the Environment Agency set 95 percentile consent standards. This is a statistical standard and requires that the effluent should meet the standard in 95 percent of the samples. Until ten years ago the most stringent limit was 5 mg/L. This has now been reduced to 2 mg/L. Statistical analysis of effluent data shows that to meet a 95 percentile ammonia nitrogen standard, the average value has to be approximately 40 percent of the standard. Therefore to comply with a standard of 2 mg/L, the average has to be less than 1 mg/L. The Environment Agency have now set 95 percentile standard of 1 mg/L ammonia nitrogen for tributaries of the River Thames which will come in to force in the next five years. These standards will apply to works with large populations which discharge to the headwaters of rivers where there is little dilution of the effluent. The key driver for this more stringent standard is the desire to improve the Atlantic salmon fishery in the Thames. Elsewhere in Europe where Atlantic salmon fisheries once survived, regulators may start to set very stringent ammonia standards. To be successful, the rivers must already be of good standard.

Regulations in Poland put year 2000 as the deadline for compliance with the minimum effluent quality of 1.5 mg P/L, and 6 mg NH_4-N/L. In case of total nitrogen (TN), the limit varies from 10 to 30 mg N/L, depending on the local state permit. The European Union adopted the 10 mg TN/L standard and Eastern Europeans are now trying to meet that. National laws (established in 1991) designate this minimum effluent quality for all plants with flows exceeding 2,000 m^3/d, regardless of the type of final receiver (rigid emission standards with no provision for exceedences). The same effluent quality is required during winter and summer. There is no statistical approach, (e.g. of min, max, average) based on the duration of the occurrence of the violation. The effluent quality has to be met 100 percent of the time. This naturally leads to conservative process designs.

3.3.5 Asia

In most parts of Asia, the permits are issued for wastewater treatment facilities based on maintaining site-specific receiving water quality objectives. For example, most of the wastewater generated in Hong Kong is discharged into the Lema Channel through a long ocean outfall after chemically enhanced primary treatment (CEPT). Smaller treatment plants that discharge into shallow embayed waters in Hong Kong (e.g. Tolo Harbour, Port Shelter) are required to meet effluent total N and bacteriological limits in order to address concerns about eutrophication and public health.

3.4 REGULATORY TRENDS TOWARDS NITRIFICATION OF WWFs & CSOs

3.4.1 Canada

In Canada, there has been very little attempt to develop regulations that require the nitrification of wet weather flows (WWFs) or combined sewer overflows (CSOs) prior to discharge to the receiving environment. However, Alberta Environment has already introduced the concept of overall "total loading" to the watershed from wastewater treatment plant outfalls, stormwater outfalls, and snow dump runoff in the permits for the Cities of Calgary and Edmonton. It plans to extend this to other major cities and large communities in Alberta in the next round of permit renewals. This new approach may mean that the ammonia loading associated with WWFs and CSOs will be included in the total ammonia load being discharged by a particular facility, and be used to calculate the effluent ammonia concentrations specified in the discharge permit for the facility.

3.4.2 USA

Much controversy has surrounded the need for and cost of treating WWFs and CSOs in the US. At present, most regulatory agencies seem to be adopting the perspective that the treatment plant should be capable of providing full treatment to its normal regulated effluent quality for flows up to approximately two to 2½ times the plant's average design flow rate. Where severe problems persist due to large amounts of inflow/infiltration into the collection system, some level of treatment is often being required. Some systems have WWFs which are in the range of 6 to 10 times average flow. For these systems, some regulatory agencies are requiring high rate TSS and floatables removal. In these cases, the regulatory agency sets discharge standards for the partially treated wastewater, usually approximately 45 mg/L BOD_5 and TSS. In other cases, the regulatory agency requires that weekly maximum and monthly average limits be met for the total plant discharge, including the partially treated storm-related flows. In many instances this requirement can be met due to the dilution of the raw wastewater during high flow situations. Ammonia or total nitrogen is not normally limited during these short-duration periods when partially treated, low pollutant concentration storm flows are being discharged.

CSO treatment is occasionally required, but again it is mostly for floatables removal, and in some instances TSS control. There has not been a move in the US to control nitrogen discharges of any kind contained in CSOs.

Table 3.1: Typical NH_3-N and Total N Limits Specified in Selected Jurisdictions in Canada

Jurisdiction	Current Limits	Possible Future Limits Under Consideration
Government of Canada:		
Department of Fisheries & Oceans	Non-toxic effluent	--
Province of Manitoba:	Surface Water Quality Objectives similar to USEPA	
Province of British Columbia:		
Coastal Communities	None	--
Okanagan Valley	Total N = 6 to 10 mg/L	Total N <6 mg/L
Province of Alberta:		
Larger Municipalities	Best Practicable Technology NH_3-N = 5/10 mg/L summer/winter	NH_3-N = 3/5 mg/L summer/winter
Province of Saskatchewan:	None	--
Province of Ontario:	Surface Water Quality Objectives Un-ionized ammonia <0.02 mg/L in the receiving water	NH_3-N = 5/10 mg/L summer/winter
Most Municipalities	None	
Some Municipalities	NH_3-N = <3 mg/L	
Few Municipalities	Total N <10 mg/L	

Table 3.2: Typical NH_3-N and Total N Limits Specified in Selected Jurisdictions in the USA

Jurisdiction	Current Limits	Possible Future Limits Under Consideration
United States of America:		
Selected NE Coastal Areas (Long Island Sound, Chesapeake Bay, etc.)	Total N <10 mg/L	
Atlanta (Chatahoochee River)	NH_3-N = 3.0 to 16.4 mg/L summer/winter	1.1 mg/L monthly avg. 1.65 mg/L weekly avg.
Midwest (Mississippi River and tributaries, e.g., Minneapolis/St. Paul)	NH_3-N = 3 mg/L summer NH_3-N = 5 to 12 mg/L spring-fall No limit in winter	NH_3-N = 5/10 mg/L summer/winder (ultimately Total N <10)
Arid Southwest Areas	Total N <10 mg/L	
Northwest (wet winter and arid summer)	NH_3-N <1.0 mg/L summer No limit in winter	
Southeast (Florida)	total N <3 to 6 mg/L	

Successfully Applied Nutrient Removal Technologies in the USA

New York	Step-feed nitrifying activated sludge process/Tertiary BAF Sludge handling return liquor treatment
Washington, DC	2-Stage activated sludge process
Minneapolis/St. Paul	Step-feed nitrifying activated sludge process/BNR
Atlanta	BNR activated sludge process
Florida	BNR activated sludge process
Reno Sparks	Phostrip/nitrifying trickling filters/susp. growth denitrification
Lake Tahoe	Ammonia stripping
Denver	Nitrifying activated sludge process/HPOAS
Phoenix	Nitrification/denitrification activated sludge process
Boulder	TFSC/nitrifying trickling filters

Table 3.3: Typical NH_3-N and Total N Limits Specified in Selected Jurisdictions in Europe

Jurisdiction	Current Limits	Possible Future Limits Under Consideration
European Community Council Directive on Urban Wastewater Treatment	Total N <15 mg/L for P.E. from 10,000 to 100,000 (annual avg.) Total N <10 mg/L for P.E. >100,000 (annual avg.)	Total N < 8 mg/L NH_3 and TN limits based on catchment wide modelling of sewers, WWTPs and receiving waters
United Kingdom	NH_3-N <5 to 10 mg/L (95%-tile)	
Germany	UWWTD*	
Netherlands	UWWTD	
France	UWWTD	
Denmark	UWWTD	
Norway	UWWTD	
Poland	UWWTD	

UWWTD – Urban Wastewater Treatment Directives

Commonly Applied Nutrient Removal Technologies in Europe

London	Nitrifying activated sludge process
Birmingham	Nitrifying trickling filters
Manchester	2-Stage biological aerated filters
Reading	2-Stage activated sludge process (HPOAS/nitrifying ASP)
Dublin	Nitrification/denitrification activated sludge process (SBR)
Paris	2-Stage biological aerated filters
Frankfurt	2-Stage activated sludge process
Copenhagen	BNR activated sludge process (Biodenitro)
Oslo	CEPT followed by 2-Stage nitrification/denitrification fixed film
Stockholm	Nitrification/denitrification activated sludge process
Malmo	High rate ASP followed by 2-Stage fixed film process
Gotenburg	High rate ASP followed by NTF with recycle to ASP
Vienna	Nitrification/denitrification activated sludge process

Table 3.4: Typical NH_3-N and Total N Limits Specified in Selected Jurisdictions in Asia

Jurisdiction	Current Limits	Possible Future Limits Under Consideration
Hong Kong	Total N <12 mg/L (95%-tile) Total N <24 mg/L (max.)	Total N <10 mg/L (95%-tile) Total N <20 mg/L (max.) NH_3-N <5 (95%-tile) NH_3-N <10 (max.)
China	Total N <10 – 15 mg/L (max.)	
Bangkok	75% removal annual avg.	
Japan	Various – dependent on receiving water quality	

Commonly Applied Nutrient Removal Technologies in Asia

Hong Kong	BNR activated sludge process
Bangkok	Nitrification/denitrification activated sludge process
China	Nitrification/denitrification activated sludge process
Japan	Hybrid suspended growth/attached growth processes

Table 3.5: Typical NH_3-N and Total N Limits Specified in Selected Jurisdictions in Australia

Jurisdiction	Current Limits	Possible Future Limits Under Consideration
Queensland	Total N <5 to 8 mg/L (50%-tile)	Total N <5 mg/L (50%-tile)
New South Wales	Total N <10 – 15 mg/L (50%-tile)	--
Victoria	85% Total N removal (annual avg.)	--

Commonly Applied Nutrient Removal Technologies in Australia

Queensland	BNR activated sludge process
New South Wales	BNR activated sludge process
Victoria	Nitrification/denitrification activated sludge process

Regulatory Trends Regarding NH_3 and TN Discharges

- Increasing concerns about ammonia toxicity in receiving water, particularly at higher pH and temperatures. Regulations being written around seasonal NH_3 concentrations.

- Regulations are being driven by surface water quality objectives. Ammonia concentrations are generally considered to be a problem when they create toxic conditions in the receiving water, not at end-of-pipe. The mixing zone concept is normally adopted for evaluation of receiving water impact.

- Concerns about TN discharges appear to be focussed more on potential for eutrophication of shallow embayed areas of the marine environment, i.e., Baltic Sea, Chesapeake Bay, Mississippi Delta, etc.

- Phosphorus is the primary nutrient of concern in inland surface water systems.

- Ammonia limits where toxicity is a concern are normally based on 95 percentile values. TN and TP limits where eutrophication is the concern are normally based on average or 50 percentile values to reflect average nutrient load to receiving water.

- No serious moves to control nitrogen discharges in WWFs or CSOs.

- The decision making mechanism involved in the establishment of effluent quality criteria is normally tempered by cost and technical considerations.

Trends in Application of Nutrient Removal Technologies

- Upgrading of existing facilities for NH_3, TN, and TP removal becoming common.

- Plant owners are under pressure to use high rate, compact processes to reduce costs and site requirements, i.e., DO MORE WITH LESS.

- Single sludge activated sludge process most common for nitrification, nitrogen removal, and biological phosphorus removal (biological nutrient removal or BNR). Only process capable of using influent BOD as a carbon source for N and P removal.

- Modifications of the activated sludge process aimed at achieving high rate nitrification or N removal include:

    - Step feed and RAS re-aeration processes
    - Hybrid suspended/attached growth processed (Ringlace, Captor, Linpor, etc.)
    - Membrane bioreactors.

- Tertiary fixed growth nitrification processes (NTFs, BAFs) used in 2-stage processes.

- Return liquor treatment for nitrification and N removal.