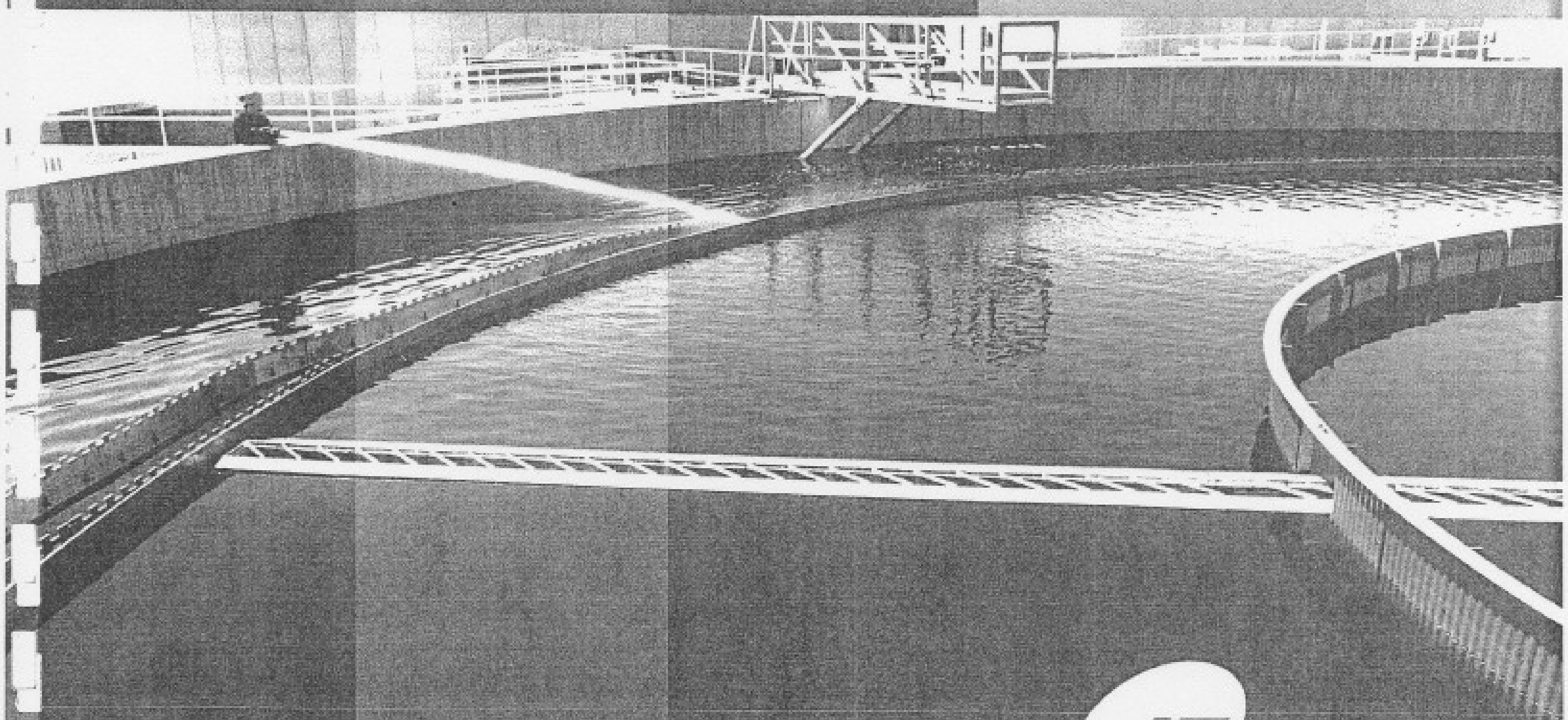
REPORT

Assessment of Cost of Nitrogen Removal from City of Winnipeg Wastewater

Prepared for the Province of Manitoba

NOVEMBER 2008



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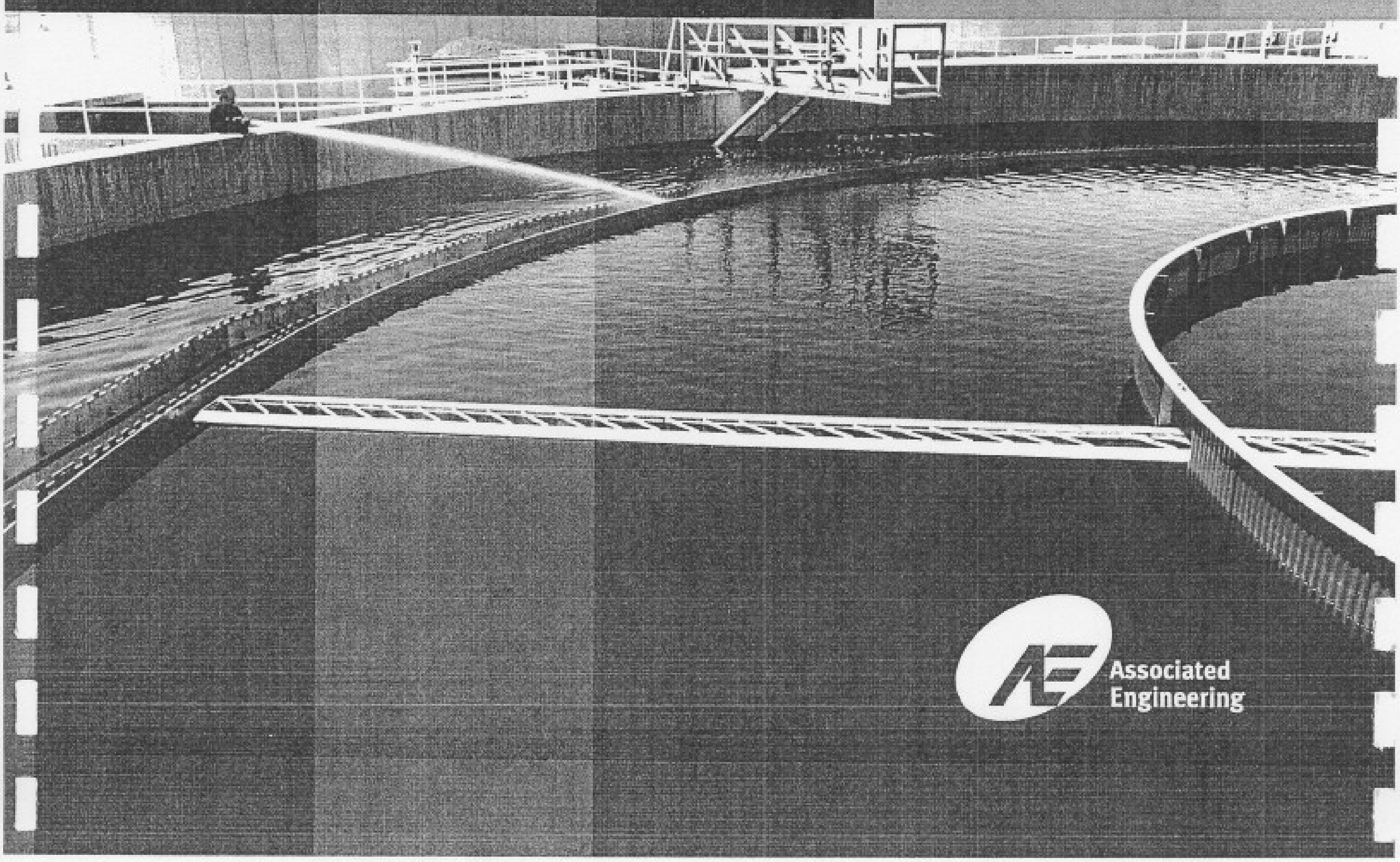

Associated Engineering

Executive Summary

The City of Winnipeg is developing upgrading / expansion strategies for the SEWPCC and NEWPCC based on the current Manitoba Environment Act Licenses. Among other requirements, these licenses require the facilities to produce effluent that meets a total nitrogen limit of 15 mg N/L by December 31 in 2012 and 2014, respectively, for the SEWPCC and NEWPCC. Based on the City's currently preferred alternatives for meeting this and other requirements for a design horizon that extends to Year 2031, the relative capital cost of the infrastructure that provides nitrogen removal is in the order of 6 to 7% of the total facility capital costs. For the SEWPCC, this cost is about $12M, in 2008 dollars, based on the latest preliminary engineering level estimate. The value for the NEWPCC is $33M, in 2007 dollars and based on a master planning level estimate. Specifically, this relative cost applies to the denitrification portion of the biological process that provides some level of total nitrogen removal.

In light of the relatively small cost of the infrastructure that provides total nitrogen removal for these preferred alternatives, there appears to be little benefit in attempting to phase nitrogen removal at either the SEWPCC or NEWPCC within the time frame of the current License requirements. Furthermore, the implementation schedule to meet the current requirements practically eliminates phasing of the required infrastructure. Finally, the ability to do so, particularly for the NEWPCC, may be precluded by site layout and constructability issues.

From a broader environmental perspective related to wastewater nitrogen removal, nitrous oxide generation within wastewater treatment bioreactors is attracting increased industry attention as municipalities and utilities consider the carbon footprint of their operations. Although there are considerable gaps in current knowledge at this time, it will be important for the City to remain aware of developments in this subject area as it plans, designs and implements its wastewater treatment infrastructure.

With the planning, design and implementation window shrinking for the SEWPCC and WEWPCC projects, urgency exists with respect to coming to a definitive conclusion on both the need for and timing of effluent total nitrogen limits. Such conclusion will assist the City in making fiscally responsible decisions while maximizing the environmental, social and economic benefits of the wastewater management service it provides.

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1 Introduction

1.1 WHY THIS ASSESSMENT?

The importance of wastewater management and its contribution to the protection of public and environmental health cannot be overstated. Humanity has long acknowledged this fact, extending back to Mesopotamian history (3500 to 2500 BC) to a time that preceded an understanding of what was implicitly known. Eventually, the mid-1800s London cholera outbreaks provided the connection between public health, contaminated water supply and the lack of effective wastewater management as a major contributor to the problem.

It is in this context that the City of Winnipeg provides treatment of wastewater generated by its community, via its North End, West End and South End Water Pollution Control Centres. This is a challenging service to bestow, since many uncertainties contribute to what could be described as opaqueness when looking through a perspective that seeks to maximize the environmental, social and economic benefits of such a service. Nitrogen management is one issue with such uncertainties and forms the focus of this assessment.

As will be discussed in the following Section, nitrogen management is a complex issue. It is relevant to the City as it plans the expansions and upgrades of its wastewater treatment facilities (WWTF). In 2003, the Clean Environment Commission (CEC) of Manitoba recommended that "the City of Winnipeg should be directed to plan for the reduction of nitrogen and phosphorous from its municipal wastewaters, and to take immediate steps in support of the nutrient reduction targets established for Lake Winnipeg". Given the ongoing scientific debate on these nutrients, the Province recently requested the CEC to reaffirm its order for the City as part of its recommended three-year review process. Simultaneously, since the WWTF upgrades represent a significant financial investment by the City of Winnipeg, its ratepayers, and the Province, the Province commissioned this Winnipeg-specific assessment to provide information on (i) current and evolving requirements in other regulatory jurisdictions, (ii) the costs associated with nitrogen reduction, and (iii) and the impacts of staging or phasing nitrogen removal on project costs. .

1.2 NITROGEN – A BROAD PERSPECTIVE

To understand the importance of nitrogen in wastewater management is to understand nitrogen from a broader perspective. As noted by Dr. James Galloway from the University of Virginia, "humans continue to transform the global nitrogen cycle at a record pace, reflecting an increased combustion of fossil fuels, growing demand for nitrogen in agriculture and industry, and pervasive inefficiencies in its use" (Galloway et al. 2008).

Nitrogen is a particularly interesting element because it is both a nutrient essential to all living organisms while simultaneously being a potential contaminant that, it could be argued, has more far-reaching environmental consequences than any other element. Consider these perspectives. Synthetic fertilizer production, which extracts di-nitrogen gas from the atmosphere and combines it with natural gas to form ammonia-nitrogen via the Haber-Bosch process, is a marvel of the industrial revolution. Estimates suggest that at least 2 billion people are alive today because of this ability to produce synthetic fertilizer and ultimately food (Galloway et al. 2008). At the same time, various nitrogen forms are notable for their potential public health and environmental impacts. High nitrate-nitrogen levels in drinking waters have long been known to cause methemoglobinemia in infants, and nitrosomines, another nitrogen form, are implicated carcinogens. Nitrous oxide, another gaseous nitrogen compound, is an extremely potent greenhouse gas (GHG) that has an assigned global warming potential approximately 300 x that of carbon dioxide. Nitric oxide, also a gas, is important in atmospheric chemistry since it catalytically destroys ozone, the latter of which shields earth from harmful ultraviolet radiation.

The wastewater industry has traditionally considered nitrogen, in the form of nitrate nitrogen, as a nutrient that can stimulate algal growth in water bodies and degrade their quality (i.e. eutrophication). Likewise, the industry has long recognized the toxic effects of ammonia-nitrogen on aquatic organisms. But increasing attention is being given to nitrous oxide as related to climate change. Under certain conditions, nitrous oxide can be generated by microorganisms in wastewater treatment bioreactors and in water bodies that receive nitrogen-bearing effluents.

Further complicating the nitrogen management issue is point source versus non-point source pollution. Point sources of nitrogen, such as WWTF effluents, can be effectively managed. However, non-point nitrogen sources, such as surface run-off from agricultural areas, are difficult to control and can be significant inputs to watersheds. The Gulf of Mexico is an infamous example, where watersheds draining into the Gulf induce hypoxic (low oxygen) "dead zones" each year that are several thousand square kilometres in area and negatively impact the aquatic ecosystem and fisheries. Inefficient synthetic fertilizer use in agriculture contributes to such problems. Nitrous oxide formation in receiving water bodies is receiving attention from a global warming view.

From the above discussion it can be seen that nitrogen management, from a broad global perspective, is indeed a complex issue with many facets. The following section further examines nitrogen from a wastewater perspective where the discussion focuses on the nuances of nitrogen removal.

1.3 NITROGEN TRANSFORMATIONS AND REMOVAL

Wastewater nitrogen removal, by virtue of its many biochemical pathways, is a complex technical subject. This section provides a short, simplified overview of wastewater nitrogen transformations and removal based on typical technology approaches in use today.

Municipal wastewater contains nitrogen primarily in two general forms. The first form is referred to as **organic nitrogen** (org N), where elemental nitrogen (N) is contained in a variety of particulate and dissolved carbon compounds such as proteins and amino acids. **Ammonia** is the second primary nitrogen form, where it exists in chemical equilibrium between ionic (ammonium, NH_4^+) and gaseous (un-ionized ammonia, NH_3) states. Together, these two forms comprise essentially all of the **total nitrogen** in municipal wastewater.

The physical separation of solids from wastewater in the primary treatment system of a WWTF provides some level of nitrogen removal and is limited to the organic nitrogen associated with the solids removed in this system. Some of this nitrogen is eventually recycled back to the liquid-stream treatment system once these solids are processed in the solids-stream system.

Most of the nitrogen transformations that occur at a WWTF do so in the biological secondary treatment system, where microorganisms (MOs), primarily bacteria, in bioreactors catalyze these reactions. MOs that degrade wastewater carbon compounds, which remain in the primary effluent, require nitrogen to synthesize new cells, thus some nitrogen is assimilated into newly grown biomass and removed from the wastewater. Also, these MOs convert some of the organic nitrogen to additional ammonia.

Biological systems that are purposely designed to provide nitrification use specific MOs to convert or transform ammonia to other nitrogen forms, with **nitrate nitrogen** (NO_3^-) typically being the desired end product. Ammonia is indeed removed from the wastewater, but the key point here is that nitrification does not change the total nitrogen content of the primary effluent entering the secondary treatment system. Rather, nitrification provides the conversion of ammonia from a reduced nitrogen form to an oxidized form (e.g. nitrate).

Biological treatment systems can be purposefully designed to provide a specified level of total nitrogen removal. In this situation, the nitrate nitrogen produced by nitrification is subsequently converted to di-nitrogen gas (N_2) via biological denitrification by other MOs in the bioreactor. The N_2 is released to the atmosphere, which is comprised of about 80% N_2, and is thus removed from the effluent discharged from the WWTF. Other nitrogen gases (i.e. nitrous oxide, N_2O; nitric oxide, NO) are also formed, both during nitrification and denitrification. However, only recently has the wastewater industry begun to seriously study the biochemical pathways that produce these gases and assess their relative production.

Figure 1 simply illustrates the relative nitrogen mass balance as primary effluent enters and secondary effluent leaves a bioreactor system. A few points are noteworthy. Bioreactor systems can be designed to remove essentially all ammonia such that secondary effluent ammonia levels are typically <1 mg N/L, allowing for some transient increases during certain operating conditions (e.g. cold weather). Some fraction, in the order of 1 or 2 mg N/L, of organic nitrogen tends to escape bioreactor systems since this material is either not degradable or may be associated with other products excreted by the MOs. Achievable secondary effluent total nitrogen levels depend on the applied technology and approach. The current limit of technology allows secondary effluent total nitrogen levels, which includes nitrate nitrogen, to be reduced to around 3 mg N/L. Considerable industry research effort is examining how to reduce this total nitrogen level, including removal of the residual organic nitrogen. Finally, some strategies historically used to enhance total nitrogen removal are being revisited due to the potential to produce nitrous oxide, which, as discussed earlier, is a powerful GHG.

1.4 DOCUMENT ORGANIZATION

The remainder of this document is organized into four main sections. Section 2 examines effluent nutrient limits, and approaches to establish these limits, in other jurisdictions in western Canada, while also considering federal approaches and requirements. Section 2 also summarizes specific effluent quality requirements applied to other major city / utility WWTFs in western Canada. Section 3 provides a review of current treatment cost estimates related to the City of Winnipeg's wastewater treatment facilities, specifically focusing on the cost of infrastructure that provides total nitrogen removal in order to meet the requirements of current licenses issued to the City under the Manitoba Environment Act. Section 4 provides comments on technology and environmental issues related to nitrogen removal, as well as cost impacts for staging or phasing nitrogen removal. Section 5 summarizes key assessment findings.

1.5 QUALIFICATION OF ASSESSMENT

As described in Section 1.1, the scope of this assessment was to provide information to the Province on wastewater nitrogen removal as related to the Winnipeg WWTFs. This high-level assessment focused on information developed previously by the City and its engineering consultants. The work is not a peer review of this information, nor was new information generated by this activity. Rather, the assessment involved the extraction, synthesis and presentation of information that already exists.

As one can imagine, the planning and design of wastewater treatment infrastructure worth hundreds of millions of dollars generates a vast amount of information. The short assessment schedule necessarily allowed examination of only select information that was deemed relevant for this assignment. All practical efforts were made to ensure no significant oversight of information examined. Similarly, the commentary provided in this report gives a broad overview of the subject material and, by nature of the assessment scope, was not intended to pursue technical points in detail.

1.6 ACKNOWLEDGEMENTS

This report has been prepared by Associated Engineering, working under contract to Manitoba Intergovernmental Affairs. The primary authors were Dr. Dean Shiskowski, P.Eng. and Mike Whalley, M.Eng., P.Eng. Project review was carried out by Rick Corbett, M.A.Sc., P.Eng. Information referenced in this report was obtained from the City and its consultants, whom we acknowledge and thank for their prompt response to our inquiries.

2 Interjurisdictional Scan

2.1 PROVINCIAL AND FEDERAL POLICY OVERVIEW

Table 1 summarizes current western Canadian provincial and federal government effluent quality requirements or limits, as well as approaches to establish the limits, for various phosphorus and nitrogen parameters. The federal government information is based on the approach that Environment Canada and the Canadian Council of Ministers of the Environment (CCME) have developed as part of the on-going work on the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent.*

As the Table 1 information suggests, most jurisdictions require site-specific assessments for many of the nutrient parameters. The Province of Saskatchewan now requires a Downstream Water Use Study be conducted for new treatment facilities, the findings of which will be used to establish phosphorus and nitrogen effluent limits (SMOE 2008). Specific to total nitrogen, only the British Columbia *Municipal Sewage Regulation* explicitly identifies a limit, which is applied only to treatment facilities located in the Okanagan Basin. For comparison, the State of Virginia's requirements for effluent discharges to the tidal waters of Chesapeake Bay are also included in Table 1. The total nitrogen limit represents the most stringent level currently in place in the United States.

2.2 MUNICIPAL / UTILITY REQUIREMENTS – POLICY IN ACTION

At this point in time the Provinces are the primary regulator of effluent discharges within their own jurisdictions. They work with municipalities and utilities to establish facility-specific effluent quality limits, based on Provincial policies, approaches and requirements, which are then incorporated into discharge permits, licenses or approvals-to-operate. Based on the Environment Canada / CCME initiative noted in Section 3.1, Environment Canada is anticipated to release a draft version of wastewater effluent regulations, under the federal Fisheries Act, in December 2009. While the details of this proposed regulation are not yet publicly known, the Provinces requirements will presumably be at least as stringent as the new federal requirements.

Table 2 summarizes the nitrogen and phosphorous effluent quality requirements for several western Canadian WWTFs that discharge effluent to river and lake systems. Of the listed facilities, only the Regina WWTF currently uses chemical precipitation as the primary process to remove phosphorus from wastewater. All other facilities use enhanced biological phosphorus removal in conjunction with some form of biological ammonia / nitrogen removal. The table also includes the three City of Winnipeg WWTFs and requirements specified in their current licenses.

There are several noteworthy points related to this information. First, for some parameters, a few facilities have "objectives" or "targets" that fall outside their legal requirements. In this context the intent is to try to meet these effluent levels with the technology that is in place – in essence demonstrating a limit of technology. As shown in Table 2, the City of Saskatoon WWTF has one such objective for total phosphorus that is included within their Permit. Alternately, Parks Canada and other stakeholders involved with the

Banff WWTF have established effluent quality Leadership Targets that are more stringent than those contained in the Alberta Environment Approval-to-Operate and are not included in the Approval itself. These targets for phosphorus (0.15 mg P/L) and ammonia (summer = 1 mg N/L, winter = 5 mg N/L) are notably more stringent than the regulatory values shown in Table 2.

Second, as shown in Table 1, besides the Winnipeg facilities, only the Penticton WWTF currently has an effluent total nitrogen limit (6 mg N/L), which is typical of the Okanagan facilities.

However, there are some evolving changes as noted in Table 2. For example, the City of Regina is currently in the process of expanding and upgrading their WWTF. At the time of project completion in 2010, the Saskatchewan Ministry of Environment will require the City to produce effluent with a total nitrogen limit of 15 mg N/L in both summer and winter (SMOE 2008). In year 2028, the total nitrogen limit will decrease to 10 mg N/L in the summer and 12 mg N/L in the winter. Unlike many inland freshwater systems in Canada, primary production in the Qu'Appelle River system, which receives Regina effluent, is limited by nitrogen rather than phosphorus inputs (Environment Canada 2001). Thus it is not surprising that the City of Regina is being directed by the Province to provide some level of total nitrogen removal at the WWTF.

The Pine Creek Water Management Centre is the City of Calgary's newest WWTF - a greenfield facility that is currently undergoing commissioning and is scheduled for start-up in mid-October. The present, draft Alberta Environment Approval-to-Operate includes a total nitrogen requirement of 15 mg N/L (City of Calgary 2008). The City anticipates Alberta Environment to sign-off on the draft Approval in 2008.

From a broader perspective, Alberta Environment has recently commissioned a province-wide receiving environment assessment study that has a nutrient focus (Alberta Environment 2008). The study findings will be considered in the upcoming review of effluent standards and used, in part, to identify needs for total nitrogen limits.

The City of Saskatoon will also be upgrading their WWTF to provide some level of total nitrogen removal, with implementation scheduled for 2011/2012. Saskatchewan Environment's anticipated effluent total nitrogen requirement is 14 mg N/L, anticipated for 2015 (SMOE, 2005).

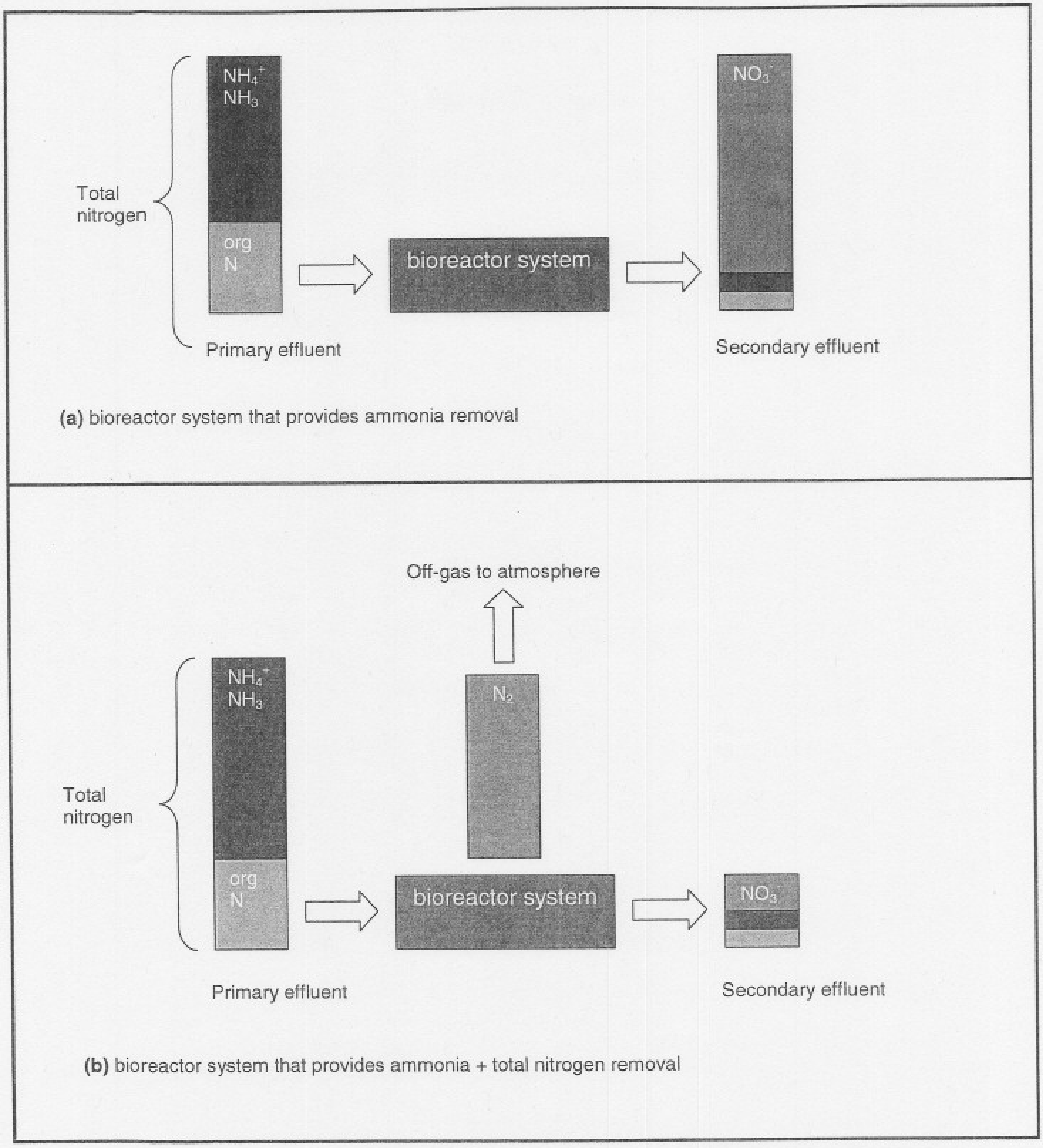

Figure 1
Simplified nitrogen mass balance for (a) bioreactor that provides ammonia removal via nitrification and (b) bioreactor that provides both ammonia removal via nitrification + total nitrogen removal via denitrification.

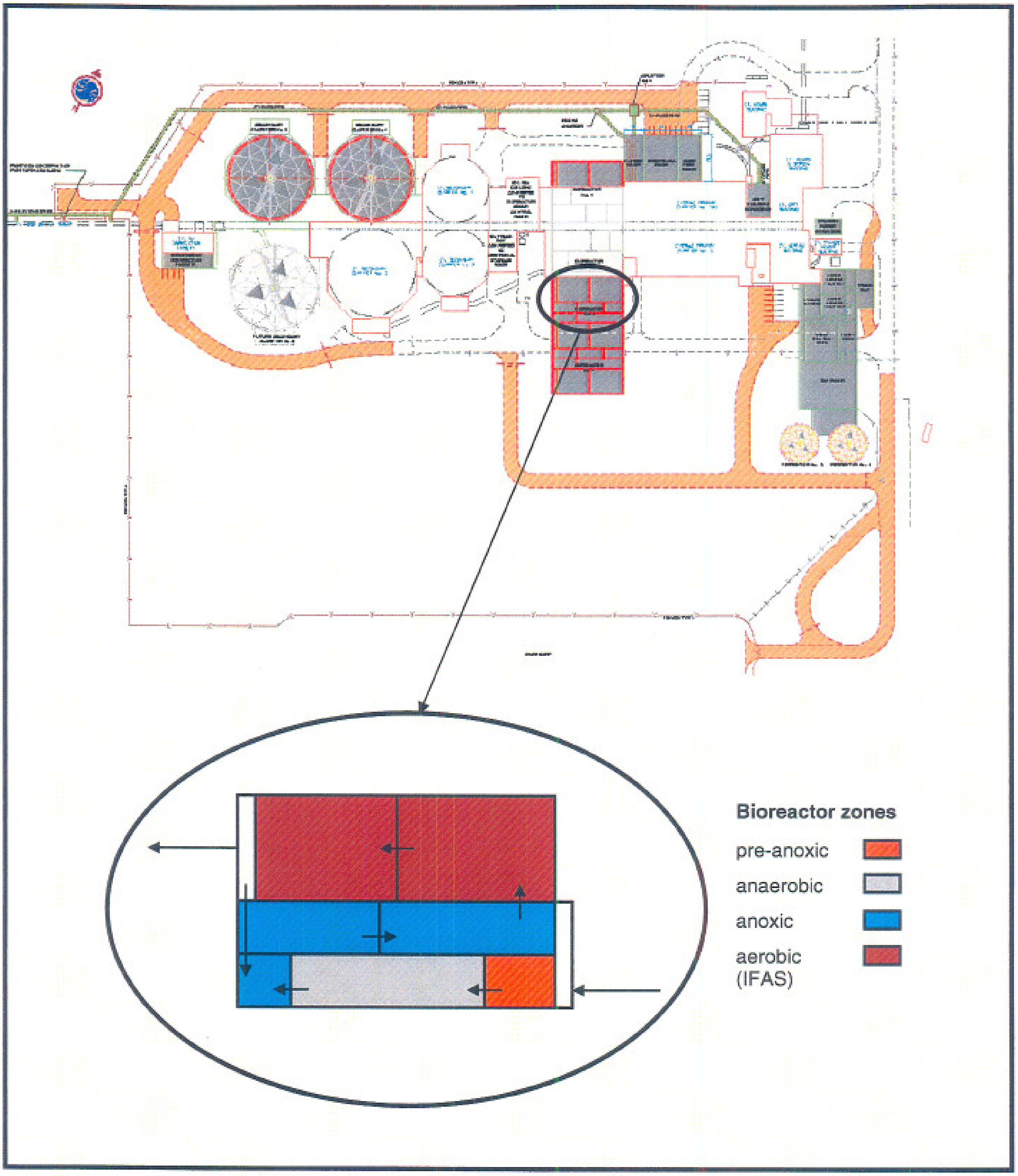

Figure 2
Plan view of SEWPCC showing existing and future works (Courtesy City of Winnipeg / Stantec). Lower figure illustrates simplified plan view of proposed Modified Johannesburg bioreactor configuration and individual zones (Adapted from Stantec (2008)).

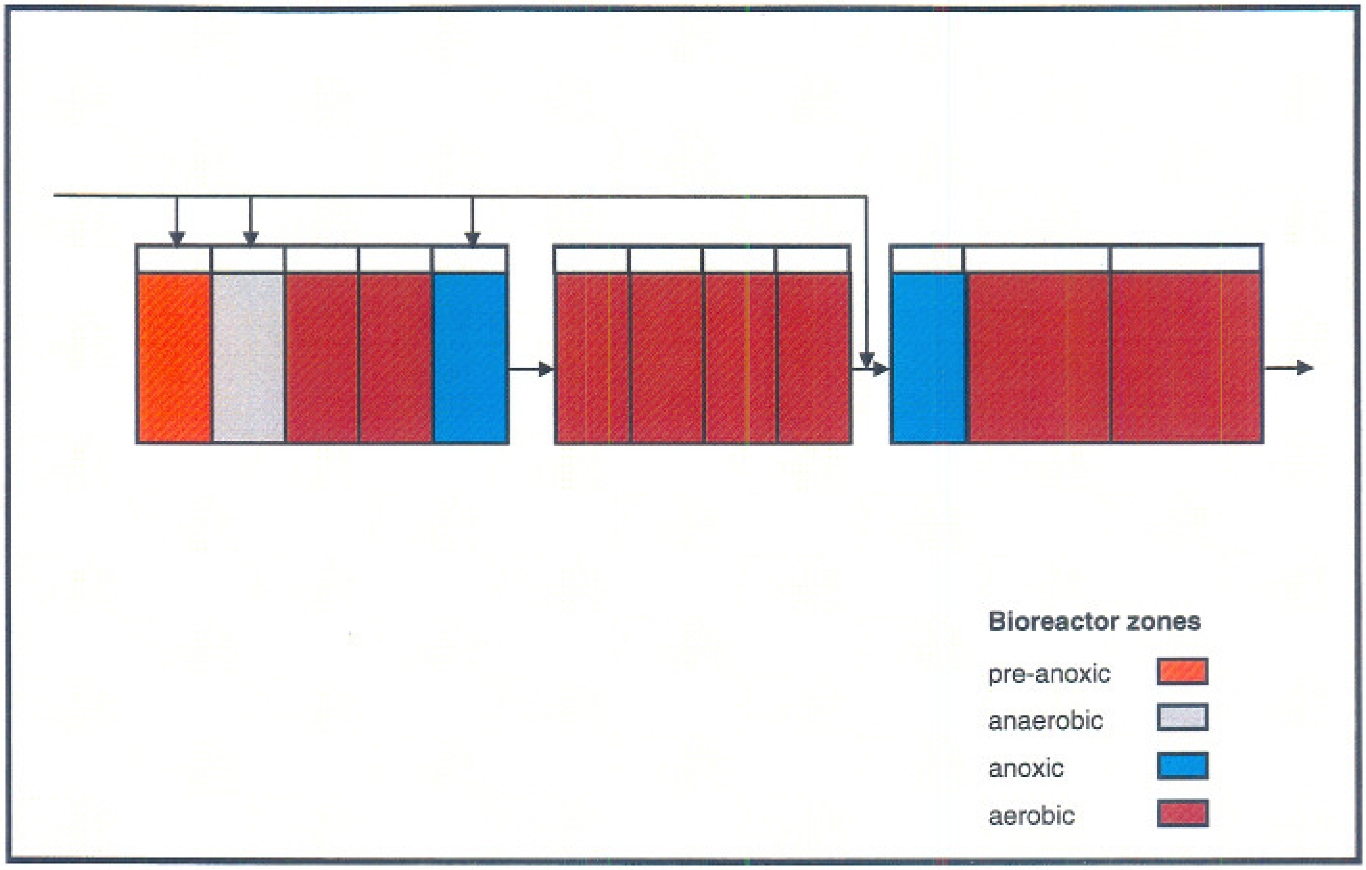

Figure 3
Simplified profile view of NEWPCC Scenario 1 Step Feed bioreactor configuration and individual zones (Adapted from EarthTech (2007)).

Table 2
Municipal / Utility Effluent Requirements

Parameter	Penticton WWTF[1]	Banff WWTF[2] Town of Banff	Gold Bar WWTF[3] City of Edmonton	Alberta Capital Region Wastewater Commission[4]	Bonnybrook WWTF[5] City of Calgary	Pine Creek WWTF[11] City of Calgary (pending)	Saskatoon WWTF[6] City of Saskatoon (existing)	Saskatoon WWTF[12] City of Saskatoon (anticipated)	Regina WWTF[7] City of Regina (existing)	Regina WWTF[13] City of Regina (pending)	Winnipeg North End WPCC[8] City of Winnipeg	Winnipeg South End WPCC[9] City of Winnipeg	Winnipeg West End WPCC[10] City of Winnipeg
Total Phosphorous (mg P/L)	0.25 Annual average value	≤ 1 Monthly arithmetic mean of daily composite samples	< 1 Monthly arithmetic mean of daily composite samples	1.0 Monthly arithmetic mean of daily composite samples	1.0 Monthly arithmetic mean of daily composite samples	≤ 0.5 Monthly arithmetic mean of daily composite samples	1.0 (calendar year average) 0.50 ("objective" calendar monthly average)	1.0 (calendar year average) 0.50 ("objective" calendar monthly average)	1.0	1.0	1.0 (on and after December 31, 2014; determined by 30 day rolling average)	1.0 (on and after December 31, 2012; determined by 30 day rolling average)	1.0 (determined by 30 day rolling average)
Ortho phosphate (mg P/L)	--	--	--	--	--	--	--	--	--	--	--	--	--
Ammonia (mg N/L)	--	≤ 10 (October 1 to June 30) ≤ 5 mg/L (July 1 to September 30) Monthly arithmetic mean of daily composite samples	< 10 (December 1 to May 31) < 5.0 mg/L (June 1 to November 30) Monthly arithmetic mean of daily composite samples	10 (December 1 to May 31) 5.0 mg/L (June 1 to November 30) Monthly arithmetic mean of daily composite samples	10 (October 1 to June 30) 5 mg/L (July 1 to September 30) Monthly arithmetic mean of daily composite samples	≤ 10 (October 1 to June 30) ≤ 5 mg/L (July 1 to September 30) Monthly arithmetic mean of daily composite samples	--	--	--	4 (summer) 10 (winter) by 2010	Seasonal mass loading value depending on month of the year	Seasonal mass loading value depending on month of the year	Seasonal mass loading value depending on month of the year
Total Nitrogen (mg N/L)	6.0 Annual average value	--	--	--	--	≤ 15 Monthly arithmetic mean of daily composite samples	--	14 by 2015	--	15 (summer/winter) by 2010 10 (summer) 12 (winter) by 2028	15 (on and after December 31, 2014; 30 day rolling average)	15 (on and after December 31, 2012; 30 day rolling average)	15 (30 day rolling average)

Notes:
[1]Ministry of Environment, Lands and Parks, City of Penticton, Operational Certificate PE 12212, Issued March 20, 1995. Typical of other Okanagan WWTFs.
[2]Alberta Environment, Town of Banff, Approval No. 382-02-00, Effective June 1, 2002
[3]Alberta Environment, City of Edmonton, Ammending Approval No. 639-02-007, Effective April 30, 2008
[4]Alberta Environment, Alberta Capital Regional District, Approval No. 486-02-00, Effective November 3, 2006
[5]Alberta Environment, City of Calgary, Approval No. 95-MUN-317, Effective January 1, 1996
[6]Saskatchewan Environment, City of Saskatoon, Alteration of Permit to Operate a Sewage Works, Permit # 00003464-01-00, Effective December 1, 2005 to March 31, 2010
[7]Saskatchewan Environment, City of Regina, Alteration of Permit to Operate a Sewage Works, Permit # 00050853-01-00, Effective December 1, 2005 to November 30, 2008; Saskatchewan Environment, City of Regina, DRAFT Alteration of Permit to Operate a Sewage Works, Permit # 00050853-02-00, Effective December 1, 2008 to November 30, 2011
[8]Manitoba Conservation, Environment Act Licence for City of Winnipeg's North End Water Pollution Control Centre, Licence No. 2684 RR Issued June 1, 2005, Most Recent Revision May 8, 2006
[9]Manitoba Conservation, Environment Act Licence for City of Winnipeg's South End Water Pollution Control Centre, Licence No. 2716 Issued March 3, 2006
[10]Manitoba Conservation, Environment Act Licence for City of Winnipeg's West End Water Pollution Control Centre, Licence No. 2669 E R Issued September 3, 2004, Most Recent Revision August 17, 2005
[11]Alberta Environment, City of Calgary, DRAFT Approval No. 17531-01-00
[12]Saskatchewan Ministry of Environment (2005)
[13]Saskatchewan Ministry of Environment (2008)

3 Review of Current Treatment Cost Estimates

3.1 OVERVIEW

The City of Winnipeg currently owns and operates three WWTFs: the North End Water Pollution Control Centre (NEWPCC), the West End Water Pollution Control Centre (NEWPCC) and the South End Water Pollution Control Centre (NEWPCC). The City operates each facility in accordance with an Environment Act License issued by Manitoba Conservation. Besides identifying current effluent quality requirements, among other items, the licenses also specify timelines for achieving new, more stringent effluent quality levels.

As a result of the license requirements, the WEWPCC was recently expanded and upgraded to meet more stringent effluent quality levels that include a total nitrogen limit of 15 mg N/L. The WEWPCC was commissioned in the summer of 2008 and is now in full operation. City staff have indicated that effluent total nitrogen levels were typically around 6 to 8 mg N/L in September 2008.

The SEWPCC License requires the facility to produce effluent that meets a total nitrogen limit of 15 mg N/L after December 31, 2012. Given the approaching implementation date, the City is fairly advanced in the planning and design of the required facility expansion and upgrade. The project is currently at what is termed in the industry as the *preliminary design* stage, which falls between *master planning* and *detailed design*. During preliminary design various alternatives are developed and evaluated, with capital costs, operating and maintenance costs and financial life-cycle analyses prepared as part of the activity. On the basis of the analysis results, fundamental decisions are made and a preferred alternative is selected for implementation. The detailed design, and eventual construction, then proceeds for the selected alternative. The City is now in the final activities of the preliminary design stage.

Finally, the NEWPCC License requires that effluent meet a total nitrogen limit of 15 mg N/L after December 31, 2014. With this more distant date, the City is currently still at the *master planning* stage of the facility expansion / upgrade program. From our discussions with City staff, we understand that one of the key objectives of work completed to date was in the context of a "foot print" analysis – essentially checking if sufficient land area is available at the existing NEWPCC site, or possibly a new greenfield site, to accommodate the required infrastructure. Simultaneously, high-level, comparative capital, operating and maintenance costs and life-cycle costs were developed for the various alternatives examined at this project stage. This information will be used to advance the planning work into an eventual preliminary design stage.

Before describing the cost assessment conducted for the City WWTFs, Section 3.2 addresses an important concept that must be considered in discussion specific to these facilities.

3.2 PROJECT STATUS VERSUS COST ESTIMATES – WHAT DO THEY MEAN?

The preceding discussion highlighted the different points along the planning / design / implementation timeline where the City's three WWTFs are positioned. This is an important consideration related to cost estimate information available at this time. The expanded and upgraded WEWPCC was recently constructed and has begun operation. The City knows the actual cost incurred for this project because it has been implemented. At the other end of the spectrum, the "comparative" cost estimation work done for the NEWPCC master planning is high-level in nature. Such cost estimates are intended to highlight relative differences between alternatives, rather than provide absolute estimates for implementation. In the middle lies the SEWPCC, where engineering design and analysis has been carried out to a level that allows the "opinion of probable cost" to be accurate, in absolute terms, within a range that various from -25% to +40% (Stantec 2008a). To provide some context for this range, as engineering work proceeds through detailed design and better defines the project infrastructure, pre-tender cost estimates are typically expected to be within about -10% to +10% of the actual tender (i.e. constructed) cost. Local market conditions for labour and materials, and uncertainty in these costs, contribute significantly to the range in cost estimate accuracy at the pre-tender stage.

In the end, the absolute accuracy of cost estimate information is highly dependent on the context within which it is generated. As shown above, the context varies significantly among the three City WWTFs. Therefore, the reader is encouraged to consider the relative nature of the cost information presented in this report rather than focusing solely on absolute cost values.

3.3 SOUTH END WATER POLLUTION CONTROL CENTRE

Based on the preliminary design activities completed to date and the current License requirements, the City has selected the preferred upgrade / expansion alternative for implementation at the SEWPCC for a design horizon that extends to Year 2031 (City of Winnipeg 2008b). All works required to accommodate this horizon would be constructed so that they are all in place by the end of 2012.

In this alternative, the liquid-stream treatment process configuration is such that all primary effluent that receives biological treatment is directed to identical bioreactor trains operated in parallel. Thus each bioreactor train provides the same level of ammonia removal via nitrification and nitrogen removal via denitrification. In general terms, for this type of process configuration and using approximate values for illustration purposes, to reach an effluent total nitrogen level of 15 mg N/L will require sufficient nitrification such that effluent ammonia levels are reduced to around 2 or 3 mg N/L from 25 to 30 mg N/L in the primary effluent. Some of the nitrate nitrogen produced by this high level of nitrification will be denitrified and converted to N_2 gas, allowing the effluent to meet the total nitrogen limit of 15 mg N/L.

Within the various required liquid-stream works for this alternative, the bioreactor configuration selected for implementation, which will provide biological phosphorus, ammonia and nitrogen removal, is termed "Option G" (Stantec 2008b,c). In wastewater process terms, the Option G configuration is a Modified Johannesburg Process with IFAS (integrated fixed-film activated sludge) media. **Figure 2** illustrates how this type of bioreactor fits into the overall SEWPCC facility. The upper portion of the figure shows a plan (overhead) view of the SEWPCC showing existing and future works. The lower portion of the figure illustrates a simplified plan view of the Option G bioreactor configuration and the individual zones within the bioreactor. There are four bioreactors in total, intended to operate in parallel. The blue-coloured anoxic (i.e. no free oxygen) zones in the bioreactors provide the total

Table 1
Provincial and Federal Policy Overview

Parameter	British Columbia[1]	Alberta[2, 7]	Saskatchewan[3]	Manitoba[4]	Federal Government[5] (MWWE)	Virginia[6] (Chesapeake Bay)
Total Phosphorous (mg P/L)	1.0 Need for, and refinement of, based on site-specific receiving environment requirements	1.0 Best Practicable Technology; may require site-specific limit (applies to populations > 20,000)	Site-specific and technology-based value	Site-specific value	Site-specific value based on environmental risk assessment	0.3 Annual average for direct discharges to tidal waters
Ortho phosphate (mg P/L)	0.5 Need for, and refinement of, based on site-specific receiving environment requirements	--	--	--	--	--
Ammonia	Maximum discharge value is determined from back calculation at end of the initial dilution zone. Back calculation must consider ambient temperature and pH of receiving environment and known water quality guidelines	Value assessed on site-specific basis (applies to populations > 20,000)	Site-specific and technology-based value	Maximum discharge value is back calculated from receiving water quality objectives that account for pH, temperature, season, and receiving water classification.	Site-specific value based on acute toxicity test results and receiving environment	--
Total Nitrogen (mg N/L)	≤ 6.0 (only Okanagan Basin facilities)	Value assessed on site-specific basis (applies to populations > 20,000)	Site-specific and technology-based value	Site-specific value	Site-specific value based on environmental risk assessment	3.0 Annual average for direct discharges to tidal waters

Notes:
[1]B.C. Reg. 129/99 Waste Management Act Municipal Sewage Regulation, April 23, 1999
[2]Alberta Environmental Protection Standards and Guidelines Branch – Environmental Assessment Division, Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems, December 1997
[3]Saskatchewan Environment – Environmental Protection Branch, Guidelines for Sewage Works Design, November 2002; Saskatchewan Environment – Environmental Protection Branch, Surface Water Quality Objectives, August 1997
[4]Manitoba Conservation, Manitoba Water Quality Standards, Objectives, and Guidelines – Final Draft, November 2002
[5]Canadian Council of Ministers of the Environment, Canada-wide Strategy for the Management of Municipal Wastewater Effluent – Draft, September 2007
[6]Virgina Administrative Code, Chapter 40, Regulation for Nutrient Enriched Waters and Discharges within the Chesapeake Bay Watershed, 9 VAC 25-40, 2007
[7]Alberta Environment (2008)

nitrogen removal. Here biological denitrification reduces nitrate nitrogen, recycled from the aerobic IFAS zones that provide nitrification, to N_2 gas.

The most recent opinion of capital cost (Stantec 2008d) estimated an overall total project capital cost of approximately $176M in 2008 dollars ($203M, expressed in dollars to reflect the 2009 to 2012 construction period). Of this total, our assessment indicates approximately $12M in 2008 dollars or 7% of the project cost is associated with the infrastructure related to the anoxic zones that provide nitrogen removal via denitrification. These costs also include impacts to other liquid-stream process units and equipment that would be affected if denitrification was not provided. Appendix A contains our assessment, which describes assumptions and methodology as well as the findings.

Provision of denitrification for total nitrogen removal does have some positive impact on annual operations costs. For example, the yield of MOs growing in anoxic zones of bioreactors is in the order of about 15% lower than that for the aerobic zones (Melcer et al. 2003). As a result, provision of total nitrogen removal would be expected to reduce the waste biological sludge (WBS) production rate. For the Option G bioreactor, which includes total nitrogen removal, the WBS is predicted to be approximately 43% of the total facility sludge production (Stantec 2008c). Without nitrogen removal, the overall WBS production rate could be in the order of 10% higher, which increases the facility total sludge production by about 5%. Stantec (2008a,d) estimated the average annual sludge hauling and tipping fee costs, for transport to the NEWPCC, for Option G to be $625K. Therefore, a 5% difference in SEWPCC total sludge production represents an annual cost of approximately $30K.

Provision of denitrification also reduces the aerobic zone oxygen requirements, since the bound oxygen contained in the nitrate generated is used by MOs in the anoxic zones for carbon oxidation. Generally speaking, this denitrification credit could be on the order of 15%, depending on the wastewater characteristics and the facility. On the basis of a variety of assumptions, some of which are from other facilities providing nutrient removal (average SEWPCC wastewater flow = 70 ML/d, unit power requirement = 350 kWh / ML wastewater treated, bioreactor aeration requirement = 40% of total facility power, power cost = $0.06/kWh), the value of this denitrification credit could be in the order of $32K per year.

In summary, by eliminating the denitrification step, the City's operating cost would be about $62K per year higher than if nitrogen removal is required.

3.4 NORTH END WATER POLLUTION CONTROL CENTRE

Based on the NEWPCC master planning activities completed to date, the City has confirmed that it currently favours an expansion / upgrade scenario similar to that of the SEWPCC: the liquid-stream treatment process configuration is such that all primary effluent that receives biological treatment is directed to identical bioreactor trains operated in parallel (City of Winnipeg 2008a). Thus each bioreactor train provides the same level of ammonia removal via nitrification and nitrogen removal via denitrification. All works required would be constructed such that they are all in place by the end of 2014 and would provide sufficient capacity to meet a Year 2031 year design horizon.

It should be noted that this currently preferred scenario, described as High Rate Wet-Weather Flow Treatment and Step Feed biological nutrient removal (Reference Scenario or Scenario 1), was one of three scenarios recommended to be carried forward for further analysis in the Phase 3 master planning activities (EarthTech 2007). Given the early stages of the project, it must be recognized that the City has not yet made a final decision on the treatment process. Rather, based on the Stage 2 master planning analysis, the City has indicated that this is the preferred scenario at this time and, as such, was selected for evaluation in this report.

Although this Scenario 1 is similar in concept to that of the preferred SEWPCC alternative, it differs in the configuration of the bioreactors used to provide biological phosphorus, ammonia and nitrogen removal. Figure 3 shows a simple profile view of the Step Feed bioreactor configuration, with this viewed used since the plan view is very complicated given the arrangement of modified existing and new bioreactors. Unlike the Modified Johannesburg Process configuration selected for the SEWPCC, the Step Feed configuration distributes the anoxic zones throughout the bioreactor. Also, the Step Feed system does not include IFAS media in the aerobic zones. While various technical and site-specific reasons explain the differences between bioreactor configurations used at the two facilities, they both provide a level of total nitrogen removal that meets the 15 mg N/L effluent criteria.

EarthTech (2007) provided a "comparative" total project capital cost estimate of $531M for this scenario, expressed in 2007 dollars. Of this total, our assessment indicates approximately $33M or 6% of the project cost is associated with the infrastructure related to the anoxic zones that provide total nitrogen removal via denitrification. These costs also include impacts to other liquid-stream process units and equipment that would be affected if denitrification was not provided. The absolute costs should not be compared directly with those for the SEWPCC since, as discussed in Section 3.2, they are based on different levels of engineering design and analysis. However, the relative cost of the denitrification infrastructure for the NEWPCC is comparable to that for the SEWPCC. Appendix B contains our assessment, which describes assumptions and methodology as well as the findings.

Given the similarity to the SEWPCC situation, it is anticipated that the relative operation cost impacts of total nitrogen removal at the NEWPCC are comparable to those of the SEWPCC discussed in Section 3.4.

4 Commentary on Nitrogen Removal

4.1 OVERVIEW

This section of the report is broken down into three main parts. Section 4.2 speaks to the practicalities of staging or phasing nitrogen removal based on the current City-preferred alternatives for the SEWPCC and NEWPCC that were developed on the assumption that total nitrogen limits will be in effect as per the current License requirements. Section 4.3 identifies the issue of nitrous oxide generation within bioreactors.

4.2 STAGING/PHASING NITROGEN REMOVAL

SEWPCC

In theory it is possible to add the nitrogen removal capability to the SEWPCC in the future. However, the physical arrangement of the proposed bioreactor configuration described in Section 3.4 would need to be modified and re-engineered to allow later construction of anoxic zones, and associated infrastructure, that provide denitrification. Assuming that the site layout can accommodate such modification, there would be challenges in maintaining facility operations while constructing the new works. Again, with sufficient planning and effort, which translates into costs, such challenges can likely be overcome. Constructing these works in the future would also exact a cost premium from the construction contract perspective. The City would incur additional contractor mobilization and demobilization costs associated with the future construction contract, as well as internal costs, plus the City would lose the inherent cost efficiencies of having the contractor on-site at one time to build all the works initially.

The current License requires the SEWPCC to produce effluent that meets the total nitrogen requirements after December 31, 2012. Given the remaining design activities, facility construction and commissioning, the implementation schedule to meet this date practically eliminates phasing of the infrastructure needed to provide nitrogen removal.

As noted in Section 2.4, the current costs associated with the provision of nitrogen removal at the SEWPCC are relatively small at an estimated 7% of the total project capital cost. On this basis, and in consideration of the factors discussed above, it can be argued that phasing nitrogen removal in this situation is of little practical monetary benefit.

NEWPCC

The nitrogen removal phasing issues and arguments presented above for the SEWPCC apply for the currently preferred scenario for the NEWPCC. Given the NEWPCC site layout and infrastructure, it would be likely even more onerous to attempt to stage nitrogen removal given the upgrade scenario, even if the bioreactor configuration could be re-engineered. EarthTech (2007) noted that the entire secondary treatment process would have to be constructed in one stage. Furthermore, although the current License requires the NEWPCC to produce effluent that meets the total nitrogen limit by a later date relative to the SEWPCC, December 31, 2014, the City is still at a master-planning stage. Given the additional planning and engineering required, and considering the substantial size of the NEWPCC project and the potential construction period, the practical opportunity to phase construction of infrastructure required for total nitrogen removal is very limited.

In light of the relatively small cost of the infrastructure that provides nitrogen removal in this scenario, and other issues identified, there again appears to be little benefit in attempting to phase nitrogen removal at the NEWPCC in this scenario.

4.3 NITROUS OXIDE GENERATION AND MITIGATION

Like many issues in the scientific and engineering world, nitrous oxide generation in wastewater treatment bioreactors has only very recently attracted significant industry attention because of a rapidly developing concern, which, in this case, is climate change. The wastewater industry has much to learn about N_2O generation mechanisms, the significance of N_2O emissions relative to the overall carbon footprint of a WWTF, and mitigation measures to reduce emissions. It will be important for the City to remain aware of developments in this subject area as it plans, designs and implements its wastewater treatment infrastructure.

5 Summary

The City of Winnipeg is developing upgrading / expansion strategies for the SEWPCC and NEWPCC based on the current Manitoba Environment Act Licenses. Among other requirements, these licenses require the facilities to produce effluent that meets a total nitrogen limit of 15 mg N/L by December 31 in 2012 and 2014, respectively, for the SEWPCC and NEWPCC. Based on the City's currently preferred alternatives for meeting this and other requirements for a design horizon that extends to Year 2031, the relative capital cost of the infrastructure that provides nitrogen removal is in the order of 6 to 7% of the total facility capital costs. For the SEWPCC, this cost is about $12M, in 2008 dollars, based on the latest preliminary engineering level estimate. The value for the NEWPCC is $33M, in 2007 dollars and based on a master planning level estimate. Specifically, this relative cost applies to the denitrification portion of the biological process that provides some level of total nitrogen removal.

In light of the relatively small cost of the infrastructure that provides total nitrogen removal for these preferred alternatives, there appears to be little benefit in attempting to phase nitrogen removal at either the SEWPCC or NEWPCC within the time frame of the current License requirements. Furthermore, the implementation schedule to meet the current requirements practically eliminates phasing of the required infrastructure. Finally, the ability to do so, particularly for the NEWPCC, may be precluded by site layout and constructability issues.

From a broader environmental perspective related to wastewater nitrogen removal, nitrous oxide generation within wastewater treatment bioreactors is attracting increased industry attention as municipalities and utilities consider the carbon footprint of their operations. Although there are considerable gaps in current knowledge at this time, it will be important for the City to remain aware of developments in this subject area as it plans, designs and implements its wastewater treatment infrastructure.

With the planning, design and implementation window shrinking for the SEWPCC and WEWPCC projects, urgency exists with respect to coming to a definitive conclusion on both the need for and timing of effluent total nitrogen limits. Such conclusion will assist the City in making fiscally responsible decisions while maximizing the environmental, social and economic benefits of the wastewater management service it provides.

References

Alberta Environment. 2008. Personal communication with B. Aidun, October 10, 2008.

Barton, P.K., Atwater, J.W. 2002. Nitrous oxide emissions and the anthropogenic nitrogen in wastewater and solid waste. Journal of Environmental Engineering, **128**(2): 137 – 150.

City of Calgary. 2008. E-mail communication with L. Amatya, October 1, 2008.

City of Winnipeg. 2008a. E-mail communication with D. Gibson, October 1, 2008.

City of Winnipeg. 2008b. Personal communication with N. Szoke, October 2, 2008.

Environment Canada. 2001. Nutrients in the environment – reporting on the state of Canada's environment.

EarthTech. 2007. NEWPCC master plan phase 2 technical memorandum 0110-A-59-10, September 2007.

Galloway, J.N., Townsend, A.R., Erisman, Y.W., Bekunda, M., Cai, Z, Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A. 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science, **320**: 889 – 897.

Melcer, H., Dold, P.L., Jones, R.M., Bye, C.M., Takacs, I., Stensel, H.D., Wilson, A.W., Sun, P., Bury, S. 2003. Methods for wastewater characterization in activated sludge modeling (99-WWF-3). Water Environment Research Foundation, Alexandria, VA.

Saskatchewan Ministry of Environment. 2005. Anticipated effluent discharge criteria for the City of Saskatoon – October 2005. Received from City of Saskatoon on October 6, 2008.

Saskatchewan Ministry of Environment. 2008. E-mail communication with S. Grainger, September 30, 2008.

Stantec. 2008a. SEWPCC Upgrading/Expansion Preliminary Design Report, March 31, 2008.

Stantec. 2008b. SEWPCC Upgrading/Expansion Technical Memorandum #24 – BNR Process Refinement, May 30, 2008.

Stantec. 2008c. SEWPCC Upgrading/Expansion Technical Memorandum #28 – BNR Process Selection, June 5, 2008.

Stantec. 2008d. SEWPCC Upgrading/Expansion Opinion of Probable Cost, August 2008.

Stantec. 2008d. E-mail communication with S. Basu, October 6, 2008.

Stantec. 2007. SEWPCC Upgrading/Expansion DRAFT Technical Memorandum #19 (Revision 1) – Regulatory Requirements, February 14, 2007.