THESIS

NUTRIENT MANAGEMENT CONTROL REGULATION AND PREPAREDNESS OF A NORTHERN COLORADO WASTEWATER TREATMENT PLANT

Submitted by

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ABSTRACT

NUTRIENT MANAGEMENT CONTROL REGULATION AND PREPAREDNESS OF A NORTHERN COLORADO WASTEWATER TREATMENT PLANT

Excessive nutrients in wastewater treatment plant (WWTP) effluents instigate eutrophication of receiving water bodies. Colorado Department of Public Health and Environment (CDPHE) adopted nutrient management control regulation, also known as regulation 85, to moderate the nutrients released by point sources such as the WWTP effluents. City of Loveland WWTP was selected as the study plant to determine a new treatment process configuration to meet the new limits of total phosphorus < 1 mg/L and total inorganic nitrogen < 15 mg/L in the effluent. BioWin, a windows based modeling software, was used to model and simulate the City of Loveland WWTP. Existing activated sludge step feed process configuration was modeled along with proposed anaerobic, anoxic, oxic (A2O) process for design influent flow of 10 MGD and 5-stage Bardenpho process for future flow of 12 MGD along with A2O process. Existing configuration was modeled to establish the accuracy of BioWin. 5 stage Bardenpho process modeling indicates that higher design HRT of 2 days for anaerobic, 4 days for anoxic, 6 days for aerobic, 4 days for secondary anoxic and 1 day for reaeration has better treatment removal efficiency for nutrients with methanol dosage of 250 gal/d and 1Q internal recycle. Model simulations for A2O process reveals that aerobic reactor to anaerobic reactor volume ratios from 3 to 4 and aerobic reactor to anoxic reactor volume ratio of 2.2 along with internal recycle of 1Q has the better nutrient removal efficiency for design flow of 10 MGD. For 12 MGD influent flow, volume of reactors was increased by 20% to compensate for 20% increase in the flow. Previously mentioned reactor volume ratios are feasible for 12 MGD influent flow with volume

ratios of 3 and 4 for aerobic to anaerobic reactors and volume ratios of 1.8 and 2 for aerobic to anoxic reactors. Modeling results indicates that increasing the reactor volume ratio for increased flow can result in better treatment for removal of nutrients with a conservative volume, reducing the operational and maintenance cost.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

Presence of nutrients in surface water has become one of the major environmental issues as they can lead to eutrophication of surface waters and cause algal growth. Point source pollution such as wastewater treatment plant effluent discharge is the main contributors of nutrients to surface waters. Eutrophication leads to hypoxia, depletion of oxygen in water body. Depleted oxygen level increases fish mortality. The increase in phytoplankton decreases water quality. Taste and odor compounds such as geosmin and 2-methylisoborneol (MIB) are detected in water with the presence of cyanobacteria. Some algae even release toxins, harmful to humans and animals if ingested (Val et al., 2002; Lanciotti et al., 2003; Wnorowski, 1992). Presence of algae in source water makes it difficult to treat it to drinking water standards.

Colorado department of public health and environment (CDPHE) has passed nutrient management control regulation known as regulation 85, setting numerical limits for nutrients in WWTP effluent. The new limit for total phosphorus is < 1mg/L and for total inorganic nitrogen <15 mg/L. To meet these effluent limits number of WWTPs' across Colorado has to upgrade their treatment process with better BNR process coupled with/without chemical addition.

This thesis contains two main chapters: Chapters 2 and 4. Chapter 2 provides literature and background information about nutrients and its consequences, various nutrient treatment methods, introduction to BioWin and basic information about City of Loveland WWTP. Chapter 3 presents the problem statement and the aim of research. Chapter 4 is in a manuscript format and covers methods for simulation of A2O and 5 stage Bardenpho processes along with results and discussion of outputs from those simulations. Appendix includes effluent concentration for all the simulations performed with graphical representation of those values

CHAPTER 2. LITERATURE AND BACKGROUND INFORMATION

2.1. Contaminants of concern in wastewater effluents

Discharge of detrimental contaminants in wastewater can severely impact the surface water quality such as the organic carbon content (McConnell, 1980), the nutrient uptake efficiency (Haggard et al., 2001; Marti et al., 2004), bacterial levels (Petersen et al., 2005), and hydrologic characteristics (Dennehy et al., 1998). Among the wastewater contaminants, the organic matter and nutrients (nitrogen and phosphorus) play a crucial role.

Organic content is measured using the biochemical oxygen demand (BOD) test, and can be treated and removed by the secondary treatment units of the wastewater treatment plants to meet the effluent discharge regulations set by the EPA (Carey and Migliaccio, 2009). Nitrogen species include: ammonia, ammonium, nitrate, nitrite and nitrogen gas itself (Carey and Migliaccio, 2009). Nutrients can be treated using biological, physical or chemical methods. Biological treatment employs microorganisms and are sensitive to environmental conditions such as temperature, pH, toxic metals, etc. Chemical treatment usually involves addition of coagulants such as alum and ferric, and precipitating out the nutrients. Stripping, a physical method works well for ammonia removal. If the nutrients are not efficiently removed, they end up in the wastewater effluent and are discharged to receiving surface bodies (Carey and Migliaccio, 2009; Hager and Schemel, 1992; Andersen et al., 2004; Gibson and Meyer, 2007).

Nutrients are introduced to surface waters also by non-point source pollution such as run off from agricultural land. Researchers have reported that the nutrients added by point sources such as wastewater effluents are in higher concentration than those added by non-point source pollution (Ahearn et al., 2005; Popova et al., 2006; Migliaccio et al., 2007). Most of the aquatic systems have very low nutrient concentrations and small shifts can result in dramatic changes in the community structure. (Miltner and Rankin, 1998; Dodds and Welch, 2000; Rabalais, 2002). The rivers and streams were assumed to be immune to nutrient enrichment by early researchers (Miltner and Rankin, 1998; Hynes, 1969). However evidence shows that surface waters are affected by excess nutrients loadings (Carey and Migliaccio, 2009; Hecky and Kilham, 1988; Matlock et al., 1998; Carey et al., 2007; Ohte et al., 2007).

2.2. Adverse impacts of nutrients on surface waters

2.2.1. Eutrophication

Sustained loading of phosphorus and/or nitrogen to surface waters leads to over enrichment of nutrients which leads to eutrophication (Correll, 1999). The common cause of eutrophication in freshwater lakes, reservoirs, streams and in headwater of estuarine system is because of excessive concentration of phosphorus. For eutrophication, it is generally assumed that phosphorus is the limiting factor in surface water and nitrogen is the limiting factor in ocean (Correll, 1999).Increased algal biomass, decreased water transparency, low dissolved oxygen (DO), increased fish mortality and frequent incidences of toxic phytoplankton are some of the issues related to eutrophication (Burkholder et al., 1992; Carpenter et al., 1998; Smith, 1998). Bioavailability of nutrients is the main factor that affects eutrophication. Decreased DO leads to release of metals and other compounds that are bound to bottom sediments including phosphorus, manganese and iron (Sundby et al., 1986). Autotrophs can assimilate only orthophosphate

2.2.3. Taste and Odor

Drinking water with off taste and odors may be related to algal blooms in surface waters. Off-flavors in source and drinking waters are caused by algal metabolites such as geosmin and 2-methylisoborneol (MIB). Cyanobacteria mostly contribute to production of geosmin and MIB during spring and summer whereas actinomycetes do so during autumn and winter. The best way to control eutrophication is to reduce the discharge of phosphorus to minimize algal blooms and hence the algal metabolites (Omur-Ozbek and Dietrich, 2005; Val et al., 2002; Lanciotti et al., 2003; Wnorowski, 1992).

2.3. Use of wastewater effluents as resource

2.3.1. Irrigation

Wastewater effluent has nutrients that can be utilized to grow crops rather than contaminating to the surface waters. Crops yield is augmented when effluent water is used for irrigation as a result of nutrients present in the wastewater. Excessive application of effluent water for irrigation should be restrained to prevent accumulation to soil. Wastewater effluent stored in reservoirs is economically profitable as it ensures availability of water to crops during dry seasons and can reduce the amount of freshwater used for irrigation. (Darwish et al., 2007; Al-Nakshabandi et al., 1997; Eduardo et al., 1996).

2.3.2. Reuse

In places where there is a substantial shortage of surface water for industrial use, wastewater effluent can be used as a source of industrial water. Using effluent requires alteration in pre-treatment of wastewater, to prevent fouling of ultra-filtration and reverse-osmosis membranes (Shang, 2011). Breweries, mining, textile industry, steel plants and as number of other industries benefit from reused wastewater effluents (Asano et al., 2007)In arid regions, wastewater effluents can be reused for domestic purpose with advanced treatment. Water reuse can be categorized into the following: Urban reuse, Agricultural reuse, Recreational impoundments, Environmental reuse and Industrial reuse. Direct contact with reused water can cause health problems like skin irritation and water borne diseases. Environmental Protection Agency has strict quality control for reclaimed water (Manuel and Bruce, 1999).

2.3.3. Recharge of Groundwater

Wastewater effluent, after suitable treatment, can be injected into aquifers for recharging. Reclaimed water should be of desirable quality to prevent the contamination of ground water with organic materials, nutrients, toxic substances and emerging contaminants. Soil aquifer treatment is a natural process that refines the percolating water. It has three processes: physical, biological and chemical. Filtration removes particles that remain in wastewater effluent. In biological treatment, the micro-organisms break down the degradable organic matter that may linger in water. Chemical process takes place through oxidation, reduction and neutralization. These steps should reduce the amount of contaminants reaching the aquifer (Bekele et al., 2011; Johnson, 2008). Effluents, if contaminated to a reasonable extent, can be mixed with fresh water and used for irrigation, recharging the aquifer indirectly (Ayni et al., 2011).

2.4. Consequences of inefficiently treated WWTP effluent

Raw wastewater has organic materials, nutrients, chemicals, suspended particles and pathogens, which needs to be treated before releasing into natural streams and rivers. Organic materials are characterized using biological oxygen demand (BOD) tests, and are oxidized by micro-organisms using oxygen. When BOD is not efficiently treated in WWTP, it contaminates natural stream consuming dissolved oxygen (DO) present in them and results in anaerobic conditions and loss of aquatic organisms. Besides causing hypoxic conditions presence of organic matter also makes water non potable for downstream users (Brian et al., 2005).

2.5. Regulation limits

2.5.1. History of regulation limits

George et al., (2003) in the book Wastewater Engineering: Treatment and Reuse states the following:

> "*From about 1970 to 1990s, treatment objectives were mainly focused on removal of suspended, colloidal and floatable material, treatment of biodegradable organics and elimination of pathogenic organisms. Implementation of Clean Water Act in 1972 in United States stimulated substantial changes in wastewater treatment to achieve the objectives of fishable and swimmable waters. Earlier objectives remained the same but the standard has risen to higher level. To improve the quality of surface waters, the state and federal agencies have undertaken many programs. These programs were based on 1) an increased understanding of the environmental effects caused by wastewater discharges; 2) a greater appreciation of the adverse long term effects caused by the discharge of constituents in wastewater; and 3) development of national concern for the protection of environment".*(George et al., 2003)

The definition of secondary treatment was updated in 1985 which includes three major effluent parameters, 5-day BOD, TSS and pH. Water Quality Act of 1987 was legislated by Congress as a key revision to Clean Water Act. Important specifications in Water Quality Act were; 1) strengthening water quality regulations by imposing penalties for permit violations, 2) financing grants for state and U.S.EPA studies for classifying toxic sources and non-point pollution, 3) gradually terminating the construction grants program as a process of funding publicly owned treatment works (POTW), 4) establishing deadlines for defiance including priorities and permit requirements for stormwater, and 5) significantly amending the CWA's formal sludge control program (George et al., 2003; Qasim, 1999). Following are some of the water pollution control legislations passed in the United States (US EPA, n.d; Qasim, 1999):

- Federal Water Pollution Control Act Of 1948
- Federal Water Pollution Control Act Of 1956
- Federal Water Pollution Control Act Amendments Of 1961

- Water Quality Act Of 1965
- Clean Water Restoration Act Of 1966
- Water Quality Improvement Act Of 1970
- Federal Water Pollution Control Act Amendments Of 1972
- Clean Water Act Of 1977
- Clean Water Act Amendments Of 1981
- Clean Water Act Amendments Of 1987

2.5.2. Regulating organizations

5.2.1. Colorado Department of Public Health and Environment (CDPHE) is responsible for protecting and maintaining the health of residents of Colorado. The Department has 13 main health and environment divisions including Family Health Services; Disease Control and Environmental Epidemiology; Consumer Protection; Hazardous Materials and Waste Management; Water and Air Pollution Control; Radiation Control; Health Statistics and Vital Records; Health Facilities; the Rocky Flats Program (coordinates the state's oversight of the Rocky Flats nuclear weapons plant northwest of Denver); Emergency Medical Services; Laboratory Division -- chemistry, microbiology, alcohol testing, and newborn screening sections, and a toxicology program; and the Division of Prevention Programs. Main objective of CDPHE is to implement the regulations set by U.S. EPA (CDPHE, n.d).

5.2.2. The U.S. Environmental Protection Agency (EPA) is an agency of the federal government of the United States bestowed with protecting human health and the environment, by setting and enforcing regulations based on the laws passed by Congress. EPA was established on December 2nd, 1970. EPA has 10 regional offices spanned across United States endeavored at upholding the highest quality of Air, Water and Land. The main legislations passed are for air, water, land, endangered species and hazardous waste. State of Colorado is under Region 8, head office is located in downtown Denver, capital of Colorado. Any concern related to environment in United States is either directly under supervision of EPA or under the supervision of state agencies which in turn is regulated by EPA. EPA gives directive to state agencies about new regulations and permits. Some of the major programs undertaken by EPA are energy star, pesticide, environmental impact statement review, safer detergents stewardship initiative, fuel economy, air quality, oil pollution, WaterSense, drinking water and radiation protection (US EPA, n.d).

2.5.3. Regulation permits

2.5.3.1. National Pollutant Discharge Elimination System (NPDES)

Under NPDES program discharge of pollutants to surface waters in United States by any point source requires NPDES permit. The administering agency model the response of the receiving body to the proposed discharge to adjudge if the receiving body is adversely affected before granting the permit. Effluent restrictions are established for conventional, non-conventional, toxic, and hazardous pollutants based on their levels of concentration in the effluent for the permit. Industrial pretreatment standards are being developed for all pollutants that "interfere with, pass through, concentrate in sludge, or otherwise are incompatible" with the publicly owned treatment works (POTWs). Two pretreatment standards are formed under the pretreatment regulations: 1) prohibited discharge and 2) categorical standards. Discharges that cause fire or explosion hazard, corrosion, obstruction, slug discharge, and heat discharge to sewers or POTWS are classified as prohibited discharge. The pollutants that set off hindrance with operation of POTWs, contamination of sludge and residue from POTWs are categorized as categorical standards. (40 CFR, Part 403 1995; Miller et al., 1991; US EPA, n.d)

2.5.3.2. Total Maximum daily Loads (TMDL)

A TMDL enumerates the maximum amount of pollutant that a water body can accept and yet meet water quality standards. It also earmarks the maximum pollutant loadings that will be supplemented by point and nonpoint sources. This is computed on a pollutant-by-pollutant basis for a list of pollutants. The TMDL computation is defined as:

$$TMDL= \Sigma\ WLA + \Sigma\ LA + MOS$$

Where,

WLA= waste load allocation, portion of TMDL assigned to existing and future point sources

LA= load allocation, portion of TMDL assigned to existing and future nonpoint sources

MOS= margin of safety

The uncertainty in relationship between loads and water quality is accounted by margin of safety. Better assessment science integrating point and nonpoint sources (BASINS) that integrates geographic information system (GIS), national watershed and meteorological data, and state–of-the-art environment assessment and modeling tools are used for developing TMDL (George et al., 2003; Mackenzie, 2011; U.S. EPA, n.d).

2.5.4. Upcoming regulations

Colorado department of Public Health and Environment is updating regulations and proposing newer regulations for improvement of water quality throughout the state. CDPHE is updating Basic Standards and Methodologies for Surface Waters also known as Regulation 31. Along with this, a more strict regulation, Nutrient Management Control Regulation known as Regulation 85 is proposed. Regulation 85 is a state wide discharge permit system, which means all the domestic wastewater treatment works (DWWTW) are required to meet the same discharge limits. DWWTW with daily flow of less than or equal to 1 million gallons per day that uses waste stabilization pond for treatment, owned by disadvantaged community and with a flow of less than 0.5 million gallons per day are excluded from the new regulation. Regulation 85 has separate regulation limits for treatment plants in operation as of May 31st, 2012 and for plant that will be operating after May 31st, 2012 (Regulation 85, 2012). Table 2.1 shows the regulation limits for treatment works discharging before May 31st, 2012 (Regulation 85, 2012).

Table 2.1: Regulation limits for discharging waterworks before May 31st, 2012

Parameters	Parameter limitations	
	Annual median[1]	95th percentile[2]
(a) Total Phosphorus	1.0 mg/l	2.5 mg/l
(b) Total Inorganic Nitrogen as N[3]	15 mg/l	20 mg/l

1 Running Annual Median: The median of all samples taken in the most recent 12 calendar months.

2 The 95th percentile of all samples taken in the most recent 12 calendar months.

3 Determined as the sum of nitrate as N, nitrite as N, and ammonia as N.

Table 2.2 shows the regulation limits for treatment works that will be discharging after May 31st, 2012 (Regulation 85, 2012).

Table 2.2: Regulation limits for waterworks discharging after May 31st, 2012

Parameters	Parameter limitations	
	Annual median[1]	95th percentile[2]
(a) Total Phosphorus	0.7 mg/l	1.75 mg/l
(b) Total Inorganic Nitrogen as N[3]	7 mg/l	14 mg/l

1Running Annual Median: The median of all samples taken in the most recent 12 calendar months.

2 The 95th percentile of all samples taken in the most recent 12 calendar months.

3 Determined as the sum of nitrate as N, nitrite as N, and ammonia as N.

2.5.5. Current limits

According to the Clean Water Acts, each state and area agencies were entailed to develop a water quality management (WQM) plan that characterizes sources and severity of pollution and required programs to control pollution. Total maximum daily loads for surface waters are established as a part of WQM process (Qasim, 1999). The water bodies are categorized as water quality-limited or effluent-limited. If water quality standards are met by uniform national discharge limits, water body is considered as effluent limited, permitting the municipal treatment works to achieve only secondary treatment. When a water body is classified as water quality-limited, it requires stricter treatment to meet state's standards. EPA uses 5 day BOD, TSS, 5 day CBOD and pH as main parameters for effluent quality monitoring. Table 2.3 shows the minimum level of effluent quality attainable by secondary treatment as defined by EPA (40 CFR, Part 133 1995; Qasim, 1999)

Table 2.3: Minimum level of effluent quality attainable by secondary treatment

30-Day average			7-Day average
Effluent parameter	Maximum concentration, mg/l	Minimum removal, %	Maximum concentration, mg/l
BOD_5	30	85	45
$CBOD_5$	25	85	40
TSS	30	85	45
pH	Between 6.0 and 9.0		

2.6. Treatment of Nutrients

2.6.1. Physical treatment

In general it is assumed that 2-3 % of organic solids in wastewater is P. Taking this into account total suspended solids (TSS) of 20 mg/L in the effluent will have 0.4-0.6 mg/L P (Strom, 2006). In wastewater treatment plants' that employ Enhanced Biological Phosphorus Removal (EBPR), P content is higher. Sand filtration, membranes, chemical precipitation and other methods of TS removal might be necessary for treatment plants with permits for low effluent TP (Reardon, 2006). Membrane Technology has been used for treatment of wastewater for many years, now with more focus on P removal. Membranes can remove P in TSS and dissolved P as well. Research indicates that treatment plants using membrane bioreactors that incorporates, membrane technology in a suspended growth secondary treatment, tertiary membrane filter and reverse osmosis (RO) have achieved levels less than 0.1 mg/L of TP in the effluent (Reardon, 2006; Strom, 2006).

2.6.2. Biological treatment

Microorganisms are used for stabilizing wastewater. They can convert colloidal and dissolved carbonaceous organic matter into gases and protoplasm. Specific gravity of protoplasm is greater than water and can be treated by gravity settling. If the protoplasm is not removed from the water, complete treatment cannot be achieved and this will emerge as BOD in the effluent. Along with helping in stabilizing the organic matter, some organisms helps to treat nutrients that affects eutrophication. Microorganisms are classified depending on the energy and carbon source, oxygen relationship and temperature (Mackenzie, 2011). Microorganism growth in reactors can be classified into attached growth reactors (e.g. trickling filter) and suspended growth reactors (e.g. oxidation ditch). For removal of nutrients, nitrogen and phosphorus, there are separate and combined methods (Mackenzie, 2011).

2.6.2.1. Nitrification/Denitrification

Nitrification utilizes a two-step biological process for conversion of ammonia to nitrite and then nitrite to nitrate under aerobic conditions. This conversion takes place with help of two specific groups of autotrophic bacteria, Nitrosomonas and Nitrobacter. Carbon dioxide is used as carbon source and inorganic chemicals as a source of energy by chemoautotrophic bacteria.

Nitrosomonas uses ammonia as an energy source while Nitrobacter uses nitrite. Stoichiometry of a reaction defines the proportion of reactants and products involved in a process. It helps us to determine which reactant will limit the reaction (WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006).

The molar ratios for oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) by Nitrosomonas is defined by the following stoichiometric equation

$$NH_4^+ + 1.5\ O_2 = NO_2^- + 2\ H^+ + H_2O$$

The equation describing the oxidation of nitrite to nitrate (NO_3^-) by Nitrobacter is as follows,

$$NO_2^- + 0.5\ O_2 = NO_3^-$$

Nitrification can take place in suspended growth system for example single sludge nitrification and separate sludge nitrification and in attached growth system for instance trickling filter and rotating biological contractors.

Denitrification is the process in which nitrite and/or nitrate is biologically reduced to nitrogen gas in the absence of dissolved oxygen. Presence of little or no oxygen in a biological environment is termed as anoxic. Organic carbons are metabolized by bacteria consuming oxygen in nitrite or nitrate. Heterotrophic bacterial species present in a typical biological treatment process can be used to remove nitrogen.

Broad range of substrates can be used by heterotrophic bacteria for achieving denitrification. Some of the substrates commonly used as a carbon source for denitrification are: acetic acid, organics present in wastewater (CBOD), methanol, food processing organic waste materials (sugars) and ethanol.

Stoichiometric equation using methanol as a carbon source for denitrification is as follows,

$$6\ NO_3 + 5\ CH_3OH + H_2CO_3 = 3\ N_2 + 8\ H_2O + 6HCO_3^-$$

Combined nitrification/ denitrification treatment is used to remove nitrogen along with CBOD using a series of several reactors and along with a common secondary clarifier. Combined system helps to reduce the capital cost and operations cost along with increased operational challenge to balance the environment of several processes (WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006).

Combined process can be classified into following ways,

- Method of aeration
- Flow regime
- Fixed growth versus suspended growth
- Staging of process sequence.

Alternating environments that are sequentially used to nitrify and denitrify is mutual among all the process. Before denitrification takes place, nitrification has to be completed atleast partially. Three main parameters that can affect denitrification and total nitrogen removal are:

- Denitrification capacity (biomass and/or detention time)
- Substrate (CBOD)
- Nitrate.

There are several processes that are used for combined removal of nitrification and denitrification.

Some of them are:

- Wuhrmann Process
- Modified Ludzac-Ettinger Process

- Bardenpho Process (Four-Stage)
- Sequencing Batch Reactors
- Cyclically Aerated Activated Sludge
- Oxidation Ditch Processes
- Countercurrent Aeration.

Sometimes hybrid systems are used for better treatment. When several technologies are combined together to create a new process it is called as hybrid system (WEF, ASCE, EWRI-MANUAL OF PRATICE NO. 30, 2006). The two common type of Hybrid system in use are:

- Integrated Fixed-Film Activated Sludge (IFAS)
- Membrane bioreactors (MBR).

2.6.2.2. Enhanced Biological Phosphorus Removal (EBPR)

Enhanced Biological Phosphorus Removal depends on microbial population that can store orthophosphates in excess of their biological growth requirements. These organisms are called as phosphate accumulating organisms (PAOs). They thrive on special conditions that put them in an advantage over others by temporarily restricting other organisms from accessing food. When this special condition befalls, they accumulate excessive orthophosphate in mixed liquor. Phosphorus removal can occur by wasting proper mixed liquor. PAOs are heterotrophic organisms that are present in almost all the secondary wastewater treatment plants that employ activated sludge process. They rely on oxygen for energy generation and organic carbon source for growth. Heterotrophs can grow with absence of oxygen and presence of other electron acceptors such as nitrate (NO_3^-), unlike autotrophs that need carbon dioxide in soluble form HCO_3^- (bicarbonate alkalinity) as carbon source for growth and strict need for oxygen. The PAOs can survive in aerobic and anoxic condition as long as the only requirement is sustained, presence of anaerobic zone ahead of secondary treatment where primary influent is introduced and there is an absence of electron acceptor (WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006).

EBPR systems success depends on the presence of following:

- Availability of organic carbon and phosphorus in the secondary influent in sufficient amounts
- Anaerobic selector zone is in exact size, preceding all the other zones where electron acceptors are maintained for their growth
- Cations such as magnesium and potassium are present in sufficient amounts to allow proper release and uptake of phosphate.

Some of the parameters that are important for operation on EBPR process are:

- Influent composition and chemical oxygen demand to phosphorus ratio
- Solids retention time and hydraulic retention time
- Temperature
- Recycle flows
    - Internal Recycle
    - Plant Recycles.

Following are the types of Enhanced Biological Phosphorus removal:

- Suspended growth system
    - Anaerobic/Oxic and Anaerobic/Anoxic/Oxic Configurations
    - Modified Bardenpho configuration
    - University of Cape Town, Modified University of Cape Town and Virginia Initiative Process Configuration
    - Johannesburg Configuration

    - Oxidation Ditches, BioDenipho and VT@ Configurations.
- Hybrid systems
    - PhoStrip Configuration
    - Biological Chemical Phosphorus And Nitrogen Removal Configuration (BCFS).

2.6.2.3. Combined nutrient removal

Removal of phosphorus and nitrogen can be achieved by biological and chemical methods. Biological removal method has significant advantages such as lower operating costs, less sludge production and scarcely or no added chemicals in the sludge. The removal of total nitrogen in a combined nitrogen and phosphorus removal wastewater treatment plant is completed in a two zone system through nitrification under aerobic conditions and denitrification, under anoxic conditions. Due to meddling of nitrates on anaerobic conditions vital for biological phosphorus removal process, three different zones are required to maintain different environmental conditions for combined removal of nitrogen and phosphorus (WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006).

The process for removal of phosphorus and nitrogen from wastewater can be easily incorporated in a activated sludge process. All these removal process has certain stages in common such as:

- An anaerobic zone free of dissolved oxygen and nitrate
- An anoxic zone for denitrification of nitrates
- An aerobic zone where conversion of ammonia to nitrates takes place.

Some of the processes used for combined removal of nutrients are:

- Five stage Bardenpho Process
    - Barnard in 1976 proposed Bardenpho process for combined nitrogen and phosphorus removal. It consist of adding an anaerobic zone ahead of high rate

non-nitrifying aeration basin or ahead of modified Ludzack-Ettinger (MLE) process or ahead of four stage Bardenpho process

- Phoredox (A^2O) Process
    - This process consist of an anaerobic zone for phosphorus removal ahead of MLE process
- University of Cape Town and Virginia Initiative Process
    - This process has influent wastewater flowing into anaerobic zone and return sludge flowing to anoxic zone. Nitrified mixed liquor from aerobic zone is pumped to anoxic zone and denitrified effluent from anoxic recycled to anaerobic zone
- Modified University of Cape Town Process
    - This process has two anoxic zone next to each other with first receiving effluent from anaerobic zone along with return sludge while the second receives mixed liquor from aerobic zone
- Johannesburg and Modified Johannesburg Processes
    - This process has the following zone in order: anoxic, anaerobic, anoxic and aerobic with influent flow going to anaerobic zone. This configuration results in endogenous denitrification
- Westbank Process
    - This same as Johannesburg process but with 10 % of influent flow to the first anoxic zone

- The Orange Water and Sewer Authority Process
  - In this treatment process anaerobic zone is provided in the sidestream reactor with phosphorus uptake taking place in aerobic zone
- Cyclical Nitrogen and Phosphorus Removal Systems
  - These are sequencing batch reactors that are extremely flexible, relatively inexpensive and very effective treatment systems for small to medium sized facilities

2.6.3. Chemical Treatment

2.6.3.1. Addition of metal salts

The chemicals can be added at different places in the treatment process. The points it can be added are:

- Raw sewage
- Primary Clarifier
- Bioreactor
- Tertiary clarification.

The chemicals can be added to one point or can be added to multiple points (Bruce, 2009). The point in which it is added can affect the treatment and removal of phosphorus.

The chemical phosphorus removal has two steps:

1) Metal hydroxide floc absorbing soluble phosphate (PO_4^{-3})
2) Metal hydroxide/phosphate floc separating from liquid phase by settling in clarifier or filtration.

Most commonly used metal salts are:

1) Iron: Ferrous (+2) chloride, Ferric (+3) and sulfate ($FeCl_3$, $FeCl_2$, $Fe_2(SO_4)_3$, Fe_2SO_4

2) Aluminum: Alum or Poly Aluminum chloride.

2.7. BioWin

2.7.1. Introduction

BioWin is a software developed by EnviroSim used for modeling and simulation of municipal wastewater treatment plants which is an accurate, powerful and easy to use Microsoft windows based simulator. BioWin has been used worldwide to simulate and predict outcome of a process before employing it in the plant (EnviroSim, 2003).

2.7.2. Applications of BioWin

Leading consultanting agencies use BioWin for modeling their clients' treatment plant. With use of BioWin those agencies can model and explain treatment process to clients by presenting them effluent data in form of tables and graphs generated in the model. There are lots of basic parameters that can be modified to exactly calibrate the plant that is being modeled. The developed WWTP model can be simulated for steady state and dynamic conditions. Diurnal flows and temperature fluctuations can be entered and obtained. Parker et al., used BioWin to predict biogas production with default COD/VSS ratio, Locke et al., did dynamic simulation of wet weather model to determine the impact of wet weather operations on total nitrogen removal during severe storm, Takács et al., did analysis of uncalibrated model and BioWin's kinetics and stoichiometric parameters were evaluated and compared with same parameters of other models used, Park et al., used BioWin model simulations and respirometric techniques to evaluate pulp and paper wastewater treatment plant performance, Ramalingam et al., modeled a two-step nitrification process in BioWin to determine its reliability to deploy in New York City Department of Environmental Protection (NYCDEP) facilities, Latimer et al., has provided comparison of the site specific data to BioWin defaults and illustrated some of the impacts and key issues to BNR/ENR modeling and design, Jones et al., simulated a whole plant model with mainstream and sidestream reactions to determine different operation modes and control strategies, Holland et al., used BioWin model to determine TN removal in modified Ludzck-Ettinger membrane bioreactor, Lei et al., modeled City of Avondale wastewater treatment plant and determined best treatment process for 15 MGD influent flow (Parker et al., 2007; Locke et al., 2006; Takács et al., 2007; Park et al., 2007; Ramalingam et al., 2007; Latimer et al., 2007; Jones et al., 2007; Holland et al., 2006; Lei et al., 2006; Sierra et al., 2006; Johannessen et al., 2006; Corominas et al., 2010; Wang et al., 2012). Figure 2.1 shows a model of WWTP in BioWin. The wastewater treatment plant has step feed activated sludge process.

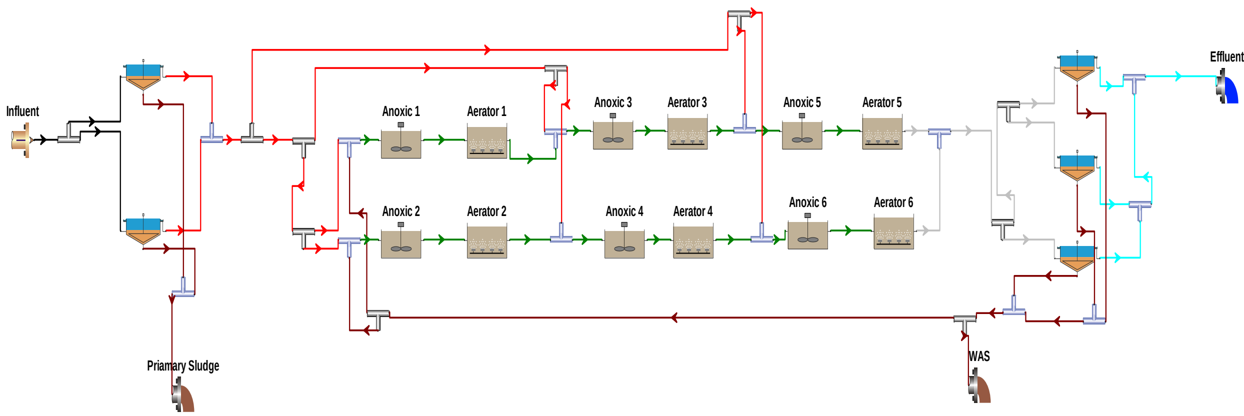

Figure 2.1. Wastewater treatment plant model in BioWin

2.7.3. Other studies utilizing BioWin Simulation

BioWin has been used by many researchers for accurately modeling the treatment plant. Some of the research papers are as follows

1) Pilot studies were conducted to determine COD characteristics, kinetics of nitrogen removal and VFA production from primary sludge. BioWin model of 4 different treatment processes was simulated. They are Modified Johannesburg process, 3 stage west bank process with chemical addition, modified Ludzack-Ettinger (MLE) process and 5 stage biological nitrogen and phosphorus removal process. Treatment process with RAS pre-denitrification zone

followed by anaerobic, anoxic and aerobic zones were selected as optimal processes for removal of TN for their influent wastewater characteristics which reduced the effluent total nitrogen to less than 10 mg N/L (Oleszkiewicz et al., 2004)

2) A calibration protocol was developed with the help of sensitivity analysis for most important parameters of the biofilm model simulated in BioWin and its predictability was verified. 5 stage calibration procedure increased the applicability of BioWin and most of the parameters was predicted with average percentage error of 0-20%.(Eldyasti et al., 2012)

3) Sensitivity analysis was performed during calibration of the model and 17 steady state or 19 dynamic conditions kinetic and stoichiometric parameters were identified as sensitive. Growth and decay of ordinary heterotrophic organisms and phosphorus accumulating organisms were reported as the most associated parameters. Mean square sensitivity measure calculations, established 10 most sensitive parameters that are in agreement under both steady state and dynamic calibration (Liwarska-Bizukojc et al., 2011).

4) BioWin model of typical full scale denitrification process configuration was simulated with different external carbon sources to determine the impact on the nitrogen removal efficiency. With equivalent COD dosage, MicroC has an edge over methanol with better performance under lowered temperature without significant increase in sludge production (Cherchi et al., 2009) .

5) Modeling approaches such as calibration and validation approaches, sensitivity analysis, the application of results to full-scale studies, designs and operations were compared for commonly used models like ASM3 (using the GPS-X simulator), GPS-X, BioWin and a variation of the Dold model methanol degradation capabilities (NGmeth within GPS-X) (Phillips et al., 2009).

CHAPTER 3. PROBLEM STATEMENT/AIM OF RESEARCH

WWTP effluents are controlled and monitored by CDPHE. With increased concern about excess nutrients in surface waters, Nutrient Management Control Regulation known as Regulation 85 was adopted on June 11th, 2012 to set numerical limits for effluent concentration of nutrients from WWTP. As nutrients were not regulated with numerical limits, a number of Colorado WWTPs have to upgrade their treatment units to meet them. Existing WWTPs should comply with the effluent limits by next permit cycle.

3.1. City of Loveland Wastewater Treatment Plant

City of Loveland is a small town located 46 miles north of Denver, Capital of Colorado, with a population of roughly 67,000. WWTP plant is operational since 1962 and upgraded to activated sludge process in 1977. With 17 lift stations, 334 miles of sewer lines and 8291 manholes, WWTP serves about 29 square miles of geographical area. It has hydraulic loading capacity of 10 million gallons per day (MGD) and organic loading capacity of 20,236 lbs/day. The 2010 influent annual and maximum monthly flows were 6.51 MGD and 7.76 MGD. The 2010 influent annual and maximum organic loadings were 15,161 lbs/day BOD_5 and 16,315 lbs/day BOD_5.The plant has a yearly average flow of 6.9 MGD and utilizes activated sludge step feed process. Figure 2.1 shows BioWin model of existing WWTP step feed activated sludge process. Figure 3.1 represents a simple flow chart of City of Loveland wastewater treatment plant. Table 3.1 shows the yearly average influent and effluent concentrations of wastewater that flows to the City of Loveland WWTP.

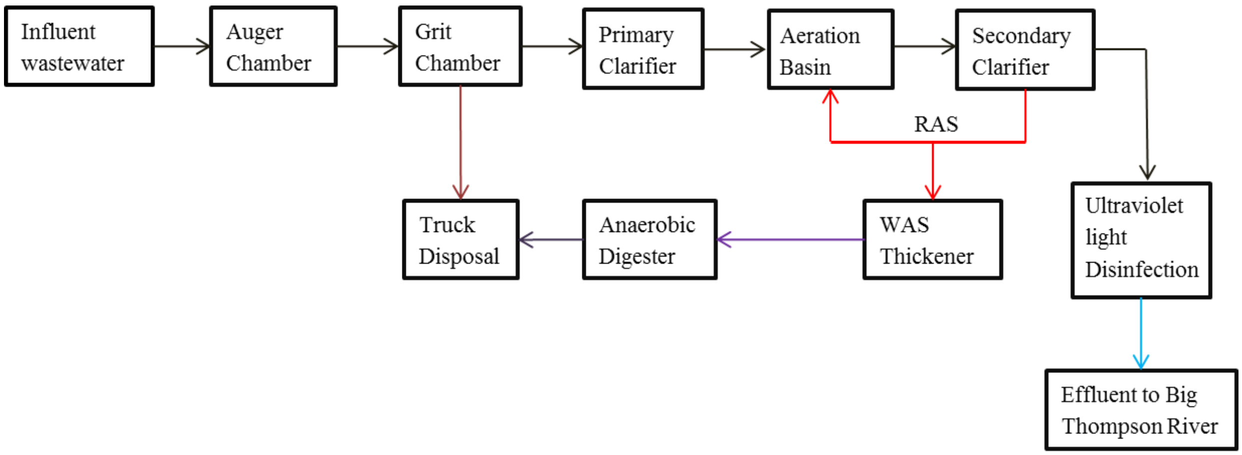

Figure 3.1: City of Loveland WWTP flow chart

Table 3.1: Influent Concentration

Parameters	Influent Concentration yearly Average	Effluent Concentration yearly Average
Flow, MGD	5.93	
Temp, 'C	16.07	16.49
BOD, mg/L	312.49	7.61
TSS mg/L	273.81	7.56
NH_3 , mg/L	23.53	0.439
TKN, mg/L	35.63	2.47
pH	7.49	6.99

3.2. Goal of the research

Goal of this research was to identify treatment processes that would work best for the existing Loveland WWTP for retrofitting to meet the new effluent limits. For this purpose BioWin software was utilized to simulate the Loveland WWTP for the influent conditions, such as BOD_5 and temperature for summer and winter, while evaluating the new reactor volumes for varied operational parameters such as internal recycle and return activated sludge flowrates. The most efficient and cost effective settings were identified based on the target nutrient concentrations and related capital, operational and maintenance costs.

Objectives of this research were as follows:

1) Simulate the A2O process with 5 aerobic to anaerobic volume ratios for each of the 5 aerobic to anoxic volume ratios totaling to 25 volume ratio cases along with 3 internal recycles varying from 100% to 300% of influent flow.
2) Model and simulate 5 stage Bardenpho process with three reactor volume cases corresponding to lower design hydraulic retention time (HRT), higher design HRT and hybrid HRT with combination of reaeration and aerobic basins from higher design HRT and anaerobic, anoxic and secondary anoxic basins from lower design HRT. Investigate necessary methanol addition as carbon source before the secondary anoxic basin.

CHAPTER 4: SIMULATION OF A NORTHERN COLORADO WASTEWATER TREATMENT PLANT TO EVALUATE PROCESS UPDATES TO MEET THE NEW NUTRIENT DISCHARGE REGULATIONS

Summary

Excessive nutrients in wastewater treatment plant (WWTP) effluents instigate eutrophication of receiving water bodies. Colorado Department of Public Health and Environment (CDPHE) adopted nutrient management control regulation also known as regulation 85 to moderate the nutrients released by point sources such as WWTP effluent. City of Loveland WWTP was reviewed to determine appropriate treatment process configuration to meet the new limits. BioWin, a windows based modeling software, was used to model City of Loveland WWTP. Modeling was performed for the existing activated sludge step feed process configuration and also for proposed anaerobic, anoxic and oxic reactors (A2O) process for design influent flow of 10 MGD and a future flowrate of 12 MGD and 5-stage Bardenpho process. Existing configuration was modeled to establish the accuracy of BioWin. 5 stage Bardenpho process modeling indicates that higher design bioreactor HRT of 2 days for anaerobic, 4 days for anoxic, 6 days for aerobic, 4 days for secondary anoxic and 1 day for reaeration has better treatment removal efficiency for nutrients with methanol dosage of 250 gal/d and 12 MGD internal recycle. Modeling result indicates that aerobic reactor to anaerobic reactor volume ratio from 3 to 4 and aerobic reactor to anoxic reactor volume ratio of 2.2 along with internal recycle of 1Q has the ideal nutrient removal efficiency for design flow of 10 MGD. While modeling for 12 MGD influent flow, volume of reactors was increased by 20% to compensate for 20% increase in the flow. Previously mentioned reactor volume ratios were also viable for 12 MGD influent flow along with volume ratios of 3 and 4 for aerobic to anaerobic reactors and volume ratios of 1.8 and 2 for aerobic to anoxic reactors.

4.1. Introduction

Nutrients, i.e. nitrogen and phosphorus, in surface waters are essential for the support of productivity and food chain. However, higher levels of nutrients cause eutrophication of the water bodies and result in algal blooms during warm summer and fall seasons (Haggard et al., 2001; Marti et al., 2004; Smith et al., 2002; Correll, 1999; Carey and Migliaccio, 2009). Algae store and release metabolites during the blooms and when they die and decompose. These metabolites include taste-and-odor compounds (McDonald et al., 2009; Khiari and Watson 2007; Proulx et al., 2007; Ahn et al., 2007; Omur-Ozbek and Dietrich, 2005; Wnorowski, 1992), toxins, and other organics which may cause disinfection by-product formation (Bouwer and Crowe, 1988). Such metabolites are a major concern for the drinking water treatment plants that utilize the surface waters as their source, as they require advanced techniques for removal (Burkholder et al., 1992; Carpenter et al., 1998; Smith 1998; YS et al., 2004; Smith et al., 2002: Lanciotti et al., 2003). Also decomposition of algae cause a significant drop in dissolved oxygen levels, adversely affecting the surface water quality and the aquatic habitat.

The nutrients are mainly introduced to the surface waters through wastewater treatment plant (WWTP) effluents (Andersen et al., 2004; Hager and Schemel, 1992; Gibson and Meyer, 2007) and agricultural and urban runoff (Ahearn et al., 2005; Popova et al., 2006; Migliaccio et al., 2007). Even though best management practices are promoted to minimize the nutrients in runoffs (Bell and Marchant, 1998; Lynch et al., 1985), more efficient way to control nutrients is to regulate the WWTPs. Nutrients in wastewater can be removed by physical, chemical and biological methods. Biological nutrient removal is one of the most common and cost effective method utilized by the WWTPs. Some of the commonly employed biological treatment systems are step-feed process, 5 stage Bardenpho process, anaerobic, aerobic, oxic (A2O) process and anoxic, oxic (AO) process. All of these processes have secondary clarifier activated sludge underflow recycled to beginning of the process (Qasim, 2002; Strom, 2006; Reardon, 2006; Davis, 2011; WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006; Johnson, 2009).

In order to protect the surface waters U.S. EPA constantly assesses the impacts of nutrients and establishes new regulations for the current conditions of the water bodies and the treatment technologies. These regulations are enforced at the state level and in Colorado, Colorado Department of Public Health and Environment (CDPHE) is the regulatory agency. CDPHE has recently updated the existing Basic Standards and Methodologies for Surface Waters, Regulation 31 and proposed the new Nutrient Management Control Regulation, Regulation 85. Regulation 85 was adopted on June 11, 2012 and became effective on September 30, 2012. This regulation has two tiers: one for the existing WWTPs and another for the new WWTPs. The regulation limits for total phosphorus (TP) are 1 mg/L and 0.7 mg/L, and for total inorganic nitrogen (TIN) are 15 mg/L and 7 mg/L for existing and new WWTPS, respectively. Existing WWTPs have to meet the new limits while filing for the renewal of their discharge permits. The objective of this study was to model a local WWTP using the BioWin software to evaluate treatment unit updates for minimum capital and operational costs, to meet the new nutrient discharge regulations and set an example for the other Coloradoan WWTPs.

4.2. Methods

City of Loveland WWTP was modeled and simulated using BioWin, proprietary software developed by EnviroSim Associates Ltd. The City of Loveland is located 50 miles north of Denver, capital of Colorado. It has a population of about 65,000. City of Loveland WWTP employs an activated sludge step feed process with an average daily flow of 6 MGD and a design capacity of 10 MGD. City of Loveland WWTP is a conventional WWTP with two identical treatment trains for the step feed activated sludge (AS) process (containing three basins each). For the AS process, primary effluent is divided among the three anoxic/aerobic basins in a predetermined ratio, with return activated sludge (RAS) (collected from the secondary clarifier) fed into the first basin only. The collected effluent from the AS trains are sent to the secondary clarifiers. Figure 4.1 shows the simplified flowchart of City of Loveland WWTP. Figure 4.2 shows the step feed process configuration of City of Loveland WWTP.

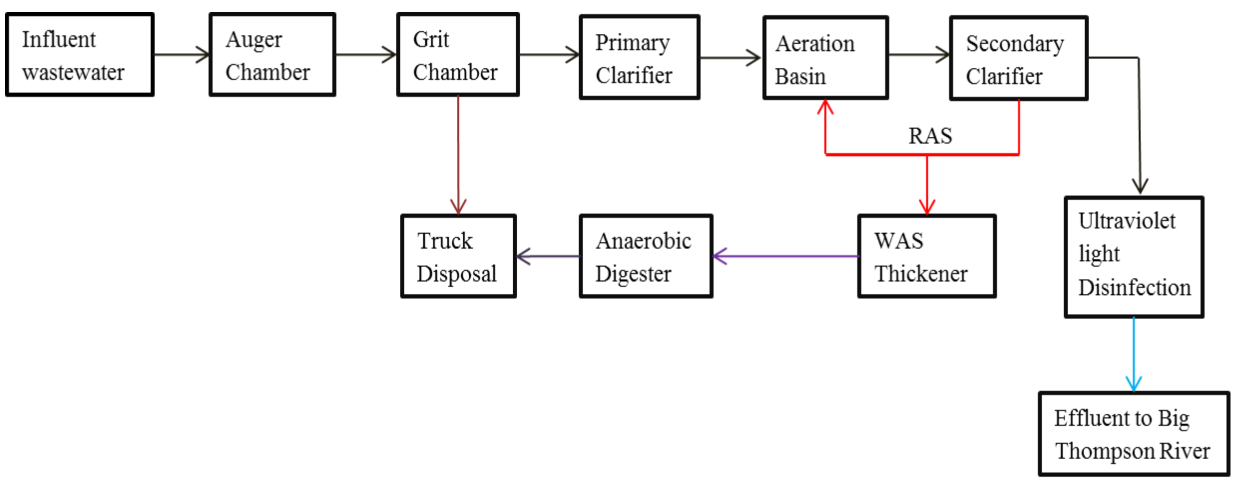

Figure 4.1: BioWin model of existing WWTP step feed activated sludge process

At present the Loveland WWTP is capable of reducing the annual TIN to 17 mg/L (with 40% removal) and the annual TP to 3.2 mg/L (with 41% removal).

BioWin simulations were performed using steady state simulation conditions. In steady state simulation, solutions are provided based on flow-weighted average influent loading to the system and not the conditions for real time (Olsson and Newell, 1999; EnviroSim, 2011; Eldyasti et al ., 2011; Phillips et al., 2009).

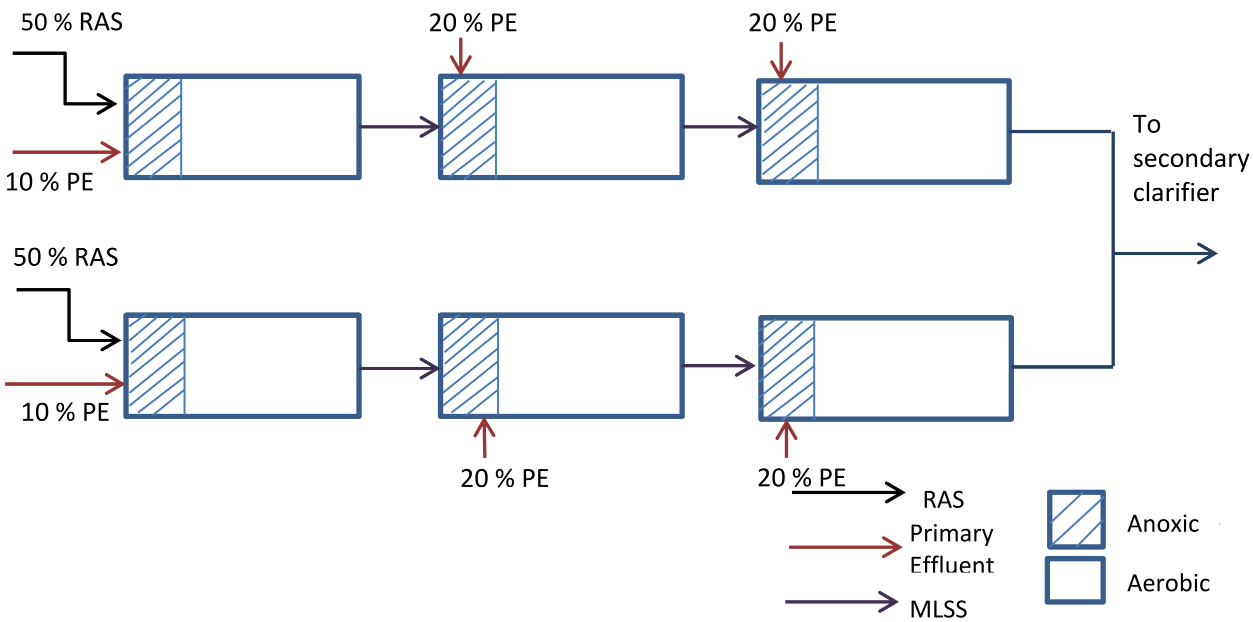

Figure 4.2: Step feed process configuration for City of Loveland WWTP

For this study, the simulations were started with the existing WWTP configuration to confirm the accuracy of the effluent concentrations reported by the software. The parameters such as the secondary clarifier settling efficiency was increased to increase the volatile suspended solids concentration in the sludge from 65% to 75% of total suspended solids and sludge wasting rate was also adjust to match the effluent data. Figure 4.3 shows the snapshot of the existing configuration modeled in BioWin and Table 4.1 provides the comparison between the actual and model effluent concentrations.

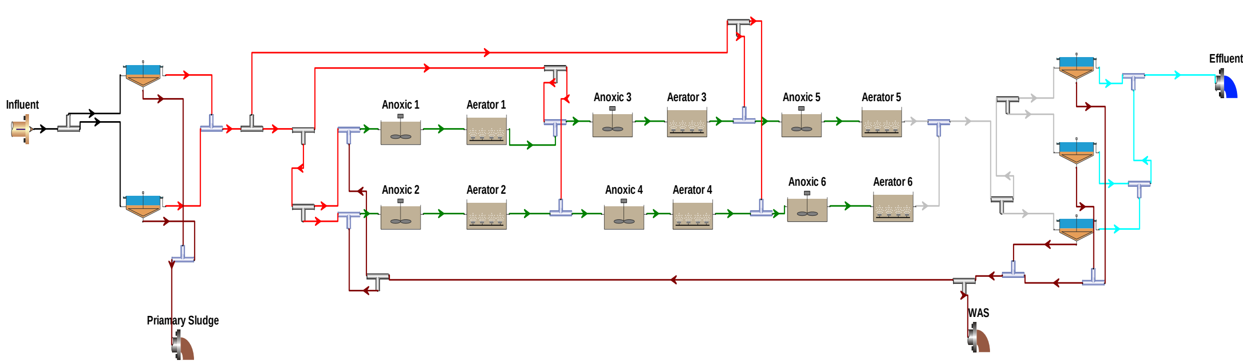

Figure 4.3: BioWin model of existing step feed activated sludge process

Table 4.1: Effluent concentrations from plant (yearly average) and BioWin model

Parameters	Actual effluent concentrations mg/L	BioWin model effluent concentrations mg/L
BOD_5	5.30	4.71
Total Suspended Solids	6.19	10.43
NH_3	0.26	1.31
Total Kjehldahl Nitrogen	2.01	3.83
Total Phosphorus	3.91	3.85

The model effluent concentrations for nutrients which were the important parameters for this research were acceptable as they were mostly over estimated by the BioWin model. Further modeling was performed for updated configuration that employed anaerobic, anoxic and oxic reactors (A2O) process for design influent flows of 10 and 12 MGD and 5-stage Bardenpho process. These processes consist of anaerobic zone for phosphorus removal followed by anoxic zone for denitrification and aerobic zone. RAS flows were returned back to the anaerobic zone with an internal recycle of MLSS to the upstream of the anoxic zone from downstream of the aerobic zone (WEF, ASCE, EWRI- MANUAL OF PRATICE NO. 30, 2006).

4.2.1. Anaerobic, Anoxic and Oxic (A2O) process modeling

A2O process was modeled with two treatment trains as in the existing step feed configuration. This was done so that the existing treatment train can be retrofitted for A2O process with a minor addition of a new anaerobic basin.

For simulation of A2O process the following were considered and modeled in combinations as indicated in Table 4.2:

1) Design influent wastewater flowrate of 10 MGD and projected future wastewater flowrate of 12 MGD
2) Effect of seasonal changes on efficiency were considered hence simulations were performed for summer (18.5^{0}C) and winter (13.5^{0}C) conditions

3) Return activated sludge flowrate for A2O process was varied from 91.9% to 98.4% of influent flowrate

4) Internal recycle (IR) flowrate of MIXED LIQUOR SUSPENDED SOLIDS (MLSS) from post aerobic zone to upstream of anoxic zone was varied from 1Q to 3Q, where Q is the influent flow. IR is varied to determine appropriate nitrate loading to pre-denitrification zone for removal of nitrate by reducing to nitrogen gas

5) Reactor volumes based on a predetermined ratio of aerobic to anoxic reactor volumes and aerobic to anaerobic reactor volumes (as given in Table 4.2)

Figure 4.4 shows the BioWin model of the A2O process. As discussed above the reactor volumes were varied according to the ratios presented in Table 4.2. To systematically observe the effects of reactor volumes, 25 volume combinations were simulated. For each volume cases the RAS flowrates were simulated and were varied for summer and winter temperatures to obtain a reasonable solids retention time and these simulations were performed for all three internal recycle flowrates. RAS flowrates are higher for winter compared with summer to cope up with decreased biological activity during winter.

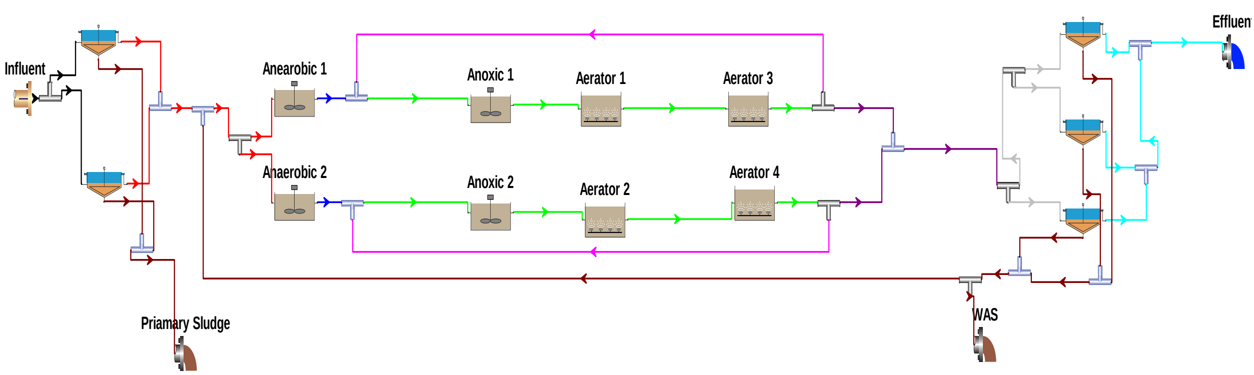

Figure 4.4: BioWin model of anaerobic, anoxic, oxic (A2O) process

The above approach can be explained as follows:

1) Determine the internal recycle flow rate. For example 1Q
2) Decide the reactor volume ratio case to be simulated. For example Case A1
3) Run the simulation for 4 RAS flowrates for summer and three RAS flowrates for winter
4) Follow the same procedure for remaining internal recycle and volume ratios
5) Compare the effluent total phosphorus and total inorganic nitrogen concentrations of all the volume cases for particular internal recycle to determine the best reactor volumes and RAS flowrate.

This approach can be easily understood by following dashed red line in table 4.2. Hence a total of 220 simulations were run for summer and 135 simulations for winter for 10 MGD influent flow.

Table 4.2: Volume matrix with reactor volumes and their ratios along with Internal Recycle and RAS flow rates in MGD

IR (Q)
1 Q
2 Q
3 Q

Q= Influent flow

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil.gal	Mil.gal	Mil.gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.280	0.507	0.912	
Case A3	3.5	0.260	0.507	0.912	
Case A4	3.75	0.240	0.507	0.912	
Case A5	4	0.220	0.507	0.912	
Case B1	3	0.310	0.490	0.930	1.9
Case B2	3.25	0.286	0.490	0.930	
Case B3	3.5	0.265	0.490	0.930	
Case B4	3.75	0.248	0.490	0.930	
Case B5	4	0.232	0.490	0.930	
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.270	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	
Case D1	3	0.320	0.458	0.960	2.1
Case D2	3.25	0.295	0.458	0.960	
Case D3	3.5	0.274	0.458	0.960	
Case D4	3.75	0.256	0.458	0.960	
Case D5	4	0.240	0.458	0.960	
Case E1	3	0.325	0.440	0.976	2.2
Case E2	3.25	0.300	0.440	0.976	
Case E3	3.5	0.278	0.440	0.976	
Case E4	3.75	0.260	0.440	0.976	
Case E5	4	0.244	0.440	0.976	

	RAS (MGD)	
	Summer	Winter
RAS 1	9.47	9.84
RAS 2	9.42	9.76
RAS 3	9.29	9.68
RAS 4	9.19	

A similar matrix (Tables 4.3 and 4.4) was used for 12MGD influent flowrate with increased reactor volumes. Volumes of each reactor were increased by 10%, 15% and 20% from the initial reactor volumes from Table 4.2 keeping volume ratios the same. Fourth change in reactor volume was to increase the aerobic reactor volume by 20% while increasing the other reactor volumes by only 10 % from those volumes specified in Table 4.2. 20% volume increase and 10% anaerobic, anoxic and 20 % aerobic volume increase was chosen to be modeled for better effluent concentrations. Observing the trends from 10 MGD simulations, only subcases 1 and 5 of cases A, C and E were modeled for 12 MGD flowrate.

Table 4.3: Volume matrix for 20 % volume increase for 12 MGD flow

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil.gal	Mil.gal	Mil.gal	Aerobic:Anoxic
Case A1	3	0.365	0.608	1.094	1.8
Case A5	4	0.264	0.608	1.094	
Case C1	3	0.378	0.567	1.135	2
Case C5	4	0.283	0.567	1.135	
Case E1	3	0.390	0.528	1.171	2.2
Case E5	4	0.293	0.528	1.171	

	RAS MGD	
	Summer	Winter
RAS 1	11.56	11.84
RAS 2	11.46	11.76
RAS 3	11.36	11.68
RAS 4	11.20	11.60
RAS 5	11.04	

Table 4.4: Volume matrix for 10% anaerobic and anoxic and 20 % aerobic volume increase for 12 MGD flow

	Total Volume Per train		
	Anaerobic	Anoxic	Aerobic /2
	Mil.gal	Mil.gal	Mil.gal
Case A1	0.330	0.55	1.094
Case A5	0.242	0.55	1.094
Case C1	0.347	0.52	1.135
Case C5	0.260	0.52	1.135
Case E1	0.358	0.48	1.171
Case E5	0.268	0.48	1.171

	RAS MGD	
	Summer	Winter
RAS 1	11.56	11.84
RAS 2	11.46	11.76
RAS 3	11.36	11.6
RAS 4	11.2	11.68
RAS 5	11.04	

4.2.2. 5 stage Bardenpho process modeling

Existing step feed AS process that already contains three basins may be updated with addition of two more basins to convert to a 5-stage Bardenpho process to achieve further nutrient removal. The Bardenpho process utilizes a series of anaerobic, anoxic, aerobic, secondary anoxic and aerobic basins (Figure 4.5). The goals of the Bardenpho process are: i) to release phosphorus in the anaerobic basin and enhance its take up in the aerobic basins; and ii) to obtain nitrogen removal through nitrification and denitrification by recycling effluent from aerobic to anoxic basin.

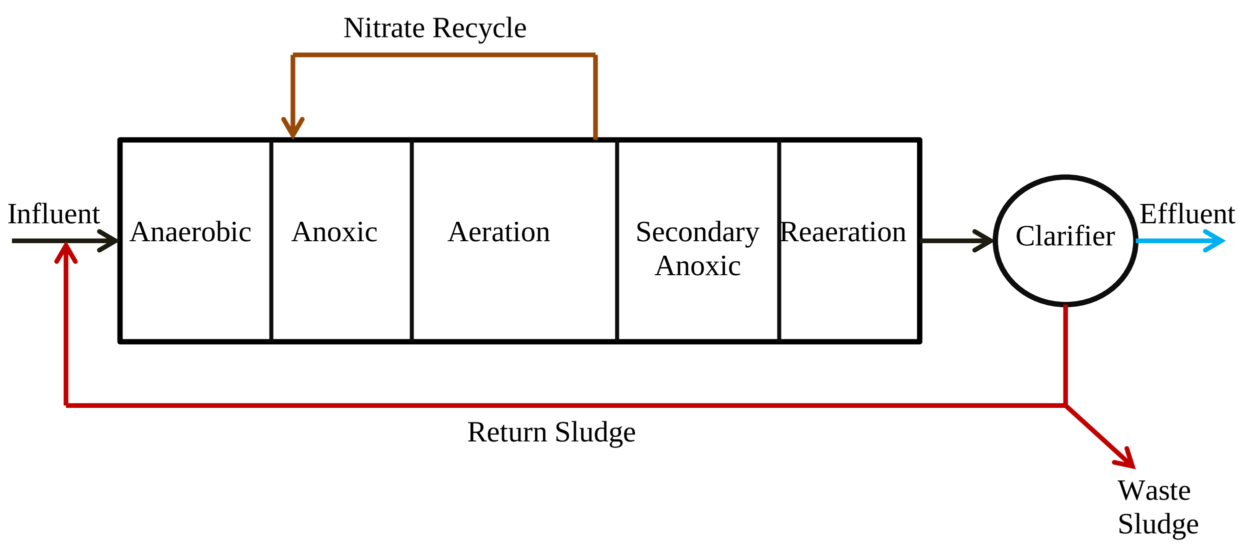

Figure 4.5: Flow diagram of 5-stage Bardenpho process

For this research, 5-stage Bardenpho process was modeled with only one treatment train instead of the two trains as in the existing configuration for a simpler design (Figure 4.6). Simulations were performed at 13.5 ºC and 18.5 ºC to mimic winter and summer wastewater temperatures, respectively. A higher influent wastewater flowrate of 12 MGD was modeled to accommodate for population growth and future plant expansion. Basin volumes were varied based on the ideal minimum and maximum hydraulic retention time (HRT) guidelines provided by wastewater treatment plants task force of the water environment federation and the american society of civil engineers. Table 4.5 shows the HRTs and volumes of the basins that were selected to simulate the 5-stage Bardenpho process

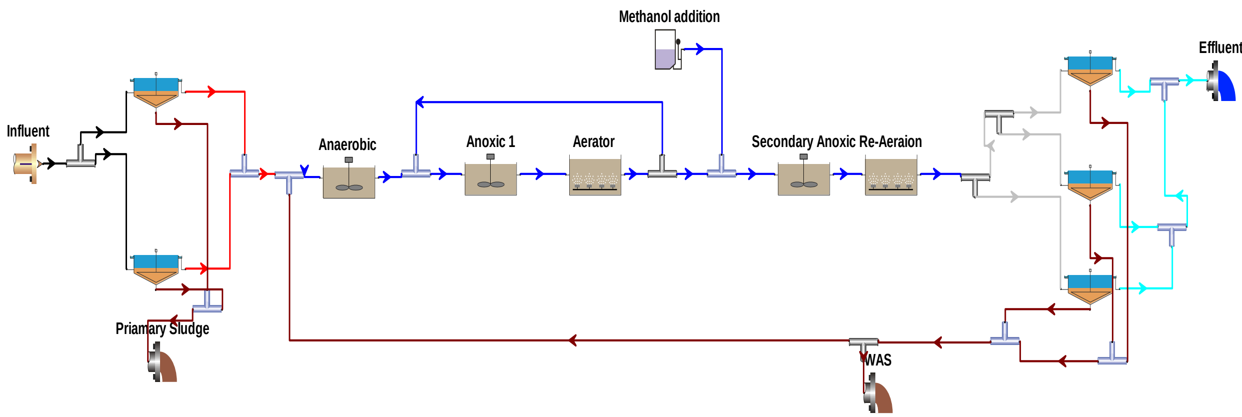

Figure 4.6: BioWin model of proposed 5-stage Bardenpho process

Table 4.5: 5-stage Bardenpho process HRTs and basin volumes

Bio-Reactor	**Lower Design HRT**		**Higher Design HRT**		**Hybrid Design HRT**	
	HRT	Vol(Mil.gal)	HRT	Vol(Mil.gal)	HRT	Vol(Mil.gal)
Anaerobic	1	0.96	2	1.92	1	0.96
Anoxic	2	1.92	4	3.84	2	1.92
Aerobic	4	3.84	6	5.76	6	5.76
Sec. Anoxic	2	1.92	4	3.84	2	1.92
Re-aeration	0.5	0.48	1	0.96	1	0.96

Internal recycle flowrate of (MLSS) was kept the same as the original influent wastewater flowrate (12 MGD) to improve nitrogen removal. To determine the optimal basin volumes for a given temperature and selected HRTs, waste activated sludge (WAS) flowrate was varied from 0.2 MGD to 1 MGD. Methanol was added to the secondary anoxic basin as an additional carbon source for microorganism growth, to improve denitrification (Swinarski et al., 2009; Cherchi et al., 2009). BioWin controller (a process control feature similar to process control equipment available in a WWTP to have real time control over aeration rate, pump speed and chemical additions) was used to determine the optimal methanol dosage by averaging the methanol flowrate determined by the software after a dynamic simulation for 24 hours, a flowrate of 250 gal/d was selected and used for the simulations. Addition to studying methanol as a carbon source, glycerin and beer wastes were also considered. Modeling glycerin involves changing acetate variable in BioWin to mimic glycerin as acetate. But with an anaerobic reactor in the treatment process it was not possible to use acetate variable and there was a need to customize entire reactor for using glycerin as a carbon source and this was outside the scope of the project and was not pursued.

4.3. Results and Discussion

4.3.1. A2O process model simulation

Steady state simulation run for the various reactor volumes, RAS and IR flowrate combinations for summer and winter wastewater temperatures (as given in Table 4.2) for 10 MGD were evaluated for the effluent concentrations of the nutrients. The results from BioWin were tabulated for the cases and total phosphorus, total inorganic nitrogen, and nitrite concentrations, and a query was run to identify the cases where the new effluent regulation limits of TP<1 mg/L and TIN<10 mg/L as well as nitrite<2 mg/L were met. Although effluent nitrite concentration is not regulated, its presence in surface water is toxic to aquatic animals (Walsh, 1995). The cases that met these limits are given in Table 4.6 for summer conditions and Table 4.7 for winter conditions.

Graph of effluent values for case E1 (aerobic: anaerobic ratio of 3 and aerobic: anoxic ratio of 2.2) with internal recycle of 12 MGD for summer and winter conditions can be seen in Figure 4.7.Simulations for summer indicated that lower RAS flowrates improve TP removal, whereas, ammonia and TIN removal is reduced. Same trend of improved TP and reduced ammonia and TIN removal is observed for winter simulations as well (Figure 4.7 and Table 4.6). This may be explained by the altered nitrification process due to insufficient nitrifier population remaining in the reactors (Liwarska-Bizukojcl and Biernacki, 2010; Liwarska-Bizukojc et al., 2011).

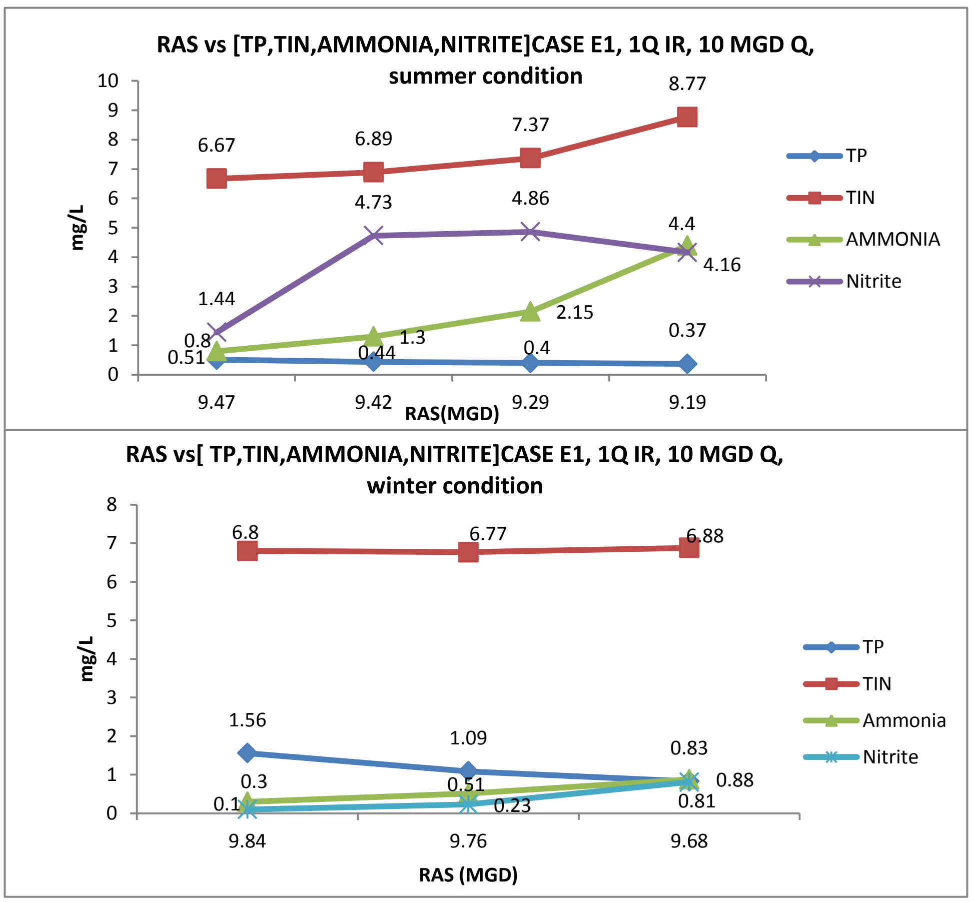

Figure 4.7: Effluent concentration for case E1 summer condition (top) and winter condition (bottom)

Table 4.6: Cases that meet effluent regulation limits with 10 MGD influent flow and summer conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	E5	RAS1	0.52	6.6	0.75	1.11
100	E4	RAS1	0.52	6.61	0.76	1.17
100	E3	RAS1	0.52	6.63	0.77	1.23
100	E2	RAS1	0.51	6.65	0.78	1.33
100	E1	RAS1	0.51	6.67	0.8	1.44
100	D5	RAS1	0.52	6.63	0.8	1.52
100	D4	RAS1	0.51	6.65	0.81	1.53
100	D3	RAS1	0.51	6.66	0.82	1.63

Table 4.7 Cases that meet effluent regulation limits with 10 MGD influent flow and winter conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	C1	RAS3	0.82	6.96	0.99	1.2
100	A5	RAS3	0.82	6.95	1.06	1.49
100	A4	RAS3	0.82	6.98	1.08	1.62
100	E5	RAS3	0.83	6.8	0.82	0.66
100	E4	RAS3	0.83	6.82	0.83	0.69
100	E3	RAS3	0.83	6.84	0.84	0.72
100	E2	RAS3	0.83	6.86	0.86	0.76
100	E1	RAS3	0.83	6.88	0.88	0.81
100	C5	RAS3	0.83	6.87	0.92	0.94
100	C4	RAS3	0.83	6.89	0.94	0.98
100	C3	RAS3	0.83	6.91	0.95	1.04
100	C2	RAS3	0.83	6.93	0.97	1.11

Comparing Table 4.6 and Table 4.7 it is clear that all cases in E from 1 to 5 meet the required effluent concentrations for both summer and winter conditions (refer Table 4.2). RAS flowrates (9.47 MGD for summer and 9.68 MGD for winter) that met the effluent limits for case E for summer and winter condition were separated by 0.21 MGD. These values can be found in Table 4.2. A RAS flow rate between these two flow rates for case E is expected be the best case for 10 MGD influent flowrate and 1Q Internal Recycle. Higher aerobic to anaerobic volume ratios along with higher aerobic to anoxic volume ratios results in better treatment, indicating the importance of volume of aerobic reactors.

Change in internal recycle influences the treatment efficiency. As shown in Tables 4.8 and 4.9 the TP concentration increases as the internal recycle changes from 1Q to 3Q. Although the difference between the TP concentrations is very small, this might be a problem during real time plant operation. The increase in TP is expected due to the increased presence of nitrates in anoxic zone along with increased dissolved oxygen due to internal recycle of nitrates from the aerobic zone causing the microorganism to use oxygen as electron acceptor instead of nitrates for phosphorus accumulation as explained by Seviour et al., (Seviour, Mino and Onuki, 2003). TIN concentration decreases, while ammonia concentration increases significantly with an increase in internal recycle. Since TIN is the sum of ammonia, nitrate and nitrite, the decrease in TIN concentration and increase in ammonia and nitrite indicates that nitrate concentration decreases as internal recycle increases.

Table 4.8: Change in effluent concentration with change in Internal Recycle for 10 MGD influent flow and summer condition

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	E1	RAS1	0.51	6.67	0.8	1.44
200	E1	RAS1	0.53	5.27	0.87	1.46
300	E1	RAS1	0.54	4.45	0.93	1.47

Table 4.9: Change in effluent concentration with change in Internal Recycle for 10 MGD influent flow and winter condition

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	E1	RAS3	0.83	6.88	0.88	0.81
200	E1	RAS3	0.85	5.51	0.96	0.9
300	E1	RAS3	0.87	4.77	1.02	0.95

Decrease in RAS flowrate decreases effluent TP concentration, but increases TIN and ammonia concentration. From Figure 4.7 it can be seen that, RAS 1 for summer condition and RAS 3 for winter conditions has optimal effluent concentration for all the parameters within the regulation limits.

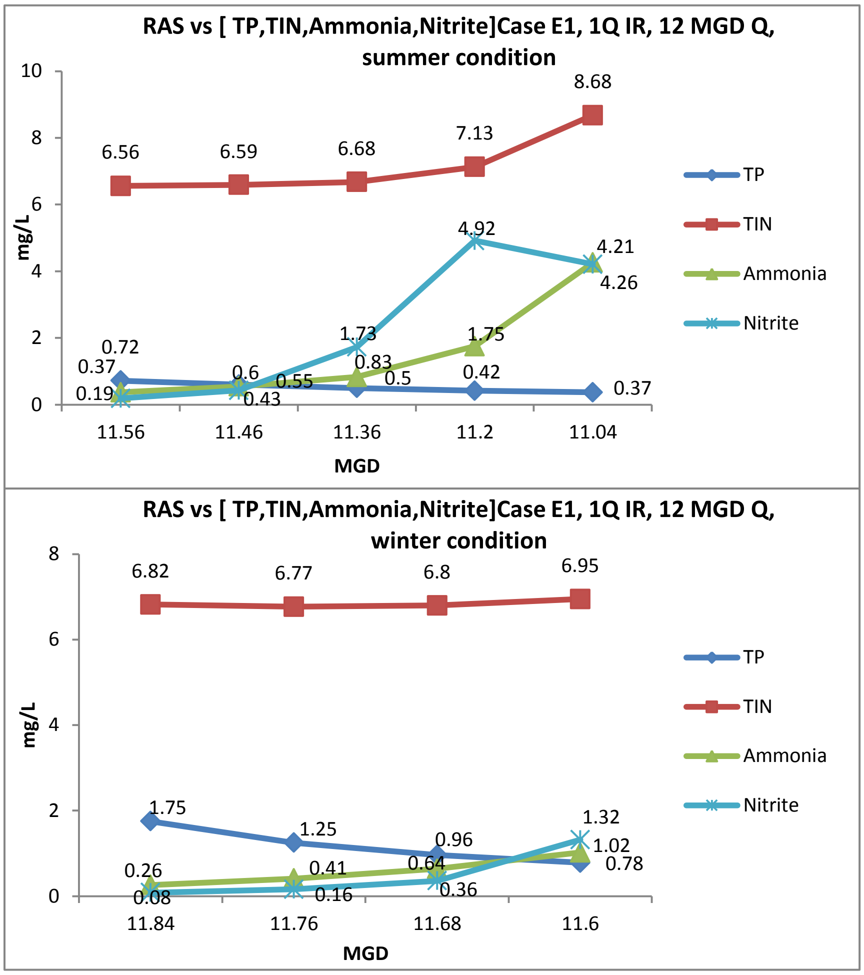

Figure 4.8: Case E1, 20 % volume increase, summer (top) and winter condition (bottom)

Comparing Tables 4.10 and 4.11 it is clear that simulation of Cases A, C and E (refer Table 4.3) for 12 MGD influent flow met the effluent regulation limit for both summer and winter conditions. For summer and winter condition case E1 meets the regulation limits with RAS1 (11.56 MGD) and RAS 4 (11.6 MGD) respectively. Difference between these RAS flowrates is

0.04 MGD and increasing the RAS flowrate for summer and decreasing the RAS flowrate for winter, optimal flowrate for case E1 for summer and winter can be determined.

Table 4.10: Cases that meet effluent regulation limits for 12 MGD influent flow, 20 % volume increase and summer conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	A1	RAS 1	0.72	6.6	0.45	0.28
100	A1	RAS 2	0.59	6.67	0.69	0.87
100	A5	RAS 1	0.72	6.54	0.42	0.24
100	A5	RAS 2	0.6	6.6	0.65	0.69
100	C1	RAS 1	0.72	6.58	0.4	0.23
100	C1	RAS 2	0.59	6.63	0.61	0.57
100	C5	RAS 1	0.72	6.52	0.38	0.2
100	C5	RAS 2	0.6	6.56	0.58	0.48
100	E1	RAS 1	0.72	6.56	0.37	0.19
100	E1	RAS 2	0.6	6.59	0.55	0.43
100	E5	RAS 1	0.73	6.5	0.35	0.17
100	E5	RAS 2	0.6	6.52	0.52	0.37
100	E5	RAS 3	0.51	6.61	0.78	1.3

Table 4.11: Cases that meet effluent regulation limits for 12 MGD influent flow, 20 % volume increase and winter conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	E5	RAS4	0.78	6.86	0.95	1.01
100	E1	RAS4	0.78	6.95	1.02	1.32
100	C5	RAS4	0.78	6.94	1.08	1.58

There are advantages of choosing cases C1, C5, A1, A5 over E1 and E5. Cases As and Cs have lesser aerobic reactor volume compared to Es, as seen in Table 4.3 . Smaller volumes would reduce the operational and maintenance cost significantly. Comparing 10 MGD and 12 MGD flowrates, 10 MGD flow had only case E that met effluent limits for summer and winter conditions, while 12 MGD flow had the cases A, C and E that met effluent limits for both summer and winter conditions. It will be efficient to retrofit the plant for 12 MGD influent flow

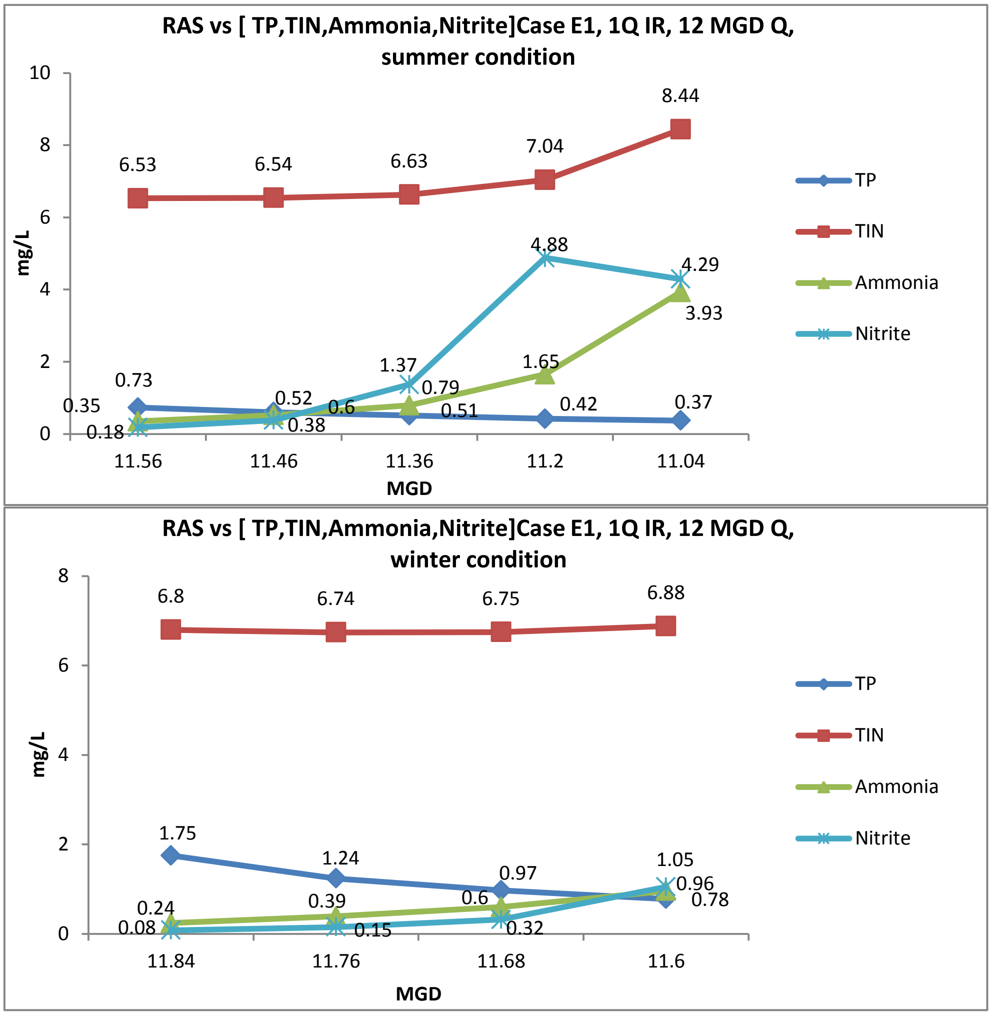

Figure 4.9: Case E1, 10 % anaerobic, anoxic volume increase, 20% aerobic volume increase, summer (top) and winter (bottom) condition

to attain an efficient nutrient removal. This can be done by changing one of the existing reactor basins to anaerobic basin or by addition of an extra basin for anaerobic purpose (Solley and Barr, 1999). For 12 MGD, increase of aerobic reactor volume by 10% more than other reactor volumes has increased the nitrogen removal efficiency considerably as shown in Figure 4.9. Tables 4.12 and 4.13 shows the cases that meet the effluent regulation limits with the aerobic reactor volume 10% greater than volumes of other reactors. Comparing Table 4.12 with Table 4.10, TP concentration has remained almost the same while TIN, ammonia and nitrite effluent concentrations have reduced in Table 4.12. Improved nitrification due to increase in aerobic reactor volume is the justification for reduced effluent TIN concentration. This is consistent for both winter and summer conditions.

Table 4.12: Cases that meet effluent regulation limits for 12 MGD influent flow, 10 % anaerobic, anoxic volume increase, 20% aerobic volume increase and summer conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	A1	RAS 1	0.72	6.56	0.42	0.25
100	A5	RAS 1	0.72	6.5	0.4	0.22
100	A5	RAS 2	0.6	6.55	0.62	0.59
100	C1	RAS 1	0.72	6.54	0.38	0.21
100	C1	RAS 2	0.6	6.58	0.58	0.5
100	C5	RAS 1	0.73	6.49	0.36	0.18
100	C5	RAS 2	0.6	6.52	0.55	0.43
100	E1	RAS 1	0.73	6.53	0.35	0.18
100	E1	RAS 2	0.6	6.54	0.52	0.38
100	E5	RAS 1	0.73	6.47	0.33	0.16
100	E5	RAS 2	0.61	6.48	0.5	0.33

Table 4.13: Cases that meet effluent regulation limits for 12 MGD influent flow, 10 % anaerobic, anoxic volume increase, 20% aerobic volume increase and winter conditions

Internal Recycle (%)	Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
100	C1	RAS4	0.78	6.97	1.09	1.65
100	C5	RAS4	0.78	6.88	1.02	1.28
100	E1	RAS4	0.78	6.88	0.96	1.05
100	E5	RAS4	0.79	6.8	0.9	0.85

Depending on the reliability of the model input data, BioWin can predict effluent concentrations with average percentage error of 5-20% (Eldyasti et al., 2012, Melcer et al, 2003, C. Bye, personal communication, July 23, 2012).Parameters such as heterotrophic yield coefficient in anoxic growth, maximum specific nitrifier growth rate, nitrifier decay rate and denitrification rate kinetics affect the performance of an uncalibrated model. Assuming that effluent concentrations from A2O process simulations has an error of 15%, some of the cases listed above effluent total phosphorus concentration will not meet the regulation limits. In such a situation chemicals such as alum or ferric can be added to the treatment train to improve phosphorus removal. However it should be noted that the addition of chemicals will lead to decrease in alkalinity and pH along with reduced biological activity and locations at which they are added have impact on the phosphorus removal efficiency as chemical addition coagulates phosphorus carrying organics settling them to be removed in clarifiers and this is described well by Gerges et al. (2006), and Minnesota Pollution Control Agency (2006). It is, however, ideal to build a chemical addition unit which can be used as a contingency during the upset of plant for treatment and removal of phosphorus. Effluent concentrations determined for adding chemicals before the primary clarifier and before the secondary clarifier are presented in Table 4.14. Chemical addition was modeled in A2O process configuration with the Case E5 with aerobic: anaerobic ratio of 3 and aerobic: anoxic ratio of 2.2. Comparing the options of lower reactor volumes and ferric chloride addition versus larger reactor volumes, it is suggested to pick the option of larger reactor volumes. The operational cost of chemical addition for 10 years (assuming the timeframe for stringent regulation) would be lesser than the capital cost to build larger reactors but larger volumes will enable the operators to meet the newer stringent regulations in 10- 15 years.

Table 4.14: Effluent concentration for chemical addition before primary clarifier and before secondary clarifier

Chemical addition 300 gal/d- Ferric chloride		
Parameter	Before Primary Clarifier	Before secondary clarifier
	Effluent Concentration (mg/L)	
Total suspended solids	10.53	11.52
Total P	0.4	0.47
Total inorganic N	6.48	6.48

4.3.2. 5 stage Bardenpho process model simulation

5 stage Bardenpho process was simulated with 100% internal recycle of the future projected flowrate of 12 MGD and with methanol dosage of 250 gal/d to upstream of secondary anoxic bioreactor. WAS flowrate was changed from 0.2 MGD to 1 MGD with increment of 0.2. Figure 4.10 and Figure 4.11 shows the graphical representation of effluent concentrations of total phosphorus and total inorganic nitrogen for lower deign HRT and higher design HRT respectively.

TP and TIN results shown in Figures 4.10 and 4.11 prove that WAS plays a key role in removal of nutrients. The following were observed for higher HRTs: TP removal increases by increasing WAS for summer, however the efficiency was maximum at a WAS flowrate of 0.6 MGD for winter and higher and lower WAS flowrates were not as effective.

Other effluent parameters determined using the higher design HRTs are provided in Table 4.15 for an influent flowrate of 12 MGD, 12 MGD internal recycle and methanol flowrate of 250 gal/d for both summer and winter temperatures. As expected, the treatment efficiency is lowered during winter due to slowed metabolic rates of the microorganisms used in the biological treatment units. Lower design HRT has better nutrient removal at WAS flow rate of 0.4 MGD

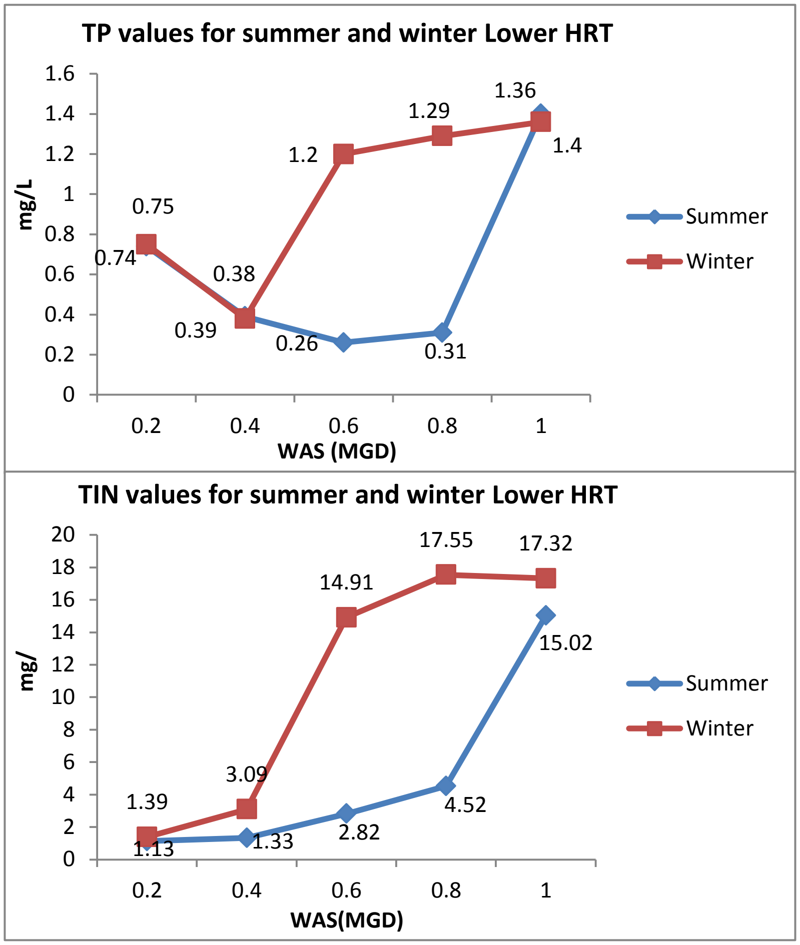

Figure 4.10: Effluent TP ant TIN concentrations for lower design HRT

For TIN removal, efficiency was inversely related to WAS flowrates for both summer and winter, and hence lower WAS flowrates should be selected. It should be noted that, except for the WAS flowrate of 1 MGD for winter temperatures, all other simulated WAS flowrates meet the regulations for TIN concentrations in effluent with 0.2 MGD close to effluent regulations concentration for TP.

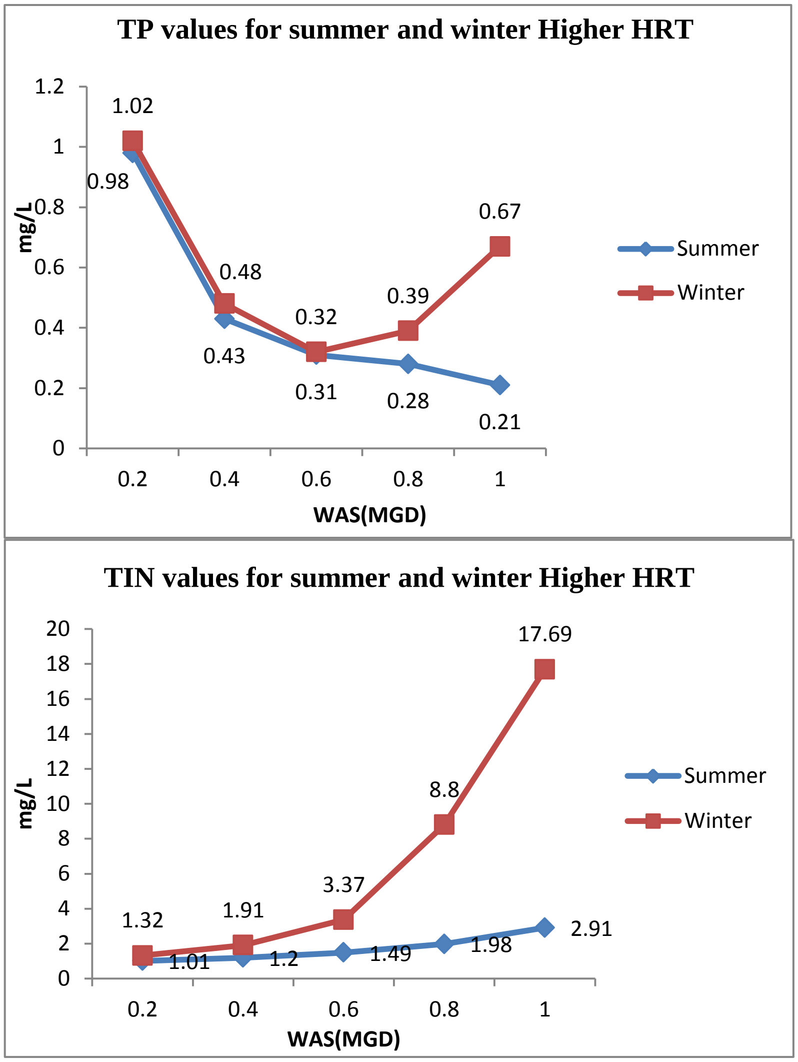

Figure 4.11: Effluent TP ant TIN concentrations for higher design HRT

Table 4.15: Effluent concentrations determined by BioWin simulations for higher design HRTs

WAS (MGD)	SUMMER				WINTER			
	TIN (mg/L)	TP (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TIN (mg/L)	TP (mg/L)	BOD_5 (mg/L)	TSS (mg/L)
0.2	1.01	**0.98**	3.98	11.83	1.32	**1.02**	4.15	11.95
0.4	1.2	0.43	3.18	7	1.91	0.48	3.33	7.06
0.6	1.49	0.31	2.74	5.05	3.37	0.32	3.29	5.04
0.8	1.98	0.28	2.57	3.97	8.8	0.39	2.96	3.95
1	2.91	0.21	2.81	3.32	**17.69**	0.67	3.13	3.26

Table 4.16: Cost comparison for different treatment processes

Parameter	A2O process (Case E5)/per year in $	A2O process with Chemical addition (Case E5)/per year in $	5 Stage bardenpho process(Methanol)/per year in $
capital cost	~20-30 million	~20-30 million	~25-35 million
Operational and maintenance Cost	~1-1.5 million (includes cost for electricity for pumps, air blowers and general maintenance)	~1.25 million-1.75 million (includes cost for electricity for pumps, air blowers and general maintenance) ~200,000$ per year for $FeCl_3$ with 300 gal/day @ 1.5$ /gallon	~2 million-2.5 million (includes cost for electricity for pumps, air blowers and general maintenance) ~ 90,000 $ per year for methanol addition with 250 gal/day @ 1$/gallon

This table shows that using A2O process without chemical addition is the less expensive option while using Bardenpho process is the most expensive option. Using a smaller volume for A20 process along with the standby unit for chemical addition in events of plant upsets is the best option for treatment and removal of nutrients. Case E1 with $FeCl_3$ addition is the ideal cost effective reactor configuration for treatment and removal of nutrients.

4.4. Conclusions

City of Loveland WWTP can get a better removal efficiency by upgrading/retrofitting their existing activated sludge step feed process to either anaerobic, anoxic, oxic (A2O) process or 5 stage Bardenpho process.

A2O process has better treatment efficiency for nutrients with the existing design flow capacity of 10 MGD. Results showed that TIN was reduced from 20 mg/L to 6.5 mg/L and TP from 6.6 mg/L to 0.5 mg/L, at 95% RAS, 100% IR and volume ratios of 4 for aerobic to anaerobic and 2 for aerobic to anoxic reactors. Case E1 that has the aerobic to anaerobic volume ratio of 3 and aerobic to anoxic volume ratio of 2.2, has optimal treatment efficiency and has a conservative volume compared to case E5 with aerobic to anaerobic volume ratio of 4. Case E1 was determined to be ideal for both summer and winter conditions. The most effective RAS flowrates for summer and winter were 9.47 MGD and 9.68 MGD respectively. Increase of internal recycle from 1Q to 3Q increases the effluent total phosphorus concentration and decreases effluent total inorganic nitrogen concentration. TP can be removed further by chemical coagulation whereas TIN can be removed only by biological process and it is possible to operate the treatment plant at 3Q internal recycle. To account for future population growth, as the daily peak influent flow has reached 80 % of the designed flow in the treatment plant, influent flow of 12 MGD was considered. To account for 20 % increase in influent flow from 10 MGD to 12 MGD, the volume for all the cases were increased by 20 %. Increase of volume increased the treatment efficiency and hence the number of cases that have optimal nutrient removal efficiency was increased. Cases A1, A5, C1 and C5 provide conservative volumes compared to cases E1 and E5. It means that operational and maintenance cost is lower for cases A1, A5, C1 and C5 compared to cases E1 and E5 due to reduced aerobic reactor volume. Increasing only the aerobic reactor volume by 20 % and keeping other reactor volumes at 10 % of the initial volume has shown better removal efficiency for nutrients comparing to overall increase of reactor volumes by 20%. Effluent concentration of total phosphorus remains the same, however, total inorganic nitrogen concentration in effluent was reduced by 0.45% with these changes in reactor volume.

Retrofitting the Loveland WWTP to 5 stage Bardenpho process will reconfigure the existing two trains to a single train treatment plant with addition of two more basins to accommodate anaerobic and anoxic bioreactors. . The design parameters suggested and the obtained effluent nutrient levels are as follows: wasting activated sludge at a flowrate of 0.6 MGD results in optimal effluent concentration of 0.31 mg/L for total phosphorus and 1.49 mg/L total inorganic nitrogen for summer (18.5 ^{o}C) and 0.32 mg/L for total phosphorus and 3.37 mg/L for total inorganic nitrogen for winter (13.5 ^{o}C). Design HRT of 2 days for anaerobic, 4 days for anoxic, 6 days for aerobic, 4 days for secondary anoxic and 1 day for reaeration was chosen with corresponding volumes of 1.92 mil.gal, 3.84 mil.gal, 5.76 mil.gal, 3.84 mil.gal and 0.96 mil.gal respectively. SRT was approximately 14 days for both summer and winter conditions.

5 stage Bardenpho process results in better treatment and removal of nutrients compared to A2O process, however capital, operational and maintenance cost in Bardenpho process is higher due to construction of additional two basins and required methanol addition. At present conditions implementation of 5 stage Bardenpho process is not as cost effective as A2O process although it has superior treatment efficiency.

So in summary this study suggested that with an influent flow of 12 MGD for A2O process, 12 MGD internal recycle and aerobic reactor to anaerobic reactor volume of 3.3 to 4.5 and aerobic reactor to anoxic reactor volume of 1.9-2.2 meets the required regulation 85 effluent discharge limits.

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APPENDIX

Appendix A-Aerobic, Anoxic process

Appendix A-1

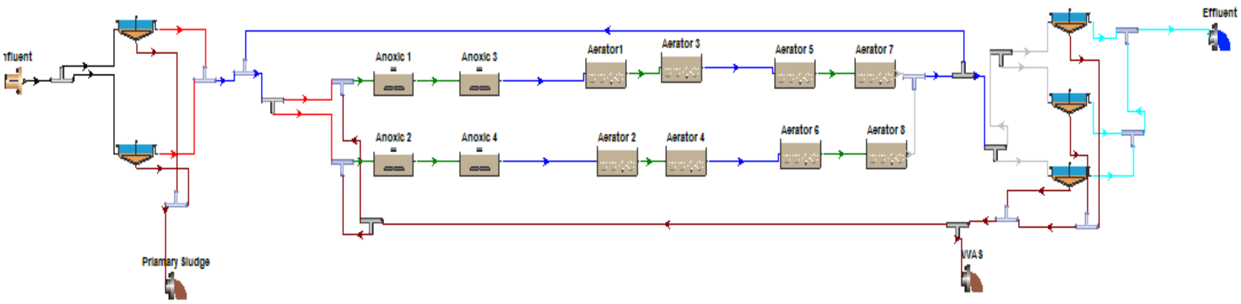

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Figure A-1: BioWin model of A/O process configuration

Table A-1: Effluent Concentration from BioWin simulation of A/O process

Parameters	Conc. (mg/L)	Mass rate (lb/d)	Notes
Volatile suspended solids	8.36	412.06	
Total suspended solids	**10.87**	535.63	
Particulate COD	12.15	599.12	
Filtered COD	29.94	1475.98	
Total COD	42.09	2075.1	
Soluble PO4-P	3.39	167.09	
Total P	**3.64**	179.46	
Filtered TKN	2.93	144.26	
Particulate TKN	0.77	37.87	
Total Kjeldahl Nitrogen	3.69	182.14	
Filtered Carbonaceous BOD	0.81	39.74	
Total Carbonaceous BOD	**5.16**	254.27	
Nitrite + Nitrate	7.94	391.53	
Total N	11.64	573.66	
Total inorganic N	**8.51**	419.57	
Alkalinity	2.88	64.44	mmol/L and kmol/d
pH	6.73		
Volatile fatty acids	0	0	
Total precipitated solids	0	0	
Total inorganic suspended solids	2.51	123.57	

Ammonia N	**0.57**	28.04	
Nitrate N	**6.96**	342.93	

Appendix B-A2O process effluent concentrations

Appendix B-1: Effluent concentrations for 10 MGD influent flow, 1Q, 2Q, 3Q internal recycle

A2O process effluent data analysis for 10 MGD influent flow and 10 MGD, 20MGD and 30MGD internal recycle.

Table B-1: Effluent concentration for A2O process configuration at summer (18.5^{o}C) temperature, 10MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	0.51	6.81	1.07	4.06
A1	RAS2	0.45	7.22	1.82	4.95
A1	RAS3	0.41	8.14	3.34	4.56
A1	RAS4	0.39	11.45	8.5	2.81
A2	RAS1	0.51	6.77	1.02	3.66
A2	RAS2	0.45	7.14	1.74	4.93
A2	RAS3	0.41	7.99	3.14	4.59
A2	RAS4	0.39	10.98	7.82	3.01
A3	RAS1	0.51	6.78	1.03	3.75
A3	RAS2	0.45	7.16	1.75	4.93
A3	RAS3	0.41	8.02	3.18	4.59
A3	RAS4	0.39	11.06	7.94	2.97
A4	RAS1	0.51	6.76	1.01	3.59
A4	RAS2	0.45	7.13	1.72	4.93
A4	RAS3	0.41	7.97	3.1	4.6
A4	RAS4	0.39	10.9	7.7	3.05
A5	RAS1	0.51	6.74	1	3.4
A5	RAS2	0.45	7.1	1.69	4.92
A5	RAS3	0.41	7.91	3.03	4.62
A5	RAS4	0.39	10.74	7.47	3.12
B1	RAS1	0.51	6.77	0.98	3.31
B1	RAS2	0.44	7.11	1.65	4.94
B1	RAS3	0.41	7.87	2.92	4.68
B1	RAS4	0.38	10.43	6.94	3.33
B2	RAS1	0.51	6.75	0.96	3.08
B2	RAS2	0.44	7.08	1.62	4.93
B2	RAS3	0.41	7.81	2.84	4.69
B2	RAS4	0.38	10.26	6.7	3.4

B3	RAS1	0.51	6.73	0.94	2.88
B3	RAS2	0.45	7.05	1.59	4.91
B3	RAS3	0.41	7.76	2.78	4.7
B3	RAS4	0.38	10.12	6.49	3.46
B4	RAS1	0.51	6.72	0.93	2.71
B4	RAS2	0.45	7.03	1.56	4.9
B4	RAS3	0.41	7.72	2.73	4.7
B4	RAS4	0.38	10.01	6.33	3.5
B5	RAS1	0.51	6.7	0.92	2.55
B5	RAS2	0.45	7.01	1.54	4.89
B5	RAS3	0.41	7.69	2.68	4.71
B5	RAS4	0.38	9.91	6.19	3.55
C1	RAS1	0.51	6.73	0.91	2.5
C1	RAS2	0.44	7.02	1.51	4.9
C1	RAS3	0.4	7.66	2.6	4.76
C1	RAS4	0.38	9.71	5.85	3.69
C2	RAS1	0.51	6.71	0.89	2.29
C2	RAS2	0.44	6.99	1.48	4.88
C2	RAS3	0.4	7.61	2.54	4.77
C2	RAS4	0.38	9.58	5.66	3.74
C3	RAS1	0.51	6.69	0.88	2.12
C3	RAS2	0.44	6.97	1.46	4.86
C3	RAS3	0.4	7.57	2.49	4.77
C3	RAS4	0.38	9.47	5.5	3.79
C4	RAS1	0.51	6.68	0.86	1.99
C4	RAS2	0.44	6.95	1.43	4.84
C4	RAS3	0.4	7.53	2.44	4.77
C4	RAS4	0.38	9.37	5.36	3.83
C5	RAS1	0.51	6.66	0.85	1.87
C5	RAS2	0.44	6.93	1.41	4.82
C5	RAS3	0.4	7.5	2.4	4.78
C5	RAS4	0.38	9.29	5.25	3.86
D1	RAS1	0.51	6.7	0.85	1.93
D1	RAS2	0.44	6.95	1.41	4.84
D1	RAS3	0.4	7.51	2.37	4.82
D1	RAS4	0.38	9.22	5.1	3.94
D2	RAS1	0.51	6.68	0.84	1.75
D2	RAS2	0.44	6.93	1.38	4.82
D2	RAS3	0.4	7.47	2.32	4.82
D2	RAS4	0.38	9.11	4.93	3.99
D3	RAS1	0.51	6.66	0.82	1.63
D3	RAS2	0.44	6.9	1.36	4.78
D3	RAS3	0.4	7.43	2.27	4.82

D3	RAS4	0.38	9.01	4.8	4.01
D4	RAS1	0.51	6.65	0.81	1.53
D4	RAS2	0.44	6.88	1.34	4.75
D4	RAS3	0.4	7.4	2.23	4.82
D4	RAS4	0.38	8.94	4.69	4.04
D5	RAS1	0.52	6.63	0.8	1.52
D5	RAS2	0.44	6.87	1.32	4.72
D5	RAS3	0.4	7.37	2.2	4.82
D5	RAS4	0.38	8.87	4.6	4.07
E1	RAS1	0.51	6.67	0.8	1.44
E1	RAS2	0.44	6.89	1.3	4.73
E1	RAS3	0.4	7.37	2.15	4.86
E1	RAS4	0.37	8.77	4.4	4.16
E2	RAS1	0.51	6.65	0.78	1.33
E2	RAS2	0.44	6.86	1.28	4.67
E2	RAS3	0.4	7.33	2.1	4.86
E2	RAS4	0.37	8.67	4.27	4.2
E3	RAS1	0.52	6.63	0.77	1.23
E3	RAS2	0.44	6.84	1.25	4.63
E3	RAS3	0.4	7.29	2.06	4.85
E3	RAS4	0.37	8.59	4.16	4.23
E4	RAS1	0.52	6.61	0.76	1.17
E4	RAS2	0.44	6.82	1.23	4.59
E4	RAS3	0.4	7.26	2.02	4.85
E4	RAS4	0.37	8.53	4.07	4.24
E5	RAS1	0.52	6.6	0.75	1.11
E5	RAS2	0.44	6.8	1.22	4.55
E5	RAS3	0.4	7.24	1.99	4.85
E5	RAS4	0.37	8.47	3.99	4.26

Table B-2: Cases that meets the effluent concentration limits for summer temperature, 10MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
D2	RAS1	0.51	6.68	0.84	1.75
D3	RAS1	0.51	6.66	0.82	1.63
D4	RAS1	0.51	6.65	0.81	1.53
D5	RAS1	0.52	6.63	0.8	1.52
E1	RAS1	0.51	6.67	0.8	1.44
E2	RAS1	0.51	6.65	0.78	1.33
E3	RAS1	0.52	6.63	0.77	1.23
E4	RAS1	0.52	6.61	0.76	1.17
E5	RAS1	0.52	6.6	0.75	1.11

Table B-3: Effluent concentration for A2O process configuration at summer (18.5^{0}C) temperature, 20MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	0.51	5.45	1.15	3.23
A1	RAS2	0.45	5.95	1.91	3.72
A1	RAS3	0.41	7.01	3.42	3.41
A1	RAS4	0.39	10.65	8.4	2.15
A2	RAS1	0.51	5.43	1.13	3.13
A2	RAS2	0.45	5.91	1.87	3.72
A2	RAS3	0.41	6.94	3.33	3.43
A2	RAS4	0.39	10.42	8.1	2.21
A3	RAS1	0.52	5.41	1.11	3.04
A3	RAS2	0.45	5.88	1.84	3.71
A3	RAS3	0.41	6.88	3.26	3.45
A3	RAS4	0.39	10.24	7.86	2.27
A4	RAS1	0.52	5.39	1.09	2.94
A4	RAS2	0.45	5.85	1.8	3.71
A4	RAS3	0.41	6.82	3.18	3.45
A4	RAS4	0.39	10.06	7.62	2.33
A5	RAS1	0.52	5.37	1.07	2.84
A5	RAS2	0.45	5.82	1.77	3.7
A5	RAS3	0.41	6.77	3.12	3.46
A5	RAS4	0.39	9.89	7.4	2.38
C1	RAS1	0.52	5.34	0.98	2.28
C1	RAS2	0.45	5.72	1.59	3.7
C1	RAS3	0.41	6.47	2.69	3.57
C1	RAS4	0.38	8.75	5.83	2.79
C2	RAS1	0.52	5.32	0.96	2.14
C2	RAS2	0.45	5.44	1.56	3.68
C2	RAS3	0.41	6.42	2.63	3.57
C2	RAS4	0.38	8.61	5.65	2.83
C3	RAS1	0.52	5.3	0.95	2
C3	RAS2	0.45	5.66	1.54	3.67
C3	RAS3	0.41	6.37	2.57	3.58
C3	RAS4	0.38	8.49	5.5	2.86
C4	RAS1	0.53	5.28	0.93	1.9
C4	RAS2	0.45	5.64	1.51	3.65
C4	RAS3	0.41	6.34	2.53	3.58
C4	RAS4	0.38	8.39	5.37	2.89
C5	RAS1	0.53	5.27	0.92	1.82
C5	RAS2	0.45	5.62	1.49	3.64

C5	RAS3	0.41	6.3	2.49	3.58
C5	RAS4	0.38	8.31	5.26	2.91
E1	RAS1	0.53	5.27	0.87	1.46
E1	RAS2	0.45	5.56	1.38	3.59
E1	RAS3	0.41	6.14	2.23	3.64
E1	RAS4	0.38	7.72	4.44	3.13
E2	RAS1	0.53	5.25	0.85	1.36
E2	RAS2	0.45	5.53	1.35	3.56
E2	RAS3	0.41	6.09	2.18	3.65
E2	RAS4	0.38	7.62	4.31	3.15
E3	RAS1	0.53	5.23	0.84	1.29
E3	RAS2	0.45	5.51	1.33	3.53
E3	RAS3	0.41	6.05	2.14	3.64
E3	RAS4	0.38	7.53	4.21	3.18
E4	RAS1	0.53	5.22	0.83	1.22
E4	RAS2	0.45	5.49	1.31	3.5
E4	RAS3	0.41	6.02	2.11	3.64
E4	RAS4	0.38	7.46	4.12	3.18
E5	RAS1	0.53	5.91	0.78	1.18
E5	RAS2	0.45	5.47	1.29	3.48
E5	RAS3	0.41	6	2.08	3.64
E5	RAS4	0.38	7.41	4.05	3.2

Table B-4: Cases that meets the effluent concentration limits for summer temperature, 20MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS1	0.53	5.91	0.78	1.18
E4	RAS1	0.53	5.22	0.83	1.22
E3	RAS1	0.53	5.23	0.84	1.29
E2	RAS1	0.53	5.25	0.85	1.36
E1	RAS1	0.53	5.27	0.87	1.46
C5	RAS1	0.53	5.27	0.92	1.82

Table B-5: Effluent concentration for A2O process configuration at summer (18.5^{o}C) temperature, 30MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	0.52	4.64	1.21	2.69
A1	RAS2	0.46	5.2	1.98	2.98
A1	RAS3	0.42	6.35	3.48	2.73

A1	RAS4	0.39	10.17	8.34	1.75
A2	RAS1	0.52	4.62	1.19	2.63
A2	RAS2	0.46	5.16	1.94	2.98
A2	RAS3	0.42	6.27	3.39	2.74
A2	RAS4	0.39	9.93	8.05	1.8
A3	RAS1	0.52	4.6	1.17	2.57
A3	RAS2	0.46	5.13	1.91	2.98
A3	RAS3	0.42	6.21	3.32	2.75
A3	RAS4	0.39	9.74	7.81	1.84
A4	RAS1	0.53	4.58	1.15	2.52
A4	RAS2	0.46	5.1	1.87	2.97
A4	RAS3	0.42	6.15	3.25	2.76
A4	RAS4	0.39	9.55	7.59	1.89
A5	RAS1	0.53	4.56	1.13	2.45
A5	RAS2	0.46	5.07	1.84	2.97
A5	RAS3	0.42	6.09	3.18	2.76
A5	RAS4	0.39	9.38	7.37	1.92
C1	RAS1	0.53	4.52	1.04	2.1
C1	RAS2	0.46	4.95	1.66	2.98
C1	RAS3	0.41	5.78	2.76	2.86
C1	RAS4	0.38	8.18	5.84	2.24
C2	RAS1	0.53	4.5	1.03	2
C2	RAS2	0.46	4.92	1.63	2.96
C2	RAS3	0.41	5.72	2.69	2.86
C2	RAS4	0.38	8.03	5.66	2.27
C3	RAS1	0.53	4.49	1.01	1.91
C3	RAS2	0.46	4.89	1.6	2.95
C3	RAS3	0.41	5.67	2.64	2.86
C3	RAS4	0.38	7.91	5.51	2.3
C4	RAS1	0.54	4.47	1	1.83
C4	RAS2	0.46	4.87	1.58	2.94
C4	RAS3	0.41	5.63	2.6	2.87
C4	RAS4	0.39	7.81	5.39	2.32
C5	RAS1	0.54	4.46	0.98	1.76
C5	RAS2	0.46	4.85	1.56	2.93
C5	RAS3	0.41	5.6	2.56	2.86
C5	RAS4	0.39	7.72	5.28	2.34
E1	RAS1	0.54	4.45	0.93	1.47
E1	RAS2	0.46	4.78	1.44	2.9
E1	RAS3	0.41	5.41	2.3	2.91
E1	RAS4	0.38	7.1	4.48	2.5
E2	RAS1	0.54	4.44	0.91	1.39

E2	RAS2	0.46	4.75	1.42	2.88
E2	RAS3	0.41	5.37	2.25	2.92
E2	RAS4	0.38	7	4.35	2.52
E3	RAS1	0.54	4.42	0.9	1.32
E3	RAS2	0.46	4.72	1.39	2.86
E3	RAS3	0.41	5.33	2.21	2.91
E3	RAS4	0.38	6.91	4.25	2.54
E4	RAS1	0.55	4.41	0.88	1.26
E4	RAS2	0.46	4.7	1.37	2.84
E4	RAS3	0.41	5.3	2.18	2.91
E4	RAS4	0.38	6.84	4.17	2.55
E5	RAS1	0.55	4.4	0.88	1.22
E5	RAS2	0.46	4.69	1.36	2.82
E5	RAS3	0.41	5.27	2.15	2.91
E5	RAS4	0.38	6.78	4.1	2.56

Table B-6: Cases that meets the effluent concentration limits for summer temperature, 30MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS1	0.55	4.4	0.88	1.22
E4	RAS1	0.55	4.41	0.88	1.26
E3	RAS1	0.54	4.42	0.9	1.32
E2	RAS1	0.54	4.44	0.91	1.39
E1	RAS1	0.54	4.45	0.93	1.47
A1	RAS4	0.39	10.17	8.34	1.75
C5	RAS1	0.54	4.46	0.98	1.76
A2	RAS4	0.39	9.93	8.05	1.8
C4	RAS1	0.54	4.47	1	1.83
A3	RAS4	0.39	9.74	7.81	1.84

Table B-7: Effluent concentration for A2O process configuration at winter (13.5^{o}C) temperature, 10MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.57	6.82	0.35	0.13
A1	RAS2	1.1	6.83	0.61	0.33
A1	RAS3	0.81	7.06	1.16	2.08

A2	RAS1	1.57	6.8	0.34	0.12
A2	RAS2	1.08	6.81	0.61	0.34
A2	RAS3	0.82	7.03	1.13	1.89
A3	RAS1	1.55	6.79	0.34	0.12
A3	RAS2	1.08	6.8	0.6	0.33
A3	RAS3	0.82	7	1.11	1.75
A4	RAS1	1.55	6.78	0.33	0.12
A4	RAS2	1.08	6.78	0.59	0.31
A4	RAS3	0.82	6.98	1.08	1.62
A5	RAS1	1.55	6.76	0.32	0.12
A5	RAS2	1.08	6.77	0.58	0.3
A5	RAS3	0.82	6.95	1.06	1.49
C1	RAS1	1.56	6.8	0.32	0.11
C1	RAS2	1.09	6.8	0.56	0.28
C1	RAS3	0.82	6.96	0.99	1.2
C2	RAS1	1.56	6.79	0.31	0.11
C2	RAS2	1.08	6.78	0.55	0.27
C2	RAS3	0.83	6.93	0.97	1.11
C3	RAS1	1.56	6.78	0.31	0.11
C3	RAS2	1.08	6.76	0.54	0.26
C3	RAS3	0.83	6.91	0.95	1.04
C4	RAS1	1.56	6.77	0.3	0.1
C4	RAS2	1.08	6.75	0.53	0.26
C4	RAS3	0.83	6.89	0.94	0.98
C5	RAS1	1.55	6.76	0.3	0.1
C5	RAS2	1.08	6.74	0.52	0.24
C5	RAS3	0.83	6.87	0.92	0.94
E1	RAS1	1.56	6.8	0.3	0.1
E1	RAS2	1.09	6.77	0.51	0.23
E1	RAS3	0.83	6.88	0.88	0.81
E2	RAS1	1.56	6.78	0.29	0.1
E2	RAS2	1.09	6.75	0.5	0.22
E2	RAS3	0.83	6.86	0.86	0.76
E3	RAS1	1.56	6.77	0.28	0.09
E3	RAS2	1.09	6.74	0.49	0.22
E3	RAS3	0.83	6.84	0.84	0.72
E4	RAS1	1.56	6.76	0.28	0.1
E4	RAS2	1.09	6.72	0.48	0.21
E4	RAS3	0.83	6.82	0.83	0.69
E5	RAS1	1.56	6.75	0.28	0.09
E5	RAS2	1.09	6.71	0.48	0.21
E5	RAS3	0.83	6.8	0.82	0.66

Table B-8: Cases that meets the effluent concentration limits for winter temperature, 10 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A2	RAS3	0.82	7.03	1.13	1.89
A3	RAS3	0.82	7	1.11	1.75
A4	RAS3	0.82	6.98	1.08	1.62
A5	RAS3	0.82	6.95	1.06	1.49
C1	RAS3	0.82	6.96	0.99	1.2
C2	RAS3	0.83	6.93	0.97	1.11
C3	RAS3	0.83	6.91	0.95	1.04
C4	RAS3	0.83	6.89	0.94	0.98
C5	RAS3	0.83	6.87	0.92	0.94
E1	RAS3	0.83	6.88	0.88	0.81
E2	RAS3	0.83	6.86	0.86	0.76
E3	RAS3	0.83	6.84	0.84	0.72
E4	RAS3	0.83	6.82	0.83	0.69
E5	RAS3	0.83	6.8	0.82	0.66

Table B-9: Effluent concentration for A2O process configuration at winter (13.5^{o}C) temperature, 20MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.63	5.31	0.39	0.14
A1	RAS2	1.14	5.38	0.67	0.37
A1	RAS3	0.83	5.67	1.25	2.01
A2	RAS1	1.56	5.3	0.41	0.15
A2	RAS2	1.12	5.37	0.68	0.38
A2	RAS3	0.83	5.64	1.22	1.86
A3	RAS1	1.61	5.28	0.38	0.14
A3	RAS2	1.12	5.35	0.67	0.37
A3	RAS3	0.84	5.61	1.2	1.74
A4	RAS1	1.6	5.26	0.38	0.14
A4	RAS2	1.12	5.33	0.65	0.36
A4	RAS3	0.84	5.59	1.17	1.63
A5	RAS1	1.6	5.25	0.37	0.13
A5	RAS2	1.11	5.31	0.64	0.35
A5	RAS3	0.84	5.56	1.15	1.53
C1	RAS1	1.62	5.33	0.36	0.13
C1	RAS2	1.12	5.37	0.62	0.32
C1	RAS3	0.84	5.56	1.08	1.27

C2	RAS1	1.62	5.3	0.36	0.13
C2	RAS2	1.12	5.34	0.61	0.31
C2	RAS3	0.85	5.54	1.06	1.19
C3	RAS1	1.61	5.29	0.35	0.13
C3	RAS2	1.12	5.32	0.6	0.3
C3	RAS3	0.85	5.51	1.04	1.12
C4	RAS1	1.61	5.27	0.34	0.13
C4	RAS2	1.12	5.31	0.59	0.29
C4	RAS3	0.85	5.49	1.02	1.06
C5	RAS1	1.61	5.26	0.34	0.12
C5	RAS2	1.12	5.29	0.58	0.28
C5	RAS3	0.85	5.47	1	1.02
E1	RAS1	1.63	5.37	0.34	0.11
E1	RAS2	1.13	5.38	0.57	0.26
E1	RAS3	0.85	5.51	0.96	0.9
E2	RAS1	1.62	5.34	0.33	0.11
E2	RAS2	1.13	5.35	0.55	0.25
E2	RAS3	0.86	5.48	0.94	0.84
E3	RAS1	1.62	5.31	0.32	0.11
E3	RAS2	1.13	5.32	0.55	0.25
E3	RAS3	0.86	5.45	0.92	0.8
E4	RAS1	1.62	5.29	0.32	0.1
E4	RAS2	1.13	5.3	0.54	0.24
E4	RAS3	0.86	5.43	0.91	0.76
E5	RAS1	1.62	5.27	0.32	0.11
E5	RAS2	1.13	5.28	0.53	0.24
E5	RAS3	0.86	5.41	0.89	0.74

Table B-10: Cases that meets the effluent concentration limits for winter temperature, 20 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A2	RAS3	0.83	5.64	1.22	1.86
A1	RAS3	0.83	5.67	1.25	2.01
C1	RAS3	0.84	5.56	1.08	1.27
A5	RAS3	0.84	5.56	1.15	1.53
A4	RAS3	0.84	5.59	1.17	1.63
A3	RAS3	0.84	5.61	1.2	1.74
E1	RAS3	0.85	5.51	0.96	0.9
C5	RAS3	0.85	5.47	1	1.02
C4	RAS3	0.85	5.49	1.02	1.06
C3	RAS3	0.85	5.51	1.04	1.12

C2	RAS3	0.85	5.54	1.06	1.19
E5	RAS3	0.86	5.41	0.89	0.74
E4	RAS3	0.86	5.43	0.91	0.76
E3	RAS3	0.86	5.45	0.92	0.8
E2	RAS3	0.86	5.48	0.94	0.84

Table B-11: Effluent concentration for A2O process configuration at winter (13.5^{o}C) temperature, 30MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.68	4.55	0.43	0.16
A1	RAS2	1.17	4.6	0.72	0.41
A1	RAS3	0.84	4.86	1.33	1.92
A2	RAS1	1.68	4.51	0.42	0.16
A2	RAS2	1.14	4.57	0.73	0.42
A2	RAS3	0.84	4.83	1.3	1.81
A3	RAS1	1.66	4.47	0.42	0.15
A3	RAS2	1.14	4.54	0.72	0.41
A3	RAS3	0.85	4.8	1.27	1.71
A4	RAS1	1.66	4.44	0.41	0.15
A4	RAS2	1.14	4.52	0.71	0.39
A4	RAS3	0.85	4.78	1.25	1.62
A5	RAS1	1.65	4.41	0.41	0.15
A5	RAS2	1.14	4.49	0.69	0.38
A5	RAS3	0.85	4.75	1.22	1.54
C1	RAS1	1.68	4.75	0.4	0.15
C1	RAS2	1.16	4.69	0.67	0.35
C1	RAS3	0.86	4.77	1.15	1.31
C2	RAS1	1.67	4.68	0.39	0.14
C2	RAS2	1.16	4.64	0.66	0.34
C2	RAS3	0.86	4.74	1.13	1.23
C3	RAS1	1.67	4.61	0.38	0.14
C3	RAS2	1.15	4.59	0.65	0.32
C3	RAS3	0.86	4.71	1.1	1.17
C4	RAS1	1.67	4.56	0.38	0.13
C4	RAS2	1.15	4.55	0.64	0.32
C4	RAS3	0.86	4.69	1.09	1.12
C5	RAS1	1.67	4.52	0.37	0.13
C5	RAS2	1.15	4.52	0.63	0.31
C5	RAS3	0.86	4.67	1.07	1.07
E1	RAS1	1.68	5.08	0.37	0.13
E1	RAS2	1.16	4.95	0.61	0.29
E1	RAS3	0.87	4.77	1.02	0.95

E2	RAS1	1.68	4.99	0.36	0.12
E2	RAS2	1.16	4.86	0.6	0.28
E2	RAS3	0.87	4.74	1	0.89
E3	RAS1	1.68	4.9	0.36	0.12
E3	RAS2	1.16	4.78	0.59	0.28
E3	RAS3	0.87	4.7	0.99	0.86
E4	RAS1	1.68	4.82	0.35	0.12
E4	RAS2	1.16	4.71	0.58	0.27
E4	RAS3	0.88	4.67	0.97	0.82
E5	RAS1	1.68	4.75	0.35	0.12
E5	RAS2	1.16	4.65	0.58	0.26
E5	RAS3	0.88	4.65	0.96	0.79

Table B-12: Cases that meets the effluent concentration limits for winter temperature, 30 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS3	0.84	4.86	1.33	1.92
A2	RAS3	0.84	4.83	1.3	1.81
A3	RAS3	0.85	4.8	1.27	1.71
A4	RAS3	0.85	4.78	1.25	1.62
A5	RAS3	0.85	4.75	1.22	1.54
C1	RAS3	0.86	4.77	1.15	1.31
C2	RAS3	0.86	4.74	1.13	1.23
C3	RAS3	0.86	4.71	1.1	1.17
C4	RAS3	0.86	4.69	1.09	1.12
C5	RAS3	0.86	4.67	1.07	1.07
E1	RAS3	0.87	4.77	1.02	0.95
E2	RAS3	0.87	4.74	1	0.89
E3	RAS3	0.87	4.7	0.99	0.86
E4	RAS3	0.88	4.67	0.97	0.82
E5	RAS3	0.88	4.65	0.96	0.79

Appendix B-2: Effluent concentration for 12 MGD influent flow

A2O process configuration simulation with 12 MGD influent flow.

Table B-13: Volume matrix of reactors with 10% increase from original reactor volume

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.33	0.55	1	1.8
Case A5	4	0.242	0.55	1	
Case C1	3	0.3465	0.52	1.04	2
Case C5	4	0.2596	0.52	1.04	
Case E1	3	0.373	0.48	1.07	2.2
Case E5	4	0.268	0.48	1.07	

Table B-14: Volume matrix of reactors with 15% increase from original reactor volume

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.3496	0.58305	1.0488	1.8
Case A5	4	0.253	0.58305	1.0488	
Case C1	3	0.362	0.543	1.08	2
Case C5	4	0.2714	0.543	1.08	
Case E1	3	0.37375	0.506	1.1224	2.2
Case E5	4	0.2806	0.506	1.1224	

Table B-15: Volume matrix of reactors with 20% increase from original reactor volume

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.3648	0.6084	1.0944	1.8
Case A5	4	0.264	0.6084	1.0944	
Case C1	3	0.378	0.567	1.135	2
Case C5	4	0.283	0.567	1.135	
Case E1	3	0.39	0.528	1.1712	2.2
Case E5	4	0.2928	0.528	1.1712	

Table B-16: Volume matrix of reactors with 10% anaerobic, anoxic reactor volume and 20%aerobic reactor volume increase from original reactor volume

	Total Volume Per train		
	Anaerobic	Anoxic	Aerobic /2
	Mil gal	Mil gal	Mil gal
Case A1	0.33	0.55	1.0944
Case A5	0.242	0.55	1.0944
Case C1	0.3465	0.52	1.135
Case C5	0.2596	0.52	1.135
Case E1	0.3575	0.48	1.1712
Case E5	0.268	0.48	1.1712

Table B-17: Effluent concentration for A2O process configuration at summer (18.5^{0}C) temperature, 12MGD influent flow, 20% volume increase, 12 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS 1	0.72	6.6	0.45	0.28
A1	RAS 2	0.59	6.67	0.69	0.87
A1	RAS 3	0.5	6.83	1.13	4.33
A1	RAS 4	0.42	7.67	2.58	4.79
A1	RAS 5	0.39	11.18	8.08	2.94
A5	RAS 1	0.72	6.54	0.42	0.24
A5	RAS 2	0.6	6.6	0.65	0.69
A5	RAS 3	0.5	6.76	1.04	3.82
A5	RAS 4	0.42	7.5	2.36	4.81
A5	RAS 5	0.39	10.51	7.12	3.24
C1	RAS 1	0.72	6.58	0.4	0.23
C1	RAS 2	0.59	6.63	0.61	0.57
C1	RAS 3	0.5	6.75	0.96	3
C1	RAS 4	0.42	7.35	2.08	4.9
C5	RAS 5	0.38	9.58	5.63	3.77
C5	RAS 1	0.72	6.52	0.38	0.2
C5	RAS 2	0.6	6.56	0.58	0.48
C5	RAS 3	0.51	6.68	0.89	2.27
C5	RAS 4	0.42	7.22	1.93	4.88
C5	RAS 5	0.38	9.17	5.06	3.93
E1	RAS 1	0.72	6.56	0.37	0.19
E1	RAS 2	0.6	6.59	0.55	0.43
E1	RAS 3	0.5	6.68	0.83	1.73

E1	RAS 4	0.42	7.13	1.75	4.92
E1	RAS 5	0.37	8.68	4.26	4.21
E5	RAS 1	0.73	6.5	0.35	0.17
E5	RAS 2	0.6	6.52	0.52	0.37
E5	RAS 3	0.51	6.61	0.78	1.3
E5	RAS 4	0.42	7.02	1.62	4.87
E5	RAS 5	0.37	8.39	3.86	4.31

Table B-18: Cases that meets the effluent concentration limits for summer temperature, 12MGD influent flow, 20% volume increase, 12 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS 1	0.73	6.5	0.35	0.17
E1	RAS 1	0.72	6.56	0.37	0.19
C5	RAS 1	0.72	6.52	0.38	0.2
C1	RAS 1	0.72	6.58	0.4	0.23
A5	RAS 1	0.72	6.54	0.42	0.24
A1	RAS 1	0.72	6.6	0.45	0.28
E5	RAS 2	0.6	6.52	0.52	0.37
E1	RAS 2	0.6	6.59	0.55	0.43
C5	RAS 2	0.6	6.56	0.58	0.48
C1	RAS 2	0.59	6.63	0.61	0.57
A5	RAS 2	0.6	6.6	0.65	0.69
A1	RAS 2	0.59	6.67	0.69	0.87
E5	RAS 3	0.51	6.61	0.78	1.3
E1	RAS 3	0.5	6.68	0.83	1.73

Table B-19: Effluent concentration for A2O process configuration at summer (18.5^{0}C) temperature,12MGD influent flow, 20% volume increase, 24 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	0.75	5.15	0.5	0.31
A1	RAS2	0.61	5.25	0.76	0.93
A1	RAS3	0.51	5.48	1.2	3.38
A1	RAS4	0.42	6.47	2.66	3.59
A1	RAS5	0.39	10.36	8	2.25
A5	RAS1	0.75	5.09	0.47	0.27
A5	RAS2	0.62	5.18	0.71	0.77

A5	RAS3	0.51	5.4	1.12	3.08
A5	RAS4	0.43	6.29	2.45	3.61
A5	RAS5	0.39	9.64	7.06	2.47
C1	RAS1	0.75	5.14	0.45	0.25
C1	RAS2	0.62	5.2	0.67	0.64
C1	RAS3	0.51	5.37	1.03	2.61
C1	RAS4	0.42	6.1	2.16	3.67
C1	RAS5	0.38	8.6	5.63	2.85
C5	RAS1	0.75	5.07	0.43	0.23
C5	RAS2	0.62	5.14	0.63	0.54
C5	RAS3	0.52	5.29	0.96	2.11
C5	RAS4	0.42	5.97	2.01	3.67
C5	RAS5	0.38	8.17	5.08	2.96
E1	RAS1	0.75	5.16	0.41	0.21
E1	RAS2	0.62	5.18	0.61	0.49
E1	RAS3	0.52	5.29	0.9	1.7
E1	RAS4	0.42	5.86	1.83	3.7
E1	RAS5	0.38	7.62	4.3	3.17
E5	RAS1	0.76	5.07	0.39	0.19
E5	RAS2	0.63	5.11	0.57	0.43
E5	RAS3	0.53	5.22	0.85	1.36
E5	RAS4	0.42	5.75	1.71	3.67
E5	RAS5	0.38	7.32	3.93	3.23

Table B-20: Cases that meets the effluent concentration limits for summer temperature, 12MGD influent flow, 20% volume increase, 24 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS1	0.76	5.07	0.39	0.19
E1	RAS1	0.75	5.16	0.41	0.21
C5	RAS1	0.75	5.07	0.43	0.23
C1	RAS1	0.75	5.14	0.45	0.25
A5	RAS1	0.75	5.09	0.47	0.27
A1	RAS1	0.75	5.15	0.5	0.31
E5	RAS2	0.63	5.11	0.57	0.43
E1	RAS2	0.62	5.18	0.61	0.49
C5	RAS2	0.62	5.14	0.63	0.54
C1	RAS2	0.62	5.2	0.67	0.64
A5	RAS2	0.62	5.18	0.71	0.77
A1	RAS2	0.61	5.25	0.76	0.93

E5	RAS3	0.53	5.22	0.85	1.36
E1	RAS3	0.52	5.29	0.9	1.7

Table B-21: Effluent concentration for A2O process configuration at summer (18.5^{o}C) temperature,12MGD influent flow, 20% volume increase, 36 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	0.77	4.36	0.54	0.34
A1	RAS2	0.62	4.42	0.81	0.99
A1	RAS3	0.51	4.68	1.26	2.78
A1	RAS4	0.43	5.77	2.73	2.87
A1	RAS5	0.39	9.86	7.95	1.83
A5	RAS1	0.77	4.26	0.51	0.3
A5	RAS2	0.63	4.35	0.76	0.82
A5	RAS3	0.52	4.59	1.18	2.58
A5	RAS4	0.43	5.58	2.51	2.89
A5	RAS5	0.39	9.09	7	1.99
C1	RAS1	0.77	4.43	0.49	0.28
C1	RAS2	0.63	4.4	0.72	0.7
C1	RAS3	0.52	4.55	1.09	2.31
C1	RAS4	0.43	5.38	2.23	2.94
C1	RAS5	0.39	8.02	5.64	2.29
C5	RAS1	0.78	4.29	0.47	0.25
C5	RAS2	0.64	4.33	0.69	0.6
C5	RAS3	0.53	4.48	1.03	1.99
C5	RAS4	0.43	5.24	2.08	2.94
C5	RAS5	0.39	7.58	5.1	2.37
E1	RAS1	0.78	4.65	0.45	0.24
E1	RAS2	0.64	4.44	0.65	0.53
E1	RAS3	0.53	4.47	0.96	1.67
E1	RAS4	0.43	5.11	1.9	2.96
E1	RAS5	0.38	7	4.34	2.53
E5	RAS1	0.78	4.38	0.43	0.22
E5	RAS2	0.65	4.34	0.62	0.47
E5	RAS3	0.54	4.41	0.91	1.37
E5	RAS4	0.43	4.99	1.77	2.94
E5	RAS5	0.38	6.68	3.97	2.59

Table B-22: Cases that meets the effluent concentration limits for summer temperature, 12MGD influent flow, 20% volume increase, 36 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS1	0.78	4.38	0.43	0.22
E1	RAS1	0.78	4.65	0.45	0.24
C5	RAS1	0.78	4.29	0.47	0.25
C1	RAS1	0.77	4.43	0.49	0.28
A5	RAS1	0.77	4.26	0.51	0.3
A1	RAS1	0.77	4.36	0.54	0.34
E5	RAS2	0.65	4.34	0.62	0.47
E1	RAS2	0.64	4.44	0.65	0.53
C5	RAS2	0.64	4.33	0.69	0.6
C1	RAS2	0.63	4.4	0.72	0.7
A5	RAS2	0.63	4.35	0.76	0.82
A1	RAS2	0.62	4.42	0.81	0.99
E5	RAS3	0.54	4.41	0.91	1.37
E1	RAS3	0.53	4.47	0.96	1.67
A1	RAS5	0.39	9.86	7.95	1.83

Table B-23: Effluent concentration for A2O process configuration at winter (13.5^{o}C) temperature,12MGD influent flow, 20% volume increase, 12 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.75	6.83	0.3	0.11
A1	RAS2	1.24	6.81	0.49	0.23
A1	RAS3	0.96	6.89	0.8	0.63
A1	RAS4	0.76	7.2	1.41	3.69
A5	RAS1	1.74	6.79	0.28	0.1
A5	RAS2	1.24	6.75	0.46	0.19
A5	RAS3	0.96	6.81	0.74	0.51
A5	RAS4	0.77	7.06	1.27	2.75
C1	RAS1	1.75	6.82	0.28	0.1
C1	RAS2	1.24	6.79	0.45	0.19
C1	RAS3	0.96	6.84	0.71	0.46
C1	RAS4	0.77	7.05	1.17	2.13
C5	RAS1	1.74	6.78	0.26	0.08
C5	RAS2	1.24	6.73	0.42	0.16

C5	RAS3	0.96	6.77	0.66	0.4
C5	RAS4	0.78	6.94	1.08	1.58
E1	RAS1	1.75	6.82	0.26	0.08
E1	RAS2	1.25	6.77	0.41	0.16
E1	RAS3	0.96	6.8	0.64	0.36
E1	RAS4	0.78	6.95	1.02	1.32
E5	RAS1	1.75	6.78	0.24	0.08
E5	RAS2	1.24	6.71	0.38	0.14
E5	RAS3	0.97	6.73	0.6	0.31
E5	RAS4	0.78	6.86	0.95	1.01

Table B-24: Cases that meets the effluent concentration limits for winter temperature, 12MGD influent flow, 20% volume increase, 12 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E5	RAS4	0.78	6.86	0.95	1.01
E1	RAS4	0.78	6.95	1.02	1.32
C5	RAS4	0.78	6.94	1.08	1.58
E1	RAS3	0.96	6.8	0.64	0.36
C5	RAS3	0.96	6.77	0.66	0.4
C1	RAS3	0.96	6.84	0.71	0.46
A5	RAS3	0.96	6.81	0.74	0.51
A1	RAS3	0.96	6.89	0.8	0.63
E5	RAS3	0.97	6.73	0.6	0.31

Table B-25: Effluent concentration for A2O process configuration at winter (13.5^{0}C) temperaeture,12MGD influent flow, 20% volume increase, 24 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.81	5.32	0.34	0.12
A1	RAS2	1.28	5.34	0.55	0.25
A1	RAS3	0.98	5.47	0.88	0.71
A1	RAS4	0.8	5.75	1.38	2.61
A5	RAS1	1.8	5.25	0.32	0.11
A5	RAS2	1.28	5.27	0.51	0.23
A5	RAS3	0.99	5.38	0.81	0.58
A5	RAS4	0.78	5.68	1.35	2.44
C1	RAS1	1.82	5.33	0.32	0.11

C1	RAS2	1.29	5.34	0.5	0.21
C1	RAS3	0.99	5.43	0.78	0.52
C1	RAS4	0.79	5.66	1.26	2.05
C5	RAS1	1.81	5.27	0.3	0.1
C5	RAS2	1.28	5.26	0.47	0.19
C5	RAS3	0.99	5.35	0.73	0.45
C5	RAS4	0.8	5.56	1.17	1.6
E1	RAS1	1.83	5.38	0.29	0.1
E1	RAS2	1.29	5.36	0.46	0.19
E1	RAS3	1	5.42	0.7	0.41
E1	RAS4	0.8	5.57	1.11	1.37
E5	RAS1	1.82	5.29	0.28	0.09
E5	RAS2	1.29	5.27	0.43	0.17
E5	RAS3	1	5.32	0.66	0.36
E5	RAS4	0.81	5.48	1.03	1.09

Table B-26: Cases that meets the effluent concentration limits for winter temperature, 12MGD influent flow, 20% volume increase, 24 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
E1	RAS4	0.8	5.57	1.11	1.37
C5	RAS4	0.8	5.56	1.17	1.6
E5	RAS4	0.81	5.48	1.03	1.09
A1	RAS3	0.98	5.47	0.88	0.71
C5	RAS3	0.99	5.35	0.73	0.45
C1	RAS3	0.99	5.43	0.78	0.52
A5	RAS3	0.99	5.38	0.81	0.58

Table B-27: Effluent concentration for A2O process configuration at winter (13.5^{0}C) temperature,12MGD influent flow, 20% volume increase, 36 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A1	RAS1	1.87	4.55	0.38	0.14
A1	RAS2	1.32	4.57	0.6	0.28
A1	RAS3	1	4.67	0.94	0.77
A1	RAS4	0.81	4.94	1.46	2.33
A5	RAS1	1.86	4.41	0.35	0.13
A5	RAS2	1.31	4.44	0.55	0.25

A5	RAS3	1.01	4.57	0.87	0.64
A5	RAS4	0.79	4.88	1.43	2.21
C1	RAS1	1.88	4.77	0.35	0.12
C1	RAS2	1.33	4.71	0.54	0.23
C1	RAS3	1.02	4.69	0.84	0.57
C1	RAS4	0.8	4.86	1.34	1.95
C5	RAS1	1.88	4.53	0.33	0.11
C5	RAS2	1.33	4.51	0.51	0.21
C5	RAS3	1.02	4.56	0.78	0.49
C5	RAS4	0.81	4.76	1.24	1.59
E1	RAS1	1.88	5.1	0.33	0.11
E1	RAS2	1.33	5.01	0.5	0.2
E1	RAS3	1.03	4.88	0.76	0.45
E1	RAS4	0.81	4.79	1.18	1.39
E5	RAS1	1.89	4.78	0.31	0.1
E5	RAS2	1.34	4.68	0.47	0.18
E5	RAS3	1.03	4.63	0.71	0.39
E5	RAS4	0.82	4.69	1.1	1.13

Table B-28: Cases that meets the effluent concentration limits for winter temperature, 12MGD influent flow, 20% volume increase, 36 MGD internal recycle

Case	RAS (MGD)	TP (mg/L)	TIN (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)
A5	RAS4	0.79	4.88	1.43	2.21
C1	RAS4	0.8	4.86	1.34	1.95
C5	RAS4	0.81	4.76	1.24	1.59
E1	RAS4	0.81	4.79	1.18	1.39
A1	RAS4	0.81	4.94	1.46	2.33
E5	RAS4	0.82	4.69	1.1	1.13

Appendix B-3: Graphical presentation of effluent concentrations

A2O process configuration with 10 MGD influent flow in reactors with varying volume for 12 MGD influent flow configuration

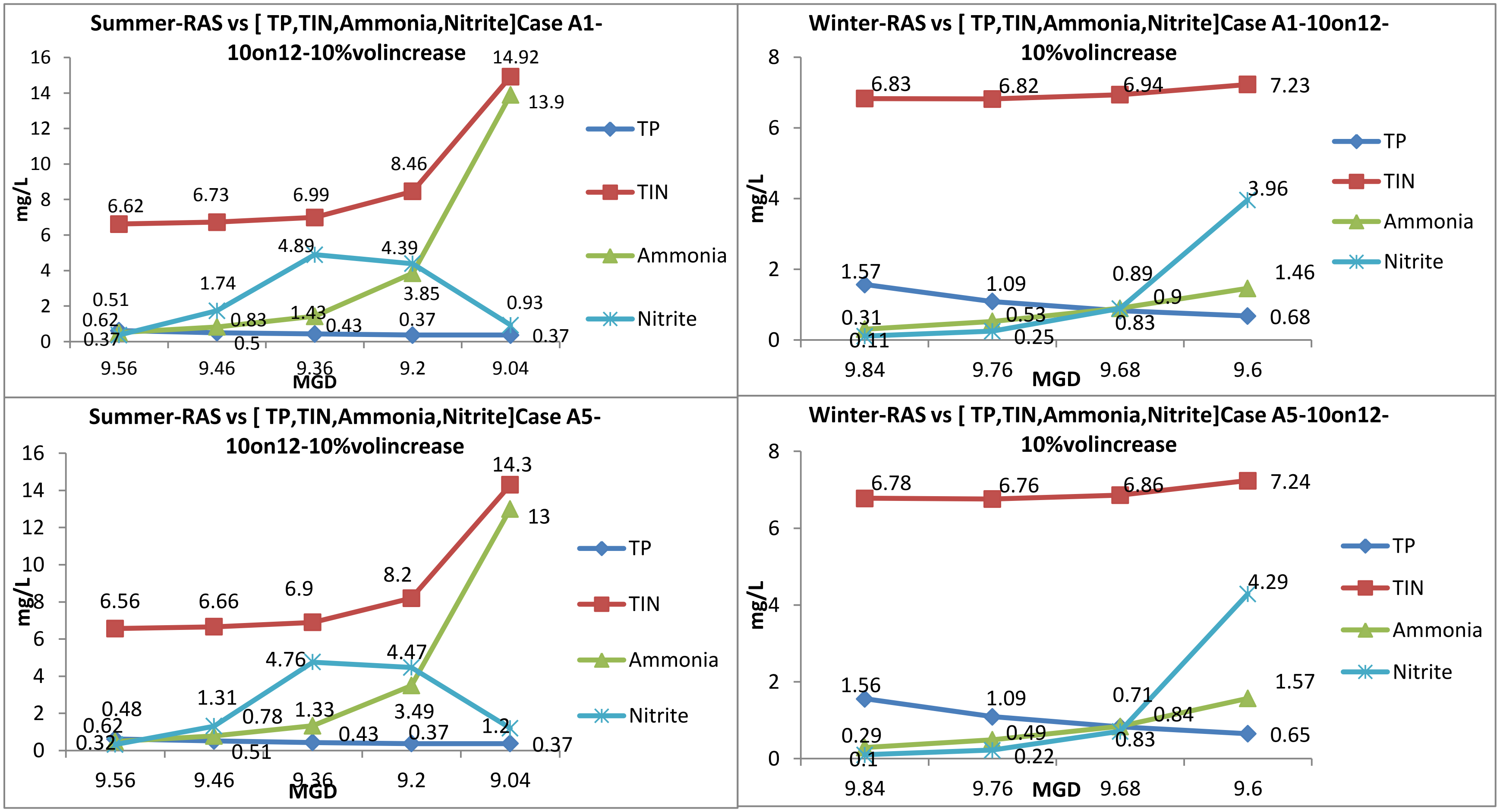

Figure B-1: Effluent concentrations for 10 MGD influent flow in reactors with 10 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases A1 and A5

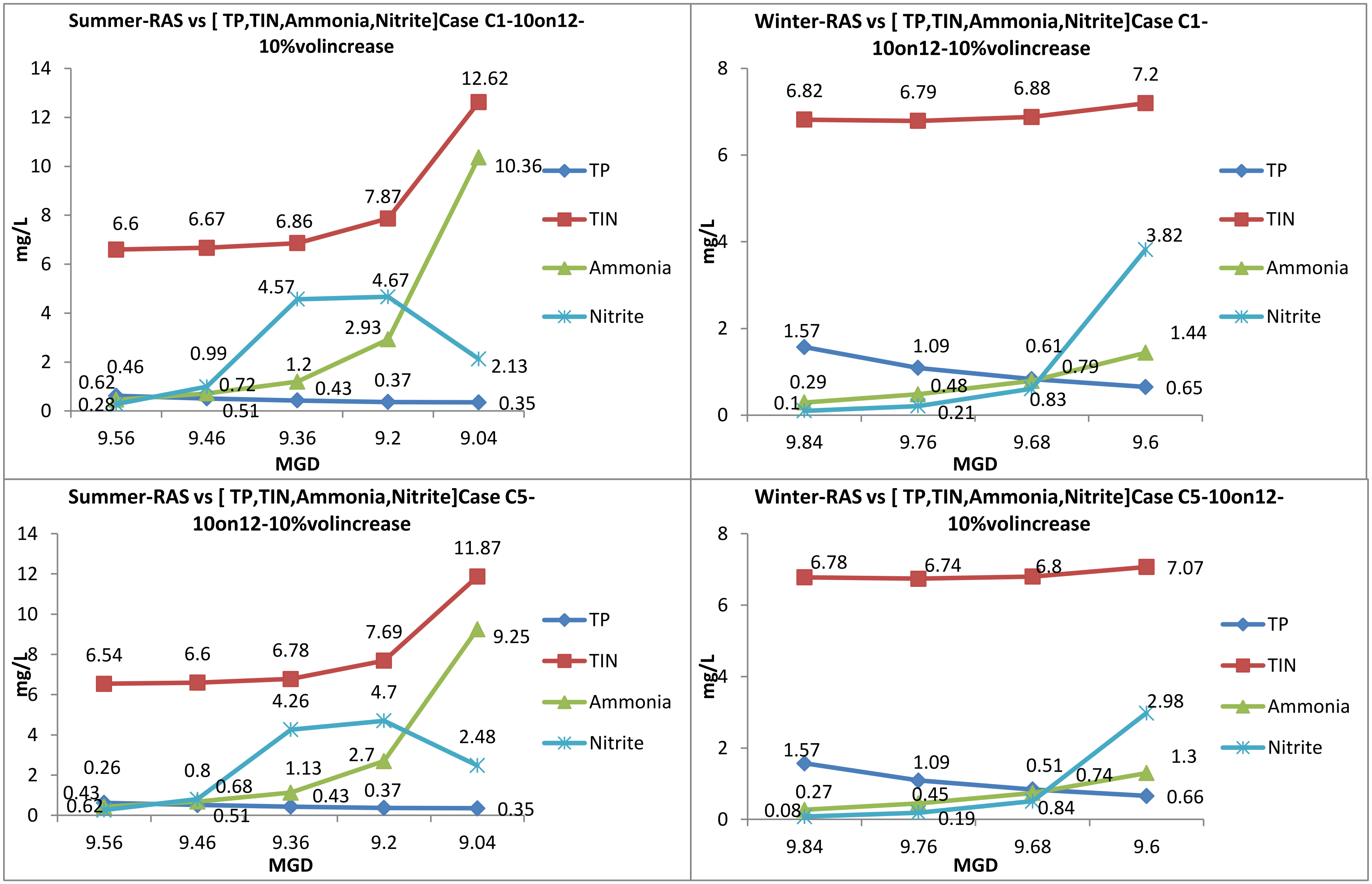

Figure B-2: Effluent concentrations for 10 MGD influent flow in reactors with 10 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases C1 and C5

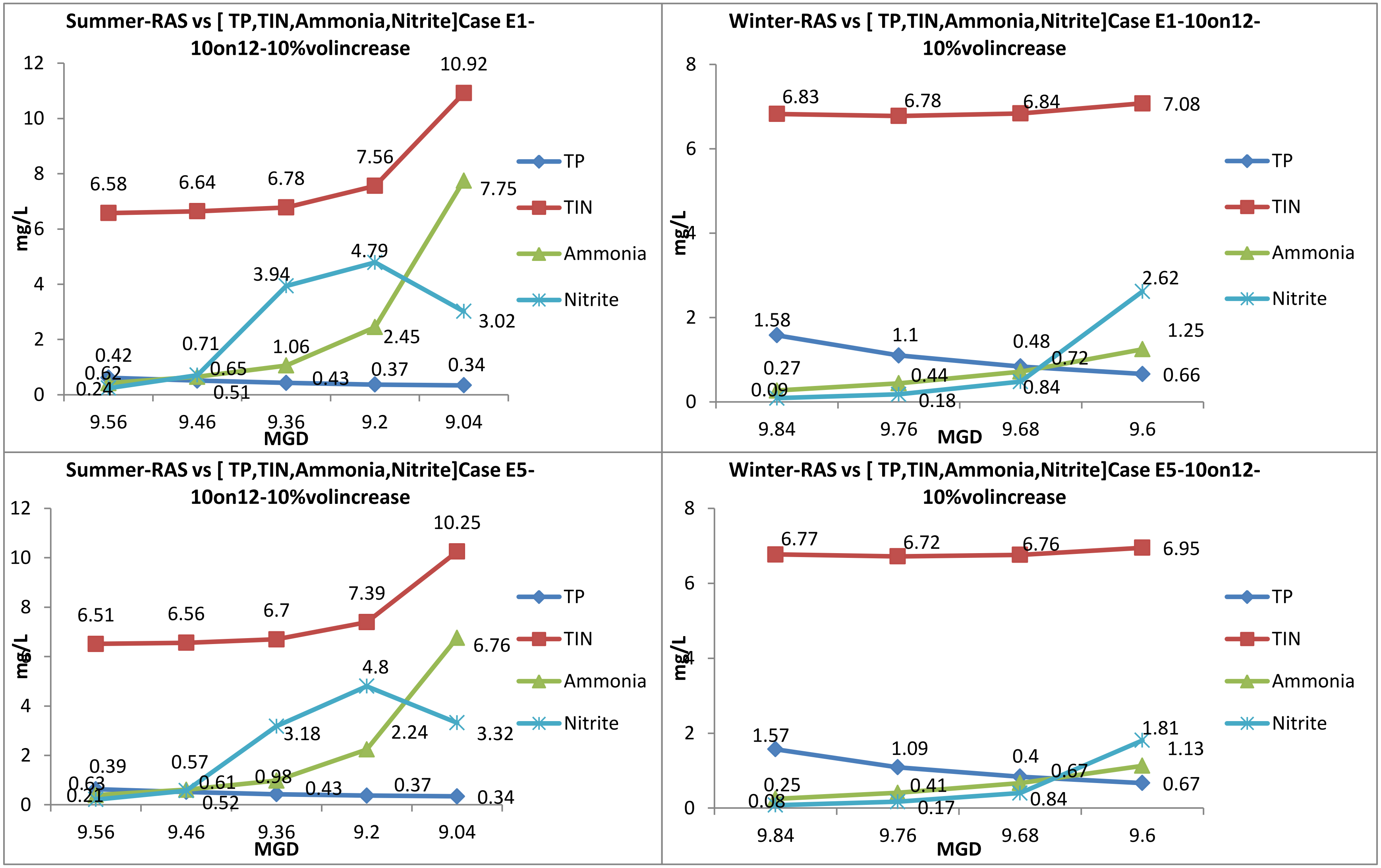

Figure B-3: Effluent concentrations for 10 MGD influent flow in reactors with 10 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases E1 and E5

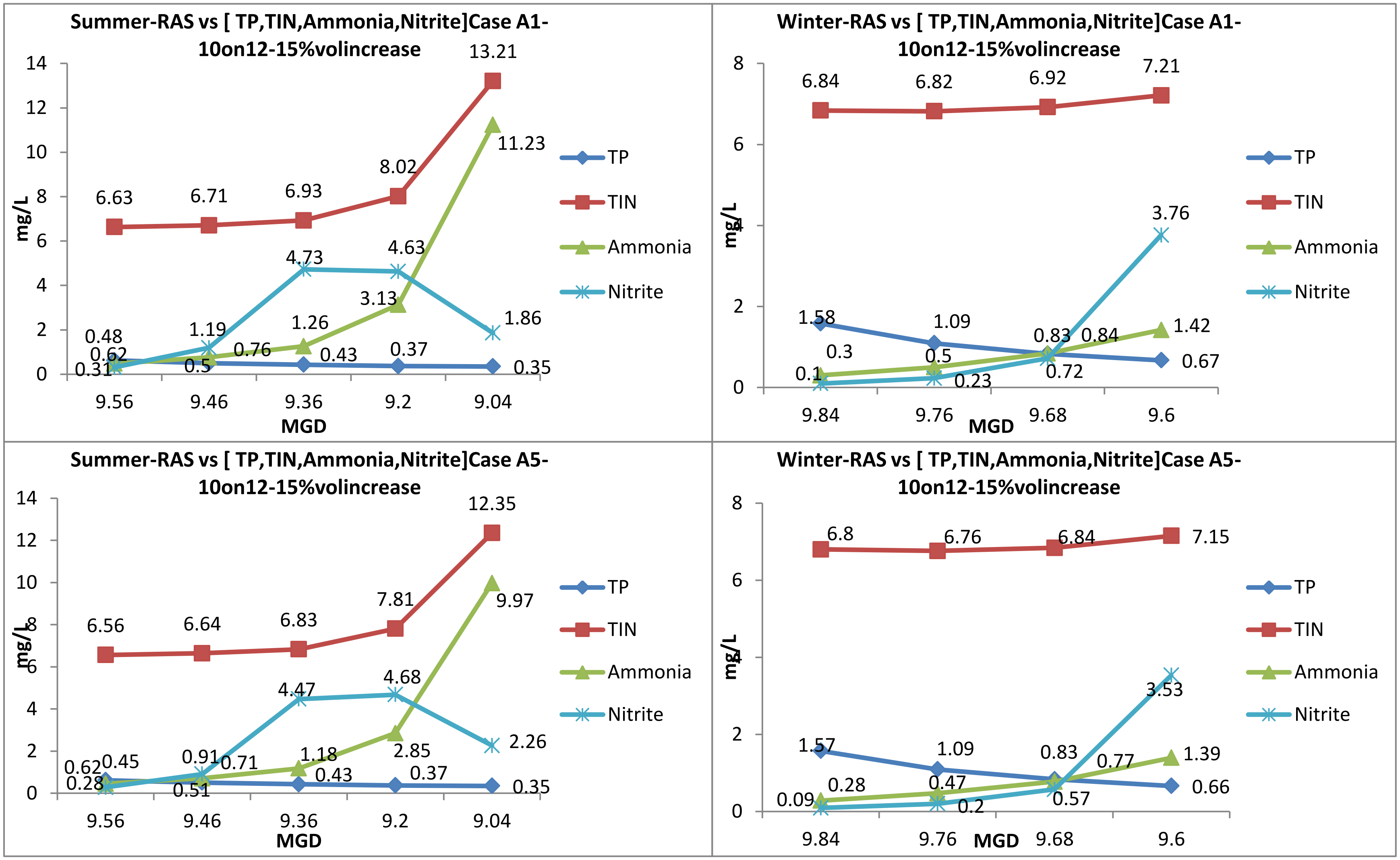

Figure B-4: Effluent concentrations for 10 MGD influent flow in reactors with 15 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases A1 and A5

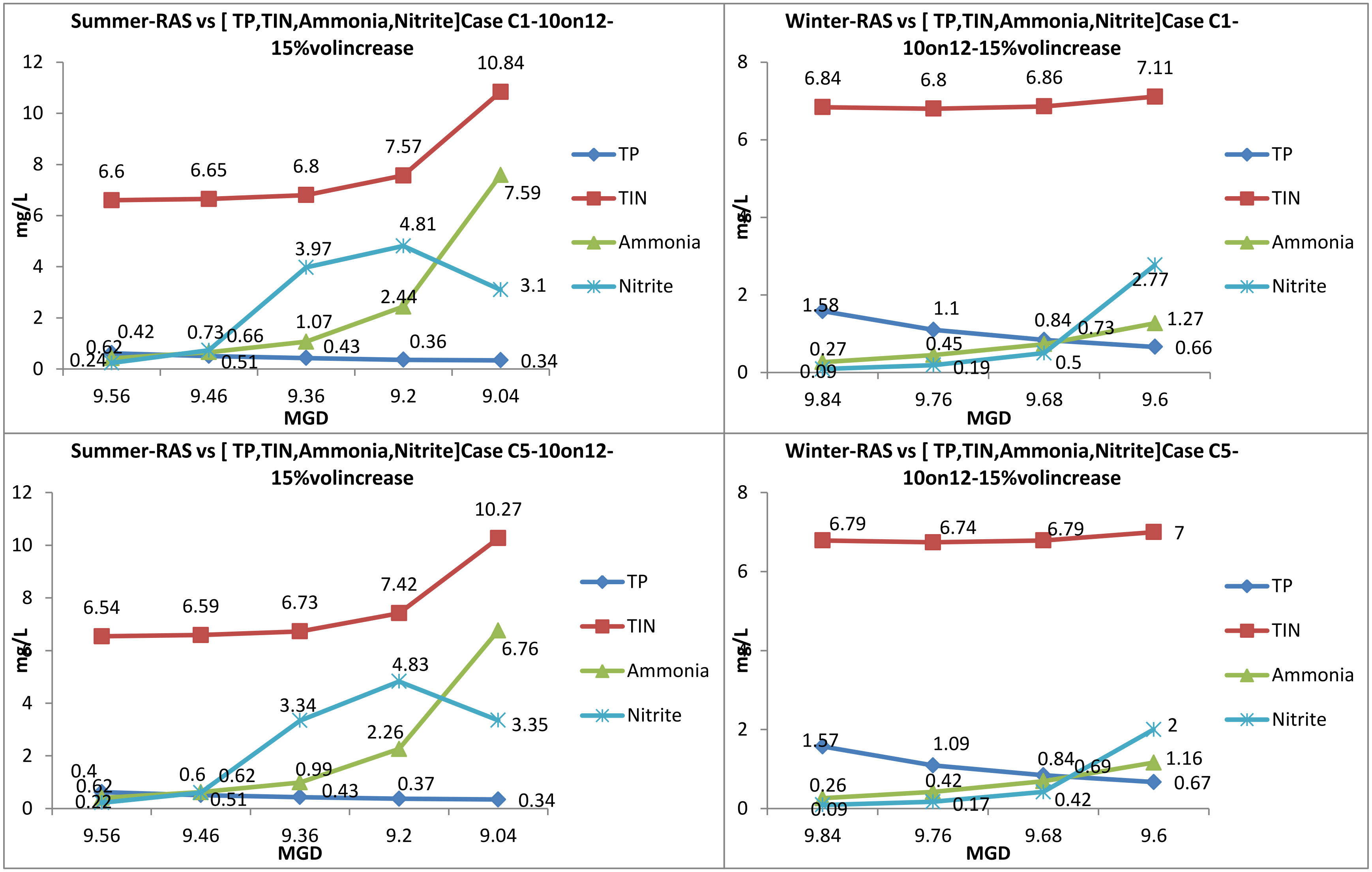

Figure B-5: Effluent concentrations for 10 MGD influent flow in reactors with 15 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases C1 and C5

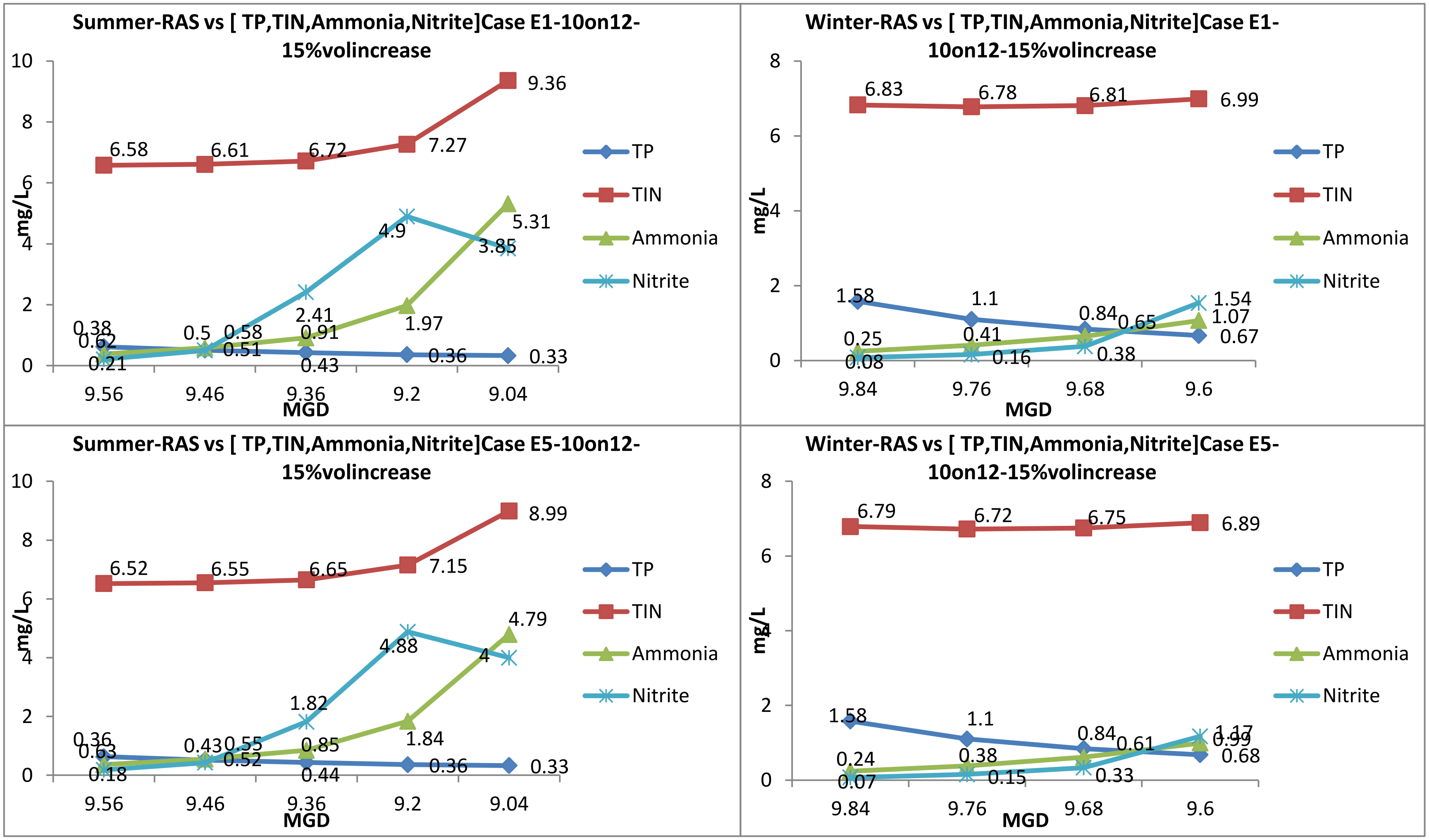

Figure B-6: Effluent concentrations for 10 MGD influent flow in reactors with 15 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases E1 and E5

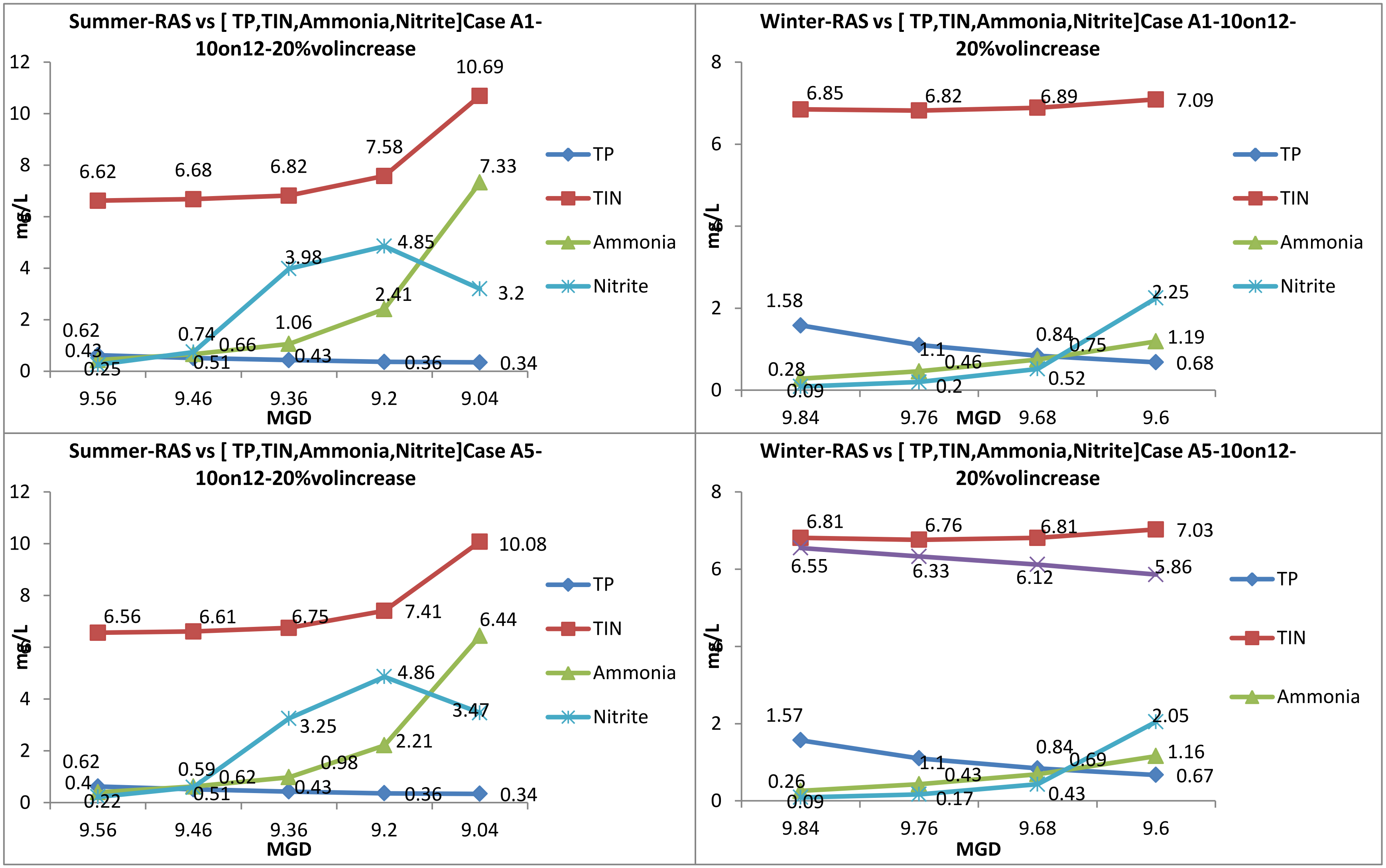

Figure B-7: Effluent concentrations for 10 MGD influent flow in reactors with 20 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases A1 and A5

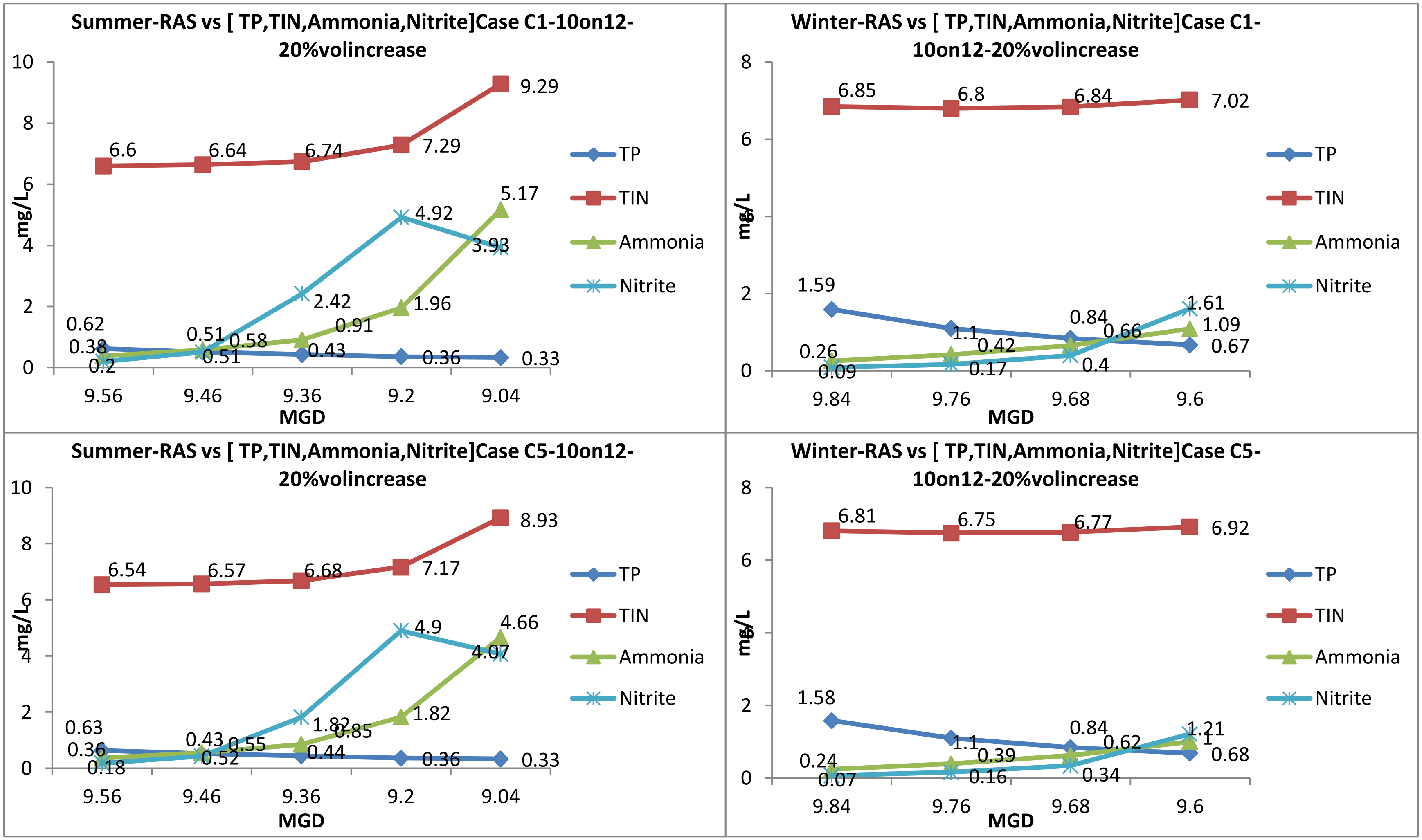

Figure B-8: Effluent concentrations for 10 MGD influent flow in reactors with 20 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases C1 and C5

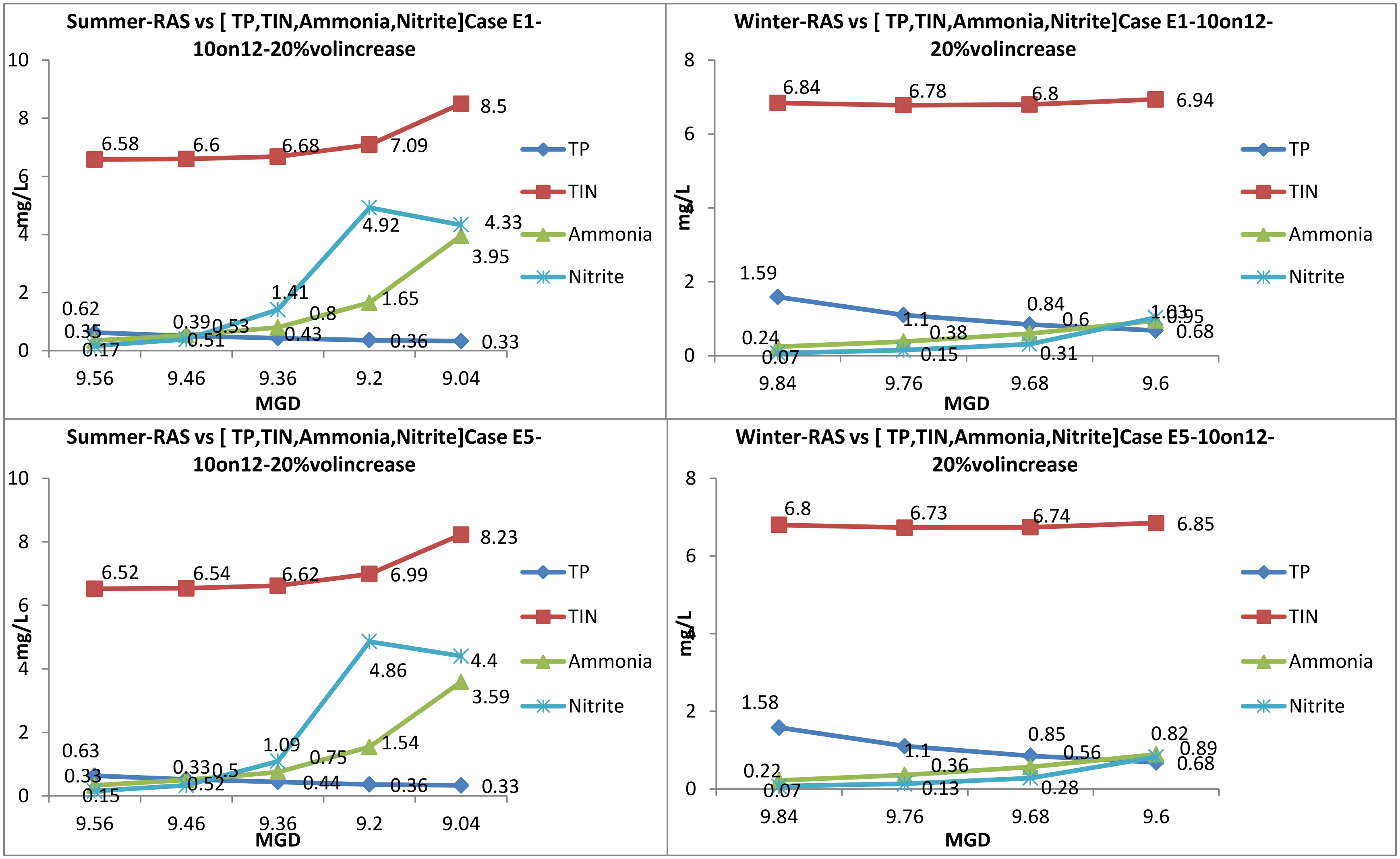

Figure B-9: Effluent concentrations for 10 MGD influent flow in reactors with 20 % increase in volume for summer and winter conditions, 10 MGD internal recycle Cases E1 and E5

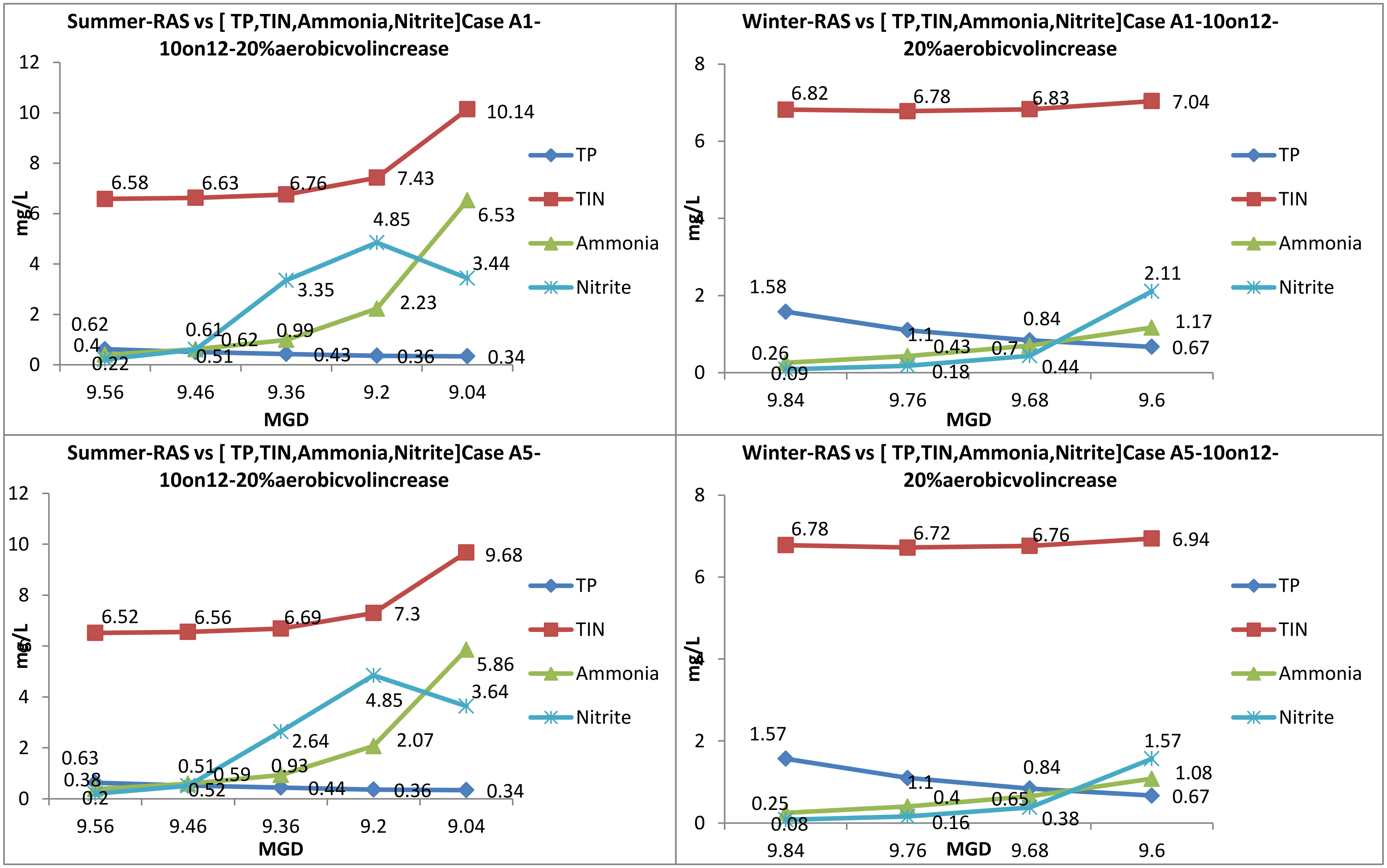

Figure B-10: Effluent concentrations for 10 MGD influent flow in reactors with10% increase in anaerobic, anoxic and 20 % increase in aerator volume for summer and winter conditions, 10 MGD internal recycle Cases A1 and A5

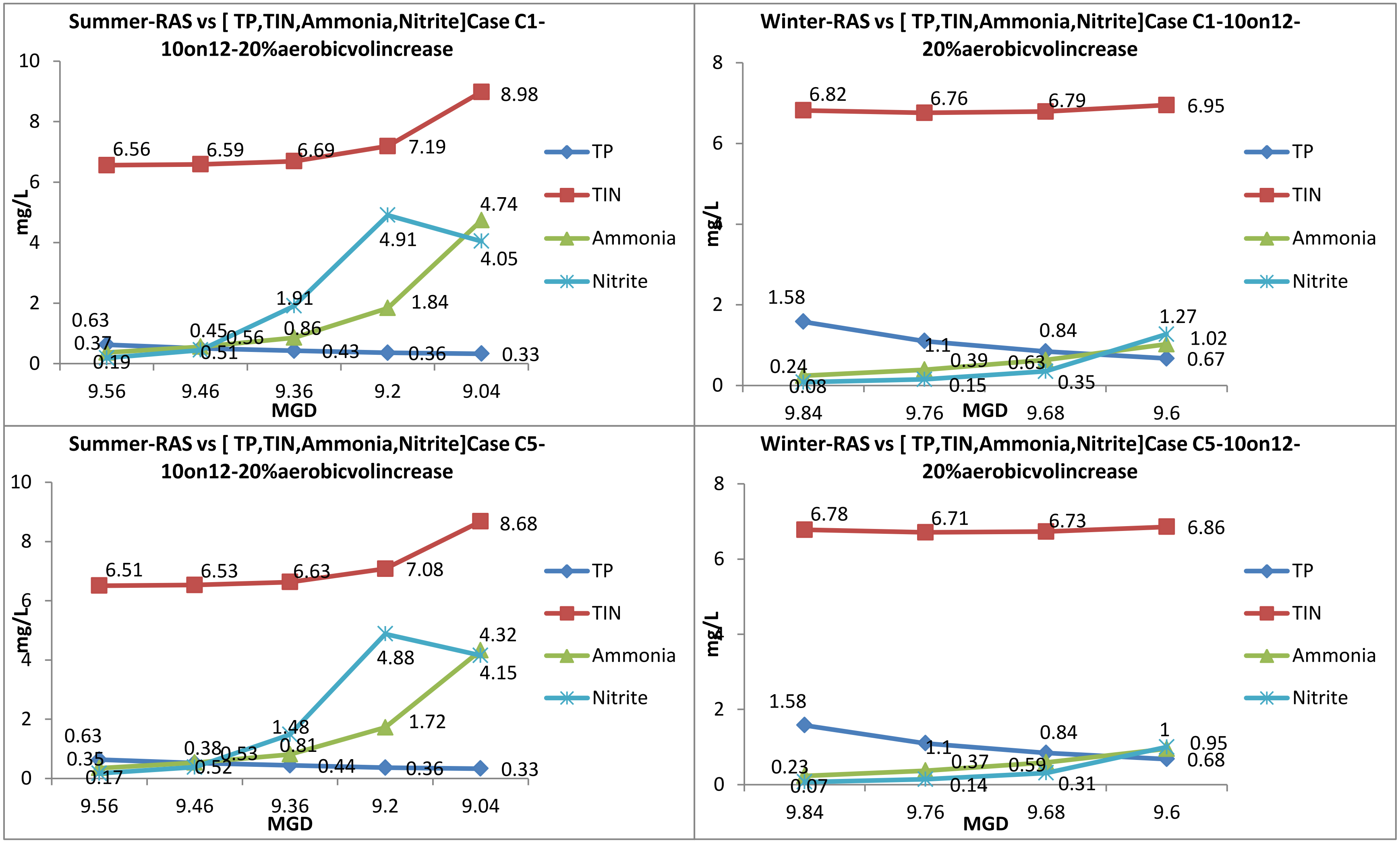

Figure B-11: Effluent concentrations for 10 MGD influent flow in reactors with10% increase in anaerobic, anoxic and 20 % increase in aerator volume for summer and winter conditions, 10 MGD internal recycle Cases C1 and C5

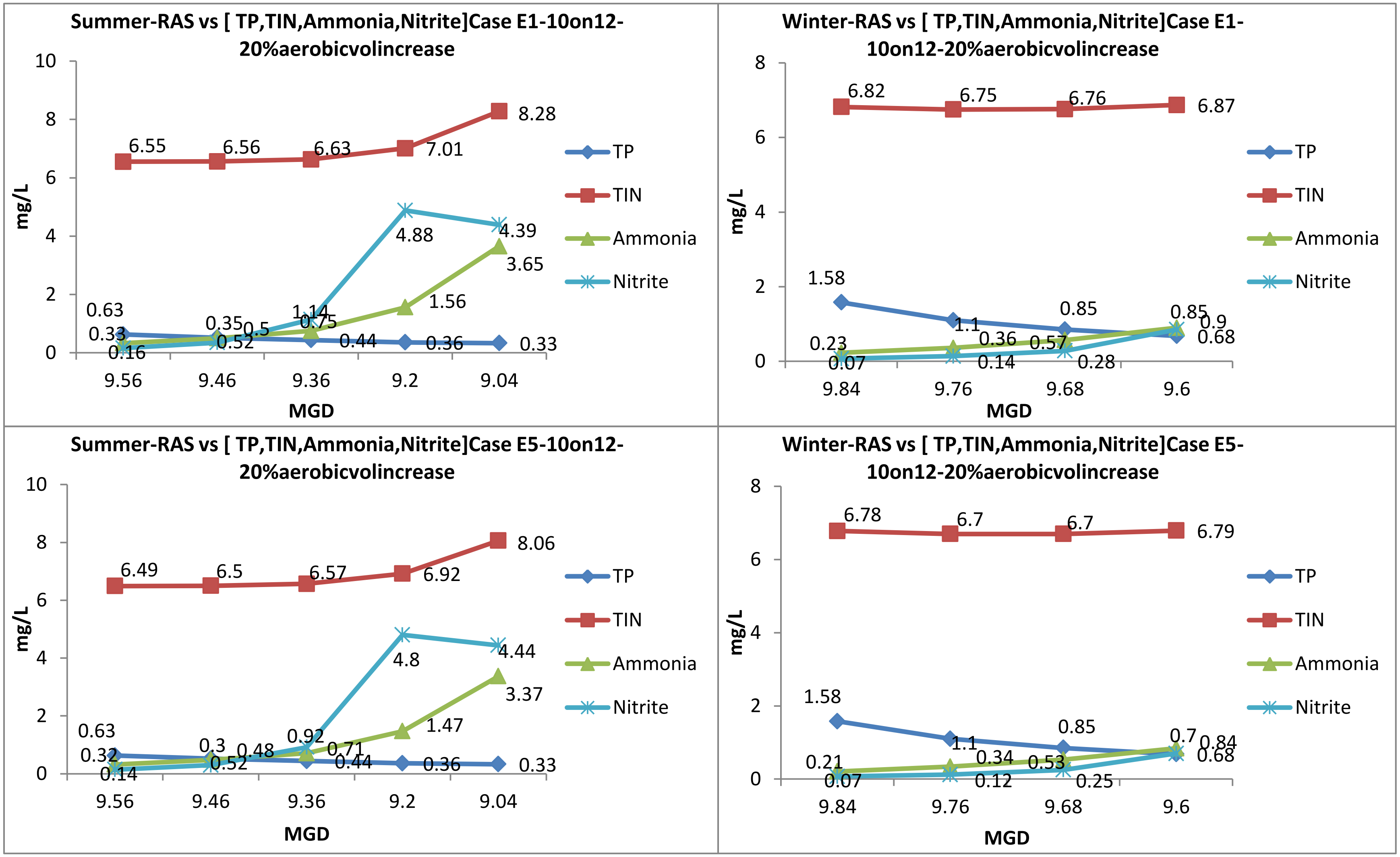

Figure B-12: Effluent concentrations for 10 MGD influent flow in reactors with10% increase in anaerobic, anoxic and 20 % increase in aerator volume for summer and winter conditions, 10 MGD internal recycle Cases E1 and E5

Summer 100 % IR

Case A

Table B-29: Basin Volume

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table B-30: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

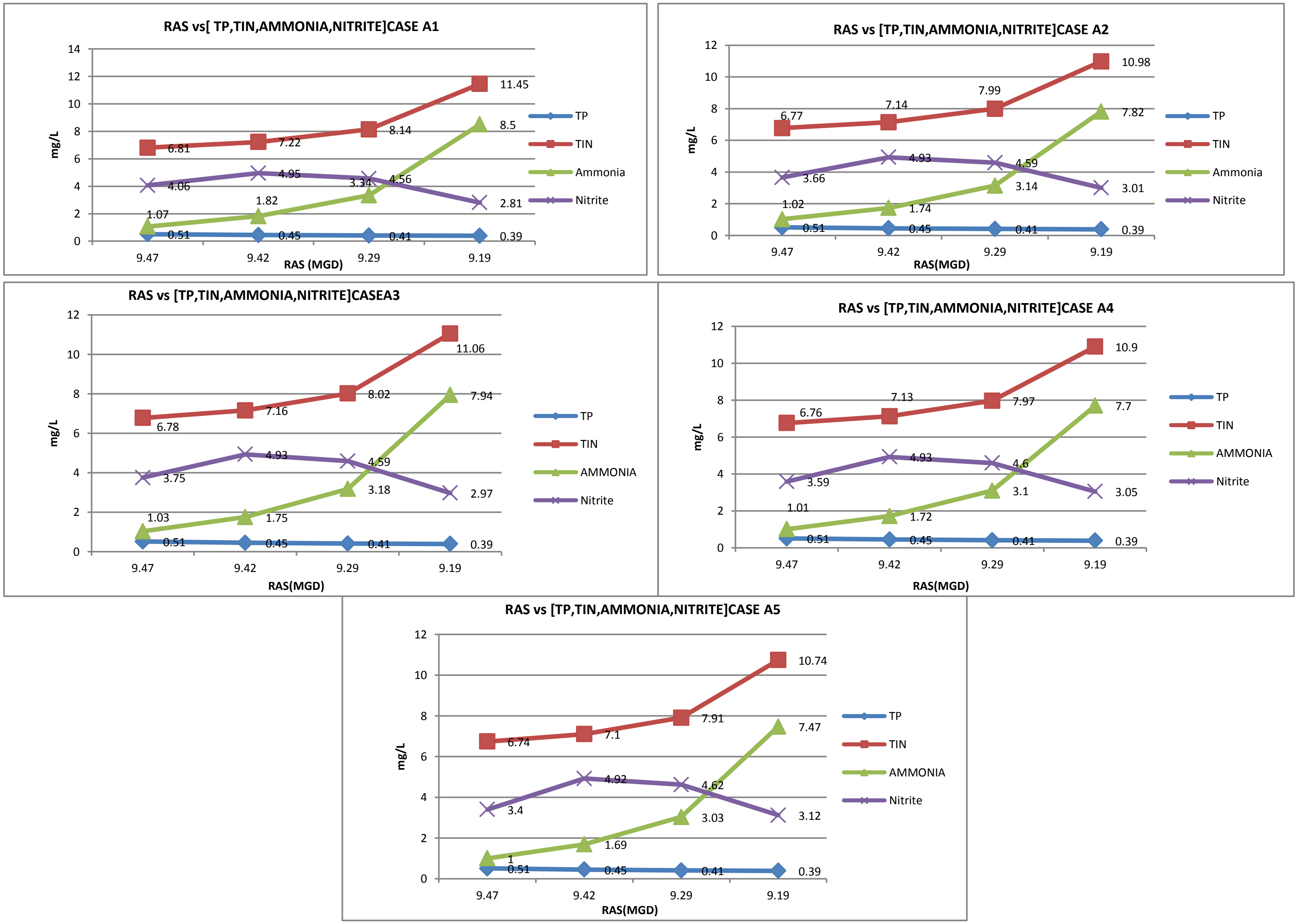

Figure B-13:Case A

Summer 100 % IR

Case C

Table-31: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table-32: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

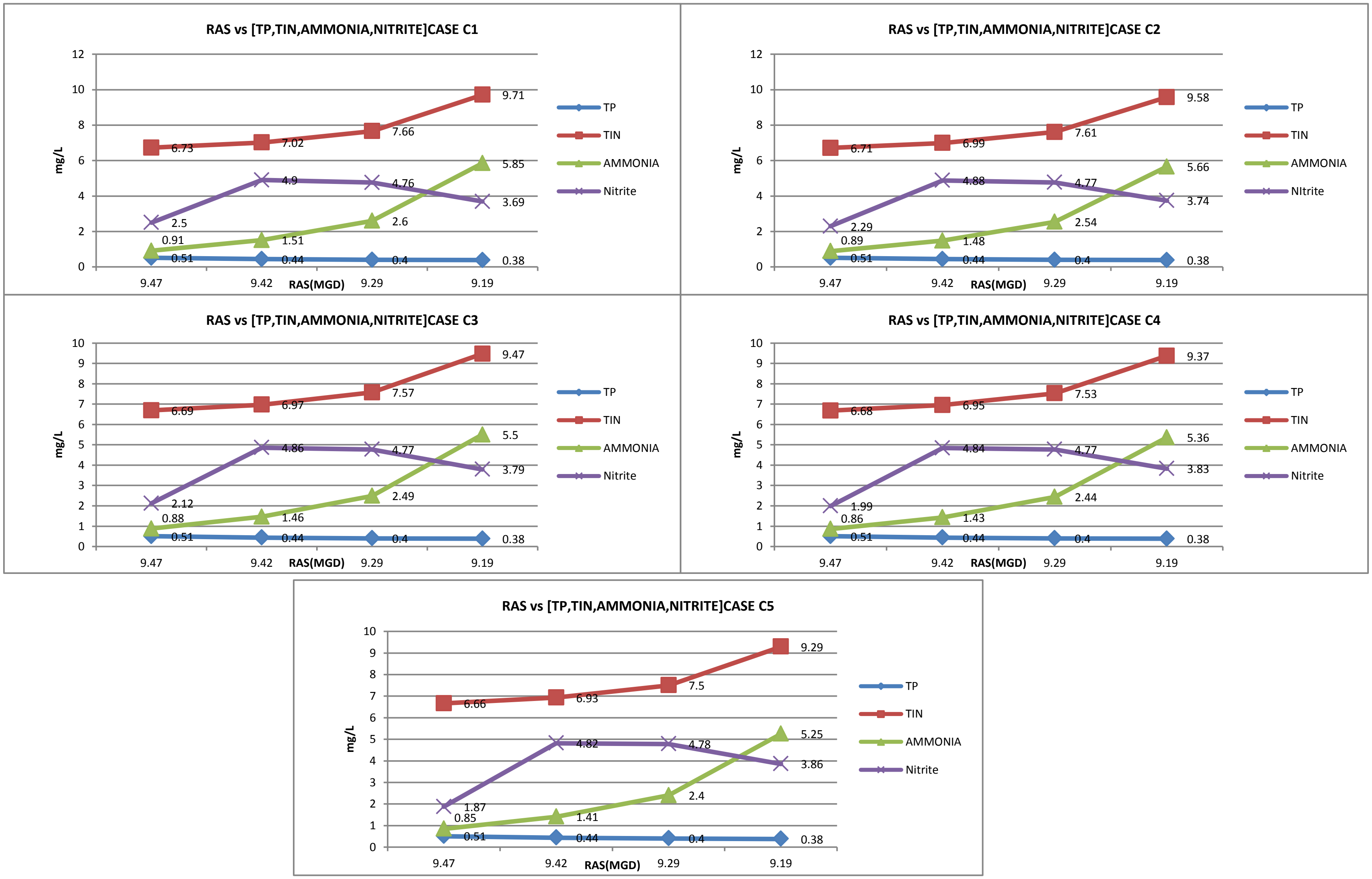

Figure B-14:Case C

Summer 100 % IR

Case E

Tabke-33: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table-34: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

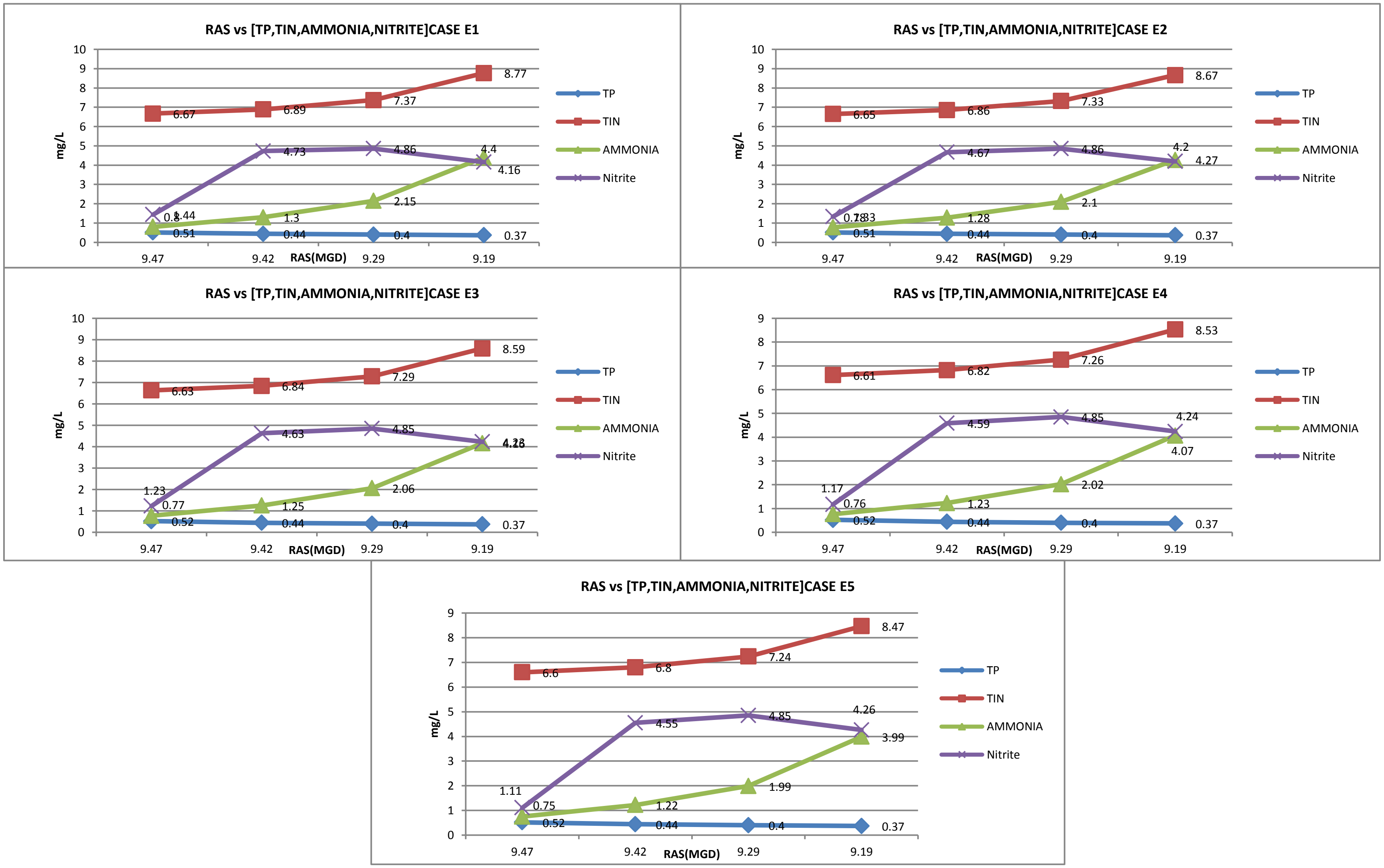

Figure B-15: Case E

Summer 200 % IR

Case A

Table-35: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table-36: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

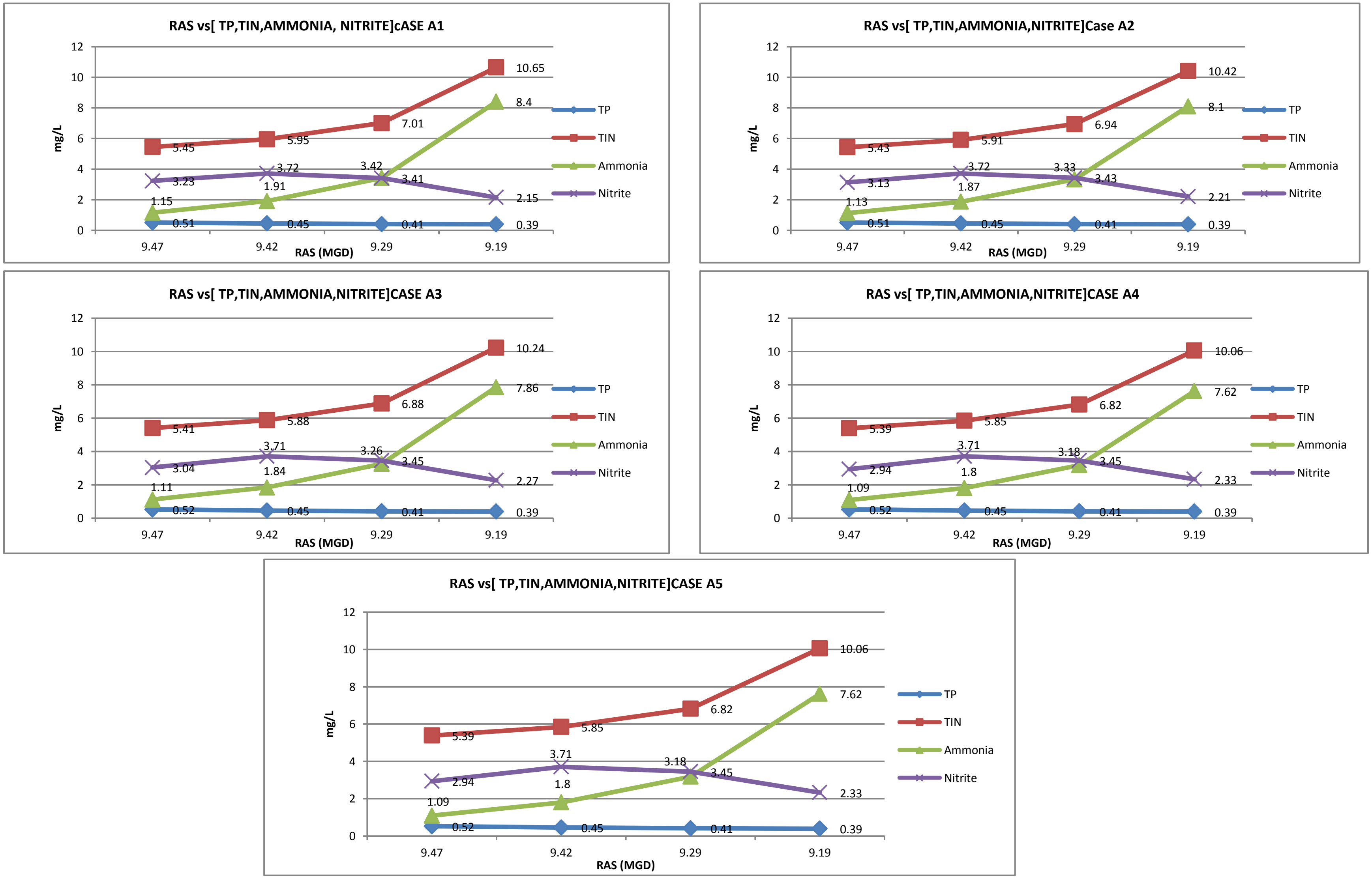

Figure B- 16: Case A

Summer 200 % IR

Case C

Table-37: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table 38: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

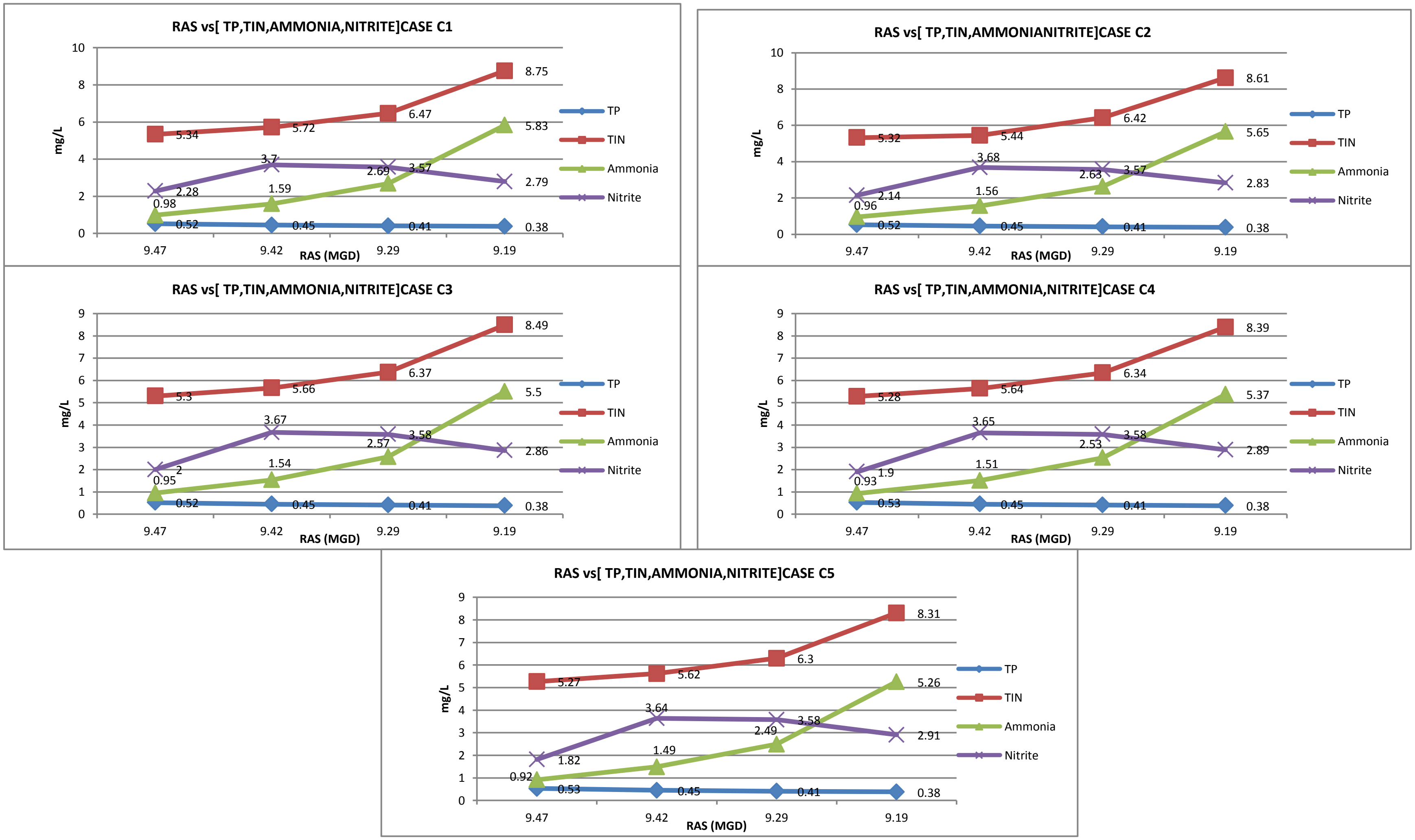

Figure B-17: Case C

Summer 200 % IR

Case E

Table 39: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table 40: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

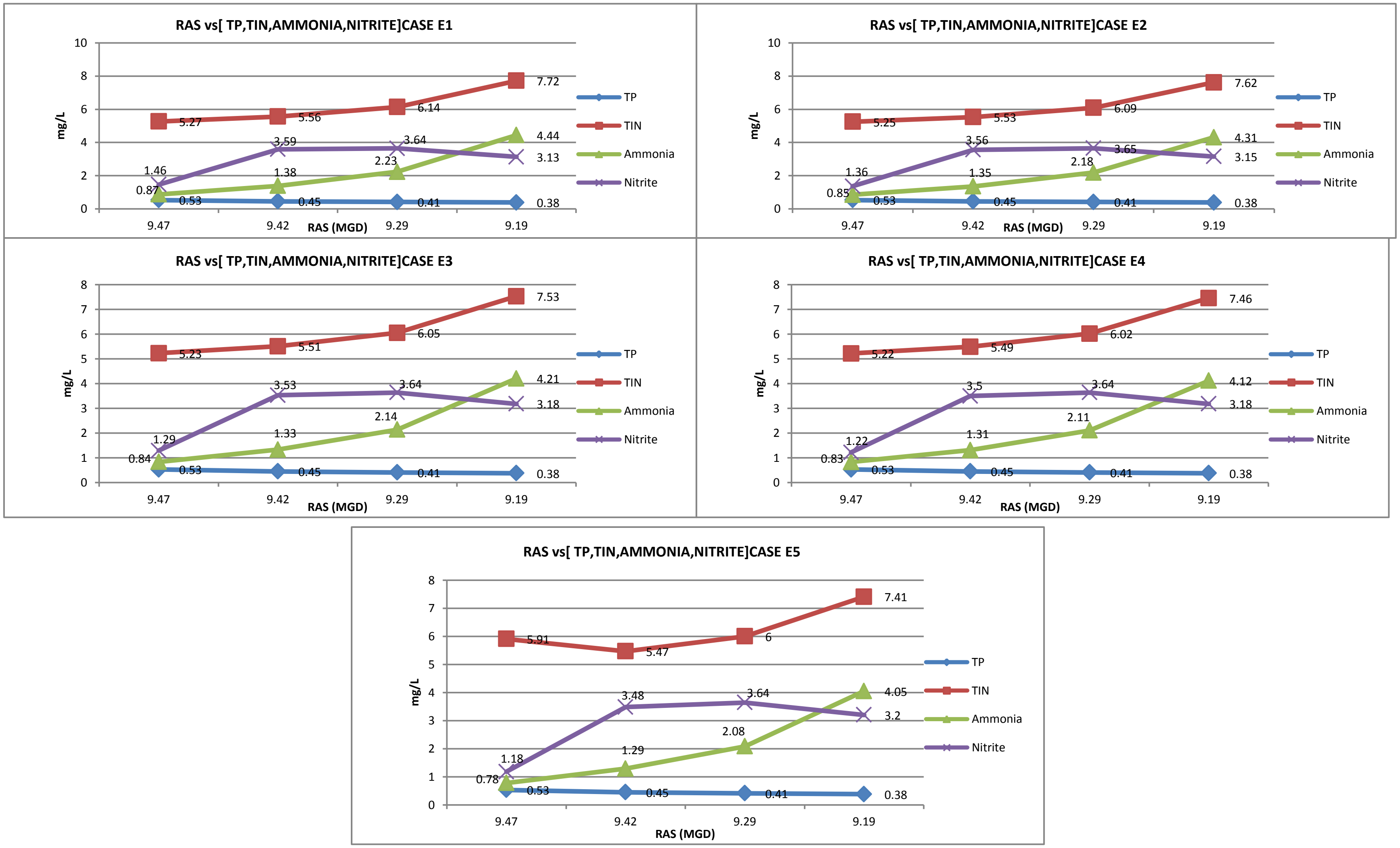

Figure B-18: Case E

Summer 300 % IR

Case A

Table-41: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table 42: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

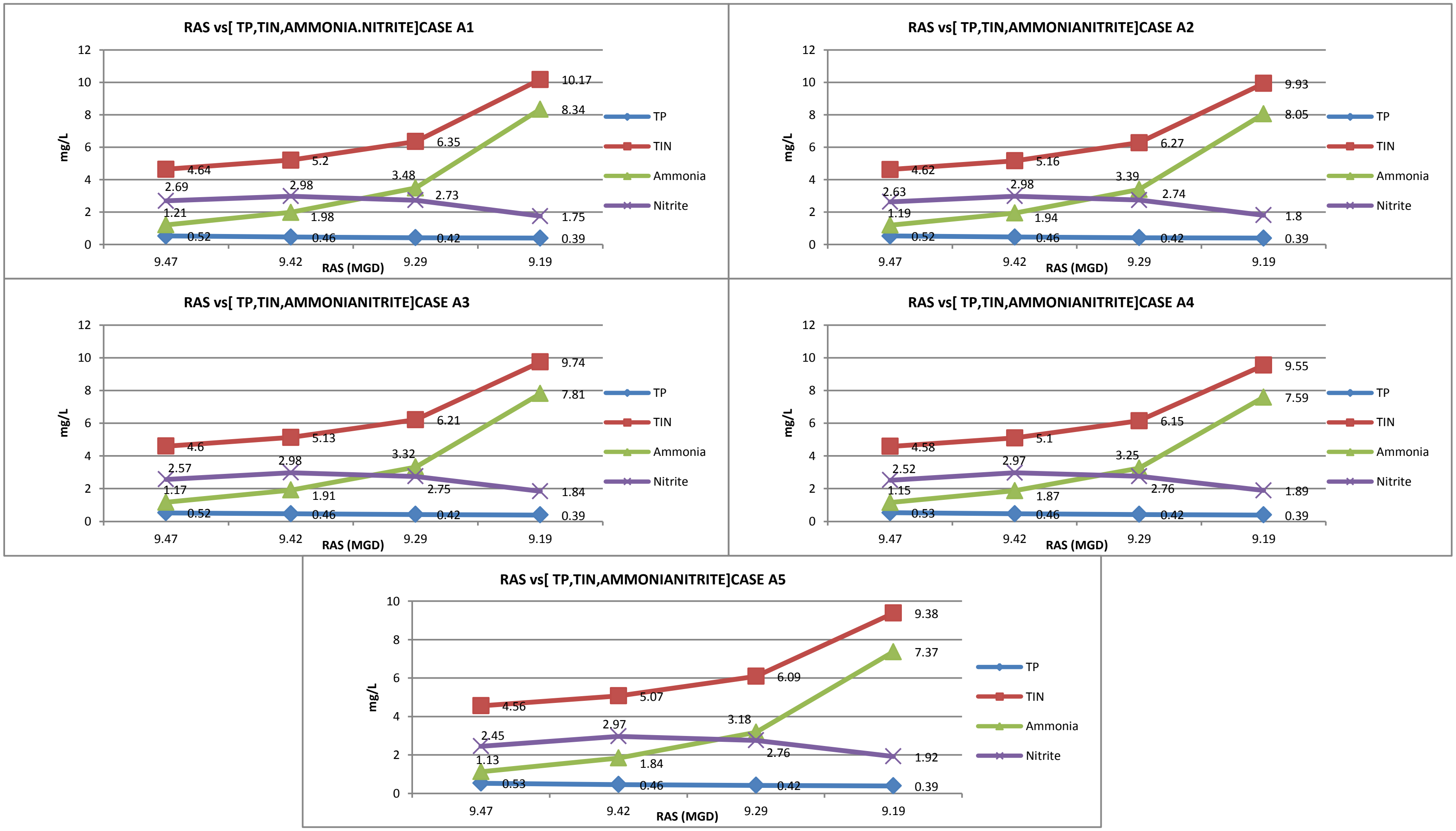

Figure B-19: Case A

Summer 300 % IR

Case C

Table-43: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table-44: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

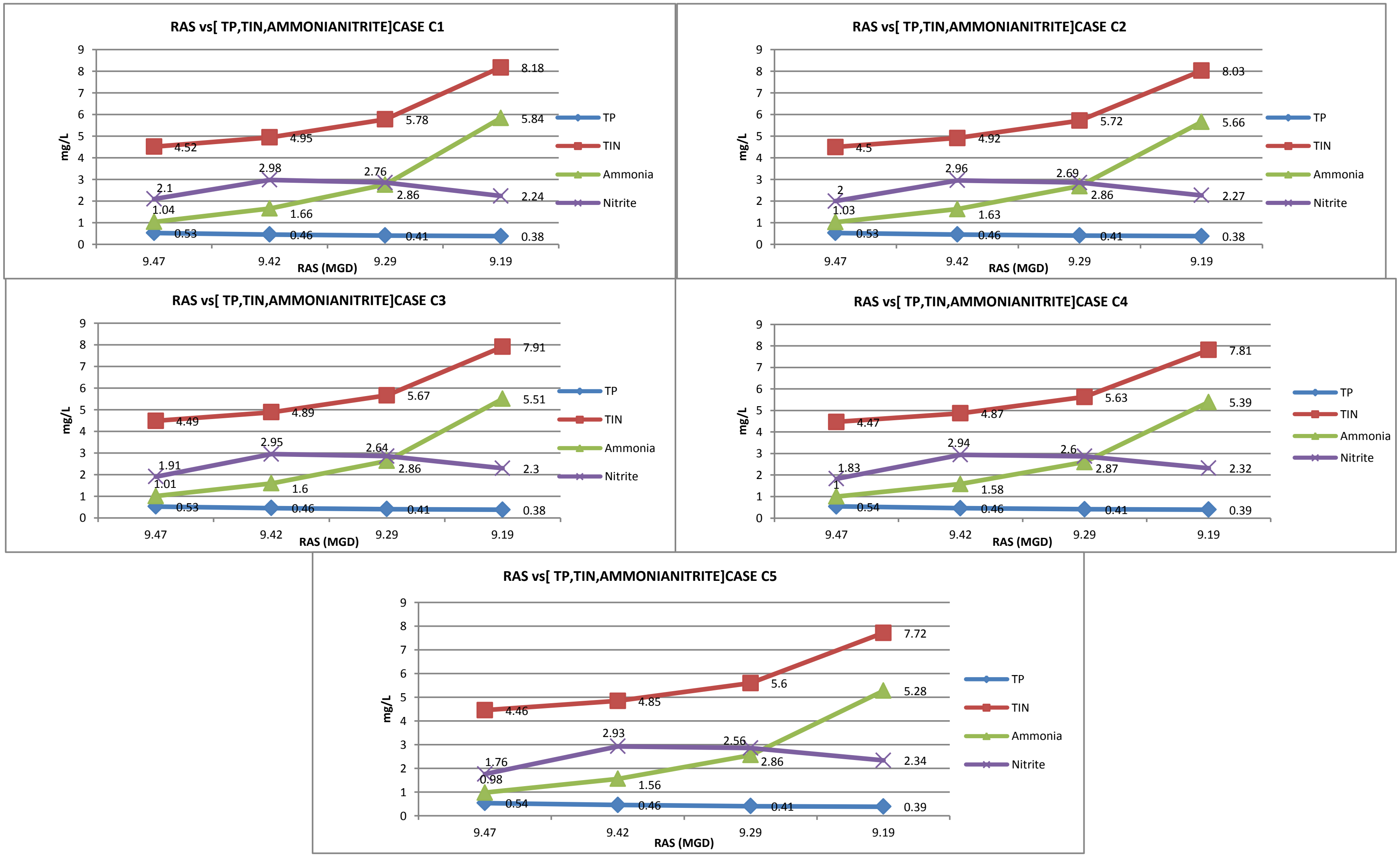

Figure B-20: Case C

Summer 300 % IR

Case E

Table 45: Basin volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table 46:RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.47	0.25
	9.38	0.29
	9.29	0.33
	9.19	0.39

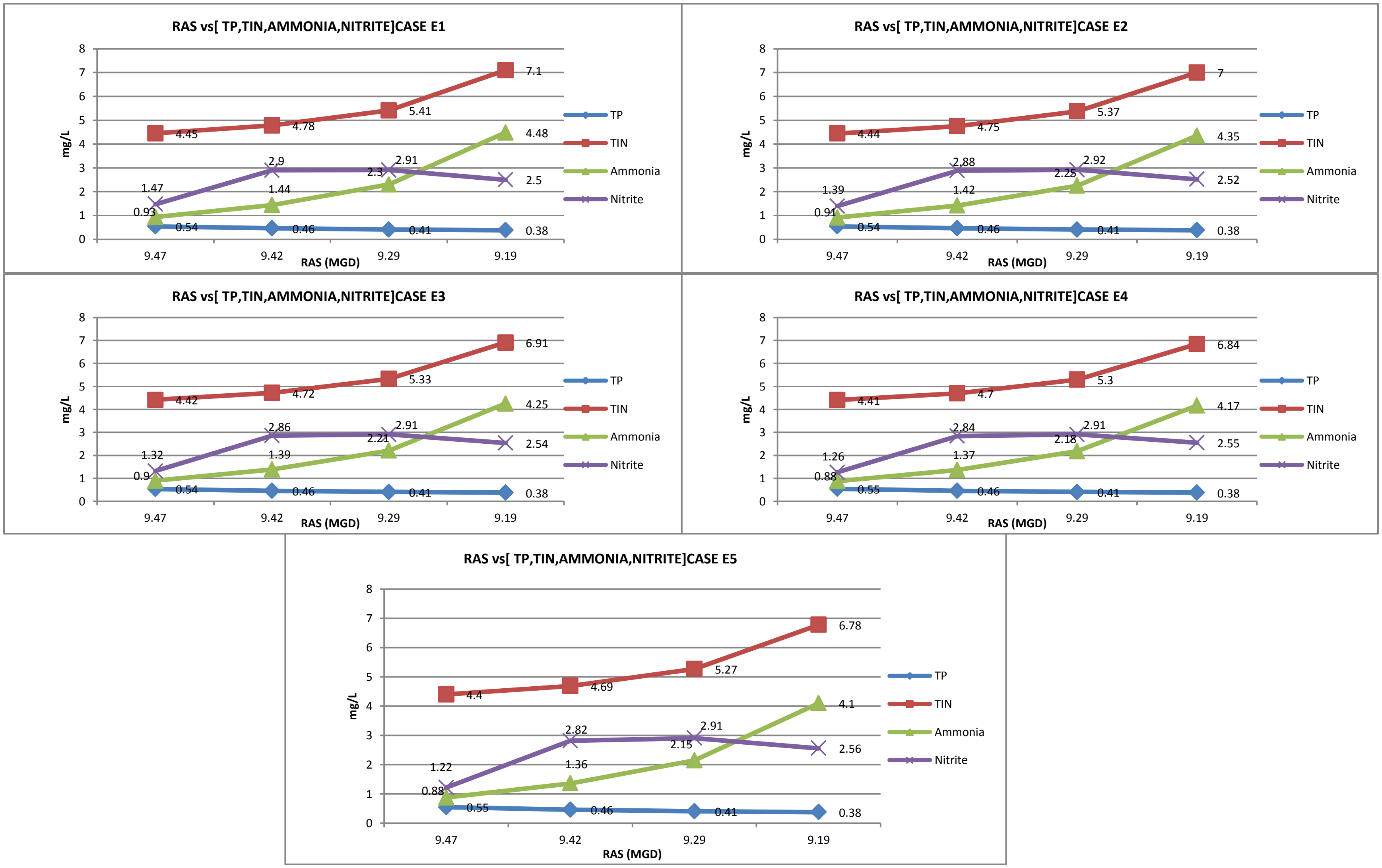

Figure B-21: Case E

Winter 100 % IR

Case A

Table 47: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table 48: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.84	0.06
	9.76	0.10
	9.68	0.14

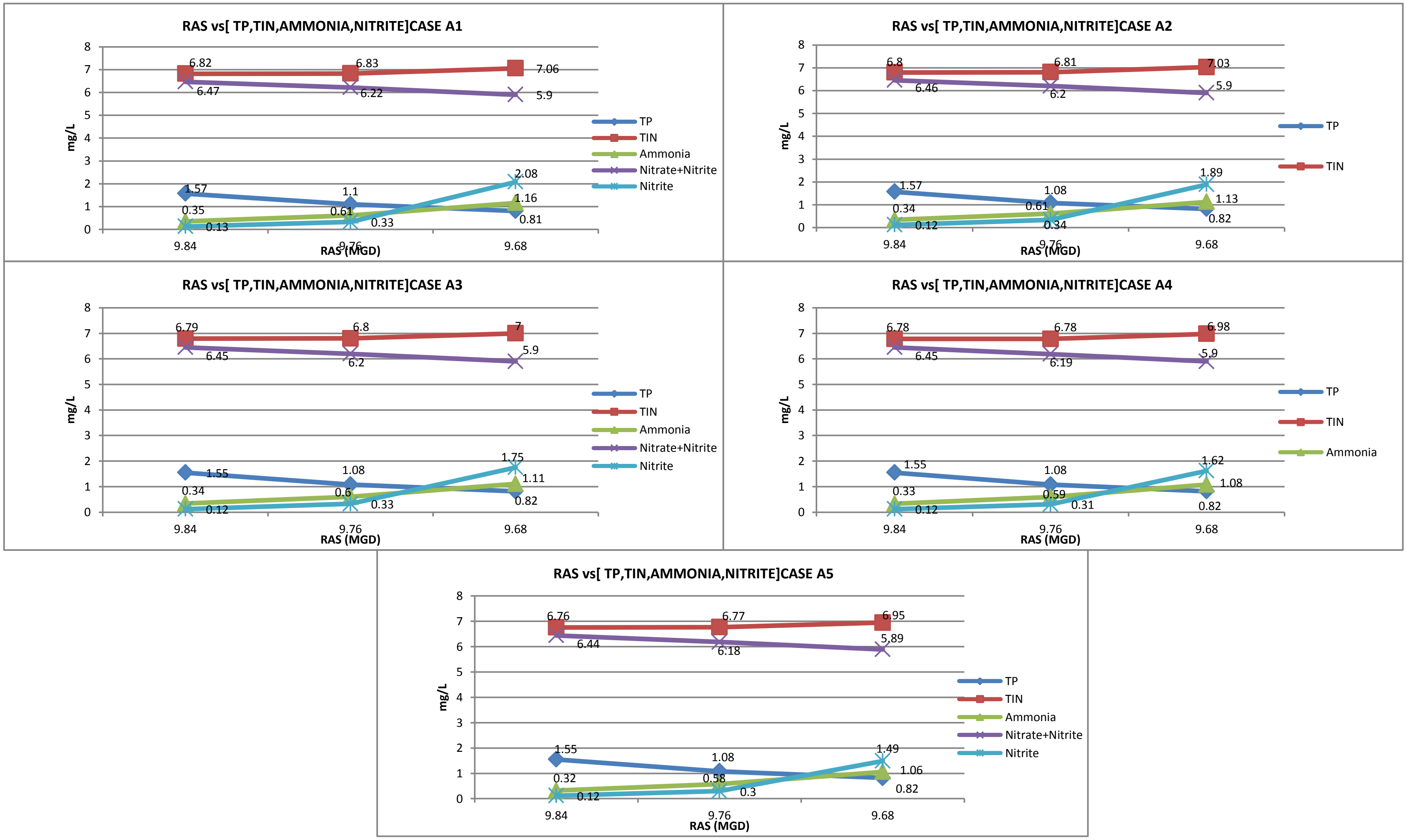

Figure B-22:Case A

Winter 100 % IR

Case C

Table 49: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table 50: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.84	0.06
	9.76	0.10
	9.68	0.14

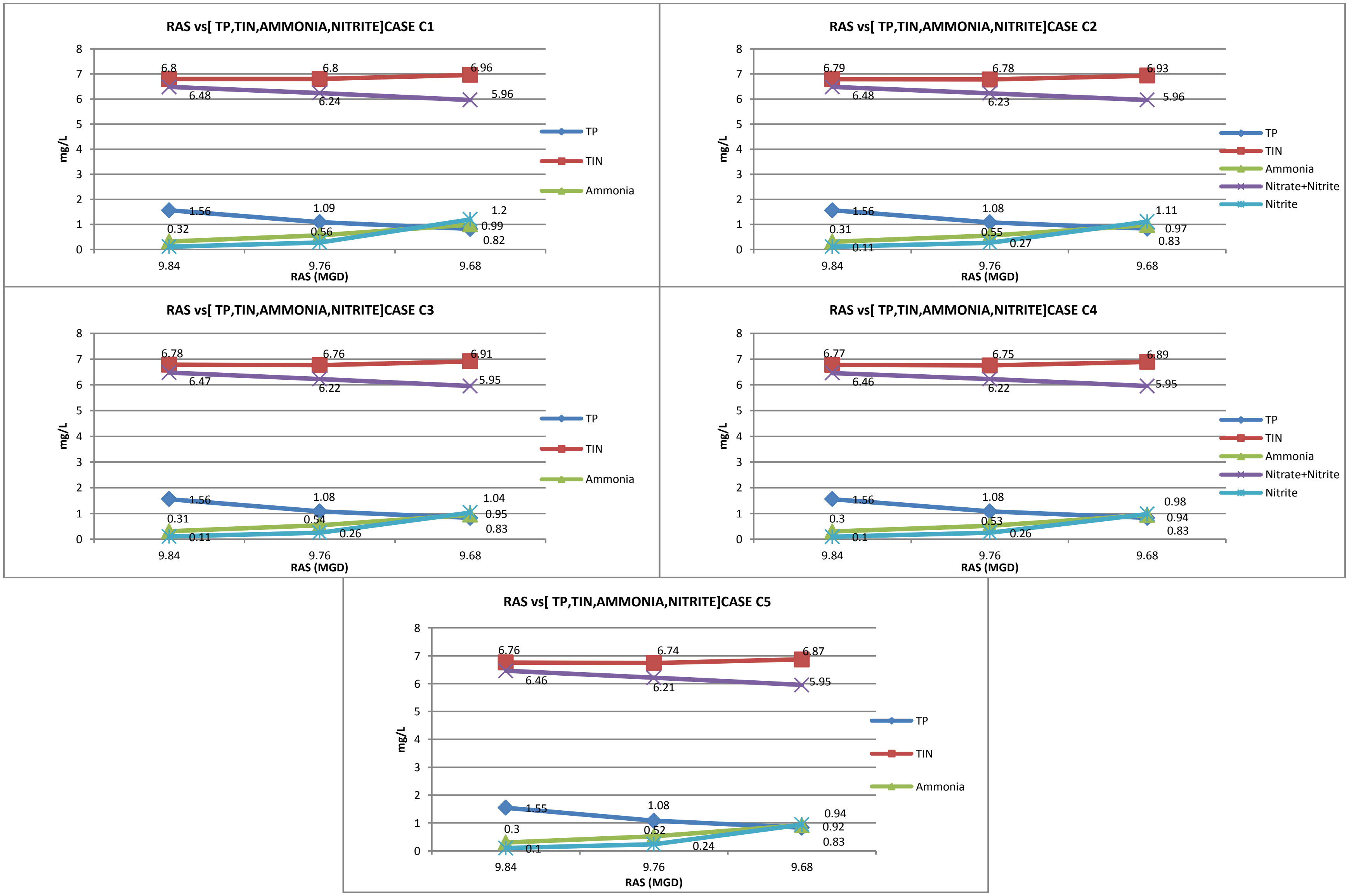

Figure B-23:Case C

Winter 100 % IR

Case E

Table 51: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table 52: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
100	9.84	0.06
	9.76	0.10
	9.68	0.14

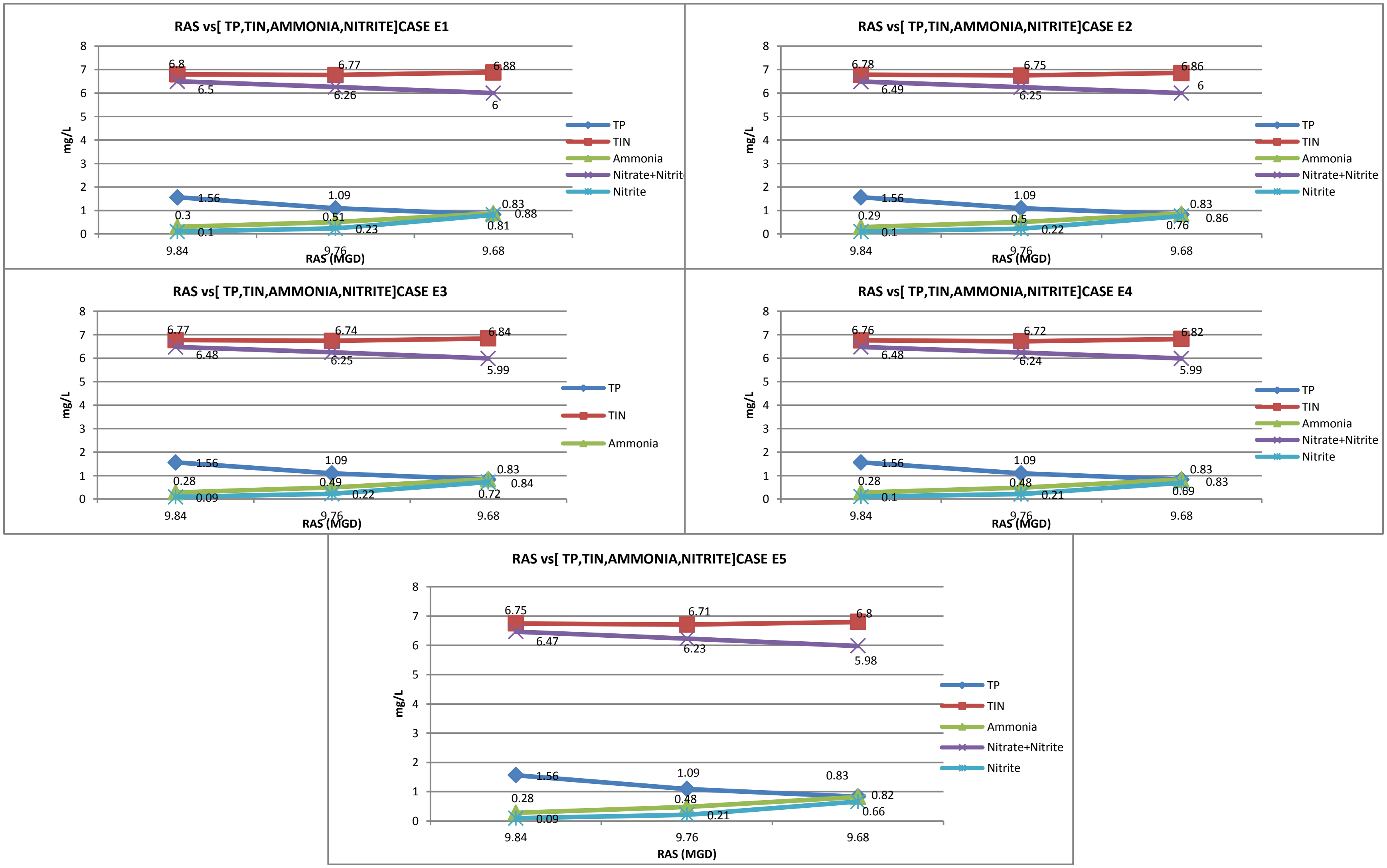

Figure B-24: Case E

Winter 200 % IR

Case A

Table 53: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table 54: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.84	0.06
	9.76	0.10
	9.68	0.14

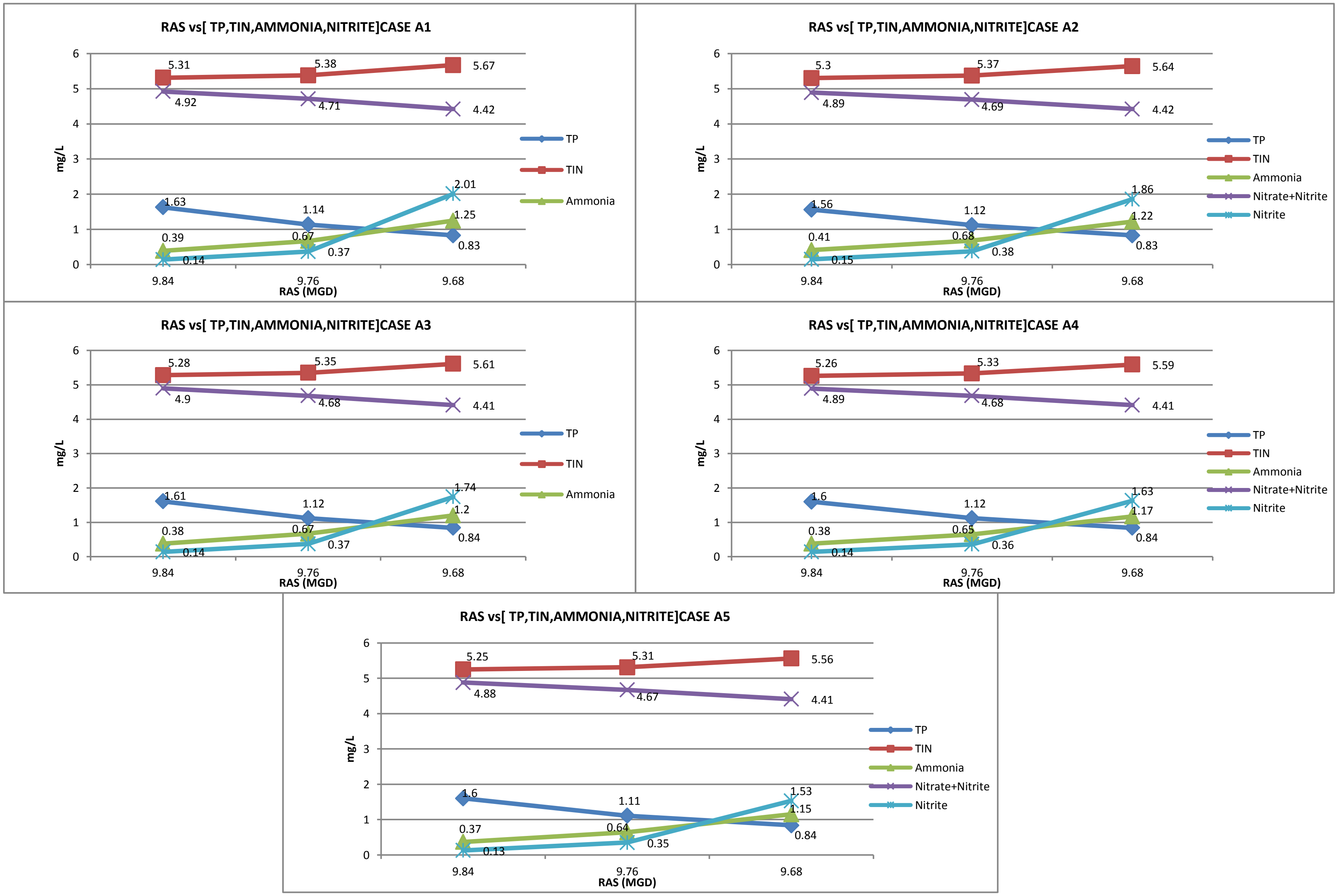

Figure B-25: Case A

Winter 200 % IR

Case C

Table 55: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table 56: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.84	0.06
	9.76	0.10
	9.68	0.14

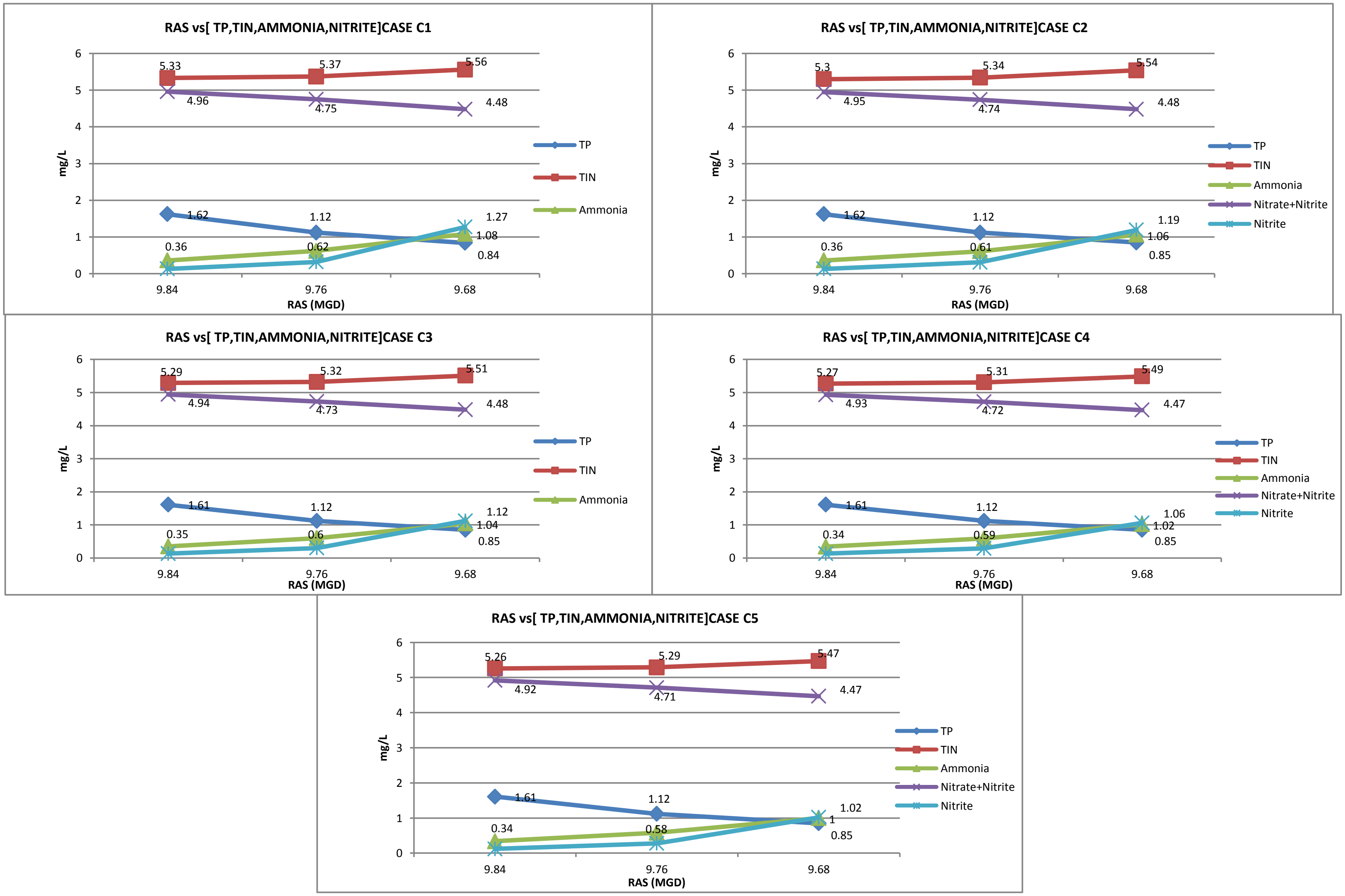

Figure B-26: Case C

Winter 200 % IR

Case E

Table 57: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table 58: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
200	9.84	0.06
	9.76	0.10
	9.68	0.14

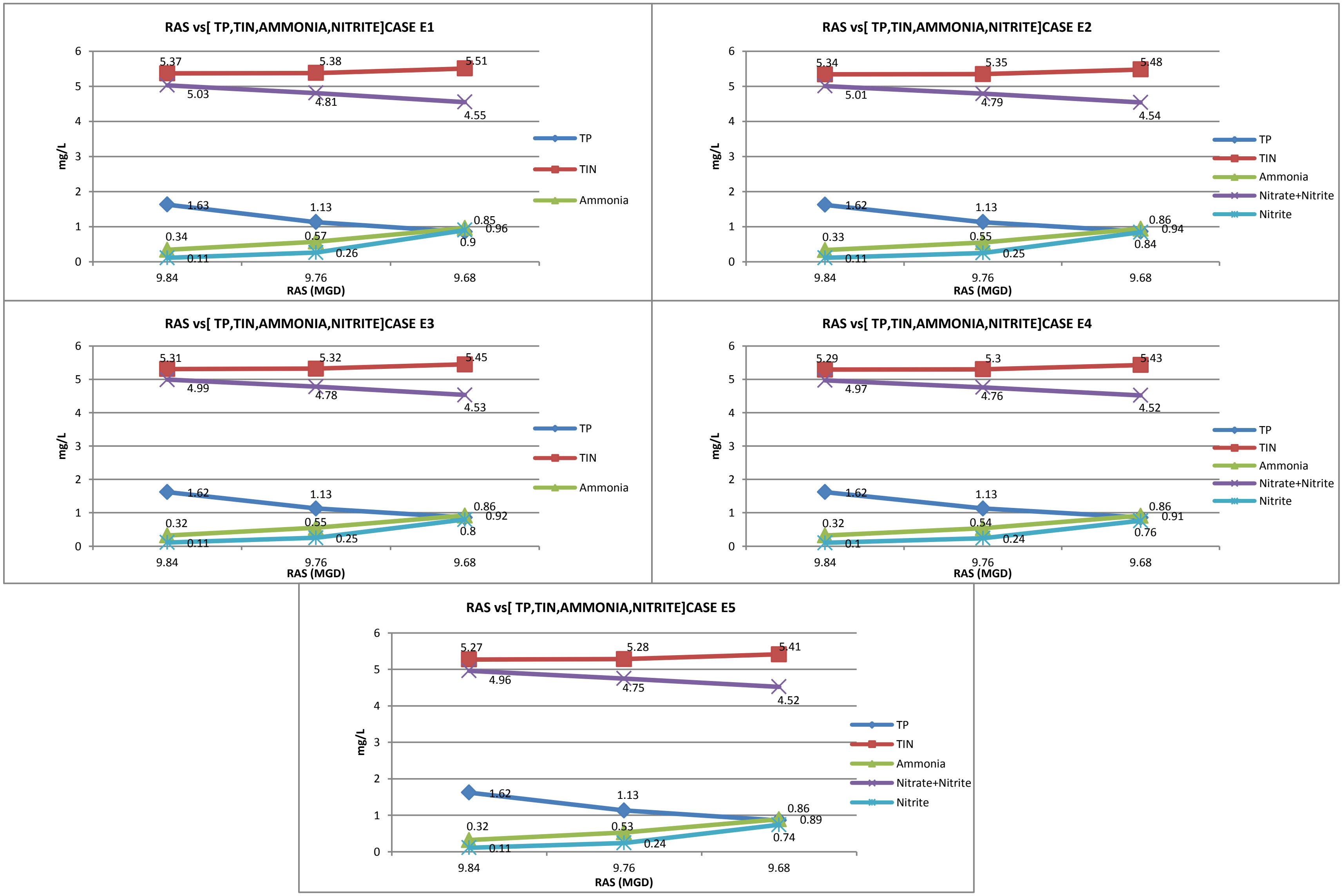

Figure B-27: Case E

Winter 300 % IR

Case A

Table 59: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case A1	3	0.304	0.507	0.912	1.8
Case A2	3.25	0.28	0.507	0.912	
Case A3	3.5	0.26	0.507	0.912	
Case A4	3.75	0.24	0.507	0.912	
Case A5	4	0.22	0.507	0.912	

Table 60: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.84	0.06
	9.76	0.10
	9.68	0.14

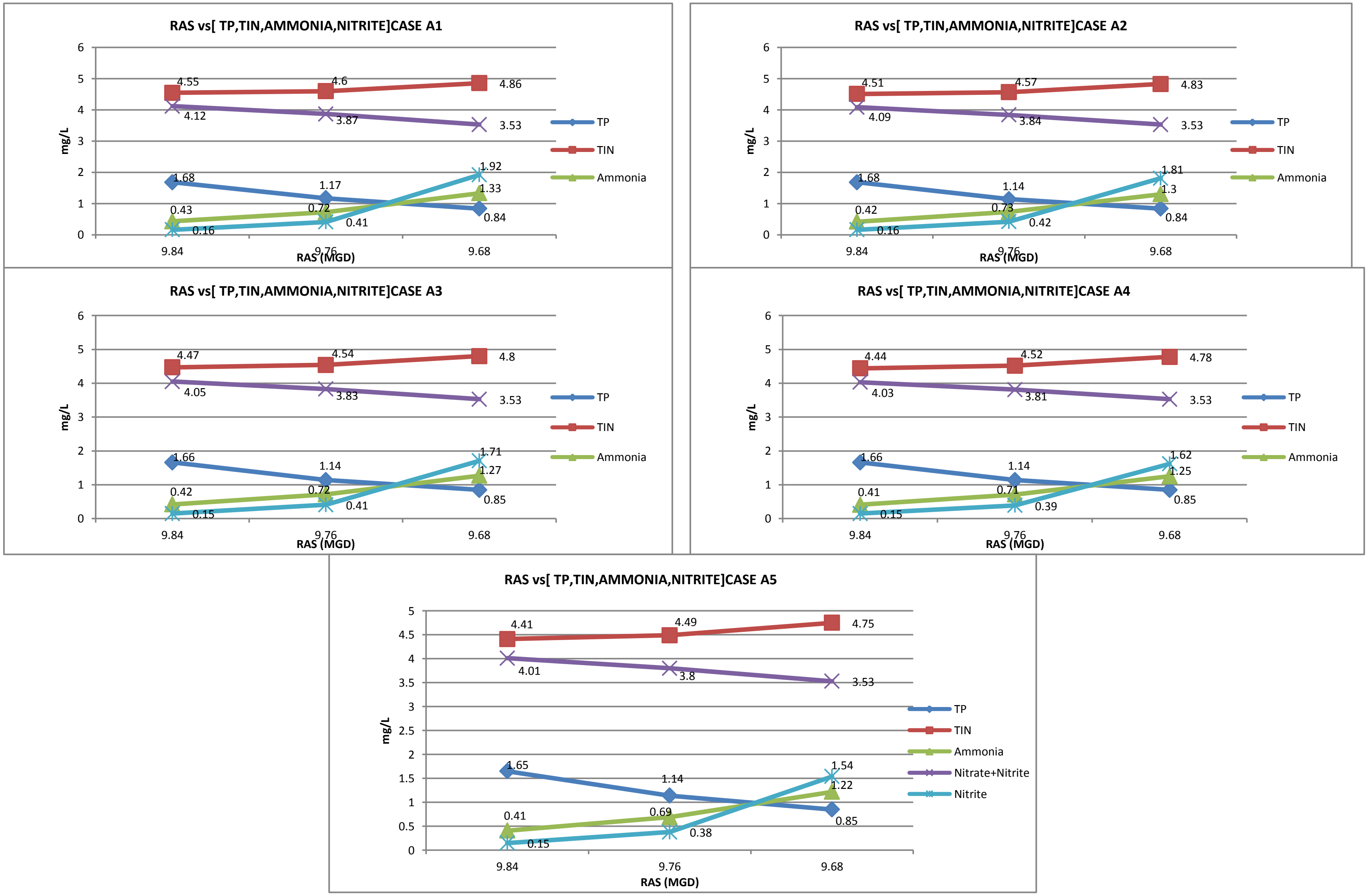

Figure B-28: Case A

Winter 300 % IR

Case C

Table 61: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case C1	3	0.315	0.473	0.946	2
Case C2	3.25	0.291	0.473	0.946	
Case C3	3.5	0.27	0.473	0.946	
Case C4	3.75	0.252	0.473	0.946	
Case C5	4	0.236	0.473	0.946	

Table 62: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.84	0.06
	9.76	0.10
	9.68	0.14

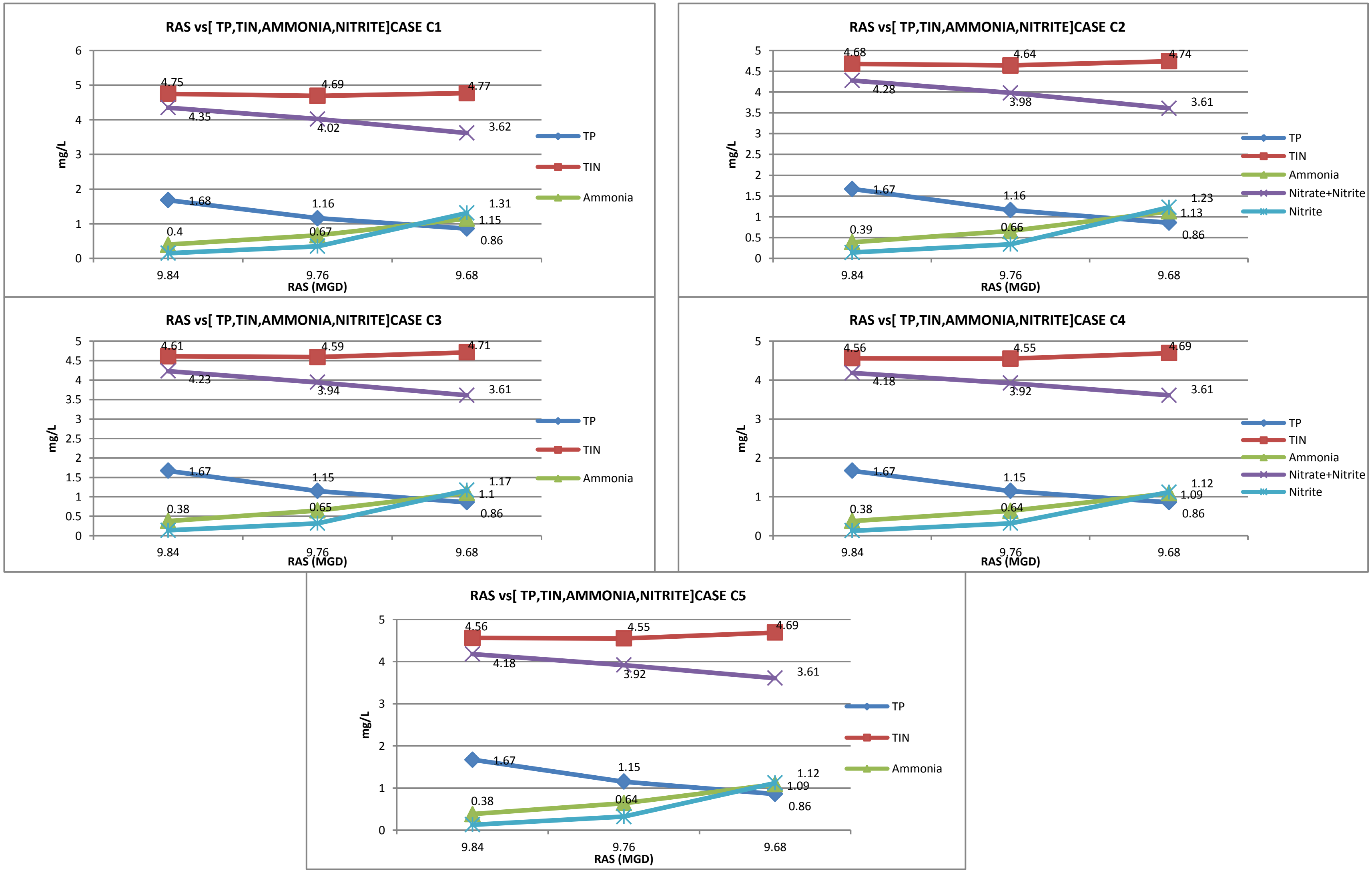

Figure B-29: Case C

Winter 300 % IR

Case E

Table 63: Basin Volumes

		Total Volume Per train			
		Anaerobic	Anoxic	Aerobic /2	
	Aerobic:Anaerobic	Mil gal	Mil gal	Mil gal	Aerobic:Anoxic
Case E1	3	0.325	0.44	0.976	2.2
Case E2	3.25	0.3	0.44	0.976	
Case E3	3.5	0.278	0.44	0.976	
Case E4	3.75	0.26	0.44	0.976	
Case E5	4	0.244	0.44	0.976	

Table 64: RAS and WAS flowrates

Internal Recycle %	Return Activated Sludge (MGD)	Waste Activated Sludge (MGD)
300	9.84	0.06
	9.76	0.10
	9.68	0.14

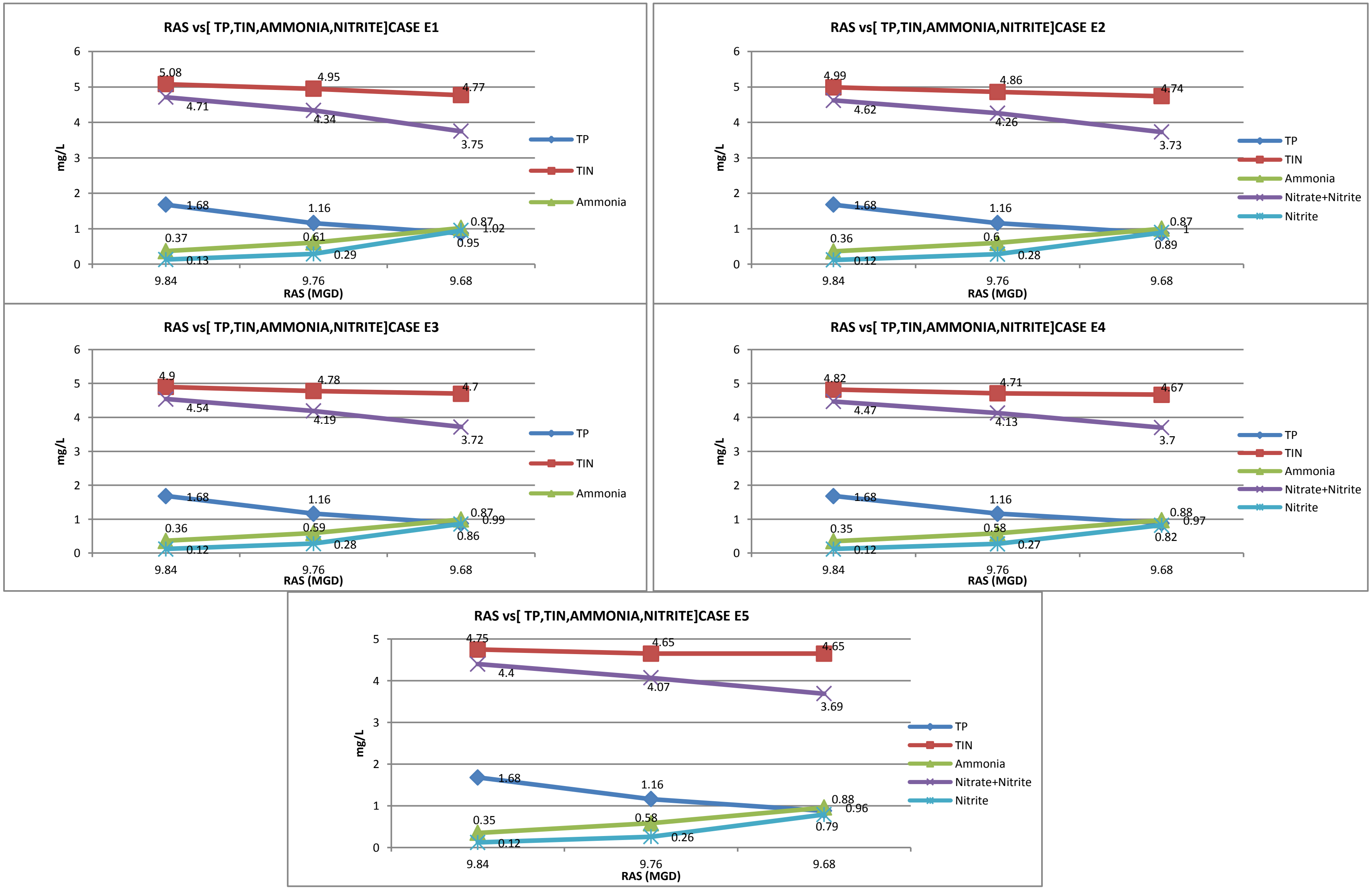

Figure B-30: Case E