SECTION 14.0
BIOLOGICAL NUTRIENT REMOVAL

14.1 INTRODUCTION

Up to this point in the report, the physical and biochemical concepts considered for application to the secondary treatment sections of the three Winnipeg water pollution control centers involve primarily BOD_5 and TSS removal, as well as nitrification. This section of the report describes how biological nutrient removal (BNR) technology can be applied to achieve phosphorus and nitrogen removal.

For the analysis of BNR technology, a target ammonia nitrogen limit equivalent to a High Level of Control of 8.0 mg/L to be met in the critical summer season has been chosen. To be assured that this criterion will be achieved, it will be necessary to design the treatment system for each plant such that nitrifying organisms can be maintained in the treatment system throughout the year. Activated sludge treatment systems that go in and out of nitrification mode on a seasonal basis are usually difficult to operate and prone to upset conditions particularly during transition periods. Therefore while the critical period for achieving the ammonia limit will be during summer operating conditions, it will be necessary to base the design on maintaining nitrifying organisms in the system through the very high flow, dilute wastewater, and cold sewage temperatures associated with the spring season in Winnipeg.

A target total phosphorus limit of 1.0 mg/L has been chosen. This limit should be achievable in a BNR system for Winnipeg provided that a primary sludge fermentation system is used to provide the volatile fatty acids necessary for good biological phosphorus removal performance.

It must be noted that the conceptual designs for BNR at each plant presented in this section of the report are very preliminary. They are subject to confirmation and further refinement following detailed wastewater characterization studies that should be conducted at each plant as well as considerably more process design work than has been done for the purposes of the material presented herein.

14.2 BIOLOGICAL NUTRIENT REMOVAL CONCEPTS

As background information for the reader who may not be familiar with BNR technology, an overview of introductory BNR concepts is presented in the following paragraphs. When reviewing this information, it is important to be mindful that BNR technology essentially involves the manipulation of the environment to which the microorganisms in the activated sludge process are exposed as they pass through the bioreactor. The manipulations are done in such a fashion that the development of certain species of microorganisms is favoured and these microorganisms have the ability to transform the carbon, nitrogen and phosphorus fractions in the untreated wastewater in ways that result in the removal of these fractions from the wastewater stream. In this regard, three environmental conditions to which the biomass may be exposed as it passes through a bioreactor are defined as follows:

- **Aerobic Conditions** Dissolved Oxygen (DO) must be present
Nitrate Oxygen (NO_3^--O) may or may not be present;
- **Anoxic Conditions** DO must not be present
NO_3^-- O must be present; and
- **Anaerobic Conditions** DO must not be present
NO_3^-- O must not be present.

By exposing the biomass in an activated sludge system to specific sequences of these three environments, certain species of microorganisms that favour the removal of specific contaminants are given a competitive advantage over other species. The result can be removal not only of carbonaceous BOD_5, TSS and NH_3-N, but also of Total Nitrogen and Total Phosphorus.

14.1.1 Conventional Activated Sludge System for $cBOD_5$ Removal

Figure 14.1 illustrates a process schematic diagram for carbonaceous biochemical oxygen demand ($cBOD_5$) removal using the conventional activated sludge process. It is intended that the system in Figure 14.1 be designed and operated as a non-nitrifying system; that is, it is operated at a relatively short solids retention time (SRT) (as indicated by the relatively short and stubby bioreactor) to preclude the oxidation of nitrogen and ammonia in the incoming wastewater. Sufficient aeration is provided in the bioreactor such that it operates under fully aerobic conditions. In the figure, the waste activated sludge (WAS) is withdrawn from the system from the mixed liquor channel between the bioreactor and the final clarifier. This provides a straightforward and simple means of SRT control as well as an opportunity to selectively waste undesirable microorganisms from the system. The ability to have good control over SRT is particularly important for the reliable operation of BNR systems. Thus the concept of mixed liquor wasting will be used in the succeeding discussion of BNR technology.

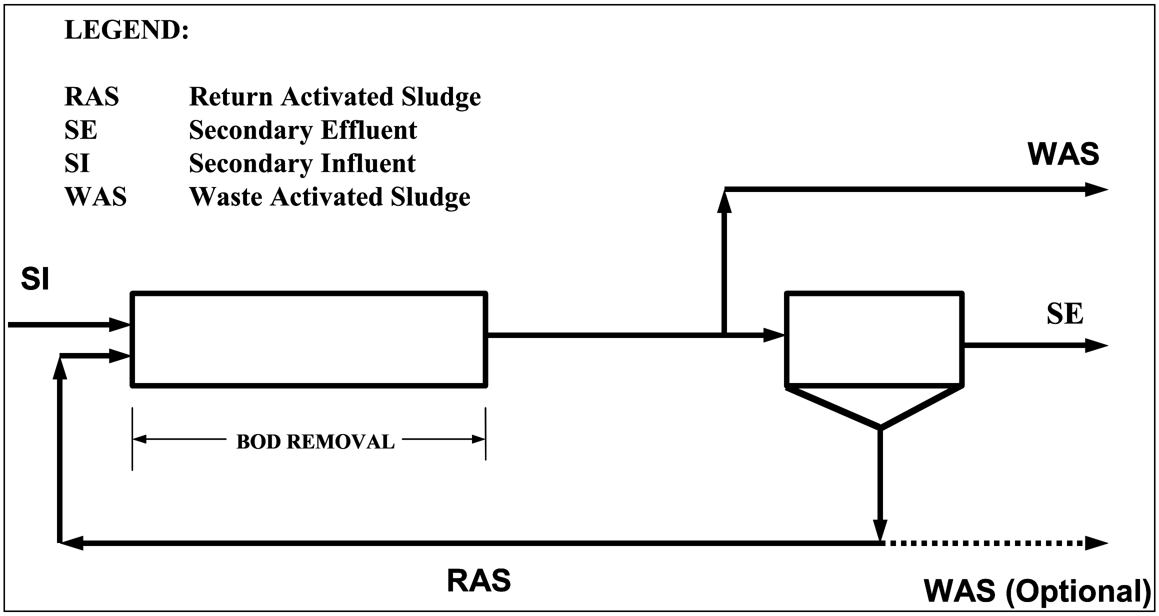

Figure 14.1: Process Schematic for a Conventional Activated Sludge BOD Removal System

14.1.2 cBOD$_5$ Removal and Nitrification

Figure 14.2 illustrates a process schematic diagram for a conventional activated sludge system designed and operated for cBOD$_5$ removal and NH_3-N removal. In comparison to Figure 14.1, the bioreactor in Figure 14.2 is larger indicating a higher SRT and possibly a longer hydraulic retention time (HRT). Only a few species of microorganisms can oxidize ammonia and these species grow at a much slower rate than the numerous species of microorganisms that are able to oxidize cBOD$_5$; hence the longer SRT. Once again, the environment in the bioreactor illustrated in Figure 14.2 is fully aerobic, as the metabolism of the nitrifying microorganisms requires DO. Because cBOD$_5$ removal is usually more rapid than is NH_3-N oxidation, the figure indicates that cBOD$_5$ removal is completed partway along the length of the bioreactor, whereas nitrification occurs along the entire length of the bioreactor.

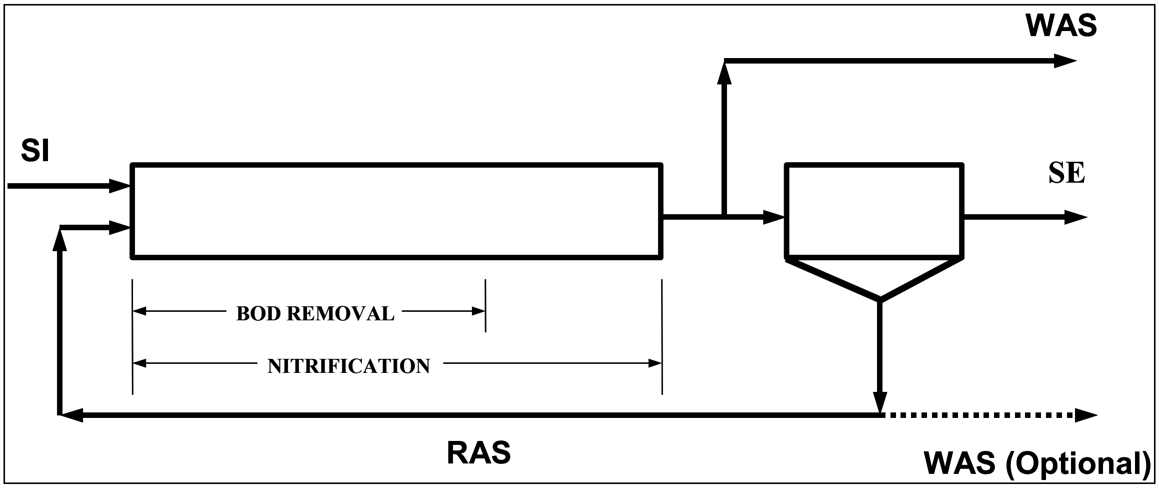

Figure 14.2: Process Schematic for BOD Removal and Nitrification System

14.1.3 cBOD$_5$ Removal, Nitrification and Partial Denitrification

Figure 14.3 illustrates the Anoxic Selector Process in which a partition is placed near the front of the bioreactor and no aeration is provided in the first zone. The SRT calculated on the basis of the aerobic biomass fraction is sufficiently high to allow for the development of nitrifying microorganisms in the aerobic zone so that nitrification occurs therein. Because the system is nitrifying, the RAS will contain nitrate ions (NO_3^-), which are the product of the oxidation of ammonia. The presence of nitrate ions in the first zone of the bioreactor, together with the absence of DO in that zone, results in an anoxic environment by definition. In the anoxic environment, the soluble readily biodegradable organic matter in the incoming secondary influent stream will be oxidized by the nitrate-oxygen returning in the RAS. Thus cBOD$_5$ removal occurs in the unaerated anoxic zone. In the first part of the aerobic zone, any remaining soluble readily biodegradable organic carbon compounds will be oxidized, together with the oxidation of the more slowly biodegradable soluble and particulate organic compounds.

The figure indicates that cBOD$_5$ removal occurs in both zones along the first part of the bioreactor with nitrification occurring only in the aerobic zone of the bioreactor. The degree of nitrogen removal that can be achieved by the process is dependent of the RAS rate, the size of the RAS-denitrification (denite) zone, and the amount of soluble readily biodegradable organic matter in the secondary influent stream.

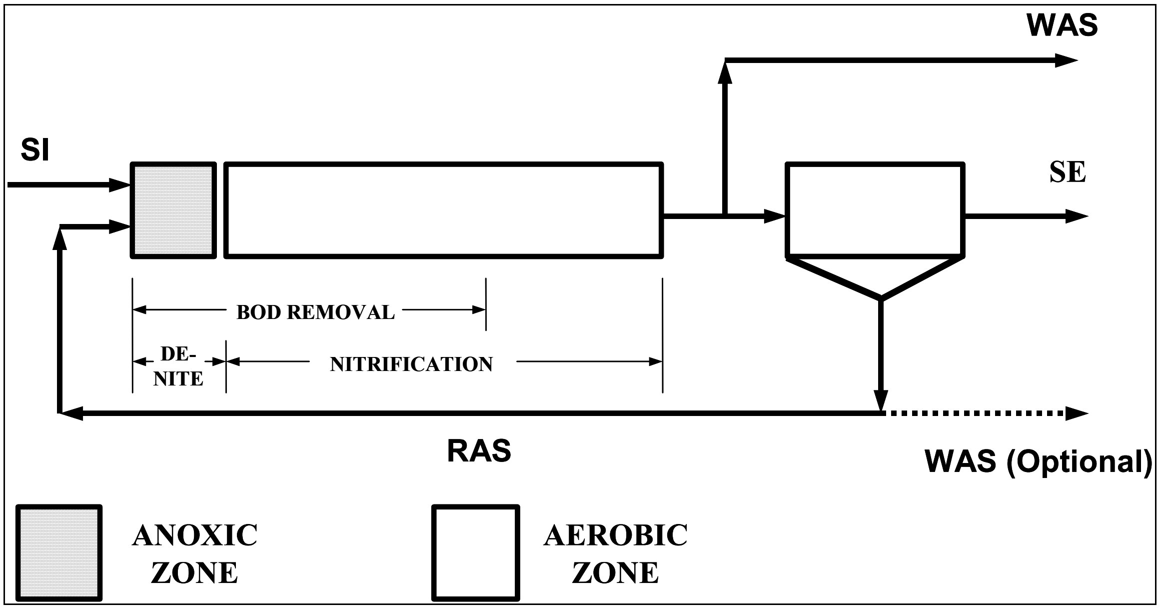

Figure 14.3: Process Schematic for BOD Removal, Nitrification and Partial Denitrification System (Anoxic Selector Process)

14.1.4 $cBOD_5$ and Total Nitrogen Removal

To improve the degree of nitrogen removal, nitrified mixed liquor from the end of the bioreactor can be recycled to the unaerated zone at the front of the bioreactor. Typically a submerged high-volume low-head submersible pump can accomplish this. The recycle rate is usually in the order of three to six times the incoming secondary influent flow rate. As illustrated in Figure 14.4, the unaerated zone at the front of the bioreactor is enlarged to accommodate the additional nitrate load from the internal nitrified mixed liquor (NMLR) recycle stream. The unaerated zone is an anoxic environment in which the soluble readily biodegradable organic carbon in the secondary influent stream is used to reduce the nitrates in both the RAS stream and in the internal NMLR stream. The degree of nitrogen removal that can be accomplished in this system is dependent on the size of the anoxic zone, the internal NMLR rate, the RAS rate, and the amount of soluble readily biodegradable organic carbon in the secondary influent stream.

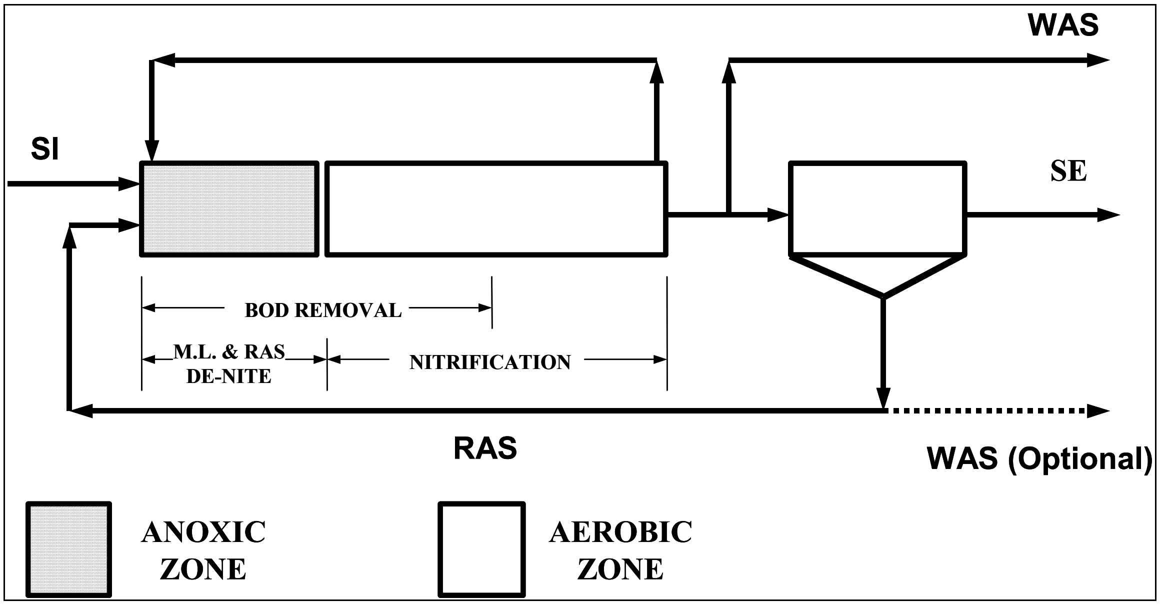

Figure 14.4: Process Schematic for BOD and Total Nitrogen Removal System (Modified Ludzak-Ettinger [MLE] Process)

14.1.5 Biological Phosphorus Removal

Figure 14.5 illustrates the basic mechanism of biological phosphorus removal. Certain species of bacteria (*acinetobacter* spp.) that commonly occur in soil as well as in activated sludge mixed cultures are capable of sequestering short chain volatile fatty acids (VFAs) from solution in an anaerobic environment and storing them as poly-β-hydroxybutyrate (PHB) inside their cells. They get the energy to do this from the release of previously stored polyphosphate into solution. When these same species of microorganisms are subsequently exposed to aerobic conditions, their metabolism changes and the PHB that was stored under anaerobic conditions is oxidized to CO_2 and H_2O. The energy produced as a result of this oxidation is used to uptake soluble phosphorus from solution and store it inside the cells as polyphosphate. A peculiar aspect of these Bio-P microorganisms is that they are capable of storing much more phosphorus than they need merely for normal metabolic purposes.

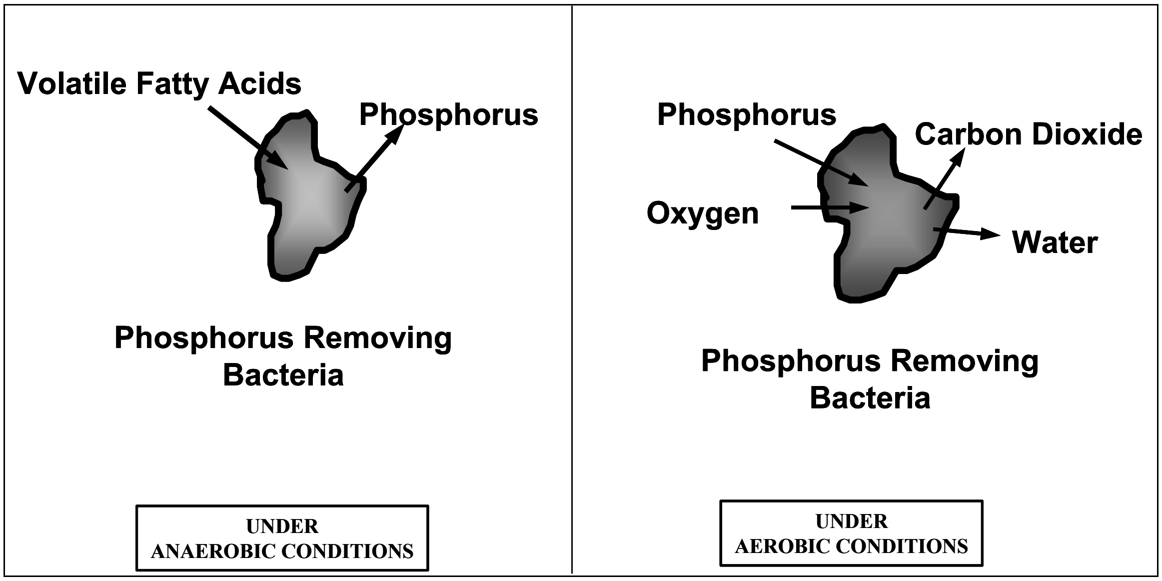

Figure 14.5: Illustration of Biological Phosphorus Removal Mechanism

The success of a continuous-flow activated sludge biological phosphorus (Bio-P) removal process depends on three factors:

1. There must be a sequential anaerobic/aerobic exposure of the mixed liquor in the bioreactor.
2. There must be an availability of short chain volatile fatty acids to the microorganisms when they are in the anaerobic environment.
3. The waste activated sludge must be withdrawn from the system at the end of the aerobic zone.

Figure 14.6 illustrates how a non-nitrifying biological phosphorus removal system can be configured in the activated sludge process. As indicated in the figure, the bioreactor is partitioned into two zones – a smaller unaerated (anaerobic) zone at the front of the bioreactor followed by a larger aerobic zone. The ability of the Bio-P bacteria to metabolize soluble readily biodegradable organic matter in the form of VFAs in the anaerobic zone, plus their ability to remove large amounts of phosphorus from solution in the aerobic zone, gives the Bio-P bacteria a competitive advantage over other heterotrophic bacteria in the activated sludge system. As a consequence, a Bio-P removal system will have a larger fraction of these microorganisms in the mixed liquor than will a corresponding conventional activated sludge system under similar loading conditions.

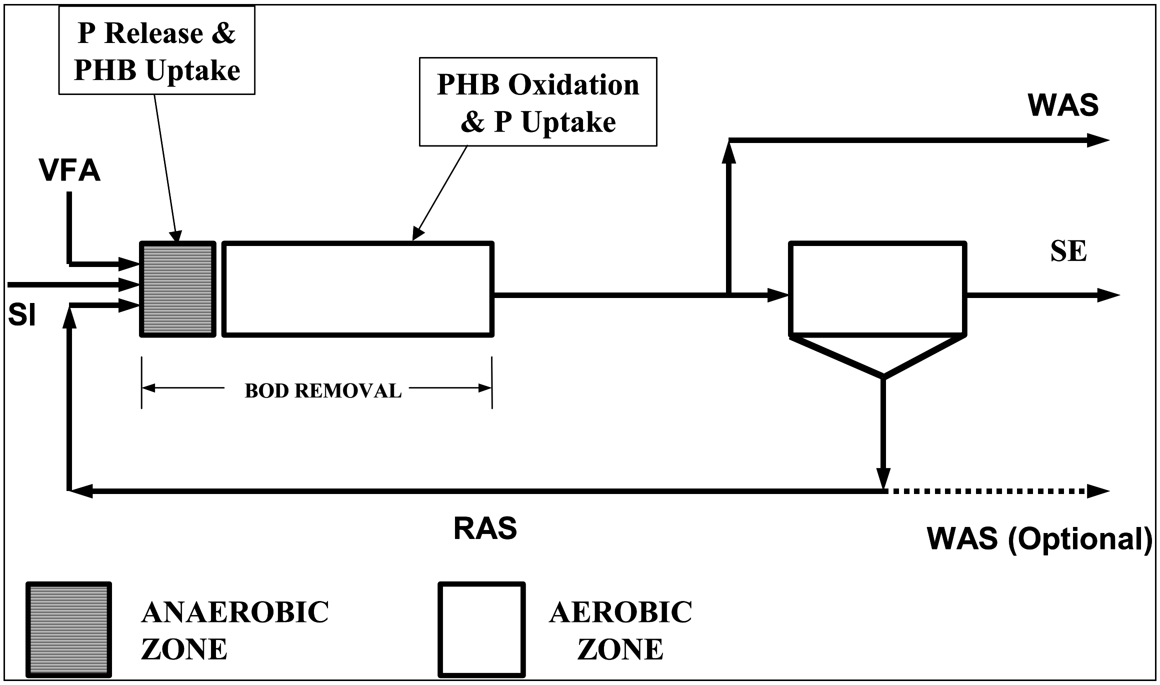

Figure 14.6: Process Schematic for BOD and Biological Phosphorus Removal in Non-Nitrifying System (A/O Process)

If the bioreactor is designed to operate in a nitrifying mode, then nitrates will be returned to the unaerated zone at the front of the bioreactor via the RAS stream. Consequently, the environment in the unaerated zone will no longer be truly anaerobic, but rather will be anoxic. The system would then be operating as an Anoxic Selector Process as pictured in Figure 14.3 and the Bio-P removal mechanism described above will fail. The Bio-P bacteria will no longer have a competitive advantage over the heterotrophic organisms commonly occurring in the activated sludge process that can utilize the nitrate ion as the terminal electron acceptor for the oxidation of soluble readily biodegradable organic matter, including the short chain VFAs.

To protect the anaerobic zone from the adverse impact of nitrate-oxygen, a second partition can be installed at the front of the bioreactor to create a RAS-denitrification zone. This system is illustrated in Figure 14.7 and is sometimes referred to as the Modified A/O Process. The incoming secondary influent is step-fed around the RAS-denite zone directly to the second zone. The RAS-denitrification zone is unaerated, operates at RAS concentration, and will provide an anoxic environment for the RAS. Denitrification will occur endogenously therein using as a carbon source the soluble biodegradable carbon produced as a result of endogenous activity in the RAS. The denitrification rate can be accelerated and the size of the RAS-denitrification zone reduced by the addition of soluble readily biodegradable carbon (such as methanol), or by metering some of the secondary influent stream into it.

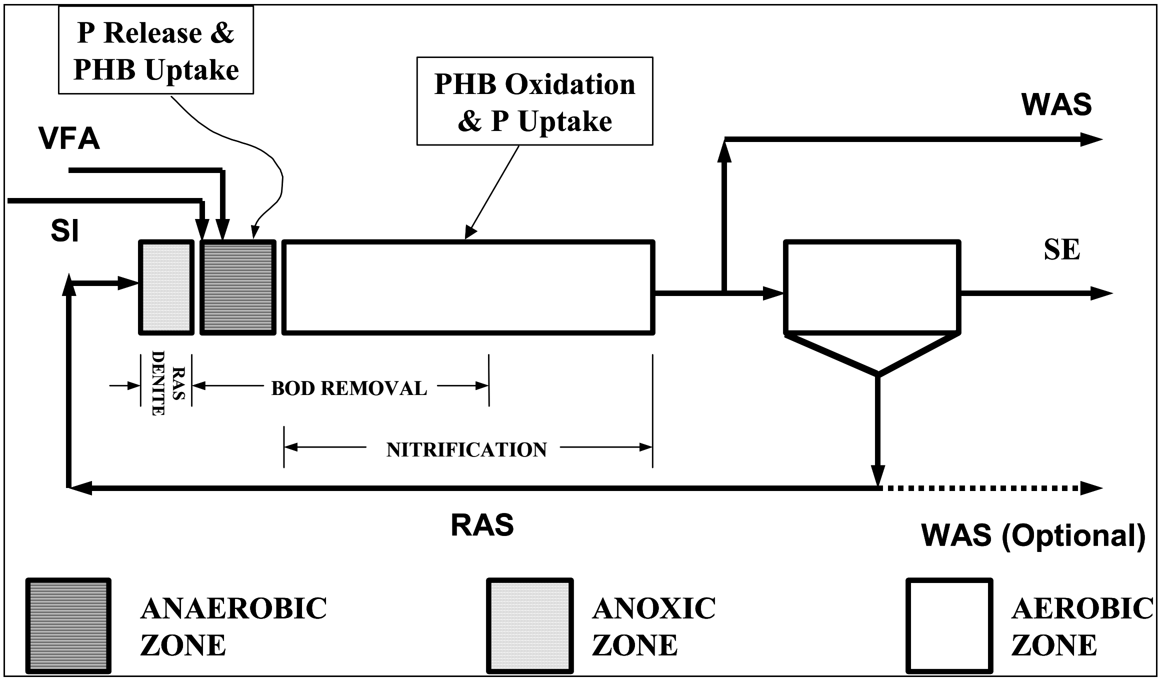

Figure 14.7: Process Schematic for BOD and Biological Phosphorus Removal in a Nitrifying System (Modified A/O Process)

A similar process that can protect the anaerobic zone from the adverse impact of nitrate-oxygen in the RAS is the VIPR Process illustrated in Figure 14.8. In this process, the readily biodegradable carbon in the secondary influent is used to encourage rapid denitrification of the RAS in an initial anoxic zone. The second unaerated zone is operated under anaerobic conditions and purchased acetic acid solution is metered directly into it to create an environment favourable to the Bio-P bacteria.

Thus the systems illustrated in Figures 14.7 and 14.8 are capable of Bio-P removal and nitrification, as well as partial nitrogen removal. The degree of nitrogen removal will be dependent on the RAS rate.

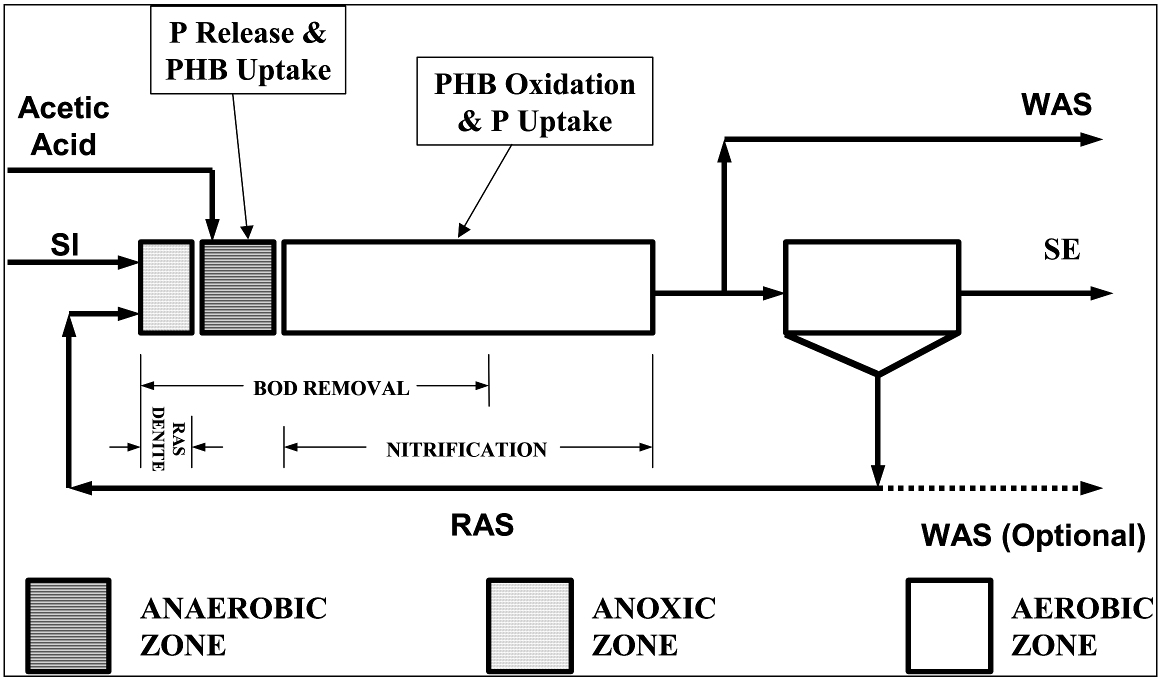

Figure 14.8: Process Schematic for BOD and Biological Phosphorus Removal in a Nitrifying System (VIPR Process)

14.6 Biological Nitrogen and Phosphorus Removal

Figure 14.9 illustrates the 3-Stage Bardenpho Process. This process combines the principles of the MLE Process with those of the A/O Process previously illustrated in Figures 14.4 and 14.6 respectively. Nitrification occurs in the aerobic zone; the nitrified mixed liquor is returned from the end of the aerobic zone to the front of the anoxic zone for denitrification; and the sequential anaerobic followed by aerobic exposure of the mixed liquor encourages the development of Bio-P bacteria if VFAs are present in the anaerobic zone.

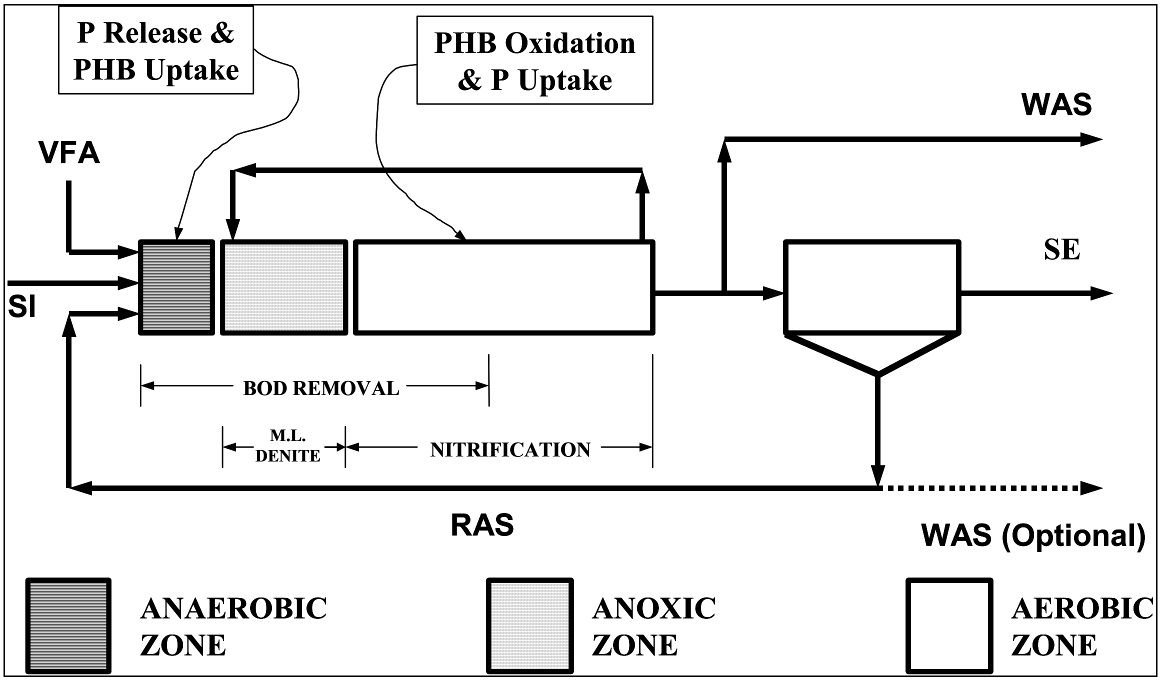

Figure 14.9: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (3-Stage Bardenpho Process)

In the 3-Stage Bardenpho Process, the anaerobic zone may not be sufficiently protected from the adverse impact of nitrate-oxygen in the RAS stream. To provide additional protection, the UCT (University of Cape Town) Process and Modified UCT Process have been developed. In the UCT Process illustrated in Figure 14.10, the RAS stream is directed to the anoxic zone in the bioreactor. Denitrified mixed liquor from the end of the anoxic zone is returned to an anaerobic zone at the front of the bioreactor. The denitrified mixed liquor return (DNMLR) rate is typically set equal to the incoming secondary influent rate. Thus the mixed liquor concentration in the anaerobic zone is half of that in the rest of the bioreactor. In the Modified UCT Process illustrated in Figure 14.11, the two functions of mixed liquor denitrification and RAS denitrification are uncoupled by partitioning the anoxic zone into two zones. The RAS stream is returned to the first anoxic zone where it is denitrified before being returned to the anaerobic zone located at the front of the bioreactor. The nitrified mixed liquor is recycled from the end of the aerobic zone to the front of the second anoxic zone thus forming a nitrification/denitrification loop in the last two zones of the bioreactor.

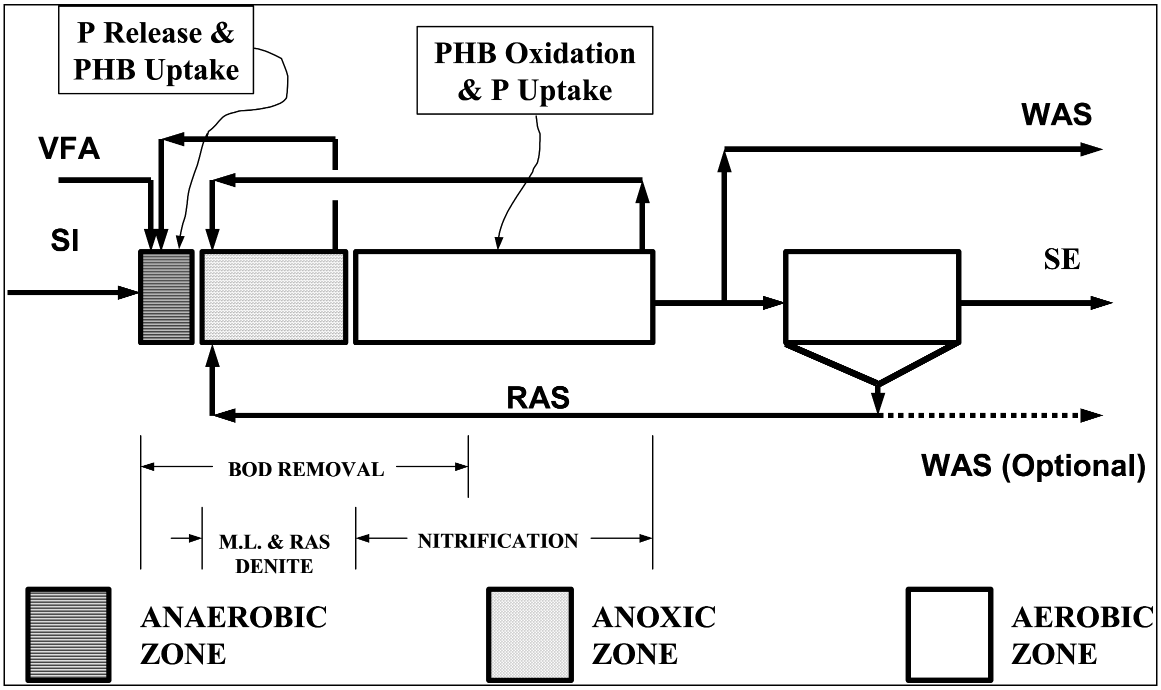

Figure 14.10: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (UCT Process)

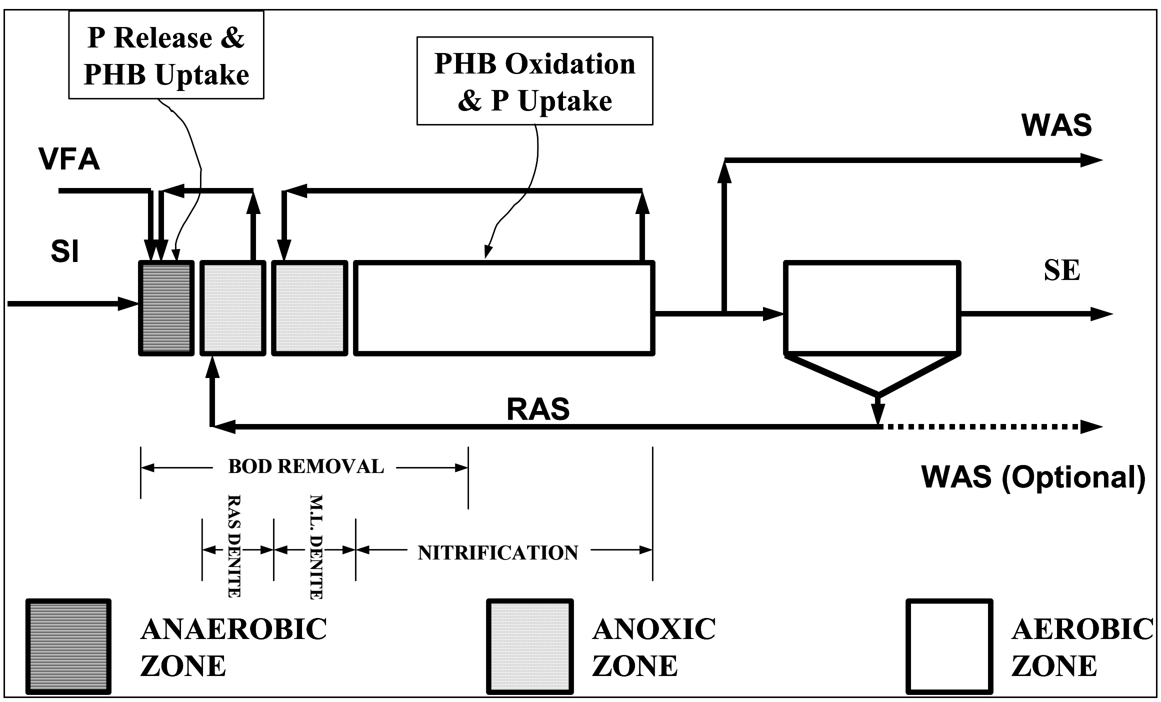

Figure 14.11: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (Modified UCT Process)

The BNR process can be optimized further by the addition of a RAS-denitrification zone at the front of the bioreactor as illustrated in Figure 14.12. This is known as the Johannesburg Process and it combines the features of the MLE Process in Figure 14.4 with the Modified A/O Process in Figure 14.7. The principles employed in the Johannesburg Process illustrated in Figure 14.12 will be used in the BNR process design concepts for the NEWPCC and WEWPCC to be discussed later in this section of the report.

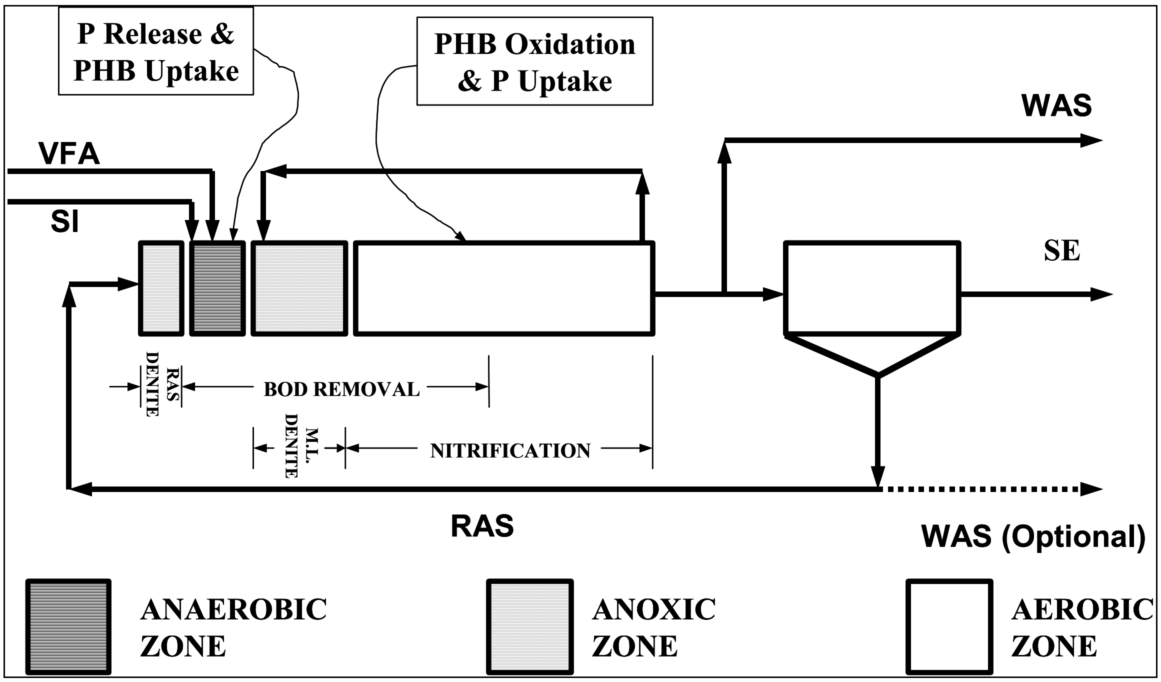

Figure 14.12: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (Johannesburg Process)

Figure 14.13 illustrates an improvement on the Johannesburg Process called the Westbank Process. In the Westbank Process, the secondary influent flow is split between the RAS denitrification zone and the mixed liquor anoxic zone. The flow split to the RAS denitrification zone should be sufficient only to denitrify the RAS for protection of the anaerobic zone. VFAs are piped directly to the anaerobic zone. In this manner, the volume of the bioreactor is maximized by operating the RAS denitrification and the anaerobic zones at as high a solids concentration as possible while accomplishing the desired result of RAS denitrification and phosphorus release respectively in these two zones.

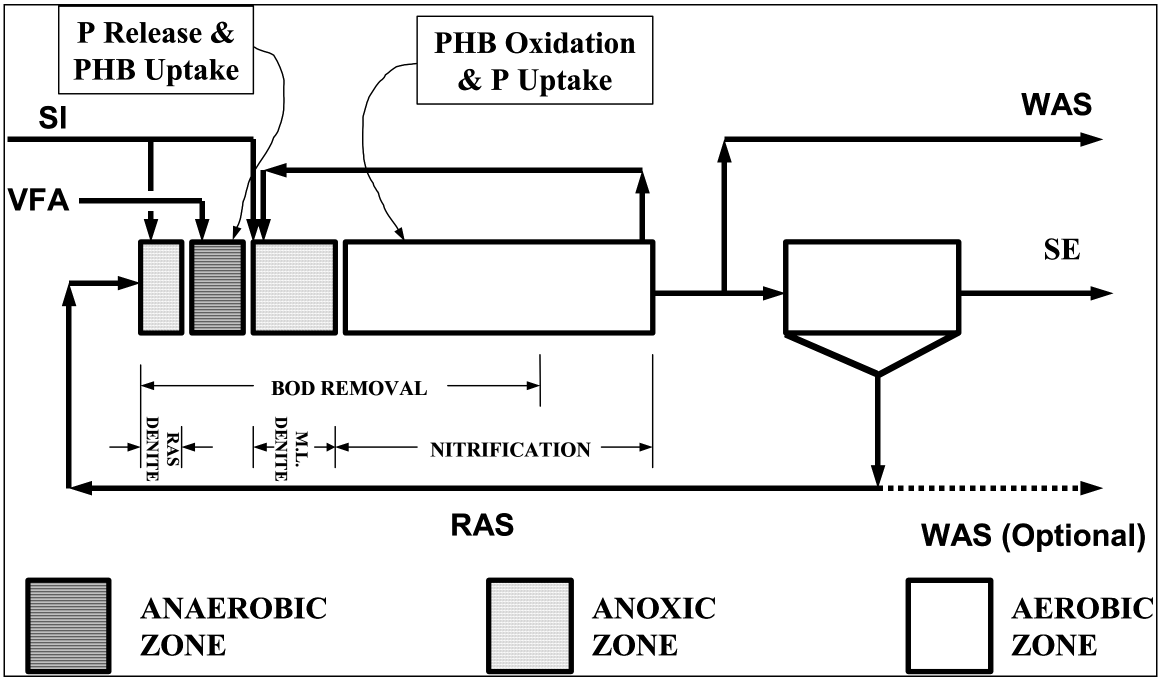

Figure 14.13: Process and Schematic for BOD, Biological Phosphorus, and Total N Removal System (Westbank Process)

A modification of the Westbank Process that can be used for systems that from time to time experience high wet weather flows is the Goldbar Process. As illustrated in Figure 14.14, the Goldbar Process incorporates a zone that can be operated in either aerated or unaerated mode that is located approximately mid-way along the aerobic zone. During periods of wet weather when the secondary influent flow is high and relatively dilute, a portion of the flow can be step fed directly to this unaerated zone. Under these conditions, it will operate as an anoxic zone with the nitrate-oxygen provided by the partial nitrification that will have occurred in the aerobic zone to this point. Introduction of secondary influent to this second anoxic zone will ensure that the soluble and colloidal organic matter will be removed, while some bleed-through of ammonia-nitrogen may occur depending on the nitrogen concentration of the secondary influent and the mixed liquor concentration and retention time in the balance of the bioreactor. Step feeding in this manner during periods of high wet weather flow will also help maintain the biomass inventory in the bioreactor rather than push it into the final clarifier and possibly cause an overload of the solids handling capacity of the final clarifier.

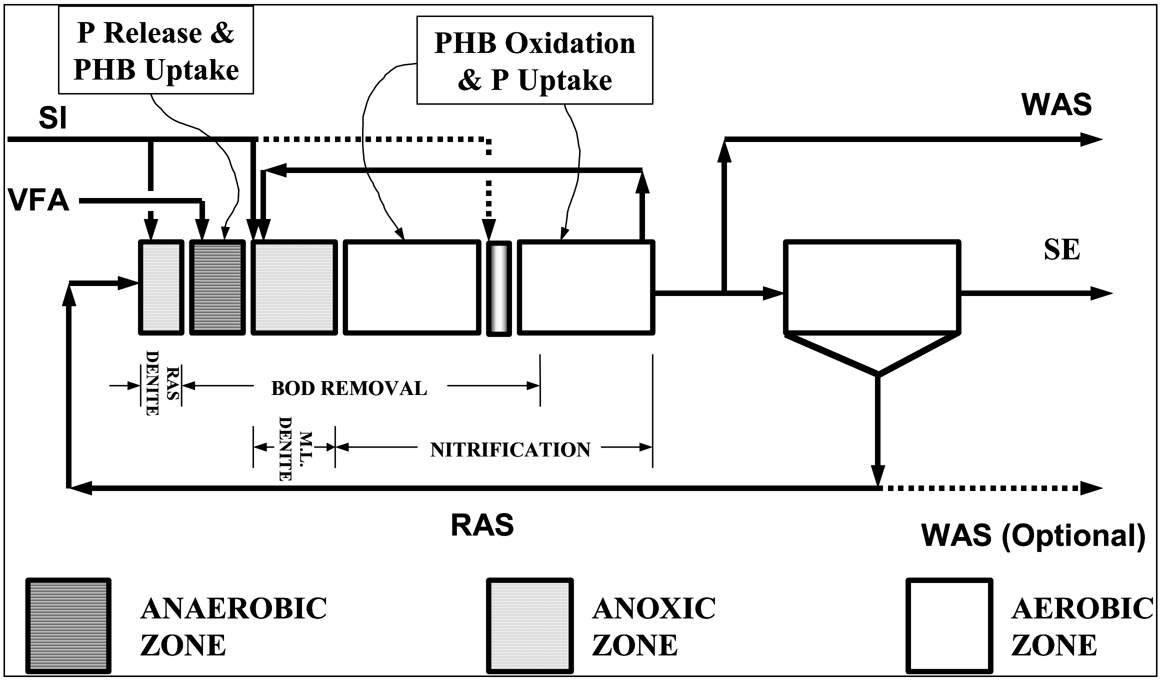

Figure 14.14: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (Goldbar Process)

Figure 14.15 illustrates the Step Bio-P Process that is an adaptation of BNR technology to deal with peak flow and loading conditions while conserving biomass in the bioreactor and protecting the final clarifier from high solids loading rates. This process would be suited to situations in which the treated effluent permit limits allow some bleed-through of ammonia, particularly under conditions of high flows and loads. The system illustrated in Figure 14.15 is a four-step process, each step consisting of anaerobic/anoxic/aerobic environments. The incoming secondary influent stream is split and fed stepwise to each anaerobic zone. The mixed liquor exiting the first three aerobic zones is directed to the anoxic zone of the next step in the process train. Denitrified mixed liquor from the end of the anoxic zones is recycled to the corresponding anaerobic zone. A variation of this process is used for the BNR design concept at the SEWPCC as presented later in this section of the report.

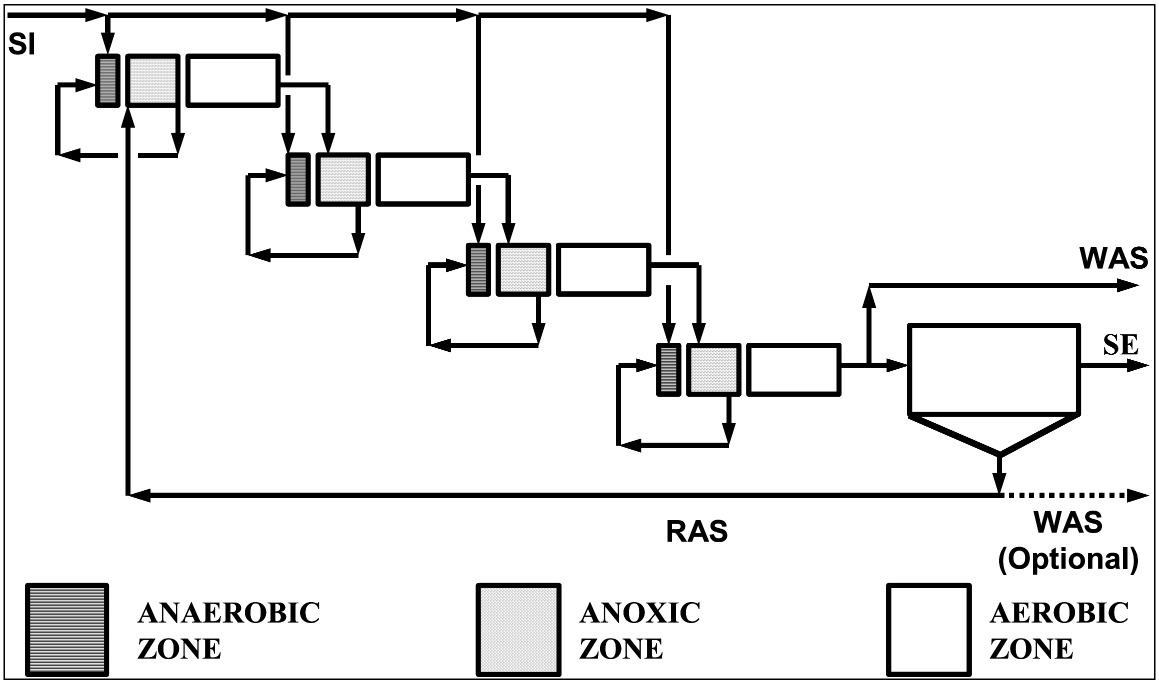

Figure 14.15: Process Schematic for BOD, Biological Phosphorus, and Total N Removal System (Step Bio-P Process)

14.3 BIOLOGICAL NUTRIENT REMOVAL AT NEWPCC

The approach taken to implement biological nutrient removal at the NEWPCC is to use the Johannesburg Process (see process schematic in Figure 14.12) and utilize as much of the existing plant tankage as possible. The approach assumes that centrate treatment employing a nitrifying complete mix activated sludge system will be implemented along with the BNR retrofit to the mainstream treatment train to lower and stabilize the TKN load. The effluent from the centrate treatment system, together with its waste activated sludge, will be directed to the first aerobic zone of the mainstream treatment process to provide a continuous source of nitrifying bacteria therein. In this manner, the mainstream treatment process can be downsized somewhat and it also will not be subject to the step-wise varying TKN loads that are commonly associated with sidestream return flows from dewatering operations.

The Johannesburg Process was selected because it will be relatively easy to implement in the existing tankage and will require a minimum of new tankage at the NEWPCC. Table 14.1 presents the design parameters for the suggested overall BNR system at the NEWPCC. A plant layout and process flow diagram are illustrated in Dwg. NE-14.1 and Dwg. NE-14.2, respectively.

The conceptual design used in applying the Johannesburg Process to the NEWPCC has the following features:

- Existing final clarifier nos. 11 to 26 will be retrofitted into four parallel multi-pass unaerated zones, each unaerated zone consisting of a RAS denitrification volume, an anaerobic volume and an anoxic volume. (When first constructed, this tankage was intended for use as bioreactor tankage and the BNR concept used here returns this tankage to its original purpose, although not as aerated tankage.) The four unaerated zones will be constructed in final clarifier nos. 23 to 26, 19 to 22, 15 to 18, and 11 to 14 respectively. Mixed liquor will flow through each unaerated zone in a four-pass serpentine fashion. Mechanical mixers will be used in the unaerated tankage to maintain the mixed liquor solids in suspension. Provision will be made to step feed portions of the incoming secondary influent stream to each anaerobic volume and to the upstream end of each anoxic pass.
- The existing HPO bioreactor tankage will be retrofitted to six parallel aerobic zones. The direction of mixed liquor flow in the retrofitted HPO tankage will be reversed from the present direction to flow from north to south, rather than from south to north. The retrofitted HPO bioreactor tankage will be fitted with flexible membrane fine bubble diffusers.
- Three new aerobic bioreactors configured in parallel will be constructed to provide the additional aerated volume necessary to achieve the target 8 mg/L summer nitrification limit. The new bioreactor tankage will be fitted with flexible membrane fine bubble diffusers. Mixed liquor exiting the new bioreactor tankage will flow into a new east-west mixed liquor channel constructed along the south wall of the new tankage.
- A portion of the mixed liquor entering the nitrified mixed liquor recycle system will flow in the new mixed liquor channel eastward from the downstream end of the new bioreactor tankage and be directed to existing square final clarifier no. 8 which will be retrofitted with aeration diffusers to act as a mixed liquor aeration zone. From there, the nitrified mixed liquor return stream will pass into existing square final clarifier no. 7 which will be retrofitted with a submerged non-aerating mixing device to act as a mixed liquor denitrification zone. A battery of submersible pumps will be installed in this zone to lift the nitrified mixed liquor recycle stream and pump it into the first anoxic portion of the four parallel unaerated zones (retrofitted existing final clarifier nos. 13, 17, 21, and 25_.
- The remainder of the mixed liquor in the new mixed liquor channel will flow to the final clarifiers. Six new final clarifiers will be constructed in the open area to the west and south of the existing HPO bioreactor tankage. The final clarifiers will be housed in a large building with the bioreactor aeration blower room located in the southeast corner and the return activated sludge pumping system located at the north wall. An air handling system and exhaust stack will be located at the northwest corner of this building.

- A primary sludge fermentation system will be constructed in existing square final clarifier nos. 1 to 6 in order to provide the volatile fatty acids necessary for maintaining a healthy biological phosphorus removal system. Each fermenter tank will be designed as a single stage static unit. The supernatant from each unit will be combined and directed to the anaerobic zones of the unaerated tankage. The thickened sludge underflow will be directed to the plant's existing anaerobic digestion system. Each fermenter unit will be covered. Odour control will be accomplished by evacuating the headspace over each unit through a duct to the new aeration blower system where the odorous air will be combined with process air produced by the new blowers to be injected into the bioreactors.
- Waste activated sludge thickening can be accomplished either by retrofitting three of the existing sludge dewatering centrifuges to thickening centrifuges as described previously in Section 4.0 or by constructing a new dissolved air flotation system. With the former, the waste activated sludge would be withdrawn from the return activated sludge stream whereas with the latter, the waste activated sludge could be taken directly from the mixed liquor. Wasting of mixed liquor is preferred over wasting from the RAS because it offers better SRT control in the bioreactor and also provides an opportunity to selectively waste undesirable high SVI and/or foam causing microorganisms from the system.
- A centrate treatment system as described previously in Section 6.0 will be constructed to reduce the TKN in the centrate load returning to the mainstream treatment process and also to provide a source of nitrifying microorganisms.

To implement the BNR system while the existing plant is in operation, construction staging will be such that the new bioreactor and final clarifier tankage would be constructed first. Once these are completed, they would be used to treat primary effluent for $cBOD_5$ and TSS removal while the existing secondary treatment tankage is taken out of service and retrofitted as described above. During retrofit of the existing secondary tankage, the primary effluent channel will be extended westward to provide a temporary feed of primary effluent to be treated in the new aeration and final clarification tankage.

The BioWin™ simulator was used to model the proposed BNR process using projected 2041 seasonal flow and load variations for the NEWPCC. Figure 14.16 illustrates the BioWin™ drawing board flow sheet as configured for the NEWPCC and as described above. The centrate treatment system is included in the configuration. Predicted outputs from the model operating at a 12 day SRT throughout the year at 30 minute intervals are described below:

- Figure 14.17 shows the predicted MLSS and MLVSS concentrations throughout the year as well as the Autotrophic bacteria (nitrifying

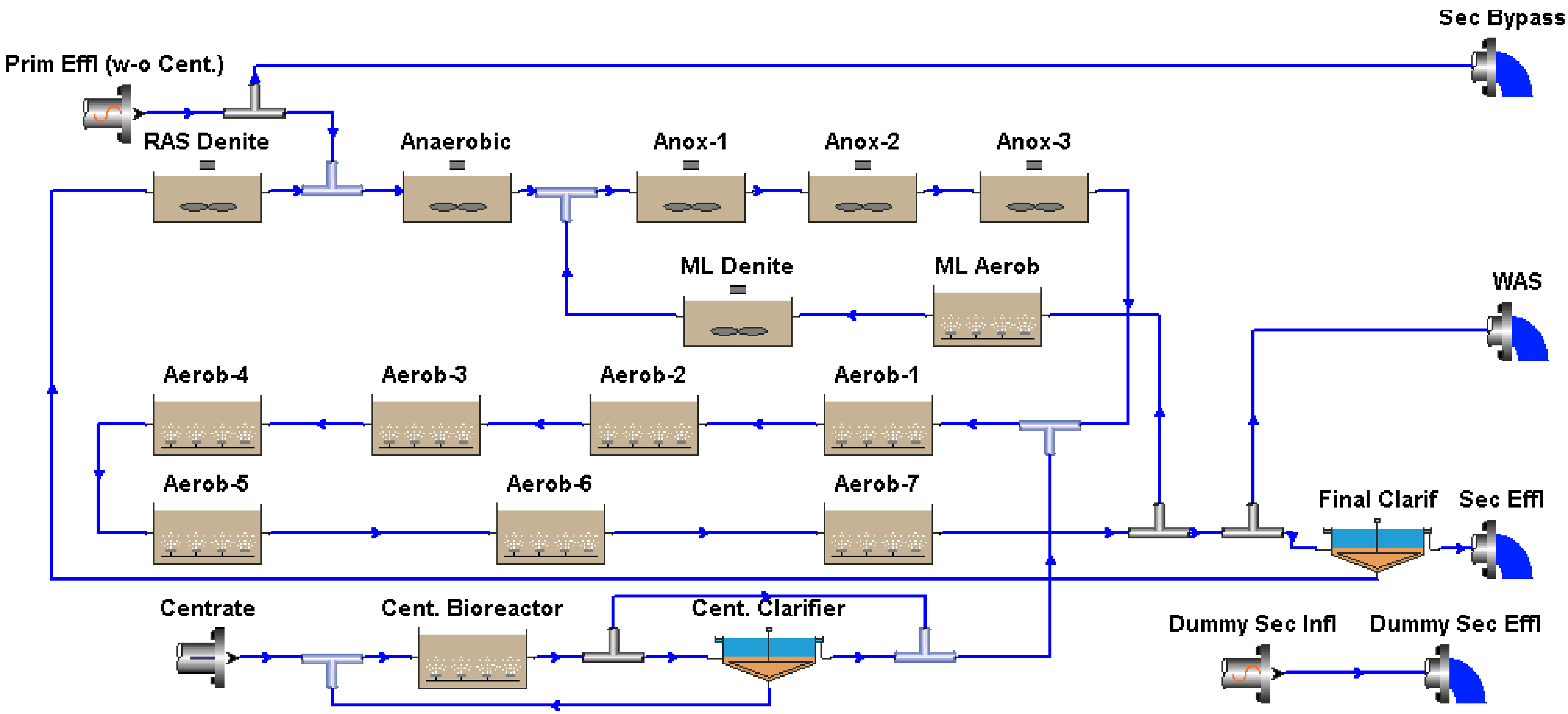

Figure 14.16: NEWPCC – BioWin™ Drawing Board Layout for BNR

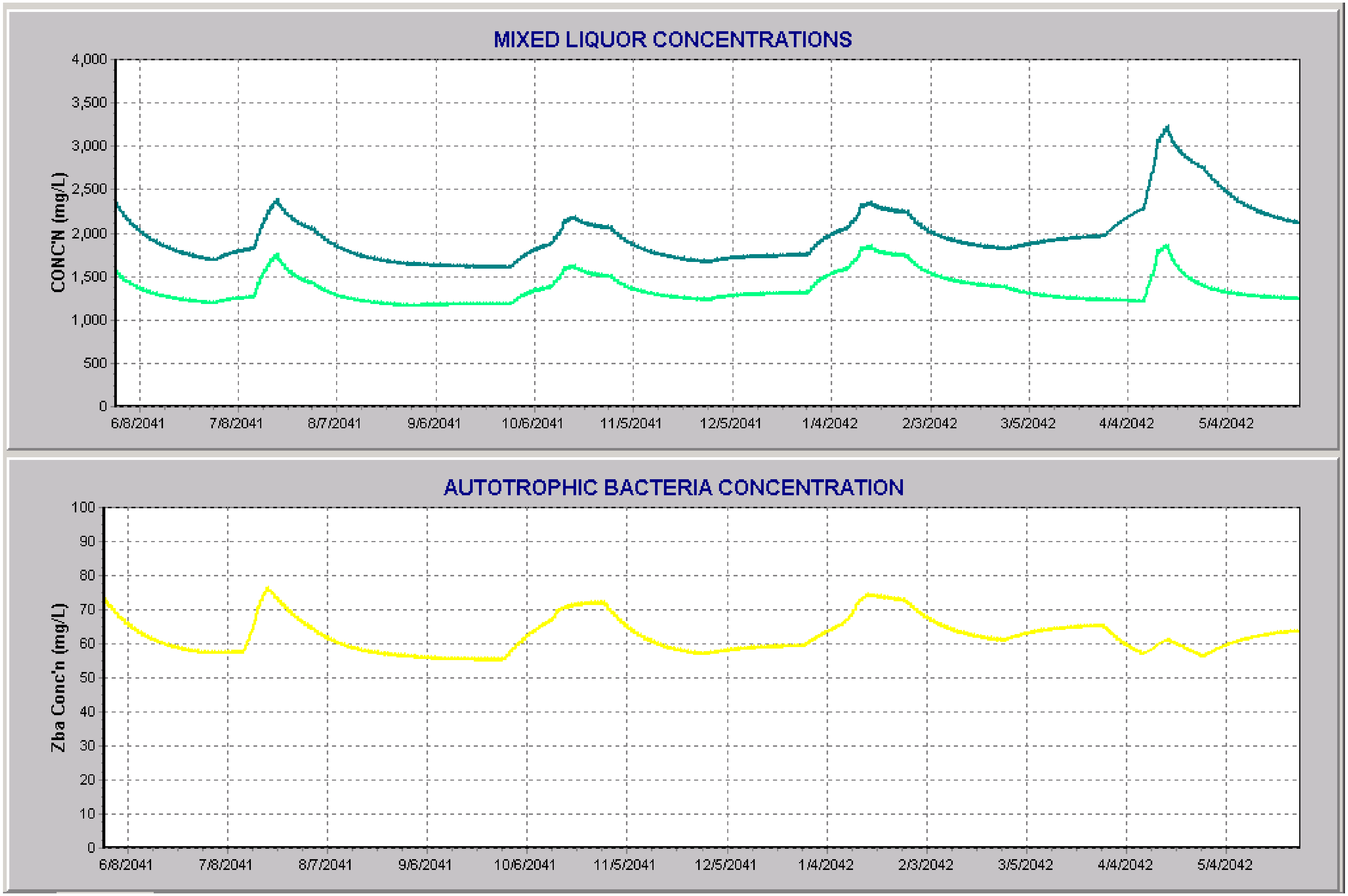

Figure 14.17: NEWPCC Model Output for BNR MLSS and Autotrophic Bacteria Concentrations

organisms) concentration. It is seen that the MLSS concentration varies from a low of about 1700 mg/L in the summer to a high of about 3200 mg/L in the spring runoff season. Variations in MLVSS concentration are from about 1300 mg/L to about 1800 mg/L and are much less pronounced than the variations in MLSS. This is because of the widely varying inert suspended solids concentration in the secondary influent stream that is particularly high during the spring runoff period. As noted in the plots, there is a considerable increase in MLSS in the spring that is not reflected nearly as much in the MLVSS, the difference being due to the contribution of the incoming inert suspended solids that become entrained in the biomass during this period. The Autotrophic bacteria concentration is relatively uniform throughout the year and varies between about 60 and 75 mg/L. A similar simulation run done without the centrate treatment system showed much more variation with a high Autotrophic bacteria concentration of about 80 mg/L in the summer and a low of about 40 mg/L in the spring. The beneficial "seeding" effect of the centrate treatment system in affording a more stable and reliable operation of the mainstream treatment train is apparent.

- Figure 14.18 shows the model output for the solids loading rate (SLR) and surface overflow rate (SOR) on the final clarifiers. In both instances, the apparent "width" of the line in the two plots reflects the diurnal variations that normally occur in the incoming wastewater flows and loads, and the resultant variations in the performance of the treatment system. Through the summer, fall and winter periods, the daily average SLR varies from about 50 to about 100 kg/m^2/d. However during the peak flow spring runoff period, the SLR increases to a high of about 170 kg/m^2/d during the peak week of the spring season. This is due to the high flows together with the increase in MLSS concentration plotted in Figure 14.17 that occurs at that time. While this peak SLR is indeed high, operating experience at the NEWPCC has indicated that the high density of the inert fraction in the mixed liquor occurring at that time of year results in sludges that settle reasonably well with a relatively low SVI. Thus it is concluded that the high SLR projected for the spring of 2041 should not have an adverse impact on plant performance. Average daily surface overflow rate (SOR) variations throughout the year are projected to be within a range of about 15 to 25 m^3/m^2/d and should not pose a problem.
- Figure 14.19 shows the predicted ammonia and phosphorus removal performance of the system. With respect to the former, the poorest performance is projected to occur in the springtime as would be expected for such low temperatures and high flows. However, the summer ammonia removal performance is within the target concentration of 8 mg/L. Likewise the predicted phosphorus removal performance is within the target concentration of 1.0 mg/L.

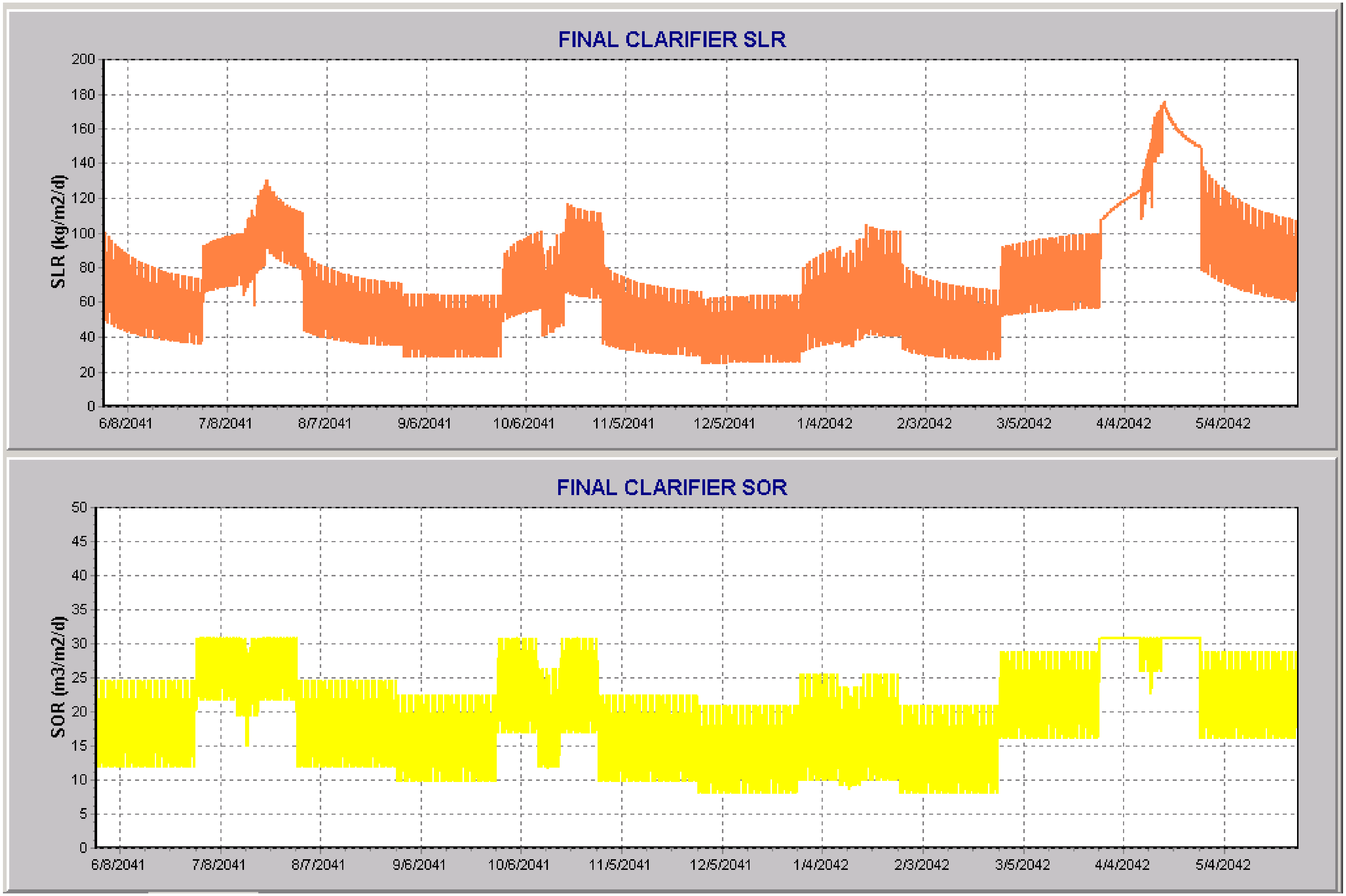

Figure 14.18: NEWPCC Model Output for BNR Final Clarifier Solids Loading Rate and Surface Overflow Rate

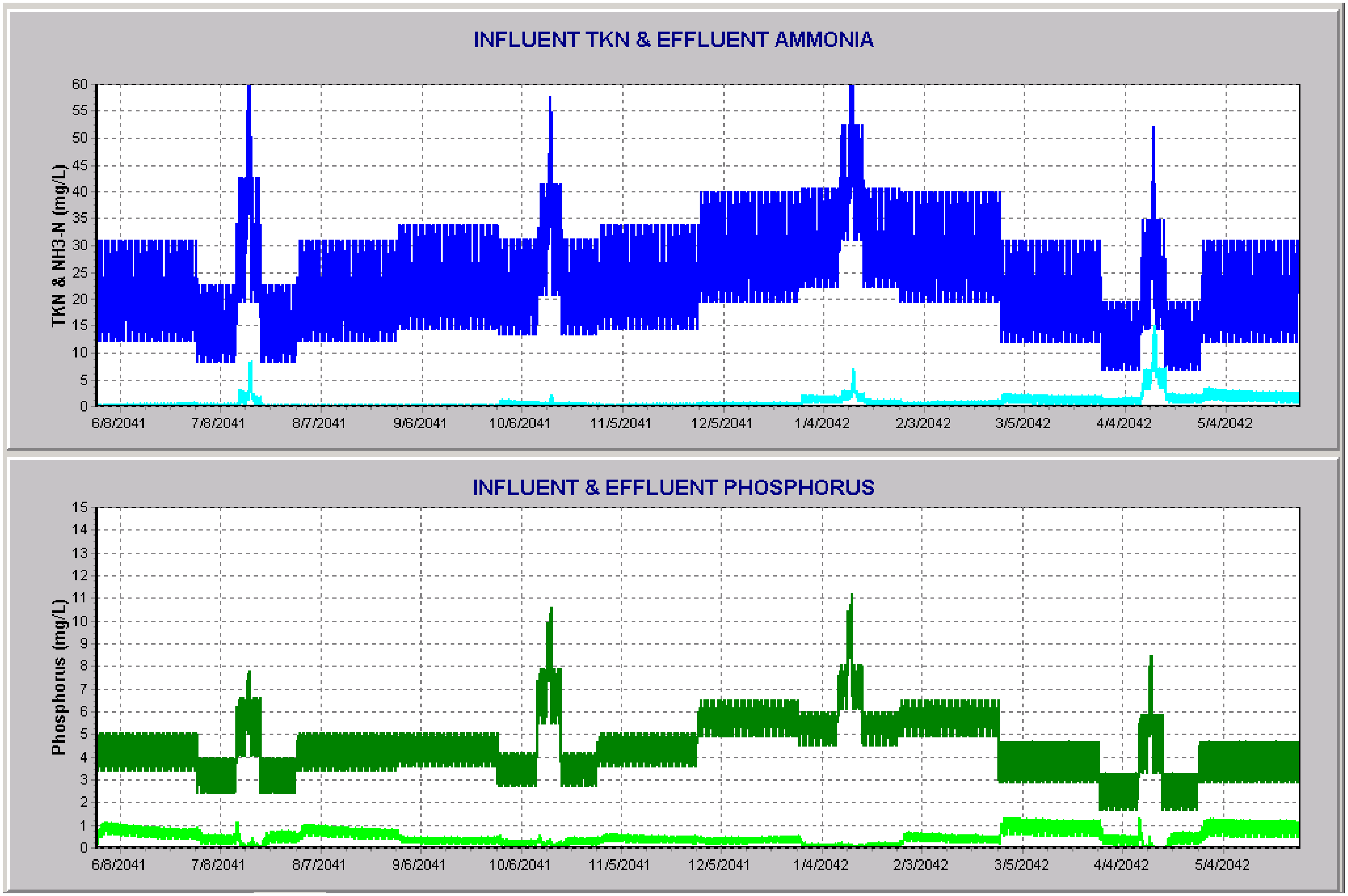

Figure 14.19: NEWPCC Model Output for BNR Ammonia and Phosphorus Removal Performance

Table 14.1: NEWPCC – Summary of Design Parameters for BNR System (for 2041 Flows & Loads)

SECONDARY TREATMENT SYSTEM:	
Bioreactors	
Total bioreactor volume	125,700 m^3
Nominal HRT @ average summer flow	10.4 h
@ at 400 ML/d	7.5 h
Nominal SRT	12 days winter / 7 days summer
Nominal MLSS concentration	1500 (summer) to 3000 mg/L (spring)
Internal partitioning for J-Burg Process:	
No. of parallel partitioned 4-pass unaerated zones (retrofitted to existing rectangular final clarifier no's 11 to 26)	4
Nominal dimensions of each pass	69.4 m L x 8.2 m W x 4.6 m SWD
Internal partitioning of each parallel unaerated zone	
RAS denite (in first pass)	17.3 m L x 8.2 m W x 4.6 m SWD
Anaerobic (in first pass)	52.0 m L x 8.2 m W x 4.6 m SWD
Anoxic (in 2'nd, 3'rd and 4'th passes)	69.4 m L x 8.2 m W x 4.6 m SWD
No. of parallel aerobic zones (retrofitted to existing HPO bioreactors no's 1 to 6)	6
Nominal dimensions of each parallel zone	68.3 m L x 17.1 m W x 4.3 m SWD
No. of parallel aerobic zones (new tankage)	3
Nominal dimensions of each zone	92.6 m L x 30,0 m W x 6.0 m SWD
Nitrified mixed liquor recycle system:	
Mixed liquor aerobic zone (retrofitted to existing square final clarifier no. 8)	20.0 m x 20.0 m x 4.6 m SWD
Mixed liquor denite zone (retrofitted to existing square final clarifier no. 7)	20.0 m x 20.0 m x 4.6 m SWD
Nitrified mixed liquor recycle pumps (new):	
No. of units	6
Type	Submersible Centrifugal
Nominal capacity each	3.0 m^3/s @ 1.0 m TDH
Overall bioreactor partitioning: [zone vol./zone vol. Fraction/mode]	
RAS-denite	3500 m^3 / 0.03 / mixed
Anaerobic	7,500 m^3 / 0.06 / mixed
Anoxic	33,350 m^3 / 0.26 / mixed
Aerobic	81850 m^3 / 0.65 / aerated
Blowers (New)	
Type	Centrifugal
No. of units	3 duty + 1 standby
Capacity per unit	8.0 nm^3/sec @ 76 kPa
Rated power per unit	850 kW
Final Clarifiers (New)	
No. of units	6
Dimensions each unit	52.0 m diam x 5.0 m SWD

Table 14.1: NEWPCC – Summary of Design Parameters for BNR System (for 2041 Flows & Loads) [continued]

SECONDARY TREATMENT SYSTEM: (continued)	
RAS System (New)	
No. of RAS pumphouses	2
No. of pump units in each pumphouse	3 duty + 1 standby
Type of pump	variable speed centrifugal
Capacity per unit	770 L/sec
PRIMARY SLUDGE FERMENTATION SYSTEM:	
Fermenter/Thickener Vessels (Existing)	
Utilize Squircle final clarifier no's 1 to 6	
No of units	6
Dimensions each unit	20.0 m x 20.0 m x 4.6 m SWD
Mechanism	Rotating reversible picket fence
Nominal solids retention time	5 days winter / 2.5 days summer
Blanket depth range	1.5 to 2.5 m
Thickened Sludge U/F Pumps (New)	
No. of units	6 duty + 2 standby
Type of pump	Variable speed progressive capacity
Capacity per unit	1.6 L/sec
WASTE ACTIVATED SLUDGE MANAGEMENT SYSTEM:	
Mixed Liquor Wasting System (New)	
Type	Selective wasting of mixed liquor
Range of SRT control	5 to 15 days
Range of MLSS concentration	1500 to 3000 mg/L
Range of total WAS flow	100 to 300 L/sec
No. of WAS pumps	3 duty + 3 standby
Type of pump	Variable speed centrifugal
Capacity (each)	100 L/s max
DAF Thickening System (New)	
No. of units	4
Type	Dissolved air flotation
Nominal solids loading rate	2.0 $g/m^2/sec$
Nominal unit dimensions (each)	14.3 m x 6.0 m rectangular
U/F circulation rate to pressurization	100%
Air : solids ratio	0.05
No. of compressors	1 duty + 1 standby
Capacity of each compressor	0.6 nm^3/sec @ 500 kPa
CENTRATE TREATMENT SYSTEM:	
Bioreactors (New)	
Type	Complete mix activated sludge
No. of bioreactors	2
Dimensions of each bioreactor	20.0 m square x 6.0 m SWD
Volume of each bioreactor	2,400 m^3
Nominal HRT	42 hours
Operating SRT	15 days

Table 14.1: NEWPCC – Summary of Design Parameters for BNR System (for 2041 Flows & Loads) [continued]

CENTRATE TREATMENT SYSTEM: (continued)	
Blowers (New)	
No. of blowers	1 duty + 1 standby
Capacity per unit	2.4 nm^3/sec @ 76 kPa
Rated power per unit	180 kW
Clarfiers (New)	
No. of clarifiers	2
Dimensions of each	12.0 m diameter x 5.0 m SWD

14.4 BIOLOGICAL NUTRIENT REMOVAL AT SEWPCC

The approach taken to implement biological nutrient removal at the SEWPCC is to utilize a step feed BNR process (employing principles similar to those illustrated in Figure 14.15) to minimize the amount of new bioreactor tankage required to meet the specified target limits of 8 mg/L ammonia nitrogen in the summer months and 1.0 mg/L total phosphorus year-round. The proposed system will incorporate a fourth clarifier with a diameter of 45.7 m due to the growth that is forecast for the south end sewer catchment area. Table 14.2 presents the design parameters for the suggested step feed BNR system at the SEWPCC.

A site layout, bioreactor layout, and process flow diagram are shown in Dwg. SE-14.1, Dwg. SE-14.2, and Dwg. SE-14.3, respectively

While there are numerous step feed BNR configurations that can be devised for application to the SEWPCC, the one chosen as the basis of the conceptual design work in this study has the following features:

- The existing four parallel HPO bioreactors will be reconfigured to serve as the unaerated bioreactor volume for the first step of a two-step feed BNR process. The retrofit will result in four similar unaerated zones that will be the front end of four separate bioreactors. Each unaerated zone will consist of a RAS denitrification volume, an anaerobic volume, and an anoxic volume.
- "Wing" tankage will be added to the side of the existing bioreactors extending to the north and south. Each wing will consist of two parallel mirror image bioreactor extensions. Each extension will contain the aerobic volume of the first step of the process, and the anaerobic, anoxic and aerobic volumes of the second step of the process.
- The aerobic volumes in the bioreactors will be fitted with fine bubble flexible membrane diffusers. A new aeration system using centrifugal blowers will be provided.

- Two submerged nitrified mixed liquor return lines will be included in each of the four parallel bioreactors – one from the end of the aerobic zone to the front of the anoxic zone in the first step, and the other likewise in the second step.
- A primary effluent step feed channel will extend part way along each wing and be located on the wall separating the two parallel bioreactors in each wing.
- A channel constructed at the extremity of each wing will collect mixed liquor exiting the two parallel bioreactors in each wing and convey it along the west wall of the wing tankage to the existing mixed liquor channel leading to the final clarifiers.
- A new primary sludge fermentation system will be constructed to provide the volatile fatty acids necessary for maintaining a healthy biological phosphorus removal system. Each of the four fermenter vessels will be designed as a single-stage static unit and the supernatant from each unit will be directed to the anaerobic zones of the unaerated tankage in the bioreactors. The headspace air in the fermentation units will be ducted to the new aeration blower system where the odorous air will be combined with process air and injected into the aerobic zones of the bioreactors for odour control.
- Waste activated sludge thickening will be provided by a new dissolved air flotation system as described previously in Section 4.0 of this report.

To implement the BNR system while the existing plant is in operation, construction staging will be such that the new bioreactor wing tanks are constructed first. Once these are completed, a temporary primary effluent line will be constructed to use them for treatment while the existing tankage is retrofitted as the unaerated volume of the first step of the proposed process.

The BioWin™ simulator was used to model the proposed step feed BNR process using the projected 2041 flow and load variations for the SEWPCC. Figure 14.20 illustrates the BioWin™ drawing board flow sheet as configured for the SEWPCC and as described above. Predicted outputs from the model operating at a 12 day SRT throughout the year at 30 minute intervals are described as follows:

- Figure 14.21 illustrates the mixed liquor concentration and the Autotrophic bacteria concentration exiting the bioreactors. The upper and lower lines in the top plot represent the MLSS and MLVSS concentrations respectively at the end of the second step of the process. The MLSS concentration going to the final clarifiers ranges from a low of about 1,300 mg/L in the late spring to a high of about 2,500 mg/L during the peak summer loading conditions. MLSS concentrations in the first step of the bioreactor are as high as 3,500 mg/L during the spring period. The Autotrophic bacteria concentration ranges from a low of about 20 mg/L in the late spring to a high of about 50 mg/L in the winter.

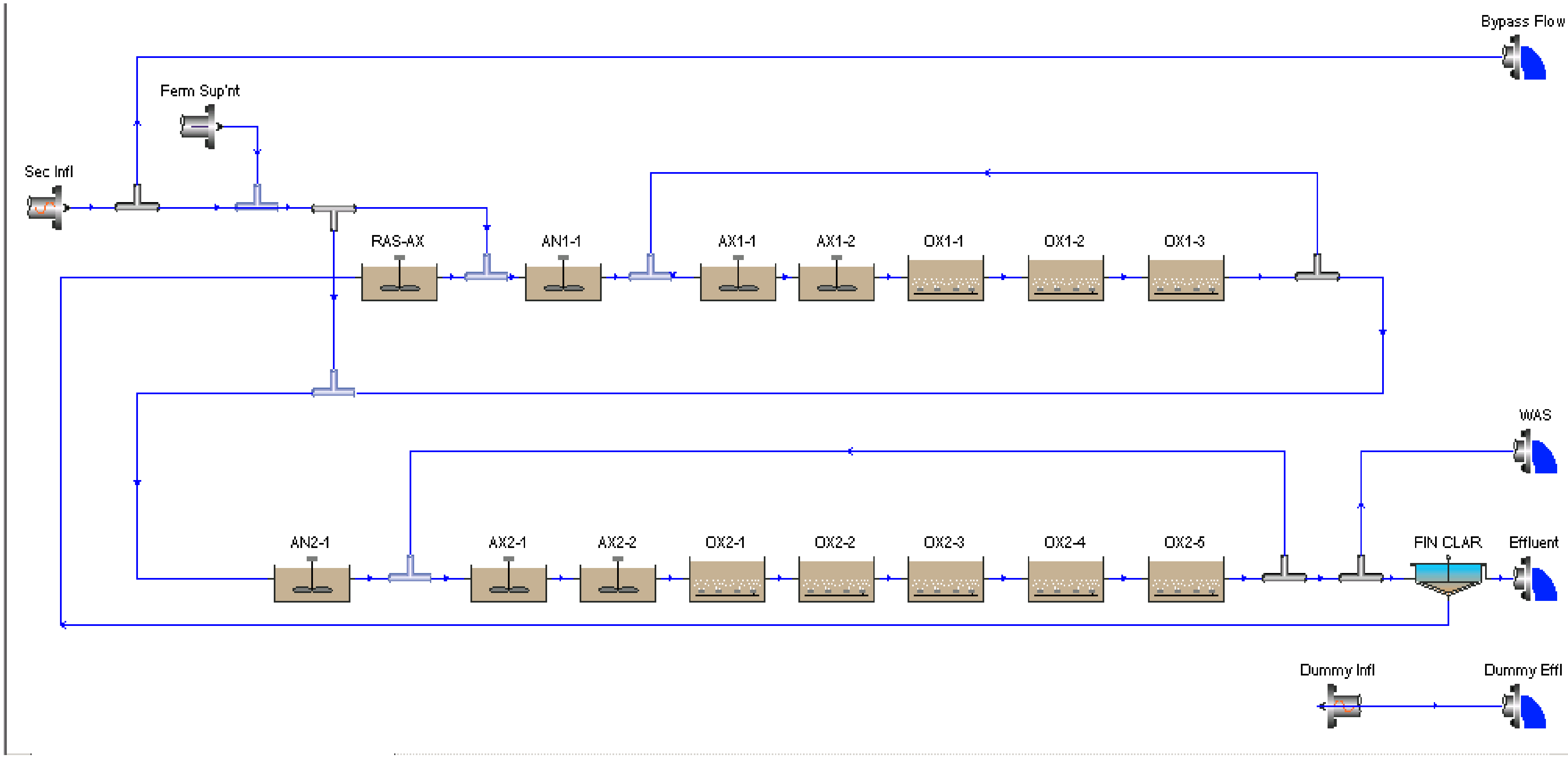

Figure 14.20: SEWPCC BioWin™ Drawing Board Layout for BNR

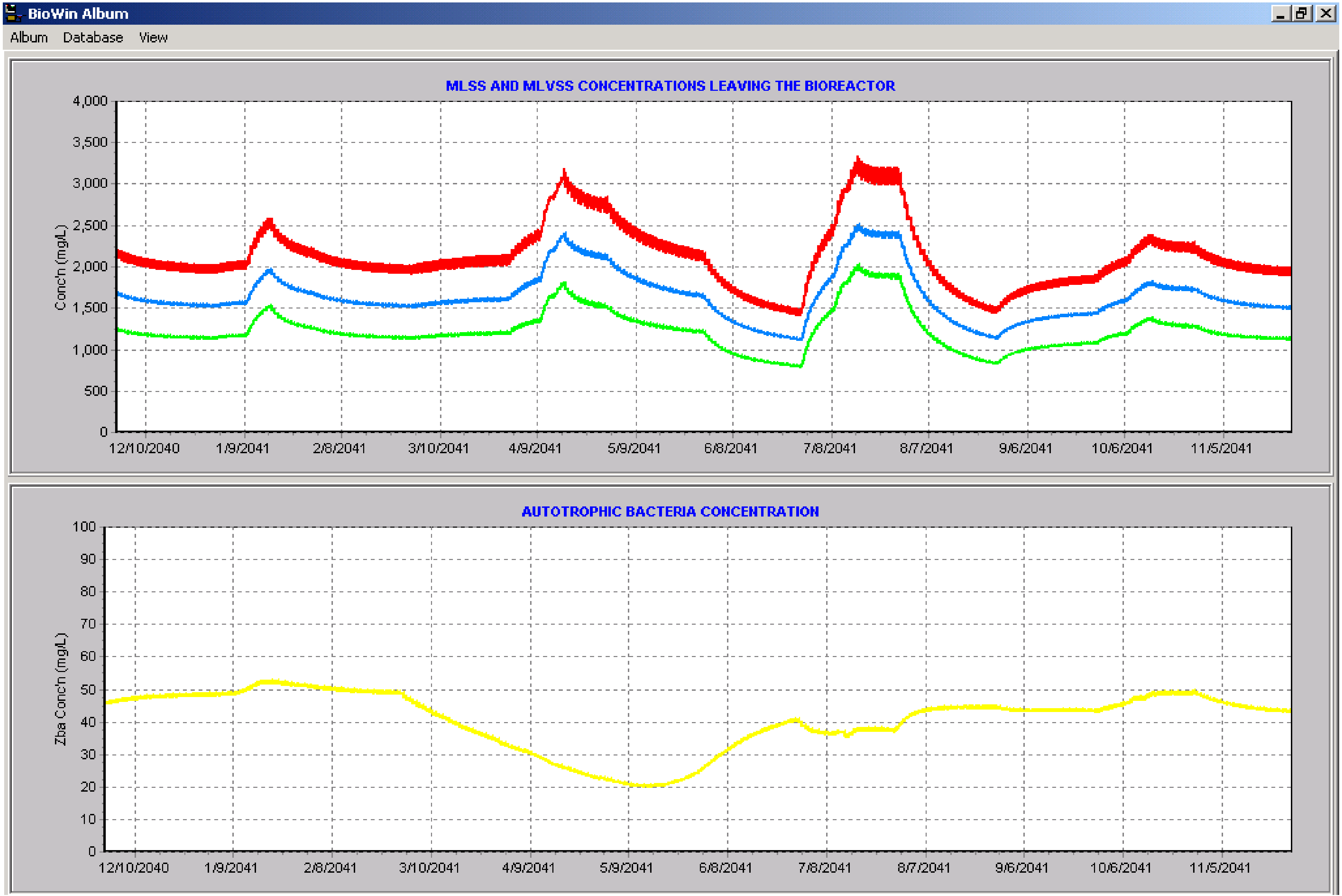

Figure 14.21: SEWPCC Model Output for BNR MLSS and Autotrophic Bacteria Concentrations

- Figure 14.22 shows the model output for the solids loading rate (SLR) and surface overflow rate (SOR) on the final clarifiers. In both instances, the apparent "width" of the line in the two plots is reflective of the diurnal variations that normally occur in the incoming wastewater flows and loads, and the resultant variations in the performance of the treatment system. The SLR peaks at about 120 kg/m^2/d during the peak flow conditions in the spring and again during peak wet weather conditions in the summertime. The SOR does not exceed 30 m^3/m^2/d during the same peak flow periods and shows a typical average day value of between about 12 to 15 m^3/m^2/d.
- Figure 14.23 shows the predicted ammonia and phosphorus removal performance of the system. With respect to the former, there is a bleed through of as much as 10 mg/L ammonia in the spring months when the Autotrophic bacteria are being stressed. However the nitrifying performance of the plant recovers in sufficient time to be well within the target limit of 8 mg/L ammonia by the critical summer period. The predicted phosphorus concentration is within an annual average target value of 1.0 mg/L.

Table 14.2: SEWPCC – Summary of Design Parameters for BNR System (For 2041 Flows & Loads)

SECONDARY TREATMENT SYSTEM:	
Bioreactors (existing to be modified and expanded)	
No. of units	4
Volume each unit	11,640 m^3
Nominal HRT @ AAF	13.8 hours
@ MMF	7.4 hours
Nominal SRT	12 days winter / 7 days summer
Nominal MLSS concentration	2000 to 3000 mg/L
Internal partitioning for Two-Step BNR Process with 60/40 split:	
First step zone volumes per bioreactor:	
RAS-denite (retrofit existing tankage)	100 m^3
Anaerobic (retrofit existing tankage)	310 m^3
Anoxic-1 (retrofit existing tankage)	410 m^3
Anoxic-2 (retrofit existing tankage)	820 m^3
Aerobic-1 (new tankage)	625 m^3
Aerobic-2 (new tankage)	625 m^3
Aerobic-3 (new tankage)	1250 m^3
Second step zone volumes per bioreactor:	
Anaerobic (new tankage)	625 m^3
Anoxic-1 (new tankage)	625 m^3
Anoxic-2 (new tankage)	625 m^3
Aerobic-1 (new tankage)	625 m^3
Aerobic-2 (new tankage)	1250 m^3
Aerobic-3 (new tankage)	1250 m^3
Aerobic-4 (new tankage)	1250 m^3
Aerobic-5 (new tankage)	1250 m^3

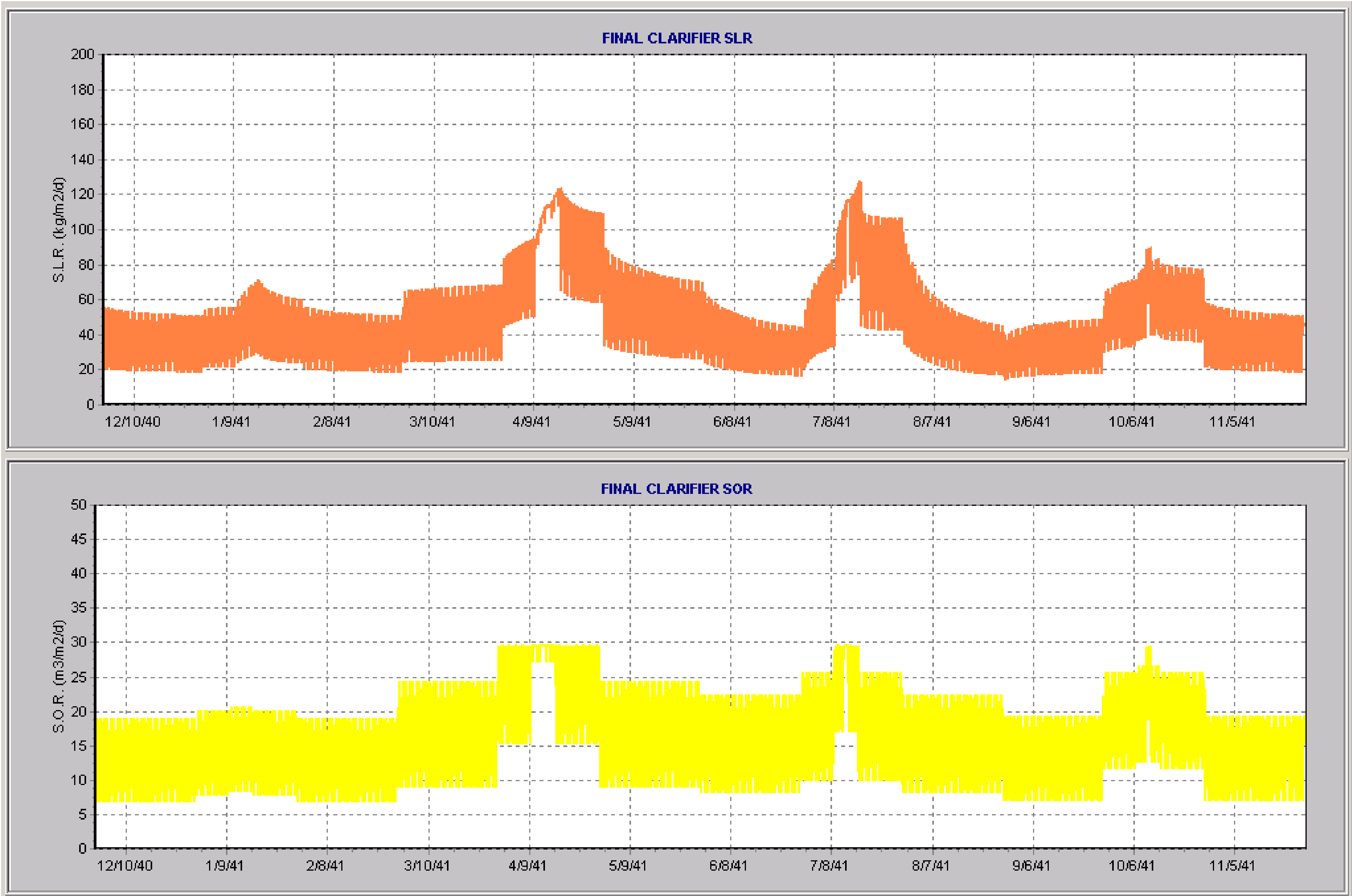

Figure 14.22: SEWPCC Model Output for BNR Final Clarifier Solids Loading Rate and Surface Overflow Rate

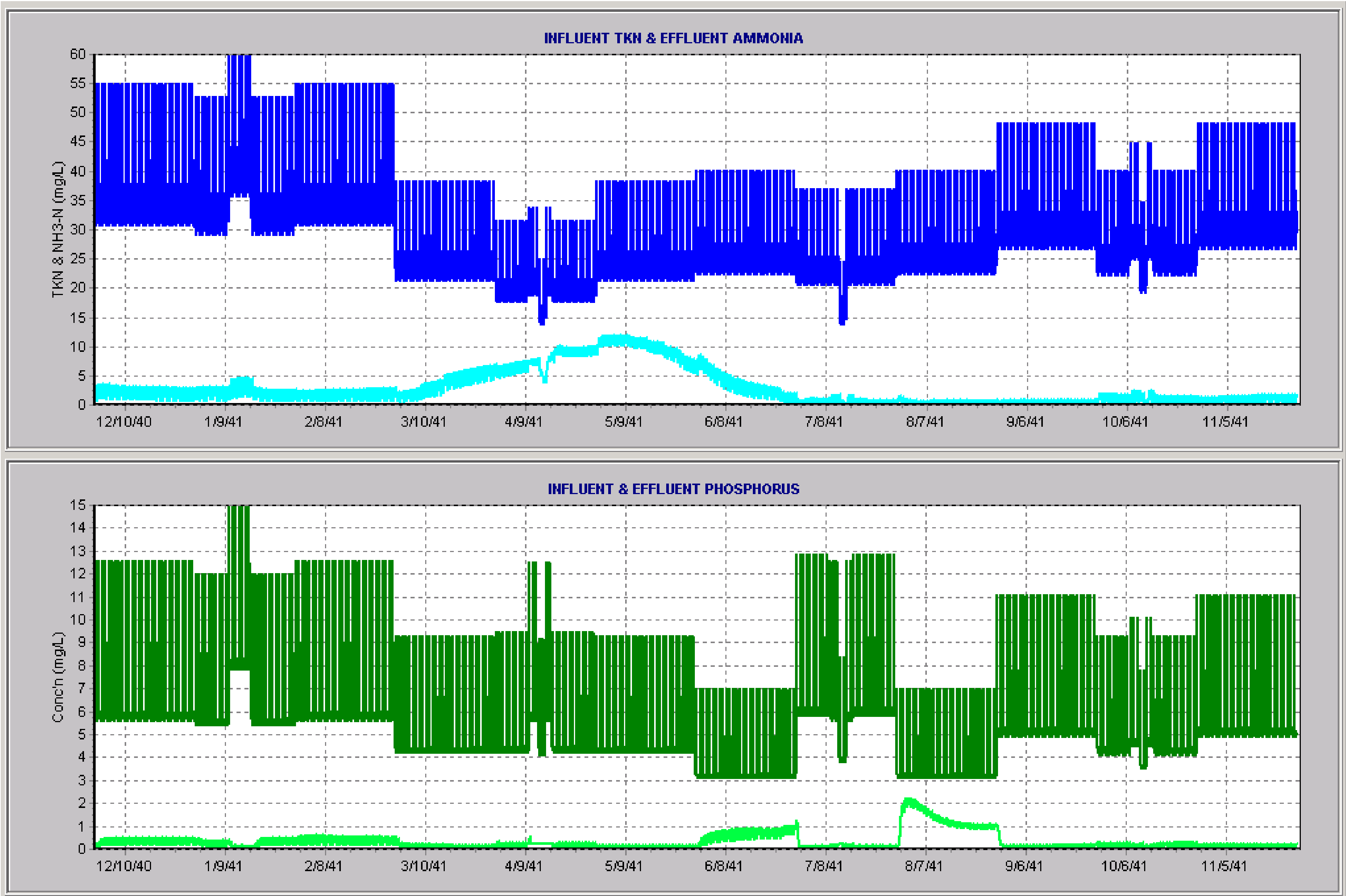

Figure 14.23: SEWPCC Model Output for BNR Ammonia and Phosphorus Removal Performance

Table 14.2: SEWPCC – Summary of Design Parameters for BNR System (For 2041 Flows & Loads) [continued]

SECONDARY TREATMENT SYSTEM: (continued)	
Bioreactors (existing to be modified and expanded) [continued]	
Nitrified mixed liquor recycle pump (new)	
No. of units	4 in first step; 4 in second step
Type	submersible propeller pump
Nominal capacity each	0.6 m^3/s first step 1.0 m^3/sec second step
Blowers (New)	
Type	Centrifugal
No. of units	3 duty + 1 standby
Capacity per unit	6.5 nm^3/sec @ 76 kPa
Rated power per unit	700 kW
Final Clarifiers	
Existing tankage:	
Dimensions	Two @ 33.5 m diam One @ 45.7 m diam
New tankage:	
Dimensions	One @ 45.7 m diam
PRIMARY SLUDGE FERMENTATION SYSTEM:	
Primary Sludge Feed Pumps (New)	
No. of units	4 duty + 2 standby
Type of pump	Progressive cavity
Capacity per unit	8.0 L/sec
Fermenter/Thickener Vessels (New)	
No. of units	4
Dimensions each unit	17.0 m diam x 4.0 m SWD
Bottom slope	1 in 8
Mechanism	Rotating reversible picket fence
Nominal solids retention time	5 days winter / 2.5 days summer
Blanket depth range	1.5 to 2.0 m
Thickened Sludge U/F Pumps (New)	
No. of units	4 duty + 2 standby
Type of pump	Variable speed progressive capacity
Capacity per unit	1.1 L/sec
WASTE ACTIVATED SLUDGE MANAGEMENT SYSTEM:	
Mixed Liquor Wasting System (New)	
Type	Selective wasting of mixed liquor
Range of SRT control	5 to 15 days
Range of MLSS concentration	2000 to 3000 mg/L
Range of total WAS flow	8 to 25 L/sec
No. of WAS pumps	4 duty + 2 standby
Type of pump	Variable speed centrifugal
Capacity (each)	30 L/sec

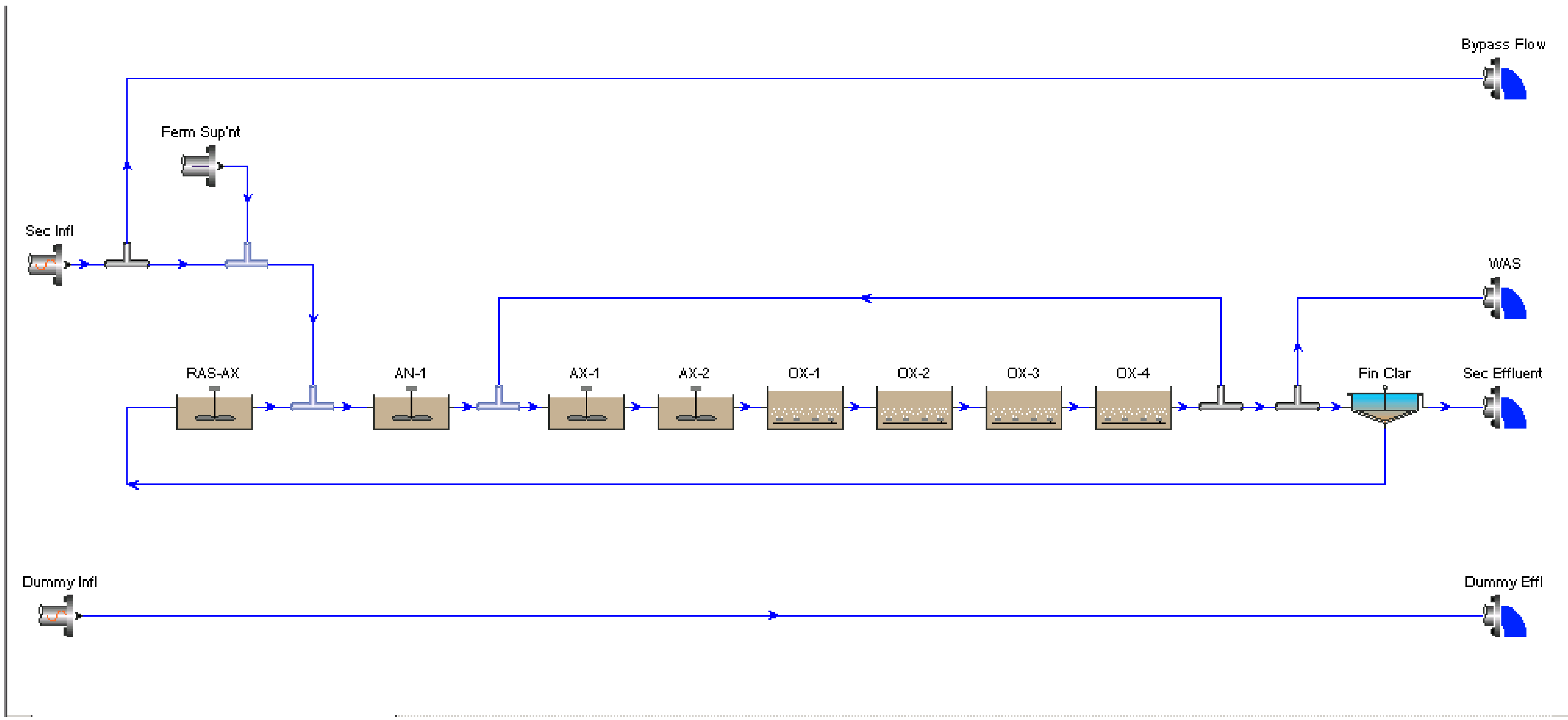

Figure 14.24: WEWPCC BioWin™ Drawing Board Layout for BNR

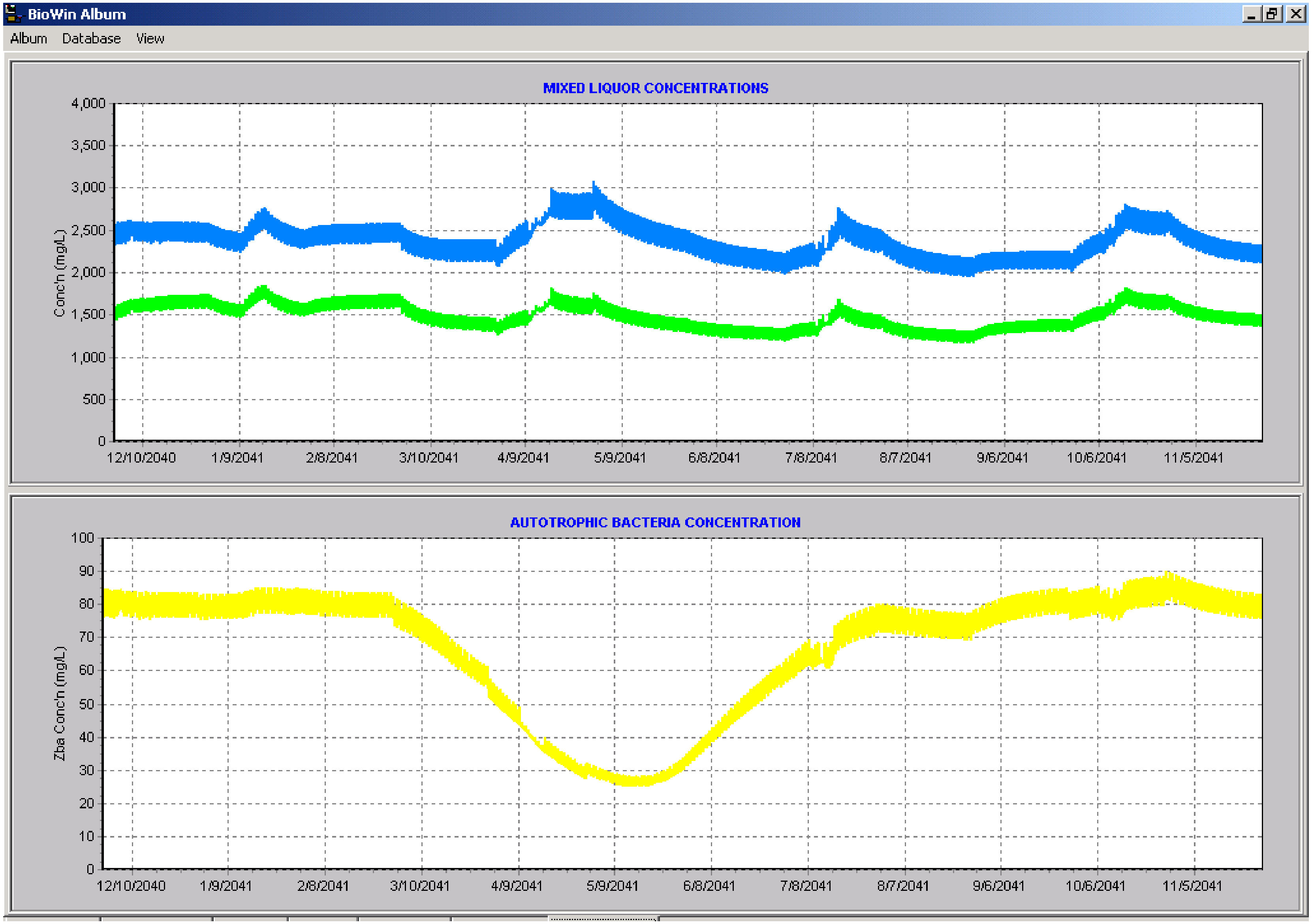

Figure 14.25: WEWPCC Model Output for BNR MLSS and Autotrophic Bacteria Concentrations

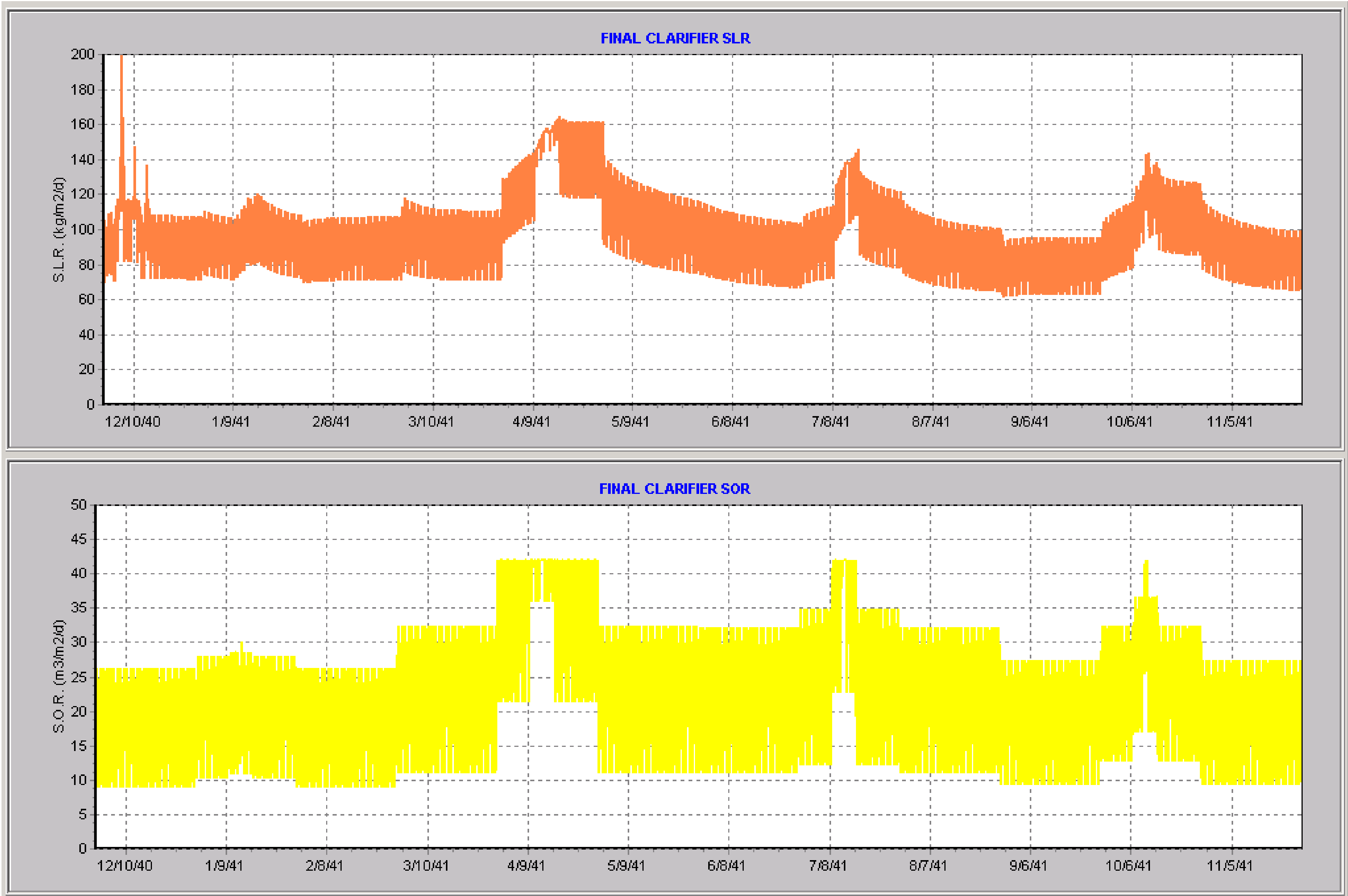

Figure 14.26: WEWPCC Model Output for BNR Final Clarifier Solids Loading Rate and Surface Overflow Rate

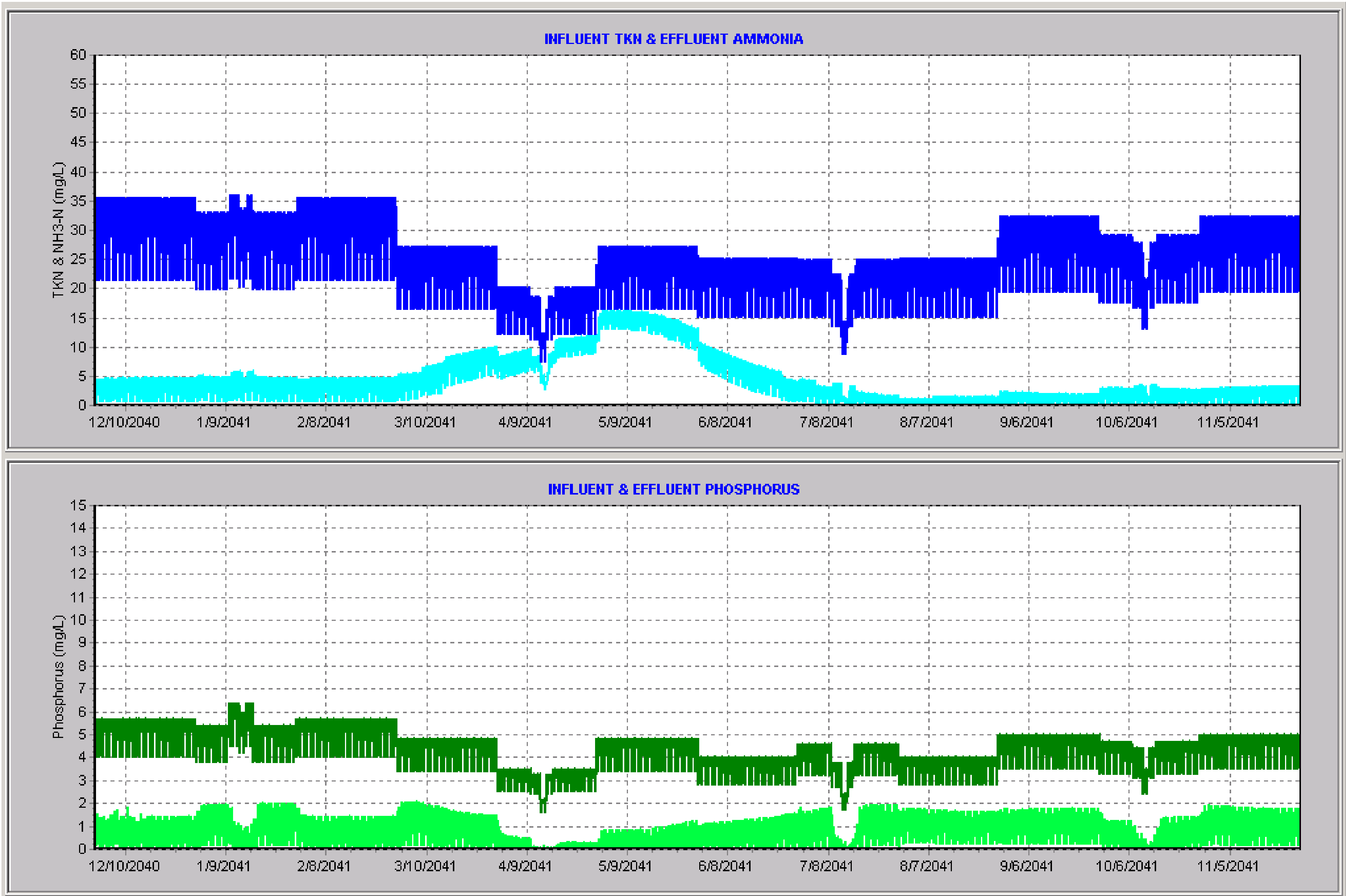

Figure 14.27: WEWPCC Model Output for BNR Ammonia and Phosphorus Removal Performance

Table 14.2: SEWPCC – Summary of Design Parameters for BNR System (For 2041 Flows & Loads) [continued]

WASTE ACTIVATED SLUDGE MANAGEMENT SYSTEM: (continued)	
DAF Thickening System (New)	
No. of units	3
Type	Dissolved air flotation
Nominal solids loading rate	1.4 g/m^2/sec
Nominal vessel dimensions (each)	6.5 m L x 3.0 m W rectangular
U/F circulation rate to pressurization	100 %
Air : solids ratio	0.05
No. of air compressors	1 duty + 1 standby
Capacity of each air compressor	0.15 nm^3/sec @ 500 kPa

14.5 BIOLOGICAL NUTRIENT REMOVAL AT WEWPCC

The approach taken to implement biological nutrient removal at the WEWPCC is to retrofit the Johannesburg Process (see process schematic in Figure 14.12) into the existing bioreactor tankage. The Johannesburg Process was selected because it is relatively simple and straightforward and can be adapted to the existing tankage with a minimum of modifications. The need for a more elaborate process configuration involving step feed points and requiring a greater degree of operator monitoring and control (such as the Westbank Process or the Goldbar Process) was not deemed necessary because the treated effluent is discharged to the lagoons as a polishing step.

Table 14.3 presents the design parameters for the proposed BNR process retrofitted to the WEWPCC. A plant layout and process flow diagram are illustrated in Dwg. WE-14.1 and Dwg. WE-14.2, respectively.

The conceptual design used in applying the Johannesburg Process to the WEWPCC has the following features:

- Each rectangular bioreactor will be partitioned into a three-pass serpentine configuration by the installation of two longitudinal walls. Further partitioning of the first pass in each bioreactor will be done to construct RAS denitrification, anaerobic and anoxic zones.
- Submerged mixing units will be installed in each unaerated zone of the two retrofitted bioreactors to maintain the mixed liquor in suspension.
- In the aerobic zones, the coarse bubble aeration system will be replaced with a flexible membrane fine bubble aeration system.
- A submersible propeller pump will be installed at the end of the third pass in each bioreactor as the mixed liquor recycle pump. This pump will discharge into a submerged pipeline extending from the end of the aerobic zone,

through the two new partition walls, and ending in the first anoxic zone of each bioreactor.

- A new primary sludge fermentation system will be constructed to provide the volatile fatty acids necessary for maintaining a healthy biological phosphorus removal system. Each fermenter tank will be designed as a single-stage static unit. The fermenter supernatant will be directed to the two anaerobic zones. The thickened sludge underflow will be pumped to the sludge storage tank. Each fermenter unit will be covered and the odorous headspace gases vented to the process air system, where they will be injected into the bioreactor aeration system as an odour control measure.
- A dissolved air flotation system will be used to thicken the waste activated sludge.

To implement the BNR system at the WEWPCC, one bioreactor will be taken out of service and retrofitted at a time while the other one will operate in non-nitrifying mode.

The BioWin™ simulator was used to model the proposed Johannesburg Process using projected 2041 seasonal flow and load variations for the WEWPCC. Figure 14.24 illustrates the BioWin™ drawing board flow sheet as configured for the WEWPCC and as described above. Predicted outputs from the model operating at a 12 day SRT throughout the year at 30 minute intervals are described below:

- Figure 14.25 shows the predicted MLSS and MLVSS concentrations throughout the year as well as the Autotrophic bacteria concentration. It is noted that the MLSS concentration varies from about 2000 to 2800 mg/L, the higher values occurring in the peak flow spring months. While the Autotrophic bacteria concentration is in the 70 to 80 mg/L range for much of the year, the impact of the cold wastewater temperatures and higher flow rate is apparent in the peak flow spring season. During this period, the Autotrophic bacteria concentration decreases to a low of about 30 mg/L.
- Figure 14.26 shows the model output for the solids loading rate (SLR) and the surface overflow rate (SOR) on the final clarifiers. In both instances, the apparent "width" of the line in the two plots is reflective of the diurnal variations that normally occur in the incoming wastewater flows and loads, and the resultant variations in the performance of the treatment system. Through the summer, fall and winter periods, the average daily SLR is in the 80 to 90 $kg/m^2/d$ range with a peak of up to about 130 $kg/m^2/d$ during the maximum summer week. However the SLR increases to about 160 $kg/m^2/d$ for the peak week in the springtime peak flow period. Daily average surface overflow rates are generally in the range of 20 $m^3/m^2/d$ for most of the year with a springtime peak to about 30 $m^3/m^2/d$.
- Figure 14.27 illustrates the predicted ammonia and phosphorus removal performance of the system. With respect to the former, the poorest

performance is projected to occur in the springtime with average daily effluent ammonia concentrations peaking at around 14 mg/L. However, with the onset of warmer wastewater temperatures once the spring peak is past, the treated effluent ammonia nitrogen is well below the target of 8 mg/L by the critical summer period. The annual average predicted effluent phosphorus target of 1.0 mg/L is also met.

Table 14.3: WEWPCC – Summary of Design Parameters for BNR System (for 2041 Flows & Loads)

SECONDARY TREATMENT SYSTEM:	
Bioreactors (existing to be modified)	
No. of units	2
Nominal dimensions of each unit	43.2 m L x 21.6 m W x 5.5 m SWD
Volume each unit	5132 m^3
Nominal HRT @ AAF	7.1 hours
@ MMF	4.1 hours
Nominal SRT	12 days winter / 7 days summer
Nominal MLSS concentration	2000 to 3000 mg/L
Internal partitioning for J-Burg Process: [zone vol./zone vol. Fraction/model]	
First pass:	
RAS-denite	103 m^3 / 0.02 / mixed
Anaerobic	411 m^3 / 0.08 / mixed
Anoxic-1	513 m^3 / 0.10 / mixed
Anoxic-2	513 m^3 / 0.10 / mixed
Second pass:	
Aerobic-1	898 m^3 / 0.175 / aerated
Aerobic-2	898 m^3 / 0.175 / aerated
Third pass:	
Aerobic-3	1796 m^3 / 0.35 / aerated
Nitrified mixed liquor recycle pump (new)	
No. of units	1 per bioreactor
Type	Submersible propeller pump
Nominal capacity each	0.8 m^3/s ~ 1.0 m TDH
Blowers (Existing)	
Type	Centrifugal
No. of units	2 duty + 1 standby
Capacity per unit	150 sm^3/min @ 62 kPa
Rated power per unit	200 kW
Final Clarifiers	
No. of units	2
Dimensions each unit	30.0 m diam X 4.0 m SWD
Mechism	Rotating with multiple draw-off tubes
RAS System (Existing	
No. of units	2 duty + 1 standby
Type of pump	variable speed centrifugal
Capacity per unit	440 L/sec

Table 14.3: WEWPCC – Summary of Design Parameters for BNR System (for 2041 Flows & Loads) [continued]

PRIMARY SLUDGE FERMENTATION SYSTEM:	
Primary Sludge Feed Pumps (New)	
No. of units	2 duty + 1 standby
Type of pump	Progressive cavity
Capacity per unit	10 L/sec
Fermenter/Thickener Vessels (New)	
No. of units	2
Dimensions each unit	14.0 m diam x 4.0 m SWD
Bottom slope	1 in 8
Mechanism	Rotating reversible picket fence
Nominal solids retention time	5 days winter / 2.5 days summer
Blanket depth range	1.5 to 2.0 m
Thickened Sludge U/F Pumps (New)	
No. of units	2 duty + 1 standby
Type of pump	Variable speed progressive capacity
Capacity per unit	1.2 L/sec
Mixed Liquor Wasting System (New)	
Type	Selective wasting of mixed liquor
Range of SRT control	5 to 15 days
Range of MLSS concentration	2000 to 3000 mg/L
Range of total WAS flow	8 to 25 L/sec
No. of WAS pumps	2 duty + 1 standby
Type of pump	Variable speed centrifugal
Capacity (each)	25 L/sec
DAF Thickening System (New)	
No. of units	2
Type	Dissolved air flotation
Nominal solids loading rate	1.4 $g/m^2/sec$
Nominal vessel dimensions (each)	8.0 m L X 3.0 m W rectangular
U/F circulation rate to pressurization	100%
Air : solids ratio	0.05
No. of air compressors	1 duty + 1 standby
Capacity of each air compressor	0.1 nm^3/sec

14.6 ESTIMATED COSTS

The cost estimating approach set out in Section 2.4 has been used to develop representative estimates of the total cost of ownership of the facilities required to implement Biological Nutrient Removal at the three WPCCs. The details of the estimates are presented in Appendix A. The 95 percent confidence limit estimates are summarized in Table 9.15.

Table 14.4: Summary of Estimated Costs – Biological Nutrient Removal

	NEWPCC	SEWPCC	WEWPCC
Capital Cost	$126,900,000	$47,200,000	$6,600,000
Operating & Maintenance Cost	$1,800,000	$580,000	$120,000
Net Present Worth Cost (4 % Discount Rate)	$164,400,000	$59,200,000	$9,400,000