IMPROVING TREATMENT PLANT UPGRADE PLANNING BY UNDERSTANDING THE CAPABILITIES OF EXISTING ASSETS

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ABSTRACT

Kaipara District Council (KDC) owns the sewerage assets for the Mangawhai area which includes reticulation, a Wastewater Treatment Plant (WWTP) and a transfer pipeline to the Lincoln Downs farm for full reuse.

Mangawhai is a tourist area and periodically receives high tourist loads up to 300 to 400% above the non-tourist periods. The plant during tourist periods is near capacity and can struggle with the sudden load increase.

To address future growth needs KDC commenced planning for the upgrade of the WWTP and effluent management system. The initial approach was to significantly change the current intermittent activated sludge process to a membrane bioreactor (MBR) process. However, after careful consideration of the current plant and several upgrade options a much less disruptive upgrade approach was identified. The approach agreed on was to keep the current technology, however progressively upgrade it over time providing more capacity and quality. The approach reduced the overall capital and operating expenses by 32 and 35% respectively. It also allowed the capital expenditure to be staged over time and saved on embodied carbon use as no new major concrete structures were required.

The upgrade approach to the WWTP is to occur in three stages. The three stages are optimisation of the current plant to unlock capacity, retrofit the current plant with hydro cyclones (using inDENSE™) to improve settling to unlock further capacity and a final retrofit of a current balance tank to an activated sludge process and upgrade to a Class A facility.

Stage 1 involved reassessing the current plant and undertaking an intensive onsite optimisation of the current asset. Stage 2 involves installation on an inDENSE™ hydrocyclone system. Both stage 1 and 2 were completed in early 2024 and has unlocked enough capacity to allow for a staged upgrade. Through extensive plant assessment and onsite optimisation, a significant improvement in the activated sludge settling rate and nutrient removal was achieved. Stable biological phosphorus removal was also achieved with a high rate of removal (> 90%) compared to the long-term historical value of 30%.

Removal of phosphorus biologically was a key focus of the optimisation phase. The polyphosphate accumulating organisms (POA) responsible for enhanced phosphorus removal are denser than other microorganisms. Improving the

population of PAOs in the process was a key first step to enable the inDENSE™ hydrocyclone system to further improve capacity by gravimetric selection.

The inDENSE™ system was commissioned in early April 2024 and initial performance is encouraging.

The key message from this work is it is often possible to make existing treatment assets perform with improved capacity and quality if there is an investment in detailed monitoring and assessment. With this information we were able to relax in built design contingences, unlock capacity and reduce capital and operating costs. The extra capacity enabled KDC to defer a major upgrade and progressively upgrade the plant resulting in lower overall costs. This alternative upgrade approach would not have been possible if the "nameplate" capacity of the plant was taken as fact.

KEYWORDS

Optimisation, upgrade, wastewater treatment, hydro cyclones, nutrient removal

PRESENTER PROFILE

Craig White is a chemical engineer with 29 years' experience in wastewater treatment operations, investigation, commissioning, and design. Craig has designed many wastewater treatment plants from small facilities to large metropolitan plants. Craig has had a long term 20-year involvement in engineering education through the University of Newcastle.

INTRODUCTION

Kaipara District Council (KDC) operates the sewerage assets for the Mangawhai area which includes reticulation, a wastewater treatment plant (WWTP) and a transfer pipeline to the Lincoln Downs farm. The Lincoln Downs Farm is commonly referred to as Browns Farm.

The Lincoln Downs Farm is the only location where effluent from the WWTP can be directed to. Tertiary treated effluent from the WWTP is pumped to a 170 ML storage dam at Lincoln Downs Farm. Pumps draw effluent from the dam to 65.5 Ha of irrigate zones using spray irrigation.

The WWTP consists of screening, flow balancing, secondary treatment, effluent balancing, dual media pressure filters and a sodium hypochlorite disinfection system prior to storage in a final effluent storage tank. After the final effluent storage tank effluent is pumped via a 13 km rising main to Lincoln Downs Farm.

Waste biological sludge from the process is discharged periodically to a sludge balancing tank. It is then pumped, and polymer dosed prior to dewatering in a single belt filter press dewatering unit. Dewatered biosolids are collected and trucked off site.

A new balance tank system has been constructed in 2022 and recently commenced commissioning in April 2023. This allows periodic storage of sewage flows above the hydraulic capacity of the biological process. When capacity is available it is later pumped back to the treatment process for treatment.

Figure 1 shows an aerial photo of the site with key process units shown.

Figure 1 – Aerial Photo of the Treatment Plant Site

The secondary treatment process consists of two cyclic activated sludge system (CASS) reactors as shown in *Figure 2*. This is an intermittent activated sludge process. There are two rectangular reactors with an upfront hydraulically mixed selector, followed by an unaerated anaerobic zone, this zone is mixed periodically with intermittent coarse aeration. The two unaerated zones occupy approximately 22% of the reactor volume. The main reactor aeration zone is a unbaffled open rectangular reactor with the floor fully covered with diffusers. Aeration is run on a typical 4-hour cycle in dry weather of 2 hours aeration, 1 hour setting and 1 hour decant. At the end aeration zone there is a pivoting decanter which is used to decant effluent during the decant phase. Decanted effluent is passed to a decant balance storage tank.

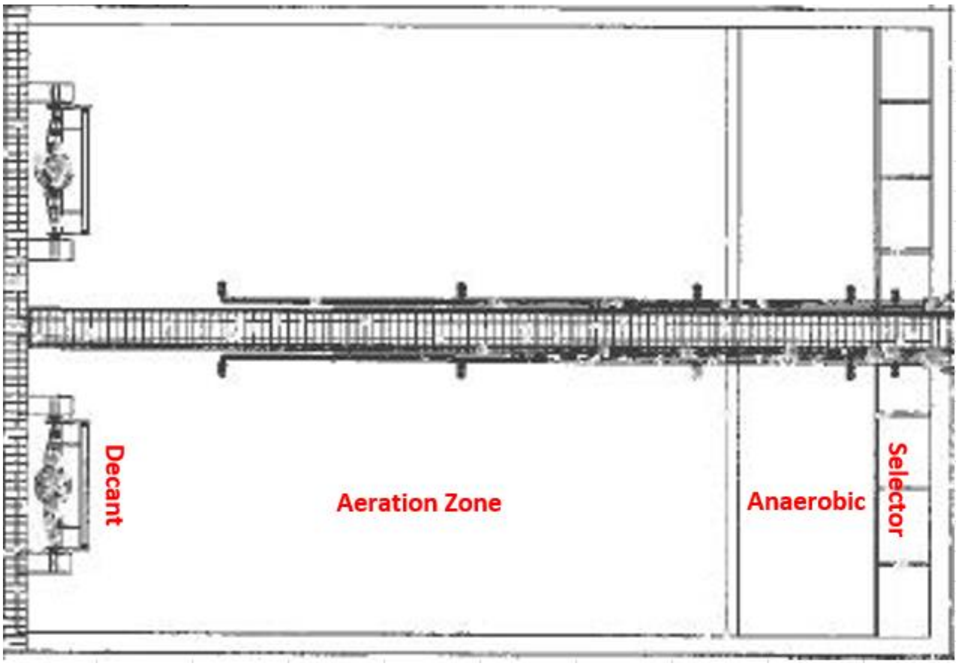

Figure 2 – Plan view of the CASS Reactors

The existing Mangawhai WWTP is experiencing high growth with a 340% increase in baseline load over 10 years as shown in *Figure 3*. Based on current projections the plant capacity is expected to be reached in 2024. In 2024 the base and holiday peak connected equivalent populations (EP) are 3,900 and 14,150 respectively. This population is projected to increase to an ultimate value of 7,750 base and 28,350 EP holiday peak by 2051. In 2051 the ultimate capacity of the system is predicted to be reached.

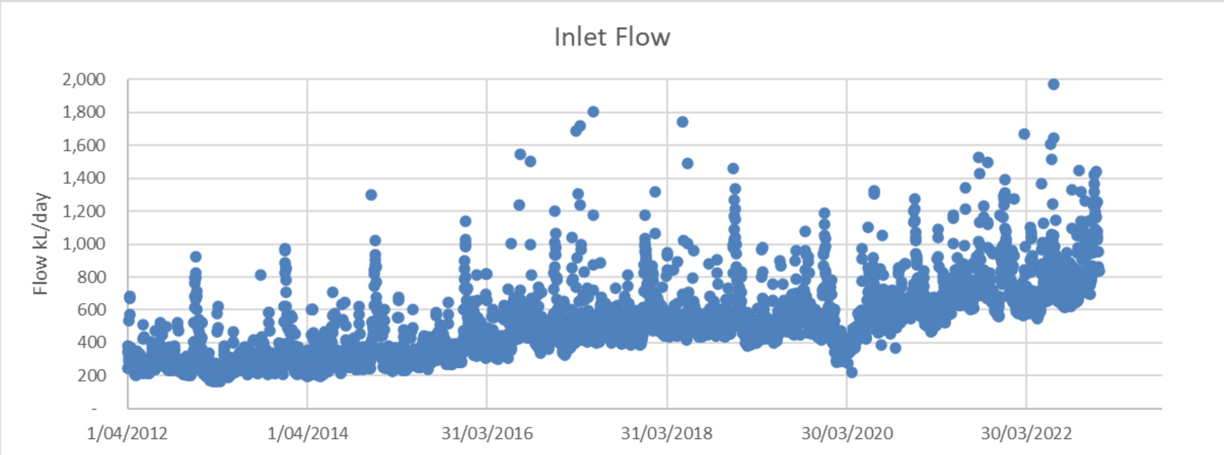

Figure 3 – Inlet Sewage Flow to Mangawhai CWWTP

Mangawhai is a tourist area and periodically receives high tourist loads which double the chemical oxygen demand (COD) and nitrogen load with a sharp peak (> 300% above normal loads) just after Christmas day as shown in *Figure 4* . The plant during tourist periods is near capacity and can struggle with the sudden load increase.

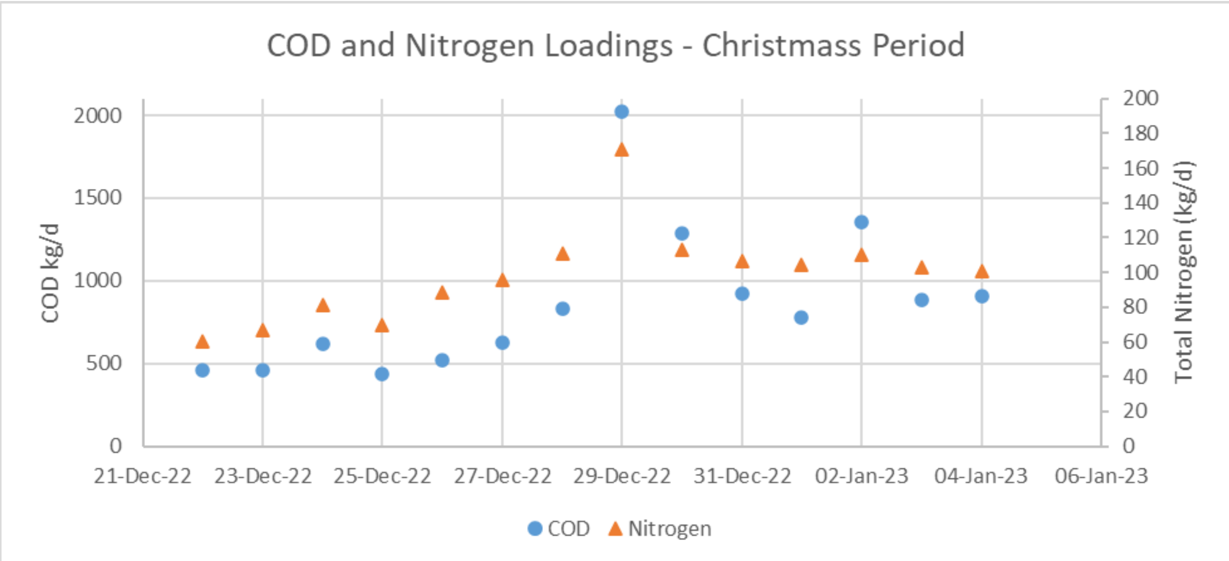

Figure 4 – COD and Nitrogen Load Increase over the Christmas Period

A capacity review of the plant undertaken by Beca Hunter H2O identified the plant will reach capacity in 2024. The irrigation and storage system would also reach capacity in 2026. Therefore, there is an urgent need to upgrade the plant.

UPGRADE PLANNING

As the existing plant is nearing capacity, KDC began to plan to upgrade the wastewater system. The initial identified approach was to:

- Seek an additional reuse location and potential disposal option which would involve seeking an additional discharge consent.
- Move promptly to augment the current WWTP to a membrane bioreactor (MBR) process.

As any reuse location will likely require production of a class A effluent quality for unrestricted use, an MBR process was chosen to provide this.

As the MBR process involved a significant change to the current plant the upgrade needed to target a high initial capacity to prevent a need to return to upgrade in a short period. In essence an upgrade to the ultimate capacity of 28,350 was required for the MBR option.

Beca Hunter H2O and SCO Consulting were requested to peer review the upgrade approach in 2022. On review it was identified the upgrade would need a major capital expenditure immediately and be required to meet the ultimate EP. However, given the time to design, procure and construct an upgrade (~3 years) it was clear the capacity would be exceeded before the upgrade occurred.

To find a way to both meet the urgent capacity needs and to assess if costs could be minimised a range of alternative options were considered. The approach adopted in the peer review was as follows:

- Engage the service of an expert construction industry cost estimator to assist with accurate costing of options.
- Undertake a detailed development of the MBR option and others that will meet the same effluent quality and growth requirements.
- Ensure the immediate need to upgrade the plant by 2024 can be achieved by at least one option.

The four options which can produce class A effluent were considered which included:

1. **MBR**. Converting the plant to MBR with UV and chlorination.
2. **Continuous conventional**. Use all the existing reactors and add secondary gravity clarifiers, tertiary membrane filtration, UV and chlorination.
3. **Progressive expansion the CASS system.** This involved converting the balance tank to a CASS with ultimately 4 CASS reactors for ultimate loads. Tertiary membrane filtration, UV and chlorination was required for Class A.
4. **Progressive expansion the CASS system with inDENSE™ hydro cyclones.** This option is similar to option 3 but required only 3 CASS reactors for the ultimate EP.

The preferred option was option 4. It was preferred as it:

- Resulted in a 32 % capital saving of an estimated $11M.
- Resulted in a 35% saving in operations cost over the MBR option.
- Capacity could be expanded in 3 stages which delayed capital expenditure.

- Ensured the immediate capacity issues would be addressed by 2024. No other option would achieve this.
- Reduced embodied carbon use. The option involved the reuse of most infrastructure on site and no need for new major concrete structures.

As well as the overall costs savings of this option a key benefit is the ability to stage capital as opposed to one large investment.

Option 4 was innovative in that it focused on using minimal capital to tackle the immediate capacity upgrade. This option used a three-stage approach which included:

1. **Plant optimisation** to "sweat the asset" to extract additional capacity. Process engineers from Beca Hunter H2O working closely with the Downer operations team to optimise the plant in early 2023.
2. **Install inDENSE^{TM} on the Current CASS reactors.** Modelling showed this would extend the capacity to 2028. This was completed in early 2024.
3. **Retrofit the existing balance tank to a CASS reactor.** This is planned by 2028. The same inDENSE^{TM} system procured in stage 2 will be used for this upgrade too. No further upgrades are planned to meet the ultimate capacity requirements.

The encouraging outcome of this project is the first two stages have now been completed for a low total cost of less than $1.2. This has provided an immediate capacity increase of 20%, improved quality, and delayed and reduced the required capital expenditure.

PLANT OPTIMISATION

Optimisation of the plant occurred in early 2023.

Prior to optimisation key operational setting were as follows:

- A high mixed liquor suspended solids (MLSS) above 4,000 mg/L was maintained in the CASS units routinely. At this MLSS the sludge retention time (SRT) was high at 28 days.
- High dissolved oxygen (DO) levels of 4 to 5 mg/L were held in the aeration phase of the CASS.
- The return activated sludge rate was making the anaerobic zone aerobic during the aeration phase.

The sludge settling was poor with a sludge volume index (SVI) on average at 250 ml/g. At times this was allowing sludge to be decanted at peak flows.

The effluent quality was within the resources consent to provide effluent for reuse. However, the total nitrogen and phosphorus effluent quality was elevated at ~ 13 mgN/L and 6 mgP/L median respectively. These values are elevated for the CASS design used.

The operational settings had been used for some time to maintain nitrification (i.e. ammonia removal) and ensure there was adequate biomass for tourist periods. However, for year-round operation a much lower SRT in the order of 15 to 20 days is only necessary to ensure nitrification. Lowering the SRT will lower the MLSS and improve sludge settling which will improve hydraulic capacity.

The key focus areas for the plant optimisation were as follows:

- Improve the sludge settling to increase hydraulic capacity.
- Grow phosphorus accumulating organisms (PAO) to achieve biological phosphorus removal.
- Improve nitrogen effluent quality.

The key changes made to optimise the plant included the following:

- MLSS was reduced to 3,000 mg/L which equated to a 20 day SRT.
- During the aeration phase the DO was reduced to an average of around 1.5 mg/L. A ramped DO profile was used to optimise denitrification (oxidised nitrogen removal) at the start of the cycle and maintain efficient nitrification (ammonia removal) towards the end of the cycle. At the start of the cycle a low DO (0.5 mg/L) was used to allow for denitrification it then gradually ramped up to 2 mg/L towards the end of the cycle.
- The return sludge rate was optimised to minimize oxygen and nitrate return to the anaerobic zone.

With these changes no significant improvement in SVI was noted, however the lower MLSS of 3,000 mg/L improved the settling velocity which improved plant capacity. These changes significantly improved the performance of the plant during the 2023/24 Christmas holiday period.

A key focus area for the optimisation was to ensure the plant was ready for the later inDENSE™ upgrade. PAO bacteria which removed phosphorus are denser than ordinary heterotrophic bacteria responsible for organics removal. When pumped through the inDENSE™ hydrocyclone these PAO denser bacteria will selectively be retained and returned to the CASS units. This will assist settling in the CASS reactors improving hydraulic capacity and biological phosphorus removal.

The improvement in both phosphorus and nitrogen achieved is presented in Figures 5 and 6.

The operational changes to DO and optimisation of the return sludge ensured the anaerobic zone remained anaerobic. This resulted in a significant improvement phosphorus removal with median levels of 6 mg/L reducing to a median of 0.8 mg/L. Microbiological analysis of the sludge after optimisation identified an abundance of PAOs in the activated sludge.

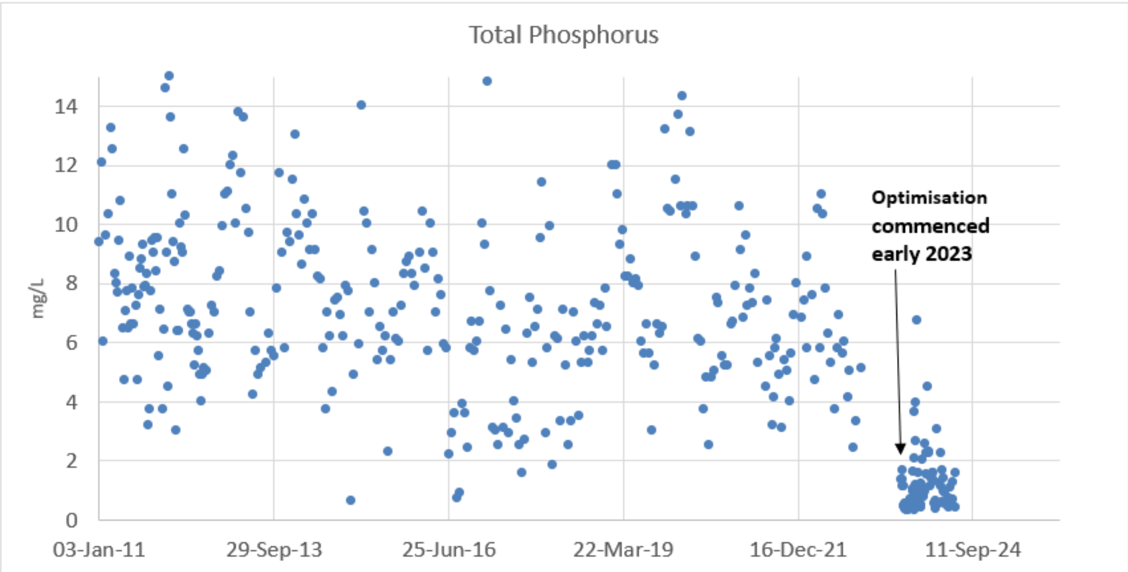

Figure 5 – Total Phosphorus Removal over Time

The reduction in DO levels and encouraging denitrification in the early phase of the aeration cycle also reduced the total nitrogen levels from a median of 13 to 6.5 mg/L.

Lowering the SRT and better utilising of oxidised nitrogen resulted in 15% savings in aeration power. Reducing the DO from 5 to 1.5 mg/L further improved the savings to 50% of the starting aeration power.

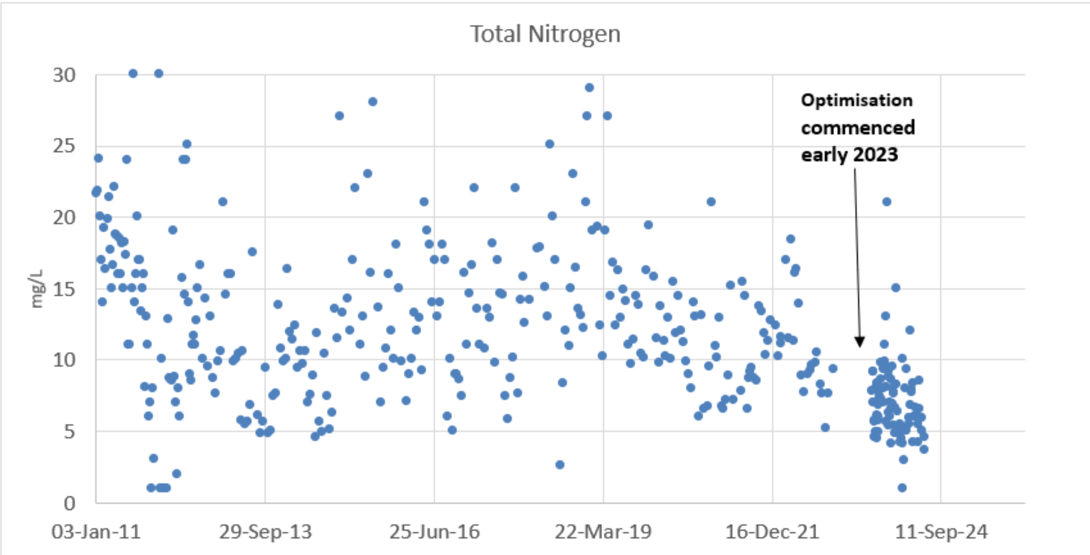

Figure 6 – Total Nitrogen Removal over Time

The improvement in effluent nutrient performance also reduced the impact on KDC’s effluent irrigation system.

HYDROCYCLONE UPGRADE

The upgrade of the inDENSE™ hydrocyclone has occurred and was commissioned in early 2024. A brief overview of current performance is presented below in Figure 9. It is proposed to prepare a paper later in 2024 to more fully document performance. Figure 7 shows a photo of the installation at Mangawhai.

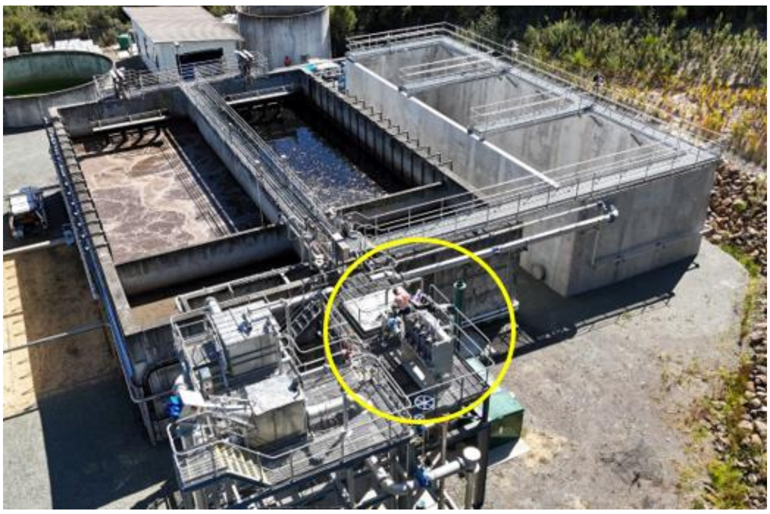

Figure 7 – Photos of the inDense™ Installation near the Inlet Works Structure at Mangawhai CWWTP

Figure 8 shows an overview of the hydrocyclone system installed.

The inDENSE™ system was installed in an existing elevated location near the sewage splitter which feeds both CASS reactors. Waste sludge from each CASS is pumped to the inDENSE™ skid for a short period of 5 to 10 minutes at the end of the CASS settle phase. The denser material (i.e. underflow) gravitates to the splitter and is returned to each CASS reactor. The lighter (less dense) material overflows to the current sludge balance tank where it is dewatered.

The process actively selects for dense sludge and returns it to the CASS reactors. The denser sludge has faster settling rates and this process has been proven in other plants to improve SVI and sludge settling velocity.

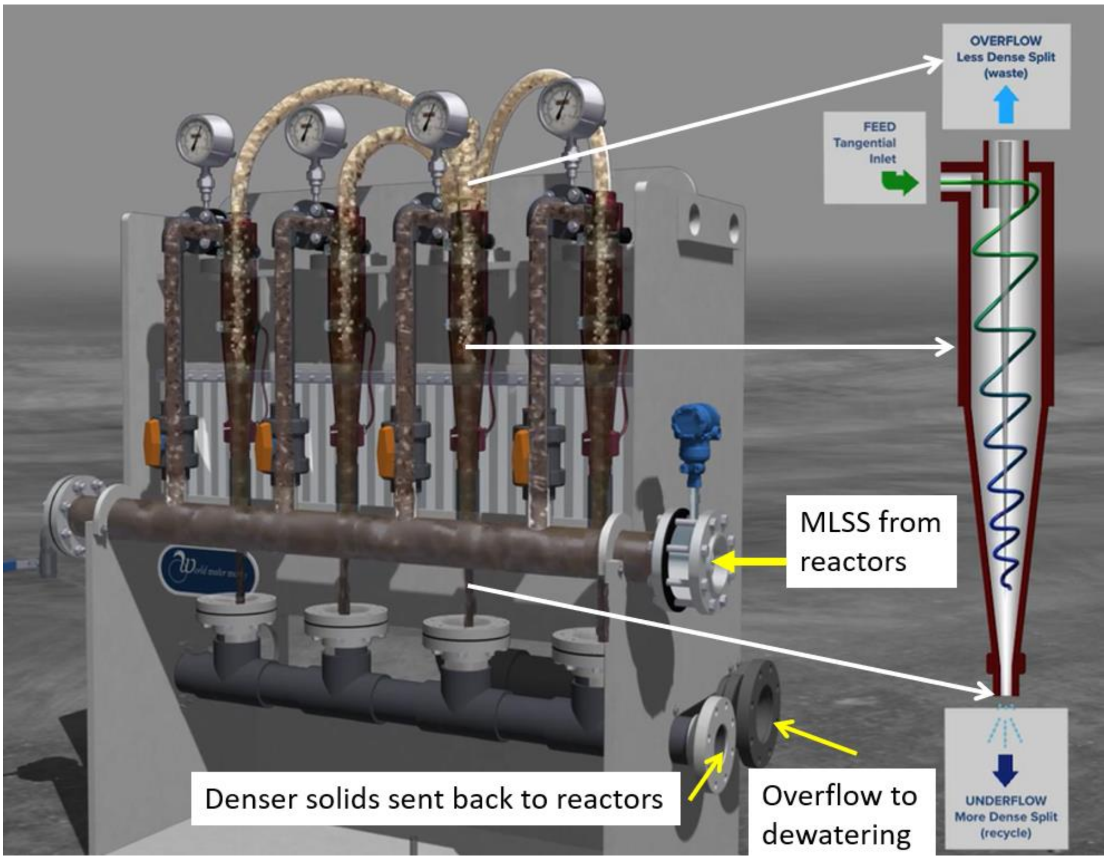

Figure 8 – Overview of the inDense™ Hydrocyclone System

Initial results after commissioning of the inDENSE™ system on 2 April 2024 are shown in Figure 9. The MLSS, SVI and Diluted SVI (DSVI) are shown. DSVI is a better measure of sludge settleability and is known to remove the bias associated with wall effects in the SVI 1 L measuring cylinder.

There is a significant trend down in both SVI and DSVI, with both halving after operation for 4 sludge retention times. A continuing trend down appears to be occurring as on late July 2024. The DSVI has reached the value required to achieve the hydraulic capacity improvement needed for loads to 2028. Continued monitoring will occur in future to quantify the capacity improvement achieved after the DSVI reaches a stable constant value.

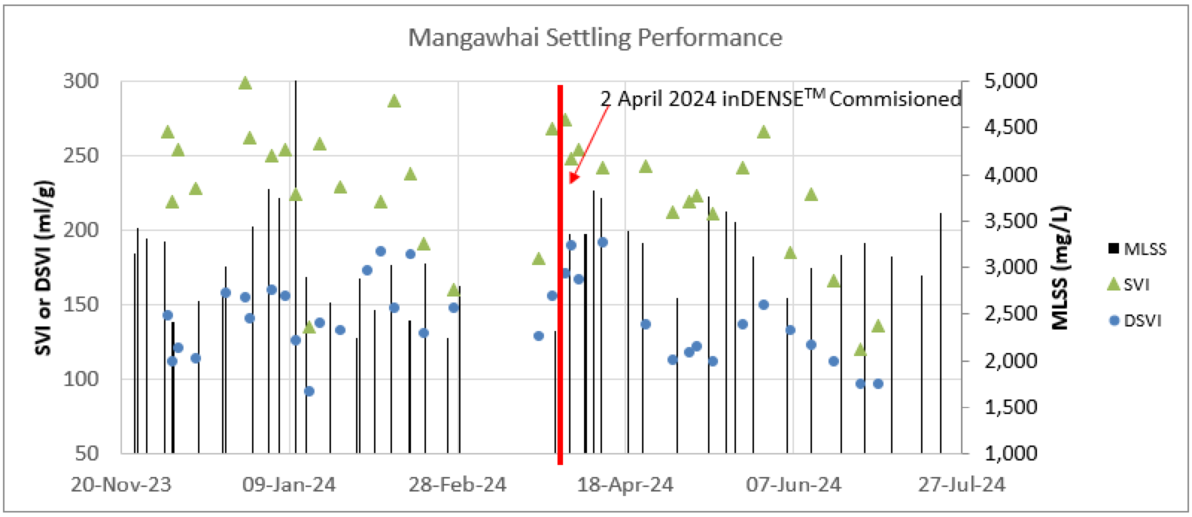

Figure 9 – CASS Activated Sludge Monitoring for MLSS, SVI and DSVI before and after inDENSE™ Commissioning.

The inDENSE™ upgrade was developed, designed and procured with the budget of $1.2 M with a 5 percent saving. It provided a rapid capacity increase of 20% within a 12-month period delaying considerable expenditure and ensure the next upgrade stage is well planned. Also, the same inDENSE™ system has reserve capacity and will not need to be expanded for the next stage 3 CASS upgrade.

This project was a good example of using practical optimisation approaches and simple low-cost innovative technology to tackle a difficult capacity issue due to high growth. This approach is readily transferable to future projects which have the same set of issues or need a low-cost upgrade to improve hydraulic capacity.

CONCLUSIONS

Kaipara District Council operate a CASS wastewater treatment plant and reuse system at Mangawhai. The Mangawhai district has historically experienced a high growth of 12 % per annum over the last 10 years. Due to the high growth the wastewater treatment plant is predicted to exceed its capacity by 2024. The plant particularly struggles during the peak Christmas tourist period where loads can reach over 3 times the non-tourist load for short periods.

Given the high growth there was a pressing need to upgrade the plant. As well an upgrade in capacity there was a need to improve the quality of the effluent to meet a Class A effluent quality standard to enable expansion of the effluent reuse system to accept more flow.

A previous strategy was developed which involved augmenting the plant to a membrane bioreactor (MBR) process to provide capacity and meet the Class A requirements. However, the upgrade represented a major reconfiguration of the current plant and was high cost. Given the high catchment growth it was not possible to provide the required capacity by 2024.

Beca Hunter H2O and SCO Consulting were engaged to review the proposed upgrade approach. Four options were considered which included the proposed MBR process. They were developed in detail to understand the costs and constraints of each option.

A preferred upgrade approach was selected which used an innovative approach of stretching the capacity of the current treatment plant and keeping the current CASS treatment approach. The proposed approach was to stage the project as follows:

1. Immediate optimisation of the current plant to improve capacity and effluent quality. The was completed in early 2023.
2. Retrofit the inDENSE™ hydrocyclone system to extend the capacity of the current plant until 2028. This upgrade occurred in early 2024.
3. Retrofit the current balance tank to a third CASS reactor and provide a Class A system and expanded effluent reuse.

The benefits of the above approach included:

- A significant 32 % capital saving of ~ $11M over the MBR option.
- A significant 35% saving in operations cost over the MBR option.
- Capacity could be expanded in 3 stages which delayed capital expenditure.
- Ensured the immediate capacity issues was addressed by 2024. No other option would achieve this.
- Reduced embodied carbon use. The option involved the reuse of most infrastructure on site and no need for new major concrete structures.

The project has achieved the first two stages under the budget allocated by Kaipara District Council. Key achievements to date with the project include:

- Establishment of biological phosphorus removal resulting in a 90% reduction in phosphorus discharged to the reuse.
- A 50% reduction in nitrogen discharged to the reuse.
- Treatment plant energy savings associated with optimisation of nutrient removal. Overall, a 50% saving in the diffused aeration power was made.
- An immediate capacity improvement after optimisation which enabled the plant to handle the 2023/24 Christmas period where it was predicted to fail.
- Installation and commissioning of the inDENSE™ hydrocyclone system in early 2024. Early results from the upgrade are encouraging with a 50% improvement in the sludge settling measures (SVI and DSVI). This indicates the plant is on track to meet the capacity required until 2028.

The project was an excellent example of challenging traditional upgrade approaches by optimising and reusing existing infrastructure. This has also led to significant cost savings for the Kaipara District Council and addressed a pressing capacity issue.

This approach of optimisation the current assets and retrofitting hydrocyclones is readily transferable to future projects which have the same set of issues or need a low-cost upgrade to improve hydraulic capacity.

ACKNOWLEDGEMENTS

This project was an excellent example of how many people came together from different organisations and delivered a significant capacity and quality upgrade at low cost in a short period of time. The author wishes to acknowledge KDC senior staff particularly Anin Nama who was supportive and provide the environment to achieve success. Clint Cantrell and Hanna Cantrell from SCO consulting services who project managed the planning phase and were instrumental in kicking off the project. Rory Bishop from Alta who undertook the cost estimating. The excellent operations staff of Aidan van Rysewyk and Terry Roche who worked closely with the Beca Hunter H2O process team to make the optimisation and inDENSE™ commissioning happen. World Water Works the supplier of inDENSE™. Vijay Reddy from Babbage Partners who managed the inDENSE™ upgrade. Liam Tamplin of Beca Hunter H2O for his technical management of all aspects of the project from inception to commissioning. Jacob Nielsen of Beca hunter H2O for his onsite commissioning assistance.