# Nitrite Shunt Pilot
# Plant Aeration Systems Project (Nitrite Shunt)



**Project Purpose:**

The purpose of the pilot project is to test at full-scale the nitrite shunt biological nutrient removal process to confirm process design criteria, impacts to sludge quality, and operational requirements. If the results are satisfactory and cost effective, the process would be considered for implementation across the entire plant.

**Project History and Status:**

The existing NSWWTP activated sludge facilities consist of two complexes, both operating an enhanced biological phosphorus removal process. These processes rely on anaerobic and aerobic zones to remove phosphorus, but do not provide significant total nitrogen removal. As part of the 2016 Liquid Processing Facilities Plan, changes to the existing processes were evaluated, including processes that could result in more effective nutrient removal while using less energy and potentially positioning the District for future total nitrogen regulations.

**Alternatives:**

The following biological nutrient removal processes were evaluated in detail in the 2016 Liquid Processing Facilities Plan:

<u>Alternative AS0–Maintain Current Activated Sludge Operation (Null Alternative)</u>

The Null Alternative assumes continued operation of existing modified UCT process with the existing aeration equipment, including blowers and diffusers.

The capacity status of the major components of the existing system is as follows:

- Blower capacity: The forecast future peak airflow for continued use of the modified UCT process under the Null Alternative is within the firm capacity of the existing east and west blower systems, assuming that diffuser air transfer efficiency is maintained at roughly current levels. However, turndown limitations limit the ability of the plant to save energy by minimizing airflow, especially on the west side of the plant.

- Diffuser capacity: The existing diffuser system capacity is sufficient, but the target minimum airflow per diffuser of 1 standard cubic foot per minute (scfm) to minimize diffuser fouling restricts blower turndown.
- Airflow Control valves: The existing process airflow control valves appear to be oversized for the projected airflow rates.
- RAS pumps: Based upon rated capacity, the existing RAS pumps have adequate firm capacity for normal load conditions and total capacity for future peak conditions. Per Madison Metropolitan Sewerage District (MMSD) staff, RAS flow testing is recommended to confirm that the installed RAS pumping capacity matches the rated capacity.

Much of the existing equipment associated with the activated sludge system is near or beyond its useful life, including ceramic diffusers, blowers, flow meters, and control valves. The age of this equipment leads to higher risk of failure as well as increased O&M costs for this alternative.

Alternative AS1–Existing Modified University of Cape Town (UCT) Process

This alternative consists of maintaining the existing modified UCT flow scheme described in Alternative AS0. System improvements under this alternative include the replacement of the existing aeration blowers, replacement of the existing ceramic disc diffusers with EPDM discs, and new aeration control valves and flow meters. This alternative assumes that the East Plant 1 two A/O trains are not modified. The replacement of old and outdated equipment in this alternative reduces O&M costs as well as the risk of equipment failure for equipment that is beyond its useful life.

As long as MMSD continues to operate using the modified UCT, the existing control strategy based on DO measurement can be continued. Alternatively, ammonia based aeration control (ABAC) could be added to provide more control and reduce aeration demands. The aeration savings from adding ammonia inputs to the aeration control system is highly dependent on how low the DO set points are in the DO-only control system. Given the low summer month $NH_3$-N permit limitations of 2 mg/L, ABAC would provide the greatest benefit during winter conditions when the monthly average $NH_3$-N limit is 4 mg/L.

Alternative AS2–UCT Process

This alternative modifies the existing plant flow scheme to the University of Cape Town (UCT process) to reduce TN discharges. This is accomplished by adding a mixed liquor recycle (MLR) flow from the last aerobic zone to the first anoxic zone, increasing the size of the existing anoxic zone, and adding a carbon source to reduce annual TN discharges below 10 mg N/L.

Simulations showed that the UCT system is carbon-limited and therefore methanol addition was included to reduce the nitrate concentration leaving the anoxic zone to 0.5 mg/L, which maintains current EBPR performance. This alternative assumes that the aerated grids in Pass 1 and the first aerated grid (33 percent) of Pass 2 are converted to anoxic zones, simplifying design and construction. In this alternative, the East Plant 1 A/O trains are also converted to the UCT flow scheme.

Plant modifications to incorporate the UCT process configuration include the following:

- New 18,000-gallon methanol storage and metering system to feed methanol to the East and West plant secondary influent channels.

- Convert Pass 1 and the first aerated grid in Pass 2 to anoxic zones by removing the associated aeration grid/system, adding two mixers to each zone, and adding a baffle wall to Pass 2
- Relocate the existing anoxic recycle pumps to the last anoxic zone and add piping to reconnect to existing recycle piping.
- Add MLR pumping to achieve 300 percent MLR flows at maximum month flows.
- Add three nitrate+nitrite ($NO_x$) sensors per plant to control methanol feed and MLR flows.
- Relocate the existing Pass 2 DO sensors to farther down the pass.

Aeration control upgrades include relocating the DO sensors is Pass 2 farther downstream at about the midpoint of the last third of the tank. A $NO_x$ sensor is included in the last anoxic zone prior to the aerated zones and is used to pace the methanol addition and MLR to the anoxic zone.

This alternative also includes a new post-aeration system with positive-displacement blowers and diffusers to increase effluent DO, especially during high flow conditions, without negatively impacting BNR performance. Biosolids production in this alternative remains essentially the same with UCT as additional solids generated from methanol addition are offset by the longer SRT, which reduces solids production.

Alternative AS3–UCT Process with Sidestream Deammonification

This alternative combines sidestream deammonification with Alternative AS2's UCT configuration in an effort to reduce UCT carbon and energy demands. Deammonification processes convert roughly 50 percent of the sidestream influent $NH_3$-N to $NO_2$-N using ammonia-oxidizing bacteria (AOB). The resulting $NO_2$-N and remaining $NH_3$-N are then converted to nitrogen gas via anammox bacteria without carbon. The key advantage of the deammonification process is that no carbon is needed to convert sidestream ammonia loadings to nitrogen gas.

This alternative assumes that a sidestream deammonification system treating the Ostara effluent is provided to maximize nitrogen removal and minimize methanol needs in the main stream process. Effluent quality for the UCT with sidestream deammonification alternative is similar to Alternative 2, UCT, decreasing the average effluent TN to 14 to 15 mg N/L without methanol addition. If effluent TN is reduced below 10 mg N/L, deammonification reduces average methanol doses by approximately 10 percent.

This alternative also includes a new post-aeration system with positive-displacement blowers and diffusers to increase effluent DO without negatively impacting BNR performance.

Alternative AS4–Main Stream Nitrite Shunt

This alternative modifies the existing operations to promote nitrite-shunt in which ammonia is oxidized to nitrite and then reduced to nitrogen gas. Key advantages of this alternative are no carbon addition is needed to meet TN reduction goals and reduced aeration demands. For this evaluation, the A/O flow scheme operated at controlled DO levels was selected. Nitrite shunt pilot testing at MMSD is being conducted to verify the kinetic parameters for detailed design.

Alternative AS4 can reduce average effluent TN discharges below 10 mg N/L without carbon addition and does not negatively impact EBPR performance. The existing aeration tank modifications to implement nitrite shunt consist of the following changes:

- Add ammonia/$NO_x$ sensor to Pass 3B and a DO sensor to Pass 1 for AVN control.
- Add a baffle wall between the second and third aeration grids in Pass 3.
- Add a new aeration control valve, meter, and DO sensor to control the aeration airflow in Zone 3C.
- Operationally, route RAS flow to the first anaerobic zone and stop pumping flow from the existing anoxic zone back to the first anaerobic zone.

This alternative also includes two additional 116’ secondary clarifiers in the West Plant and a polymer addition system for both the East and West plants to address poor sludge quality (SVI) resulting from low DO operation. A new post-aeration system with positive-displacement blowers and diffusers to increase effluent DO without negatively impacting BNR performance is also included in this alternative.

One of the major impacts of incorporating a nitrite shunt process is increased process control complexity. This includes ammonia versus nitrite/nitrate (AVN) control to operate at the optimal point on a TN reduction using ammonia and $NO_x$ sensors. These sensors determine whether aeration in Pass 1, 2 and first 2/3 of Pass 3 should be increased or decreased to maintain the ammonia and NOX concentration in Zone 3B at equal levels. The DO in the final aeration zone of Pass 3 must be tightly controlled by a new control valve, airflow meter, and DO sensor to reduce ammonia levels to comply with permit requirements.

<u>Alternative AS5–CEPT with Nitrite Shunt</u>

This alternative combines Alternative AS4 with CEPT to divert more carbon to the anaerobic digesters for increased biogas/energy production while reducing TN discharges without adding carbon (methanol). CEPT is implemented by adding $FeCl_3$ and polymer upstream of the primary clarifiers in locations such as the grit tank influent and effluent channels. The amount of ferric chloride ($FeCl_3$) added to promote additional carbon capture must be balanced with maintaining sufficient primary effluent $PO_4$-P to promote EBPR, which is needed for the existing Ostara struvite recovery process. This alternative assumes that 15 mg/L of $FeCl_3$ is added to reduce primary effluent $PO_4$-P by 1 mg/L or 35 percent of the Alternative AS4 primary effluent $PO_4$-P to enhance energy production and still maintain struvite recovery.

It is estimated that CEPT will result in an increase in annual biogas production by roughly 65 scfm or 15 percent. In the near term, use of this additional gas would be limited by the existing engine capacity and heat demands. If a new biogas combined heat and power (CHP) system is installed in the future, this additional gas could be used to increase the CHP output by approximately 260 kilowatts (kW). Compared to Alternative AS0 and AS1, this alternative would increase biosolids production by approximately 1.1 DT/d and reduce struvite production by approximately 0.9 T/d. Adding 15 mg/L of $FeCl_3$ results in increasing the effluent chloride levels by roughly 10 mg/L, but is not expected to impact ultraviolet (UV) system operation.

As in Alternative AS4, this alternative also includes two additional 116’ secondary clarifiers in the West Plant and a polymer addition system for both the East and West plants to offset the decrease in sludge quality resulting from low DO operation. In addition, Alternative AS5 includes a chemical building with $FeCl_3$ storage tank, $FeCl_3$ metering pumps, and polymer feed equipment. A new post-aeration system with positive-displacement blowers and diffusers to increase effluent DO without negatively impacting BNR performance is also included in this alternative.

**Key Risks and Issues**

The key social, environmental, and other nonmonetary considerations of each alternative are summarized in Table 1.

**Economic Analysis**

The present worth analysis completed for the Liquid Processing Facilities Plan is presented in Table 2.

**Project Recommendation**

If bench-scale testing is successful, full-scale demonstration testing of the nitrite shunt process (Alternative AS4) is recommended to further confirm process design criteria, impacts to sludge quality, and operational requirements. The full-scale demonstration test will require one plant to be operated as a nitrite shunt only plant. Converting the existing ceramic diffusers to membrane disc diffusers is required to reduce aeration airflow to the basins and provisions to independently control Zone 3C aeration is needed, or needs to be evaluated in further detail to ensure that combined discharges will meet the plant's WPDES permit. The components of AS4 that are required to complete the nitrite shunt pilot study are presented below in the Opinion of Probable Cost in Table 3. The primary costs to implement the nitrite shunt process across the entire plant are shown in Table 4.

**Table 3 – Opinion of Probable Cost for Nitrite Shunt Pilot**
**2019$**

| Component | Opinion of Probable Cost |
|---|---|
| Nitrite Shunt Pilot Study | |
| Membrane Strip Diffusers | $1,061,000 |
| Polymer Feed System | $637,000 |
| AVN Instrumentation | $658,000 |
| Pilot Study Operational Assistance | $42,000 |
| **Total** | **$2,398,000** |

**Table 4 – Opinion of Probable Cost for Plant Aeration Systems Project (Nitrite Shunt) 2019$**

| Component | Opinion of Probable Cost |
|---|---|
| Replace diffusers | $1,804,000 |
| Control valves and flow meters | $371,000 |
| RAS Chlorination/Polymer feed system | $424,000 |
| Two 116-ft circular secondary clarifiers | $8,169,000 |
| AVN instrumentation and nitrate sensors | $1,591,000 |
| Post-aeration blower and diffusers | $647,000 |
| Subtotal | $13,006,000 |
| Contingency and professional services | $5,899,000 |
| **Grand Total** | **$18,905,000** |

**Table 1 - BNR Alternative Nonmonetary Considerations Summary**

| Alternative | Benefits | Limitations |
|---|---|---|
| ASO: Null alternative | ▪ Plant staff familiarity<br>▪ Performance well proven at NSWWTP<br>▪ Opportunity to wait for emerging technologies to mature | ▪ Does not improve energy efficiency<br>▪ Does not address risks related to aging equipment |
| AS1: Existing Modified UCT | ▪ Same as Null alternative<br>▪ Blower turndown with membrane diffusers<br>▪ New equipment | ▪ Uncertainty related to site-specific fouling characteristics of new diffuser technologies |
| AS2: UCT | ▪ Plant staff are familiar with this configuration<br>▪ Can be designed for flexible operations in nitrite shunt mode | ▪ IMLR and supplemental carbon add some complexity for operations |
| AS3: UCT with Sidestream Deammonification | ▪ Can be designed for flexible operations in nitrite shunt mode<br>▪ Reduces supplemental carbon requirements by 10% compared to UCT alternative<br>▪ Takes advantage of shortcut denitrification process to reduce carbon addition<br>▪ Deammonification is a simple robust process that is automated<br>▪ Potential to bioaugment mainstream with Anammox biomass | ▪ Deammonification systems are patented<br>▪ Additional process to operate increases complexity<br>▪ Heating required in sidestream reactor to maintain deammonification activity<br>▪ Deammonification installations downstream of Ostara process not proven |
| AS4: Nitrite Shunt | ▪ Emerging technology which could set precedence for other utilities to follow<br>▪ Can be designed for flexible operations in modified UCT mode | ▪ Limited installations<br>▪ May require chemical addition for low effluent TP<br>▪ More complex to operate than UCT alternatives—additional nitrogen sensors and accurate aeration control required<br>▪ Reduced SVI impact on secondary clarifiers and anticipated polymer feed and RAS chlorination to control settling. |
| AS5: CEPT with Nitrite Shunt | ▪ Same as nitrite shunt | ▪ Same as nitrite shunt plus the following:<br>▪ Additional aeration savings not predicted to be significant<br>▪ CEPT operations add more complexity |

**Table 2 – Economic Analysis (*note 2018$, as promulgated in original business case*)**

| | **Alternative AS0** | **Alternative AS1** | **Alternative AS2** | **Alternative AS3** | **Alternative AS4** | **Alternative AS5** |
|---|---|---|---|---|---|---|
| Total Opinion of Capital Cost | | | | | | |
| BNR Improvements | $0 | $4,100,000 | $16,800,000 | $22,700,000 | $18,500,000 | $19,400,000 |
| BNR Improvements and New Blowers | $0 | $8,600,000 | $21,300,000 | $26,200,000 | $22,900,000 | $23,800,000 |
| Annual O&M | | | | | | |
| Existing Blowers | $960,000 | $700,000 | $2,700,000 | $2,500,000 | $610,000 | $1,600,000 |
| New Blowers | $590,000 | $470,000 | $2,500,000 | $2,200,000 | $390,000 | $1,300,000 |
| | | | | | | |
| Present Worth | | | | | | |
| O&M | | | | | | |
| Existing Blowers | $16,500,000 | $13,000,000 | $48,300,000 | $45,700,000 | $12,300,000 | $30,200,000 |
| New Blowers | N/A | $8,000,000 | $43,500,000 | $41,500,000 | $7,400,000 | $25,300,000 |
| Increased biogas production and reduced natural gas | $0 | ($100,000) | ($50,000) | ($100,0000) | ($80,000) | ($300,000) |
| | | | | | | |
| **Total Opinion of Present Worth** | | | | | | |
| **Existing blowers** | **$16,500,000** | **$17,000,000** | **$65,100,000** | **$67,300,000** | **$29,900,000** | **$46,700,000** |
| **New blowers** | **N/A** | **$16,500,000** | **$64,800,000** | **$67,600,000** | **$29,500,000** | **$46,200,000** |
| **Avoided clarifier tank addition** [a] | **N/A** | **N/A** | **N/A** | **N/A** | **$17,800,000** | **$34,500,000** |

a. *Net present worth estimate for scenario in which clarifier stress testing finds that clarifier addition is not required prior to the end of the planning period in 2040. This estimate is based on the new blower scenario, but excludes $7,700,000 in clarifier capital costs and $3,900,000 in related contingency and technical services from the base case estimate.*

**Project Schedule:**

**Nitrite Shunt Pilot**

| | Start Date | Completion Date |
|---|---|---|
| Planning & bench scale testing | 2016 | 2020 |
| Design | 2021 | 2021 |
| Construction | 2022 | 2022 |

**Plant Aeration Systems Projects (Nitrite Shunt)**

| | Start Date | Completion Date |
|---|---|---|
| Planning | 2016 | 2023 |
| Design | 2024 | 2024 |
| Construction | 2025 | 2026 |

**Financial Summary (2019$):**

**Nitrite Shunt Pilot**

| **Total Project Cost** | |
|---|---|
| District Staff & Engineering | $400,000 |
| Contractor | $1,998,000 |
| Total | $2,398,000 |

**Plant Aeration Systems Projects (Nitrite Shunt)**

| **Total Project Cost** | |
|---|---|
| District Staff & Engineering | $3,158,000 |
| Contractor | $15,790,000 |
| Total | $18,948,000 |

**Fiscal Allocation (2019$):**

**Nitrite Shunt Pilot**

| | **2021** | **2022** |
|---|---|---|
| Engineering | $202,000 | $198,000 |
| Construction | $0 | $1,998,000 |
| Total | $202,000 | $2,196,000 |

**Plant Aeration Systems Projects (Nitrite Shunt)**

| | 2024 | 2025 | 2026 |
|---|---|---|---|
| Engineering | $1,071,000 | $1,043,000 | $1,043,000 |
| Construction | $0 | $7,895,000 | $7,895,000 |
| Total | $1,071,000 | $8,938,000 | $8,938,000 |