# Wastewater Reclamation for Potable Reuse

# Symposium & Water-Tech Summit Topics

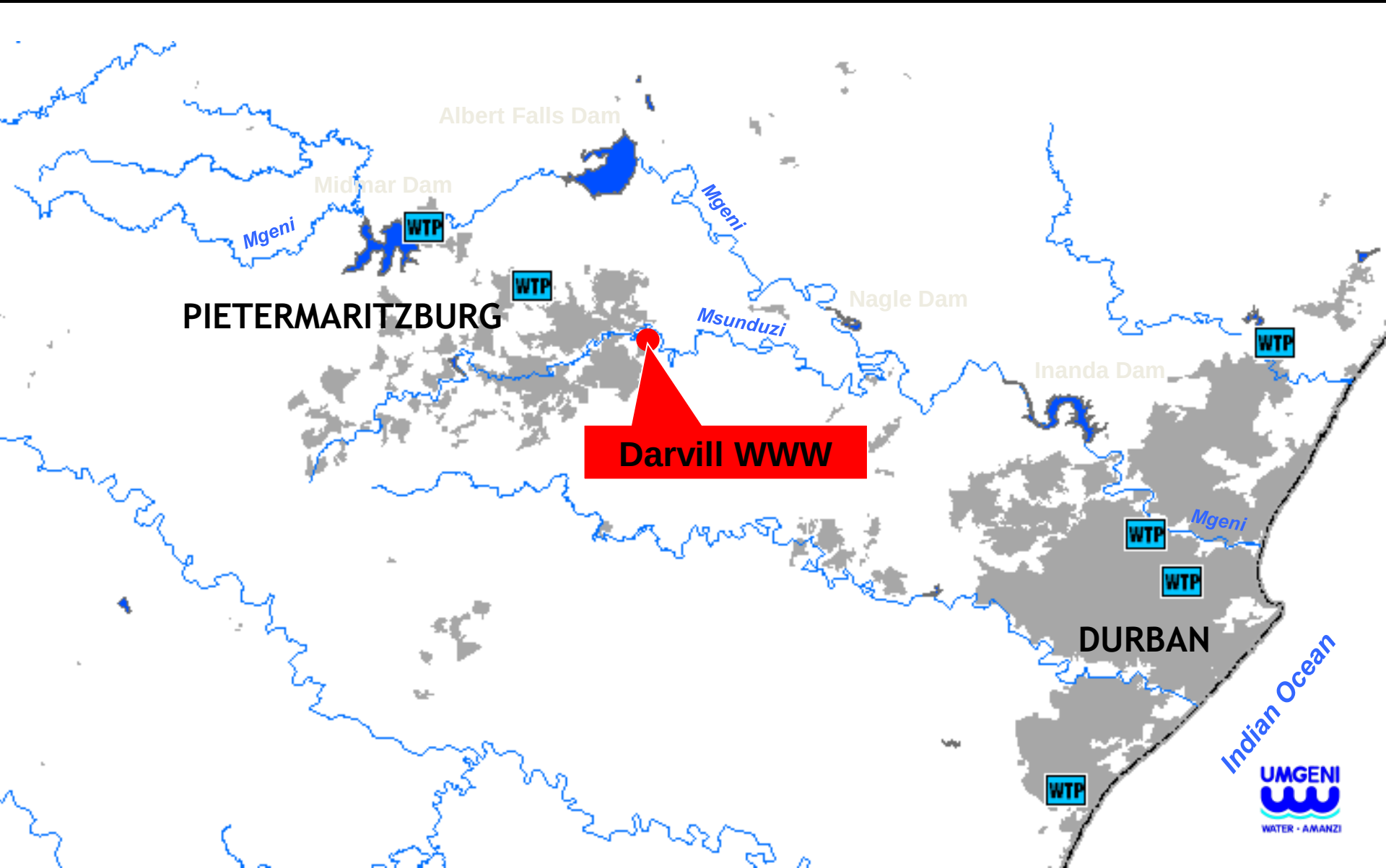
Accelerate the adoption of advanced technologies by both municipal and industrial water users

# Project Aim & Objective

The aim of this project was to pave the way for technology that will enable South African water suppliers to produce consistent, acceptable drinking water quality through reclamation.

The main objective of this research project was to evaluate the performance of a range of configurations of advanced water treatment technologies, with a membrane bioreactor (MBR) as pre-treatment step to produce potable water.

# LOCALITY MAP



# Phased Approach

**Phase 1**

Evaluate performance of MBR technologies (as pre-treatment) for tertiary wastewater treatment

- Compare MBR performance and operability
- Compare MBR performance against conventional secondary treatment i.e. Darvill Final Effluent

**Phase 2**

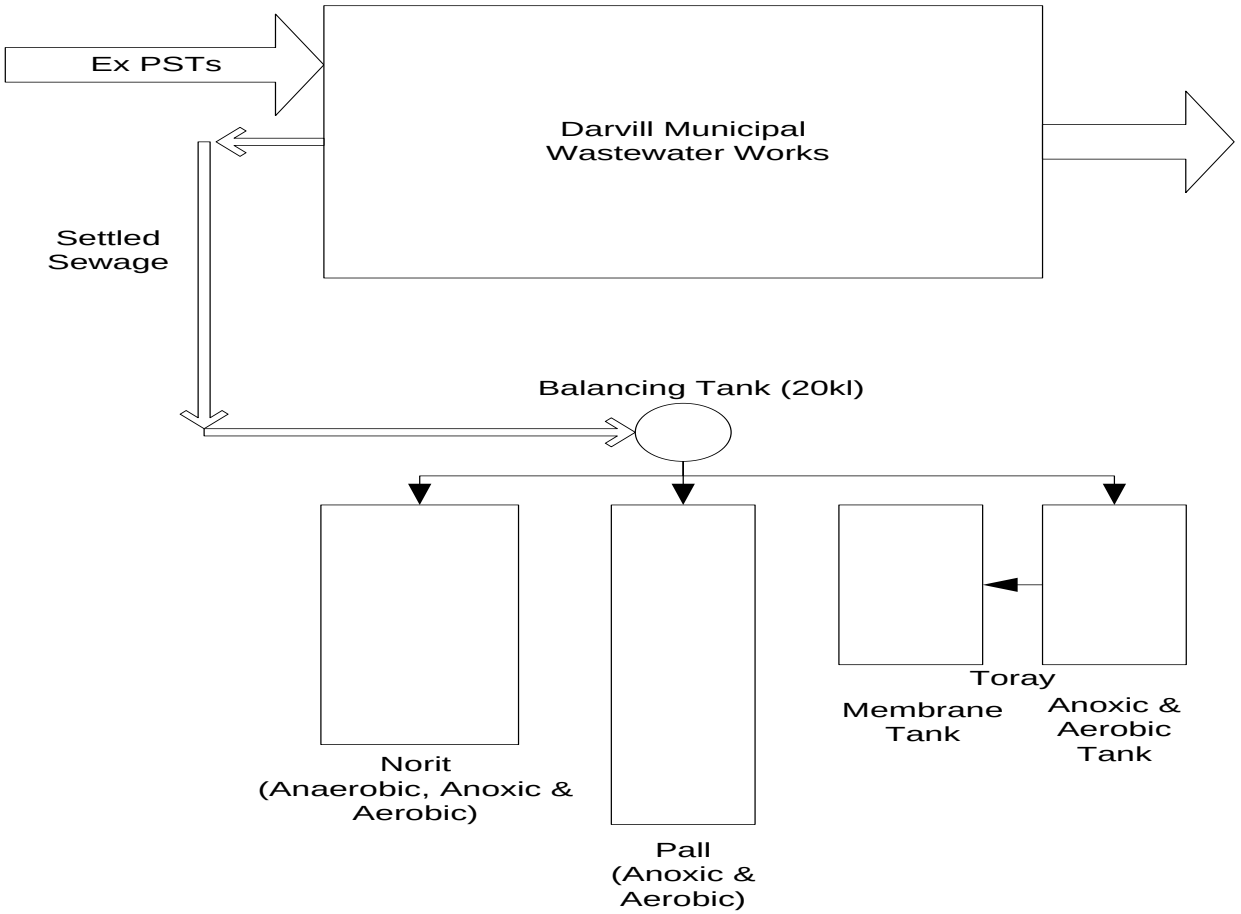
Laboratory evaluation of advanced water treatment processes to treat wastewater to potable standards

# MBR

- Table 1: MBR Technologies and Configurations

| | | Process Configuration | |
|---|---|---|---|
| | | **Submerged** | **Sidestream** |
| **Membrane Configuration** | Flat Sheet (FS) | Brightwater<br>**Toray**<br>Kubota | Novasep-Orelis |
| | Hollow Fibre (HF) | Asahi-Kasei<br>Koch Puron<br>Mitsubishi Rayon<br>**Pall Corporation**<br>Siemens Memcor<br>Zenon | |
| | Multitube (MT) | Millennimpore | **Norit-Xflow** |

# Site Plan




**Plan Layout of MBR Demonstration Plants**

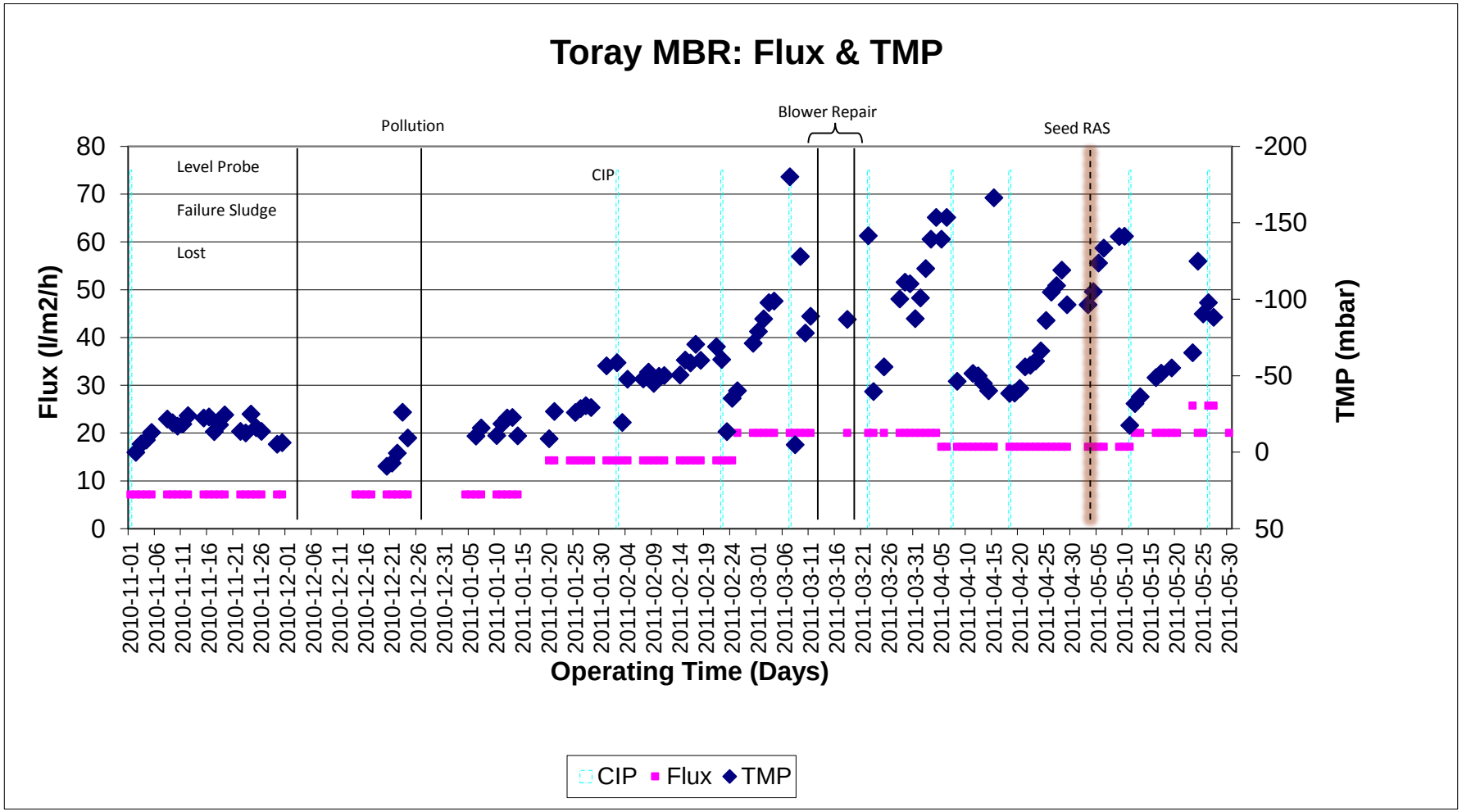
# Darvill MBR Pilot Plants

# MBR WQ Objectives

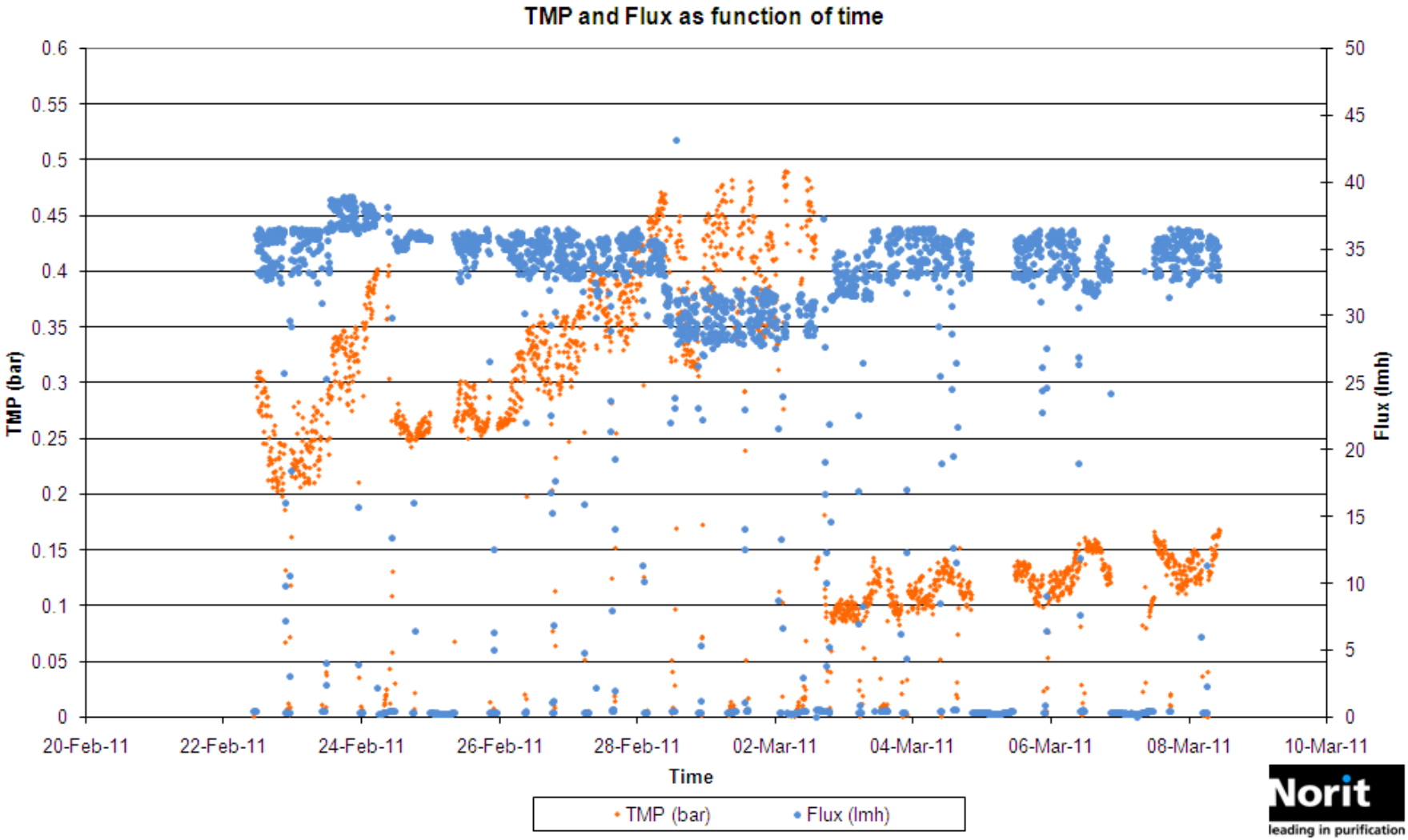
**Table 9: Target Permeate Water Quality Objectives for MBR Demonstration Plants**

| Parameter | Target (mg/l) |
|---|---|
| $BOD_5$ | 2 |
| COD | <20 |
| TSS | <1 |
| TOC | 7 |
| Turbidity (NTU) | <1 |
| O&G | 2 |
| Ammonia ($NH_3$-N) | <1 |
| Nitrate ($NO_3$) as N | <5 |
| Nitrite ($NO_2$) as N | <2 |
| Total Nitrogen (TKN+$NO_3$+$NO_2$) | <10 |
| Ortho Phosphate (SRP ) | 1 |
| $UV_{254}$ (abs/$cm^{-1}$ ) | 0.065 |
| Total Coliforms (CFU/100ml) | <10 |
| Ecoli (CFU/100ml) | 0 |
| Coliphage (PFU/100ml) | 0 |

# Membrane Performance



# Norit Membrane Performance




Norit
leading in purification

# Process Challenges

## Pollution incidences

- Industrial effluent entering works → contaminate influent to pilot plants
- Results in foaming within bioreactor
- 4 major incidences in 6 months
- Rapid increase in Trans Membrane Pressure (Norit: 0.3 bar – 0.5bar)
- Destroys activated sludge down to +/- 300mg/L from +/- 5000mg/L
- Permeate quality compromised
- Bioreactor draining and re-seeding required following these events
- Consequences → Operational downtime

# Mechanical Challenges

Equipment breakdowns

- Major breakdowns
  - → Compressor (Norit)
  - → Membrane Tank Blower (Toray)
  - → Screen (Toray)
- Minor breakdowns
  - → Pipe bursts, pumps & valves
  - → Level sensors/float switches - random failing leads to sludge loss in tanks or over pumping and spillage

# MBRs v Darvill

| Parameter | Units | Darvill Final Effluent | Toray MBR Permeate | Norit MBR Permeate |
|---|---|---|---|---|
| | | Median | | |
| Conductivity | mS/m | 77 | 64 | 69 |
| SS | mg/l | 17 | <4 | <4 |
| COD | mg/l | 41 | <20 | <20 |
| E.Coli | CFU/100 ml | 140 | 1 | 0 |
| Ammonia | mg/l | 13 | 0.5 | 0.5 |
| Nitrite | mg/l | 0.5 | 0.5 | 0.5 |
| Nitrate | mg/l | 0.5 | 6.1 | 0.5 |
| O&G | mg/l | 1.2 | 1.2 | 1.2 |
| SRP | mg/l | 0.3 | 1.3 | 0.1 |

# Performance of MBRs

**Permeate Water Quality**

- The MBRs performed well in terms of solids removal with Turbidity's <0.5 NTU being achieved.
- The plants performed well in terms of pathogen removal achieving log removals of 6,3 & 5 for *E.Coli*, Coliphages and Total Coliforms.
- The biological processes worked well with COD <20 mg/l being achieved.
- Nitrification worked well with median $NH_3$ values less than the target of 1 mg/l.
- Denitrification worked well with median $NO_3$ values less than the target of 5 mg/l for Norit and < 7 mg/l for Toray.
- MBRs generally outperform Darvill conventional secondary treatment for same period.

# CECs (EDC)

- Sample Points
  - Henley Dam (control sample) – Upstream
  - Msunduzi River above Darvill WWW
  - Msunduzi River below Darvill WWW
  - Darvill Raw influent
  - Darvill WWW effluent
  - Toray MBR Pilot Plant Permeate
  - Norit MBR Pilot Plant Permeate

# CEC Results

**Darvill WWW and MBR Pilot Plant EDC Results**

| | | March 2010 | | October 2010 | | February 2011 | | June 2011 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pg/ml | Estrone | 17B-Estradiol | Estrone | 17B-Estradiol | Estrone | 17B-Estradiol | Estrone | 17B-Estradiol | Estriol | EE2 | Testosterone | Progesterone |
| No | ID | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean |
| 1 | Henley Dam | 1 | 0 | | | | | | | | | | |
| 2 | Duzi u/s | 2 | 1 | 7 | 12 | 3 | 3 | 1 | 2 | 0 | 0 | 0 | 5 |
| 3 | Duzi d/s | 2 | 2 | 2 | 4 | 5 | 5 | 2 | 2 | 0 | 1 | 0 | 3 |
| 4 | Darvill Raw | 13 | 20 | 30 | 33 | 39 | 57 | 47 | 93 | 3 | 19 | 334 | 119 |
| 5 | PC Snap | | | 35 | 34 | | | 40 | 71 | 2 | 17 | 412 | 201 |
| 6 | Pilot Influent | | | 35 | 33 | | | 26 | 78 | 1 | 20 | 351 | 56 |
| 7 | SSTs | | | 8 | 7 | | | 4 | 2 | 0 | 2 | 0 | 6 |
| 8 | Darvill Effluent | 3 | 5 | 11 | 9 | 13 | 22 | 5 | 4 | 0 | 2 | 0 | 6 |
| 9 | Toray Pilot Effluent | | | 8 | 9 | 34 | 7 | 4 | 2 | 0 | 1 | 0 | 3 |
| 10 | Norit Pilot Effluent | | | | | | | 6 | 4 | 0 | 1 | 0 | 5 |

# Summary

- Phase 1
  - MBR  product water quality is excellent and pathogen free
  - Outperforms conventional secondary treatment in this scenario and this is in-line with what is reported in the literature.
  - Ideal for as pre-treatment technology for reclamation

# Phased Approach

**Phase 1**

Evaluate performance of MBR technologies (as pre-treatment) for tertiary wastewater treatment

- Compare MBR performance and operability
- Compare MBR performance against conventional secondary treatment i.e. Darvill Final Effluent

**Phase 2**

Laboratory evaluation of advanced water treatment processes to treat wastewater to potable standards

# Phase 2: Laboratory Scale Testing

## Advanced Water Treatment Processes

1. **Wastewater → MBR → $O_3$/GAC → NF → UV/peroxide**
2. **Wastewater → MBR → RO → UV/peroxide**
3. Wastewater → MBR → NF → UV/peroxide
4. Wastewater → MBR → NF → $O_3$/GAC → UV/peroxide

# Multiple Barriers

| Water Quality Parameter | Treatment Barrier | |
|---|---|---|
| | Process 1<br><br>Membrane | Process 2<br><br>Ozone /GAC |
| Suspended Solids | MBR, RO | MBR, GAC, NF |
| BOD / COD | MBR, RO | MBR, GAC, NF |
| Nutrients (N,P) | MBR, RO* | MBR, NF* |
| Microbiological | MBR, RO, UV | MBR, $O_3$, NF, UV |
| Metals | MBR, RO | MBR, NF |
| Micro-organics | MBR, RO, UV | MBR, $O_3$, GAC, NF, UV |

# Water Quality Objectives

**Summarized Treated Water Quality Objectives**

| Parameter | Specified/Design |
|---|---|
| SS Removal (NTU) | < 0.5 |
| Ammonia (mg/l) | < 1 |
| Total Nitrogen (mg/l) | < 10 |
| TOC (mg/l) | < 1 |
| $UV_{254}$ ($cm^{-1}$) | 0.065 |
| Total Coliforms (CFU/100ml) | ND |
| Faecal Coliforms (CFU/100ml) | ND |
| Coliphages -Somatic (PFU/100ml) | ND |
| Pathogens Removal (%) | 5-log (99.999%) |

# Membrane Specifications

| Membrane | | Supplier | Type | Salt Rejection (NaCl), % |
|---|---|---|---|---|
| NF 90 | (NF 1) | Dow | Nanofiltration | 97 |
| ESNA | (NF 2) | Hydranautics | Nanofiltration | 91 |
| Nano sw | (NF 3) | Hydranautics | Nanofiltration | 91 |
| UTC70B | (RO 1) | Toray | Reverse Osmosis | 97.2 |
| UTC70UB | (RO 2) | Toray | Reverse Osmosis | 95 |
| LFC 3 LD | (RO 3) | Hydranautics | Reverse Osmosis | 99.7 |

# MBR-$O_3$/GAC-NF Spiral Wound Trials

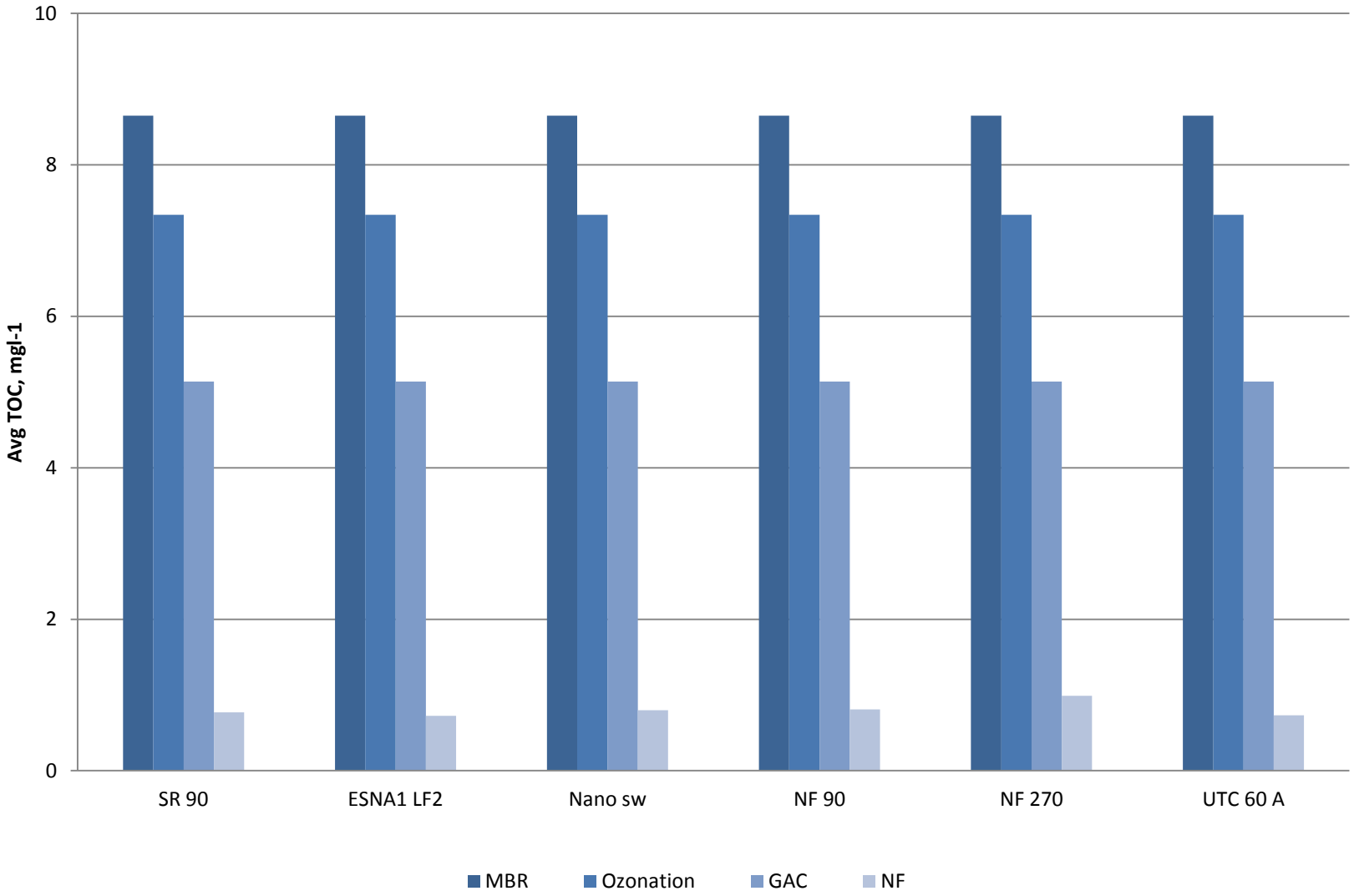
# Ozone / GAC Permeate Water Quality

| | | MBR Out | | | | O3 Out | | | | GAC Out | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Units | Mean | Median | STD | 95% | Mean | Median | STD | 95% | Mean | Median | STD | 95% |
| Alkalinity | mE/L | 145 | 141 | 34 | 196 | 146 | 136 | 43 | 210 | 129 | 135 | 47 | 189 |
| COD | mg/l | 20 | 20 | 0 | 20 | 20 | 20 | 0 | 20 | 20 | 20 | 0 | 20 |
| Coliforms | CFU/100ml | 38 | 14 | 49 | 135 | 10 | 0 | 15 | 33 | 57 | 3 | 168 | 284 |
| Coliphages | PFU/100ml | 2 | 0 | 4 | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 8 | 4 |
| Conductivity | mS/m | 80 | 82 | 9 | 93 | 80 | 80 | 11 | 91 | 79 | 79 | 10 | 86 |
| E. coli | CFU/100ml | 2 | 1 | 4 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NH3 | mg/l | 2.7 | 0.5 | 5.0 | 14.5 | 4.5 | 0.9 | 6.5 | 17.4 | 3.0 | 0.5 | 4.8 | 13.8 |
| NO3 | mg/l | 6 | 6 | 4 | 12 | 5 | 5 | 4 | 11 | 6 | 6 | 3 | 11 |
| SRP | mg/l | 0.5 | 0.2 | 0.6 | 1.9 | 1 | 0 | 1 | 2 | 1 | 0 | 1 | 2 |
| TP | mg/l | 0.8 | 0.5 | 0.5 | 1.6 | | | | | 0.7 | 0.5 | 0.4 | 1.3 |
| TOC | mg/l | 6.2 | 6.3 | 1.3 | 7.4 | 6.4 | 6.4 | 1.4 | 8.6 | 4.2 | 4.2 | 1.1 | 5.4 |
| Turbidity | mg/l | 0.4 | 0.4 | 0.2 | 0.8 | 0.3 | 0.3 | 0.2 | 0.9 | 0.3 | 0.3 | 0.1 | 0.5 |
| pH | | 7.5 | 7.5 | 0.1 | 7.7 | 7.8 | 7.7 | 0.5 | 9.2 | 7.6 | 7.6 | 0.2 | 8.1 |

# MBR - O3/GAC - NF Permeate Water Quality

| | | NF1 Permeate | | | | NF2 Permeate | | | | NF3 Permeate | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Units | Mean | Median | STD | 95% | Mean | Median | STD | 95% | Mean | Median | STD | 95% |
| Alkalinity | mE/L | 47 | 33 | 49 | 108 | 15 | 15 | 2 | 17 | 35 | 32 | 8 | 43 |
| Coliforms | CFU/100ml | 231 | 28 | 354 | 1001 | 16 | 15 | 12 | 29 | 17 | 16 | 14 | 31 |
| Coliphages | PFU/100ml | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EC | mS/m | 30 | 29 | 7 | 42 | 7 | 6 | 3 | 11 | 25 | 22 | 7 | 34 |
| E. coli | CFU/100ml | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NH3 | mg/l | 1.2 | 0.5 | 1.6 | 5.4 | 1.1 | 1.0 | 0.7 | 1.8 | 2.1 | 1.7 | 1.9 | 4.1 |
| NO3 | mg/l | 6.2 | 6.3 | 3.2 | 11.7 | 1.2 | 1.1 | 0.8 | 2.3 | 5.2 | 5.4 | 2.8 | 8.6 |
| SRP | mg P/l | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 |
| TP | mg P/l | 0.5 | 0.5 | 0.0 | 0.5 | 0.5 | 0.5 | 0.0 | 0.5 | 0.5 | 0.5 | 0.0 | 0.5 |
| TOC | mg/l | 0.8 | 0.7 | 0.3 | 1.3 | 0.7 | 0.7 | 0.0 | 0.7 | 1.4 | 0.7 | 1.5 | 3.4 |
| Turbidity | mg/l | 0.24 | 0.22 | 0.14 | 0.39 | 0.19 | 0.15 | 0.11 | 0.32 | 0.2 | 0.3 | 0.1 | 0.3 |
| pH | | 8.0 | 7.9 | 0.4 | 8.5 | 7.8 | 7.9 | 0.4 | 8.2 | 7.8 | 8.0 | 0.5 | 8.2 |

# MBR - O3/GAC – NF 1 - 6 TOC Removal (mg/l)



# Comments

- The median TOC achieved for all NF membranes is < 0.7 mg/l
- Micro-biological contaminants such as E.Coli and Coliphages were removed entirely and recorded zero for all NF membranes.
- The median turbidity for all three NF membranes is 0.2 mg/l.
- Only one MBR-GAC-NF process does not meet the SANS 241-1 (2015) < 11 mg/l Nitrate standard at the 95% percentile. This highlights the importance of the preceding biological process (Nitrification & Denitrification)

# MBR – RO Permeate Water Quality

| | | RO1 Permeate | | | | RO2 Permeate | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Units | Mean | Median | STD | 95% | Mean | Median | STD | 95% |
| Alkalinity | mE/L | 13 | 10 | 7 | 26 | 25 | 10 | 43 | 84 |
| Coliforms | CFU/100ml | 106 | 37 | 171 | 404 | 199 | 24 | 452 | 783 |
| Coliphages | PFU/100ml | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EC | mS/m | 2 | 1 | 1 | 4 | 3 | 1 | 5 | 17 |
| E. coli | CFU/100ml | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NH3 | mg/l | 0.5 | 0.5 | 0.0 | 0.5 | 0.5 | 0.5 | 0.0 | 0.6 |
| NO3 | mg/l | 0.5 | 0.5 | 0.2 | 0.5 | 0.8 | 0.5 | 1.5 | 0.6 |
| SRP | mg P/l | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 |
| TP | mg P/l | 0.5 | 0.5 | 0.0 | 0.5 | 0.5 | 0.5 | 0.0 | 0.5 |
| TOC | mg/l | 0.7 | 0.7 | 0.1 | 0.9 | 0.7 | 0.7 | 0.1 | 0.7 |
| Turbidity | mg/l | 0.3 | 0.3 | 0.1 | 0.5 | 0.2 | 0.2 | 0.2 | 0.4 |
| pH | | 7.6 | 6.1 | 0.8 | 8.9 | 7.3 | 7.2 | 0.8 | 8.8 |

# Performance Comparison

| | MBR-GAC-NF | MBR-RO |
|---|---|---|
| TOC (mg/l) | < 0.7 | < 0.7 |
| EC (mS/m) | 5-40 | 1-5 |
| $NH_3$ | 0.5 - 6 | < 0.5 |
| $NO_3$-N (mg/l) | 1-12 | 0.5 – 1.4 |
| NTU | < 1 | < 1 |
| Alkalinity (mg/l $CaCO_3$) | 10 - 218 | 10 -160 |
| E.Coli (CFU/100 ml) | 0 | 0 |
| Coliphages (PFU/100 ml) | 0 | 0 |

- The MBR-RO process exceeds the SANS 241-1: 2015 drinking water standards.
- The MBR-GAC-NF process does not meet the < 11 mg/l Nitrate standard at the 95% percentile.

# CEC Removal Performance

Steroid hormones:-

- Estrone (E1),
- 17β-Estradiol (E2),
- Estriol (E3),
- 17α-Ethinyl-Estradiol (EE2),
- Testosterone and Progesterone.

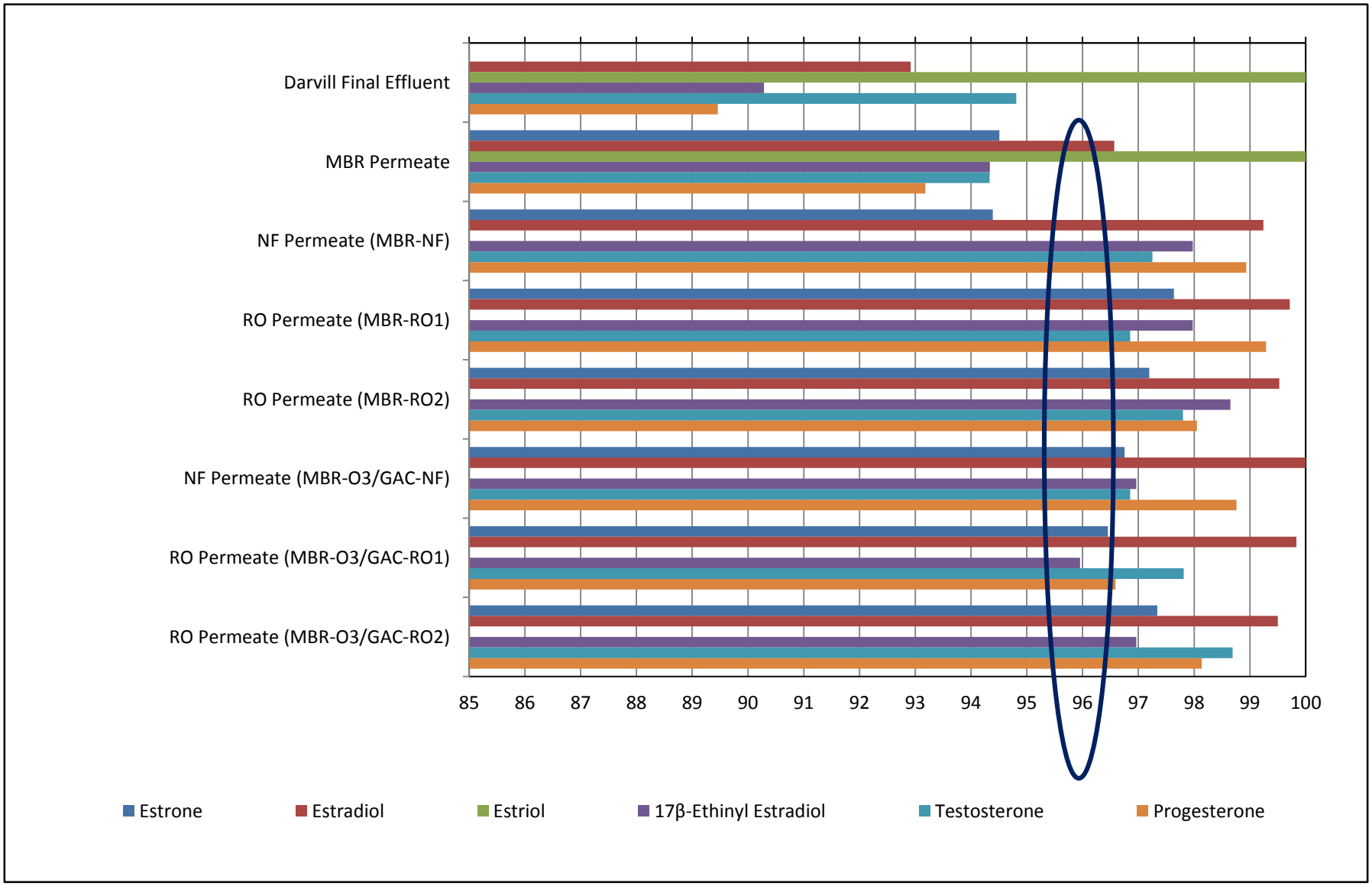
Antibiotics

- Flouroquinolones
- Sulphamethoxazole

# EDC Removal Performance

| Mean (pg/ml) | Estrone | % Removal | 17β-Estradiol | % Removal | Estriol | % Removal | EE2 | % Removal | Testosterone | % Removal | Progesterone | % Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Darvill Raw | 52 | | 157 | | 5 | | 32 | | 265 | | 121 | |
| Darvill Settled | 118 | | 167 | | 3 | | 25 | | 286 | | 81 | |
| Darvill Final Effluent | 30 | 42 | 10 | 94 | 0 | 100 | 2 | 94 | 16 | 94 | 8 | 93 |
| Darvill Prechlorinated Final Effluent | 25 | 52 | 23 | 85 | 0 | 100 | 2 | 94 | 25 | 90 | 5 | 96 |
| Toray Permeate | 7 | 94 | 5 | 97 | 0 | 100 | 1 | 96 | 16 | 94 | 5 | 94 |
| Post Ozonation | 5 | 28 | 3 | 40 | 0 | | 1 | 0 | 8 | 50 | 1 | 80 |
| GAC Permeate | 4 | 20 | 1 | 80 | 0 | | 1 | 0 | 7 | 13 | 1 | 0 |
| NF Permeate (MBR-NF) | 9 | 93 | 1 | 99 | 0 | | 1 | 96 | 8 | 97 | 1 | 99 |
| RO Permeate (MBR-RO1) | 3 | 97 | 1 | 99 | 0 | | 1 | 96 | 9 | 97 | 1 | 99 |
| RO Permeate (MBR-RO2) | 3 | 97 | 1 | 99 | 0 | | 0 | 100 | 6 | 98 | 2 | 98 |
| NF Permeate (MBR-O3/GAC-NF) | 4 | 96 | 0 | 100 | 0 | | 1 | 96 | 9 | 97 | 1 | 99 |
| RO Permeate (MBR-O3/GAC-RO1) | 4 | 96 | 0 | 100 | 0 | | 1 | 96 | 6 | 98 | 3 | 96 |
| RO Permeate (MBR-O3/GAC-RO2) | 3 | 97 | 1 | 99 | 0 | | 1 | 96 | 4 | 99 | 2 | 97 |

# EDC % Removal




Analysis Period: 12/7/2012 – 27/11/2012 Samples 11 No.

# EDC % Removal

The highest remaining EDC concentration was observed for Testosterone (9 ng/l)

Australian Drinking Water Guideline (2008 ) safe limit for Testosterone is 7 µg/l.

# Conclusions

Various combinations of advanced treatment technologies can be used to achieve the desired outcome of consistently producing water of a potable standard.

# Cost Estimate

## Cost Estimate – Treatment Works

| Plant | CAPEX (R '1000) | OPEX | |
|---|---|---|---|
| 100 Ml/day | | Per day | Per $m^3$ |
| MBR-RO-AOP | R950 000 | R249 755 | R2.49 |
| MBR-$O_3$/GAC-NF-AOP | R1 012 000 | R292 790 | R2.93 |

*Excludes: Stabilisation, Product Water Storage and Chlorination

<u>Sludge Disposal using Evaporation Ponds</u>

Effluent: 12 Ml/day (3700 mg/l) requires 100 x 43 000 $m^2$ ponds

Cost estimate R450 million

# Cost Estimate

Alternative treatment train

MBR-$O_3$/GAC-UF-AOP

Capital Cost – R752 million (R196 million saving)

Concentrate disposal to land

# Conclusions

- Membrane based treatment processes (NF/RO) are suitable for coastal applications, where the brine can be discharged to sea e.g. MBR-RO-AOP
- For inland systems $O_3$/GAC based treatment processes are more applicable to avoid the issue of concentrate disposal e.g. MBR-$O_3$/GAC-UF-AOP

# Way Forward

- Umgeni Water building a 2 Ml/day reclamation plant at the Darvill Wastewater Works

  Coagulation/Floculation-RGF-$O_3$/GAC-UF

- Plant will serve dual purpose
  - Provide wash water for works
  - Produce potable drinking water
- Reclamation plant will be used as a demonstration facility to undertake further research and for education purposes
- Stakeholders, officials, scholars and members of the community will be invited to tour the facility and learn about the benefits of potable reuse.

# Acknowledgements


- Dr N Kalebaila - Water Research Commission
- Dr Jo Burgess – Water Research Commission
- Mr. Steve Gillham – GM ESS Umgeni Water
- Prof. Lingum Pillay – Durban University of Technology
- Mr. Peter Thompson – Process Services Manager
- Mr. Cyprian Murutu - Durban University of Technology
- Process Technicians – Mr. S Chiburi, Mr. N Gumede, Mr. L Mkhwanazi, Ms. N Mbambo
- Umgeni Water Staff
- WRC Reference Group


# Other

What is the UV254 water quality test parameter? UV254, also known as the Spectral Absorption Coefficient (SAC), is a water quality test parameter which utilizes light at the UV 254nm wavelength to be able to detect organic matter in water and wastewater. This is due to the fact that most organic compounds absorb light at the UV 254nm wavelength. Unlike other organic test parameters, UV254 has a bias towards reactive or aromatic organic matter which has double bonded ring structures and is typically the most problematic form of organics in water. UV254 is typically represented as a calculation of UV absorbance (UVA) or UV transmittance (UVT). - See more at: http://www.realtechwater.com/resources/faq#sthash.4krNJo9v.dpuf

# Other

What is SUVA and how is that related to UVA? The Specific UV Absorbance (SUVA) calculation is typically performed for the purpose of determining disinfection by-product (DBP) formation potential. SUVA is simply the UV absorbance at the 254nm wavelength (UVA) divided by the DOC of a water sample. This allows the aromatic biased UV254 measurement to be normalized over the overall organic load in the water. A characterization of the aromaticity of the water independent from the general level of organics in the water can then be obtained. A high SUVA indicates that a large portion of the organics present in the water are aromatic. Since aromatic organics have a greater tendency to react with disinfectants to create DBPs, a high SUVA indicates there is a high potential for the formation of DBP's. For further details about measuring SUVA for regulatory purposes click here to link to EPA Method 415.3 - See more at: http://www.realtechwater.com/resources/faq#sthash.4krNJo9v.dpuf

# Other

- Additional steady state studies of flux sustainability at the recommended aeration rates were conducted. Results of steady-state operation indicated specific aeration demand of the membrane ($SAD_m$) values of 0.34-0.74 with accompanying $SAD_p$ (permeate) values of 7.6-27, the lowest arising for the sidestream air-lift configured technology (Norit) for which supplementary sludge pumping was employed (**Table 6**).
- The Ro unit consisted of two single pass trains and was operated at 50% recovery and 20 $\ell m^2 h^{-1}$ throughout the study period. The RO membranes operated for a period of more than 1300 hours on MBR effluent without requiring a chemical clean

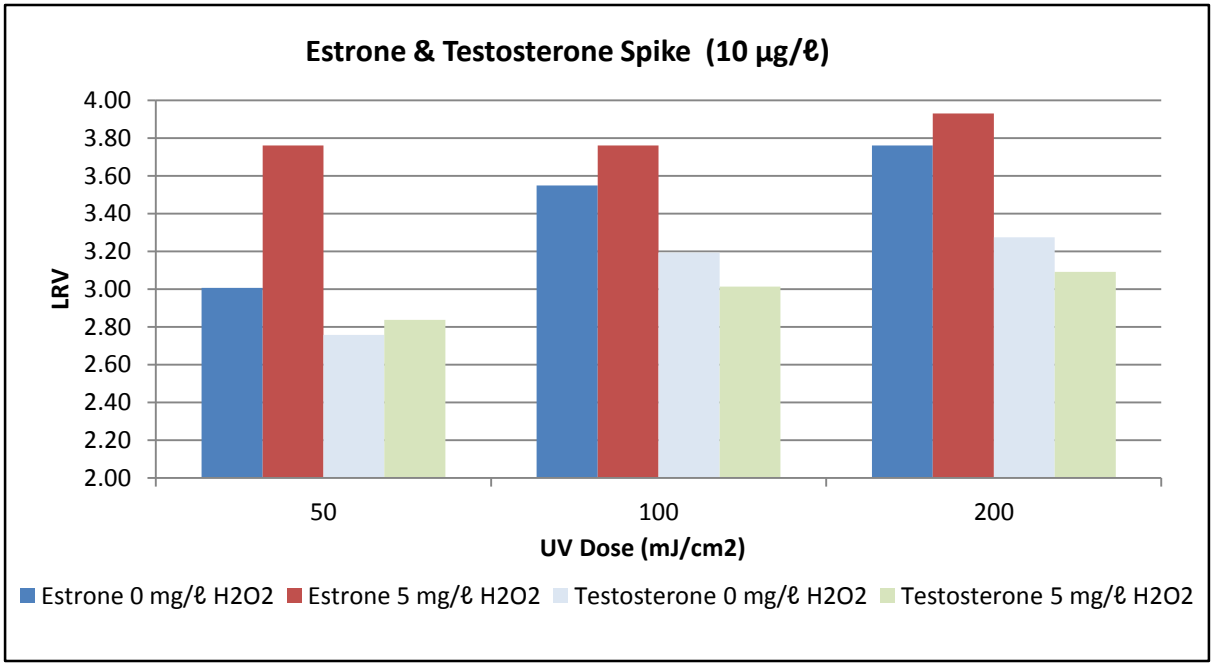
# Other

**LC-OCD Analyses**

- $UV/H_2O_2$ samples were also sent to Germany for identification of the carbon molecular weight distribution. A very sensitive separation technique known as Liquid Chromatography - Organic Carbon Detection (LC-OCD) was used. Separation is based on size-exclusion chromatography (SEC) followed by multi-detection with organic carbon (OCD), UV-absorbance at 254 nm (UVD) and organic bound nitrogen (OND). The additional LC-OCD analyses were necessitated as the RO permeate used as a feed to the $UV/H_2O_2$ is very clean water. There was therefore no meaningful distinction between the RO permeate water quality results and the $UV/H_2O_2$ permeate water quality results, because measurement was beyond the Umgeni Water laboratory analyses detection limits. The benefits of contaminant removal using $UV/H_2O_2$ could therefore not be assessed.

- Results obtained from the LC-OCD analyses show that MBR-RO-UV results in a 93% removal of Dissolved Organic Carbon (DOC) which confirms the TOC permeate results obtained by the Umgeni Water laboratory (< 0.7 mg/ℓ). The RO membrane reduces DOC concentration to < 400 ppb (0.4 mg/ℓ). This is reduced further by the UV radiation unit process to < 250 ppb (0.25 mg/ℓ).The UV radiation achieves this by reducing the Low Molecular Weight (LMW) neutrals. This fraction includes alcohols, aldehydes, ketones and amino acids. $UV/H_2O_2$ reduces the concentration of organics by approximately 38%.

# Other


Estrone & Testosterone Spike (10 µg/ℓ)
LRV
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
50
100
200
UV Dose (mJ/cm2)
Estrone 0 mg/ℓ H2O2
Estrone 5 mg/ℓ H2O2
Testosterone 0 mg/ℓ H2O2
Testosterone 5 mg/ℓ H2O2