Attachment 4

A Presentation onboard Golden Princess

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Why trials?

- **Current AWPs can not meet the limits.**
- **There is a lack of evidence the requirements can be consistently met for shipboard applications.**
- **Unique shipboard conditions, such as**
  - **High Temperature**
  - **High concentrations**
  - **Fluctuations**
  - **Constraints on space and operational resource**
- **Technologies – well proven in land based applications only**
  - **N – biological nitrogen removal**
  - **P – chemical precipitation**

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Nitrogen compounds

Terminologies

TN =Total Kjeldahl nitrogen (TKN) + Total oxidised nitrogen (TON)

TKN = Ammonia (NH-N) + organic nitrogen

NH-N = Ammonia (NH-N)

TON = nitrite-N + nitrate-N

In untreated wastewater, TKN > NH-N. TON is absent.

In treated wastewater, TKN ≈ NH-N due to hydrolysis of organic N. Present of TON is the result of nitrification.

Nitrification

- **Two-step reaction:**

  $NH_4^+ + O_2 \rightarrow NO_2^-$ (nitrite) + $H_2O + H^+$ (by Nitrosomonas)

  $NO_2^- + O_2 \rightarrow NO_3^-$ (nitrate) (by Nitrobactor)

  Bacteria involved are generally termed Nitrifiers - slow growing and valnerable.

- **Oxygen requirement 4.6 kg/kg N oxidised**
- **Alkalinity requirement 7.14 kg as $CaCO_3$/kg N oxidised**

- **Nitrite will accumulate at inhibitive (e.g. low DO), high temperature, or transition conditions.**

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Influential factors to nitrification

- **Longer sludge age > 8~15 days**
  - **Nitrifiers grow slower and less**
- **More aeration demand, DO >1.5~2 mg/l**
  - **Nitrobacters are inhibited at low DO. (Double of carbon removal)**
- **Alkalinity demand. Optimum pH 7.5~8.**
  - **Nitrification tends to reduce pH. Nitrifiers are pH sensitive. Rate at pH6 is 10% of that at pH7.**
- **Temperature is important, optimal 25 ^{o}C~35 ^{o}C**
  - **Nitrifiers are temperature sensitive.**
- **Toxic and inhibitory compounds**
  - **Nitrifiers are very vulnerable to toxicity and a wide range of organic and inorganic compounds comparing to heterotrophs**

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Effect of Temperature - uncertainties

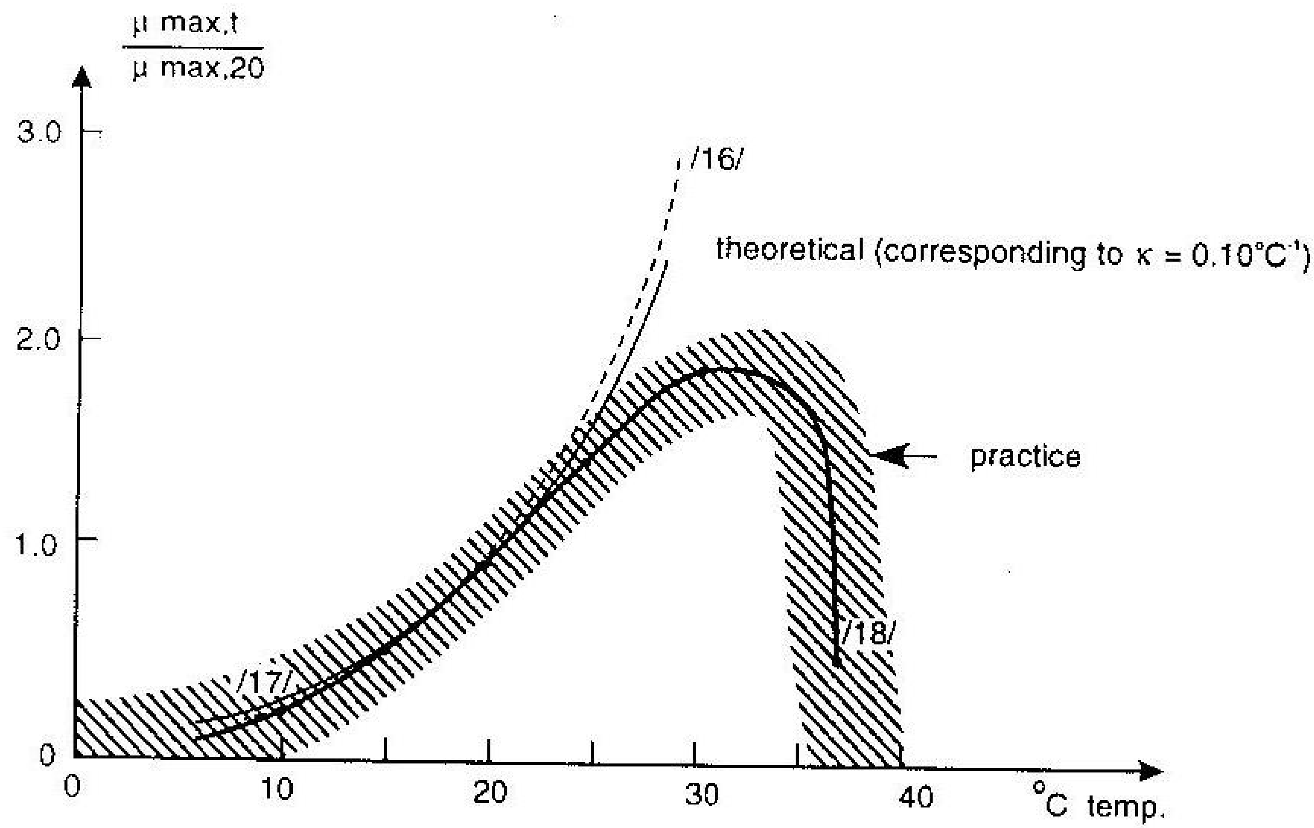

Fig 3.7 *Nitrification as a function of temperature. As opposed to the other biological processes in wastewater treatment, thermophilic nitrifying bacteria are unknown.*

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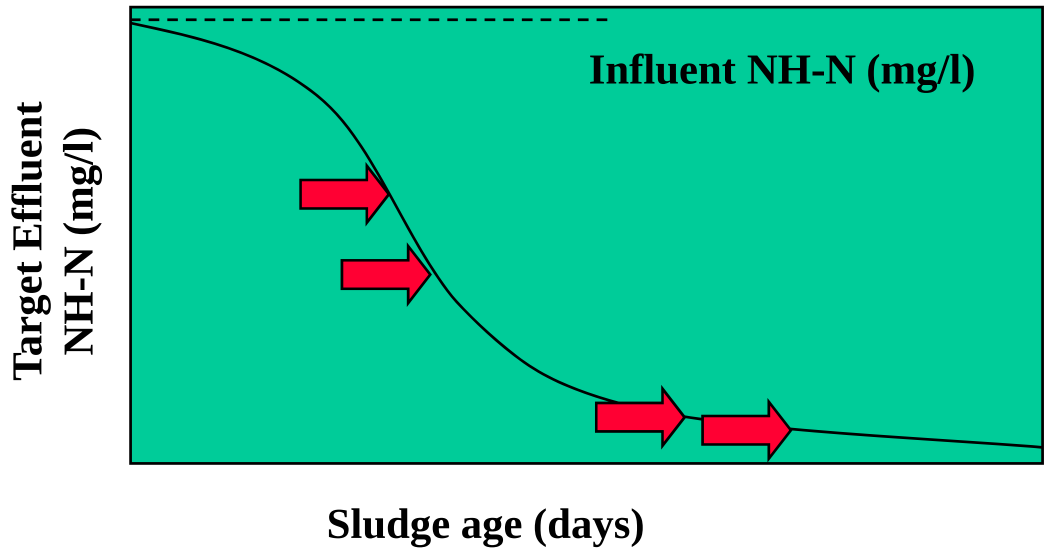
Nitrification Design – Discharge limit

- Treatment standards
  - A lower NH-N limit requires nitrifiers to domain under a low NH-N environment, at a lower growth rate.

$\mu_{NH\text{-}N} = \mu_{NH\text{-}N,\ MAX} \times [NH\text{-}N]/(K_N + [NH\text{-}N])$



- Standards ↑ →design F:M ↓ → Biomass ↑ → Reactor V ↑

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Denitrification

- Anoxic condition - present of Nitrate with no DO.
- NO_3^- + C (or BOD) $\rightarrow$ CO_2 ($\uparrow$) + N_2 ($\uparrow$) + OH^- (by heterotrophs)

- Total BOD requirement 2.86 kg/kg N denitrified.
- Alkalinity producted 3.57 kg as $CaCO_3$/kg N denitrified.

- Denitrification reduces the total power consumption.
- Denitrification assists to stabilise the alkalinity balance.

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Conditions for Denitrification

- DO <0.3 mg/l.
  - DO inhibits denitrification.
  - To limit DO in the re-circulation
  - To avoid air entrapment in anoxic zone mixing etc.
  - To avoid cascading
- Need readily degradable organic materials (good food).
  - Govern the reaction rate, hence the size of anoxic tank.
- Less sensitive to pH.
- Higher temperature benefits reaction rate?

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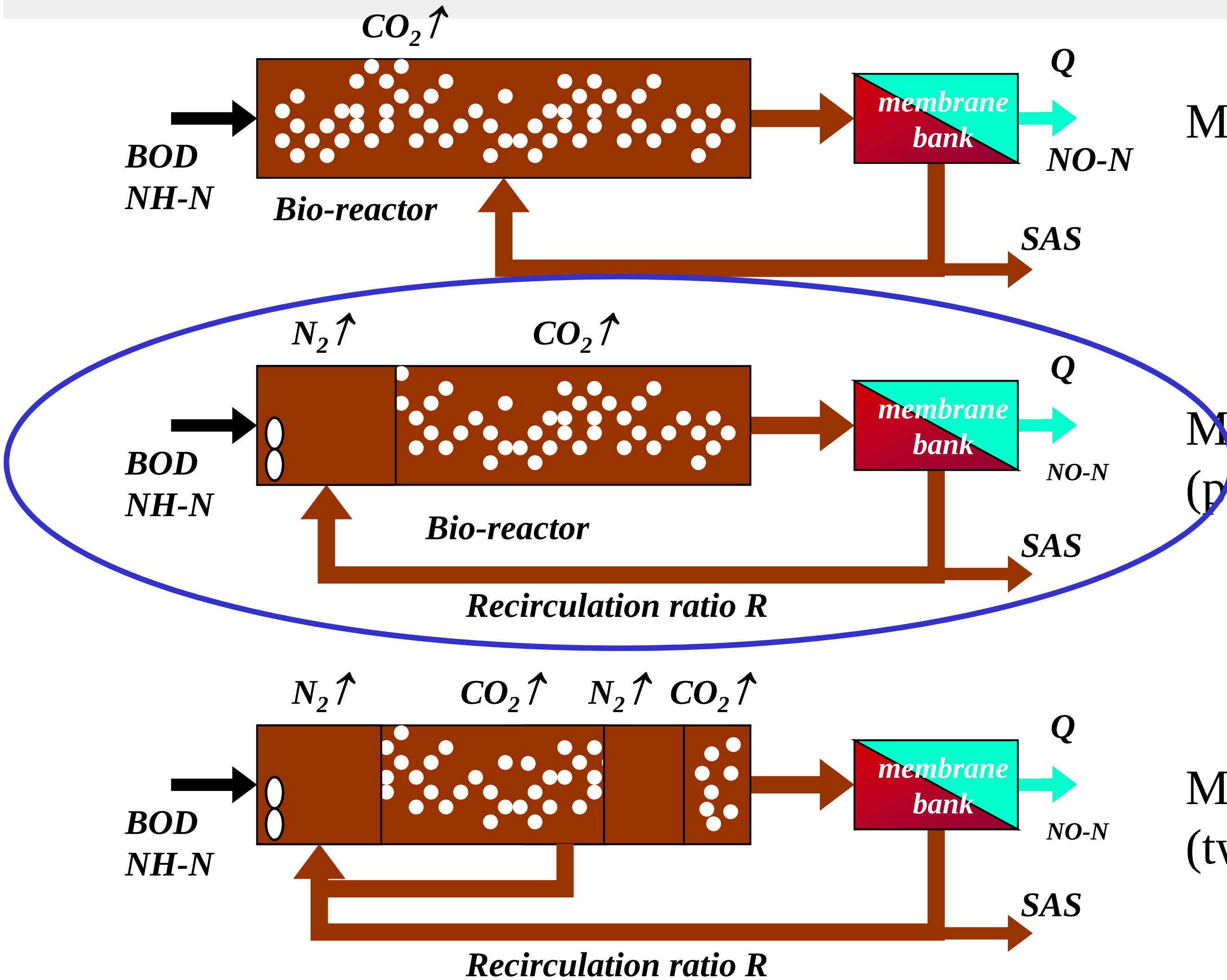
MBR for Nitrogen Removal on Ship



MBR for Nitrification

MBR for TN removal (pre-denitrification)

MBR for TN removal (two anoxic zones)

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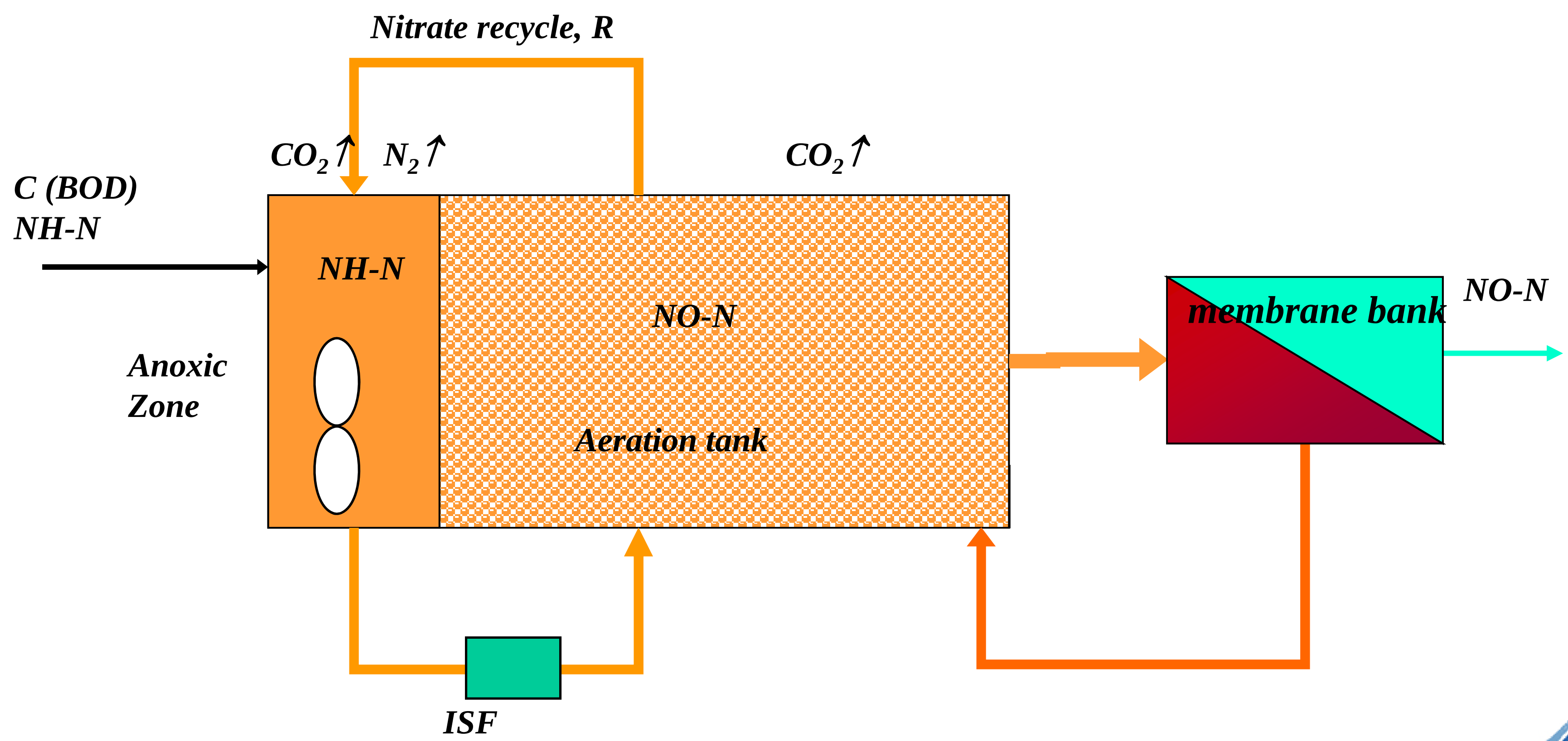
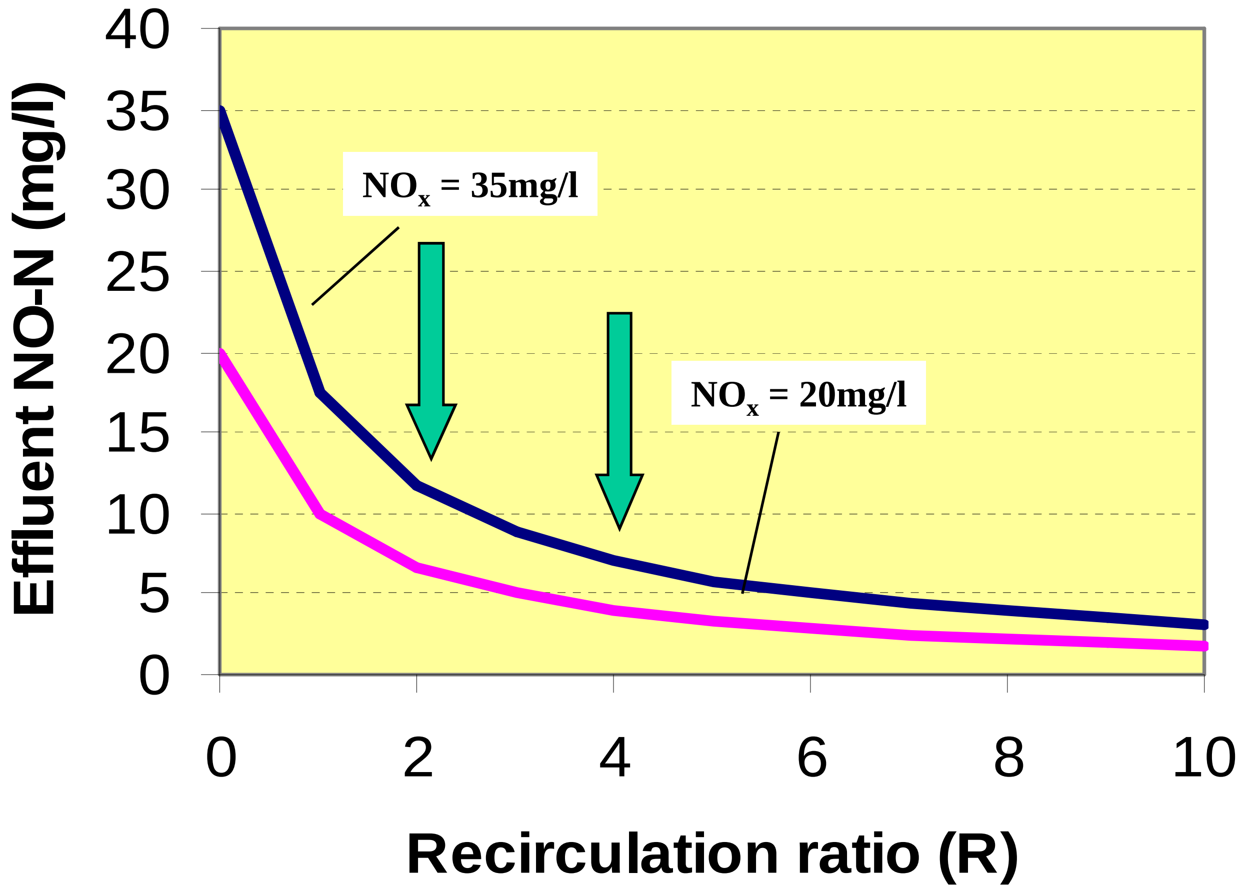
Diagram of N-DN process



Effluent NO-N and Recirculation R



P removal – chemical precipitation

- **Iron and aluminium salts are used to precipitate the phosphorus from wastewater.**

- **P is removed with de-sludge.**

- $Fe^{2+} + O_2 \rightarrow Fe^{3+}$
- $Fe^{3+} + PO_4^{2-} \rightarrow Fe_2\,(PO_4)_3\,(\downarrow)$

- **Typical ratio Fe:P = 2:1**

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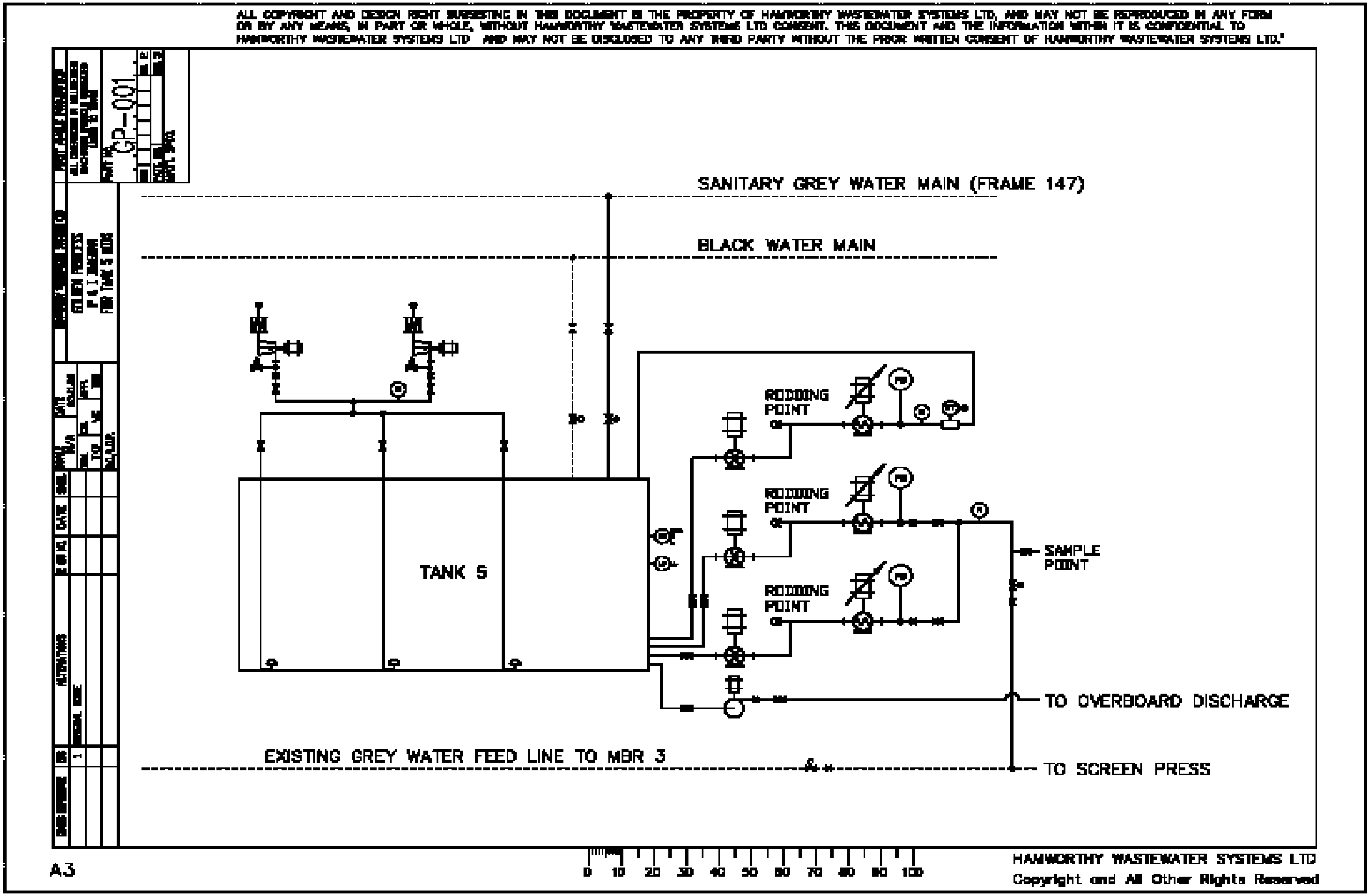
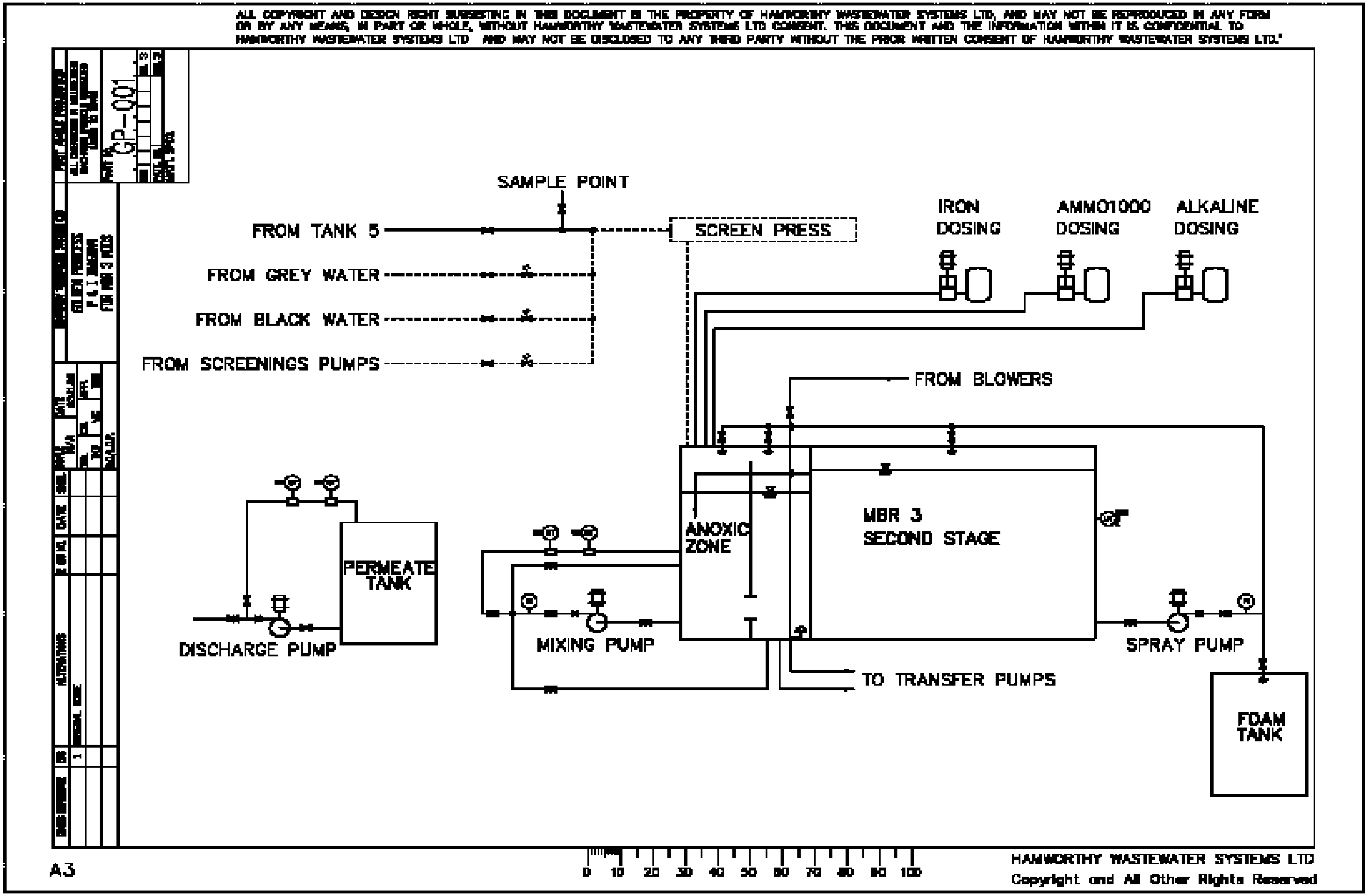
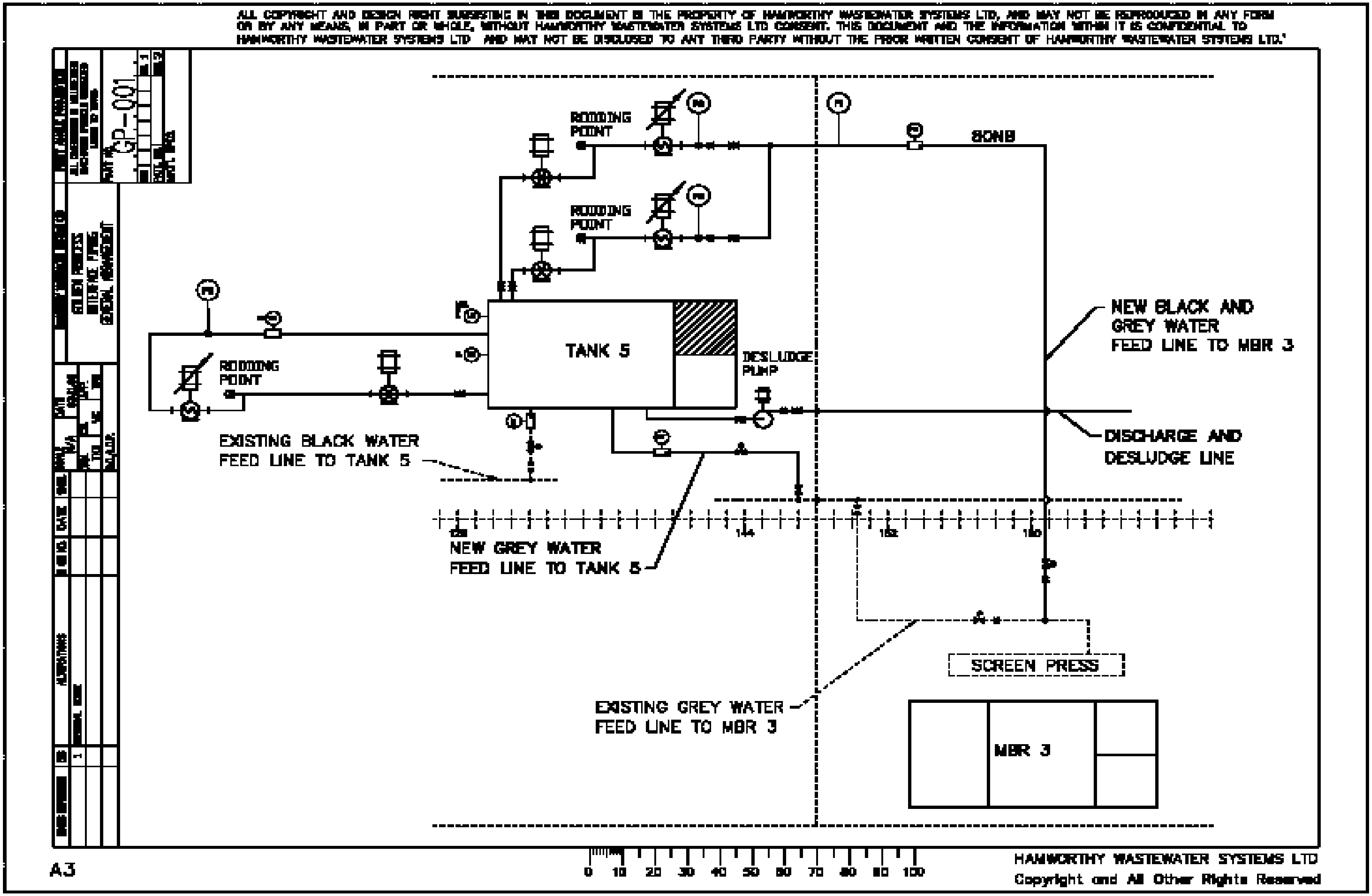
Golden Princess Trial Plant - configurations



Golden Princess Trial Plant - configurations



Golden Princess Trial Plant - configurations



Program

➢ **Ship survey completed**	**Nov 2008**
➢ **Scope of work and contract agreement**	**Jan 2009**
➢ **Phase 1 (wastewater characterisations) completed**	**Apr 2009**
➢ **Phase 2 (installation and commissioning) completed**	**Jun 2009**
➢ **Phase 3 (trial period) started**	**Jul 2009**
➢ **Scenario 0 (setting up) completed**	**Jul 2009**
➢ **Scenario 1 completed**	**Sep 2009**
➢ **Scenario 2 completed**	**Oct 2009**
➢ **Scenario 3 (P removal) to be completed**	**Nov 2009**
➢ **Scenario 4/5**	**Jan 2010**

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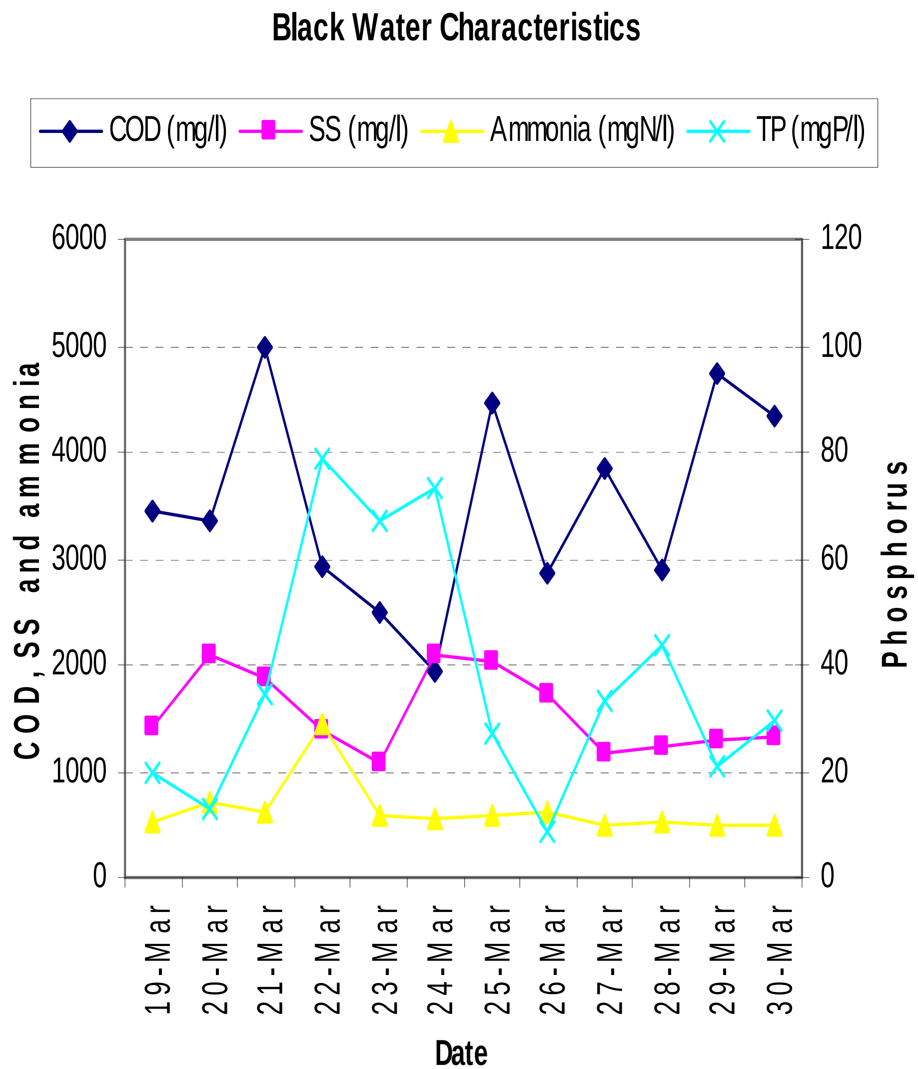
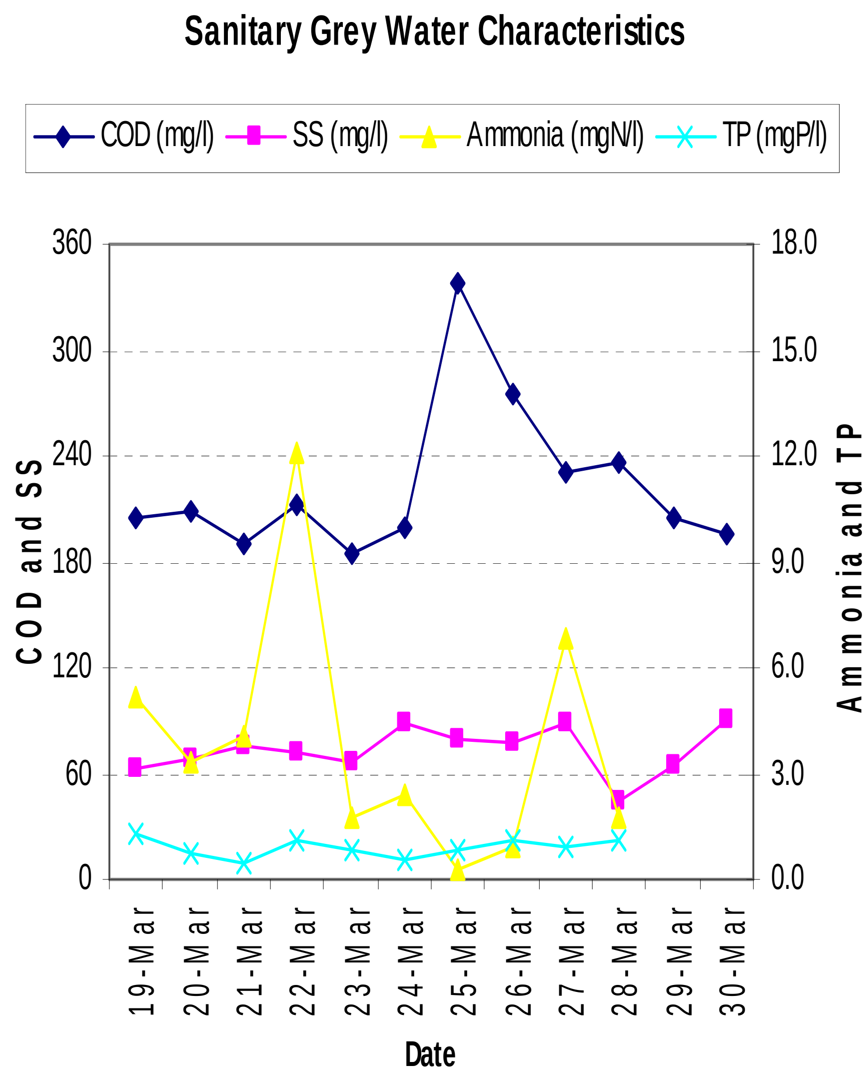
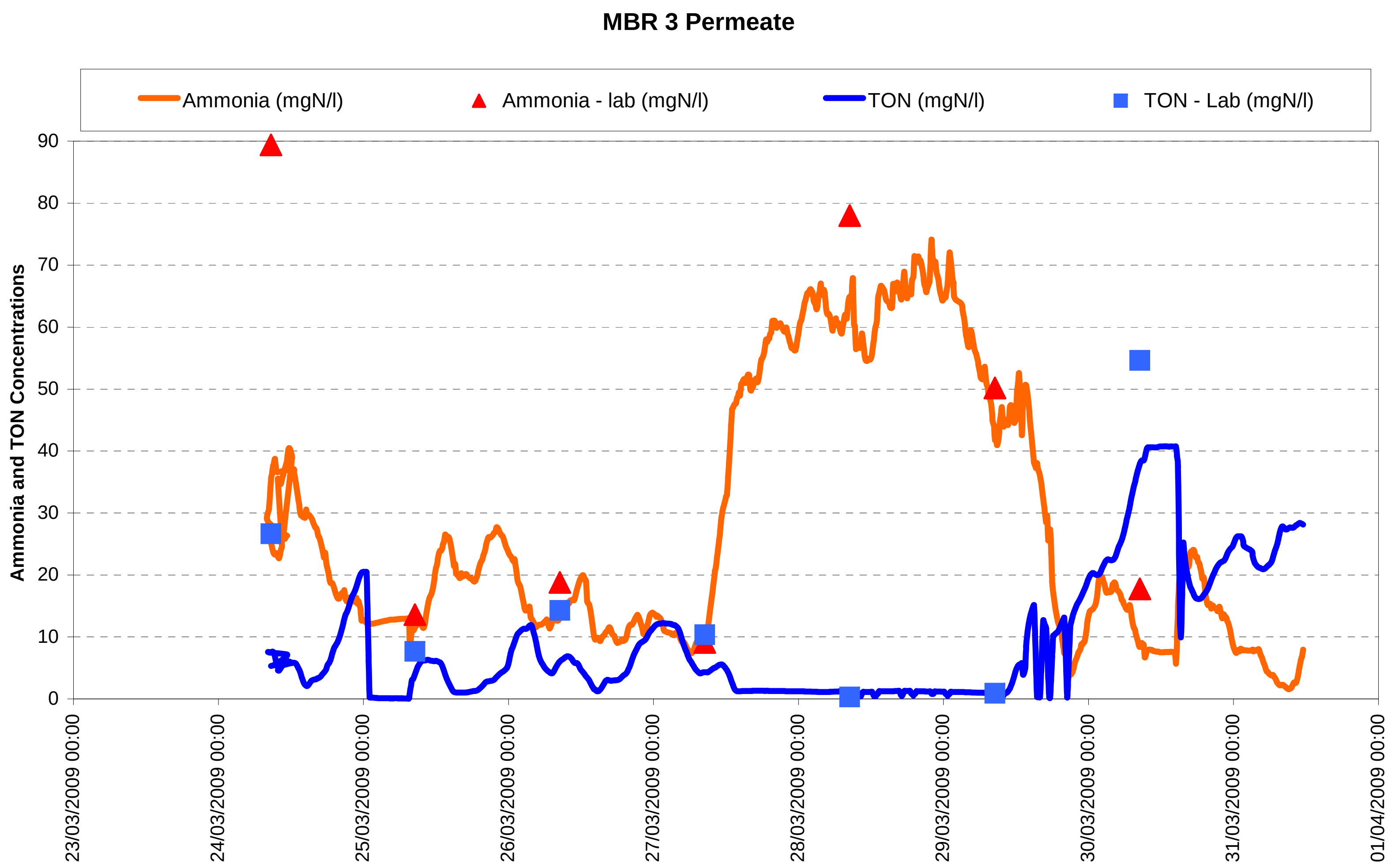
Phase 1 Findings





Phase 1 Findings



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Phase 1 Findings

- **Black water ammonia has 600-1000 mgN/l comparing to 40-60 mgN/l in the municipal sewage.**
- **Grey water has very low ammonia concentrations. Grey water treatment in MBR (3~4:1) dilutes black water ammonia.**
- **Extreme fluctuation of wastewater and permeate characteristics.**
- **Partial nitrification occurs in MBR.**
- **High temperature.**
- **The on-line ammonia monitoring was proven.**
- **A set of MBR improvements identified.**

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Phase 3 – Scenario 0-1

- Data log sheets and communication were established.

- A set of operational parameters.
  - MBR capacity reduced to 90-100 m3/day.
  - Stable sludge age maintained to 18-30 days.
  - ISF flows being regulated.
  - Anoxic zone started.
  - DO increased to >1.5 mg/l.
  - Target grey:black ratio of 2:1.
  - Tank 5 level increased to improve buffering.
  - Alkaline dosing.

- Nitrification established.

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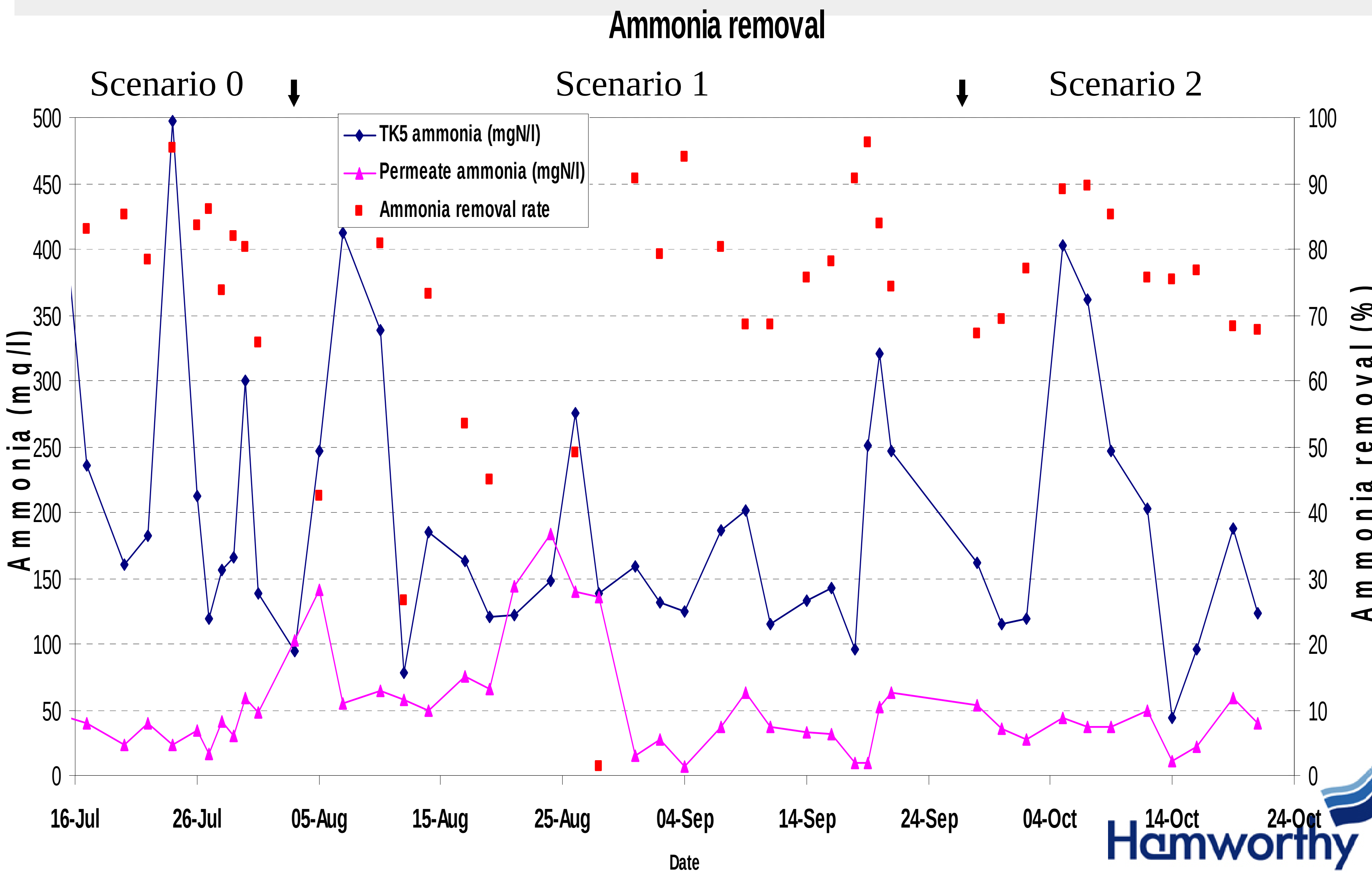
Scenario 0-1 Findings



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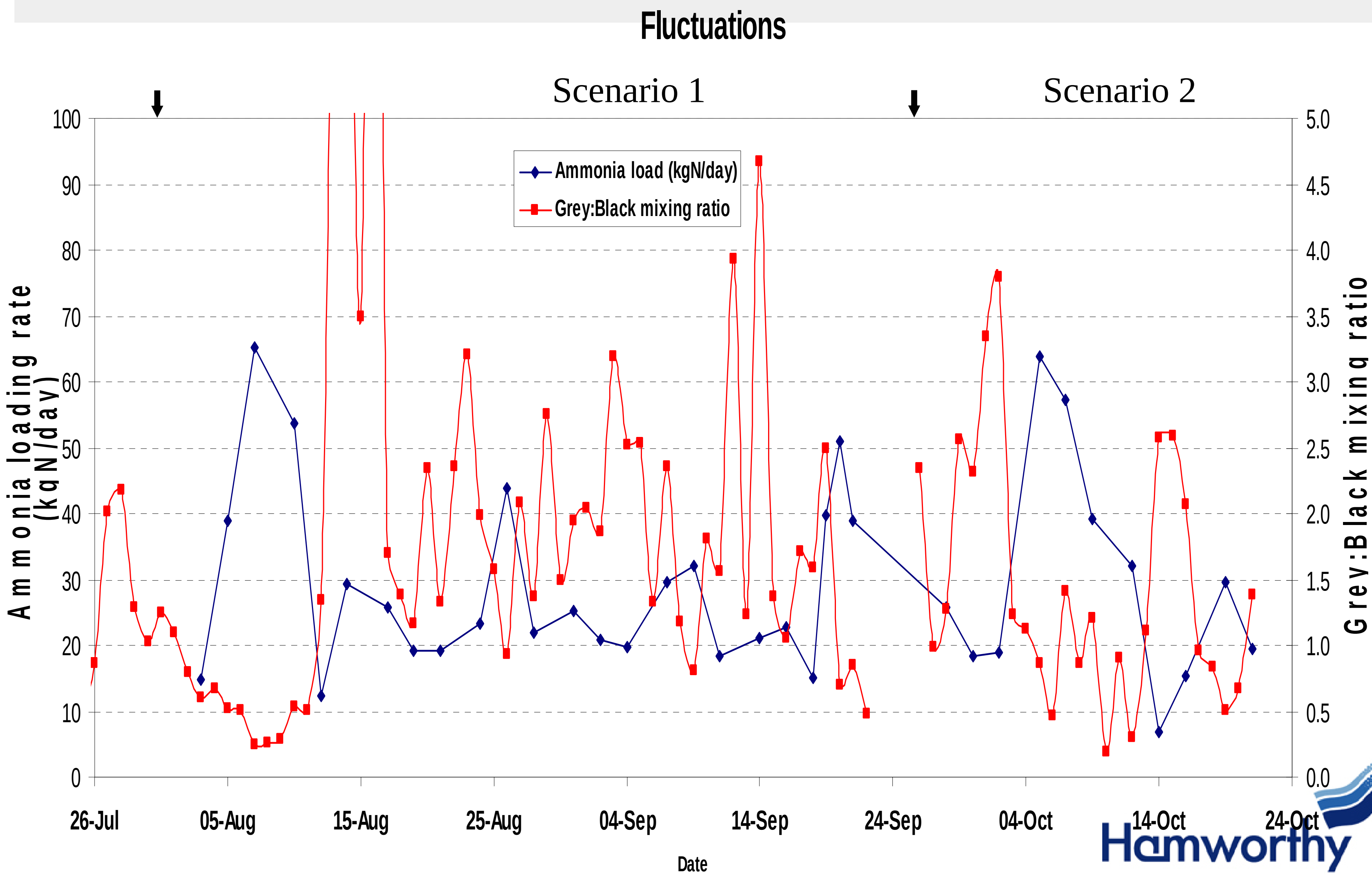
Scenario 0-1 Findings



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Scenario 0-1 Findings

- Grey and black water mixing ratio is difficult to control. High fluctuation of ammonia in feed water.
- Constraints to some operational parameters in Alaska.
- Nitrification happens, but the ammonia reduction is not sufficient for compliance. (Temperature, ammonia too high, fluctuation)
- Stable denitrification could not be established. High nitrite. (Carbon limiting, temperature, mixing).

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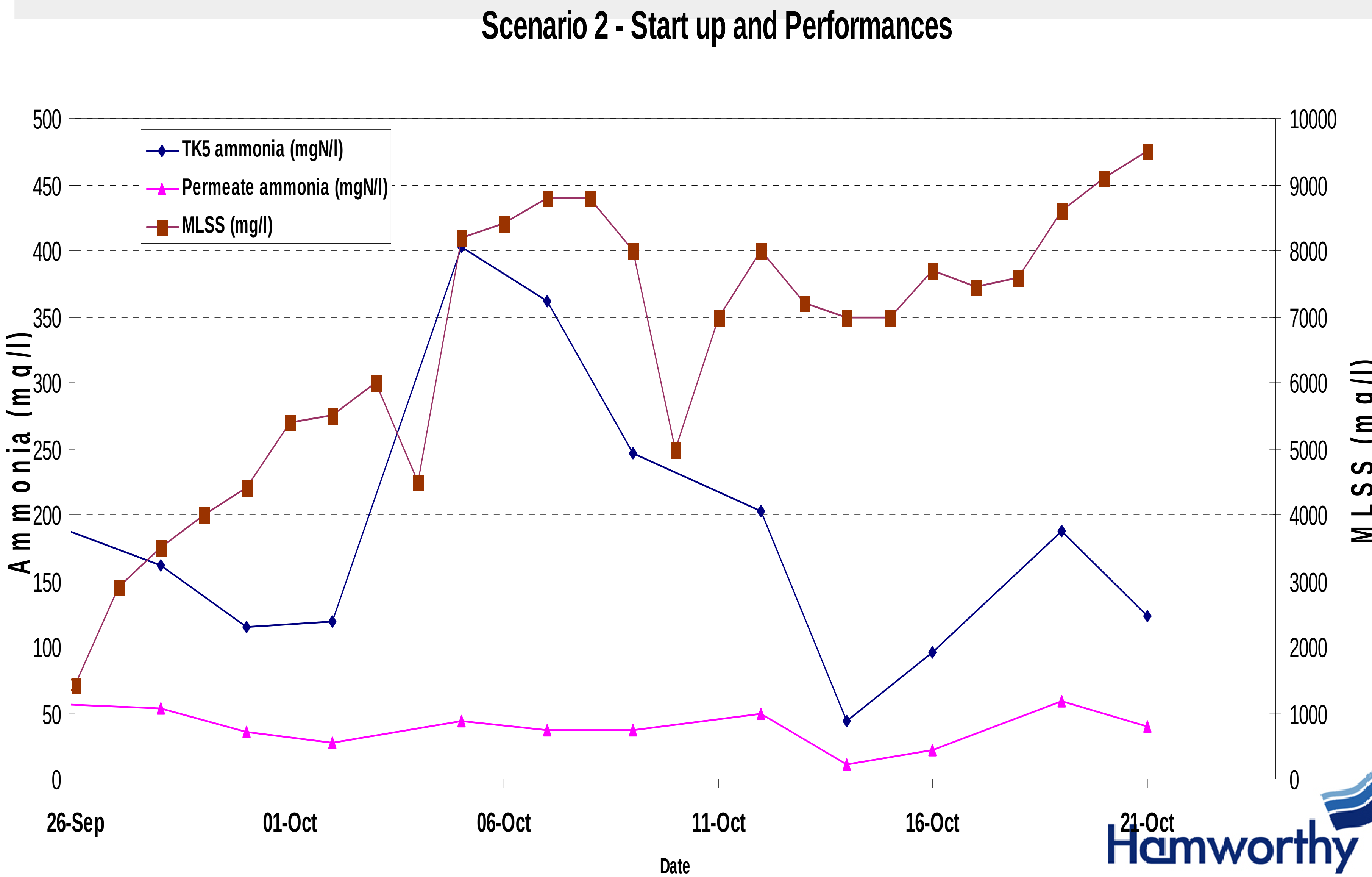
Scenario 2 Findings



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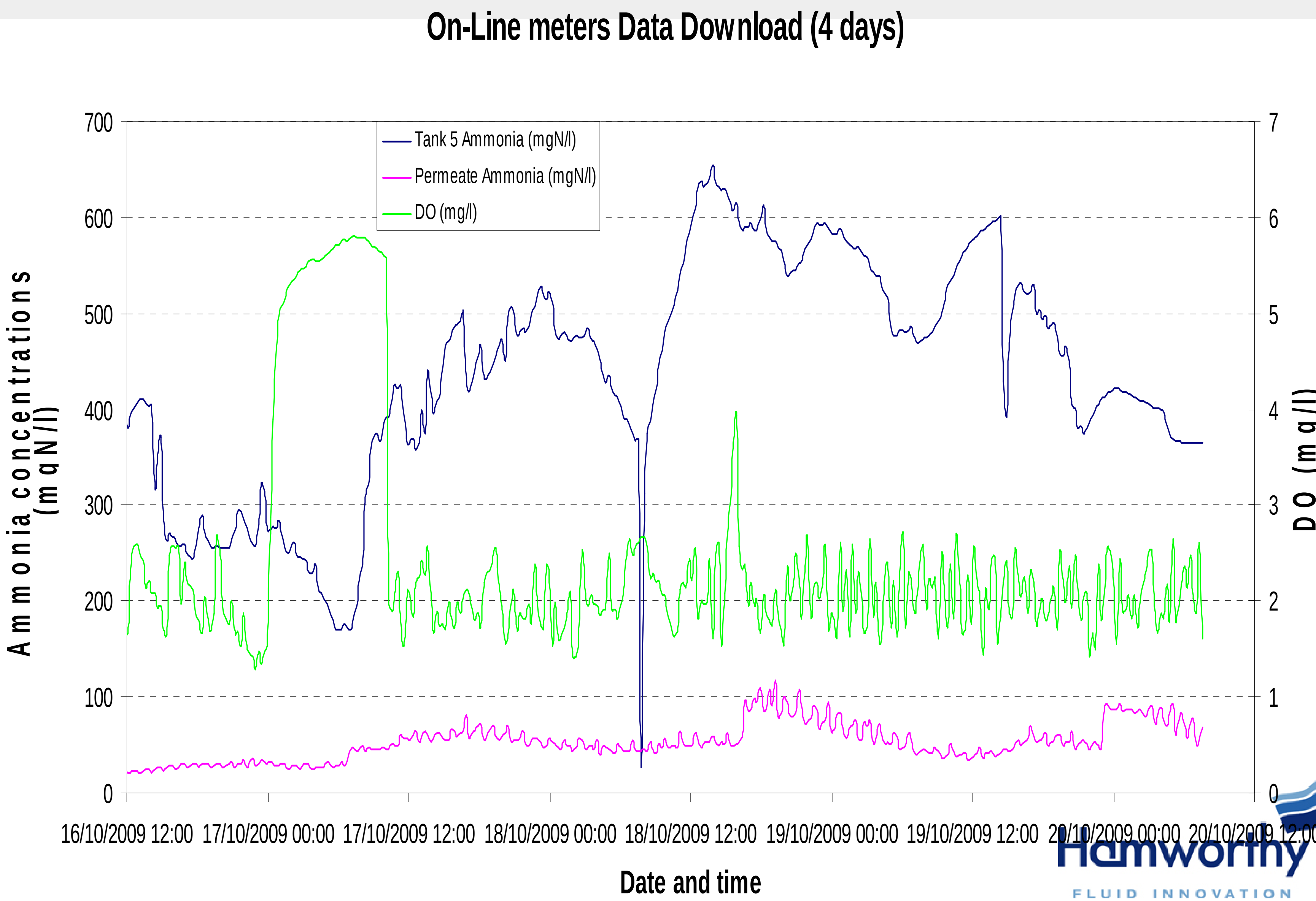
Scenario 2 Findings



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Scenario 2 Findings

- Quick start-up of nitrification process when seeded from other MBR
- Nitrification has not improved further, by
  - Lower treatment capacity
  - Higher DO
  - Longer sludge age
- Accumulation of nitrate and nitrate

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Further trial scenarios

- **Challenges**
  - **Plant observations and diagnosis**
  - **Data interpretation**
  - **Process stability**
- **Further scenarios**
  - **To increase Grey:Black ratio to 3:1**
  - **To treat all black water in MBR No.3**

Impact of increasing grey water treatment

Waste streams	Ammonia in combined black and grey water (mgN/l)	BOD/Ammonia ratio of the combined wastewater	Treated water due to biomass growth/disposal (mgN/l)	Reduciton (%)
Blk+50% sanitary	150	3.8	122	19%
Blk+100% sanitary	82	4.8	62	24%
Blk+sanitary +laundry	68	5	51	25%
Blk+sanitary +laundry+ galley	50	8	30	40%
Blk+sanitary +laundry+ galley +pulper water	50	11	23	55%

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