final report

Project Code: A.ENV.0074
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Date published: June 2009

PUBLISHED BY
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Economic Analysis of Demineralisation

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Contents

1 Background

The extended drought, and the probability of climate change causing more frequent drought periods, has resulted in a drive within the Australian meat industry to reduce water consumption at meat processing plants. Coupled with this reduction in water consumption there is a focus in the meat processing industry to minimise energy consumption.

The disposal of high salinity brine from membrane-based water treatment is problematic for most meat industry operations. There is a trend for municipal water authorities to tighten the salinity thresholds of wastewater discharges that will be received by their wastewater treatment plants. As a consequence there is a need to consider alternate beneficial uses for the high salinity brine streams within the meat processing operation

2 Project Objective

The objective of this project is to establish the technical and economic feasibility of membrane based demineralisation treatment for use in meat processing industry plants in Australia.

This project focused on the reduction of the salt content of water supplied to meat processing plants, rather than a review of meat processing plant wastewater treatment and potential reuse. By lowering the "baseload" of incoming salts to the meat processing plants, a corresponding lowering of the salt load in the plant effluent is inferred (provided the removed salts can be used beneficially within the operation and not be allowed to re-join the wastewater effluent for discharge.

Furthermore, a lowering of the salt load to the "internal" meat processing industry plant processes in cooling towers and boilers) could be of potential benefit by a consequent reduction of:

- the chemical consumption requirements for cooling systems;
- reduced blowdown from boilers (associated with the lower salinity incoming water supply); and
- associated energy savings opportunities.

Meat processing plants are large consumers of water. They frequently operate in parts of Australia where incoming water from the town supply or the meat company's groundwater supply contain substantial quantities of salt. Demineralisation can reduce the incoming quantity of the total dissolved salts (TDS).

Application of this membrane based demineralisation technology can be particularly useful for cooling towers and boilers which concentrate the salts using evaporation. Blow down (disposal of a portion of the boiler system water) is employed to prevent scale and corrosion in these systems by removing a portion of the concentrated salts. Even with an optimised system blow down regime, there is a net loss of water and energy from the system, with associated chemical consumption. A sub-optimal control over boiler / cooling tower blow down results in additional losses in terms of water, energy, and chemical consumption.

Notwithstanding the potential benefits cited above, a major challenge will be dealing with the high TDS concentrate stream (termed "brine") from the demineralisation/ membrane-treatment process utilised for treating the meat processing plant water supply stream. If the brine stream can be applied for beneficial use it could render membrane based demineralisation an attractive option. On the other hand, if the brine stream must be disposed of, or requires further treatment, the prohibitive treatment cost could make demineralisation technology uneconomic.

Alternate uses for the brine stream in a meat processing plant have been considered as part of this review.

3 Design Basis

In consultation with the MLA, the following design basis was adopted for this study

- A minimum flow rate to the demineralisation plant of 40 kL/ day, a medium flow rate 150 kL/ day, and a maximum feed flow rate of 500 kL/ day were chosen (recognising although that some meat processor operations can consume up to 2,000 kL/ day of water).
- For the low salinity option, the salinity of the Brisbane Municipal water supply with a total dissolved salt (TDS) content of nominally 350 mg/L was selected. For the high salinity option a TDS of 2,000 mg/L was selected
- For the purpose of this study. the cooling tower and boiler feedwater requirement within the meat processing operation is defined as 10% of the total meat processing plant usage.
- It was assumed that the majority of meat processing plants use their wastewater for irrigation purposes and not to discharge to the local town sewage system
- Although it is accepted that most meat processing plants operate for 5 days per week and on a single 8 hour shift and in some cases up to double 8 hour shifts per day, it was decided as the basis of the design the cooling towers operate continuously for 24 hours per day 7 days per week
- It was assumed that the meat processing plants do not use any pre-treatment other than chemical dosing for their cooling tower make-up to prevent scaling and biological growth in the cooling tower.

4 General Methods

4.1 Task 1 - Data Collection

4.1.1 Average water use in abattoirs

The average water consumption for modern integrated meat processing plants published in 2005[1] was 10.6 kL per ton of Hot Standard Carcass Weight (kL/tHSCW). Since this publication, it is understood from information provided by the MLA, that by the application of a variety of water conservation measures, water consumption has been significantly reduced. As the basis for this study a water consumption of 7.0 kL/tHSCW was used.

It is also noted that this water consumption reduction has been achieved by water saving approaches that did not require high capital expenditure investment and that had attractive payback periods. As agreed with the MLA at the commencement of this study, to compensate for a reduction in water consumption in other areas of the abattoir, the percentage of water used by the meat processing plant services has been adjusted to a figure of 10%. The base line information for water use at a typical meat processing plant as detailed in Table 4.1 is based on the MLA Red Meat Processing Industry Energy Efficiency Manual [2].

Table 4-1: Breakdown of water use at a typical meat processing plant

Area	Description	% of Total Water Consumption	
Stock yards	Stock watering	1.0	23
	Stock washing	6.5	
	Stockyard washing	12.0	
	Truck washing	3.5	
Slaughter and evisceration	Viscera table and wash sprays	5.6	10
	Head wash	0.3	
	Carcase wash	4.0	
	Carcase splitting saw	0.1	
Paunch, gut and offal washing	Paunch dump and rinse	7.5	18
	Tripe / bible washing	2.5	
	Gut washing	5.5	
	Edible offal washing	2.5	
Rendering	Rendering separators	1.2	2
	Rendering plant wash down	0.8	
Sterilisers and wash stations	Knife sterilisers	6.0	10
	Equipment sterilisers	2.0	
	Hand wash stations	2.0	
Amenities	Exit / entry hand, boot wash stations	4.0	7.0
	Personnel amenities	3.0	
Plant cleaning	Wash down during shifts	2.0	20
	Cleaning and sanitising at end of shift	15.0	
	Washing tubs, cutting boards and trays	3.0	
Plant services	Condensers and refrigeration defrost	5.0	10
	Cooling tower makeup	2.5	
	Boiler feed makeup	2.5	

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[1] MLA (2005) Industry Environmental Performance Review: Integrated Meat Processing Plants. Prepared by URS Australia as Project PRENV.033 final report, April 2005. MLA, North Sydney.

[1] MLA (2009) Red Meat Processing Industry Energy Efficiency Manual. Prepared by Hydro Tasmania Consulting as Project A.ENV.0065 Final Report, January 2009. MLA North Sydney.

4.1.2 Average energy use in abattoirs

To estimate potential energy cost savings from the implementation of demineralisation technology, we used an average energy consumption published figure for an Australian abattoir of 3,006 MJ/tHSCW (1), and adopted an average total water consumption figure of 7.0 kL/tHSCW as applicable for a typical meat processing plant. We then used these figures to calculate an average energy usage number from the meat processing plant total water consumption adopted for the abattoir.

The average energy usage split between thermal (coal) and electricity is 70%: 30%. This reference study[2] comprised 12 modern integrated facilities.

In cases where natural gas is used instead of coal, the outcomes of this study will still be relevant to the meat industry. In general, the direct cost of natural gas per megajoule is higher than that for coal. The potential cost savings for natural gas dependant facilities will therefore be higher than that reported for coal based facilities on which this report has focussed.

4.2 Task 2 – Generic Water and Salt Balance

The following scenario's provided in Table 4.2 were adopted for the demineralisation technology options and used as the basis for the generic water and salt balance provided in Appendix 8.1

Table 4.2 – Scenario's for Generic Water and Salt Balance

Option	Scenario	Feedwater Flowrate (kL/ day)	Feedwater Salinity (TDS mg/L)
1a LFLS without RO	Low Feedrate/ Low Salinity (LFLS)	40	350
1b LFLS with RO	Low Feedrate/ Low Salinity (LFLS)	40	350
2a MFLS without RO	Medium Feedrate/ Low Salinity (MFLS)	150	350
2b MFLS with RO	Medium Feedrate/ Low Salinity (MFLS)	150	350
3a HFLS without RO	High Feedrate/ Low Salinity (HFLS)	500	350
3b HFLS with RO	High Feedrate/ Low Salinity (HFLS)	500	350
4a LFHS without RO	Low Feedrate/ High Salinity (LFLS)	40	2,000
4b LFHS with RO	Low Feedrate/ High Salinity (LFHS)	40	2000
5a MFHS without RO	Medium Feedrate/ High Salinity (MFHS)	150	2000
5b MFHS with RO	Medium Feedrate/ High Salinity (MFHS)	150	2000
6a HFHS without RO	High Feedrate/ High Salinity (MFHS)	500	2000
6b HFHS with RO	High Feedrate/ High Salinity (MFHS)	500	2000

The following approach was followed to establish a generic salt balance for meat processing operations.

A reverse osmosis (RO) plant recovery of 85% was selected as the design basis for the mass balance. It is recommended that the 15% RO brine concentrate stream that is generated from this RO facility be mixed with water being used for stock yard washdown and stockwatering. If a lower RO recovery (for example 75%) is used in practice, the productivity for the RO plant will need to be increased to match the production flow requirement equivalent to that for the 85% RO recovery unit. However the total salt balance would remain the same.

For the low salinity feedwater option the salinity of the water for stockyard washdown would increase from 350 mg/L TDS to 447 mg/L TDS. The same ratio would be applicable to the high salinity feedwater option where salinity levels would rise from 2,000 mg/L TDS to 2,815 mg/L TDS. This equates to a 27% increase in salinity for the low level salinity case and a 40% increase in salinity level for the high salinity case.

4.2.1 Cooling Tower Feedwater

Cooling towers are used to reject low grade heat from a water-cooled system. Heat is transferred by evaporation of a portion of the water stream into the air stream. As the latent heat of evaporation of water is much greater than the heat capacity of water, only a small portion of the water needs to be evaporated to achieve the required cooling effect for the bulk of the water flow.

As the process water is re-circulated, the mineral concentration will increase as a result of the evaporative losses. When the recirculated process water is concentrated to twice the original mineral content, it is referred to as 2 cycles of concentration (COC). The purpose of a water treatment program is to maximise the COC while minimising scaling, corrosion and microbiological growth.

Since it would be desirable to operate near the maximum acceptable TDS concentration in order to obtain maximum use of the water, and noting that the dissolved impurities are electrolytes (therefore conductive), water conductivity is typically measured and used to control the blowdown of the system. Makeup water is typically controlled based on level control in the cooling tower sump.

There are three classes of problems common to all cooling systems which are influenced by water quality:

- corrosion
- scale
- biological growth

Corrosion

Corrosion can be minimised by the addition of a corrosion inhibitor chemical to the cooling water system. Inhibitors are chemicals that either react with a metallic surface to prevent attack (passivation), or by scavenging and neutralising the corrosive species in the cooling water system. pH measurement is used to measure and control the alkalinity level of the water in order to prevent corrosion, with pH correction made by dosing a phosphoric acid based treatment chemical system.

Only by disposing of a percentage of the re-circulated water (blow-down) and by adding fresh make-up water to the cooling tower can the concentration of total dissolved solids (TDS) be maintained within control limits, and water chemistry optimised. Poor control in maintaining the water chemistry can result in system corrosion, typically of ferrous metals.

Scaling

The most important factor relating to cooling tower performance is scaling, which is typically caused by the over saturation of calcium compounds in the cooling water (poor control over COC).

Impurities in makeup water (town's water / bore water) are normally alkaline in nature, usually in the form of calcium bicarbonate and magnesium bicarbonate. The concentration of these impurities must be controlled to prevent scale formation within the cooling system. These impurities, especially calcium bicarbonate, are less soluble at higher pH values, therefore more likely to form scale on the system. Acid is added to the circulating water to lower the pH, though it must always be kept above a pH of 6.0. This maintains the calcium species in a dissolved state, so they can be removed by the blow down of the system.

Biological growth

The efficiency of cooling water systems can be severely affected by biological growth. Additionally, the human health aspects of maintaining cooling tower disinfection require application of maintenance regimes, most notably targeting *Legionella Sp*. To mitigate biological growth the recirculating cooling water is treated by disinfectants and/ or biocides.

For the low salinity scenarios, the COC in the cooling towers was assumed to be between 3 and 4. After RO pre-treatment, it could be possible to increase the COC to 10 without increasing the TDS in the cooling water above base case conditions. The new operating parameters would result in a 20% saving in water consumption.

For the high salinity scenarios, the COC in the cooling towers was assumed to be 2. After RO pre-treatment, it was possible to again increase the COC to 10 without increasing the TDS in the cooling water above the current base case. These operating parameters would result in a 35% saving in water consumption.

4.2.2 Boiler feed water

Municipal water or groundwater cannot generally be used directly as boiler feed water, and typically would require some form of pre-treatment. Feed service water constituents such as iron, copper, silica and hardness are known to be undesirable in the boiler feedwater, leading to operational problems with boiler tube scaling and the potential for hot-spotting. Dissolved oxygen is another contaminant in the boiler feed water that has the potential to cause corrosion in the boiler tubes or steam pipes.

Typical boiler feedwater requirements (for up to 20 bar operating pressure) are provided below

pH	8.3 -10.0
Iron as Fe	< 0.10 mg/L
Copper as Cu	< 0.05 mg/L
Total Hardness (as $CaCO_3$)	< 0.30 mg/L

Contaminants in the feedwater are concentrated in the boiler kettle as the steam is raised. Water treatment chemicals are added to maintain the boiler water chemistry to avoid precipitation and scale formation. The principle control of the boiler water quality is by regular blow-down of the boiler water. Depending on the capacity of the boiler, blow-down can either be an automated or a manual operation.

Reducing the dissolved salts from the boiler feedwater can enable an increase in the number of cycles of concentration that can be achieved in the boiler. The current best practice is to adopt a pre-treatment employing RO. In most cases, RO has been shown to be economically beneficial if the feed water TDS is above 300 mg/L. The higher the TDS, the greater the potential benefits are for RO.

The following are typical benefits of using RO as a pre-treatment step for boiler make up water

- Reduced fuel cost through lower heat loss
- Increase in boiler cycles with reduced blowdown
- Reduced boiler system chemical treatment costs
- Improved operation and steam purity
- Reduced risk (most boiler failures occur due to tube failures)
- Improved condensate corrosion control

Implementation must be considered on a case by case basis. The following factors needs to be considered.

- Current cycles of concentration
- Capacity of the boiler
- Feed water quality
- % of feed water make up to % hot condensate return
- Is there a use for RO brine?

For the low salinity feedwater scenarios, we have assumed that COC in the boilers would be around a figure of 10. After RO pre-treatment, we estimate that it is possible to increase the COC to nominally a figure of 100 without increasing the total salinity in the cooling water. On this basis we estimate that it could be possible to achieve a saving in water consumption of 35%.

For the high salinity feedwater scenarios, we have assumed that the COC in the boilers would be nominally a factor of 2. After RO pre-treatment, we estimate that it could be possible to increase the COC to 10 without increasing the salinity in the cooling water. On this basis we estimate that it could be possible to achieve a water consumption saving, similar to that for the low salinity feedwater option, of 35%.

4.2.3 Chiller and condenser feed water

We estimate that for the chiller and condenser feed water the water savings would be similar to that identified for the cooling towers. No provision, however, has been made for any energy savings.

4.3 Task 4 - Energy Analysis

4.3.1 Case Study: Use of Ro for Boiler Water Pre-Treatment

Vendor: GE Water & Process Technologies RO Technology
Client: Unilever Plant, Rexdale Ontario, Canada

A case study data sheet is provided in Appendix E

The following is a summary of the impact of implementing RO pre-treatment as a replacement for conventional boiler water pre-treatment.

- Plant boiler capacity = 100 000 tonnes of steam per year.
- Make up water source: Municipal Water (TDS of 350 mg/L), chemically softened and dealkalised water.
- COC increased from nominally 10 to 100
- Boiler blowdown reduction of more than 80% was achieved
- RO plant payback period was less than 16 months
- Natural gas consumption was reduced by 8%
- Reduction in boiler chemicals and commodity softening chemicals

Although this case study suggests that higher energy savings can be expected, conservative energy savings have been adopted for this study. We estimate that a 1% energy saving is more realistic for low salinity water with a figure of 8% for the high salinity water option.

Table 4-3– Energy Analysis

Option	Base case (no RO)		With RO		Change	
	MWhr/annum	kWhr/t HSCW	MWhr/annum	kWhr/t HSCW	MWhr/annum	kWhr/t HSCW
Option 1 (LFLS)	11 919	835	11 810	827	109	8
Option 2 (MFLS)	44 735	835	44 323	827	412	8
Option 3 (HFLS)	149 110	835	147 736	827	1 374	8
Option 4 (LFHS)	11 919	835	10 965	768	954	67
Option 5 (MFHS)	44 735	835	41 156	768	3 579	67
Option 6 (HFHS)	149 110	835	137 181	768	11 929	67

4.4 Task 5 - Economic Analysis

The method we used to calculate any economic benefit of installing an RO system was to compare the operation cost without RO against the operating cost with RO.

4.4.1 Utilities

The total cost of water is not only the purchased price for water, but must include the cost of pre-treatment before the water is suitable for use in the abattoir, together with the treatment cost of waste streams and the associated disposal cost. Typical costs were used for town water for the low salinity option and for groundwater for the high salinity option.[i]

Table 4-4 Actual Cost of Water ($/kL)

Water Source	**Town**	**Groundwater**
Salinity	Low	High
Purchase	$1.20	N/A
Water pre-treatment and pumping	N/A	$0.56
Wastewater treatment	$1.29	$0.40
Wastewater discharge	$0.64	N/A
Total	**$ 3.13**	**$0.96**

<u>Annual cost increase for water and energy</u>

Water and energy costs are expected to increase at higher rates than the annual inflation rate. For this study we have adopted an average annual increase of 7%.

<u>Energy</u>

We have adopted a cost for the electricity supply of ten cents per kilowatt hour. For coal, only the direct cost of coal of $50 per tonne was used to calculate the energy saving.

4.4.2 RO Plant Capital Cost

The capital cost estimate for the supply of an RO plant for the high capacity, low salinity feedwater RO plant is based on industry advice of a unit rate of $2,500/ m^3/ day. The estimated capital cost for the high salinity feedwater RO plant, including the additional pre-treatment cost, would add approximately 60% to the capital cost compared to the low TDS case.

For the medium capacity plant option the unit cost was increased by nominally 20% to compensate for the reduced treatment quantity. For the low capacity plant option, the unit cost was increased by 40% above the baseline cost. For the high salinity feedwater plant, the costs were increased by similar percentages. These factors are summarised in Table 4-5.

Table 4-5 Summary of Estimated Unit rates for RO Plant Capital Costs

Feedwater	**Low TDS**			**High TDS**		
Capacity	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Basis			$2,500			
Factor	1.4	1.2	1	2.24	1.92	1.6
Capital cost ($/m^3/day)	$3,500	$3,000	$2,500	$5,600	$4,800	$4,000
Operating Cost ($/ m^3)	$0.60	$0.60	$0.60	$0.80	$0.80	$0.80

4.4.3 RO Operating Cost

The operating cost for RO was derived from a literature search and includes the membrane replacement cost and treatment chemicals but does not include the cost for labour for the operations and maintenance staff. An annual escalation cost of 7% was adopted for the RO operation, the same as that used for water and energy.

4.4.4 Internal rate of return calculation

The internal rate of return (ROR) was calculated over a 15 year period. For this ROR calculation, the capital was deemed to have been spent in year 0 and written off over a 10 year period. Depreciation was shown as a positive cashflow, because of the reduction in tax paid. This was calculated at 40% of the depreciation over 10 years.

4.4.5 Task 5 – Economic Analysis

Table 4-6 Summary of Economic Analysis

Option	**Without RO**		**With RO**		**With RO**	
	NPV, 15 years	$/tHSCW/yr	IRR, 15 years	$/tHSCW/yr	NPV, 15 years (@ 4%)	Payback period years
Option 1 (LFLS)	0	0	5.2	-0.05	$11,100	10.0
Option 2 (MFLS)	0	0	6.9	-0.11	$89,400	9.0
Option 3 (HFLS)	0	0	9.1	-0.17	$455,900	8.2
Option 4 (LFHS)	0	0	0.0	+0.21	($46,000)	14
Option 5 (MFHS)	0	0	1.0	+0.15	($120,000)	13
Option 6 (HFHS)	0	0	2.1	+0.09	($234,000)	12

The economic analysis is based on the following assumptions*:

1. Cost of electricity, water, coal and RO operating cost all escalate at 7% per year. This is probably very conservative as the cost of water and electricity is expected to increase substantially above the rate of inflation in the near future... The IRR of the project increases when these rates are increased.
2. Depreciation is written off over a period of 10 years. For each year, the depreciation is taken as a tax saving at a rate of 40% and is added to the project as a cash flow... If this is not the case, the IRR decreases by between 4.5 and 5.5%
3. Cost of water as per Table 4-4. If the real cost of water is higher, then an increase in the IRR of a project is expected.

4. Energy split with thermal coal supplying 70% of requirements. If the thermal coal proportion is lower, then the IRR decreases. No savings in electricity consumption were used for the calculations.
5. The cost of thermal coal that was used for the analysis is $50 per tonne. If the cost of coal increases, the IRR increases.
6. The estimated unit RO capital cost are as detailed in Table 4-5 for the different scenarios. The IRR decreases with higher RO capital cost,
7. The RO operating cost for the low and high salinity options is respectively $0.6/m^3 and $0.80/m^3. The IRR decreases with higher the RO operating cost,
8. The RO membranes are replaced every five years for the high salinity option and every 6 years for the low salinity option. If the interval between membrane replacements is increased, the IRR of the project increases.
9. No savings on chemical consumption in the cooling towers and boilers were used for this economic analysis

For the low salinity option the water savings contribution is approximately 5 times that of the energy contribution. For the high salinity option, the energy savings component is approximately 1.5 times that of the water savings contribution.

The detailed economic analysis is provided in Appendix D.

5 Technical Review of Demineralisation Technologies

Although some substances dissolved in water, such as calcium carbonate, can be removed by chemical treatment, other common constituents, like sodium chloride, require a molecular separation process, collectively known as demineralisation. In the past, the difficulty and expense of desalination rendered brackish water technically and economically unattractive as a source of potable water. However, due to significant improvements to demineralisation technology, from the early 1970's desalination of brackish water became commercially viable and practicable in Australia.

All demineralisation processes involve three major liquid streams: the saline feedwater (ranging from low salinity water to high salinity brackish water), a low-salinity product water, and high salinity concentrate (brine or reject water). There are also cleaning / regeneration waste streams which are minor in volume, but may require further treatment or other disposal destinations, for instance chemical washed for membranes.

The salinity of the product water from the demineralisation process would have a TDS ranging from nominally 50 mg/L to 500 mg/L. This product water would be suitable for most domestic, industrial, and agricultural uses.

The brine stream is a concentrated salt solution, generally with a TDS ranging from 2000 mg/L to more than 10 000 mg/L. Brine can be disposed of by discharge into deep saline aquifers or to surface waters if the salinity of the brine stream is acceptable for the receiving environment. Brine can also be diluted with treated effluent and disposed of by irrigating crops, golf courses and/or other open space areas providing that the salinity of the blended water is acceptable for crops and grasses

The following demineralisation technologies have been evaluated in this investigation:

- Reverse Osmosis
- Electro-Dialysis Reversal (EDR)
- Nanofiltration
- Thermal Technology

Although the following emerging demineralisation technologies were considered, as they are at an early development stage, they have not been evaluated further

- Forward Osmosis
- Capacitive Deionisation
- Improvements in RO technology

Detailed technical descriptions of these demineralisation technologies are provided in Appendix D.

Ion Exchange (IX) technology was also considered as one of the demineralisation technology options but has been discounted as non viable as it is not practicable from technical and economic terms for treating water with TDS levels > 300 mg/L .

Table 5.1 – Comparison of Demineralisation Technology Options

Technology	Principle	Features	Benefits	Commercialisation
RO	Pressure driven membrane process	• Ideal for treating brackish water with TDS > 300 mg/L. • Established as preferred brackish water demineralisation technology globally • Requires good pre-treatment • Creates a brine concentrate that can be difficult and costly to dispose of	• Compact • Modular • High overall recovery • High product quality	• Proven technology • RO systems have been applied in Australia for brackish water desalination since the early 1970's. •
Thermal technology	Mechanical evaporation process driven by heat transfer for condensing steam across a metallic heat transfer surface	• High capital; investment cost • High energy requirement • Exotic steels required for longevity	• Highest recovery technology (from 95% to 99%) • Has potential to produce solid (i.e. salt) which could be sold	• Well proven technology • Commercialised over 30 years ago in the Middle East using waste heat as energy source. • No known reuse applications in Australia •
EDR	Membrane technology that uses direct current (DC) potential across anion and cation permeable membranes to desalinate water	• Relatively low energy technology (but higher than RO) • Not economically viable for brackish waters with TDS > 3,000 mg/L	• Potentially simpler pre-treatment than for RO. • Compact • Modular • Medium to high overall recovery • Medium to high product quality	• Proven technology • Limited applications in Australia
Nanofiltration	Pressure driven membrane process	• Most suited for alkaline brackish waters • Lower energy than RO (nominally up to 30% less) • Not suited to reduction of divalent ions	• Similar features to RO but with lower capital & operating cost	• Not proven technology • Limited commercial application to date.

Table 5.2 – Comparison of Emerging Demineralisation Technologies

Technology	**Principle**	**Features**	**Benefits**	**Commercialisation**
Forward Osmosis (also referred to as engineered osmosis)	Uses an osmotic pressure gradient instead of pressure or heat to force water through a purifying membrane	• Not proven technology	• Potentially lower energy requirement compared with pressure driven technologies such as NF & RO.	• Unproven. • At early demonstration stage.
Capacitive deionization	Uses carbon aerogel, a porous material with a high surface area and extremely low electrical resistance and a small direct current to desalinate water	• High cost of aerogel • Only at small scale development phase	• Potentially low energy desalination technology	• Unproven • At an early development phase
Advances in RO technology	1. Hydrophilic, membrane process embedding nanoparticles to a water purifying membrane to potentially double the membrane efficiency with only 5 percent additional production costs 2. Carbon nanotube-based membranes could reduce cost of purifying water from the ocean.	1. Membrane has the ability to filter out contaminants 2. Potentially could provide a solution to water shortages.	• Potentially low energy desalination technology	• Unproven technology • At very early development stage

6 Technical and economic assessment of application of demineralisation using membrane systems to meat processing plants

For this study, the 10% of water being used for services was earmarked for demineralisation. Several studies have shown that water and energy savings can be made from using RO to treat either cooling water or boiler feed water.

Demineralisation of water used in the other areas of the abattoir also has the potential to improve the quality of the water. Each abattoir will have to do an assessment on the perceived benefits of having better quality water, but it cannot be justified purely from an economical point of view.

Combining all the estimated parameters into a cost benefit analysis, the potential internal rate of returns that are calculated are summarised in Table 6.1.

Table 6-1 Illustrative Rate of Return on Investment

	Salinity of feed water source	
RO Plant Capacity	**Low salinity (towns water)**	**High salinity (bore water)**
Low	5.2%	0.0%
Medium	6.9%	1.0%
High	9.1%	2.1%

The estimated benefit of an RO system is more significant for low salinity municipal water than for high salinity feed water. Any saving in water usage will have an increased cost effect because of the higher disposal cost of water in towns.

7 Feasibility study of the use of RO brine stream for supply to water consuming activities in the meat processing plant Discussion

The RO brine stream could be used for the following applications:

- Feed stock watering
- Stock yard washing

The following estimates of the RO brine quantity and quality for the various options together with the potential water quantity reduction and water quality effects is provided in Table 7-1

Table 7.1 - Estimates of RO Brine Quantity and Quality

Option	Potential savings (kL/day)	Potential water quality effects	Estimates of RO 'brine' quantity and quality
Option 1	8	Feed TDS 350 mg/L reduced to 70 mg/L for utility/ services , Feed to stockyard wash down and stock watering TDS increases from 350 mg/L to 447 mg/L	TDS = 1937 mg/L Flow = 5.6 kL/d
Option 2	30	Feed TDS 350 mg/L reduced to 70 mg/L for utility/ services , Feed to stockyard wash down and stock watering TDS increases from 350 mg/L to 447 mg/L	TDS = 1937 mg/L Flow = 21.2 kL/d
Option 3	100	Feed TDS 350 mg/L reduced to 70 mg/L for utility/ services , Feed to stockyard wash down and stock watering TDS increases from 350 mg/L to 447 mg/L	TDS = 1937 mg/L Flow = 70.6 kL/d
Option 4	14	Feed TDS 2000 mg/L reduced to 70 mg/L, Feed to stockyard wash down and stock watering TDS increases from 2000 mg/L to 2815 mg/L	TDS = 12937 mg/L Feed = 6.0 kL/d
Option 5	52	Feed TDS 2000 mg/L reduced to 70 mg/L, Feed to stockyard wash down and stock watering TDS increases from 2000 mg/L to 2815 mg/L	TDS = 12937 mg/L Feed = 22.4 kL/d
Option 6	175	Feed TDS 2000 mg/L reduced to 70 mg/L, Feed to stockyard wash down and stock watering TDS increases from 2000 mg/L to 2815 mg/L	TDS = 12937 mg/L Feed = 74.6 kL/d

8 Conclusions

The application of membrane based demineralisation (RO) technology in the meat processing industry to demineralise the incoming water supply has the potential to provide water and energy savings. This treatment however would be restricted to nominally 10% of the total abattoir water consumption.

RO is a commercially proven demineralisation technology that could provide significant benefits for cooling tower and boiler make up water applications in the meat processing industry, particularly for high salinity water situations. Using desalinated water would allow higher cycles of concentration (COC) to be achieved with no adverse effects to existing systems. The additional benefit could be substantial reductions to the cooling tower make- up water requirements. Overall, RO treated water if used in these systems could reduce the water treatment chemical consumption.

For the low feedwater salinity scenarios, a COC in the cooling towers without RO treatment of nominally between 3 and 4 was adopted. After RO pre-treatment, it was identified that it could be possible to increase the COC to nominally as high as 10 (without increasing the salinity in the cooling water) with a potential saving in water consumption of 20%. In the case of the high salinity feedwater scenario, a COC in the cooling towers without RO treatment of nominally 2 was adopted. After RO pre-treatment, it was identified that it could be possible to increase the COC to nominally as high as 10 (without increasing the salinity in the cooling water) with a potential water saving consumption of 35%.

For the low salinity feedwater, the use of RO as a pre-treatment for the boiler feedwaters could achieve an increase in the COC from typically 10 to as high as 100 cycles. Similarly, for the high salinity feedwater case, the estimated increase change in the COC in the boilers could be from 2 to 100 cycles. This would result in a significant lower boiler blowdown demand, with subsequent savings in water, energy, and chemicals.

In terms of energy savings, from the literature reviews and case study presented, we have estimated that a 2% energy saving could be achievable for a low salinity feed water, whilst a higher energy saving, in the order of 8%, could be achieved for the high salinity water feedwater.

The disposal of the RO brine stream on-site to the stockyard washdown would only slightly increase the washdown water salinity. This approach offers a simple and viable method for disposal of the RO brine.

9 Recommendations

Although it has been identified in this study that there are potential water and energy savings by using an RO plant to desalinate the feed water to the abattoir services area, the savings are not considered significant enough to justify the application of RO membrane demineralisation on economic terms alone. Under a different situation, where carbon dioxide emissions are taxed, the attractiveness of using an RO plant may be markedly different.

It is anticipated that reducing the salinity of the feedwater by the application of RO to boilers and cooling towers could provide additional benefits, such as increased equipment life and reduced chemical consumption. However these potential benefits have not been quantified in this study. In situations of water scarcity, water conservation could be a critically important consideration so that the application of RO may be worthwhile considering to reduce the abattoir water resource requirement.

It is recommended that consideration be given to validate the findings of this study by undertaking a trial with a rental pilot RO plant. Such a pilot demonstration, at a suitable abattoir, could be invaluable to evaluate savings relating to energy, water and chemical consumption for make-up water to the cooling tower and boiler systems. The outcomes from this pilot trial could establish an industry benchmark on the viability of applying RO demineralisation technology for the Australian meat processing industry.

10 Bibliography

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2. MLA (2009) Red Meat Processing Industry Energy Efficiency Manual. Prepared by Hydro Tasmania Consulting as Project A.ENV.0065 Final Report, January 2009. MLA North Sydney.
3. Best Practice Wastewater Treatment, Wastewater Manual, July 1998
4. HERO process volume reduction of cooling tower blowdown as pre-concentrator for ZLD application, Charles H. Fritz, Black & Veatch Corporation, Kansas City, Missouri, Bipin Ranade, Aquatech International Corporation
5. General Electric Case study, GE’s RO system helps Unilever reduce water, natural gas consumption and chemical usage.
6. Guidelines for the handling treatment and disposal of abattoir waste, draft 1 - 29 August 2001
7. Water supply and Wastewater Treatment at proposed Bacchus Marsh Abattoir.

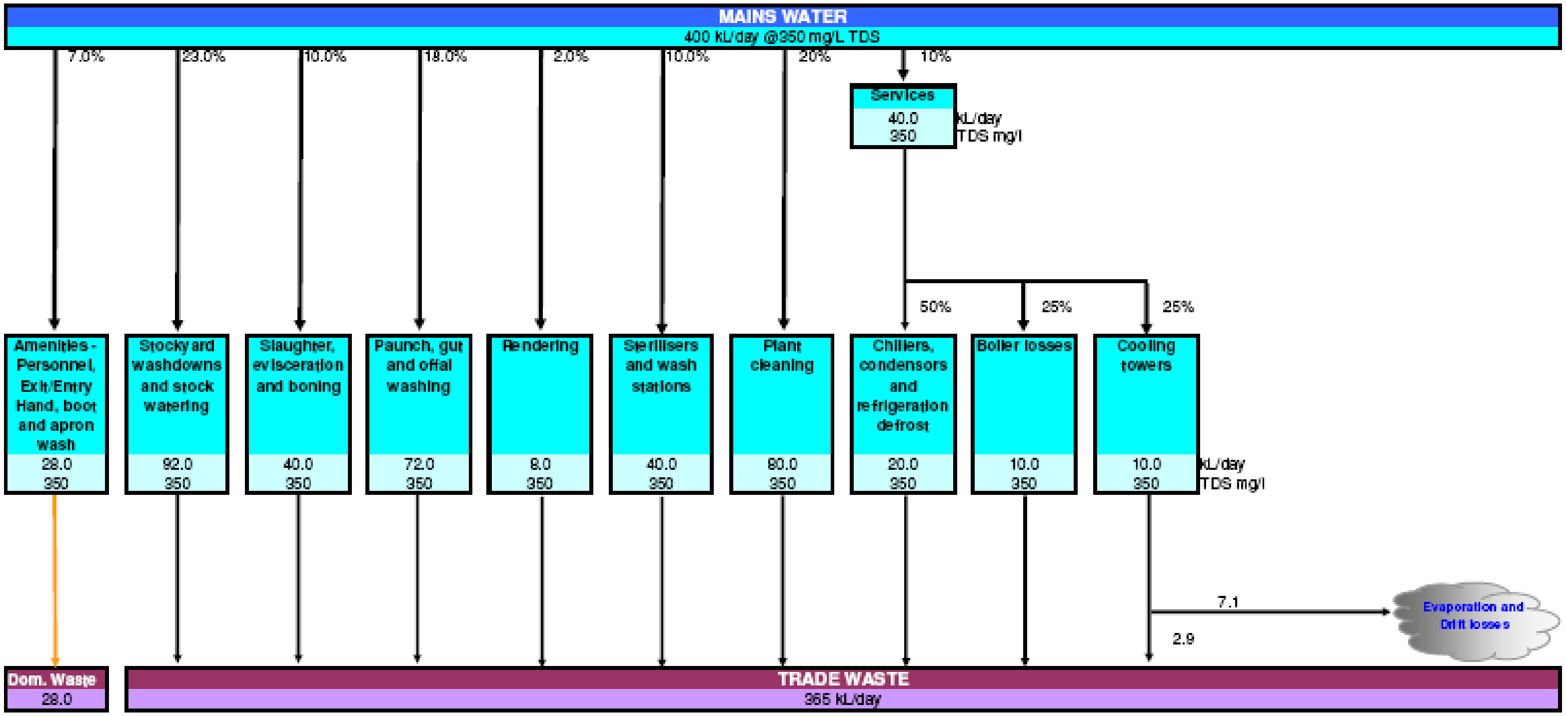
Appendices

Appendix A Mass Balances for Options 1 to 6

Option 1a	Low salinity / Low use
Option 1b	Low salinity / Low use with RO
Option 2a	Low salinity / Medium use
Option 2b	Low salinity / Medium use with RO
Option 3a	Low salinity / High use
Option 3b	Low salinity / High use with RO
Option 4a	High salinity / Low use
Option 4b	High salinity / Low use with RO
Option 5a	High salinity / Medium use
Option 5b	High salinity / Medium use with RO
Option 6a	High salinity / High use
Option 6b	High salinity / High use with RO

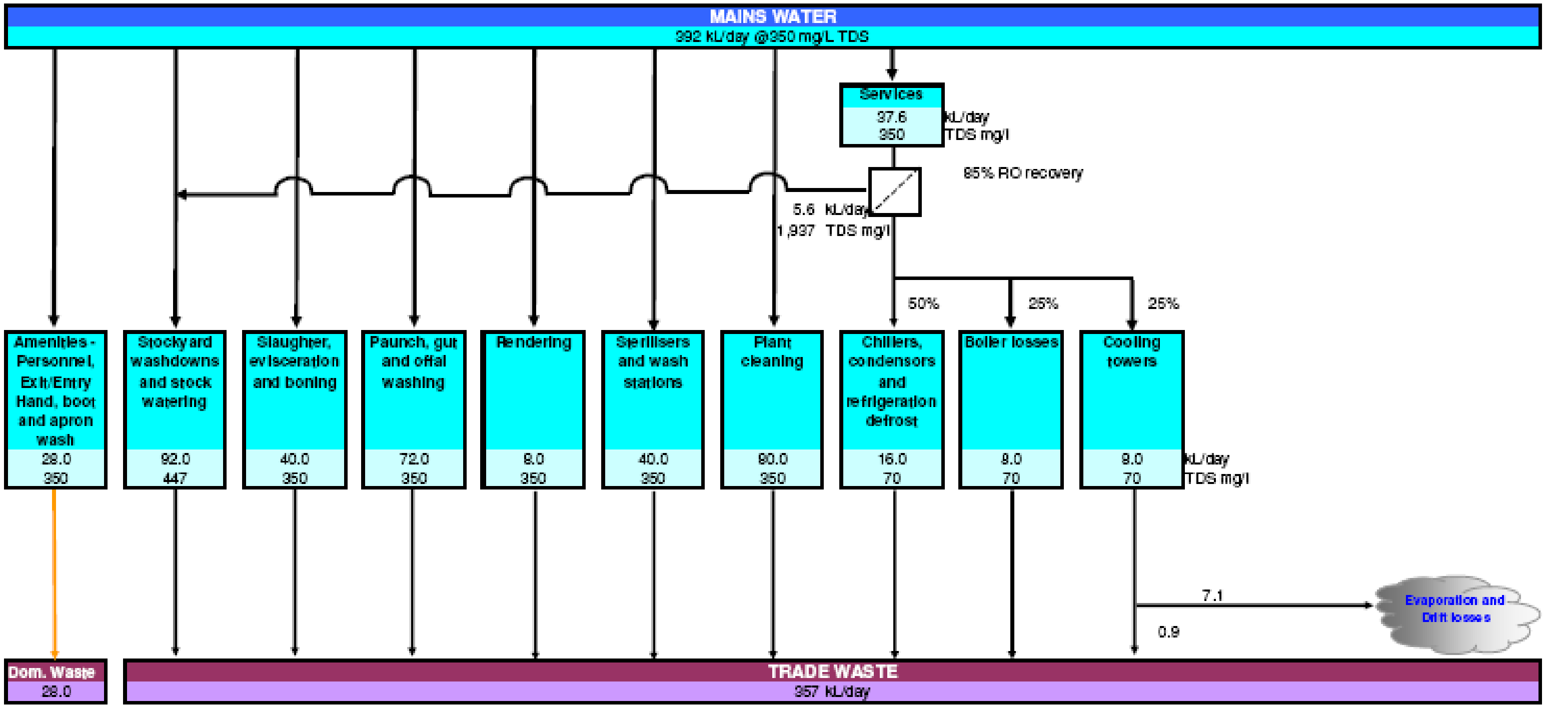
ABATTOIR WATER USE FLOW CHART

Option 1a - Low use / Low salinity



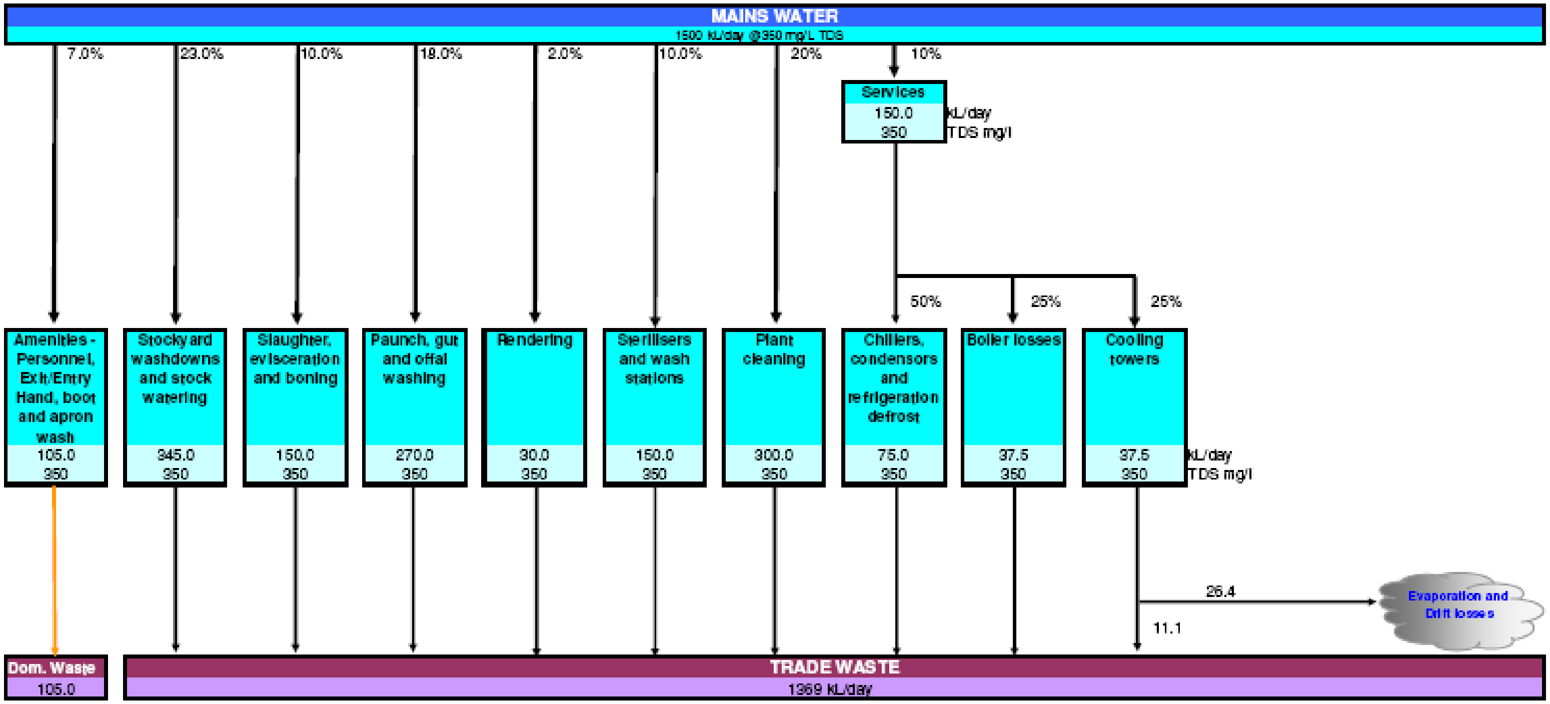
ABATTOIR WATER USE FLOW CHART

Option 1b - Low use / Low salinity with RO



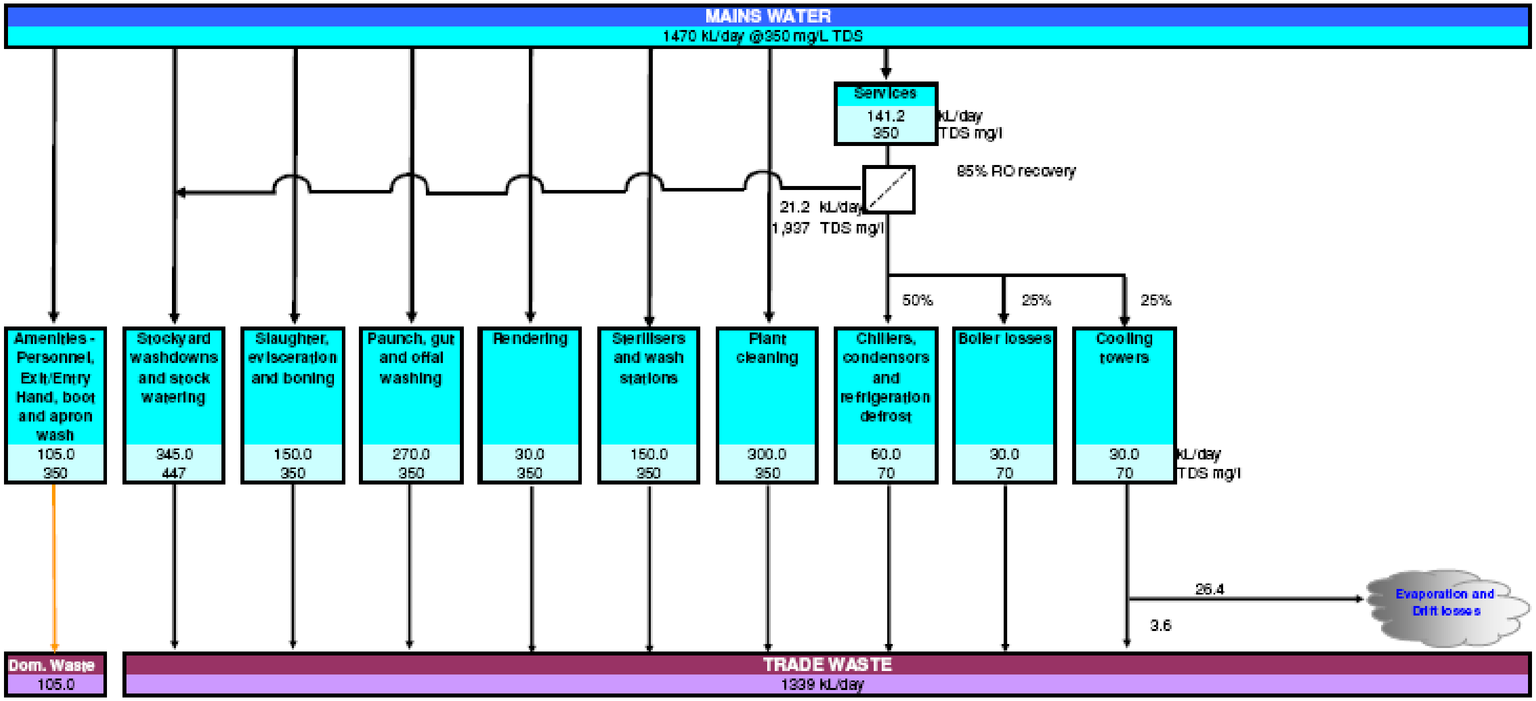
ABATTOIR WATER USE FLOW CHART

Option 2a - Medium use / Low salinity



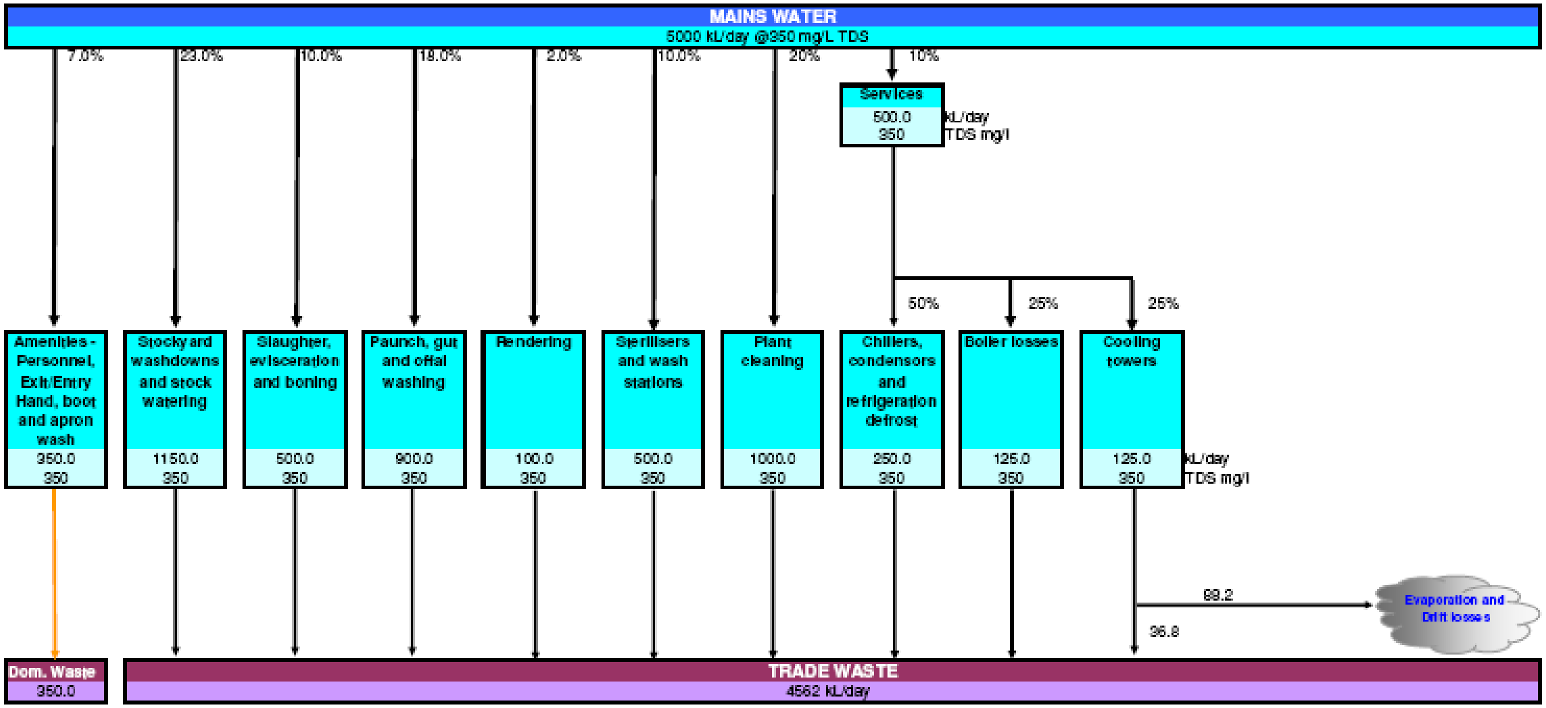
ABATTOIR WATER USE FLOW CHART

Option 2b - Medium use / Low salinity with RO



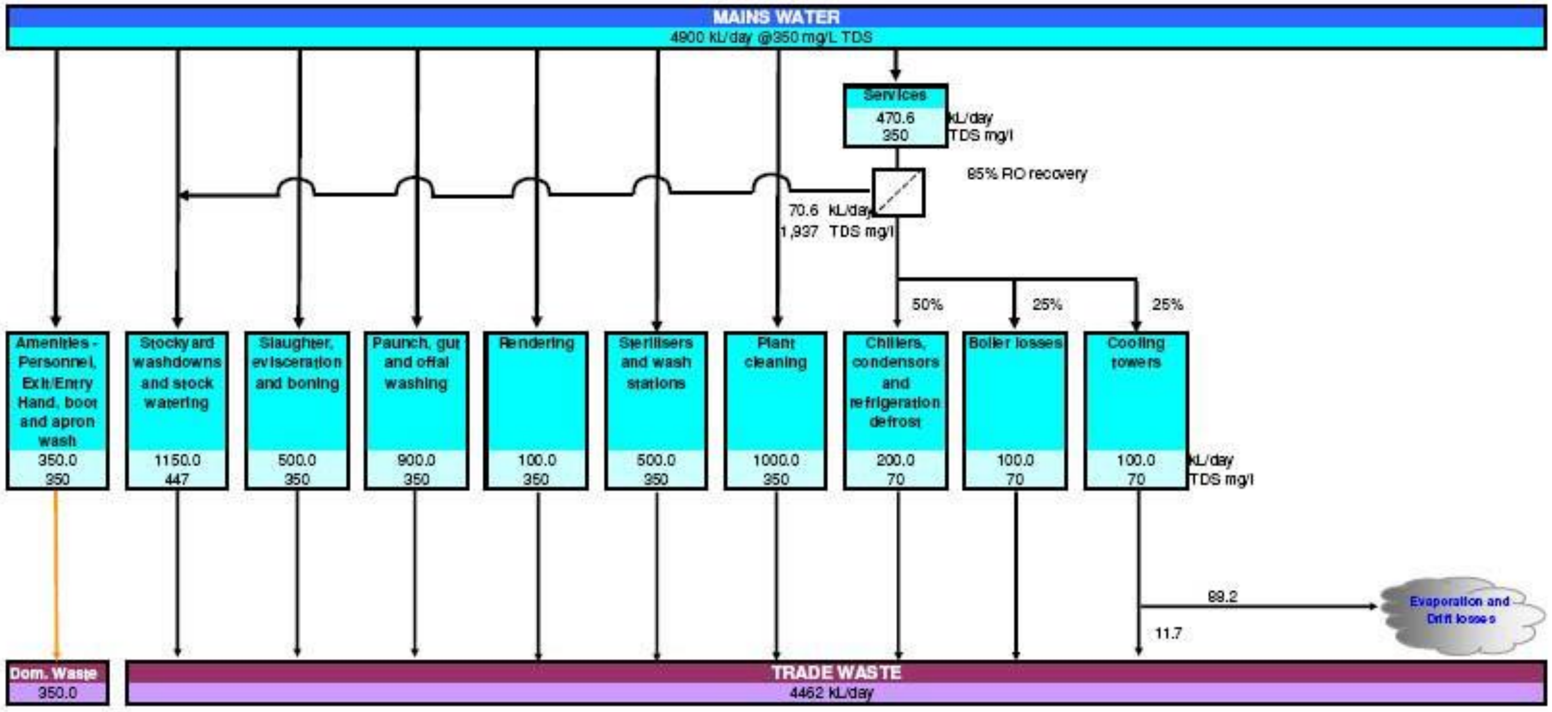
ABATTOIR WATER USE FLOW CHART

Option 3a - High use / Low salinity



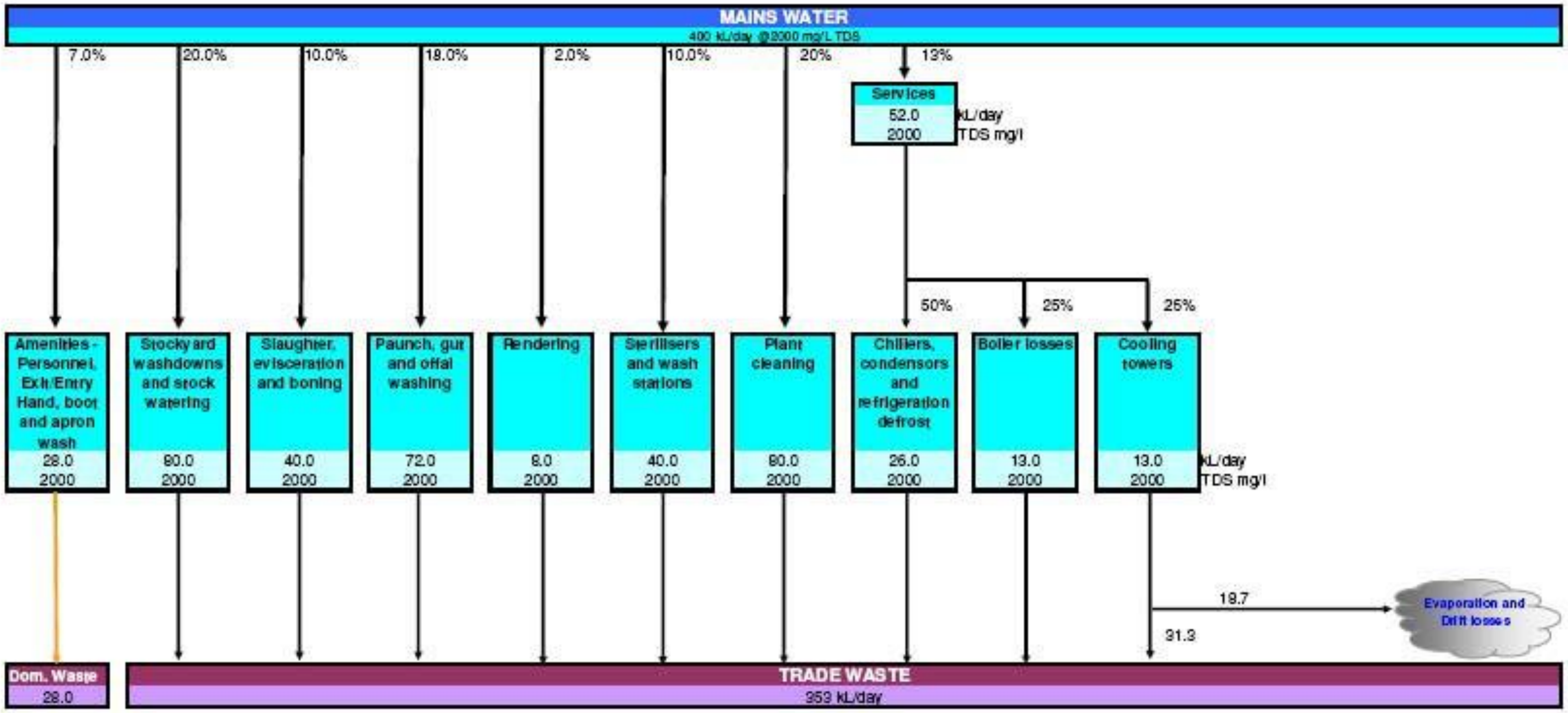
ABATTOIR WATER USE FLOW CHART

Option 3b - High use / Low salinity with RO



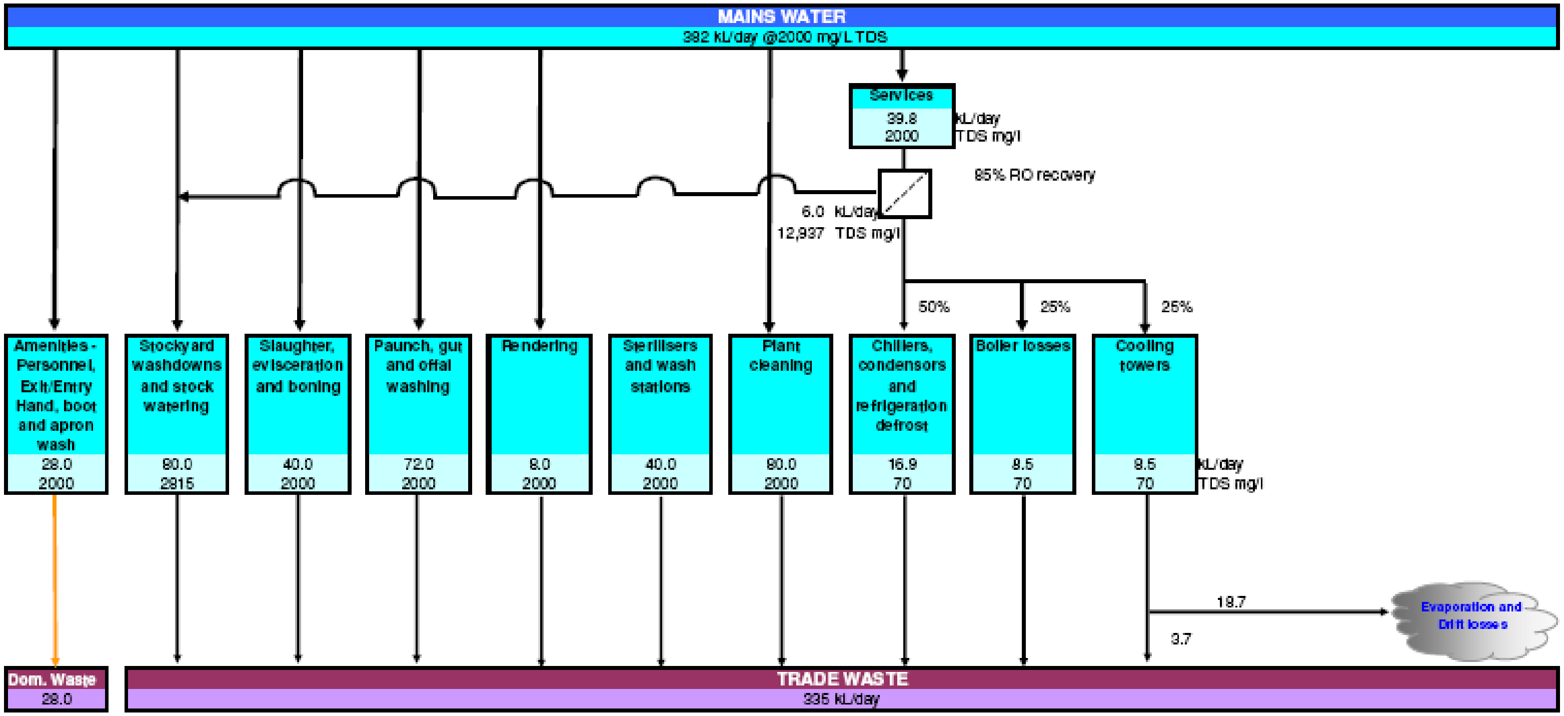
ABATTOIR WATER USE FLOW CHART

Option 4a - Low use / High salinity



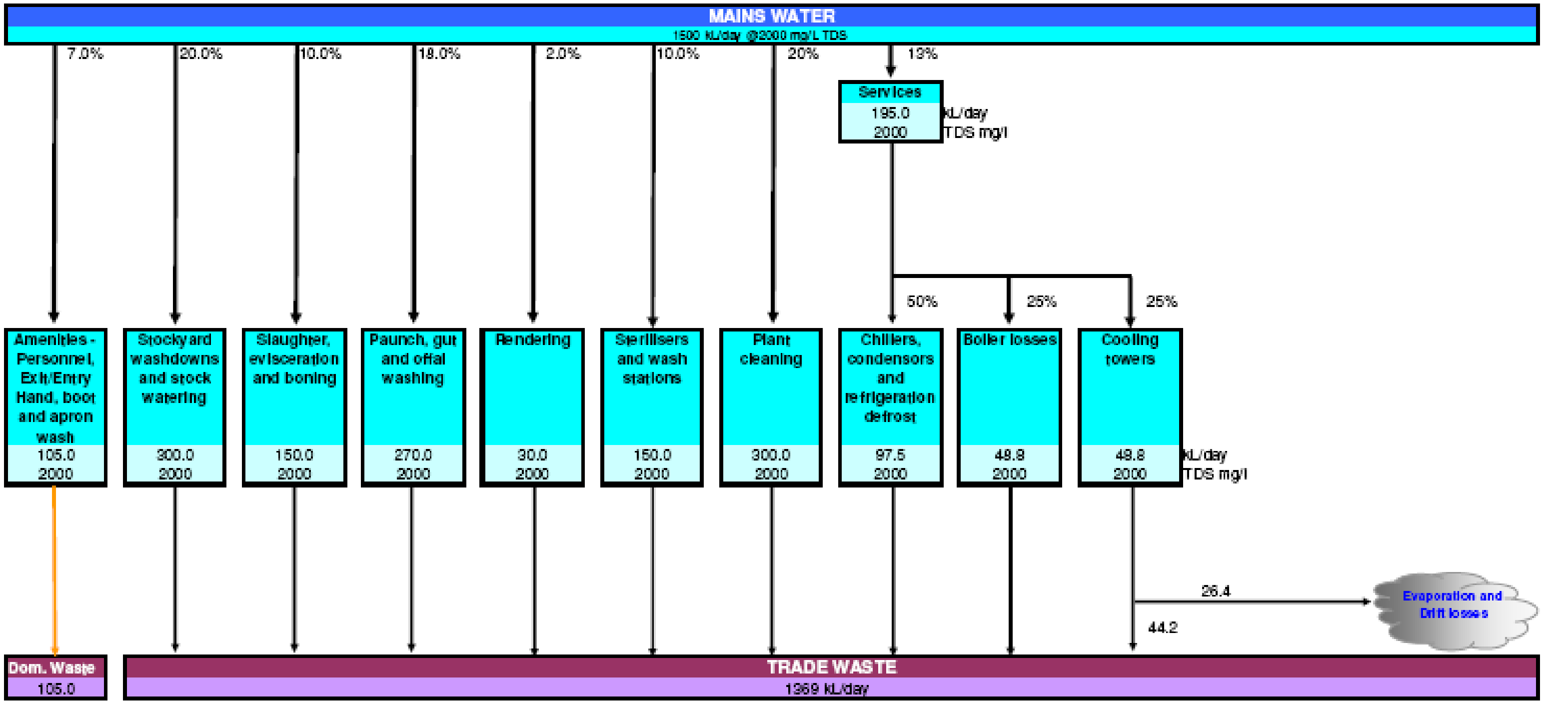
ABATTOIR WATER USE FLOW CHART

Option 4b - Low use / High salinity with RO



ABATTOIR WATER USE FLOW CHART

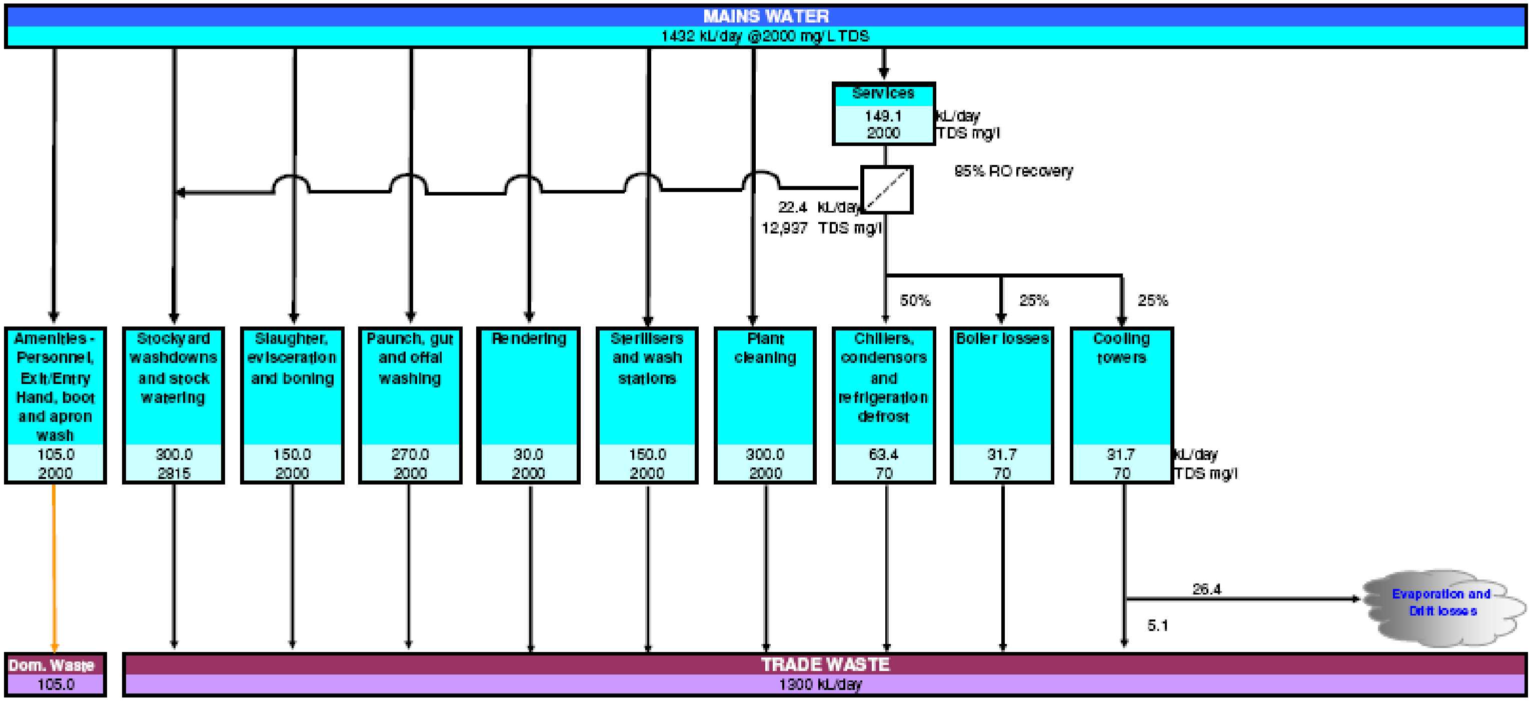
Option 5a - Medium use / High salinity



Economic Evaluation of Demineralisation

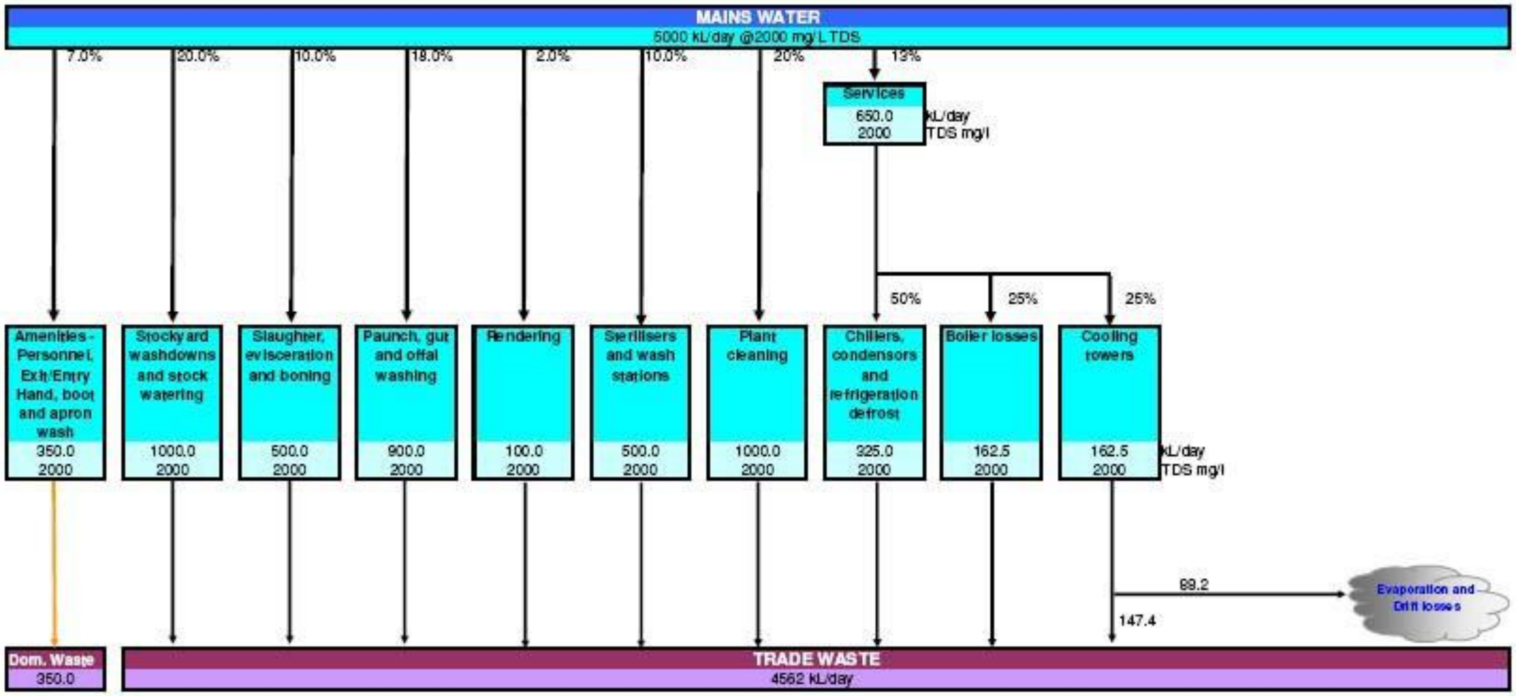
ABATTOIR WATER USE FLOW CHART

Option 5b - Medium use / High salinity with RO



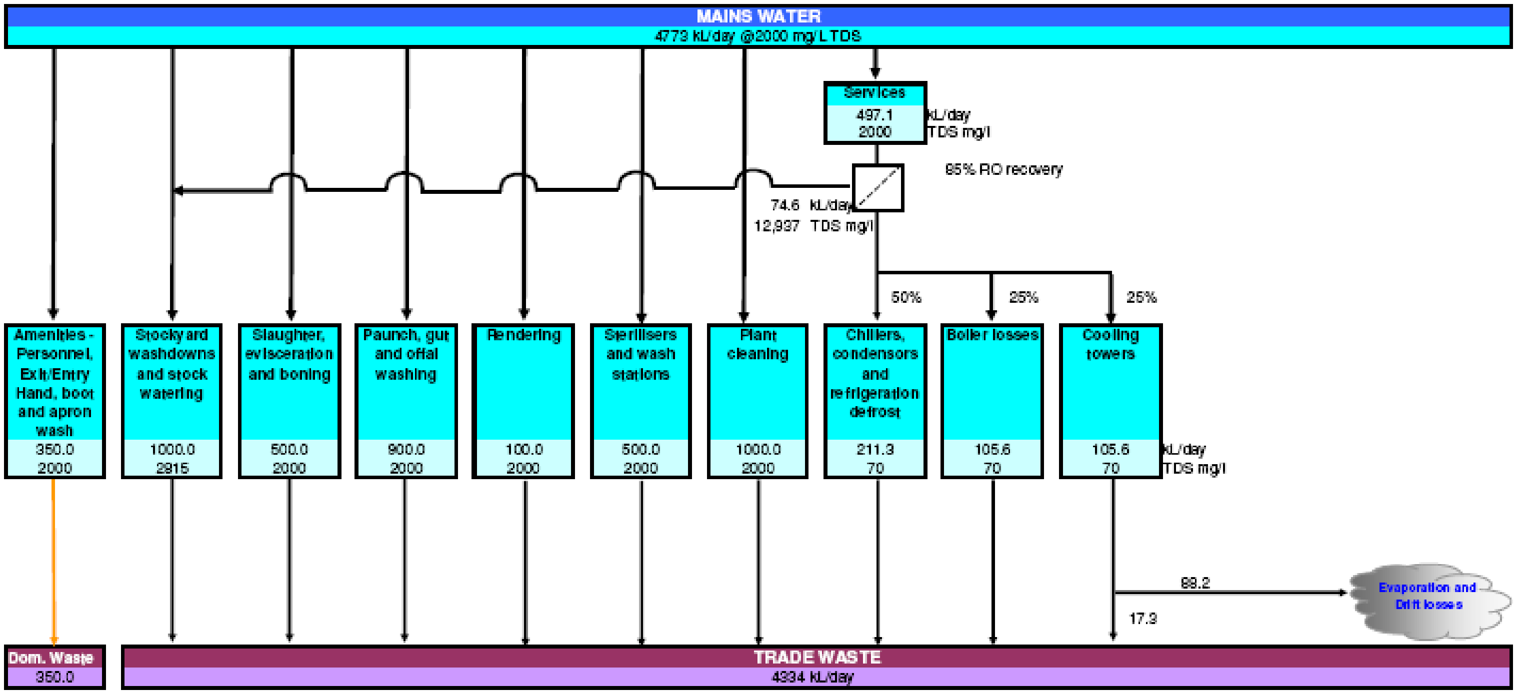
ABATTOIR WATER USE FLOW CHART

Option 6a - High use / High salinity



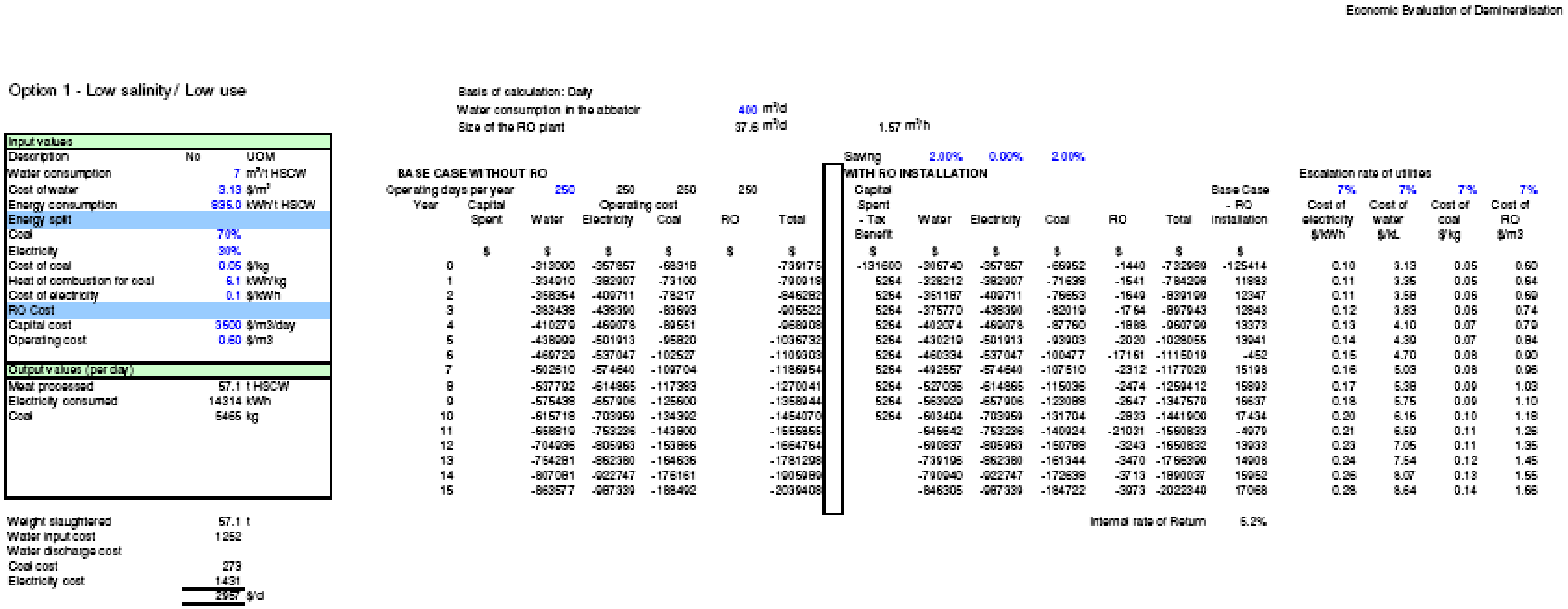
ABATTOIR WATER USE FLOW CHART

Option 6b - High use / High salinity with RO



Appendix B Financial Calculations

- Financial calculation Option 1 - Low salinity / Low use with RO
- Financial calculation Option 2 - Low salinity / Medium use with RO
- Financial calculation Option 3 - Low salinity / High use with RO
- Financial calculation Option 4 - High salinity / Low use with RO
- Financial calculation Option 5 - High salinity / Low use with RO
- Financial calculation Option 6 - High salinity / Low use with RO



Economic Evaluation of Demineralisation

Option 1 - Low salinity / Low use

Input values		
Description	No	UOM
Water consumption	7	m^3/t HSCW
Cost of water	3.13	\$/m^3
Energy consumption	835.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	\$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	\$/kWh
RO Cost		
Capital cost	3500	\$/m3/day
Operating cost	0.60	\$/m3

Output values (per day)		
Meat processed	57.1	t HSCW
Electricity consumed	14314	kWh
Coal	5465	kg

Weight slaughtered	57.1	t
Water input cost	1252	
Water discharge cost		
Coal cost	273	
Electricity cost	1431	
	2957	\$/d

Basis of calculation: Daily

Water consumption in the abbatoir 400 m^3/d

Size of the RO plant 37.6 m^3/d 1.57 m^3/h

BASE CASE WITHOUT RO

Operating days per year		250	250	250	250	
Year	Capital	Operating cost				
	Spent	Water	Electricity	Coal	RO	Total
	\$	\$	\$	\$	\$	\$
0		-313000	-357857	-68318		-739175
1		-334910	-382907	-73100		-790918
2		-358354	-409711	-78217		-846282
3		-383439	-438390	-83693		-905522
4		-410279	-469078	-89551		-968908
5		-438999	-501913	-95820		-1036732
6		-469729	-537047	-102527		-1109303
7		-502610	-574640	-109704		-1186954
8		-537792	-614865	-117383		-1270041
9		-575438	-657906	-125600		-1358944
10		-615718	-703959	-134392		-1454070
11		-658819	-753236	-143800		-1555855
12		-704936	-805963	-153866		-1664764
13		-754281	-862380	-164636		-1781298
14		-807081	-922747	-176161		-1905989
15		-863577	-987339	-188492		-2039408

Saving 2.00% 0.00% 2.00%

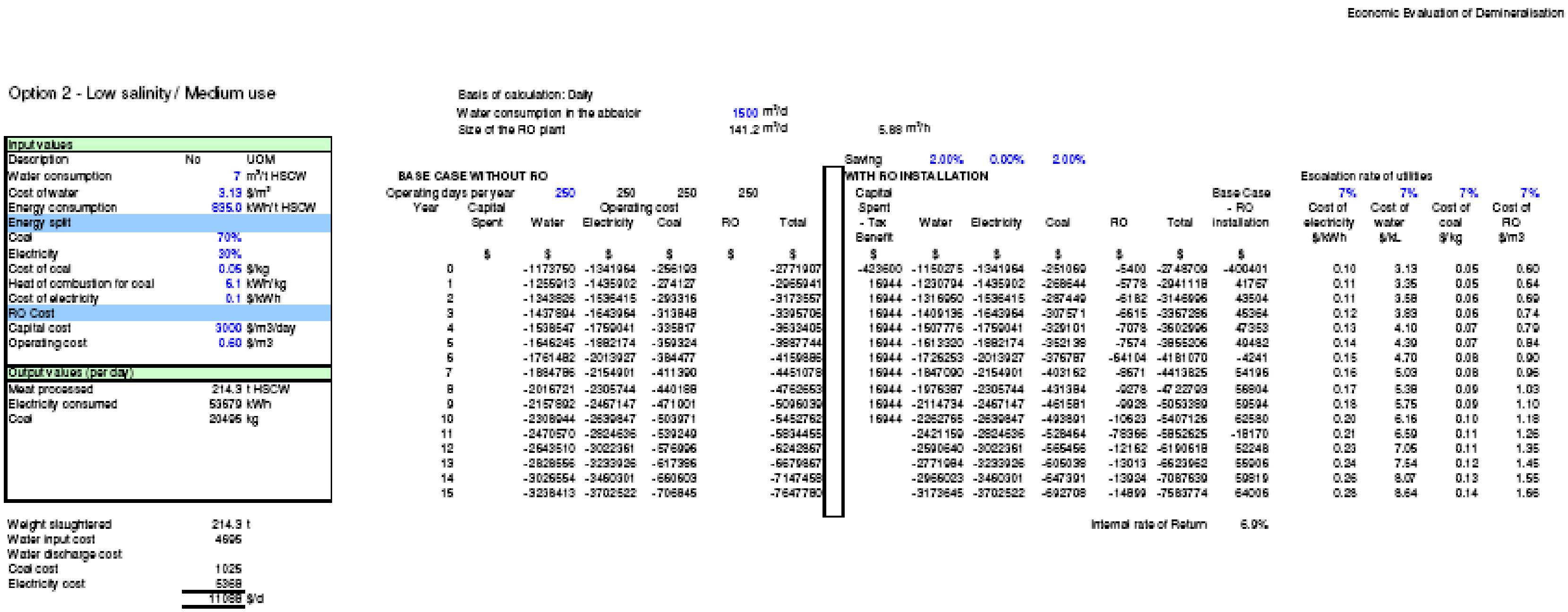
WITH RO INSTALLATION

Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation
\$	\$	\$	\$	\$	\$	\$
-131600	-306740	-357857	-66952	-1440	-732989	-125414
5264	-328212	-382907	-71638	-1541	-784298	11883
5264	-351187	-409711	-76653	-1649	-839199	12347
5264	-375770	-438390	-82019	-1764	-897943	12843
5264	-402074	-469078	-87760	-1888	-960799	13373
5264	-430219	-501913	-93903	-2020	-1028055	13941
5264	-460334	-537047	-100477	-17161	-1115019	-452
5264	-492557	-574640	-107510	-2312	-1177020	15198
5264	-527036	-614865	-115036	-2474	-1259412	15893
5264	-563929	-657906	-123088	-2647	-1347570	16637
5264	-603404	-703959	-131704	-2833	-1441900	17434
	-645642	-753236	-140924	-21031	-1560833	-4979
	-690837	-805963	-150789	-3243	-1650832	13933
	-739196	-862380	-161344	-3470	-1766390	14908
	-790940	-922747	-172638	-3713	-1890037	15952
	-846305	-987339	-184722	-3973	-2022340	17068

Internal rate of Return 5.2%

Escalation rate of utilities

7%	7%	7%	7%
Cost of electricity \$/kWh	Cost of water \$/kL	Cost of coal \$/kg	Cost of RO \$/m3
0.10	3.13	0.05	0.60
0.11	3.35	0.05	0.64
0.11	3.58	0.06	0.69
0.12	3.83	0.06	0.74
0.13	4.10	0.07	0.79
0.14	4.39	0.07	0.84
0.15	4.70	0.08	0.90
0.16	5.03	0.08	0.96
0.17	5.38	0.09	1.03
0.18	5.75	0.09	1.10
0.20	6.16	0.10	1.18
0.21	6.59	0.11	1.26
0.23	7.05	0.11	1.35
0.24	7.54	0.12	1.45
0.26	8.07	0.13	1.55
0.28	8.64	0.14	1.66



Economic Evaluation of Demineralisation

Option 2 - Low salinity / Medium use

Input values		
Description	No	UOM
Water consumption	7	m^3/t HSCW
Cost of water	3.13	\$/m^3
Energy consumption	895.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	$/kWh
RO Cost		
Capital cost	3000	$/m3/day
Operating cost	0.60	$/m3

Output values (per day)		
Meat processed	214.3	t HSCW
Electricity consumed	53679	kWh
Coal	20495	kg

Weight slaughtered	214.3	t
Water input cost	4695	
Water discharge cost		
Coal cost	1025	
Electricity cost	5368	
	11088	$/d

Basis of calculation: Daily
Water consumption in the abbatoir 1500 m^3/d
Size of the RO plant 141.2 m^3/d 5.88 m^3/h

	BASE CASE WITHOUT RO						WITH RO INSTALLATION							Escalation rate of utilities			
Saving								2.00%	0.00%	2.00%							
Operating days per year		250	250	250	250									7%	7%	7%	7%
Year	Capital Spent	Water (Operating cost)	Electricity (Operating cost)	Coal (Operating cost)	RO (Operating cost)	Total	Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation	Cost of electricity $/kWh	Cost of water $/kL	Cost of coal $/kg	Cost of RO $/m3
	$	$	$	$	$	$	$	$	$	$	$	$	$				
0		-1173750	-1341964	-256193		-2771907	-423600	-1150275	-1341964	-251069	-5400	-2748709	-400401	0.10	3.13	0.05	0.60
1		-1255913	-1435902	-274127		-2965941	16944	-1230794	-1435902	-268644	-5778	-2941118	41767	0.11	3.35	0.05	0.64
2		-1343826	-1536415	-293316		-3173557	16944	-1316950	-1536415	-287449	-6182	-3146996	43504	0.11	3.58	0.06	0.69
3		-1437894	-1643964	-313848		-3395706	16944	-1409136	-1643964	-307571	-6615	-3367286	45364	0.12	3.83	0.06	0.74
4		-1538547	-1759041	-335817		-3633405	16944	-1507776	-1759041	-329101	-7078	-3602996	47353	0.13	4.10	0.07	0.79
5		-1646245	-1882174	-359324		-3887744	16944	-1613320	-1882174	-352139	-7574	-3855206	49482	0.14	4.39	0.07	0.84
6		-1761482	-2013927	-384477		-4159886	16944	-1726253	-2013927	-376787	-64104	-4181070	-4241	0.15	4.70	0.08	0.90
7		-1884786	-2154901	-411390		-4451078	16944	-1847090	-2154901	-403162	-8671	-4413825	54196	0.16	5.03	0.08	0.96
8		-2016721	-2305744	-440188		-4762653	16944	-1976387	-2305744	-431384	-9278	-4722793	56804	0.17	5.38	0.09	1.03
9		-2157892	-2467147	-471001		-5096039	16944	-2114734	-2467147	-461581	-9928	-5053389	59594	0.18	5.75	0.09	1.10
10		-2308944	-2639847	-503971		-5452762	16944	-2262765	-2639847	-493891	-10623	-5407126	62580	0.20	6.16	0.10	1.18
11		-2470570	-2824636	-539249		-5834455		-2421159	-2824636	-528464	-78366	-5852625	-18170	0.21	6.59	0.11	1.26
12		-2643510	-3022361	-576996		-6242867		-2590640	-3022361	-565456	-12162	-6190618	52248	0.23	7.05	0.11	1.35
13		-2828556	-3233926	-617386		-6679867		-2771984	-3233926	-605038	-13013	-6623962	55906	0.24	7.54	0.12	1.45
14		-3026554	-3460301	-660603		-7147458		-2966023	-3460301	-647391	-13924	-7087639	59819	0.26	8.07	0.13	1.55
15		-3238413	-3702522	-706845		-7647780		-3173645	-3702522	-692708	-14899	-7583774	64006	0.28	8.64	0.14	1.66

Internal rate of Return 6.9%

Option 3 - Low salinity / High use

Input values		
Description	No	UOM
Water consumption	7	m^3/t HSCW
Cost of water	3.13	\$/m^3
Energy consumption	835.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	\$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	\$/kWh
RO Cost		
Capital cost	2500	\$/m3/day
Operating cost	0.60	\$/m3
Output values (per day)		
Meat processed	714.3	t HSCW
Electricity consumed	178929	kWh
Coal	68318	kg

Weight slaughtered	714.3	t
Water input cost	15650	
Water discharge cost		
Coal cost	3416	
Electricity cost	17893	
	36959	\$/d

Basis of calculation: Daily
Water consumption in the abbatoir 5000 m^3/d
Size of the RO plant 470.6 m^3/d 19.61 m^3/h

	BASE CASE WITHOUT RO						WITH RO INSTALLATION							Escalation rate of utilities			
							Saving	2.00%	0.00%	2.00%							
Operating days per year		250	250	250	250									7%	7%	7%	7%
Year	Capital Spent	Operating cost Water	Electricity	Coal	RO	Total	Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation	Cost of electricity \$/kWh	Cost of water \$/kL	Cost of coal \$/kg	Cost of RO \$/m3
	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$				
0		-3912500	-4473214	-853977		-9239692	-1176500	-3834250	-4473214	-836898	-18000	-9162362	-1099170	0.10	3.13	0.05	0.60
1		-4186375	-4786339	-913756		-9886470	47060	-4102648	-4786339	-895481	-19260	-9803727	129803	0.11	3.35	0.05	0.64
2		-4479421	-5121383	-977719		-10578523	47060	-4389833	-5121383	-958164	-20608	-10489988	135595	0.11	3.58	0.06	0.69
3		-4792981	-5479880	-1046159		-11319019	47060	-4697121	-5479880	-1025236	-22051	-11224287	141792	0.12	3.83	0.06	0.74
4		-5128489	-5863471	-1119390		-12111351	47060	-5025920	-5863471	-1097002	-23594	-12009988	148423	0.13	4.10	0.07	0.79
5		-5487484	-6273914	-1197747		-12959145	47060	-5377734	-6273914	-1173792	-25246	-12850687	155519	0.14	4.39	0.07	0.84
6		-5871608	-6713088	-1281590		-13866286	47060	-5754175	-6713088	-1255958	-214013	-13937235	-23889	0.15	4.70	0.08	0.90
7		-6282620	-7183005	-1371301		-14836926	47060	-6156968	-7183005	-1343875	-28904	-14712751	171234	0.16	5.03	0.08	0.96
8		-6722403	-7685815	-1467292		-15875510	47060	-6587955	-7685815	-1437946	-30927	-15742644	179927	0.17	5.38	0.09	1.03
9		-7192972	-8223822	-1570002		-16986796	47060	-7049112	-8223822	-1538602	-33092	-16844629	189227	0.18	5.75	0.09	1.10
10		-7696480	-8799490	-1679903		-18175872	47060	-7542550	-8799490	-1646306	-35409	-18023753	199179	0.20	6.16	0.10	1.18
11		-8235233	-9415454	-1797496		-19448183		-8070529	-9415454	-1761546	-262887	-19510416	-62233	0.21	6.59	0.11	1.26
12		-8811700	-10074536	-1923320		-20809556		-8635466	-10074536	-1884854	-40539	-20635395	174161	0.23	7.05	0.11	1.35
13		-9428519	-10779753	-2057953		-22266225		-9239948	-10779753	-2016794	-43377	-22079872	186352	0.24	7.54	0.12	1.45
14		-10088515	-11534336	-2202010		-23824860		-9886745	-11534336	-2157969	-46414	-23625463	199397	0.26	8.07	0.13	1.55
15		-10794711	-12341739	-2356150		-25492600		-10578817	-12341739	-2309027	-49663	-25279246	213355	0.28	8.64	0.14	1.66

Internal rate of Return 9.1%

Economic Evaluation of Demineralisation

Option 4 - High salinity / Low use

Input values		
Description	No	UOM
Water consumption	7	m³/t HSCW
Cost of water	0.96	$/m³
Energy consumption	835.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	$/kWh
RO Cost		
Capital cost	5000	$/m3/day
operating cost	0.80	$/m3

Output values (per day)		
Meat processed	57.1	t HSCW
Electricity consumed	14314	kWh
Coal	5465	kg

Weight slaughtered	57.1	t
Water input cost	384	
Water discharge cost		
Coal cost	273	
Electricity cost	1431	
	2088	$/d

Basis of calculation: Daily

Water consumption in the abbatoir	400	m³/d
Size of the RO plant	39.8	m³/d
	1.66	m³/h

BASE CASE WITHOUT RO

Operating days per year		250	250	250	250	
Year	Capital Spent	Operating cost Water	Electricity	Coal	RO	Total
	$	$	$	$	$	$
0		-96000	-357857	-68318		-522175
1		-102720	-382907	-73100		-558728
2		-109910	-409711	-78217		-597839
3		-117604	-438390	-83693		-639687
4		-125836	-469078	-89551		-684465
5		-134645	-501913	-95820		-732378
6		-144070	-537047	-102527		-783644
7		-154155	-574640	-109704		-838499
8		-164946	-614865	-117383		-897194
9		-176492	-657906	-125600		-959998
10		-188847	-703959	-134392		-1027198
11		-202066	-753236	-143800		-1099102
12		-216210	-805963	-153866		-1176039
13		-231345	-862380	-164636		-1258362
14		-247539	-922747	-176161		-1346447
15		-264867	-987339	-188492		-1440698

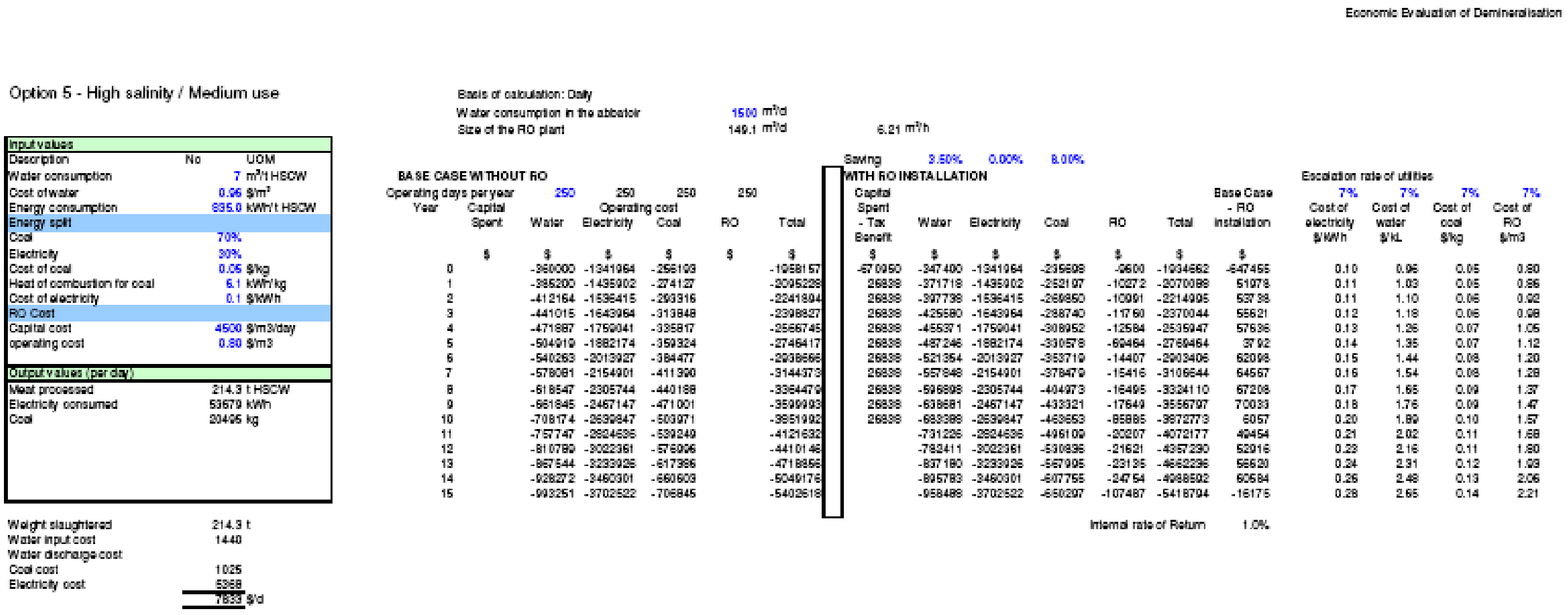
WITH RO INSTALLATION

Saving	3.50%	0.00%	8.00%			
Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation
$	$	$	$	$	$	$
-199000	-92640	-357857	-62853	-2560	-515910	-192735
7960	-99125	-382907	-67252	-2739	-552024	14664
7960	-106064	-409711	-71960	-2931	-590665	15133
7960	-113488	-438390	-76997	-3136	-632012	15635
7960	-121432	-469078	-82387	-3356	-676253	16173
7960	-129932	-501913	-88154	-18591	-738590	1748
7960	-139028	-537047	-94325	-3842	-774242	17363
7960	-148760	-574640	-100928	-4111	-828439	18021
7960	-159173	-614865	-107993	-4399	-886429	18725
7960	-170315	-657906	-115552	-4706	-948479	19479
7960	-182237	-703959	-123641	-23036	-1032873	2285
	-194993	-753236	-132296	-5388	-1085914	13188
	-208643	-805963	-141556	-5766	-1161928	14111
	-223248	-862380	-151465	-6169	-1243263	15099
	-238875	-922747	-162068	-6601	-1330291	16156
	-255597	-987339	-173413	-29063	-1445412	-4713

Internal rate of Return 0.0%

Escalation rate of utilities

7%	7%	7%	7%
Cost of electricity $/kWh	Cost of water $/kL	Cost of coal $/kg	Cost of RO $/m3
0.10	0.96	0.05	0.80
0.11	1.03	0.05	0.86
0.11	1.10	0.06	0.92
0.12	1.18	0.06	0.98
0.13	1.26	0.07	1.05
0.14	1.35	0.07	1.12
0.15	1.44	0.08	1.20
0.16	1.54	0.08	1.28
0.17	1.65	0.09	1.37
0.18	1.76	0.09	1.47
0.20	1.89	0.10	1.57
0.21	2.02	0.11	1.68
0.23	2.16	0.11	1.80
0.24	2.31	0.12	1.93
0.26	2.48	0.13	2.06
0.28	2.65	0.14	2.21



Economic Evaluation of Demineralisation

Option 5 - High salinity / Medium use

Input values		
Description	No	UOM
Water consumption	7	m^3/t HSCW
Cost of water	0.96	\$/m^3
Energy consumption	835.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	\$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	\$/kWh
RO Cost		
Capital cost	4500	\$/m3/day
operating cost	0.80	\$/m3

Output values (per day)		
Meat processed	214.3	t HSCW
Electricity consumed	53679	kWh
Coal	20495	kg

Weight slaughtered	214.3	t
Water input cost	1440	
Water discharge cost		
Coal cost	1025	
Electricity cost	5368	
	7833	\$/d

Basis of calculation: Daily
Water consumption in the abbatoir 1500 m^3/d
Size of the RO plant 149.1 m^3/d 6.21 m^3/h

BASE CASE WITHOUT RO

Operating days per year	250	250	250	250		
Year	Capital Spent	Operating cost Water	Electricity	Coal	RO	Total
	\$	\$	\$	\$	\$	\$
0		-360000	-1341964	-256193		-1958157
1		-385200	-1435902	-274127		-2095229
2		-412164	-1536415	-293316		-2241894
3		-441015	-1643964	-313848		-2398827
4		-471887	-1759041	-335817		-2566745
5		-504919	-1882174	-359324		-2746417
6		-540263	-2013927	-384477		-2938666
7		-578081	-2154901	-411390		-3144373
8		-618547	-2305744	-440188		-3364479
9		-661845	-2467147	-471001		-3599993
10		-708174	-2639847	-503971		-3851992
11		-757747	-2824636	-539249		-4121632
12		-810789	-3022361	-576996		-4410146
13		-867544	-3233926	-617386		-4718856
14		-928272	-3460301	-660603		-5049176
15		-993251	-3702522	-706845		-5402618

WITH RO INSTALLATION

Saving	3.50%	0.00%	8.00%			
Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation
\$	\$	\$	\$	\$	\$	\$
-670950	-347400	-1341964	-235698	-9600	-1934662	-647455
26838	-371718	-1435902	-252197	-10272	-2070098	51978
26838	-397738	-1536415	-269850	-10991	-2214995	53738
26838	-425580	-1643964	-288740	-11760	-2370044	55621
26838	-455371	-1759041	-308952	-12584	-2535947	57636
26838	-487246	-1882174	-330578	-69464	-2769464	3792
26838	-521354	-2013927	-353719	-14407	-2903406	62098
26838	-557848	-2154901	-378479	-15416	-3106644	64567
26838	-596898	-2305744	-404973	-16495	-3324110	67208
26838	-638681	-2467147	-433321	-17649	-3556797	70033
26838	-683389	-2639847	-463653	-85885	-3872773	6057
	-731226	-2824636	-496109	-20207	-4072177	49454
	-782411	-3022361	-530836	-21621	-4357230	52916
	-837180	-3233926	-567995	-23135	-4662236	56620
	-895783	-3460301	-607755	-24754	-4988592	60584
	-958488	-3702522	-650297	-107487	-5418794	-16175

Internal rate of Return 1.0%

Escalation rate of utilities

7%	7%	7%	7%
Cost of electricity \$/kWh	Cost of water \$/kL	Cost of coal \$/kg	Cost of RO \$/m3
0.10	0.96	0.05	0.80
0.11	1.03	0.05	0.86
0.11	1.10	0.06	0.92
0.12	1.18	0.06	0.98
0.13	1.26	0.07	1.05
0.14	1.35	0.07	1.12
0.15	1.44	0.08	1.20
0.16	1.54	0.08	1.28
0.17	1.65	0.09	1.37
0.18	1.76	0.09	1.47
0.20	1.89	0.10	1.57
0.21	2.02	0.11	1.68
0.23	2.16	0.11	1.80
0.24	2.31	0.12	1.93
0.26	2.48	0.13	2.06
0.28	2.65	0.14	2.21

Option 6 - High salinity / High use

Input values		
Description	No	UOM
Water consumption	7	m^3/t HSCW
Cost of water	0.96	\$/m^3
Energy consumption	835.0	kWh/t HSCW
Energy split		
Coal	70%	
Electricity	30%	
Cost of coal	0.05	\$/kg
Heat of combustion for coal	6.1	kWh/kg
Cost of electricity	0.1	\$/kWh
RO Cost		
Capital cost	4000	\$/m3/day
operating cost	0.80	\$/m3

Output values (per day)		
Meat processed	714.3	t HSCW
Electricity consumed	178929	kWh
Coal	68318	kg

Weight slaughtered	714.3	t
Water cost	4800	
Water discharge cost		
Coal cost	3416	
Electricity cost	17893	
	26109	\$/d

Basis of calculation: Daily

Water consumption in the abbatoir	5000	m^3/d
Size of the RO plant	497.1	m^3/d
	20.71	m^3/h

BASE CASE WITHOUT RO

Operating days per year		250	250	250	250	
Year	Capital		Operating cost			
	Spent	Water	Electricity	Coal	RO	Total
	\$	\$	\$	\$	\$	\$
0		-1200000	-4473214	-853977		-6527192
1		-1284000	-4786339	-913756		-6984095
2		-1373880	-5121383	-977719		-7472982
3		-1470052	-5479880	-1046159		-7996090
4		-1572955	-5863471	-1119390		-8555817
5		-1683062	-6273914	-1197747		-9154724
6		-1800876	-6713088	-1281590		-9795555
7		-1926938	-7183005	-1371301		-10481243
8		-2061823	-7685815	-1467292		-11214930
9		-2206151	-8223822	-1570002		-11999975
10		-2360582	-8799490	-1679903		-12839974
11		-2525822	-9415454	-1797496		-13738772
12		-2702630	-10074536	-1923320		-14700486
13		-2891814	-10779753	-2057953		-15729520
14		-3094241	-11534336	-2202010		-16830586
15		-3310838	-12341739	-2356150		-18008727

WITH RO INSTALLATION

Saving		3.50%	0.00%	8.00%			
Year	Capital Spent - Tax Benefit	Water	Electricity	Coal	RO	Total	Base Case - RO installation
	\$	\$	\$	\$	\$	\$	\$
0	-1988400	-1158000	-4473214	-785659	-32000	-6448873	-1910082
1	79536	-1239060	-4786339	-840655	-34240	-6900295	163936
2	79536	-1325794	-5121383	-899501	-36637	-7383315	169202
3	79536	-1418600	-5479880	-962466	-39201	-7900147	175479
4	79536	-1517902	-5863471	-1029839	-41945	-8453158	182195
5	79536	-1624155	-6273914	-1101928	-231882	-9231879	2981
6	79536	-1737846	-6713088	-1179062	-48023	-9678020	197070
7	79536	-1859496	-7183005	-1261597	-51385	-10355481	205298
8	79536	-1989660	-7685815	-1349909	-54982	-11080365	214101
9	79536	-2128936	-8223822	-1444402	-58831	-11855991	223521
10	79536	-2277961	-8799490	-1545510	-287949	-12910910	8600
11		-2437419	-9415454	-1653696	-67355	-13573924	164848
12		-2608038	-10074536	-1769455	-72070	-14524098	176388
13		-2790601	-10779753	-1893317	-77115	-15540785	188735
14		-2985943	-11534336	-2025849	-82513	-16628640	201946
15		-3194959	-12341739	-2167658	-358289	-18062645	-53918

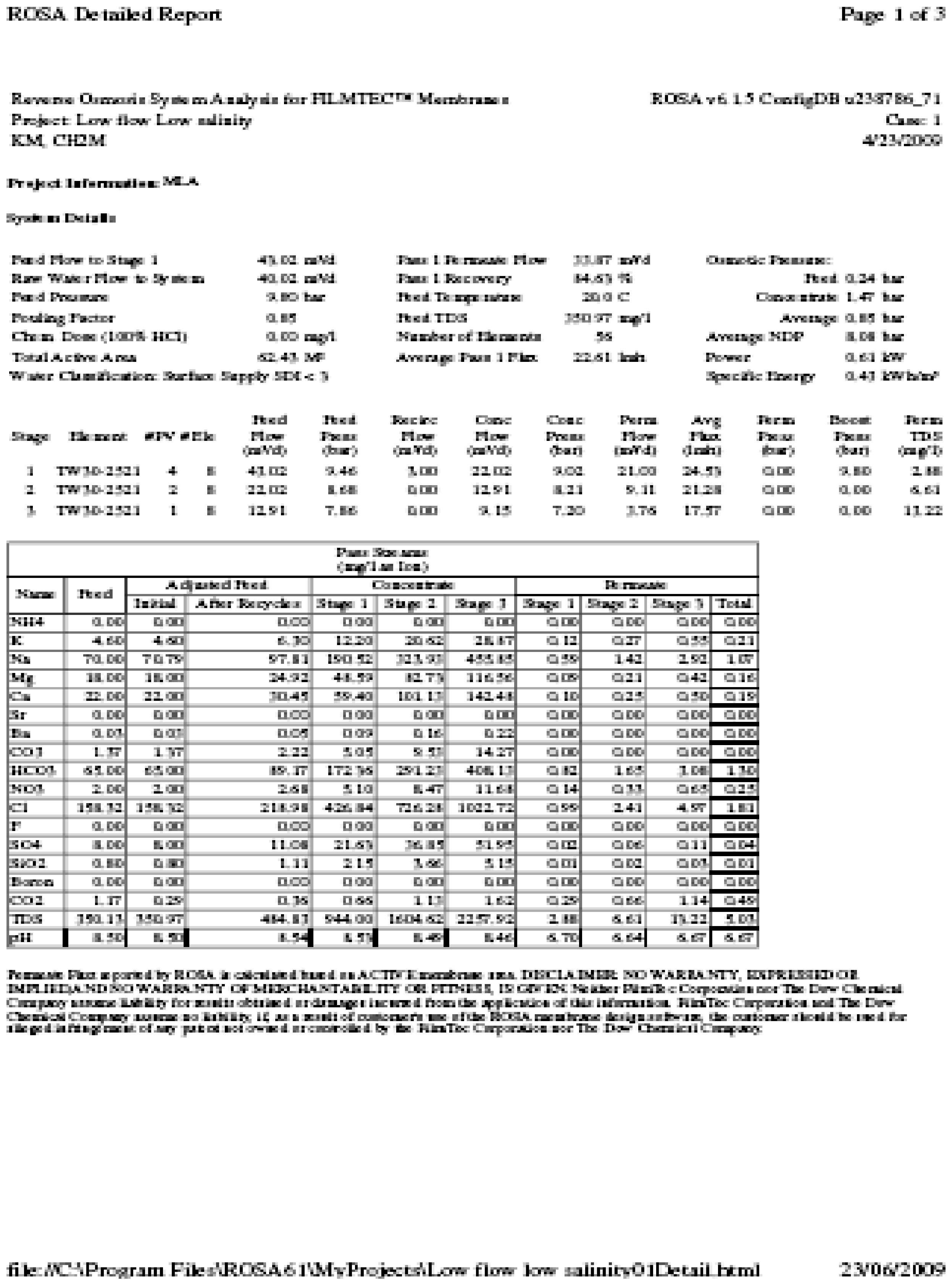
Internal rate of Return 2.1%

Escalation rate of utilities

Year	7%	7%	7%	7%
	Cost of electricity \$/kWh	Cost of water \$/kL	Cost of coal \$/kg	Cost of RO \$/m3
0	0.10	0.96	0.05	0.80
1	0.11	1.03	0.05	0.86
2	0.11	1.10	0.06	0.92
3	0.12	1.18	0.06	0.98
4	0.13	1.26	0.07	1.05
5	0.14	1.35	0.07	1.12
6	0.15	1.44	0.08	1.20
7	0.16	1.54	0.08	1.28
8	0.17	1.65	0.09	1.37
9	0.18	1.76	0.09	1.47
10	0.20	1.89	0.10	1.57
11	0.21	2.02	0.11	1.68
12	0.23	2.16	0.11	1.80
13	0.24	2.31	0.12	1.93
14	0.26	2.48	0.13	2.06
15	0.28	2.65	0.14	2.21

Appendix C RO Projections & Water Compositions

- Low salinity
- High salinity



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Reverse Osmosis System Analysis for FILMTEC™ Membranes | ROSA v6.1.5 ConfigDB u238786_71
Project: Low flow Low salinity | Case: 1
KM, CH2M | 4/23/2009

Project Information: MLA

System Details

Feed Flow to Stage 1	43.02 m³/d	Pass 1 Permeate Flow	33.87 m³/d	Osmotic Pressure:	
Raw Water Flow to System	40.02 m³/d	Pass 1 Recovery	84.63 %	Feed	0.24 bar
Feed Pressure	9.80 bar	Feed Temperature	20.0 C	Concentrate	1.47 bar
Fouling Factor	0.85	Feed TDS	350.97 mg/l	Average	0.85 bar
Chem. Dose (100% HCl)	0.00 mg/l	Number of Elements	56	Average NDP	8.08 bar
Total Active Area	62.43 M²	Average Pass 1 Flux	22.61 lmh	Power	0.61 kW
Water Classification: Surface Supply SDI < 3				Specific Energy	0.43 kWh/m³

Stage	Element	#PV	#Ele	Feed Flow (m³/d)	Feed Press (bar)	Recirc Flow (m³/d)	Conc Flow (m³/d)	Conc Press (bar)	Perm Flow (m³/d)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	TW30-2521	4	8	43.02	9.46	3.00	22.02	9.02	21.00	24.53	0.00	9.80	2.88
2	TW30-2521	2	8	22.02	8.68	0.00	12.91	8.21	9.11	21.28	0.00	0.00	6.61
3	TW30-2521	1	8	12.91	7.86	0.00	9.15	7.20	3.76	17.57	0.00	0.00	13.22

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate			Permeate			
		Initial	After Recycles	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Total
NH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	4.60	4.60	6.30	12.20	20.62	28.87	0.12	0.27	0.55	0.21
Na	70.00	70.79	97.81	190.52	323.93	455.85	0.59	1.42	2.92	1.07
Mg	18.00	18.00	24.92	48.59	82.73	116.56	0.09	0.21	0.42	0.16
Ca	22.00	22.00	30.45	59.40	101.13	142.48	0.10	0.25	0.50	0.19
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.03	0.03	0.05	0.09	0.16	0.22	0.00	0.00	0.00	0.00
CO3	1.37	1.37	2.22	5.05	9.53	14.27	0.00	0.00	0.00	0.00
HCO3	65.00	65.00	89.37	172.36	291.23	408.13	0.82	1.65	3.08	1.30
NO3	2.00	2.00	2.68	5.10	8.47	11.68	0.14	0.33	0.65	0.25
Cl	158.32	158.32	218.98	426.84	726.28	1022.72	0.59	2.41	4.97	1.83
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	8.00	8.00	11.08	21.63	36.85	51.95	0.02	0.06	0.11	0.04
SiO2	0.80	0.80	1.11	2.15	3.66	5.15	0.01	0.02	0.03	0.01
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	1.17	0.29	0.36	0.66	1.13	1.62	0.29	0.66	1.14	0.48
TDS	350.13	350.97	484.83	944.00	1604.62	2257.92	2.88	6.61	13.22	5.03
pH	8.50	8.50	8.54	8.53	8.49	8.46	6.70	6.64	6.67	6.67

Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area. DISCLAIMER: NO WARRANTY, EXPRESSED OR IMPLIED, AND NO WARRANTY OF MERCHANTABILITY OR FITNESS, IS GIVEN. Neither FilmTec Corporation nor The Dow Chemical Company assume liability for results obtained or damages incurred from the application of this information. FilmTec Corporation and The Dow Chemical Company assume no liability, if, as a result of customer's use of the ROSA membrane design software, the customer should be sued for alleged infringement of any patent not owned or controlled by the FilmTec Corporation nor The Dow Chemical Company.

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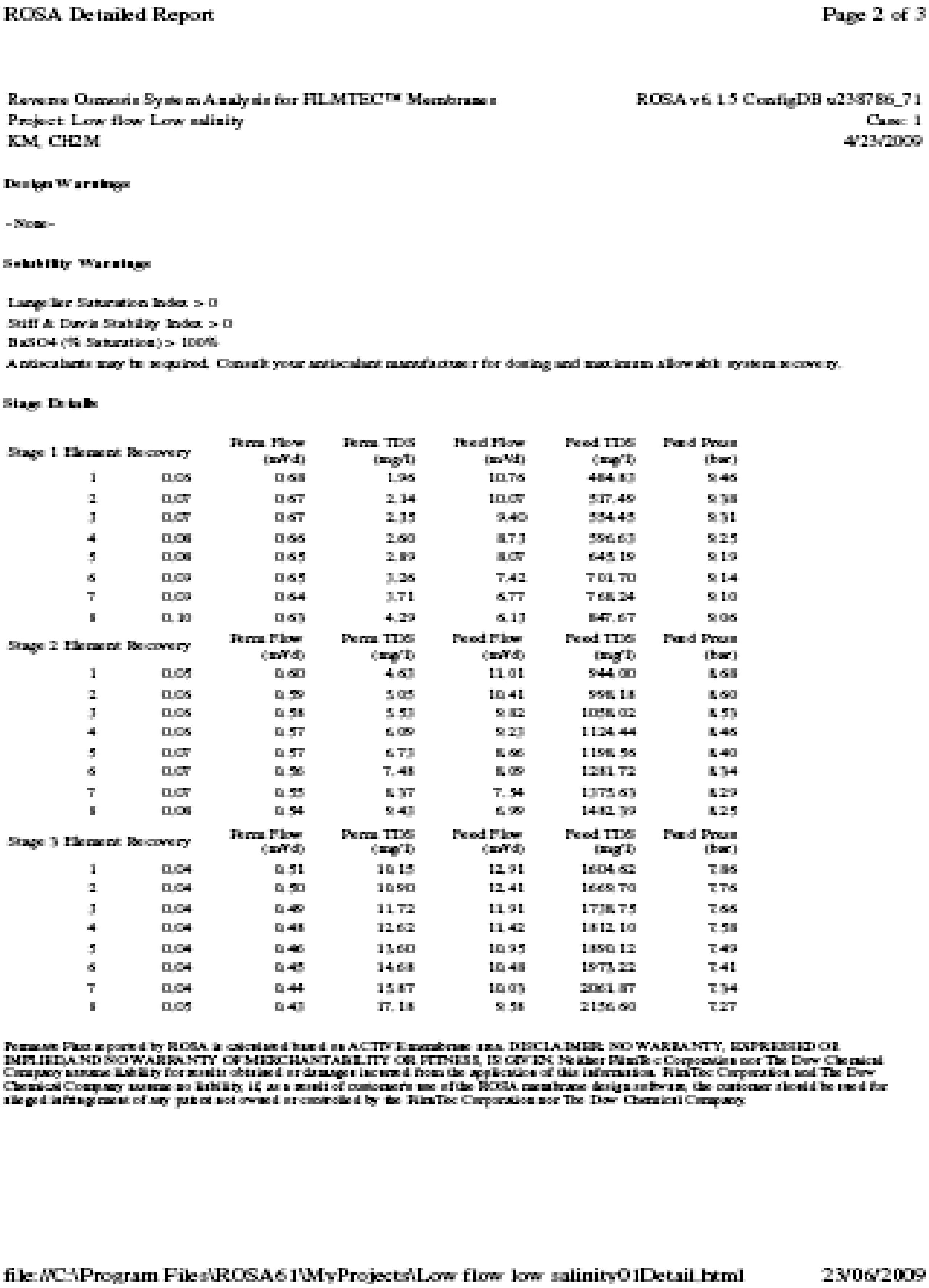

ROSA Detailed Report

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Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Low flow Low salinity
KM, CH2M

ROSA v6.1.5 ConfigDB u238786_71
Case: 1
4/23/2009

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (m³/d)	Perm TDS (mg/l)	Feed Flow (m³/d)	Feed TDS (mg/l)	Feed Press (bar)
1	0.06	0.68	1.96	10.76	484.83	9.46
2	0.07	0.67	2.14	10.07	517.49	9.38
3	0.07	0.67	2.35	9.40	554.45	9.31
4	0.08	0.66	2.60	8.73	596.63	9.25
5	0.08	0.65	2.89	8.07	645.19	9.19
6	0.09	0.65	3.26	7.42	701.70	9.14
7	0.09	0.64	3.71	6.77	768.24	9.10
8	0.10	0.63	4.29	6.13	847.67	9.06
Stage 2 Element	**Recovery**	**Perm Flow (m³/d)**	**Perm TDS (mg/l)**	**Feed Flow (m³/d)**	**Feed TDS (mg/l)**	**Feed Press (bar)**
1	0.05	0.60	4.63	11.01	944.00	8.68
2	0.06	0.59	5.05	10.41	998.18	8.60
3	0.06	0.58	5.53	9.82	1058.02	8.53
4	0.06	0.57	6.09	9.23	1124.44	8.46
5	0.07	0.57	6.73	8.66	1198.56	8.40
6	0.07	0.56	7.48	8.09	1281.72	8.34
7	0.07	0.55	8.37	7.54	1375.63	8.29
8	0.08	0.54	9.43	6.99	1482.39	8.25
Stage 3 Element	**Recovery**	**Perm Flow (m³/d)**	**Perm TDS (mg/l)**	**Feed Flow (m³/d)**	**Feed TDS (mg/l)**	**Feed Press (bar)**
1	0.04	0.51	10.15	12.91	1604.62	7.86
2	0.04	0.50	10.90	12.41	1665.70	7.76
3	0.04	0.49	11.72	11.91	1738.75	7.66
4	0.04	0.48	12.62	11.42	1812.10	7.58
5	0.04	0.46	13.60	10.95	1890.12	7.49
6	0.04	0.45	14.68	10.48	1973.22	7.41
7	0.04	0.44	15.87	10.03	2061.87	7.34
8	0.05	0.43	17.18	9.58	2156.60	7.27

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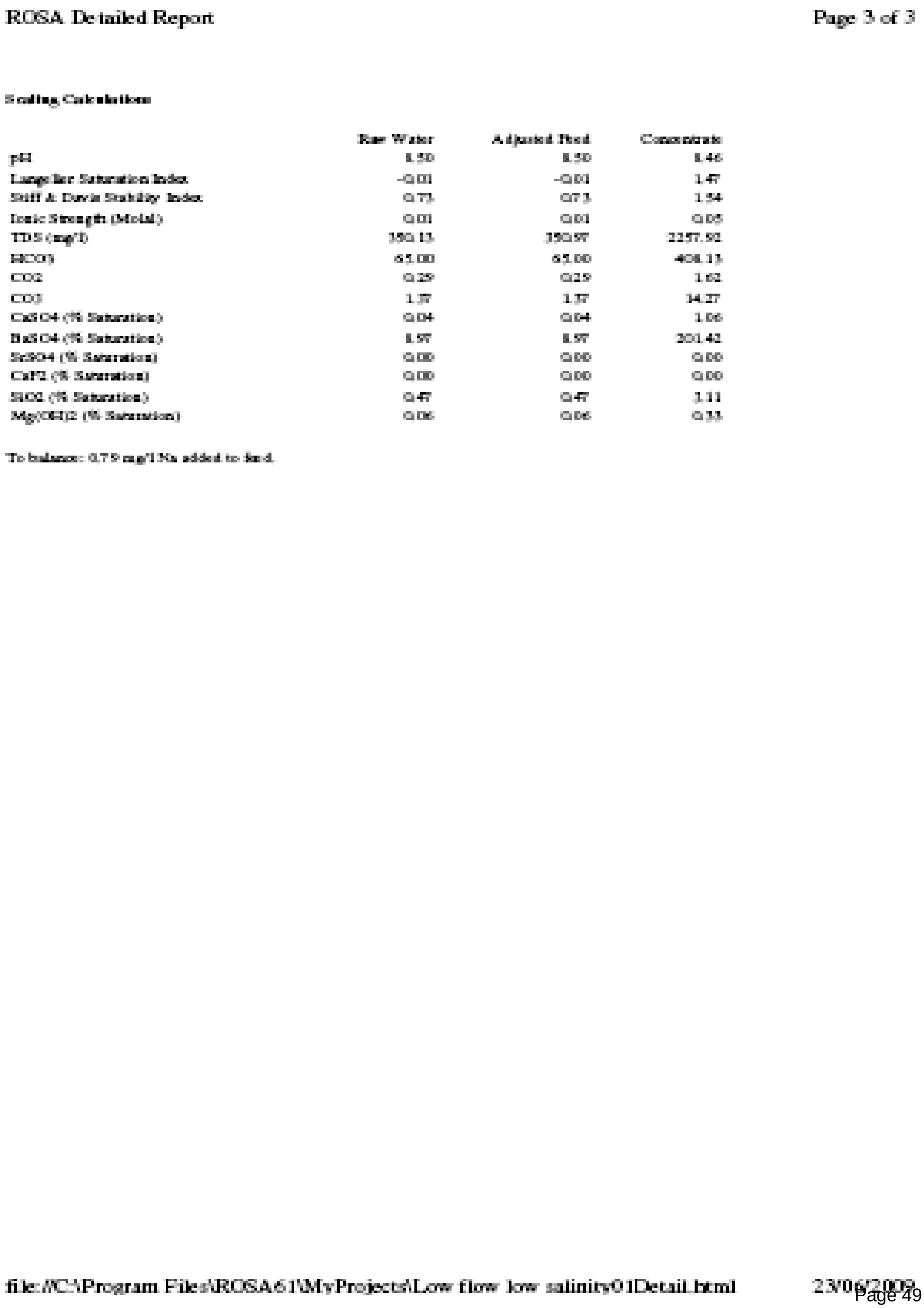
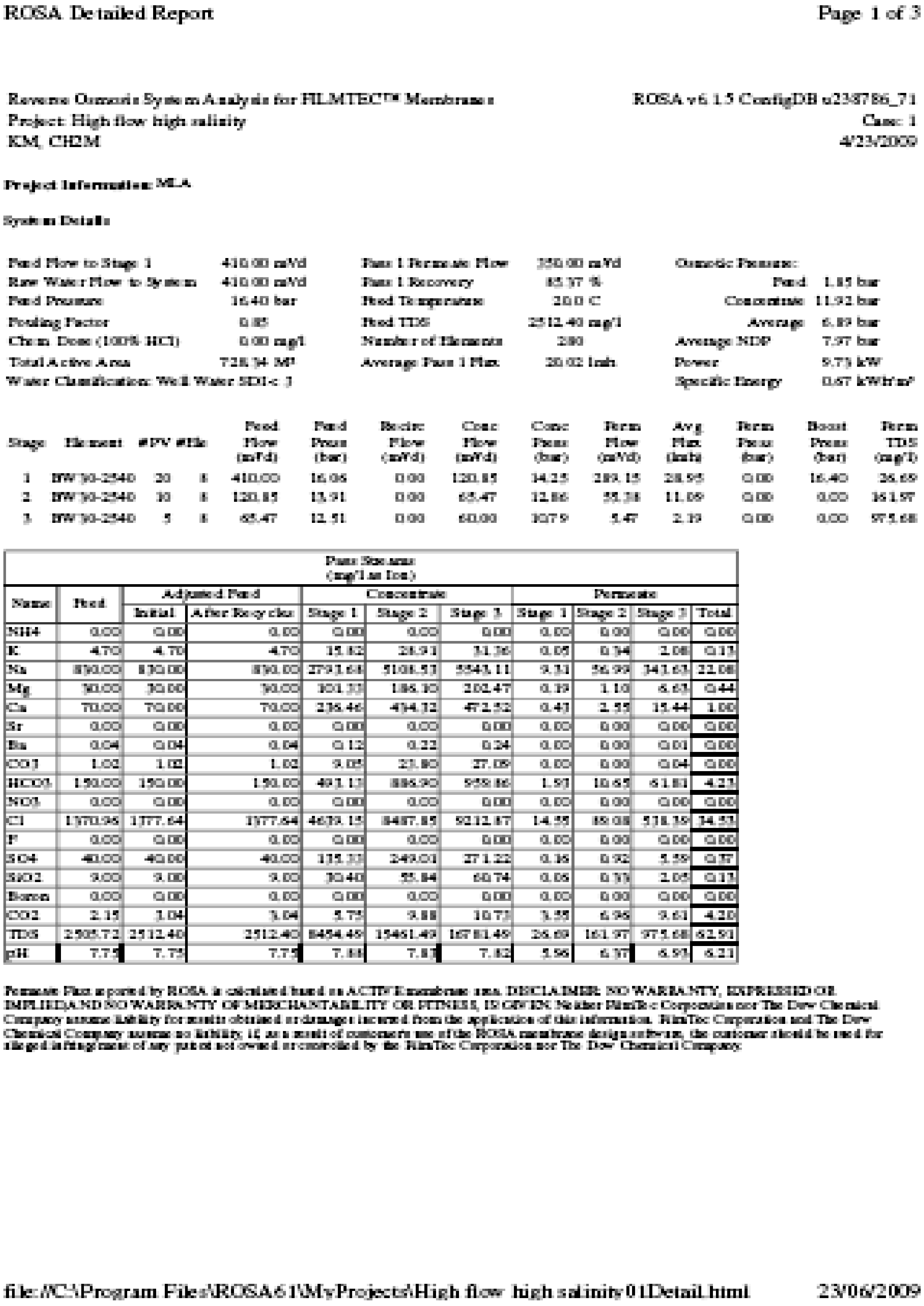


Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	8.50	8.50	8.46
Langelier Saturation Index	-0.01	-0.01	1.47
Stiff & Davis Stability Index	0.73	0.73	1.54
Ionic Strength (Molal)	0.01	0.01	0.05
TDS (mg/l)	350.13	350.97	2257.92
HCO3	65.00	65.00	408.13
CO2	0.29	0.29	1.62
CO3	1.37	1.37	14.27
CaSO4 (% Saturation)	0.04	0.04	1.06
BaSO4 (% Saturation)	8.57	8.57	201.42
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	0.00	0.00	0.00
SiO2 (% Saturation)	0.47	0.47	3.11
Mg(OH)2 (% Saturation)	0.06	0.06	0.33

To balance: 0.79 mg/l Na added to feed.



ROSA Detailed Report

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Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: High flow high salinity
KM, CH2M

ROSA v6.1.5 ConfigDB u238786_71
Case: 1
4/23/2009

Project Information: MLA

System Details

Feed Flow to Stage 1	410.00 m³/d	Pass 1 Permeate Flow	350.00 m³/d	Osmotic Pressure:	
Raw Water Flow to System	410.00 m³/d	Pass 1 Recovery	85.37 %	Feed	1.85 bar
Feed Pressure	16.40 bar	Feed Temperature	20.0 C	Concentrate	11.92 bar
Fouling Factor	0.85	Feed TDS	2512.40 mg/l	Average	6.89 bar
Chem. Dose (100% HCl)	0.00 mg/l	Number of Elements	280	Average NDP	7.97 bar
Total Active Area	728.34 M²	Average Pass 1 Flux	20.02 lmh	Power	9.73 kW
Water Classification: Well Water SDI < 3				Specific Energy	0.67 kWh/m³

Stage	Element	#PV	#Ele	Feed Flow (m³/d)	Feed Press (bar)	Recirc Flow (m³/d)	Conc Flow (m³/d)	Conc Press (bar)	Perm Flow (m³/d)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	BW30-2540	20	8	410.00	16.06	0.00	120.85	14.25	289.15	28.95	0.00	16.40	26.69
2	BW30-2540	10	8	120.85	13.91	0.00	65.47	12.86	55.38	11.09	0.00	0.00	161.97
3	BW30-2540	5	8	65.47	12.51	0.00	60.00	10.79	5.47	2.19	0.00	0.00	975.68

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate			Permeate			
		Initial	After Recycles	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Total
NH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	4.70	4.70	4.70	15.82	28.91	31.36	0.05	0.34	2.08	0.13
Na	830.00	830.00	830.00	2791.68	5108.53	5543.11	9.31	56.99	341.63	22.08
Mg	30.00	30.00	30.00	101.33	186.30	202.47	0.19	1.10	6.63	0.44
Ca	70.00	70.00	70.00	236.46	434.32	472.52	0.43	2.55	15.44	1.00
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.04	0.04	0.04	0.12	0.22	0.24	0.00	0.00	0.01	0.00
CO3	1.02	1.02	1.02	9.05	23.80	27.09	0.00	0.00	0.04	0.00
HCO3	150.00	150.00	150.00	493.13	886.90	959.86	1.93	10.65	61.81	4.23
NO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	1370.96	1377.64	1377.64	4639.15	8487.85	9212.87	14.55	89.08	538.35	34.53
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	40.00	40.00	40.00	135.33	249.01	271.22	0.16	0.92	5.59	0.37
SiO2	9.00	9.00	9.00	30.40	55.84	60.74	0.06	0.33	2.05	0.13
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	2.15	3.04	3.04	5.75	9.88	10.73	3.55	6.96	9.61	4.20
TDS	2505.72	2512.40	2512.40	8454.49	15461.49	16781.49	26.69	161.97	975.68	62.91
pH	7.75	7.75	7.75	7.88	7.87	7.82	5.96	6.37	6.95	6.21

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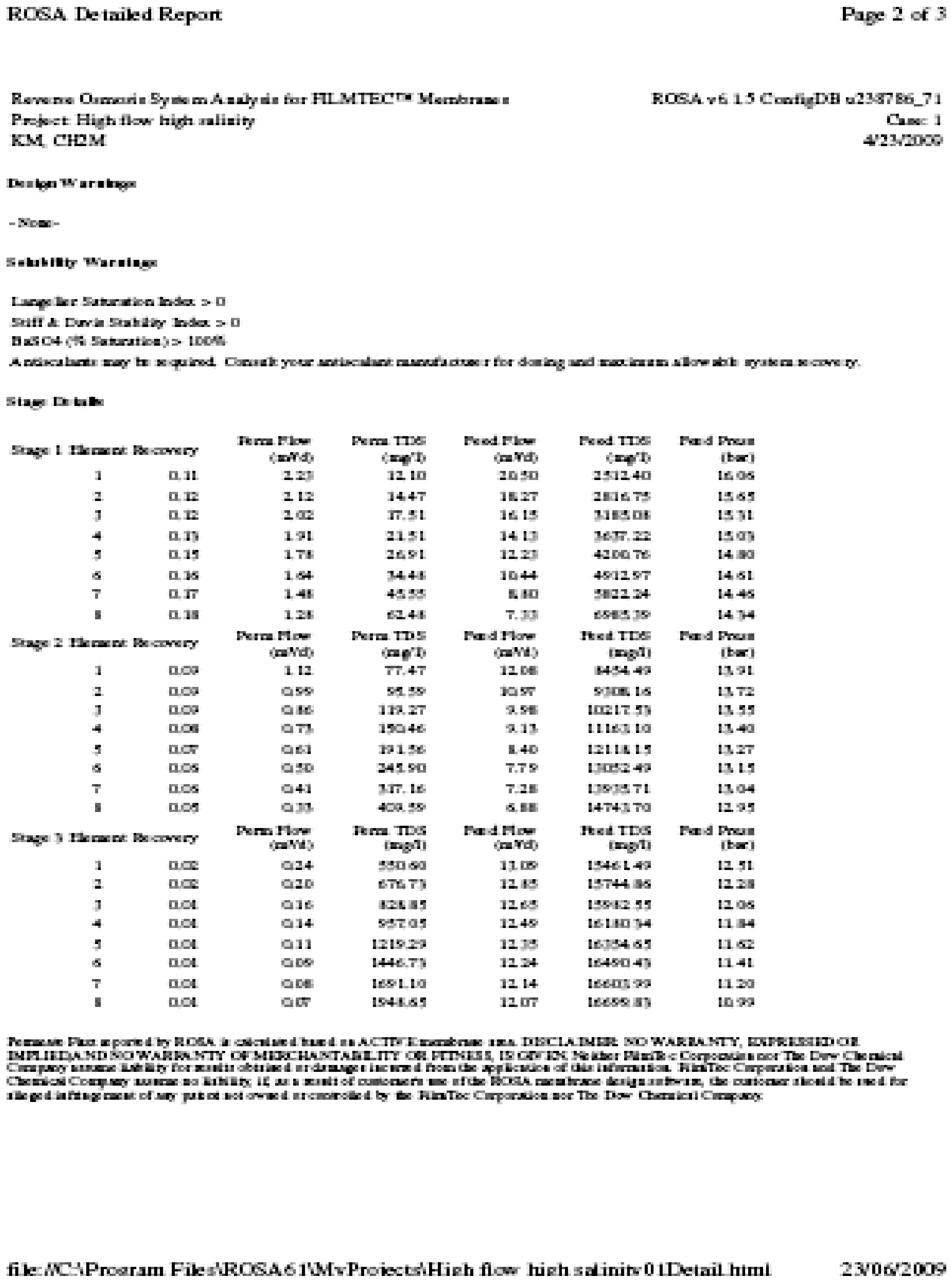

ROSA Detailed Report

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Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: High flow high salinity
KM, CH2M

ROSA v6.1.5 ConfigDB u238786_71
Case: 1
4/23/2009

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (m3/d)	Perm TDS (mg/l)	Feed Flow (m3/d)	Feed TDS (mg/l)	Feed Press (bar)
1	0.11	2.23	12.10	20.50	2512.40	16.06
2	0.12	2.12	14.47	18.27	2816.75	15.65
3	0.12	2.02	17.51	16.15	3185.08	15.31
4	0.13	1.91	21.51	14.13	3637.22	15.03
5	0.15	1.78	26.91	12.23	4200.76	14.80
6	0.16	1.64	34.48	10.44	4912.97	14.61
7	0.17	1.48	45.55	8.80	5822.24	14.46
8	0.18	1.28	62.48	7.33	6985.39	14.34
Stage 2 Element	**Recovery**	**Perm Flow (m3/d)**	**Perm TDS (mg/l)**	**Feed Flow (m3/d)**	**Feed TDS (mg/l)**	**Feed Press (bar)**
1	0.09	1.12	77.47	12.08	8454.49	13.91
2	0.09	0.99	95.59	10.97	9308.16	13.72
3	0.09	0.86	119.27	9.98	10217.53	13.55
4	0.08	0.73	150.46	9.13	11163.10	13.40
5	0.07	0.61	191.56	8.40	12118.15	13.27
6	0.06	0.50	245.90	7.79	13052.49	13.15
7	0.06	0.41	317.16	7.28	13935.71	13.04
8	0.05	0.33	409.59	6.88	14743.70	12.95
Stage 3 Element	**Recovery**	**Perm Flow (m3/d)**	**Perm TDS (mg/l)**	**Feed Flow (m3/d)**	**Feed TDS (mg/l)**	**Feed Press (bar)**
1	0.02	0.24	550.60	13.09	15461.49	12.51
2	0.02	0.20	676.73	12.85	15744.86	12.28
3	0.01	0.16	828.85	12.65	15982.55	12.06
4	0.01	0.14	957.05	12.49	16180.34	11.84
5	0.01	0.11	1219.29	12.35	16354.65	11.62
6	0.01	0.09	1446.73	12.24	16490.43	11.41
7	0.01	0.08	1691.10	12.14	16603.99	11.20
8	0.01	0.07	1948.65	12.07	16699.83	10.99

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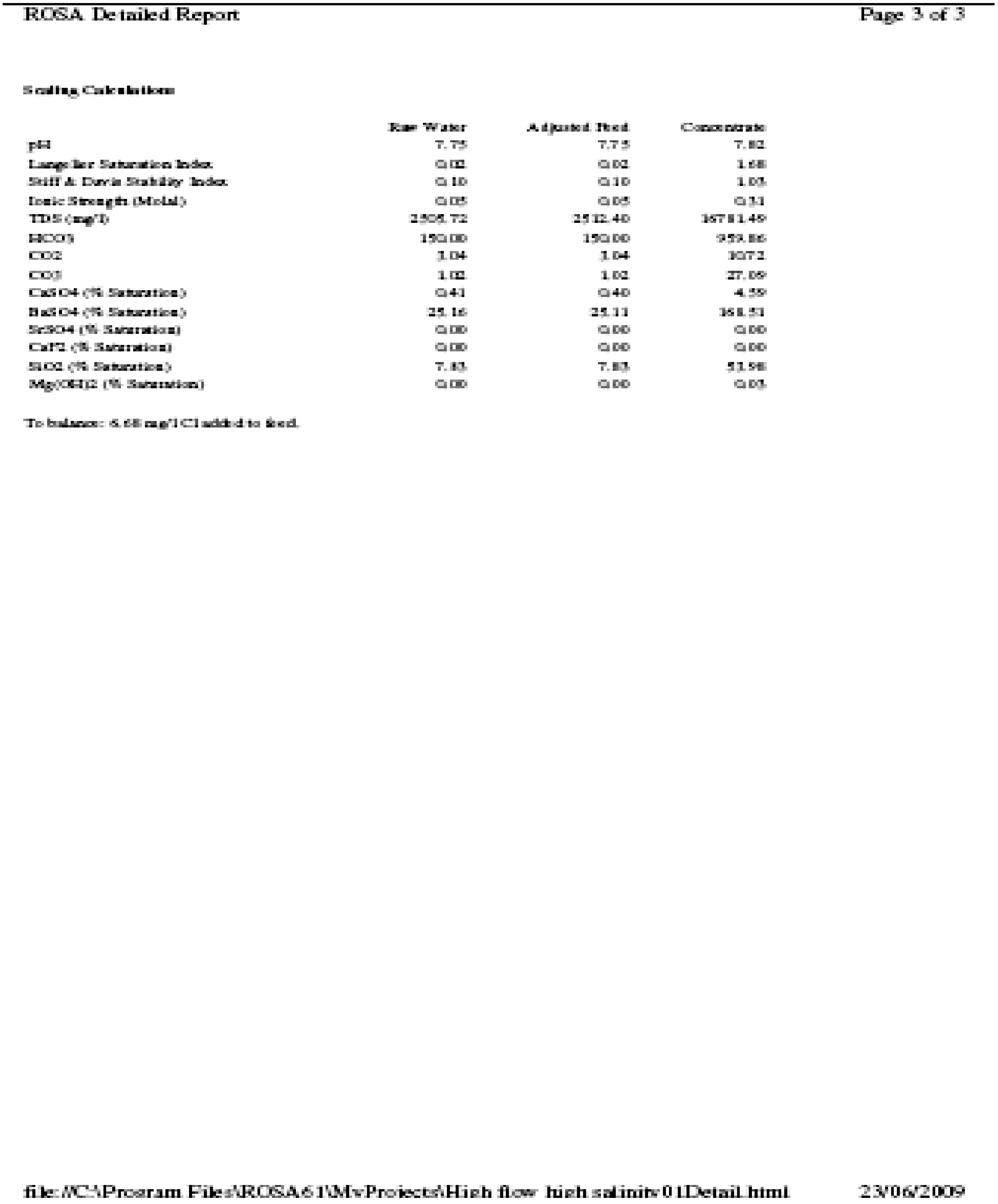

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Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.75	7.75	7.82
Langelier Saturation Index	0.02	0.02	1.68
Stiff & Davis Stability Index	0.10	0.10	1.03
Ionic Strength (Molal)	0.05	0.05	0.31
TDS (mg/l)	2505.72	2512.40	16781.49
HCO3	150.00	150.00	959.86
CO2	3.04	3.04	10.72
CO3	1.02	1.02	27.09
CaSO4 (% Saturation)	0.41	0.40	4.59
BaSO4 (% Saturation)	25.16	25.11	168.53
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	0.00	0.00	0.00
SiO2 (% Saturation)	7.83	7.83	53.98
Mg(OH)2 (% Saturation)	0.00	0.00	0.03

To balance: 6.68 mg/l Cl added to feed.

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Appendix D Technology Review

- Reverse Osmosis
- Electro-Dialysis Reversal (EDR)
- Nanofiltration
- Thermal technology
- Forward Osmosis
- Capacitive deionisation
- Improvements in RO technology

D1 Technical & Economic Review of Demineralisation Technologies

Demineralisation for this project refers to the membrane separation RO process (not ion exchange) used to reduce the dissolved salt content of saline water sources to a level that enables use within the meat processing operations.

The saline feedwater is drawn from marine or underground water sources. It is separated by the demineralisation process into the two output streams: the low-salinity product water and high salinity concentrate streams.

Although some substances dissolved in water, such as calcium carbonate, can be removed by chemical treatment, other common constituents, like sodium chloride, require more sophisticated separation methods, collectively known as demineralisation. In the past, the difficulty and expense of removing various dissolved salts from water rendered saline waters impractical as a source of potable water. However, starting in the 1950s, demineralisation began to appear to be economically practical for most uses, under certain circumstances.

The product water of the demineralisation process is generally water with less than 500 mg/L of dissolved solids, which is suitable for most domestic, industrial, and agricultural uses.
A by-product of demineralisation is the brine stream. Brine is a concentrated salt solution, generally with more than 10 000 mg/L of dissolved solids. Brine must be disposed of, generally by discharge into deep saline aquifers or surface waters with a higher salt content. Brine can also be diluted with treated effluent and disposed of by spraying on golf courses and/or other open space areas

D1.1 Reverse Osmosis

RO is currently the most common approach for demineralisation, with the market for this technology expected to grow at a rate of 10% annually.

RO is a valuable water purification process when mineral-free water is the desired end product. RO involves forcing a solution through a semi-permeable membrane using hydraulic pressure. Most mineral constituents of the source water are physically larger than water molecules so that they are trapped by the semi-permeable RO membrane and removed by the system. Such minerals include sodium chloride, lead, manganese, iron, and calcium.

The permeate (the liquid flowing through the membrane) is passed through the membrane by the pressure differential created between the pressurised feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurized side of the reactor as brine. No heating or phase change takes place. The major energy requirement is for the initial pressurization of the feedwater. For brackish water desalination the operating pressures range from 17 to 28 bar, and for seawater desalination from 55 to 68 bar.

In practice, the feedwater is pumped into a closed container against the membrane to establish an operating pressure. As the product water passes through the membrane, the remaining feedwater and brine solution becomes more and more concentrated. To reduce the concentration of dissolved salts remaining, a portion of this concentrated feedwater-brine solution is withdrawn from the container. Without this discharge, the concentration of dissolved salts in the feedwater would continue to increase, requiring ever-increasing energy inputs to overcome the naturally increased osmotic pressure.

The membrane material used for reverse osmosis is usually an organic thin-film membrane, typically a polyamide material perforated with tiny holes. These holes are small enough to let water pass through, but they block salt and other contaminants.

A RO system consists of four major components/processes: (1) pre-treatment, (2) pressurization, (3) membrane separation, and (4) post-treatment stabilization.

Pre-treatment: The incoming feedwater is pre-treated to be compatible with the membranes by removing potential physical and biological contaminants (e.g. suspended solids) that could otherwise foul the RO membranes. An inhibitor chemical may also be required as part of the pre-treatment to control and prevent scaling caused by constituents such as calcium sulphate as they are concentrated within the pressurised modules.

Pressurisation: The RO feed pump raises the pressure of the pre-treated feedwater to overcome the osmotic pressure and resistance losses across the membrane.

Separation: The permeable membranes inhibit the passage of dissolved salts while permitting the pure product water (typically called permeate) to pass through. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water. RO membranes are arranged in a variety of configurations. Two of the most popular are spiral wound and hollow fine fibre membranes. They can be made of cellulose acetate, aromatic polyamides, or, thin film polymer composites. Spiral wound membranes have become the RO membrane of choice for brackish water and seawater desalination, although the specific membrane and the construction of the pressure vessel may vary according to the different operating pressures and types of feedwater.

Stabilisation: The RO product water usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 to a value close to 7. In many cases, this water is discharged to a storage cistern for later use.

Today's state-of-the-art technology uses thin film composite membranes in place of cellulose acetate and polyamide membranes. The composite membranes work over a wider range of pH, at higher temperatures, and within broader chemical limits, enabling them to be more tolerant to potentially fouling feed water supplies and for conditions commonly experienced in most industrial applications. In general, the recovery efficiency of RO desalination plants increases with time as long as there is no fouling of the membrane.

Advantages

- The RO processing system is simple; the only challenge is to obtain good definition and representative information on the feedwater quality which enables the designer to identify the appropriate pre-treatment to ensure a robust a reliable system is installed to protect the RO membranes.
- Systems may be assembled in pre-packaged modular designs for production capacities ranging from a few litres per day to massive quantities per day for brackish and seawater desalination applications. The modular system allows for high mobility, making RO technology suitable for expansion

- RO plants have been used for emergency water supply.
- Installation costs are relatively low.
- RO plants have a very high space/production capacity ratio, ranging from 25 000 to 60 000 l/day/m^2.
- RO technologies can be used to remove organic and inorganic contaminants.
- Aside from the need to dispose of the brine, it is considered that the RO process has negligible environmental impact.
- The RO technology makes minimal use of chemicals.

Disadvantages

- The membranes are sensitive to fouling so if inappropriate pre-treatment is employed the membrane life could be short resulting in high membrane replacement costs.
- The feedwater usually needs to be pre-treated to remove particulates (in order to prolong membrane life).
- Due to the corrosive nature of the saline water the RO plant requires a high quality standard for materials and equipment.
- There is often a need for specialist assistance to design, construct, and operate plants.
- Brine must be carefully disposed of to avoid deleterious environmental impacts.
- There is a risk of bacterial contamination of the membranes; while bacteria are retained in the brine stream, bacterial growth on the membrane itself can introduce tastes and odours into the product water.
- RO technologies require a reliable energy source.
- Demineralisation technologies have a high cost when compared to other methods, such as groundwater extraction or rainwater harvesting.

The energy requirement for the brackish water RO process typically ranges from 1 to 3 kWhr per cubic metre of product water.

Typical RO produced water costs range from nominally \$0.70 to \$1.00 per cubic meter (this is inclusive of RO capital cost).

D1.2 Thermal Technology

The mechanical evaporation process is driven by heat transfer from condensing steam to the lower temperature across a metallic heat transfer surface. The absorbed heat causes vaporization of water and an increase in the salt concentration. The vapour is then condensed becoming distillate for reuse.

Evaporators can be categorized according to the arrangement of their heat transfer surface and the method used to impart heat to the feed solution. Common types of evaporators include the following:

- Single effect
- Multiple effect
- Vapour compression
- Vertical tube falling film
- Horizontal tube spray film
- Forced circulation

Evaporators are usually employed as a final concentration step to minimise brine reject volume from RO process. The most common combination of evaporators to accomplish full evaporation of membrane reject streams is vertical tube falling film-vapour compression evaporation followed by a crystallization/landfill step. The typical steps in the mechanical evaporation process are summarised as follows:

1. Brine concentrate is pumped through a heat exchanger that raises its temperature to the boiling point.

2. Hot feed combines with the brine/concentrate slurry in the sump. The brine/concentrate slurry is constantly circulated from the sump to a flood box at the top of a bundle of heat transfer tubes. Calcium sulphate crystals can be seeded into the brine/concentrate slurry to act as precipitation nuclei for scalants that would otherwise scale the heat transfer surfaces.

3. Some of the brine/concentrate evaporates as it flows in a falling film through the tubes and back into the sump.

4. The vapour passes through mist eliminators and enters the vapour compressor, which heats it slightly. Compressed vapour flows to the outside of the heat transfer tubes. Mechanical compressors are used in most applications. The mechanical vapour compressor is responsible for about 80 percent of the minimum 25 kilowatt-hours (kWh) energy usage per cubic meter of brine/concentrate concentrator feed.

5. Heat from the compressed vapour is transferred to the cooler brine/concentrate falling inside the tubes, causing some of the brine/concentrate to evaporate. As the compressed vapour gives up heat, it condenses as product water. This condensate is highly pure with a TDS content from 5 mg/L to 10 mg/L, making it an excellent water source for boiler make-up, cooling water make-up, and process use.

6. The high-purity distillate is pumped through the heat exchanger, where it gives up heat to the incoming membrane reject. Total product-water recovery across the brine/concentrate concentrator is between 95 and 99 percent.

7. From 1 percent to 5 percent of the brine/concentrate slurry is blow down from the sump to control the brine/concentrate density between 20 percent and 30 percent (200,000 to 300,000 mg/L). Blow down is sent to a crystalliser feed tank and then on to the forced circulation crystalliser.

The concentrated brine can be further treated in a forced circulation crystalliser (FCC). The water recovery from this process is expected to be 80% and the final product salt stream would be a crystallised solid.

A forced circulation crystalliser (FCC) is a mechanical evaporation process that uses heat and pressure differentials to flash-boil water, generating distilled liquid and solid salts. Some suppliers integrate the crystalliser with the mechanical vapour compression falling film exchanger vessel.

The typical steps in the FCC process are summarised as follows:

1. The 20 to 30 percent brine/concentrate (from the upstream brine concentrator) is recirculated through a heat exchanger under pressure to prevent boiling and subsequent scale formation in the tubes.

2. The pressurized brine/concentrate then enters a separator chamber operating at a slightly lower pressure or partial vacuum, resulting in flash evaporation of water and formation of insoluble salt crystals in the brine.

3. The vapour passes through mist eliminators and enters the vapour compressor, which heats it slightly. Compressed vapour flows to the outside of the heat transfer tubes heating the recirculated brine/concentrate flowing inside the heat transfer tubes. Mechanical compressors are used in most applications. The mechanical vapour compressor is responsible for about 80 percent of the 66 kWhr/kL energy usage for the FCC feed.

4. One to five percent of the brine/crystal liquor is wasted to separate the insoluble salt from the liquor. Salt crystals are typically separated from the liquor with a centrifuge or filter press. Salt can be disposed in a landfill or to market, and the filtrate liquor is returned to the FCC feed tank.

5. Total product water recovery across the brine concentrator and crystalliser is estimated to be between 95 and 99 percent. The condensate from both process units can be delivered to the main product-water stream.

Crystalliser systems can help to reduce wastewater discharges and, in many cases, capture revenue-producing products. The technology reduces environmental impacts and help to achieve zero liquid discharge.

By controlling the feedwater chemistry, crystallisers can recover specific salts that can be sold to offset operating costs. Because industrial wastewaters often contain mixtures of salts in variable concentrations, the design of an effective crystallizer system requires special expertise.

The crystallisers are simple to install, generally skid-mounted and fully packaged with all auxiliary equipment and controls. Automated controls and wash systems make the equipment easy to operate.

Thermal systems have a high capital and a high operating cost. A system with a mechanical vapour compression typically uses between 25 and 30 kWh/m^3 of produced condensate. These systems are normally used as a final concentration stage in a zero liquid discharge (ZLD) application.

D1.3 Electro-Dialysis Reversal (EDR)

Electro Dialysis (ED) is based on the principles governing the behaviour of an ionic solution when it is subject to direct current (DC) potential. In ED, alternating anion and cation permeable membranes (called anion transfer and cation transfer membranes) are placed in layers with an anode on one side of the assembly and a cathode on the other. When a current is applied to the system, water within one group of channels is “de-ionised”. Cations migrate through the cation transfer membrane towards the cathode, and the anions migrate through the anion transfer membrane towards the anode. In the adjacent channels, the membranes do not allow migration in the direction the ions are drawn (cations cannot migrate through the anion membrane and anions cannot migrate through the cation membrane). Thus, alternating channels are formed of deionised product water and ion-rich concentrate stream.

The ED stack contains two distinct flow channels, one for feed water and one for concentrate recycle. This allows concentrate to be recycled and only feed water to flow through demineralising channels. The concentration of ions in the concentrate is the limiting factor only to the extent that very high ion concentrations lead to precipitation which will foul membranes. Therefore, some concentrate is continuously blown down to waste and made-up with feed water.

Electrodialysis Reversal (EDR) is an advanced water treatment process based on electro-dialysis. EDR removes ions and other charged species from water and other fluids using small quantities of electricity to transport charged species through membranes composed of ion exchange material. EDR generates a purified water stream, and concentrated brine stream.

EDR technology is designed for up to 94% water recovery. EDR systems have an automatic Polarity Reversal self-cleaning feature that reduces the fouling tendencies of the water by reversing the polarity of the electrodes every 15 to 20 minutes. This change in polarity causes scale and organics to disassociate from the membranes.

In addition, EDR membranes can operate on waters with up to 0.5 mg/L chlorine to control the biological nature of feed water, and can also be shock-chlorinated up to 30 mg/l for maximum cleaning efficiency if required.

EDR is used to desalinate challenging brackish waters such as surface waters and waste waters. Applications for EDR technology include municipal drinking water, industrial process water, and wastewater reuse projects.

EDR have been used for the removal of radium, arsenic, and perchlorate as well as demineralisation of well and surface waters. Electrodialysis Reversal reliably desalinates water to customer specifications for industrial process requirements, such as boiler make up water. Additionally, because of its rugged membranes and high chlorine tolerance, EDR membranes are ideal for wastewater reuse projects.

Installed EDR systems vary in capacity from 15 m3/day to 6,000 m3/day per unit, and are able to achieve a removal of 50% to 94% of TDS in process streams with up to 12,000 mg/L TDS. By using multiple stages (stacks in series), systems can be optimized to handle a wide range of treatment needs.

D1.4 Nanofiltration

Nanofiltration (NF) is mainly used for the removal of divalent ions and the larger monovalent ions such as heavy metals. In simple terms NF technology can be regarded as a coarse RO membrane system and has the ability to remove divalent ions (e.g. calcium, magnesium, ferric ions, and sulphate) and trivalent ions (e.g. aluminium and ferrous ions) but will allow monovalent ions (e.g. sodium, chloride and nitrate) to pass through the membrane and be present in the NF product water (normally termed permeate).

Since NF uses a more open membrane structure, the feed pressure for the system can typically be 30% lower compared to RO systems. .

NF has limited application as a demineralisation technology.

D1.5 Ultrafiltration (UF)

Ultrafiltration (UF) is the separation of macro-molecules, fine emulsions, or colloidal material across a semi-permeable membrane, with pore sizes ranging from 0.005mm to 0.1 mm. The removal of this material occurs in a cross-flow filtration process, where the feed and concentrate flows are parallel to the membrane surface and the permeate flow is perpendicular to the membrane surface.

Pressure is applied to the feed side of the membrane, forcing the water through the membrane to the permeate side. High turbulent flow minimizes boundary layer fouling and sludge build-up on the membrane surface.

It has limited application as a demineralisation technology.

D1.6 Microfiltration (MF)

MF separation technology has cut-off of nominally 0.2 microns and removes larger size particulate matter (e.g. physical contaminants such as suspended solids, colloidal and biological material) in the feedwater compared with UF. MF systems operate at a lower pressure than for UF. MF can be also used as an alternative to centrifugation.

Both MF and UF are primarily used as the pre-treatment steps for RO.

D2 Technical & Economic Review of Emerging Technologies

D2.1 Forward Osmosis

This technology is also referred to as engineered osmosis. Unlike conventional demineralisation systems, an osmotic pressure gradient is established to force water through a purifying membrane (instead of using pressure or heat). The approach exploits the fact that water naturally flows from a dilute region to one that's more concentrated when the two solutions are separated by a semi permeable material, thereby saving the energy normally needed to drive the process.

An approach is to add a "draw solution" on one side of the membrane to extract clean water from dirty water. The solution is designed to have a high osmotic pressure and be easy to remove through heating.

Forward osmosis is not a new technology, but trying to find the optimal draw solution to make it efficient is critical. To date, only a pilot scale plant has been reported, producing one cubic meter of water per day. This technology still has a long way to before it can be considered suitable commercially at the scale of RO facilities.

D2.2 Capacitive Deionisation (CD)

Capacitive deionisation (CD) is a demineralisation technique invented a decade ago at the Lawrence Livermore National Laboratory. It exploits carbon aerogel, an extremely porous material originally developed for aerospace applications.

Composed almost entirely of air, aerogel looks like "frozen smoke," in one common description. The capacitive deionization approach to demineralisation takes advantage of two of aerogel's distinctive properties: its extremely high surface area and extremely low electrical resistance.

In operation, the salty water flows between paired sheets of aerogel. Electrodes embedded in the aerogel apply a small direct current; positively charged ions attach to the sheet with the negative electrodes, and negatively charged ions cling to the sheet with the positive electrodes. After a suitable number of hours or days, the current is reversed, rinsing the ions off into a concentrate stream.

This technology is still unproven on commercial scale. Capacitive deionisation's biggest issue remains the cost of manufacturing aerogel.

D2.3 Improvements in RO technology

Embedded nanoparticles change the properties of RO membranes, making them hydrophilic (water-attracting, so that water passes through more easily) while retaining their ability to filter out contaminants. Adding nanoparticles to a water purifying membrane can double its efficiency, adding just 5 percent to production costs

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