Volume 4 – Reference Information[1]

Pilot Summary

1. **General**

One of the main goals of the Yarkon river reclamation project was to increase the river flow. The flow deterioration was caused by years of agricultural direct consumption from the river body. In order to omit this flow reduction, an alternative water source for these consumers was to be found.

The chosen alternative suggested the Yarkon river will flow freely with no direct consumption from the water body and the alternative water solution for agriculture will be treated river water caught downstream at Seven Mills. At this point the Yarkon overflows to the saline part of the river and eventually connects to the Mediterranean Sea. The downstream water will be caught, treated and supplied for agricultural and gardening usage including the Yarkon river direct consumers.

2. **Motivation**

The chosen water treatment for the Yarkon river should supply effluent complied with the Israeli regulation, be cost effective, compact and show high endurance to altering water quality and.

In order to choose such a treatment, a massive Yarkon river sampling plan was applied to define the inlet water quality. After a year, the sampling program results were analyzed and the varying quality of the river throughout the year was understood. Massive algae bloom was observed intermittently at summertime whereas high turbidity events were seen at winter[1].

To meet the effluent quality regulation needs considering the seasonal variance of the river quality, required to test in practice on the river water various

[1] Without derogating from the standing and effect of this Volume 4 including and constituting Reference Information, it should be further noted the data provided herein was assembled by the entity who has performed the pilot and relates to samplings extracted between 2010-2013. The Yarkon river constitution changes annually therefore, sampling and pilot results refer in this volume are representative (per the data collected by the aforesaid entity) for the specific quality in the applicable timeframe.

technologies known. Therefore, Mekorot established a pilot plant beside the Yarkon river.

3. **Pilot Technologies**

Prior the pilot stage, a thorough literature survey was done mapping the technologies capable of reducing both algae and turbidity with minimum chemical addition and footprint to meet the regulation requirement.

The survey conclusions were:

(i) Membrane ultrafiltration (UF) was to be the main treatment technology

(ii) Different UF membranes should be tested

(iii) Proper UF pretreatment was to be piloted.

(iv) Known pretreatments for algae and turbidity reduction are: dissolved air flotation (DAF) and sedimentation.

4. **Pilot Objectives**

The main objective of the Yarkon river pilot was to find the proper treatment scheme that:

(a) Met specific treated water parameters and kept high quality filtered water with no suspended solids, low turbidity and minimum pathogens and bacteria

(b) Demonstrated robust and stable process performance against different feed conditions like turbidity and algae peaks

(c) Minimizes footprint and chemical consumption

5. **Pilot Participants**

The pilot participants were chosen based on the technology offered by their company. Participants offering pilot plants for Uf membrane filteration, DAF and sedimentation were approached.

The companies and technologies participated in the pilot are presented in table 1.

Table 1: Participants in Yarkon river water treatment pilot

No.	Technology	Supplier	Pilot Operation
1	Dissolve Air Flotation Clari-DAF®	Leopold (Xylem)	August 2011 – February 2012.
2	Enhanced sedimentation (ES), DensaDeg®	Degremont	October 2012 - February 2013.
3	Pressurized UF membrane, Aquaflex water filtration pilot	Norit	September 2011 – September 2012
4	Pressurized UF Membrane	DOW	August 2012 - March 2013.
5	Immersed UF Membranes ZEEWEED	Zenon (SUEZ)	February 2013 - April 2013

6. Pilot Treatment Alternatives

Three treatment alternatives were tested at the pilot:

(i) **Alternative A** - DAF (Leopold) followed by pressurized UF Membrane (Norit). Refer to Section 7 below.

(ii) **Alternative B -** ES (Degremont) followed by pressurized UF Membrane (Dow). Refer to Section 8 below.

(iii) **Alternative C** - Immersed UF Membrane (SUEZ) with no prior pretreatment. Refer to Section 9 below.

7. Alternative A: DAF → Pressurized UF

7.1 Description

7.1.1 DAF

The raw river water inlet was inserted into the DAF treatment container consisting of a first coagulation- flocculation stage. This included insertion of $FeCl_3$ as a coagulant agent followed by a rapid mix and a slow mix step. The flocculated water then flowed to the flotation tank.

An approximated 10% portion of the final effluent from the DAF treatment was sent to a pressurized tank in order to be saturated by air. This saturated stream is then released into the bottom of the flotation tank at atmospheric pressure causing the formation of many tiny bubbles. These travel from the bottom of the tank to the water surface causing the flotation of the flocculated suspended solids. Sludge is slowly built at the water surface and is removed by a skimmer to a sludge tank.

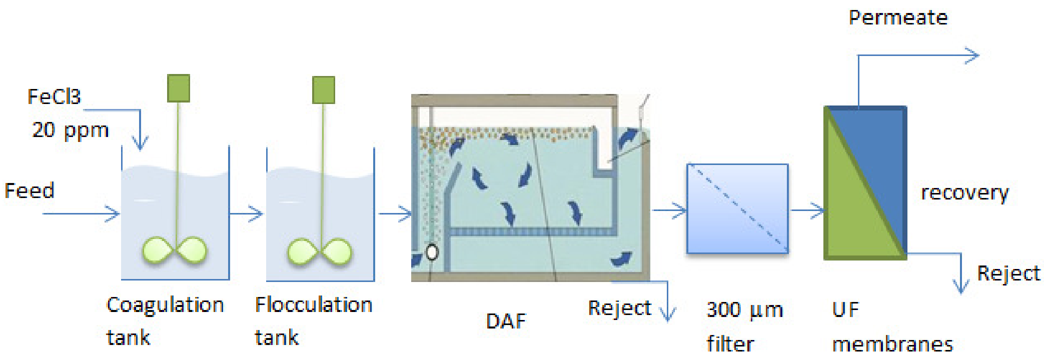
The DAF effluent entered the pressurized UF membrane for further treatment.

7.1.2 NORIT Pressurized UF membranes

The Norit pressurized membranes were of a hollow fiber type filtering the water from the inside to the outside of the fibers. Water after an automatic self cleaning filtration unit was pumped to a pressure vessel at the inner part of the membranes causing the water to flow out of the porous fibers. In order to clean the solid buildup inside the fiber, the membrane flow is reversed periodically and air scouring is applied on the membrane fibers. This enables to flush the accumulated solids on the membrane to the drain. The process occurs in cycles where each cycle consists of a filtration and a backwash step.

Every optimized amount of backwashes a chemical enhanced backwash is performed where proper chemicals are dosed to the reversed backwash flow. This enhances the cleaning of the membranes and reduces the energy needed to push the water through the membranes.

7.2 **The Treatment Scheme**



7.3 **Process Evaluation Criteria**

The following process parameters were analyzed to conclude this alternative's performance:

- The DAF effluent quality
- Hydraulic DAF process retention time
- Chemical consumption – coagulant and flocculant
- UF membrane performance – flux, filtration cycle duration time and CEB

7.4 **Results and Conclusions**

1. At summer time where the river turbidity is relatively low (<50 NTU), the DAF product is lower than 10 NTU , enabling good membrane performance with average fluxes of 80 lmh
2. At winter time whenever river water turbidity exceeds 100NTU unstable effluent quality was achieved and therefore none optimal membrane performance was observed with lower recovery and fluxes
3. At turbidity levels exceeding 100 NTU high coagulant doses were required leading to residual ferric concentrations at the product.
4. At an algae loading test the DAF system succeeded in removing 85% of the algae to UF membrane recommended values.
5. Whenever good DAF effluent quality was achieved the pressurized membrane showed good performance with expected good: recovery, flux, filtration cycle duration and CEB optimization.

As a conclusion:

The DAF technology was found unsuitable for the treatment of the of the Yarkon River water, especially because it can not provide adequate treatment for the river water during winter time when the water turbidity is high.

8. Alternative B: Enhanced sedimentation (ES) → Pressurized UF

8.1 Description

8.1.1 Enhanced Sedimentation

The ES process pilot included three main compartments: coagulation tank, maturation tank and sedimentation tank.

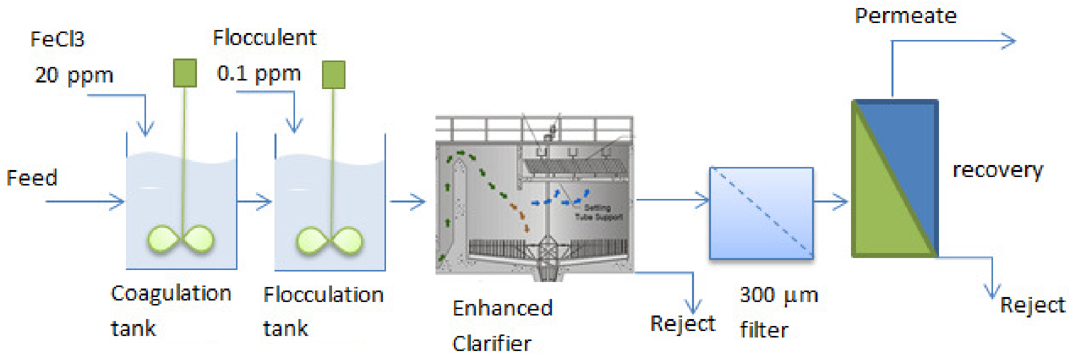
The raw river water dosed with $FeCl_3$ (coagulant) was pumped to the first coagulation step where rapid mixing was done. The coagulated water was then dosed with a polymer (flocculent) and entered the maturation tank. The maturation tank feed consisted of 97% coagulated water and 3% returned sludge which was constantly mixed. This mixture overflows to the third sedimentation tank with installed lamellas where solid settlement is to be performed.

The sludge builds up at the lower part of the sedimentation tank and is removed in a batch sequence to final disposal and as the return flow to the maturation tank.

8.1.2 DOW Pressurized UF Membranes

The DOW pressurized membranes were of a hollow fiber type filtering the water from the outside to the inside of the fibers. Water after an automatic self cleaning filtration unit was pumped to a pressure vessel at the outer part of the membranes causing the water to flow through the porous fibers. In order to clean the solid buildup outside of the fiber, the membrane flow is reversed periodically and air scouring is applied on the membrane fibers. This enables to flush the accumulated solids on the membrane to the drain. The process occurs in cycles where each cycle consists of a filtration and a backwash step. Every optimized amount of backwashes a chemical enhanced backwash is performed where proper chemicals are dosed to the reversed backwash flow. This enhances the cleaning of the membranes and reduces the energy needed to push the water through the membranes.

The Treatment Scheme



8.2 **Results and Conclusions**

1. Desired effluent turbidity for good following membrane performance from the ES was achieved necessarily after dosing both $FeCl_3$ and polymer flocculent . Insertion of a polymer can lead to residual concentrations in the membrane inlet. According to UF membrane manufacture, it is not advised to feed the membranes with polymers since this can cause membrane fouling.
2. The ES effluent turbidity was similar to the DAF
3. At winter time the required hydraulic load and consequent retention time needed for the ES process was higher than summertime.
4. At algae loading test the ES removed maximum 50% of the algae. This resulted in inlet chlorophyll levels to the membrane higher than recommended by the membrane manufactures.
5. The ES effluent had residual ferric concentrations that caused frequent backwashes at the membrane compartment.
6. The UF when fed low ferric concentration and good ES effluent with low turbidity showed good process performance.

As a conclusion:

The ES technology was found unsuitable for the treatment of the of the Yarkon River water, especially because it can not provide adequate treatment for the river water during summer time when the water Algae loading is high.

9. Alternative C: Immersed Membrane (IM)

9.1 Description

9.1.1 Immersed membrane

The IM process pilot included 2 main process units. The first unit included a short self cleaning filtration system, low dosage of coagulant ($FeCl_3$) and a short retention time coagulation tank. The water flows from the first unit into an atmospheric tank where the immersed membranes are installed. The membrane where of a reinforced hollow fiber type and filtration occurred from the outside of the membrane fibers to the inside. The inner part of the fibers where connected to a pump inlet. The suction pressure applied at the pump caused water to flow from the outside of the fibers into the inside gradually building a solid cake. In order to clean the solid buildup outside of the fiber, the membrane flow is reversed periodically and air scouring is applied on the membrane fibers. Every few filtration cycles a tank drain and refill occurs.

In order to sustain membrane performance a chemical cleaning regime was applied.

The IM technology was tested for 2 months and showed stable operation during high turbidity condition sand high Algae loading. The pilot workplan is presented in the table 2.

Table 2: The pilot workplan

	Phase 1	Phase 2	Phase 3	Phase 4
Description	• **Ramp Up**	• **Nominal Operation**	• **Acceleration Tests – High recovery**	• **BW aeration – Low Energy**
Duration of Phase	• 2 Weeks	• 6 Weeks	• 2 weeks	• 10 Days
Instantaneous Flow set point	• 1.0-1.36 L/s	• 1.67 L/s	• 1.36 L/s , later 1,5 L/s	• 1.5 L/s
Instantaneous Flux [l/(m²h)]	• 30-40	• 49.0	• 43	• 44
Backwash Sequence	• 1/tank drain + 2 between tank drains	• 1/tank drain + 2 between tank drains	• 1/tank drain + 4 between tank drains	• 1/tank drain + 2 between tank drains
Backwash Flux [l/(m²h)]	• 40	• 49	• one to one	• 44-55
Backwash Interval [min]	• 15.0	• 15.0	• 27.0	• 25
Backwash duration [sec]	• 20 (at capacity)	• 20 (at capacity)	• 20 (at capacity)	• 20 (at capacity)
Tank Drain mode	• Full Tank Backwash Aeration	• Full Tank Sequential Aeration	• Full Tank Sequential aeration	• Full Tank BW aeration
Tank Drain Interval [min]	• 45	• 45	• 135	• 75

The flux operation ranged from 31 to 48 lmh, depending on the feed water quality. The turbidity of the water at the different pilot stages is presented in figure 1.

The main operational parameters (flux, recovery and TMP) during the entire pilot are presented in figure 2 and the permeability in figure 3[2].

[2] This volume 4 does not include Information regarding aeration, membrane cleaning regimes and chemical consumptions.

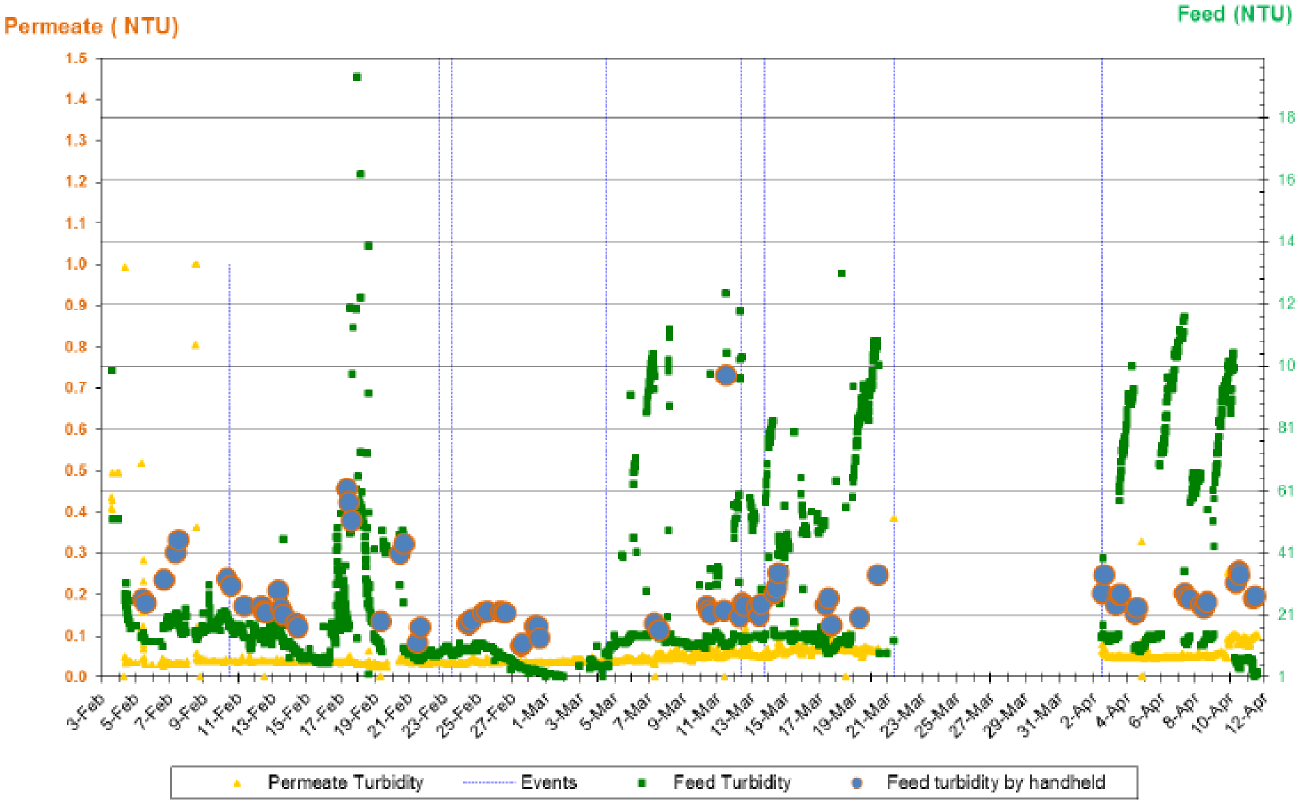


Figure 1: Turbidity Analysis (mg/L)

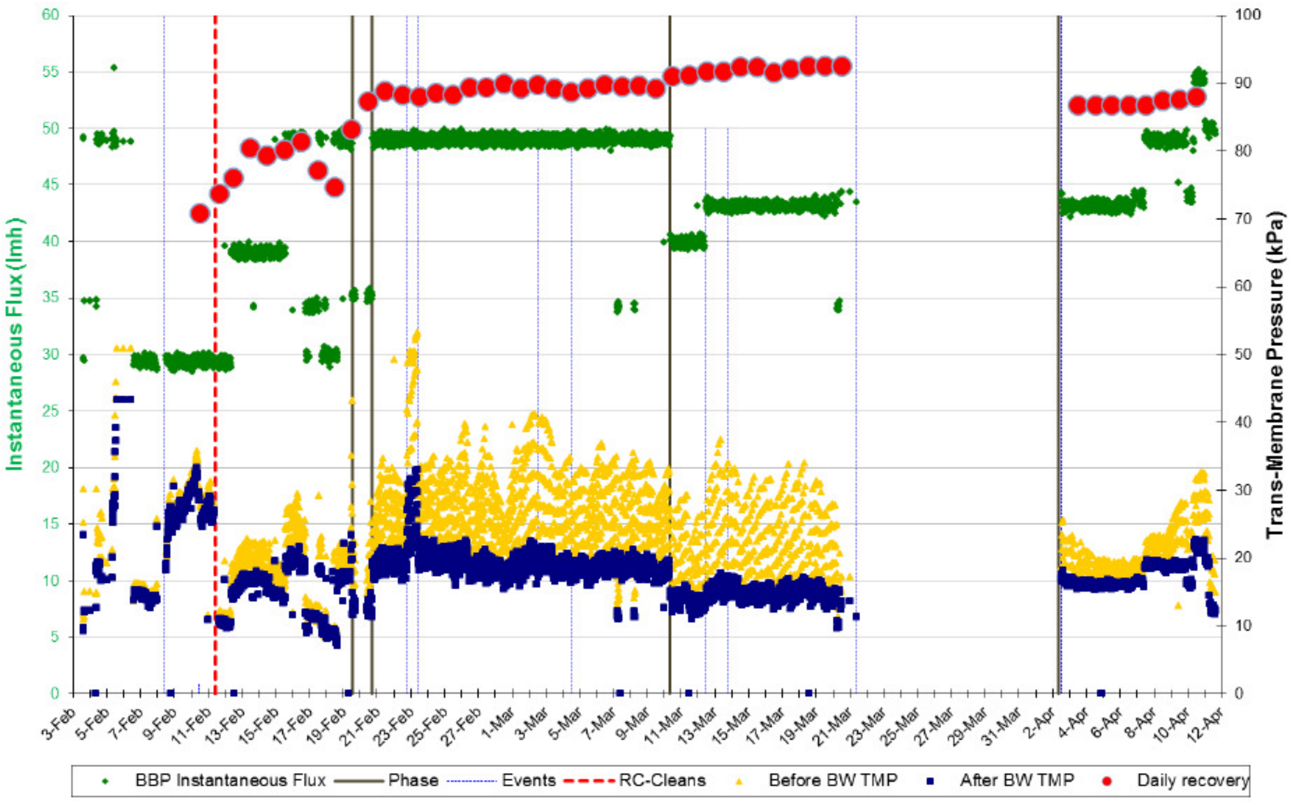


Figure 2 : UF Flux, TMP and recovery for the entire pilot study

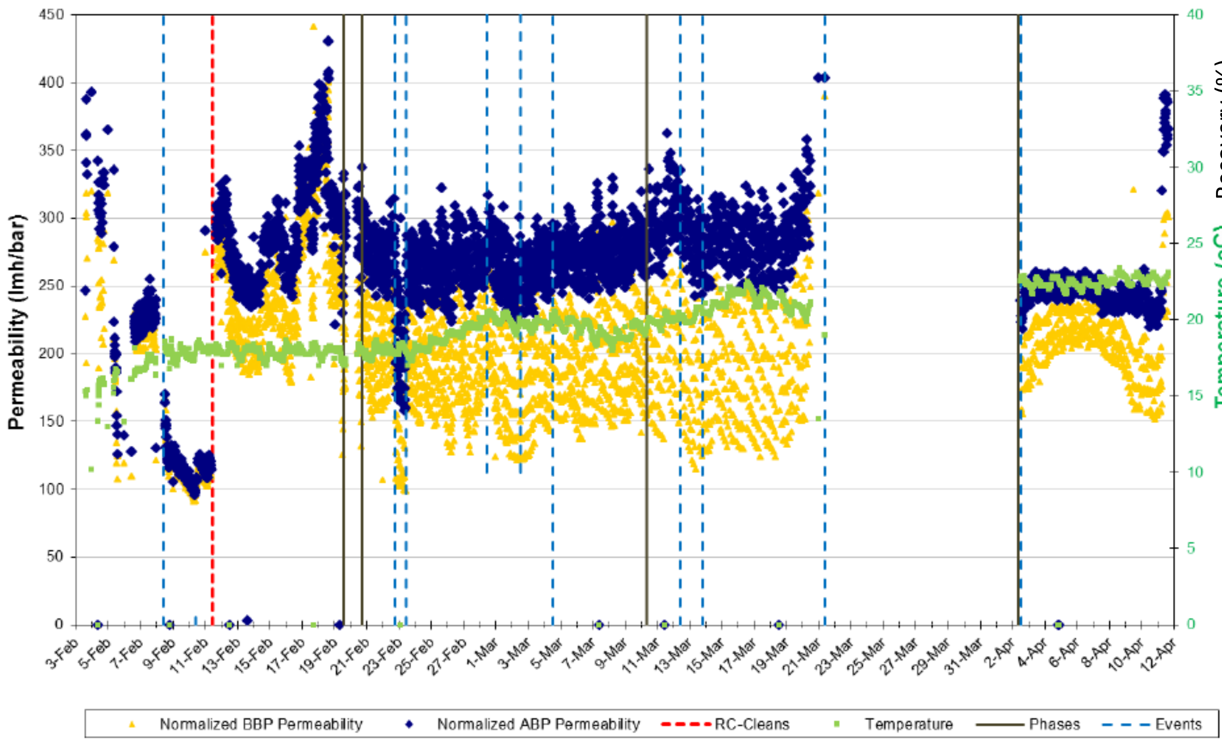
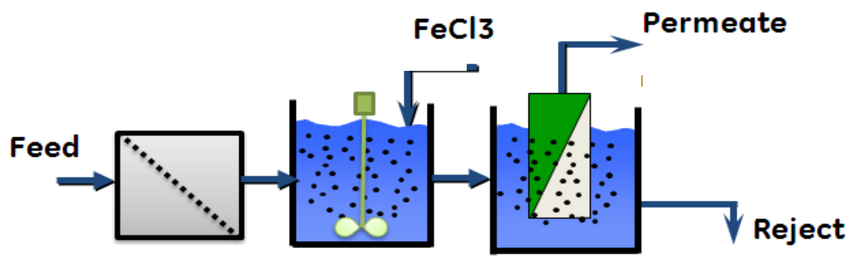


Figure 3: Temperature Corrected Permeability profile for the entire pilot study

Note: (BBP= before back pulse ; ABP= after back pulse)

9.2 **The Treatment Scheme**



9.3 **Results and Conclusions**

1. The IM effluent was stable and constant and met the desired product water quality regardless the influent river water quality.
2. The required $FeCl_3$ dosage to achieve good product quality was low.
3. At an algae loading test the IM demonstrated 99% removal of algae under stable operation.

As a conclusion:

Immerged Membrane technology showed robust and stable operation at minimum footprint and chemical consumption during different influent quality conditions, producing the required product quality with low suspended solids, turbidity and pathogens and bacteria count.

10. **<u>Summary</u>**

Relating to the main objectives of the Yarkon river pilot the immersed UF treatment scheme was chosen (Alternative C) mainly for the endurance of the membranes and the constant effluent quality achieved regardless the influent river water quality.

This treatment as compared to the others met specific treated water parameters and kept high quality filtered water with no suspended solids, low turbidity and minimum pathogens and bacteria. Moreover, it demonstrated robust and stable process performance against different feed conditions like turbidity and algae peaks and had minimum footprint and chemical consumption.

These above advantages together with the fact that immersed membrane is a global well known technology offered by several manufacturers led to the decision that this will be the base of the Yarkon river treatment process.