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ZERO BRINE

D2.2 Wastewater characterization Physiochemical analyses on the wastewater composition of WP2

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

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1. Overview of the project

The ZERO BRINE project aims to facilitate the implementation of the Circular Economy package and the SPIRE roadmap in various process industries by developing necessary concepts, technological solutions and business models to redesign the value and supply chains of minerals and water while dealing with present organic compounds in a way that allows their subsequent recovery.

These resources will be recovered from saline impaired effluents (brines) generated by the process industry while eliminating wastewater discharges and minimizing the environmental impacts of industrial operations through brines (ZERO BRINE). ZERO BRINE brings together and integrates several existing and innovative technologies to recover products of high quality and sufficient purity to represent good market value.

A large-scale demonstration plant will be tested in the Energy Port and Petrochemical cluster of Rotterdam Port by using the waste heat from one of the factories in the port. The quality of the recovered products will be aimed to meet local market specifications. Additionally, three large-scale pilot plants will be developed in other process industries in Poland, Spain, and Turkey, providing the potential for immediate replication and uptake of the project results after its successful completion.

2. Objectives

This report aims to provide information about the water composition that will be used for the Site 1 and Site 2 at the Work Package two (WP2). This information will be used for the laboratory experiments done by the involved partners of WP2, making PHREEQC simulations and for adjustment to refine the designs of Site 1 and Site 2 pilots at the Demi Water Plant (DWP) of Evides in the Botlek area (Rotterdam, The Netherlands).

The provided information is part of the public data and can be accessed by other work packages of the ZERO BRINE project and the public interested in the results from the ZERO BRINE project.

3. Background information

Work Package two (WP2) aims to demonstrate the circular economy in the Demi Water Plant (DWP) of Evides in the Botlek industrial area (Rotterdam, The Netherlands) through redesigning the current situation (Figure 1). To this aim, two designs will be demonstrated during the WP2 activities: one design (Site 1) for the treatment of the regenerant of the cationic ion exchange columns of the DWP and another design (Site 2) for the treatment of the concentrate of reverse osmosis unit of the DWP.

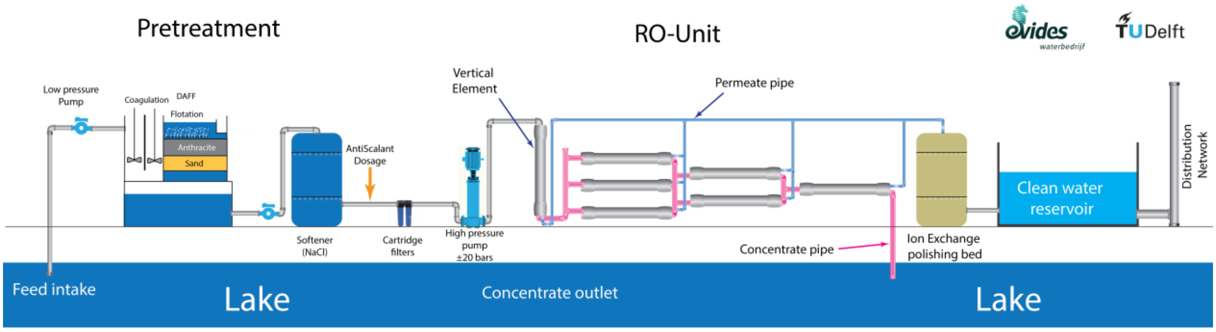

Figure 1: Schematic view of the current processes at the demineralized water plant of Evides at Botlek (Rotterdam, The Netherlands). The aim of WP2 is to treat the regenerant from the ion exchange softener (Site 1) and to treat the concentrate of reverse osmosis (site 2) and recover and reuse of salts from the wastewater.

The DWP at Evides Botlek area (Figure 1) is fed with the water from Brielse Meer, which is one of the branches of the river Maas. The DWP produces a high-quality water by using several purification techniques. This high-quality water is supplied to a large number of companies in the Botlek area.

The current DWP includes dissolved air flotation filtration (DAFF) to remove suspended matters from the intake water, cationic ion exchange (IEX) columns for removing divalent cations and soften the water , Reverse Osmosis (RO) to remove monovalent salts, and mixed bed ion exchange columns for polishing the RO permeate, that is: to remove traces of salts and charged organics, and make the permeate ready to be used by the companies.

The operation of IEX columns is typically a discontinuous process and exists of a service run (loading phase) and regeneration. In cationic IEX columns, when water containing dissolved cations comes in contact with positively charged resin (usually coated with sodium), the loosely held cations (sodium) ions on the resins are replaced with the cations in the feed water. In IEX units that are used to soften the water, the calcium and magnesium ions, that are responsible for water hardness, take the place of sodium ions on the resins. Eventually, a point is reached when very few sodium ions remain on the resins and either no more or a very small portion of divalent ions can be removed from the feed water. The resin at this point is called exhausted or spent. At this exhaustion point, the column needs to be regenerated to recover its initial or a great part of its initial capacity. The typical regeneration procedure consists of the following steps:

1. Removing of suspended solids by demineralized water
2. Injection of salt solution (regenerant) with a specific concentration and flow to replace divalent ions and recover the IEX capacity
3. Rinsing the column

The produced water during the regeneration cycle called spent regenerant, which is typically considered as the wastewater and is disposed to water bodies in most cases. Spent regenerant disposal is often problematic with regard to costs and environment and is subject to regenerant quality, the site of the treatment plant and local laws and regulations. Disposal of the spent regenerant is not environment friendly mostly due to a high salt concentration of the solution. The salt concentration in spent regenerant is highest during the second step of regeneration cycle (as mentioned above); i.e. during the replacement of captured ions with ions present in the injected chemicals. For instance, magnesium and calcium are important ions in the spent regenerant of the cationic IEX columns of the DWP of Evides.

The high cost of ion exchange spent regenerant disposal, the cost of the regenerant and the ban on spent regenerant disposal in most European countries warrant more thinking about coupling ion exchange with other technologies to reduce the negative impact of regenerant on the production cost and on the environment (Wachinski 2016). Site 01 of ZERO BRINE offers a solution to the regenerant disposal challenge in the DWP of Evides in the Rotterdam port area. At Site 01, the spent regenerant from the IEX in the second step of the regeneration will pass through a nanofiltration (NF) unit that is able to separate the spent regenerant into a permeate and a concentrate. The NF will be chosen in a way that allows as much as possible monovalent ions to pass through the membrane; i.e. the concentrate will contain only a small portion of monovalent ions and will be rich of other (divalent) ions. Then the NF concentrate passes through a membrane crystallisation unit wherein the calcium and magnesium will be removed from the concentrate. An evaporation unit is the last step of Site 01, which receives the monovalent rich NF permeate and the effluent of the membrane crystallisation unit. The effluent of the evaporator consists of purified water and a flow with a high NaCl concentration. The products of Site 01 (magnesium, calcium, purified water and NaCl rich flow) can be reused in the DWP or other industries.

In the current operation of the DWP, the IEX effluent (softened water) during the service run is be used as the feed water for the RO unit. In the RO, the feed water is separated into a permeate and a concentrate. The RO unit consists of three stages where the concentrate of the first stage is fed into the second stage and the concentrate of the second stage is fed to the third stage. The permeate of the first stage is mixed with the permeate of the second and third stage and the mixture is fed to the IEX mixed bed polishing unit to remove traces of salts and charged organics.

The concentrate stream produced in the last stage of RO contains salts and organic matters. In the case of the DWP, the concentrate stream is discharged to the sea. Although the concentration of salts and organics in the concentrate stream of RO is lower than the seawater, it could have negative environmental effects on the sea ecosystem due to use of chemicals added in the pretreatment of RO such as antiscalants. These added chemicals are rejected by the membrane and therefore will be present at a higher concentration, than concentration they are added, in the concentrate stream. Site 02 of ZERO BRINE aims to treat the concentrate of the current RO of the DWP. To this aim, an anionic IEX will be used to remove the anions and charged organic matters from the RO concentrate. The spent regenerant of anionic IEX will be fed to TOC removal unit to remove the organics. The virtually organic-free stream will then be fed to an NF unit. The NF concentrate contains a high concentration of multivalent anions such as sulphate and monovalent ions. The NF concentrate is sent to a Eutectic Freeze Crystallisation (EFC) unit, wherein the concentrate will be separated into ice and salts.

The effluent of the anionic IEX column will pass an RO unit, which will be operated with a recovery of around 85%. The permeate of the RO unit can be used as the process water and the concentrate will be sent to the evaporator, wherein it will be separated into pure water (condensate) and salts.

Monovalent-rich (mostly NaCl) permeate of NF could be mixed with the condensate of the evaporator and be used for regeneration of the anionic IEX column.

The two pilot designs described above may need to be adjusted based on the detailed analysis of the spent regenerate of the DWP cation IEX softener and the concentrate of the last stage of the DWP RO, and by considering the seasonal variation of the feed water composition. In this light, this report aims to describe the analysis results obtained for the composition of spent regenerant of the cationic IEX and the RO concentrate.

4. Experimental

The samples from the DWP at the Botlek area, Rotterdam, the Netherlands, were provided by Evides. The concentration of inorganic substance was determined in the water laboratory of TU Delft. The concentration of organic substances was measured in triplicate by “Het Waterlaboratorium” in Haarlem, the Netherlands. The samples were taken at four different moments (Table 1) to take into account seasonal variations. In the first analysis, the RO samples were taken at two different moments. Once for measuring the inorganic substances and once for measuring the organics because the time between taking samples and analysing them was more than a week. From the second series on, the RO samples were taken at the delivery day to “Het Waterlaboratorium” in Haarlem; i.e. samples used for organic measurement were not more a day in refrigerator of TU Delft before delivering to “Het Waterlaboratorium”.

Table 1: Information related to the samples taken at the Evides DWP.

No.	Name	Sampling period	Sampling location	No of samples taken	Additional Information
01	EXP01	12-11-2017 to 27-12-2017	DWP Evides	11 bottles of which two had very strange results	RO samples for determining organic matters are taken separately at 14-02-2018
02	EXP02	14-03-2018 to 28-03-2018	DWP Evides	9 bottles (5 samples from IEX and 4 from RO)	RO samples for determining organic matters are taken at the same day on 14-03-2018
03	EXP03	03-04-2018	DWP Evides	9 bottles (5 samples from IEX and 4 from RO)	RO samples for determining organic matters are taken at the same day on 03-04-2018
04	EXP04	11-07-2018	DWP Evides	8 bottles (4 samples from IEX and 4 from RO)	RO samples for determining organic matters are taken at the same day on 11-07-2018

The anions were measured first by ion chromatograph (Metrohm 881-IC compact pro, Switzerland) equipped with *Supp 5 150/4.0* column in the first two tries and the bicarbonate concentration was calculated based on the ionic balance of the major components of the water assuming all missing anions required to counterbalance the cations were solely bicarbonates. However, the results showed a great deviation from expected values and from pre-existing data that were known by Evides. Therefore, the anion measurement of the first two series was repeated using measurements kits mentioned in Table 2. The same test kits (Table 2) were used for determining concentration of anions in the third and fourth series. The obtained results from the ion chromatograph were used for first estimation of chloride concentration. However, the chloride concentration from ion chromatograph was adjusted to reach the ion balance in samples.

Table 2: Test kits used for measurement of anions

Element	Measuring kit	Measurement range	Company
Nitrate	LCK 339	1-60 mg/L NO_3	Hatch Lange, the Netherlands
Sulphate	LCK 153	40-150 mg/L SO_4	Hatch Lange, the Netherlands
Phosphate	LCK 348	1.5-15 mg/L PO_4	Hatch Lange, the Netherlands

The amount of bicarbonate was measured by a potentiometric titrator (702 SM Titrino, Metrohm). In this method the pH of solution was lowered to 4.3 by adding either 0.1 or 0.01 M HCl to sample. The concentration of standard HCl, the (starting) volume of sample and added volume of acid was used to calculate the alkalinity of solution. It is assumed that the contribution of carbonate to alkalinity was zero because all samples had a pH below 9.0.

The concentration of cations was assessed in duplicate by using Inductively coupled plasma—mass spectrometry (Plasma Quant MS, Analytik Jena, Germany).

Determination of organics has been done by using Liquid chromatography – organic carbon detection (LC-OCD). LC-OCD is an analytical technique for identification and quantification of natural organic matter (NOM) constituents in aquatic environments and water-soluble synthetic organic matter in technical waters. The principle behind NOM fractionation by LC-OCD is based on three separation processes, namely, size exclusion, ion interaction, and hydrophobic interaction. Size exclusion chromatography (SEC) is based on steric interactions or physical sieving where the difference in speed of diffusion for smaller and larger molecules is used to identify the different NOM fractions in the mobile phase (e.g., buffered water sample). The stationary phase is a packing of porous beads which allows smaller molecules to diffuse into the bead interior while preventing the larger molecules to diffuse through. As a consequence, larger molecules have less volume to traverse and travel faster through the chromatogram column (shorter elution time) than smaller molecules. The current LC-OCD system has an online organic carbon detector (OCD), UV detector (UVD), and organic nitrogen detector (OND) to continuously measure the relative signal response of organic carbon, UV, and organic nitrogen, respectively, at different retention times. In principle, the analysis technique is as follows: (1) injection of buffered particle-free water sample to a chromatographic column to separate fractions of NOM, (2) non-destructive UV detection at 254 nm wavelength, (3) organic carbon detection based on high-sensitivity TOC analysis, and (4) simultaneous detection of organic nitrogen in bypassed samples after the UV detector. The chromatogram data generated by the three detectors are processed to calculate organic carbon concentrations of biopolymers, humic substances, building blocks, low molecular weight (LMW) acids, and neutrals fractions of NOM based on area integration of the fractional peaks.

5. Results and discussions

a. Site 01

Table 3 shows the average concentration of ion in spent regenerant of cationic IEX columns at the DWP of Evides. In this table, "IEX" at the column heading indicate that the results belong to IEX columns and EXP01 to EXP04 indicates in which sampling period the samples were taken (Table 1).

Table 3: Average concentration of ions in spent regenerant of cationic ion exchange column

Element	Symbol	MW	Unit	IEX_EXP01	IEX_EXP02	IEX_EXP03	IEX_EXP04
Sodium	Na	23	mg/L	1703	7974	8145	6307
Magnesium	Mg	26	mg/L	1248	1337	1069	1414
Potassium	K	39	mg/L	236	228	321	257
Calcium	Ca	44	mg/L	6523	8538	7211	7038
Silica	SiO2	28	mg/L	1.97	0	0	0
Iron	Fe	56	mg/L	0	4.13	0.49	0.25
Strontium	Sr	88	mg/L	25	42	35	40
Titanium	Ti	47	µg/L	0.00	17.04	31.99	41.60
Vanadium	V	51	µg/L	84.57	274	0.58	0.00
Chromium	Cr	52	µg/L	13.77	154	40.0	6.14
Arsenic	As	75	µg/L	15.31	0	1.76	2.38
Selenium	Se	78	µg/L	3.63	0.66	43.7	28.23
Lithium	Li	7	µg/L	119	363	64.3	114
Boron	B	11	µg/L	20	67	1807	2223
Aluminum	Al	27	µg/L	0.14	1020	4.32	2447
Manganese	Mn	55	µg/L	10.21	226.81	0	0
Cobalt	Co	59	µg/L	0	88.98	4.86	2.35
Nickel	Ni	60	µg/L	205	2858	82.4	3.63
Copper	Cu	65	µg/L	34.16	59.52	0	60.45
Zinc	Zn	66	µg/L	103	156	173	44.6
Molybdenum	Mo	95	µg/L	1.27	13.81	7.61	0.37
Silver	Ag	107	µg/L	0.04	11.12	17.98	18.21
Cadmium	Cd	114	µg/L	0.35	0	14.19	12.22
Antimony	Sb	121	µg/L	0.59	22.8	0	0
Barium	Ba	137	µg/L	3554	4919	4436	5279
Thallium	Tl	205	µg/L	0.52	0	0	0
Lead	Pb	207	µg/L	0.03	220	502	424
Chloride	Cl	35	mg/L	17821	31305	28569	26440
Nitrate	NO3	62	mg/L	43.7	22.9	51.9	30.2
Phosphate	PO4	94	mg/L	1.78	0.29	0.02	0.72
Bicarbonate	HCO3	61	mg/L	143	140	115	109
Sulphate	SO4	96	mg/L	149	212	124	77
Total dissolved solids	**TDS**	**-**	**mg/L**	**27874**	**49772**	**45614**	**41683**
Electrical conductivity	**EC**	**-**	**mS/cm**	**43.4**	**80.25**	**76.4**	**69.6**
Averaged pH	**pH**	**-**	**-**	**7.26**	**7.08**	**6.86**	**6.66**

The average results mentioned in Table 3 were obtained by averaging at least four samples from four different IEX columns. The taken samples from Evides are diluted before being measured. The dilution factor was determined by the information about the measuring range of instrument used and initial concentration of Na and Cl in the original sample, which was estimated by converting electrical conductivity of samples to NaCl concentration. Detailed measurements of the IEX columns are given in Appendix A.

For measuring cations, three concentration factors were used (1000, 2000, 4000 times) and the best matches were used for calculating the average concentration. During determination of the concentration of anions, samples were diluted where the concentration of samples were out of test kit range.

The results from Table 3 show that chloride, calcium, sodium and magnesium had the highest concentration of all ions. Remarkably, the concentration of calcium was about 5-7 times higher than magnesium which is of utmost importance in designing the multi-flow plug flow reactor (MF-PFR) and its operation conditions for recovery of magnesium and calcium. That is important because the competition of calcium and magnesium at high pH and the effect that calcium could have on the purity of recovered magnesium.

The concentration of bicarbonate and sulphate was relatively high. The high concentration of sulphate in spent regenerate of IEX column was due to the fact that in DWP of Evides the regenerant is prepared by using the effluent of IEX column itself. The treatment steps before the ion exchange are not able to remove the sulphate of the water from the river and because the IEX columns are cationic IEX, the sulphate will appear in the effluent of the IEX columns and consequently in the spent regenerant.

Relatively high concentrations of bicarbonate and sulphate will affect the operation conditions of nanofiltration because these ions can cause scaling of the membrane at high recoveries particularly when the concentration of divalent ions such calcium and magnesium is very high in the feed water of nanofiltration. Also a relatively high concentration of barium (3-5 mg/L) could cause membrane scaling at high recoveries because the solubility of barium sulphate is even lower than calcium and magnesium sulphate.

While the concentration of potassium, lithium and aluminium is relatively low compared to chloride, they could pass the NF membrane and appear in the permeate water, which will be used as the feed water for evaporator. This could result in production of a low quality NaCl stream that is aimed to be used as the regenerant for IEX columns, and therefore could result in less effective regeneration of the IEX columns and higher costs. Therefore, before using this stream for regeneration, the NaCl purity of this stream should be studied carefully.

It is very difficult to mention something on the seasonal variation of the ions because it was not possible to take samples at exactly the same moment by each column and by each experiment.

b. Site 02

i. Inorganic

Table 4 shows the average concentration of ions in the concentrate at the last stage of RO in Evides DWP. In this table, "RO" in the column heading indicate that the results belong to the reverse osmosis stage and EXP01 to EXP04 indicate in which period the samples were taken (Table 1).

Table 4: The concentrate composition of the last RO-stage. The values shown in this table are average values of four (4) RO production lines at DWP of Evides.

Element	Symbol	MW	Unit	RO_EXP01	RO_EXP02	RO_EXP03	RO_EXP04
Sodium	Na	23	mg/L	845	1202	959	1056
Magnesium	Mg	26	mg/L	0.17	2.17	0.07	0.06
Potassium	K	39	mg/L	13.4	14.3	0	18.3
Calcium	Ca	44	mg/L	0.52	3.34	2.16	2.30
Silica	SiO2	28	mg/L	42	38	28	16
Iron	Fe	56	mg/L	0	0.30	0.02	0.02
Strontium	Sr	88	mg/L	2.85	0	8.15	8.18
Titanium	Ti	47	µg/L	1.19	0	0	0
Vanadium	V	51	µg/L	5.38	4.72	0.05	0.16
Chromium	Cr	52	µg/L	1.81	4.09	11.3	5.10
Arsenic	As	75	µg/L	1.01	0	0.99	2.01
Selenium	Se	78	µg/L	0.69	1.75	8.27	7.35
Lithium	Li	7	µg/L	45.8	83.3	49.9	93.5
Boron	B	11	µg/L	122	123	183	98
Aluminum	Al	27	µg/L	0.70	2.70	0.06	0.06
Manganese	Mn	55	µg/L	0	0	0	0.45
Cobalt	Co	59	µg/L	0	2.92	1.61	1.81
Nickel	Ni	60	µg/L	9.02	13.6	20.1	22.1
Copper	Cu	65	µg/L	12.9	0	51.2	7.54
Zinc	Zn	66	µg/L	18.0	0	71.6	36.3
Molybdenum	Mo	95	µg/L	9.31	10.7	7.63	12.7
Silver	Ag	107	µg/L	0.15	0	0.83	0.99
Cadmium	Cd	114	µg/L	0.01	0	0.04	0.03
Antimony	Sb	121	µg/L	1.56	1.77	1.26	1.87
Barium	Ba	137	µg/L	0.60	0	4.62	3.10
Lead	Pb	207	µg/L	0.16	7.10	3.63	4.25
Chloride	Cl	35	mg/L	514	1122	704	846
Nitrate	NO3	62	mg/L	39.4	7.32	53.4	22.4
Phosphate	PO4	94	mg/L	0	2.93	0.03	0.05
Bicarbonate	HCO3	61	mg/L	871	863	947	955
Sulphate	SO4	96	mg/L	371	335	271	320
Total dissolved solids	**TDS**	**-**	**mg/L**	**2696**	**3591**	**2966**	**3237**
Electrical conductivity	**EC**	**-**	**mS/cm**	**3.22**	**4.03**	**3.30**	**4.09**
Averaged pH	**pH**	**-**	**-**	**9.8**	**8.81**	**8.87**	**8.79**

The values shown in each column of Table 4 were obtained by averaging the values from four streets of reverse osmosis in Evides DWP. Similar to the IEX samples, also these samples were diluted before being measured. For measuring cations, the original samples were diluted three times with dilution factor of 50, 100, 200 times and only the reliable data were used. For anions, samples were diluted only when the concentration was out of the range of the test kits. The reliable data for a specific ion were averaged over different dilution factors and the results were represented as the sample (one street) concentration (Appendix B).

Table 4 shows that chloride, sodium, bicarbonate and sulphate had the highest concentration of ions in the concentrate stream of IEX column.

Remarkably, the silica concentration was high (16-42 mg/L). Silica will not be removed by anionic IEX in the ZERO BRINE pilot and will reach the RO membranes, and therefore will limit its recovery in the case that no antiscalant is used.

Sulphate concentration is a more important parameter influencing organic matter removal than the concentration of other anions such as bicarbonate, nitrate, and bromide, because sulphate is the main competitor for organic matter during the anionic IEX process. Therefore, it is interesting to investigate the affinity and efficiency of anion-exchange resins for natural organic matter (NOM) removal in waters with moderate sulphate concentration such as the concentration measured in this study (300-400 mg/L).

Comparing the concentrations of ions at different periods shows that concentration of most ions was highest during March when water temperature starts to increase.

ii. Organics

Table 5 shows the average concentration of organic matters in the concentrate stream of last stage of RO in Evides' DWP. In this table, EXP01 to EXP04 indicate in which period the samples were taken (Table 1).

Table 5: Averaged concentration of organics in concentrate stream of third stage of RO in DWP of Evides

Sample name	biopolymers	Humic Substances	Building Blocks	LMW Neutrals	LMW Acids	HOC	POC	CDOC	DOC	TOC
	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)
EXP01	239	5215	1975	1708	<200	325	38	9133	9460	9498
EXP02	630	6911	2432	2841	<200	957	18	12800	13750	13800
EXP03	492	6583	2068	2413	<200	722	60	11550	12275	12325
EXP04	262	5528	2073	8935	<200	901	-82	10600	11500	11425

Total organic carbon (TOC) consists of a dissolved fraction (DOC) and a particulate fraction (POC). DOC substances could be hydrophobic (HOC) or hydrophilic (CDOC). Chromatography fractionation of organic carbon (CDOC) is hydrophilic part of DOC and consist of biopolymers, humic substances, building blocks and low molecular weight (LMW) neutral.

Concentrations shown in Table 5 were averaged over four RO streets. The results of detained measurement are mentioned in Appendix C.

Table 5 shows that the highest concentration of organic matters was during the months March-May. However, this cannot be used as a general rule because of the high ambient temperature in Europe and the Netherlands during the period June – August 2018.

The negative concentration reported for POC is because POC is calculated by subtracting the DOC value from the TOC values. The TOC value could not be measured with the same method as the dissolved organic matter (DOC), and because of the different accuracy the values had to be rounded.

6. Conclusions

The provided data show the measurements of the inorganic composition for the Site 1 and Site 2 of Evides' DWP, during the winter season. Cations were measured with ICPMS, anions with test kits and organic matters with LC-OCD method.

It is difficult to give a clarification for the seasonal variation of ion concentration obtained for the spent regenerant of IEX because taking samples at the same moment was difficult. The highest concentration ions as well as organic matter in concentrate of RO was in March and May when ambient temperature started to increase.

7. Bibliography

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8. Appendixes

a. Appendix A: Detailed measurement of spent regenerant of IEX

Table 6: December 2017

Description				Dilution 1000 times							Dilution 2000 times						
Element	Symbol	MW	Unit	ZB-1000-IEX2	ZB-1000-IEX3	ZB-1000-IEX4	ZB-1000-IEX5	ZB-1000-IEX6	ZB-1000-IEX7	ZB-1000-IEX8	ZB-2000-IEX2	ZB-2000-IEX3	ZB-2000-IEX4	ZB-2000-IEX5	ZB-2000-IEX6	ZB-2000-IEX7	ZB-2000-IEX8
Sodium	Na	23	mg/L	1010.6	213.0	848.0	317.5	499.9	0.0	4804.7	920.4	199.9	815.0	322.1	505.3	8648.9	4738.4
Magnesium	Mg	26	mg/L	989.8	65.8	1720.9	313.7	948.1	2403.1	2757.5	906.7	63.1	1602.1	298.8	905.2	2122.4	2368.5
Potassium	K	39	mg/L	195.1	13.3	55.5	49.1	43.6	872.1	519.3	176.5	11.1	50.8	48.4	41.9	776.6	452.6
Calcium	Ca	44	mg/L	3634.4	382.7	9801.9	1442.6	5770.2	13905.8	11748.4	3729.9	391.2	9600.4	1464.4	5868.0	12986.5	10592.6
Silica	SiO2	60	mg/L	4.2	2.5		2.2	1.0	0.8	1.1							
Iron	Fe	56	mg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Titanium	Ti	47	µg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vanadium	V	51	µg/L	53.4	8.5	102.7	21.5	61.3	194.6	166.6	56.9	11.3	101.2	18.1	55.5	182.7	149.8
Chromium	Cr	52	µg/L	7.5	2.0	16.2	4.0	9.7	28.2	29.7	12.8	2.1	16.5	1.9	8.9	29.0	24.3
Arsenic	As	75	µg/L	4.0	0.5	22.6	5.0	13.6	55.8	45.5	2.1	0.0	10.7	0.0	11.9	25.1	17.5
Selenium	Se	78	µg/L	0.0	0.5	0.0	8.5	13.1	5.8	0.0	0.0	0.0	0.0	0.0	22.8	0.0	0.0
Lithium	Li	7	µg/L	114.2	23.9	147.9	44.0	100.2	229.6	181.9	90.4	21.6	133.3	44.7	97.2	210.7	225.7
Beryllium	Be	9	µg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boron	B	11	µg/L	26.9	30.4	24.1	24.0	27.7	36.4	44.0	12.8	5.1	5.8	6.7	6.9	15.5	18.5
Aluminum	Al	27	µg/L	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Manganese	Mn	55	µg/L	6.0	0.0	11.8	0.5	8.8	17.0	41.5	0.0	0.0	5.8	0.0	6.0	11.6	34.1
Cobalt	Co	59	µg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nickel	Ni	60	µg/L	115.8	14.7	302.1	46.4	174.3	420.0	393.4	144.7	17.0	279.7	47.9	167.9	392.2	354.7
Copper	Cu	65	µg/L	50.4	4.5	43.7	8.5	20.4	56.3	52.9	33.0	10.3	40.9	13.3	28.8	56.1	59.4
Zinc	Zn	66	µg/L	88.8	17.5	112.0	33.0	70.5	161.6	217.5	90.4	29.8	119.7	40.9	86.3	165.3	215.0
Strontium	Sr	88	µg/L	17351	1998	45322	6864	27608	0	49130	17376	1961	44962	6893	28290	61782	47324
Molybdenum	Mo	95	µg/L	1.0	1.0	1.5	1.5	1.5	1.9	1.5	1.1	1.0	1.0	1.0	1.0	1.9	1.0
Silver	Ag	107	µg/L	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cadmium	Cd	114	µg/L	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.0	1.0	0.0	1.0	0.0	1.0
Antimony	Sb	121	µg/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	1.0	1.0	1.0	1.0	1.0
Barium	Ba	137	µg/L	2175	244	5599	852	3356	7896	5221	2179	235	5479	866	3390	7370	4891
Thallium	Tl	205	µg/L	0.5	0.0	0.0	0.0	0.5	1.9	0.5	0.0	0.0	0.0	0.0	1.0	1.9	1.0
Lead	Pb	207	µg/L	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chloride	Cl	35	mg/L	8860.0	928.0	19548.0	2768.0	10708.0	36516.0	29576.0	8483.0	1241.0	19677.5	3519.0	10582.5	36439.5	34238.0
Fluoride	F	18	mg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Nitrate	NO3	62	mg/L	45.7	42.7	44.3	43.5	38.6	42.8	48.3							
Bromide	Br	80	mg/L	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Phosphate	PO4	95	mg/L	1.9	0.8	1.3	0.9	1.3	2.3	2.5							
Bicarbonate	HCO3	61	mg/L	189.3	137.4	89.1	137.4	133.9	150.5	161.5							
Sulphate	SO4	96	mg/L	193.6	109.8	83.0	153.3	153.7	174.4	176.7							

Table 7: March 2018

Description				Dilution 1000 times					Dilution 2000 times					Dilution 4000 times				
Element		MW		ZB-1000-IEX1	ZB-1000-IEX2	ZB-1000-IEX4	ZB-1000-IEX5	ZB-1000-IEX8	ZB-2000-IEX1	ZB-2000-IEX2	ZB-2000-IEX4	ZB-2000-IEX5	ZB-2000-IEX8	ZB-4000-IEX1	ZB-4000-IEX2	ZB-4000-IEX4	ZB-4000-IEX5	ZB-4000-IEX8
Sodium	Na	23	mg/L	10348	1126	4026	10801	13873	11610	1314	4762	11416	15019	8505	1070	3527	9924	12286
Magnesium	Mg	26	mg/L	887	792	2687	1357	932	1000	886	3061	1457	1067	748	702	2360	1273	845
Potassium	K	39	mg/L	76	125	398	89	312	97	141	563	120	399	81	132	401	136	356
Calcium	Ca	44	mg/L	8109	3159	13393	10080	6620	8880	3395	14799	11468	7399	7635	3072	12867	10554	6640
Silica	SiO2	28	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	Fe	56	mg/L	1.75	1.63	1.89	1.89	2.46	5.26	3.34	1.92	3.30	6.42	5.50	6.68	5.05	8.22	6.63
Titanium	Ti	47	µg/L	0	0	0	0	0	0	0	256	0	0	0	0	0	0	0
Vanadium	V	51	µg/L	274	119	368	347	295	254	99	413	395	375	195	78	235	347	317
Chromium	Cr	52	µg/L	69	49	70	69	157	254	79	177	99	277	117	116	118	347	317
Arsenic	As	75	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenium	Se	78	µg/L	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
Lithium	Li	7	µg/L	78	148	189	99	187	98	217	1082	178	672	273	854	392	386	595
Beryllium	Be	9	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boron	B	11	µg/L	0	0	0	0	0	528	0	452	0	20	0	0	0	0	0
Aluminum	Al	27	µg/L						294		2085		968				733	
Manganese	Mn	55	µg/L	0	0	0	0	550	0	0	0	0	968	0	0	0	0	1151
Cobalt	Co	59	µg/L	10	10	20	20	79	39	40	59	79	198	39	78	78	270	317
Nickel	Ni	60	µg/L	298	149	498	472	4829	459	176	857	664	8480	933	260	506	11358	12934
Copper	Cu	65	µg/L	0														119
Zinc	Zn	66	µg/L	0	306	20	0	452	0	0	8496	158	7409	0	4116	0	2623	4603
Strontium	Sr	88	µg/L	43003	15678	63760	53547	33205	46536	16026	69797	59650	36670	39114	13008	59751	54501	31863
Molybdenum	Mo	95	µg/L	10	10	10	10	29	20	20	79	20	79	39	39	39	77	79
Silver	Ag	107	µg/L	0	0	0	0	10	0	20	20	20	20	0	39	39	0	0
Cadmium	Cd	114	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Antimony	Sb	121	µg/L	10	0	0	10	29	59	0	20	20	40	0	0	0	116	40
Barium	Ba	137	µg/L	4596	1837	7640	6408	4305	4814	2055	8968	6972	4801	3627	1359	6622	6210	3571
Thallium	Tl	205	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead	Pb	207	µg/L	49	59	50	60	69	117	138	295	158	514	585	349	235	309	317

Chloride	Cl	35	mg/L	28221	7455	34965	34601	27748	27674	7092	34572	33562	30908	35525	6747	49063	34674	31060
Fluoride	F	19	mg/L	0														
Nitrate	NO3	62	mg/L	23	22	25	22	22										
Bromide	Br	80	mg/L	0	0	0	0	0										
Phosphate	PO4	95	mg/L	0.08	0.27	0.74	0.15	0.24										
Bicarbonate	HCO3	61	mg/L	140	144	141	122	151										
Sulphate	SO4	96	mg/L	174	186	197	239	265										

Table 8: May 2018

Description				Dilution 1000 times					Dilution 2000 times					Dilution 4000 times				
Element		MW		ZB-1000-IEX3	ZB-1000-IEX4	ZB-1000-IEX5	ZB-1000-IEX7	ZB-1000-IEX8	ZB-2000-IEX3	ZB-2000-IEX4	ZB-2000-IEX5	ZB-2000-IEX7	ZB-2000-IEX8	ZB-4000-IEX3	ZB-4000-IEX4	ZB-4000-IEX5	ZB-4000-IEX7	ZB-4000-IEX8
Sodium	Na	23	mg/L	9715	7600	9638	10251	8768	9793	7802	9550	10520	8857	10439	7975	9751	10764	8869
Magnesium	Mg	26	mg/L	1450	1971	1970	754	566	1501	2021	1990	788	569	1574	2088	2003	781	555
Potassium	K	39	mg/L	358	465	592	339	260	359	475	587	362	268	378	543	586	402	273
Calcium	Ca	44	mg/L	8183	13812	14382	5996	4170	8227	14006	14284	6304	4199	8609	13894	13781	6369	4392
Silica	SiO2	28	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron	Fe	56	mg/L	0	0	0	0	0	2	0	0	0	1	3	1	0	0	0
Titanium	Ti	47	µg/L	44	71	86	30	20	52	49	35	23	0	41	83	17	0	0
Vanadium	V	51	µg/L	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Chromium	Cr	52	µg/L	35	41	50	20	9	78	63	29	32	83	97	127	45	50	20
Arsenic	As	75	µg/L	3	6	6	0	1	0	4	2	0	3	0	1	0	7	0
Selenium	Se	78	µg/L	65	47	49	22	15	98	116	76	9	22	187	186	128	54	20
Lithium	Li	7	µg/L	163	117	64	110	10	89	48	17	43	0	183	82	0	0	0
Beryllium	Be	9	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boron	B	11	µg/L	1384	1719	4253	1654	116	3347	3823	1611	3743	482	8290	9315	3310	8154	1408
Aluminum	Al	27	µg/L	5	6	9	2	0	11	12	1	3	0	28	27	3	6	0
Manganese	Mn	55	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cobalt	Co	59	µg/L	0	22	0	7	0	0	15	0	0	0	29	31	0	0	0
Nickel	Ni	60	µg/L	0	0	8	0	0	0	0	0	0	742	0	0	0	0	0
Copper	Cu	65	µg/L	0	0	0	0	0	0	0	534	0	0	0	0	0	0	0
Zinc	Zn	66	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strontium	Sr	88	µg/L	50846	58415	64316	28877	19842	50274	59490	64321	28145	19729	50242	58871	63867	28081	19835
Molybdenum	Mo	95	µg/L	24	4	1	0	0	26	8	0	0	8	20	4	0	0	0

Silver	Ag	107	µg/L	17	17	32	11	3	39	41	17	26	6	91	117	33	59	16
Cadmium	Cd	114	µg/L	18	21	14	3	0	40	29	12	8	9	101	97	0	9	0
Antimony	Sb	121	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barium	Ba	137	µg/L	5983	7401	8955	4015	2766	5822	7469	8528	3843	2624	5870	7723	8795	4065	2579
Thallium	Tl	205	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead	Pb2	207	µg/L	534	565	819	273	70	1169	1166	321	606	133	2563	2515	853	1035	246
Chloride	Cl	35	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fluoride	F	19	mg/L	0														
Nitrate	NO3	62	mg/L	0	91	79	22	16	0	0	0	0	0	0		0	0	0
Bromide	Br	80	mg/L	0					0					0				
Phosphate	PO4	95	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	HCO3	61	mg/L															
Sulphate	SO4	96	mg/L	0	98	260	75	65	0	0	0	0	0	0	0	0	0	0

Table 9: July 2018

Description				Dilution 1000				Dilution 2000				Dilution 4000			
Element	Symbol	MW	Unit	ZB-1000-IEX4	ZB-1000-IEX5	ZB-1000-IEX6	ZB-1000-IEX7	ZB-2000-IEX4	ZB-2000-IEX5	ZB-2000-IEX6	ZB-2000-IEX7	ZB-4000-IEX4	ZB-4000-IEX5	ZB-4000-IEX6	ZB-4000-IEX7
Sodium	Na	23	mg/L	3018	7042	9713	9138	2980	8307	9956	9344	3277	8444	9926	9446
Magnesium	Mg	26	mg/L	1964	1933	1458	1476	1963	2355	1517	1518	2096	2396	1504	1514
Potassium	K	39	mg/L	432	186	169	270	477	218	193	256	526	254	228	261
Calcium	Ca	44	mg/L	7104	12156	8438	8834	7236	13260	8827	8827	6908	13571	8694	8936
Silica	SiO2	28	mg/L	0	0	0	0	0	0	0	0	0	0	0	0
Iron	Fe	56	mg/L	0	0	1	0	0	0	0	0	0	0	0	0
Titanium	Ti	47	µg/L	61	47	31	51	83	49	33	32	37	0	0	0
Vanadium	V	51	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Chromium	Cr	52	µg/L	43	0	0	0	0	0	0	0	0	0	0	0
Arsenic	As	75	µg/L	3	7	5	3	0	2	5	2	3	5	9	0
Selenium	Se	78	µg/L	50	27	25	9	77	23	22	15	164	59	67	45
Lithium	Li	7	µg/L	238	32	195	36	175	24	155	0	151	0	52	0
Beryllium	Be	9	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Boron		11	µg/L	2785	801	1338	1983	6426	1832	2727	305	14563	4037	5688	249
Aluminum	Al	27	µg/L	4705	444	496	838	10529	568	563	0	21046	1306	1311	0
Manganese	Mn	55	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Cobalt	Co	59	µg/L	0	0	0	0	0	0	0	16	0	0	35	0
Nickel	Ni	60	µg/L	13	0	0	0	0	0	0	12	0	0	0	0
Copper	Cu	65	µg/L	0	0	0	423	0	0	0	0	0	0	0	0
Zinc	Zn	66	µg/L	24	0	0	288	0	0	0	0	0	0	0	0
Strontium	Sr	88	µg/L	38962	72469	49302	51374	39544	78170	50024	51343	40045	78680	50204	50921
Molybdenum	Mo	95	µg/L	3	0	0	0	0	0	0	0	4	0	0	0
Silver	Ag	107	µg/L	24	7	9	14	55	17	24	2	120	38	48	4
Cadmium	Cd	114	µg/L	18	3	6	4	45	10	11	0	106	27	20	0
Antimony	Sb	121	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Barium	Ba	137	µg/L	5493	9062	6254	6923	5056	9861	6472	6757	5326	9987	6349	6833
Thallium	Tl	205	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Lead	Pb	207	µg/L	624	179	242	223	1393	328	444	39	2766	709	723	133
Fluoride	F	19	mg/L												
Nitrate	NO3	62	mg/L	16	66	24	14								

Bromide	Br	80	mg/L												
Phosphate	PO4	95	mg/L	0	0	0	0								
Bicarbonate	HCO3	61	mg/L												
Sulphate	SO4	96	mg/L	62	90	73	81								

b. Appendix B: Detailed measurement of inorganics at the concentrate stream of RO

Table 10: December 2017

Description				dilution 50 times				Dilution 100 times			
Element		MW		ZB-50-RO1	ZB-50-RO2	ZB-50-RO3	ZB-50-RO4	ZB-100-RO1	ZB-100-RO2	ZB-100-RO3	ZB-100-RO4
Sodium	Na	23	mg/L	860.26	836.31	828.22	823.87	846.90	865.65	851.58	843.99
Magnesium	Mg	26	mg/L	0.18	0.17	0.17	0.16	0.17	0.18	0.19	0.17
Potassium	K	39	mg/L	15.89	12.22	11.90	12.26	16.82	13.17	12.79	12.39
Calcium	Ca	44	mg/L	0.55	0.48	0.30	0.71	0.40		0.65	0.54
Silica	SiO2	60	mg/L	41.23	46.47	39.71	40.14	42.02	41.43	42.11	41.37
Iron	Fe	56	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Titanium	Ti	47	µg/L	0.99	1.99	1.19	1.39	0.41	0.00	87.04	17.23
Vanadium	V	51	µg/L	5.34	5.96	5.24	5.17	5.10	5.40	5.40	5.41
Chromium	Cr	52	µg/L	1.68	1.89	1.78	1.89	1.43	1.60	2.20	2.00
Arsenic	As	75	µg/L	0.99	1.09	0.99	0.99	1.02	1.00	1.00	1.00
Selenium	Se	78	µg/L	0.99	0.79	0.59	0.70	0.61	0.40	0.40	1.00
Lithium	Li	7	µg/L	45.59	44.58	43.24	44.95	46.55	47.00	48.02	46.27
Beryllium	Be	9	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	B	11	µg/L	132.21	118.96	119.73	102.62	126.79	119.20	150.66	104.17
Aluminum	Al	27	µg/L	0.10	0.79	0.49	1.49	0.61	0.00	596.06	119.79
Manganese	Mn	55	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cobalt	Co	59	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	Ni	60	µg/L	8.97	8.69	8.35	8.83	9.47	9.40	9.39	9.06
Copper	Cu	65	µg/L	13.35	12.51	12.96	13.62	12.05	12.60	13.41	12.82
Zinc	Zn	66	µg/L	13.94	13.70	13.66	14.22	18.17	17.60	32.61	19.83
Strontium	Sr	88	µg/L	2.97	2.68	2.47	2.78	3.06	2.40	3.80	2.60
Molybdenum	Mo	95	µg/L	9.20	9.04	8.81	9.25	8.98	9.20	10.60	9.42
Silver	Ag	107	µg/L	0.10				0.20			
Cadmium	Cd	114	µg/L	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	Sb	121	µg/L	1.48	1.59	1.48	1.49	1.63	1.60	1.60	1.60
Barium	Ba	137	µg/L	0.89	0.10	1.19	0.40	0.82	0.20		
Thallium	Tl	205	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	Pb	207	µg/L	0.20	0.10	0.10	0.10	0.20	0.20	0.20	
Chloride	Cl	35	mg/L	48.10	46.00	45.30	45.80	52.00	53.40	54.40	54.60

Fluoride	F	18	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	NO3	62	mg/L	39.66	38.69	39.35	40.02				
Bromide	Br	80	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate	PO4	95	mg/L	<0.05	<0.05	<0.05	<0.05	0.00	0.00	0.00	0.00
Bicarbonate	HCO3	61	mg/L	899.97	860.52	850.77	873.41				
Sulphate	SO4	96	mg/L	359.73	393.91	363.91	365.35				

Table 11: March 2018

Description				Dilution 50 time				Dilution 100 time				Dilution 200 times			
Element	Symbol	MW		ZB-50-RO2	ZB-50-RO4	ZB-50-RO6	ZB-50-RO8	ZB-100-RO2	ZB-100-RO4	ZB-100-RO6	ZB-100-RO8	ZB-200-RO2	ZB-200-RO4	ZB-200-RO6	ZB-200-RO8
Sodium	Na	23	mg/L	1272.53	1352.04	1176.46	1263.83	1406.20	1319.19	1364.45	1368.10	1141.97	1102.04	1191.63	1113.17
Magnesium	Mg	26	mg/L	3.19	2.55	2.42	0.53	3.56	2.35	2.62	0.64	3.08	2.62	2.60	0.36
Potassium	K	39	mg/L	17.96	15.41	14.22	7.55	19.84	17.14	17.65	9.06	18.14	15.52	16.60	9.24
Calcium	Ca	44	mg/L	4.41	2.36	2.02	2.11	4.55	3.34	4.32	1.82	4.27	5.05	3.71	2.79
Silica	SiO2	28	mg/L	22.72	11.80	8.50	8.84	50.92	33.03	37.72	22.54	76.21	60.92	54.02	58.11
Iron	Fe	56	mg/L	0.31	0.20	0.11	0.08	0.39	0.30	0.40	0.25	0.40	0.18	0.56	0.57
Titanium	Ti	47	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	V	51	µg/L	6.92	5.52	4.90	4.82	5.03	4.74	5.85	4.76	3.96	3.77	3.89	3.93
Chromium	Cr	52	µg/L	2.97	2.51	5.39	2.41	3.02	2.84	3.90	2.85	3.96	3.77	5.84	5.90
Arsenic	As	75	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Selenium	Se	78	µg/L	1.48	1.00	0.98	0.96	1.01	0.95	1.95	1.90	1.98	1.89		3.93
Lithium	Li	7	µg/L	85.06	79.36	76.99	75.26	86.53	86.26	89.70	75.13	87.10	86.75	93.42	82.55
Beryllium	Be	9	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	B	11	µg/L	143.42	115.52	116.23	126.40	144.89	125.12	133.58	140.75	138.56	99.95	122.61	119.90
Aluminum	Al	27	µg/L	29.67	0.00	0.00	0.00	0.00	27.49	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	Mn	55	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cobalt	Co	59	µg/L	2.47	1.51	0.98	0.96	5.03	3.79	2.93	3.80	3.96	5.66	3.89	3.93
Nickel	Ni	60	µg/L	16.88	10.15	10.21	11.13	12.74	12.05	13.40	12.40	12.27	20.31	13.47	14.19
Copper	Cu	65	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc	Zn	66	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	Sr	88	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum	Mo	95	µg/L	9.89	10.05	9.32	9.65	11.07	10.43	10.73	10.46	11.88	11.32	11.68	11.79
Silver	Ag	107	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	Cd	114	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	Sb	121	µg/L	1.98	1.51	1.47	1.45	3.02	1.90	1.95	1.90	1.98	1.89	1.95	1.97
Barium	Ba	137	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thallium	Tl	205	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	Pb	207	µg/L	17.80	2.01	1.96	1.93	3.02	4.74	4.88	3.80	9.90	7.54	7.78	7.86

Chloride	Cl	35	mg/L	49	483	482	480	489	431	444	461	391	395	418	445
Fluoride	F	19	mg/L	0											
Nitrate	NO3	62	mg/L	7.40	7.22	7.32	7.35								
Bromide	Br	80	mg/L	0	0	0	0								
Phosphate	PO4	95	mg/L	2.88	2.08	3.12	3.64								
Bicarbonate	HCO3	61	mg/L	787	821	909	936								
Sulphate	SO4	96	mg/L	376	317	323	325								

Table 12: May 2018

Description				Dilution 50 times				Dilution 100 times				Dilution 200 times			
Element		MW		ZB-50-RO3	ZB-50-RO4	ZB-50-RO5	ZB-50-RO6	ZB-100-RO3	ZB-100-RO4	ZB-100-RO5	ZB-100-RO6	ZB-200-RO3	ZB-200-RO4	ZB-200-RO5	ZB-200-RO6
Sodium	Na	23	mg/L	976	998	896	929	969	946	950	897	1047	983	962	955
Magnesium	Mg	26	mg/L	0.28	0.02	0.09	0	0.04	0.01	0.16	0	0	0	0.26	0
Potassium	K	39	mg/L	5.37	4.92	5.36	5.18	5.14	5.18	5.64	5.14	4.69	4.74	5.64	5.24
Calcium	Ca	44	mg/L	1.41	1.42	1.25	0.44	0.34	1.88	2.81	0	4.35	2.50	7.95	1.54
Silica	SiO2	28	mg/L	29.1	19.2	25.0	17.7	36.8	15.4	28.1	26.2	42.9	31.0	33.3	28.9
Iron	Fe	56	mg/L	0.04	0	0	0.03	0.00	0.10	0	0	0	0	0.02	0.00
Titanium	Ti	47	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Vanadium	V	51	µg/L	0	0.59	0	0	0	0	0	0	0	0	0	0
Chromium	Cr	52	µg/L	1.96	0.95	0.97	4.77	4.03	10.3	4.48	1.40	4.95	1.73	94.8	4.81
Arsenic	As	75	µg/L	1.34	0.96	1.04	0.72	0.56	0.99	1.54	0.77	1.20	1.00	0.89	0.90
Selenium	Se	78	µg/L	6.58	3.17	2.85	3.12	9.35	6.29	6.12	8.06	16.3	14.5	11.1	11.8
Lithium	Li	7	µg/L	45.9	43.9	39.4	36.4	48.8	43.4	47.1	39.6	105	50.4	52.9	46.0
Beryllium	Be	9	µg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	B	11	µg/L	108	110	119	125	122	148	192	190	225	216	300	343
Aluminum	Al	27	µg/L	0.19	0.02	0.02	0	0.11	0.08	0.10	0.08	0.09	0	0	0
Manganese	Mn	55	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Cobalt	Co	59	µg/L	1.18	1.89	0.78	0.78	1.52	0	1.48	2.39	1.50	1.51	4.69	1.60
Nickel	Ni	60	µg/L	5.25	8.59	2.68	5.68	0.00	185	8.40	2.28	0	0	23.3	0
Copper	Cu	65	µg/L	56.6	36.4	2.89	150	48.6	145	0	0	48.5	0	109	17.5
Zinc	Zn	66	µg/L	49.3			75.7	54.1			84.5				94.3
Strontium	Sr	88	µg/L	8.63	3.66	6.10	3.03	8.04	7.40	11.9	7.19	10.6	3.87	21.0	6.22
Molybdenum	Mo	95	µg/L	7.21	6.76	6.55	7.40	6.89	8.61	7.14	6.76	6.36	6.62	15.4	5.89
Silver	Ag	107	µg/L	0.33	0.40	0.37	0.49	0.41	0.64	0.82	0.96	1.23	1.24	1.40	1.72
Cadmium	Cd	114	µg/L	0	0	0.07	0	0.41	0	0	0	0	0	0	0

Antimony	Sb	121	µg/L	1.49	1.44	1.23	1.27	1.35	1.27	1.38	1.11	1.56	0.92	1.09	0.98
Barium	Ba	137	µg/L	5.84	0	1.71	0	1.27	0	15.1	2.63	13.4	0	15.0	0.45
Thallium	Tl	205	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Lead	Pb	207	µg/L	1.86	2.24	1.65	3.46	4.31	3.45	6.39	3.46	0.00	3.46	8.76	4.54
Chloride	Cl	35	mg/L	0	0	0	0	0	0	0	0	0	0	0	0
Fluoride	F	19	mg/L	0											
Nitrate	NO3	62	mg/L	46.5	59.7	50.3	57.0								
Bromide	Br	80	mg/L	0	0	0	0								
Phosphate	PO4	95	mg/L	0.08	0.01	0.00	<0.05								
Bicarbonate	HCO3	61	mg/L												
Sulphate	SO4	96	mg/L	261	261	281	281								

Table 13: July 2018

Description				Dilution 50 times				Dilution 100 times				Dilution 200 times			
Element		MW		ZB-50-RO3	ZB-50-RO6	ZB-50-RO7	ZB-50-RO8	ZB-100-RO3	ZB-100-RO6	ZB-100-RO7	ZB-100-RO8	ZB-200-RO3	ZB-200-RO6	ZB-200-RO7	ZB-200-RO8
Sodium	Na	23	mg/L	1053	1049	1033	981	1099	1059	1056	1043	1144	1097	1608	998
Magnesium	Mg	26	mg/L	0.11	0.07	0.08	0.07	0.15	0.04	0.06	0.13	0	0	94.5	0
Potassium	K	39	mg/L	18.0	17.8	17.8	18.2	18.2	19.0	17.9	18.2	18.15	18.66	67.69	19.51
Calcium	Ca	44	mg/L	1.39	1.20	1.18	1.17	3.09	2.39	2.50	2.62	3.43	3.26	382	3.01
Silica	SiO2	28	mg/L	20.5	19.1	16.0	7.53	23.9	10.7	15.5	7.73	29.4	20.3	11.9	8.33
Iron	Fe	56	mg/L	0.02	0.05	0.00	0.07	0	0	0	0	0	0	316	0.06
Titanium	Ti	47	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Vanadium	V	51	µg/L	0.11	0	0	0	0.28	0.34	0.43	0.13	0.44	0	0	0
Chromium	Cr	52	µg/L	2.80	3.95	0.74	7.11	0	6.62	26.1	5.19	0	3.53	0	0
Arsenic	As	75	µg/L	2.06	1.77	1.84	2.12	1.63	2.41	2.11	2.34	1.13	2.25	40.1	2.47
Selenium	Se	78	µg/L	4.46	3.89	3.56	3.76	8.51	6.19	5.07	5.96	14.94	15.14	11.03	9.39
Lithium	Li	7	µg/L	95.4	88.0	85.7	82.1	104	93.1	90.6	88.4	112	100	104	88.3
Beryllium	Be	9	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Boron	B	11	µg/L	118.4	131.7	69.2	71.2	172	206	161	180	256	371	809	395
Aluminum	Al	27	µg/L	0	0	0	0	0	0	0	0.67	0	0	596	0
Manganese	Mn	55	µg/L	4.91	0	0	0	0	0	0	0	0	0	3738	0
Cobalt	Co	59	µg/L	1.15	0.38	1.14	1.19	0.80	2.41	0.76	2.46	3.17	3.22	530	3.22
Nickel	Ni	60	µg/L	2.21	1.86	2.27	169	0	0	4.81	0.82	0	0	27616	61.5
Copper	Cu	65	µg/L	0	0	25.5	0	44.3	0	0	13.1	0	0	1108	0
Zinc	Zn	66	µg/L	32.3	24.1	55.9	32.9	236	148	155	136	112	120	0	57.2
Strontium	Sr	88	µg/L	5.23	5.34	5.00	4.95	11.2	7.26	9.52	8.84	13.7	9.34	1237	9.49
Molybdenum	Mo	95	µg/L	9.67	9.56	9.88	24.5	10.1	11.0	10.2	17.0	8.97	11.5	0	17.7
Silver	Ag	107	µg/L	0.31	0.54	0.09	0.12	0.65	0.95	0.56	0.79	2.90	1.95	5.12	2.03
Cadmium	Cd	114	µg/L	0	0	0	0	0	0	0.22	0.10	0	0	0	0
Antimony	Sb	121	µg/L	1.97	1.91	1.94	1.85	2.09	1.95	1.84	1.94	1.77	1.74	58.7	1.52
Barium	Ba	137	µg/L	0	0.85	1.52	0.50	0	5.76	4.33	3.36	0	3.04	1350	14.7
Thallium	Tl	205	µg/L	0	0	0	0	0	0	0	0	0	0	0	0
Lead	Pb	207	µg/L	1.96	5.44	0	0.93	0.25	7.99	3.76	3.85	4.48	6.32	12.09	11.80
Chloride	Cl	35	mg/L	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoride	F	19	mg/L	0											
Nitrate	NO3	62	mg/L	21.9	21.1	22.6	24.0								

Bromide	Br	80	mg/L	0.00	0.00	0.00	0.00								
Phosphate	PO4	95	mg/L	<0.05	<0.05	<0.05	<0.05								
Bicarbonate	HCO3	61	mg/L												
Sulphate	SO4	96	mg/L	311	336	315	318								

c. Appendix C: Detailed measurements of organics in concentrate of RO

Sample name	biopolymers	Humic Substances	Building Blocks	LMW Neutrals	LMW Acids	HOC	POC	CDOC	DOC	TOC
Unit	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)	(µg/L C)
EXP01_RO01	338	5250	2080	1730	<200	287	30	9390	9680	9710
EXP01_RO06	184	5140	1960	1640	<200	335	53	8920	9260	9310
EXP01_RO07	201	5030	1940	1690	<200	379	6	8860	9240	9250
EXP01_RO08	232	5440	1920	1770	<200	298	64	9360	9660	9720
EXP01_Ave	239	5215	1975	1708	<200	325	38	9133	9460	9498
EXP02_RO02	615	6974	2320	2818	<200	917	30	12700	13600	13700
EXP02_RO04	609	6999	2307	2816	<200	1000	36	12700	13700	13800
EXP02_RO06	647	6812	2541	2868	<200	953	17	12900	13800	13800
EXP02_RO08	650	6860	2560	2861	<200	959	-12	12900	13900	13900
EXP02_Ave	630	6911	2432	2841	<200	957	18	12800	13750	13800
EXP03_RO03	480	6707	1938	2489	<200	704	40	11600	12300	12400
EXP03_RO04	563	6698	1984	2443	<200	718	23	11700	12400	12400
EXP03_RO05	539	6741	1906	2428	<200	677	50	11600	12300	12300
EXP03_RO06	385	6186	2443	2291	<200	788	126	11300	12100	12200
EXP03_Ave	492	6583	2068	2413	<200	722	60	11550	12275	12325
EXP04_RO03	259	5440	2140	2730	<200	847	-38	10600	11400	11400
EXP04_RO06	252	5550	2080	2700	<200	877	-89	10600	11500	11400
EXP04_RO07	308	5550	2040	2710	<200	854	-94	10600	11500	11400
EXP04_RO08	230	5570	2030	27600	<200	1024	-107	10600	11600	11500
EXP04_Ave	262	5528	2073	8935	<200	901	-82	10600	11500	11425