Greater Beirut Water Supply Project:
Independent Technical Review of Source Water Quality

Final Report

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Created for the World Bank
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Summary and Key Findings

Summary

The Water Institute at UNC was asked to provide an independent technical review concerning the suitability of water in the Joun Reservoir as a source for a water treatment facility serving the Greater Beirut area of Lebanon built as part of the Greater Beirut Water Supply Project (GBWSP). This review is based on water quality data obtained from weekly samples taken over a one year period beginning April 2010, daily samples taken in April and May 2011, and historic water quality data. It is also informed by an April 2011 site visit to Lebanon by a senior UNC water engineer, and on data obtained from the Beirut Mount Lebanon Water Establishment (BMLWE), Litani River Authority (LRA), the Council for Development and Reconstruction (CDR), and the Ministry of Environment (MOE).

As part of this review, the Water Institute was also asked to comment on the relevancy of the data for helping solicit a design-build-operate (DBO) contract for the water treatment plant and to provide operational recommendations as appropriate within existing project design and context.

Water available to the GBWSP is of sufficient quality such that conventional water treatment technologies can produce potable water meeting Lebanese and international health- and aesthetic-based standards and guidelines. The available data will be an important input for those designing and operating the water treatment plant.

The provision of high quality potable water to the end user depends not only on sound treatment plant design and operation, but also on establishing a framework addressing water quality challenges present from the catchment, through treatment, and conveyance of finished water to the point of supply, as is done with water safety plans and other similar preventive management approaches.

Key Findings and Assumptions

Key findings

- ***<u>Microbial Water Quality</u>*. Water from Joun Reservoir is of sufficient quality such that conventional water treatment technologies can produce potable water meeting Lebanese and international health- and aesthetic-based standards and guidelines.** Although microbial contamination exists in the source waters, standard water treatment should be able to reduce contamination and result in product water meeting drinking water quality standards.

- ***<u>Pesticides and Organic Chemicals</u>*. Levels of pesticides and organic chemicals were consistently below guidelines or limits of detection for all existing data.** The dataset consists of four sampling dates in 2010 and 2011 and five in 1999. Detectable levels present in one sample in 1999 were attributed to contamination from a hydroelectric plant that will be downstream of the water treatment plant intake when operational. Should a need for treatment develop, a variety of methods are available. Periodic monitoring for these parameters should continue as a matter of good practice.

- ***Heavy Metals.*** ***Data from eight measurements on samples from the Joun Reservoir taken between 1999 and 2011 indicate that metals removal is not a high concern.*** No instances were found of levels above the allowable maximum contaminant level. Metals are removed as part of the conventional treatment process, which can be optimized should metals removal become a concern.

- ***Other Water Quality Parameters. Nitrite levels, turbidity, and color will have to be addressed during treatment but are well within the limits of treatability.*** Nitrite levels can be addressed through appropriate water treatment, for example oxidation via chlorination or ozonation. Turbidity and color will also need to be addressed during treatment, but this is a common challenge addressed with standard treatment processes. Lastly, fluoride levels are very low and fluoridation should be considered as a public health measure to assist in control of dental carries.

- ***Source Water Protection. Understanding the effect of catchment activities on source water quality and including water quality protection in the management plan for the watersheds will help preserve source water quality into the future.*** The MOE Business Plan for Combating Pollution of the Qaraoun Lake contains recommendations to protect the upper Litani River. Such strategies should also be considered for other rivers in Lebanon, including the Awali River.

- ***Design-build-operate Contracts.*** ***Consideration of the full range of treatment options is important to the successful design and implementation of a water treatment facility. Design-build-operate contracts provide one effective mechanism to achieve this.*** Competent oversight of the process will be needed in order to evaluate proposals on a variety of parameters in addition to capital costs, including treatment effectiveness, flexibility, operation and maintenance cost, and robustness.

Key Assumptions

- ***Available water quality data are representative of long-term water quality.*** Comprehensive sampling is available for only one year, with limited historic data and daily measurements. Although the historic and recent datasets appear consistent, there is no assurance that the inter-year variability has been captured.

- ***Efforts to improve source water quality will be implemented.*** The risk associated with the prior assumption is ameliorated if concrete steps are taken towards source water protection. Improving the water quality in the Litani River Basin has been an objective for many years. Implementation of measures, such as those in the business plan for combating lake pollution, is needed to assure water quality does not degrade and to reduce risk of water treatment upsets.

1. Introduction

A 250,000 cubic meter per day water treatment plant will be constructed as part of the Greater Beirut Water Supply Project. Source water for this water treatment plant will be obtained from an intake structure receiving water from the Joun Reservoir, a reservoir that is fed by the Litani River, which is impounded upstream at Karoun Reservoir, two springs (near Jezzine and Ain Zarqa), and by the Awali/Bisri River.

The objective of this technical review is to:

1) Review Joun Reservoir water quality data and assess its fitness as a source-water for a water treatment plant producing water meeting Lebanese and international health- and aesthetic-based guidelines.
2) Assess the value of having prior source water quality data prior to soliciting proposals for Design-Build-Operate (DBO) contracts and the suitability of DBO contracts.
3) Generate other implementation/operational recommendations as appropriate within existing project design and context.

1.1 Project Background

According to the Awali-Beirut Conveyor Project Feasibility Study Update[1], the location of the water treatment plant was chosen as the preferred option in 1994 and was judged to remain a viable option in 2010. This report mentions that past analyses of raw water quality (1968/1972, 1984, 1994/1995, and 2001) are either too old to be relevant to current conditions or limited either in the temporal distribution of samples or the number of parameters measured. As a result, weekly sampling of a broad set of parameters was undertaken by the BMLWE starting in April 2010, and has recently been completed for a full calendar year, in order to capture levels, variability, and seasonal trends in water quality.

1.2 Description of the System

The most proximate source of water for the drinking water treatment plant intake is the Joun Reservoir. It receives water from a variety of sources that vary seasonally. During the wet season, water is abundantly available from the Awali River and from springs near Jezzine and at Ain Zarqa, as well as from the Litani River. The Karoun Reservoir[2] is recharged during the wet season, which can reduce the Litani River contribution. During the dry season, water originating from the Karoun Reservoir can make up the majority of water entering Joun Reservoir. A schematic of the system is shown in Figure 1.

Water from Karoun Reservoir makes its way to Markabi Reservoir either through the tunnel and Markabi hydroelectric plant (HEP) or through the Litani River downstream of the dam. Water from the

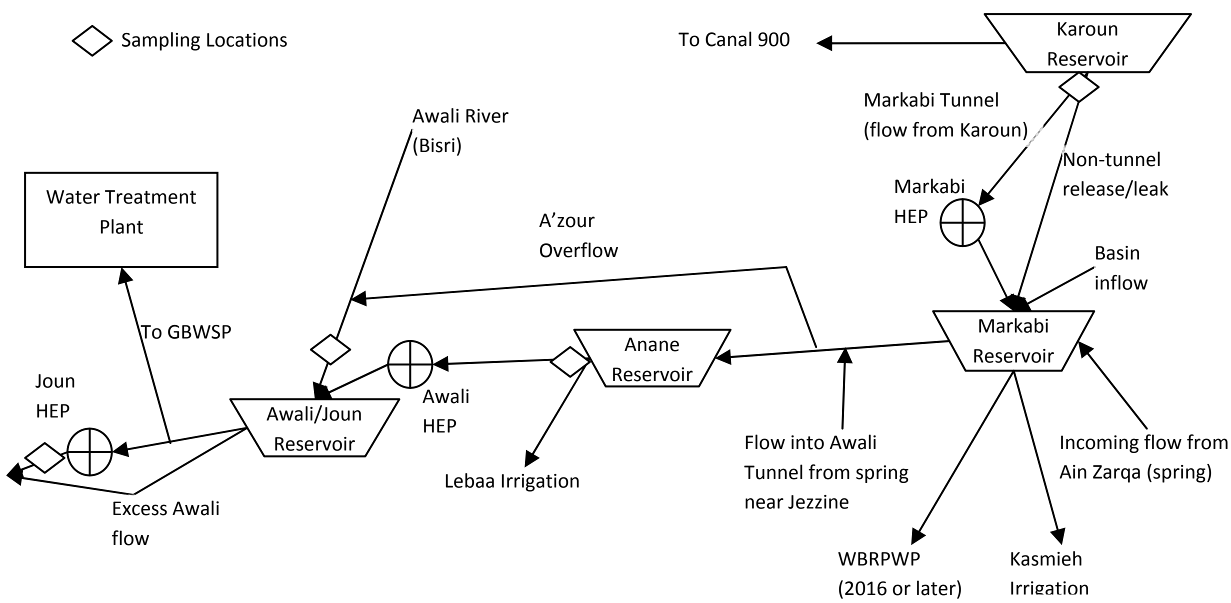
[1] Awali-Beirut Conveyor Project Feasibility Study Update: First Submission. Report for the Council of Development & Reconstruction, MWH ME Limited – Dubai Branch. April 2010

[2] There is no standard spelling of Karoun, which is alternately spelled Qaraoun and Karaoun, and which is referred to both as a lake and a reservoir.

catchment downstream of the dam, as well as from the Ain Zarqa spring, is added to the reservoir while withdrawals for irrigation and, eventually, the West Bekaa and Rechaya Potable Water Project (WBRPWP) are removed. These flows are seasonal; it is unusual for there to be flow from the Litani Basin downstream of the dam during the dry season. Separately, water from Karoun Reservoir is provided to the Canal 900 irrigation project.

Flow from the Markabi Reservoir travels through the Awali Tunnel under open-flow conditions. Water from a spring near Jezzine is added directly into the tunnel. To avoid pressurizing the tunnel, there is an overflow at A'zour which takes excess flow from the Awali Tunnel and discharges it into the Awali River.

Figure 1. Schematic of water sources and water withdrawals affecting availability of water for the GBWSP



Source: reconstructed from flow schematic, maps, and supporting literature obtained during April site visit.

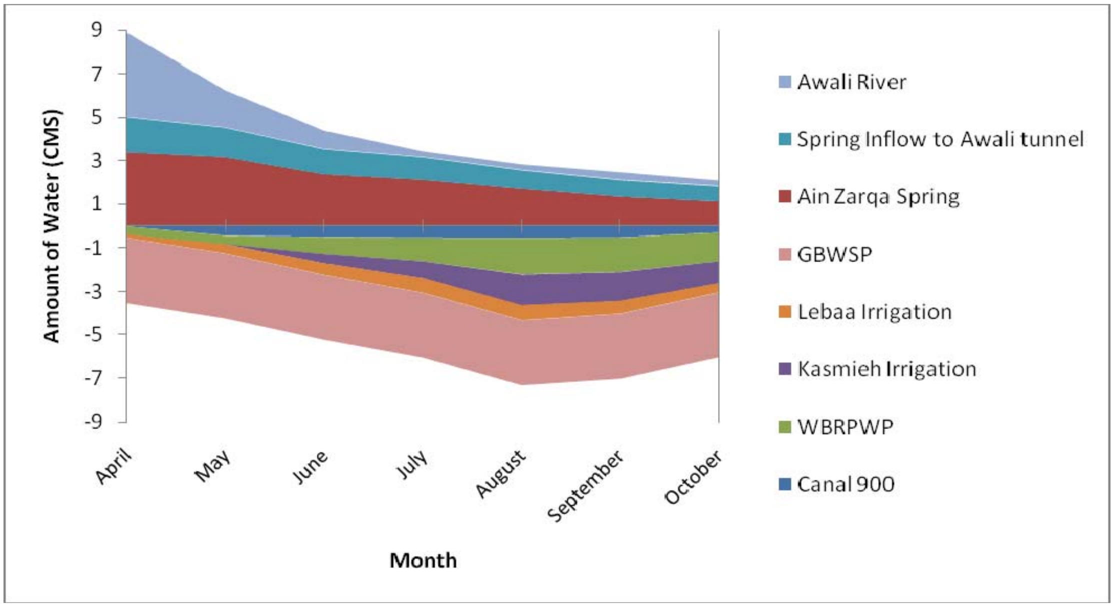
The Awali Tunnel discharges into the Anane Reservoir and is then piped under pressure to the Awali HEP. Some of the water is also used for irrigation at Lebaa. The Awali HEP discharges into the Joun Reservoir, which also receives flow from the Awali River (including any overflow from A'zour). Water from this reservoir is piped under pressure to the Joun HEP.

Water for the GBWSP will be withdrawn at a location upstream of the Joun HEP. Excess water at the Joun Reservoir continues to flow in the Awali River where it is joined by the outflow of the Joun HEP and travels to the sea.

1.3 Variations in Flow Contributions to Joun Reservoir

The contribution to the Joun Reservoir from upstream sources varies during the dry season, being more heavily influenced by the Awali River early in the dry season and by the springs and releases from Karoun Reservoir later in the dry season. Average monthly flows and withdrawals from the system from data obtained from the Litani River Authority from 2003 through 2009 are shown in Figure 2.

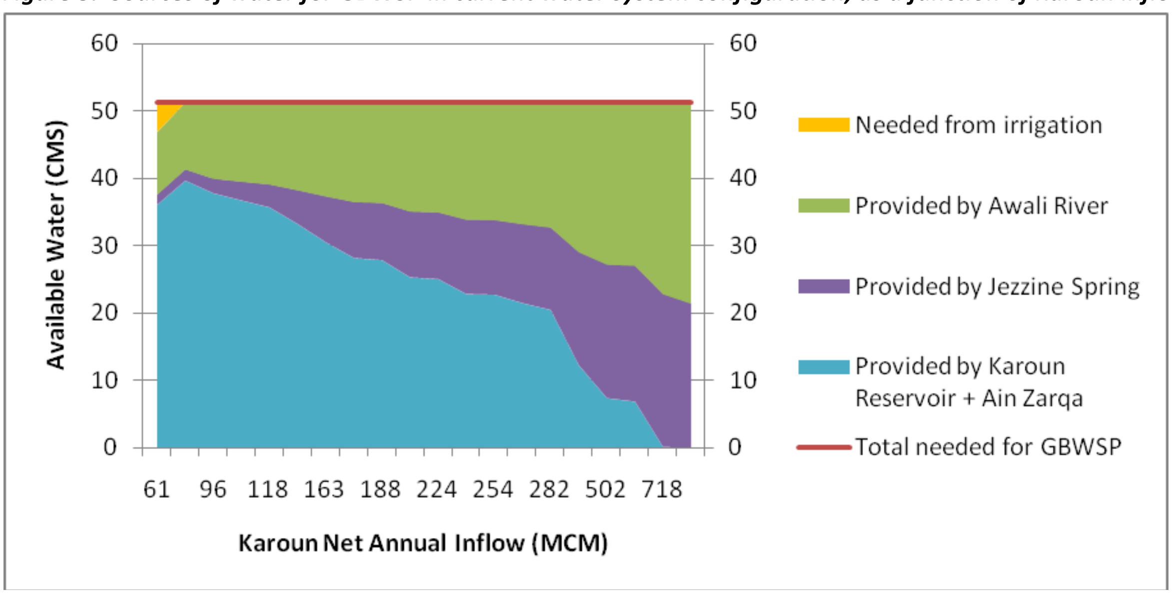
Figure 2. Average monthly inflows and withdrawals in water system[3]



Note: Inflows are positive values above x-axis; withdrawals are negative values below x-axis. Withdrawals for the Greater Beirut Water Supply Project are assumed to be constant at the design level (3 CMS) for the dry period (April 15 to October 31).

The contribution to the Joun Reservoir also changes year to year. During dry years contributions from the Awali River and from the springs are reduced, requiring a greater contribution from the Karoun Reservoir. As years become wetter, more water is provided by the Awali River and the spring near Jezzine. Figure 3 shows estimates of the contributions from each source, using the Karoun Net Annual Inflow as a measure of annual dryness.[3]

Figure 3. Sources of water for GBWSP in current water system configuration, as a function of Karoun inflows



[3] From: Greater Beirut Water Supply Project: Independent Technical Review of Source Water Quantity. Created for the World Bank Sustainable Development Department, Middle East and North Africa Region, by the Water Institute at UNC. May 31, 2011

2.0 Source Water Data

2.1 Description of Datasets

2.1.1 Beirut Water & Mount Lebanon Quality Management Central Laboratory in Dbayeh

As recommended in the Awali-Beirut Conveyor Project Feasibility Study Update, microbial and chemical analysis of weekly samples began on 20 April 2010 and is ongoing. The data used in this review cover one year, ending in 26 April 2011 and are from samples from the Joun Reservoir, Awali/Bisri River, Anane Reservoir, and Karoun Reservoir. Weekly analyses did not include heavy metals or complex chemicals such as pesticides or volatile organics. A time series of the data for the Joun Reservoir and box plots of the data for all sample sites are plotted in Annex 1.

On two days (03 June 2010 and 11 May 2010) samples from the four sites were analyzed for 82 complex chemicals including pesticides, volatile organics, semi-volatile organics, and organo-halides. The May sample was analyzed for heavy metals.

2.1.2 American University of Beirut

Because source water quality is typically measured daily for an active water treatment plant, daily water samples from the Joun Reservoir were analyzed for microbial contamination and basic water quality characteristics for approximately 31 days in April and May of 2011. Data were also obtained at the three other locations mentioned in section 2.1.1 at less frequent intervals. Analysis for heavy metals was performed on samples from all locations twice during this period (20 April and 27 April) and analysis for complex chemicals was performed on one sample from each location on 20 April.[4]

2.1.3 Draft Business Plan for Combating Pollution of the Qaraoun Lake

The United Nations Development Program funded a MOE report for improving the water quality of water flowing into Karoun Reservoir.[5] This report summarizes sources of pollution in the upper Litani Basin as well as the results of water quality testing in Karoun Reservoir from 16 reports dated between 2000 and 2011, including the February 2011 report of the Litani River Basin Management Support Program.[6]

2.1.4 Raw Water Monitoring Report

This report presents data collected by Montgomery Watson in 1999 as requested by CDR. The report sampled near the four sites described in section 2.1.1 four times in 1999. Only the samples from the Joun Reservoir were analyzed for the suite of 93 elements and compounds while the remaining samples were used only when a particular chemical was detected, in which case the samples from the other three sites were tested only for the constituents that were detected in the Joun sample.

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[4] Testing frequency depends on many factors. Common practice is to monitor for microbial contamination in product water daily and to test for metals and complex chemical contaminants several times a year.

[5] Business Plan for Combating Pollution of the Qaraoun Lake (LB-EQM-UND-CPQ-10): Progress Report II: Draft Business Plan. Submitted 05 April 2011. Prepared by Earth Link and Advanced Resources Development S.A.R.L. (ELARD), Submitted to the United Nations Development Program (UNDP).

[6] Litani River Basin Management Support Program Water Quality Survey (Summer 2010), Volumes 1 and 2. USAID – Lebanon. February 2011

2.1.5 Water Establishment for Beirut & Mount Lebanon Chemical Analysis

The Water Establishment had samples collected on 14 March 2011 just upstream of the Joun Reservoir (from Lake Anan and the Awali River) and the Joun Reservoir analyzed for 11 heavy metals, 16 complex compounds (including pesticides), and cyanide.

2.2 Summary of Data

The data from the weekly microbial and chemical analysis for Joun reservoir is plotted in Annex 1 of this report and is summarized in Table 1. Box plots of the data for the four sampling locations (Joun, Anane, and Karoun reservoirs plus the Awali River) show values from the four locations to be generally equivalent.

2.2.1 Microbiological Data

Levels of bacteria are typical for agricultural and developed areas, with high levels seen when precipitation is present and basin activities are high. Measurements of the most common indicator bacteria, total thermotolerant coliform (sometimes referred to as fecal coliform) and *E. coli*, from the weekly sampling are presented in Figure 4.

Figure 5 presents a summary of the same data for the four sampling locations, showing the median and range of the data. The data on total coliform are consistent between locations. There is greater variability in the *E. coli* data although it is not extreme. This is reassuring as this means the quality of the water in the Joun Reservoir does not depend greatly on the original source of the water.

The *E. coli* values measured in the Karoun Reservoir samples are substantially lower than at the other three sampling locations, with many values being zero; this is in contrast with the reputation of Karoun Reservoir as a highly impaired water body.

Assuming the data are correct (Karoun samples were measured concurrently with the other samples) this could be explained by the Karoun Reservoir acting as a settling basin where *E. coli* numbers are reduced by settling and by die-off. It is unclear why the trend is less pronounced with total thermotolerant coliform, although this might reflect the fact that the total thermotolerant coliform measurement includes multiple species of bacteria (of which *E. coli* is one) and thus encompass the variation in characteristics affecting settling and die-off as well as the presence of environmental sources.

The results of the daily sampling (Figure 6) for Joun Reservoir fall within the range observed weekly over the prior year. The observed variation in the daily data indicate that, for this period, weekly sampling would have captured similar information as is present in the daily samples.

Table 1: Summary of 2010/2011 Raw Water Quality Data

Parameter	Units	Mean	Median	Min	Max	Guidelines	Number Exceeding
pH	-	7.7	7.7	7.3	8.0	6.5-8.5[a,c]	0
Turbidity	FTU	65	4	0	1313	4[b,c]	18
Color	TCU	379	13	1	12550	15[a,c]	21
Conductivity	µs/cm	451	469	378	500	250[a]	46
Total coliform	CFU/100ml	43033	24150	3370	140600	0[b]	46
Total thermal-tolerant coliforms	CFU/100ml	11848	9038	875	59200	0[b]	46
Escherichia coli	CFU/100ml	1070	453	0	5010	0[b]	40
Citrobacter freundi	CFU/100ml	12816	8215	625	111500		
Enterobacter cloacae	CFU/100ml	1	0	0	10		
Chysemonas luteola	CFU/100ml	9436	1013	0	100000		
Kleb. pneum. ozaenae	CFU/100ml	200	78	0	1400		
Non fermenter spp	CFU/100ml	1420	20	0	42280		
Pseudomonas aeruginosa	CFU/100ml	18	23	0	30		
Flavi. oryzihabitans	CFU/100ml	20858	5000	0	100000		
Salmonella typhimurium	CFU/100ml	n/d	n/d	n/d	n/d	0[b]	0
Acidity as $CaCO_3$	mg/l	5.4	5.0	5.0	10.0		
Total alkalinity as $CaCO_3$	mg/l	144	145	105	180		
Calcium hardness as $CaCO_3$	mg/l	176	190	120	210		
Magnesium hardness as $CaCO_3$	mg/l	42.3	40.0	35.0	50.0	50 [b,c]	0
Total hardness as $CaCO_3$	mg/l	219	230	160	260	150-500 [a,c]	0
Chloride Cl^-	mg/l	21.4	25.0	10.0	30.0	200[b,c]	0
Sulfate $SO4^{--}$	mg/l	33.1	35.0	19.0	43.0	250 [b,c]	0
Phosphate as P	mg/l	0.1	0.1	0.0	0.2		
Phosphorous as P_2O_5	mg/l	0.1	0.1	0.0	0.3		
Dissolved Fe2+	mg/l	0.2	0.1	0.0	1.7	0.2[b,c]	9
Ammonium as NH_4+	mg/l	0.5	0.4	0.2	1.3	0.5[b,c]	13
Nitrites as NO_2^-	mg/l	0.2	0.2	0.0	0.4	0[b,c,d] , 0.2[a,d]	21
Nitrates as NO_3^-	mg/l	10.8	10.6	0.8	16.4	50[d]	0
Dissolved oxygen	mg/l	5.1	5.0	2.0	7.0		
Total dissolved solids as NaCl	mg/l	228	236	189	273	1500 [b,c]	0
Virtual mineralization	mg/l	323	335	270	358		
CO_2	mg/l	5.5	6.0	2.0	13.0		
Fluoride	mg/l	0.2	0.1	0.1	0.9	1.5 [b]	0
Manganese	mg/l	0.1	0.1	0.0	0.3	0.5[b,c]	0
Sulfur	mg/l	0.0	0.0	0.0	0.0		

a. From WHO guidelines[7]
b. Lebanese standards or guidelines[8]
c. Categorized as undesirable outside of range shown, not a maximum contaminant standard
d. WHO guideline specifies the sum of the ratios of the concentrations of nitrate and nitrite to their respective guidelines should not exceed 1. The WHO guideline for nitrite is 0.2mg/l

[7] Guidelines for Drinking-water Quality, Third Edition, Volume 1. World Health Organization. 2004

[8] A compendium of drinking-water quality standards in the Eastern Mediterranean Region. World Health Organization, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities, CEHA, 2006

Figure 4. Total thermaltolerant coliform and E. coli measured weekly at the Joun Reservoir in 2010 and 2011

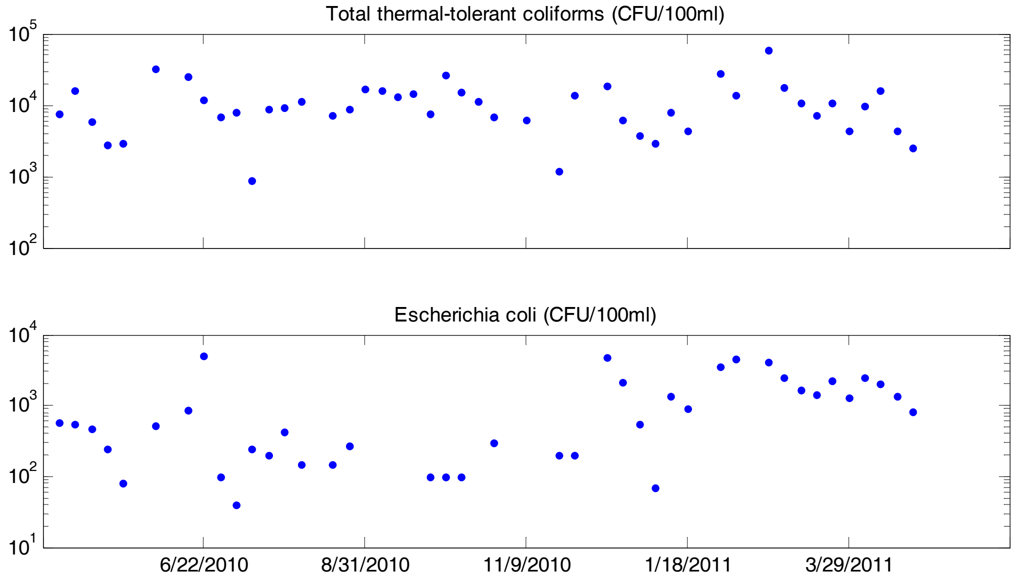
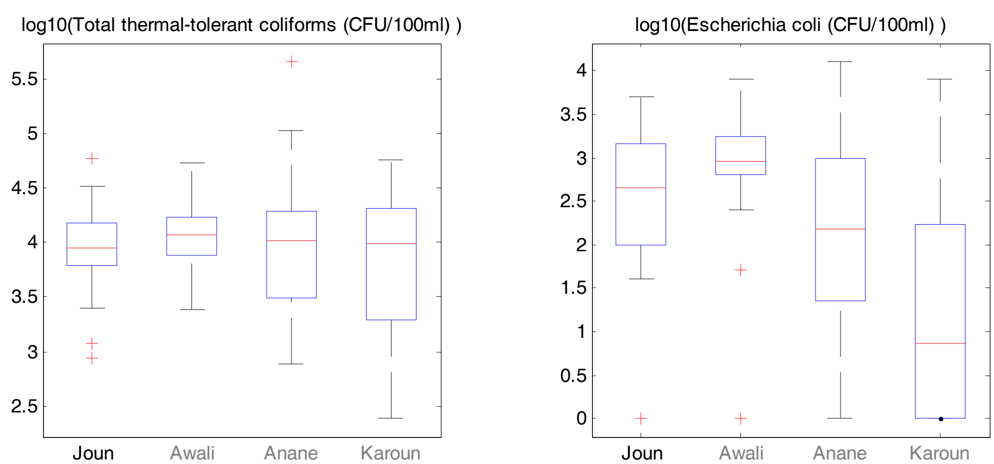
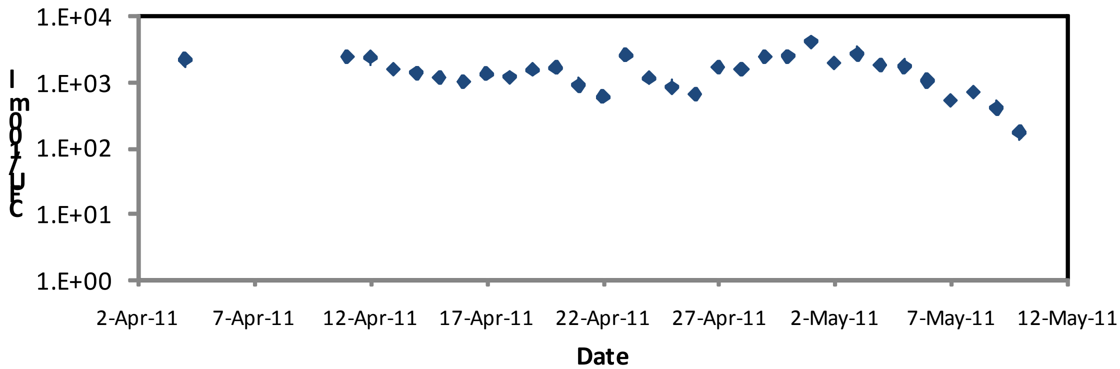


Figure 5. Summary of total thermaltolerant coliform and E. coli measured weekly at four locations in 2010 and 2011[9]



[9] On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. Outliers are those points falling more than 1.5 times the difference between the 25th and 75th percentiles from either edge of the box. This corresponds to approximately 99.3 percentile coverage if the data are normally distributed.

Figure 6. Total thermotolerant coliform measured daily in April and May 2011



2.2.2 Organic Chemicals

Data from the analysis of nine Joun Reservoir samples were reviewed for complex chemicals, including pesticides, volatile organics, semi-volatile organics, and organo-halides. The results are summarized in Table 2.

Table 2: Data sources for review of complex chemical compounds

Data Source	Sample Dates	Number of compounds	Results
Beirut Water & Mount Lebanon Quality Management Central Laboratory (2.1.1)	May 2010 June 2010	82	All values either below detection limit or measured at levels below standard or guideline values. .
American University of Beirut (2.1.2)	April 2011	76	All values are below detection limits.
Raw Water Monitoring Report (2.1.4)	March 1999 July 1999 September 1999 November 1999 January 2000	>90	Three constituents were detected at levels above guideline or allowable levels.
Water Establishment for Beirut & Mount Lebanon Chemical Analysis (2.1.5)	March 2011	16	All values below the detection limits.

All measurement within the last 10 years have values below the corresponding guideline values and, in most cases, the values are below the detection limit of the analytical technique[10].

The authors of the Raw Water Monitoring Report on samples from 1999 identified three substances of concern: oil, petroleum ether extractables, and phenolic substances. The samples were extracted from the tailrace water of the Joun HEP, which is cited as a possible reason for their presence. The report states:

> "The latest results confirm that there seems to be few grounds for concern over the quality of the raw water for the Awali scheme at present. The results for the few substances for which

[10] There are cases where the detection limit exceeds the standard or guideline value so the result is inconclusive. It is important that the capacity to measure these values be developed to ensure compliance with standards.

additional testing was called for are summarized in Table 1 below [not reproduced here]. It can be seen from this table that the upstream samples do not confirm the presence of the substances detected in the tail race of the Charles Helou HEPS. It therefore seems probable that the levels of Oil, Petroleum Ether Extractables, and Phenolic Substances found there are the result of contamination from the HEPS itself."

The four most recent samples occur in April through June 2011. Although these samples indicate contaminant levels are likely low, samples should be routinely collected throughout the year (at least quarterly) to verify compliance with standards and guidelines.

2.2.3 Heavy Metals

Eight samples from the Joun Reservoir were analyzed for heavy metals. Four of these samples occurred in March through May and the other samples were taken throughout the year. Values, shown in Table 3, were generally below the detection limit while those present at measurable levels were below the maximum standard or guideline value. Samples analyzed from the other three sites on 11 May 2010, 20 April 2011, and 27 April 2011 showed similar levels, all of which were below the maximum contaminant level.

Table 3: Results of heavy metals analysis of Joun Reservoir Samples

Metal	MCL (mg/L)	source of MCL	Raw Water Monitoring Report (2.1.4)					AUB 2010 (2.1.1)	AUB 2011 (2.1.2)	
			18 Mar 99	07 Jul 99	04 Oct 99	01 Nov 99	07 Jan 00	11 May 10	20 Apr 11	27 Apr 11
Antimony	0.01	a	<0.0004	<0.0004	0.0026	<0.0004	<0.0004		<0.002	<0.002
Arsenic	0.05	a	<0.0004	0.0004	0.0007	0.0008	<0.0004		<0.002	<0.002
Barium	0.7	b	<0.0004	<0.004	<0.004	<0.004	<0.004		0.02	0.018
Beryllium	0.004	c							<0.002	<0.002
Cadmium	0.005	a	<0.0005	<0.0005	<0.0005	0.0006	<0.0005	<0.002	<0.002	<0.002
Chromium	0.05	a	0.0009	<0.0006	<0.0006	0.0014	0.0006	<0.002	<0.002	<0.002
Copper	2	b						0.003	<0.002	<0.002
Lead	0.05	a	<0.003	<0.001	<0.001	0.002	<0.001	<0.002	<0.002	<0.002
Mercury	0.001	a	<0.00005	<0.00005	<0.00005	<0.00005	0.00027	0.0007	<0.0005	<0.0005
Selenium	0.01	a	<0.0008	<0.001	0.001	<0.001	<0.001		<0.002	<0.002
Thallium	0.002	c							<0.002	<0.002

a) Lebanon Drinking Water standard, b) WHO drinking water guideline (no Lebanese standard), c) USEPA (no Lebanese or WHO standard)

During the April 2011 site visit, a concern was raised that the Joun Reservoir water quality would be compromised with heavy metals during the dry season when the Karoun Reservoir becomes a major source of water. In response, water quality data from the MOE Draft Business Plan for Combating Pollution of the Qaraoun Lake was reviewed (see section 2.1.3) for heavy metals.

Because the Karoun Reservoir acts as a settling basin, especially during the dry season when inflows are very low, water quality varies from the inlet from the Litani River to the dam. Because water is withdrawn through the dam, only samples closest to the dam (designated as clusters 62b and 65 in the report) were reviewed. These are presented in table 4.

The Draft Business Plan compared metals concentrations to drinking water guidelines and concluded "No exceedance was noted for aluminum, arsenic, barium, chromium, copper, manganese, molybdenum, nickel, and zinc." There were exceedances in the overall dataset for cadmium, copper, lead, and mercury, but there was only one exceedance of one metal (mercury) in samples from the two clusters of interest. The value was during the wet season in 1999 and was five times the drinking water maximum contaminant limit.

Table 4: Results of heavy metals analysis of Karoun Reservoir for the two clusters near the dam

Season	cluster	Year	Cd	Cu	Pb	Hg
Dry	65	1999		OK		
Dry	65	2005	OK		OK	OK
Dry	65	2007				
Dry	65	2008	OK		OK	OK
Dry	65	2010	OK	OK	OK	
Dry	62b	1995		OK		
Dry	62b	2005	OK		OK	OK
Dry	62b	2008	OK	OK	OK	OK
Dry	62b	2010	OK	OK	OK	OK
Wet	65	2005	OK		OK	OK
Wet	62b	1999	OK	OK	OK	0.005 mg/L*
Wet	62b	2005	OK	OK	OK	OK

Note: Green indicates values below allowable or guideline levels, white that no measurement was taken, and orange a value above the drinking water maximum contaminant level.
** The drinking water maximum contaminant level for mercury is 0.001 mg/L.*

The report also includes analysis of heavy metals in sediment. These were not included in this review because metals generally bind to sediment[11] and are unlikely to be stirred up during the dry season, when flows into the reservoir are very low. During the wet season the Awali River and the springs near Jezzine and Ain Zarqa make up a larger proportion of the total flow into the Joun Reservoir.

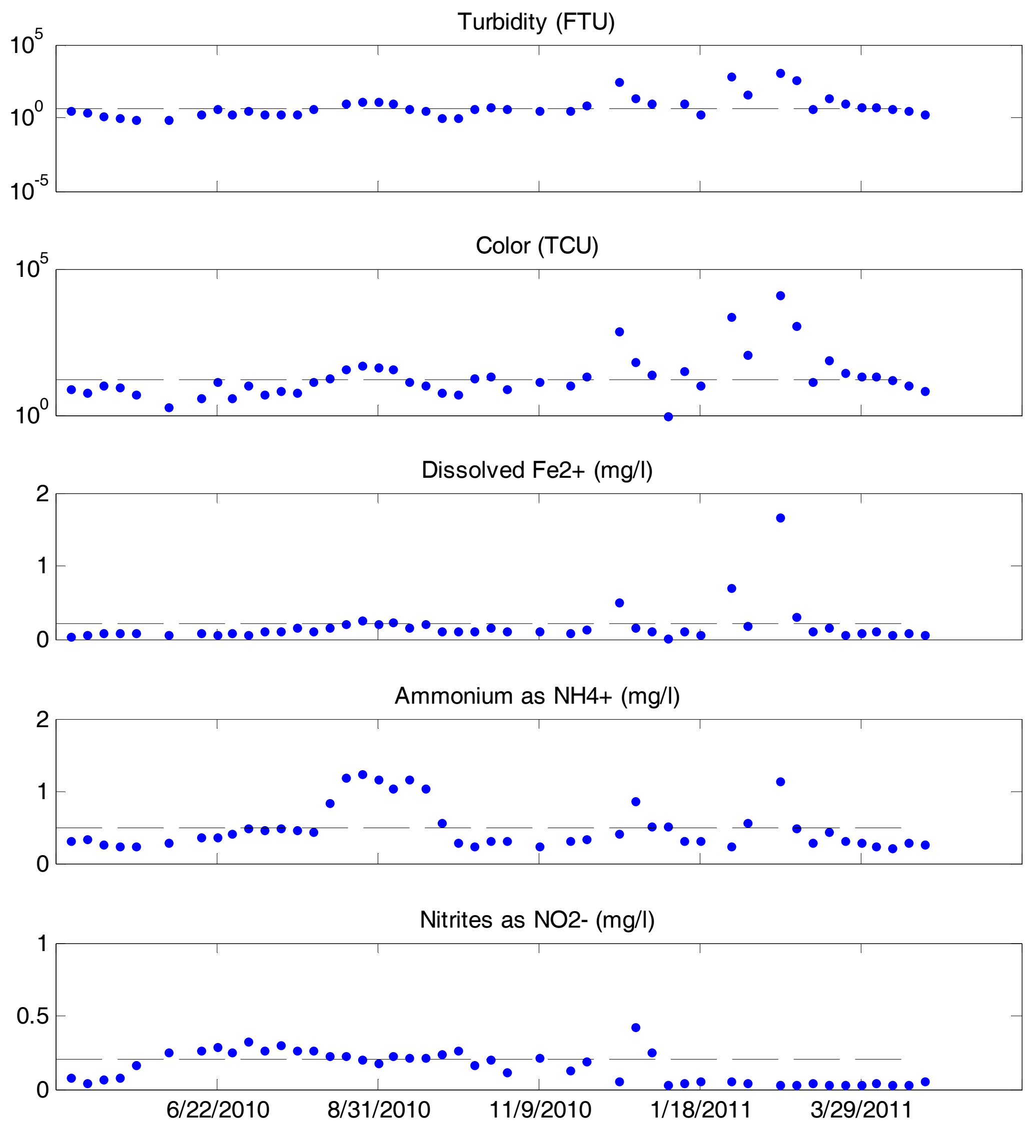
2.3.4 Other Water Quality Parameters

Table 1 shows five parameters that exceeded a target value during the sample period: turbidity, color, dissolved iron, ammonium, and nitrites. Of these, only the nitrite target value is a health-based maximum contaminant limit. The others are target values based on desirability for other reasons, such as consumer acceptance. The weekly sample data for these constituents is presented in Figure 7.

[11] A discussion of precipitation and partitioning of metals can be found in: Novotny, V. **Water Quality, Diffuse Pollution and Watershed Management.** John Wiley & Sons. New Jersey. 2003. Pages 293-

There is a strong peak in ammonium in August and September, corresponding with agricultural activity. Other trends are far less pronounced. Turbidity and color are also very high in December and January 2011, likely because of high precipitation leading to high runoff. The daily sampling data from April and May 2011 are consistent with the weekly data taken a year ago during the same months.

Figure 7. Weekly data on parameters exceeding guideline values.

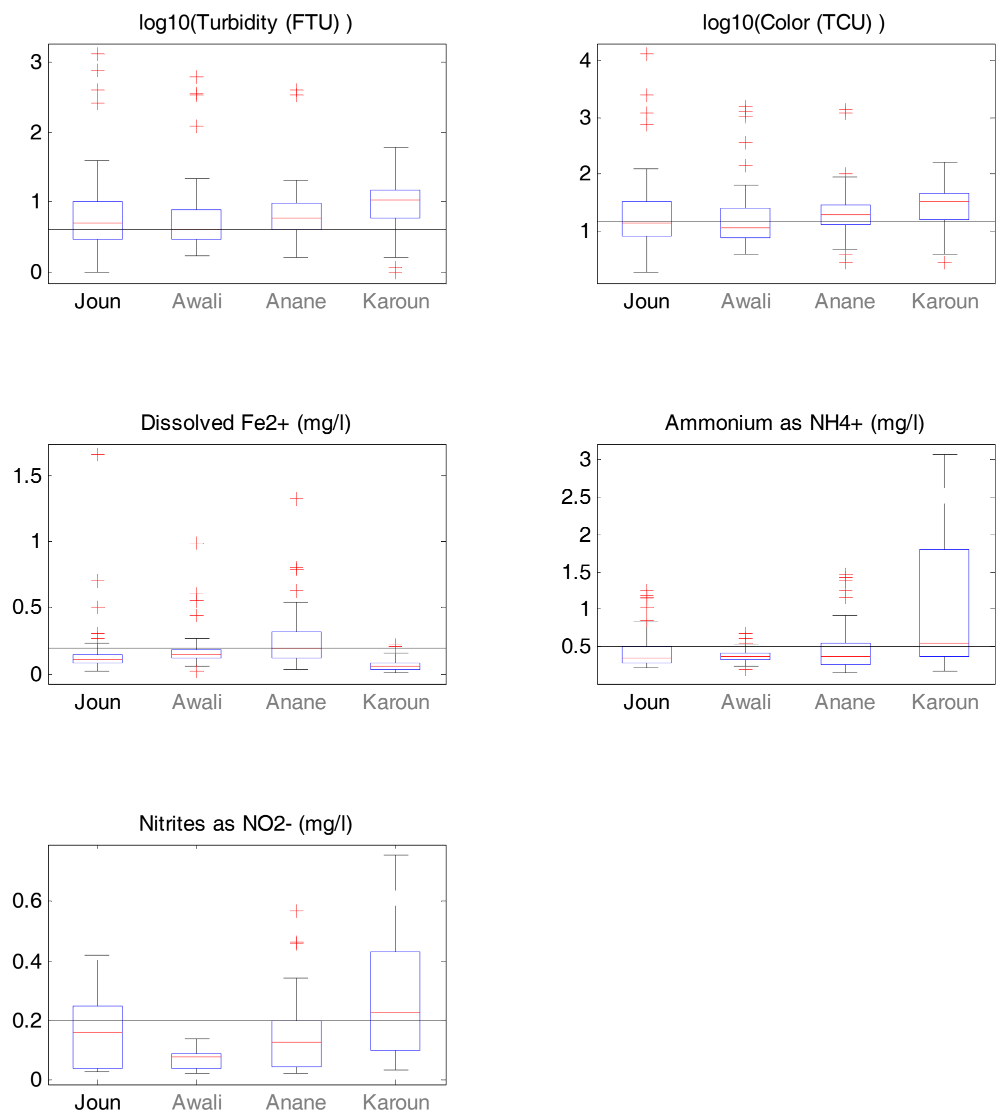


Note: Dashed lines represent guidelines based on desirable characteristics for turbidity, color, and dissolved iron and the maximum contaminant limit for nitrites.

Figure 8 compares these parameters at the four measurement locations. The water from the Karoun Reservoir has higher values for most of the parameters, especially for ammonium and nitrites. Some of this increased variation is attributable to variation in the Karoun Reservoir measurement location.

Because water isn't always released through the dam and because of a desire to obtain "worst case" water samples, water was not always sampled in the same location; some samples were downstream of the dam, others upstream of the dam, and still others where the Litani River enters the reservoir. This would explain the high ammonia and nitrite levels as the Litani River, when flowing during the early agricultural season, carries significant agricultural runoff. These high levels do not carry over to Anane, which is a mix of water from the Karoun Reservoir and two intermediate springs. During the dry period, when spring inputs to the Anane Reservoir might be reduced and more water comes from Karoun, measured levels are kept in check because there are no inputs to Karoun Reservoir from the Litani River.

Figure 8. Box plots of weekly values for water quality parameters at four measurement locations.



3.0 Treatability

The water quality data indicate that water from Joun Reservoir is of sufficient quality such that conventional water treatment technologies can produce potable water meeting Lebanese and international health- and aesthetic-based standards and guidelines. The challenges for treating the raw water appear typical of water impacted by agricultural and settled catchments.

3.2.1 Treatment for Microbiological Contamination

Microbial values, although high, are typically reduced by 99% during the first clarifying steps in water treatment including processes such as coagulation, flocculation, and sedimentation.[12, 13] These steps also address turbidity and some color concerns. Disinfection through ozonation or chlorination (i.e., free chlorine, monochloramine, chlorine dioxide) is effective at eliminating the remaining bacteria[14]. Disinfection by free chlorine or chloramines is a common choice because they can also be used as residual disinfectants in the drinking water distribution system. Residual disinfection provides partial maintenance of water quality safety during transport.

The water samples were tested for bacteria. Other microbial threats, such as viruses and protozoan cysts, were not measured. Chemical disinfection practices for bacteria are largely effective for viruses; however, protozoan cysts (i.e., *Giardia lamblia*[15], and *Cryptosporidium parvum* oocysts) may be orders of magnitude more resistant to usual chlorine and monochloramine treatments. As a result, if protozoan cysts were a concern in the source waters, UV light irradiation, or advanced filtration may need to be considered as treatment options.

3.2.2 Organic Chemicals

Data on the organic compounds show virtually all measurements to be below the corresponding guideline values and, in most cases, the values are below the detection limit of the analytical technique. The most efficient strategy to protect drinking water quality is to implement strategies of source water protection, such as those in the MOE Business Plan for Combating Pollution of the Qaraoun Lake. Should a need for treatment develop in the future, a variety of methods are available including granular activated carbon and air stripping.

3.2.3 Heavy Metals

The data presented in 2.2.3 show no instances of metals measured in samples from the Joun Reservoir above the allowable maximum contaminant level. This alleviates concerns that extraordinary measures will be needed to ensure relevant drinking water standards are met. Metals are removed as part of the

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[12] Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by Mark W LeChevallier and Kwok-Keung Au. Published by IWA Publishing, London, UK. 2004

[13] Microfiltration is able to remove most bacteria. and removal effectiveness increases with smaller pore sizes found in ultra-, nano-, and reverse osmosis filters.[13]

[14] Water Quality Treatment: A Handbook of Community Water Supplies. American Water Works Association. Fifth Edition. McGRaw Hill. 1999.

[15] Giardia infection can cause a variety of intestinal symptoms, which include diarrhea, gas or flatulence, greasy stool that can float, stomach or abdominal cramps, upset stomach or nausea, and dehydration.

conventional treatment process. Metals tend to associate with organic matter and other (negatively charged) particles, and organic matter and particles are removed during coagulation + flocculation + sedimentation + filtration (C+F+S+F), where one or more of those steps may not be used. As a result, anything that is associated (attached) to the organic matter and particles are also removed with them (i.e., the metals).

Watershed protection, as part of a comprehensive risk based water quality management strategy, is the best way to ensure levels of metal remain low. Should levels become a concern, operations can be optimized towards metal removal by adjusting C+F+S+F conditions that are the best compromise between metal removal, turbidity, costs and other concerns.

3.2.4 Other Water Quality Parameters

Nitrite levels, turbidity, and color will have to be addressed during treatment. Lebanese guidelines specify that any value of nitrite concentration above zero is undesirable. The WHO guideline value is 0.2mg/l for nitrite and 50 mg/l for nitrate with the caveat that nitrate and nitrite should be considered together because of toxicological interaction; specifically that the sum of the ratio of concentrations of nitrate and nitrite to their respective guidelines should not exceed 1. This sum in the raw water often exceeds 1, but this can be addressed through appropriate water treatment. For example, nitrites can be converted to nitrates through oxidation via chlorination or ozonation. Nitrate by itself is well below the guideline value and is otherwise removable[16].

Turbidity and color are typically largely improved during coagulation + flocculation + sedimentation + filtration and are one of the primary inputs driving treatment control. However reducing these parameters by source protection can be a more cost-effective strategy as such practices improve the quality of the source water generally. Best management practices, such as riverine buffer strips, soil conservation practices, detention basins, and erosion management at construction sites are examples of accepted methods of protecting ambient water quality.

According to the WHO Guidelines for Drinking-water Quality, ammonia is not of direct relevance to health at levels below the taste threshold (1.5 mg/liter for ammonia, 35 mg/liter for ammonium). Observed values are below these levels.

Lastly, fluoride levels are very low and fluoridation should be considered as a public health measure to assist in control of dental carries.

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[16] 5 mg/l of nitrate should be achievable by using, for example, ion exchange. Biological denitrification is also a viable option in some settings.

4.0 Design-build-operate contracts

Consideration of the full range of treatment options is important to the successful design and implementation of a water treatment facility. Design-build-operate contracts provide one effective mechanism to achieve this.

DBO contracts are a viable means of securing safe drinking water at the point of production. The year's worth of weekly data will be of great value in the development of an appropriate specification for the DBO contract, and also to the firm ultimately charged with running the water treatment facility. Competent oversight of the process will be needed in order to evaluate proposals on a variety of parameters in addition to capital costs, including treatment effectiveness, flexibility, operation and maintenance cost, and robustness to water quality variability.

Water treatment plant operations, and specifications for DBO contracts, typically focus on water quality and quantity as the metrics of performance and this parallels the historic method of verifying compliance with drinking-water standards. Reliance on end-of-pipe testing and steady-state performance may be insufficient for health protection. Rather proactive preventive management, failure-mode analysis, and understanding of inter-dependencies among processes are essential.

The incorporation of water safety plans in the 2004 WHO Guidelines for Drinking-water Quality and, subsequently, in national practice in many countries world-wide reflects the evolution from output- to input-based approaches to ensuring safe water; that is from periodic assessment of the quality of product water (end of pipe testing) to incorporation of a preventive risk management perspective by complementing conventional monitoring with assessment of the adequacy of processes and procedures to ensure the ongoing safety of drinking water. In cases where this has been done, compliance has required verification that water safety plan procedures are in-place through an independent audit, either through a government regulatory body or a specifically-constituted external review group.

The DBO contract should include responsibility for participating in a wider risk management strategy with other participants overseeing the catchment and distribution systems, perhaps led by the Beirut Mount Lebanon Water Establishment (BMLWE).

5.0 Implementation and Operational Recommendations

A water treatment plant is one part of a system to ensure the provision of safe water. Robust delivery requires protecting source water, effective process monitoring, and ensuring distribution of safe water to the point of use. This has been reflected in the MOE Business Plan for Combating Pollution of the Qaraoun Lake

Water safety plans and similar preventive management approaches use a risk-based metric to prioritize control measures and identify necessary monitoring and management strategies for source water, water treatment, and water distribution.

5.1 Catchment management

Experience has shown the value of engagement with catchment users (agriculture, industry, human settlement) in efforts to minimize the risks and costs associate with source water contamination. The available data indicates current source water quality is sufficient to be treatable to meet drinking water standards. Understanding the effect of catchment activities on source water quality and including water quality protection in the management plan for the watersheds will help preserve source water quality into the future by allowing the development of source protection strategies. For example, new settlement or agricultural activities can be required to use best practices to prevent contamination and to ensure continued water availability. Incentives or phased-in regulation could be used to upgrade existing land use practices.

5.2 Water conveyance

As with any conveyance structure, recontamination is a possibility in the conveyance tunnel after water treatment. Careful consideration of residence time, residual, and infiltration potential is needed to ensure the water remains safe. Infiltration is a concern especially in tunnels that are not always fully pressurized; residence time can be a concern if the capacity of the tunnel is based on future rates of withdrawal.

In the short term, the GBWSP treated water tunnel will be operated intermittently because its carrying capacity is well above the current water utilization rate, with the tunnel being at least partially empty at times. This creates an opportunity for infiltration, the effects of which should be mitigated. Activities with the potential to introduce contaminants into the conveyance tunnel should also be monitored and, if necessary, controlled to protect both the groundwater near the tunnel and the risk of contamination from infiltration. Routine analysis of the initial portion of water through the tunnel when flow resumes would assist in assessing any concerns from infiltration. This concern will be far reduced in the future when the tunnel is continuously pressurized.

Intermediate storage facilities need to be managed to ensure sufficiently short residence times. Water quality can be monitored in these storage systems, but it is also necessary to ensure the stored water is well mixed or, at the least, there are not regions of unmixed water remaining in storage for long periods of time.

5.3 Water distribution

A rigorous system of codes covering the distribution system, storage, and piping internal to buildings (between the point of delivery and the point of use) should be adhered to. Codes ensure adequate design, materials and operation, reduce the potential for contamination from cross-connections, and create a culture of good practice. The Lebanese building code was not reviewed as part of this assignment.

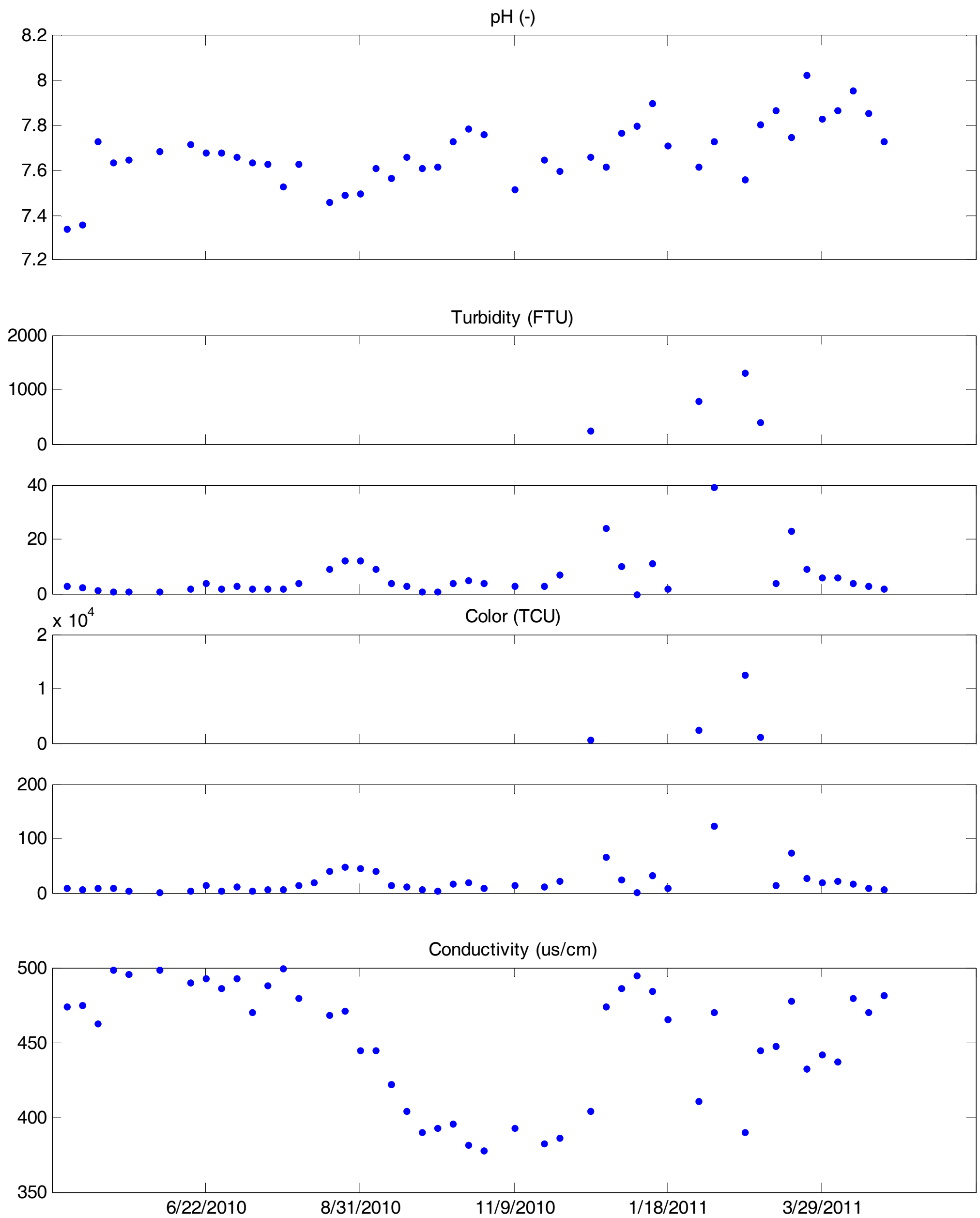
The maintenance of distribution pressure is critical. Leaks in distribution systems are unavoidable; typical systems have leakage rates in excess of 15%. During low pressure events the sites of leaks become areas where infiltration can occur. Low pressure events can also cause backflow in buildings, leading to non-potable water at higher elevations, or stored under pressure entering the internal distribution system. Maintaining pressure should be achieved by a comprehensive leak management program combined with ensuring adequate supply through sufficient drinking water production in conjunction with appropriate conservation practices.

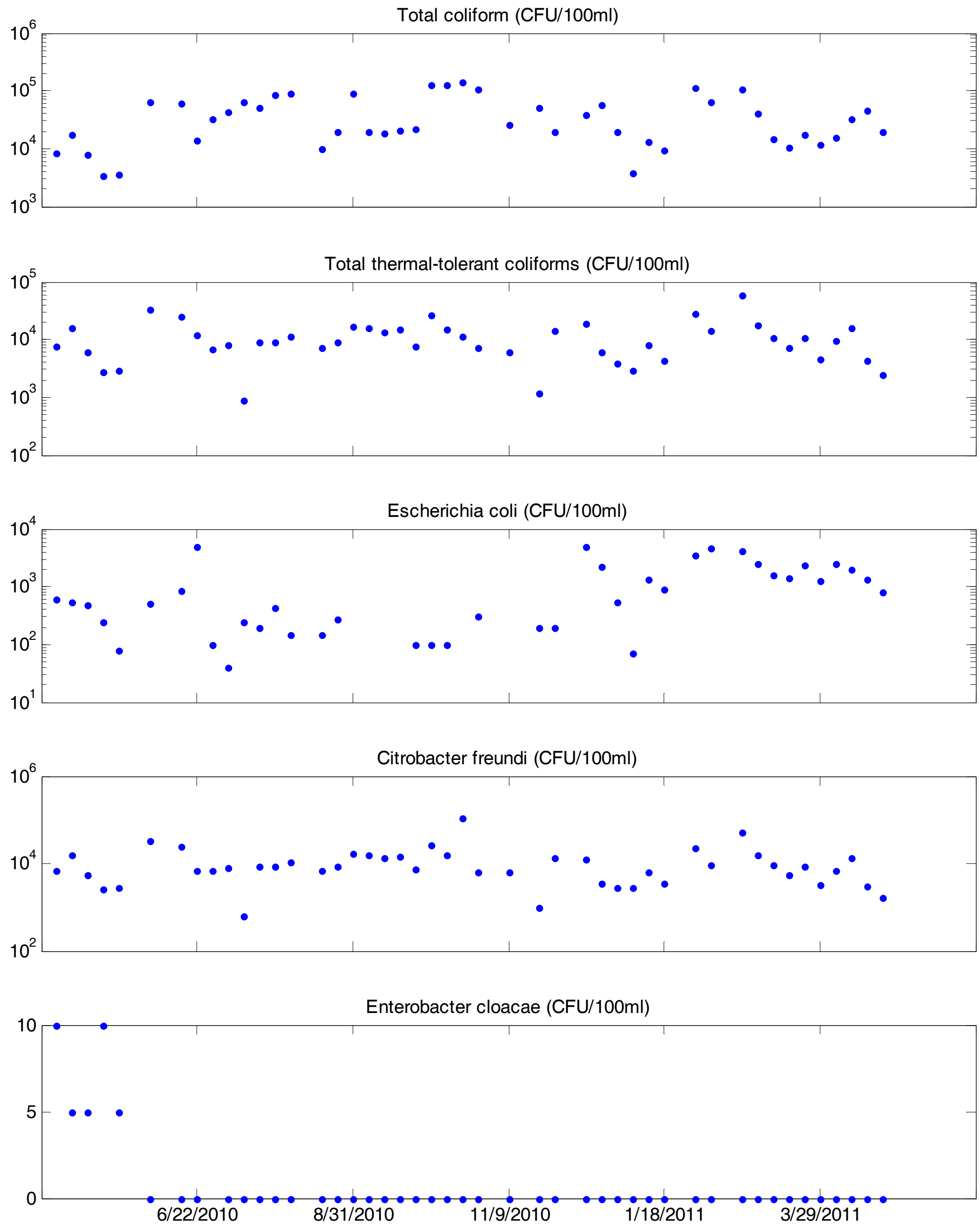
Joining old and new distribution systems can be a challenge as the path water flows can be complex. “Legacy systems” are more likely to have problems with infiltration, dead-end connections, and cross-connections and can have biological and physical impairments. Consideration should be given to improving these legacy systems and ensuring that atypical flow patterns, which might occur during low pressure events or transient pressure changes, do not result in contamination. The designs of the distribution network were not reviewed as part of this assignment.

Annex 1: Data Summary

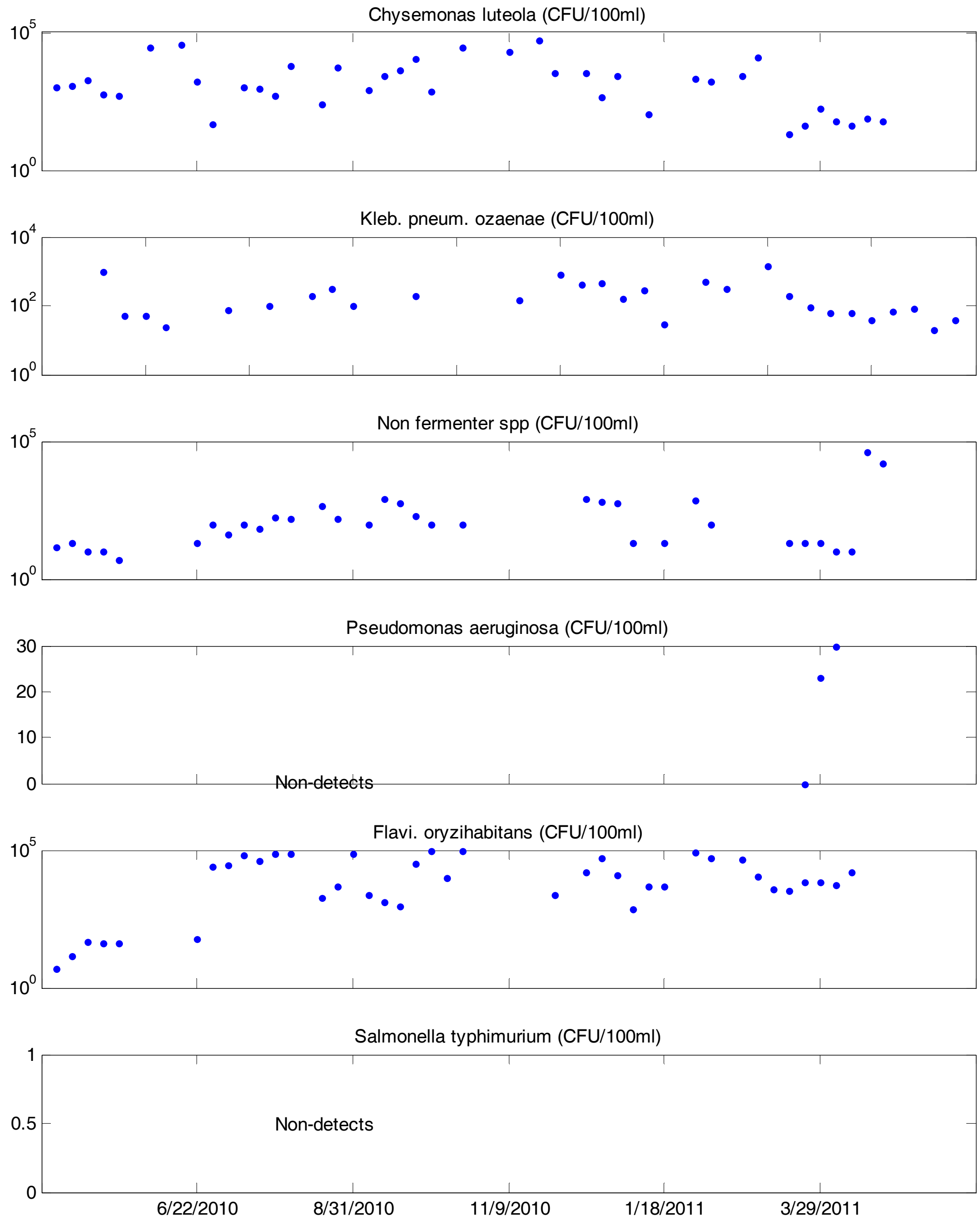
Microbial and chemical analysis of weekly samples beginning on 20 April 2010 and ending in 08 February 2011 from the Joun Reservoir were reviewed for this report. Data are missing for seven weeks within this period: 24 May, 08 June, 10 August (bacteria missing), 01 November, 15 November, and 05 December in 2010, 24 January 2011 and 15 February 2011. The 09 November 2010 value for nitrate was modified from the reported value of 1018 mg/l, more than 100 times any other value. The laboratory has confirmed this to be a typographical error and that the correct value is 10.18 mg/l.

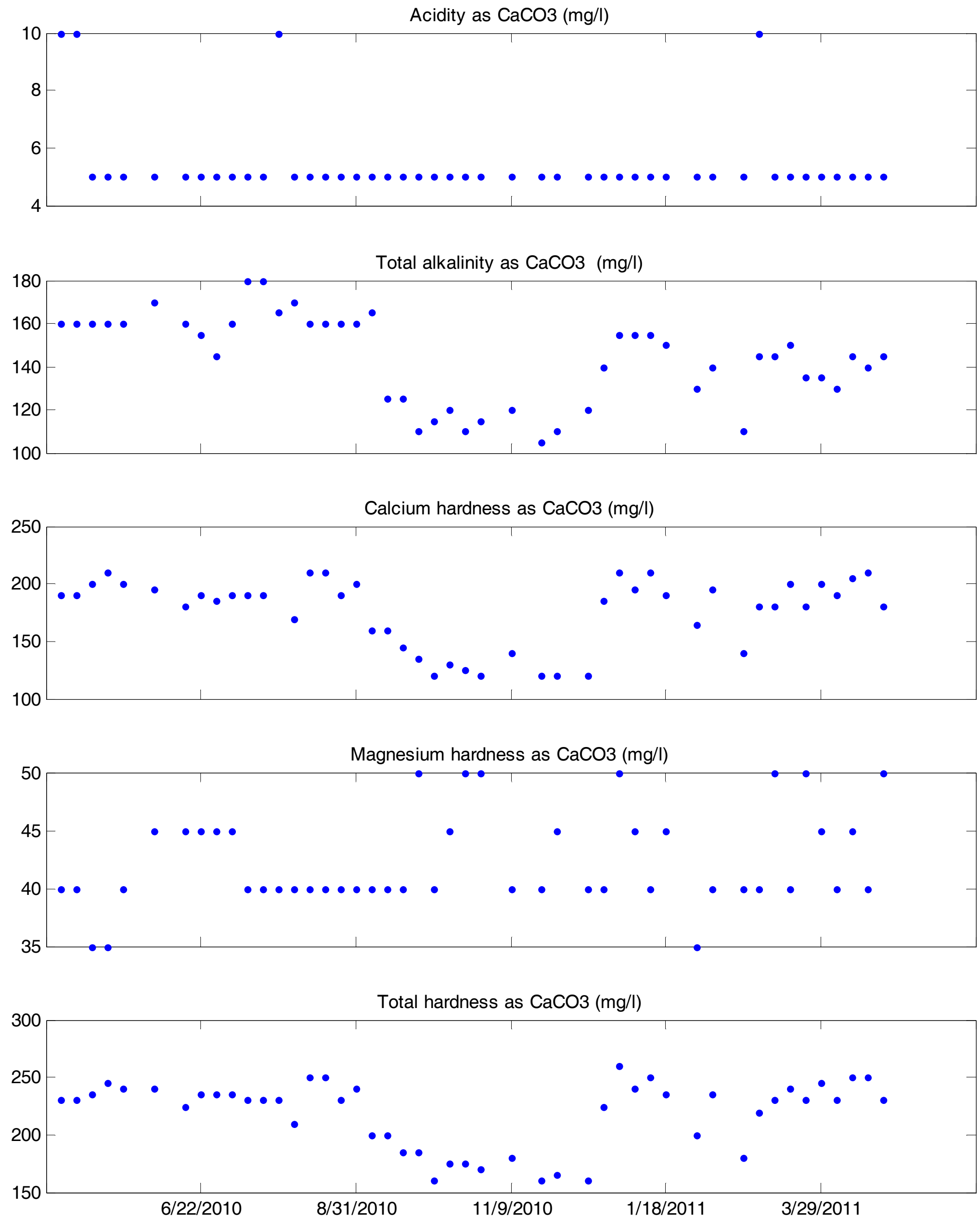
Time series plots of weekly results from Joun Reservoir samples.



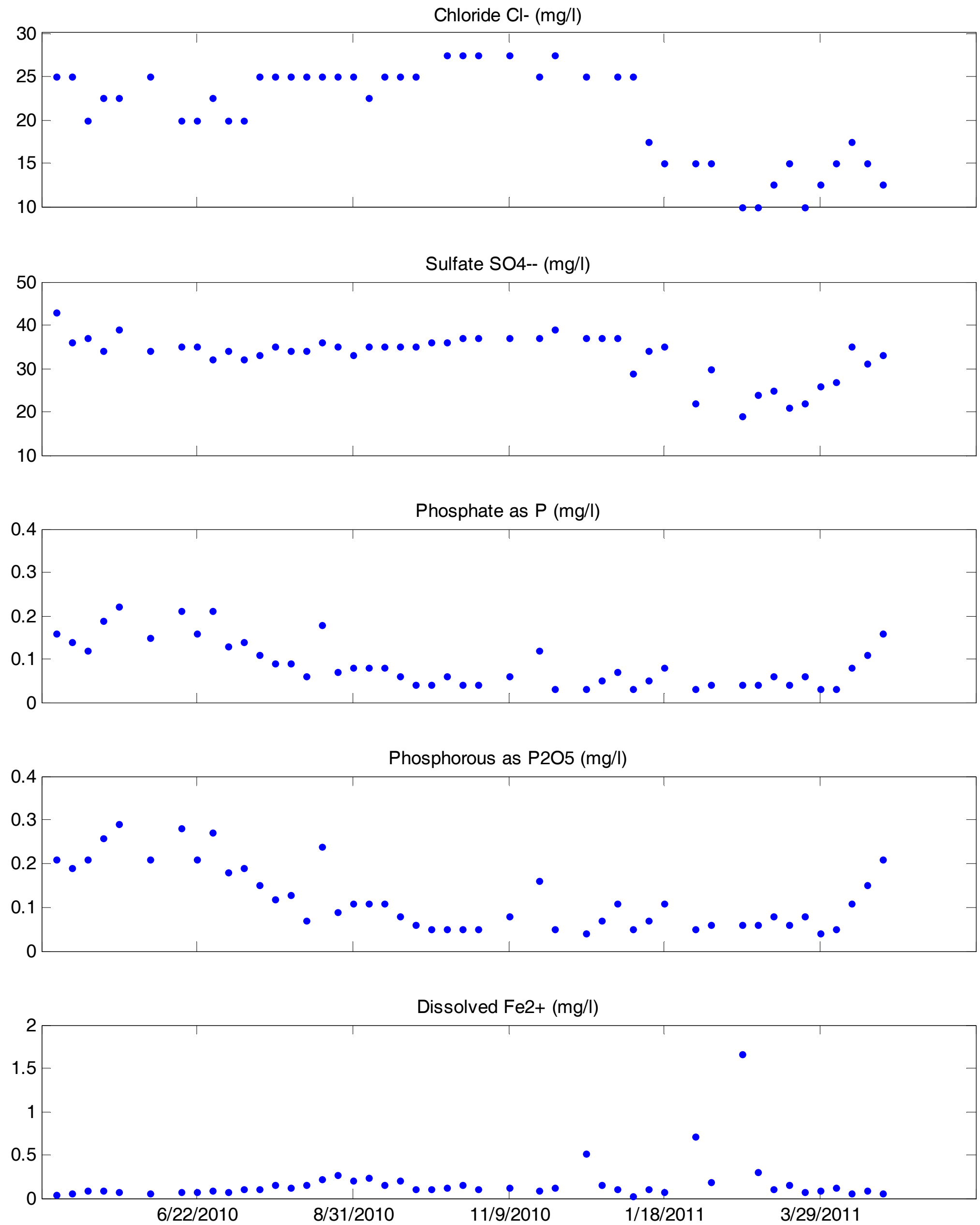


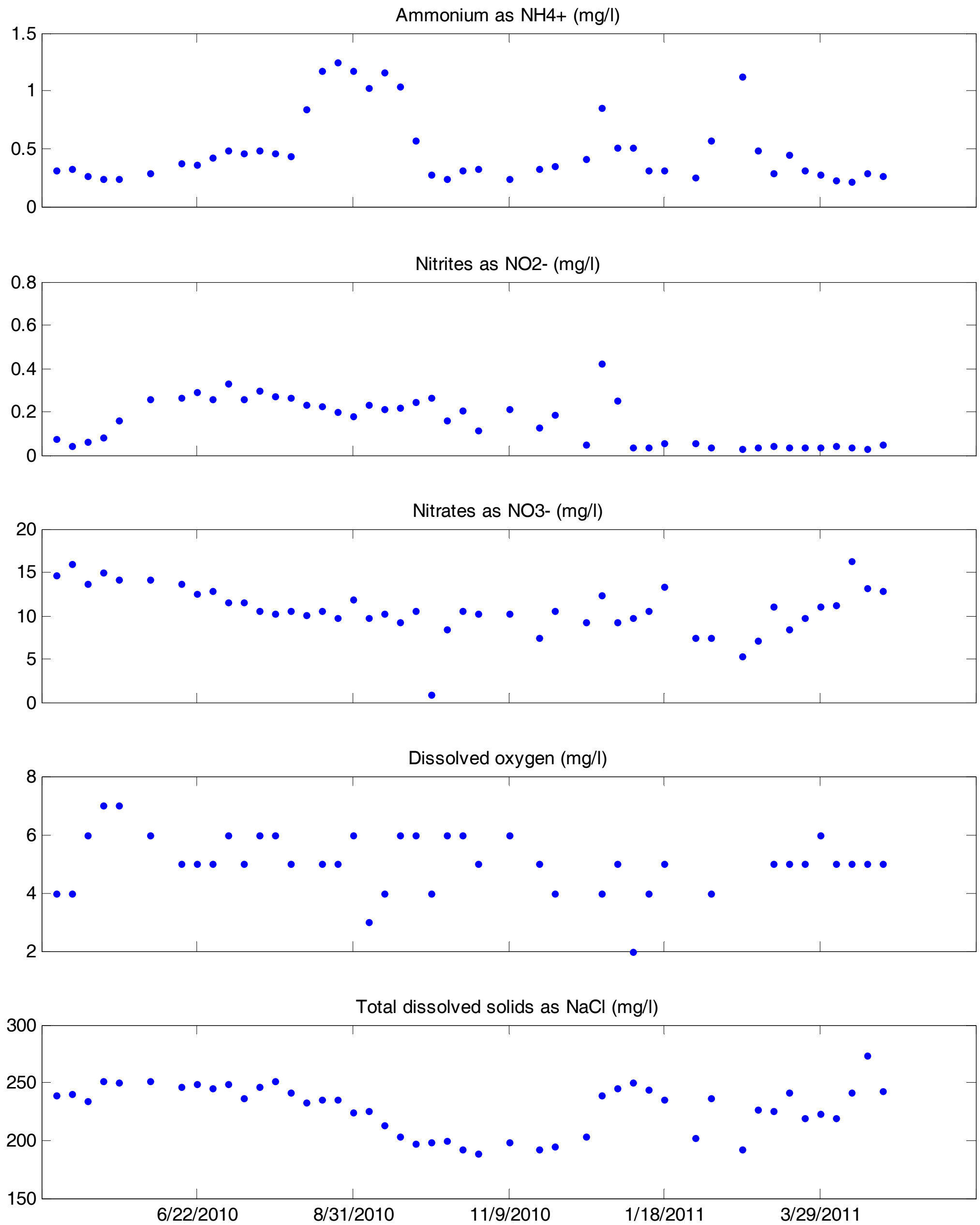
Total coliform (CFU/100ml)
10^6
10^5
10^4
10^3
Total thermal-tolerant coliforms (CFU/100ml)
10^5
10^4
10^3
10^2
Escherichia coli (CFU/100ml)
10^4
10^3
10^2
10^1
Citrobacter freundi (CFU/100ml)
10^6
10^4
10^2
Enterobacter cloacae (CFU/100ml)
10
5
0
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011


Chysemonas luteola (CFU/100ml)
10^5
10^0
Kleb. pneum. ozaenae (CFU/100ml)
10^4
10^2
10^0
Non fermenter spp (CFU/100ml)
10^5
10^0
Pseudomonas aeruginosa (CFU/100ml)
30
20
10
0
Non-detects
Flavi. oryzihabitans (CFU/100ml)
10^5
10^0
Salmonella typhimurium (CFU/100ml)
1
0.5
0
Non-detects
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011

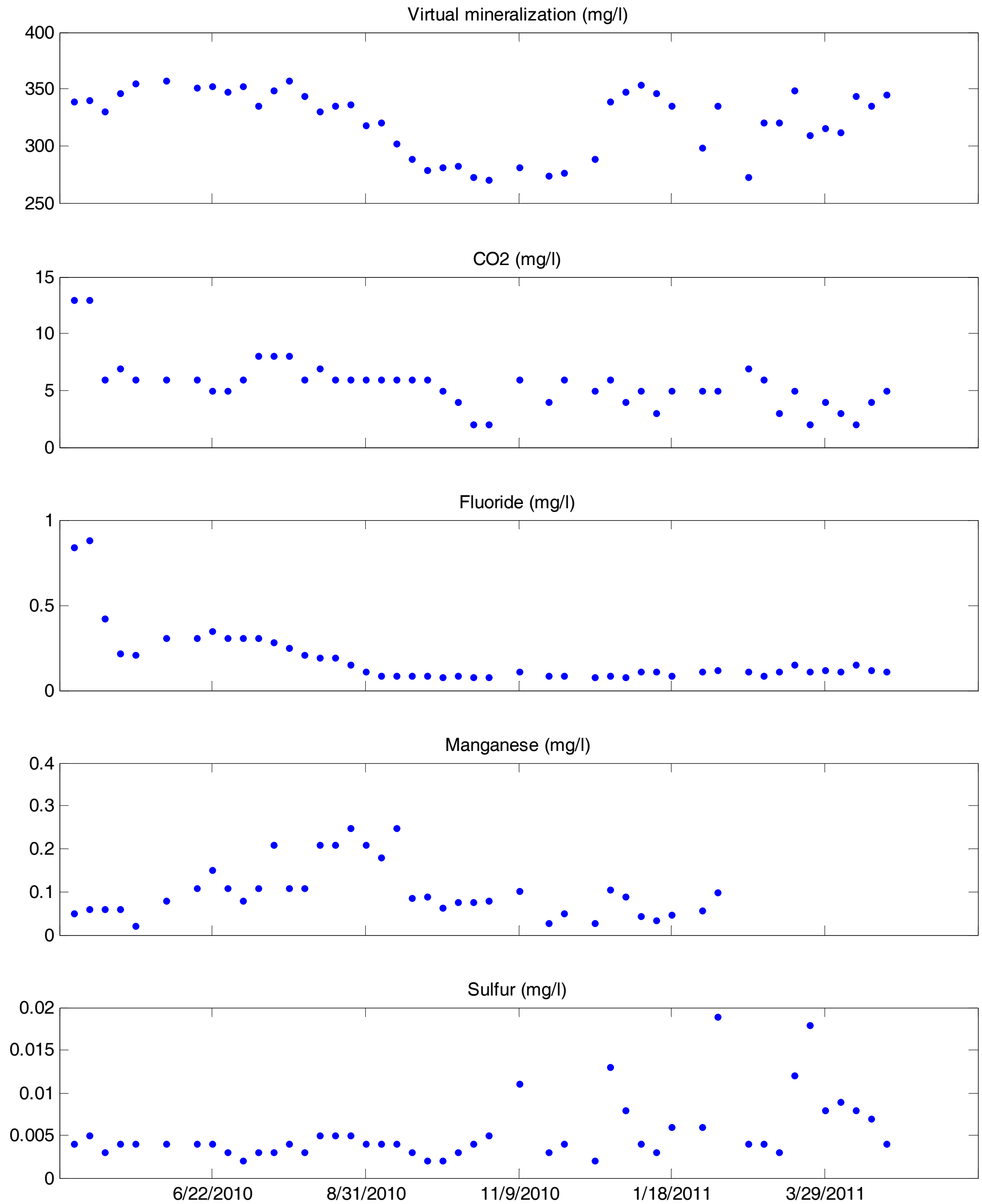


Acidity as CaCO3 (mg/l)
10
8
6
4
Total alkalinity as CaCO3 (mg/l)
180
160
140
120
100
Calcium hardness as CaCO3 (mg/l)
250
200
150
100
Magnesium hardness as CaCO3 (mg/l)
50
45
40
35
Total hardness as CaCO3 (mg/l)
300
250
200
150
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011


Chloride Cl- (mg/l)
Sulfate SO4-- (mg/l)
Phosphate as P (mg/l)
Phosphorous as P2O5 (mg/l)
Dissolved Fe2+ (mg/l)
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011

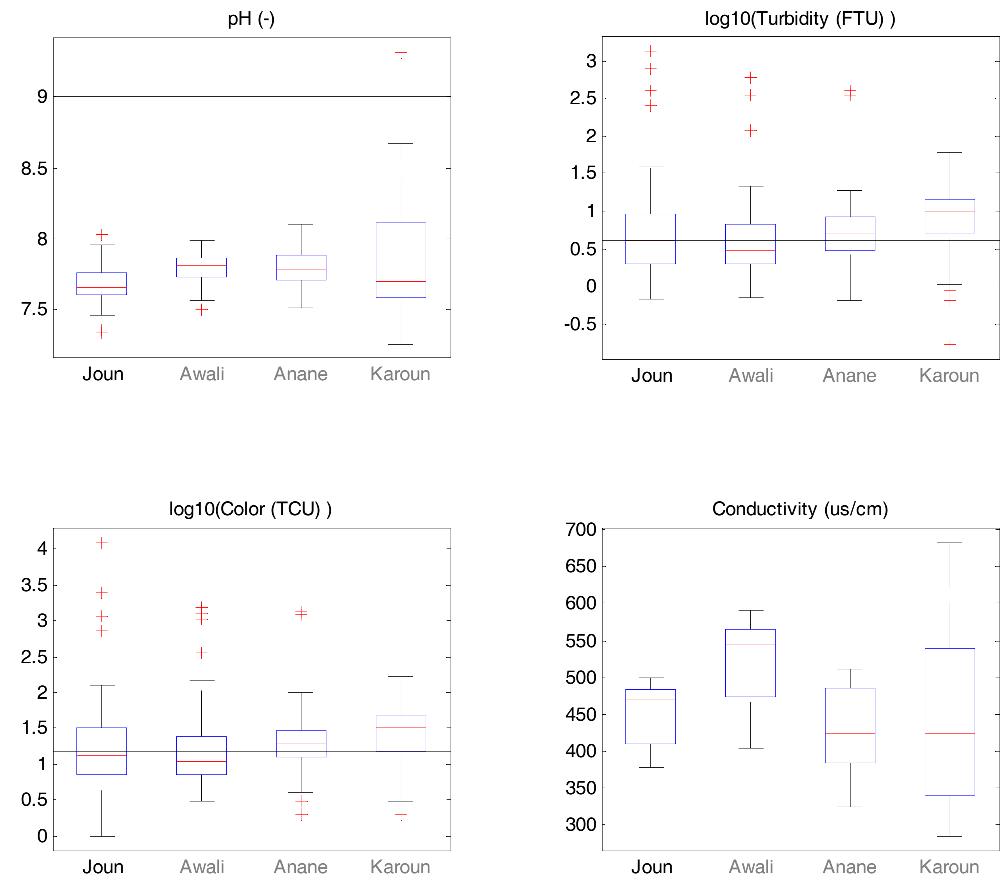


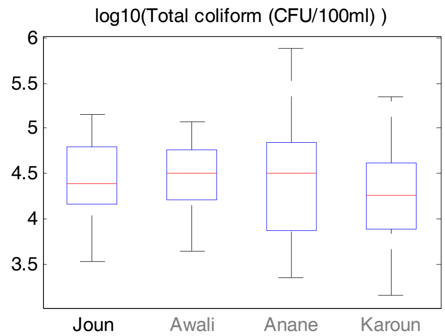
Ammonium as NH4+ (mg/l)
1.5
1
0.5
0
Nitrites as NO2- (mg/l)
0.8
0.6
0.4
0.2
0
Nitrates as NO3- (mg/l)
20
15
10
5
0
Dissolved oxygen (mg/l)
8
6
4
2
Total dissolved solids as NaCl (mg/l)
300
250
200
150
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011

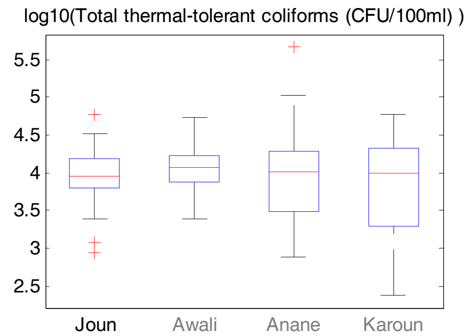

Virtual mineralization (mg/l)
400
350
300
250
CO2 (mg/l)
15
10
5
0
Fluoride (mg/l)
1
0.5
0
Manganese (mg/l)
0.4
0.3
0.2
0.1
0
Sulfur (mg/l)
0.02
0.015
0.01
0.005
0
6/22/2010
8/31/2010
11/9/2010
1/18/2011
3/29/2011

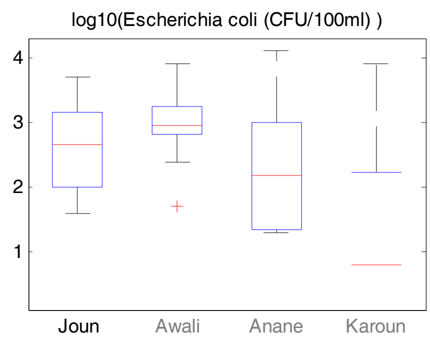
Box plots of results from samples at four measurement locations

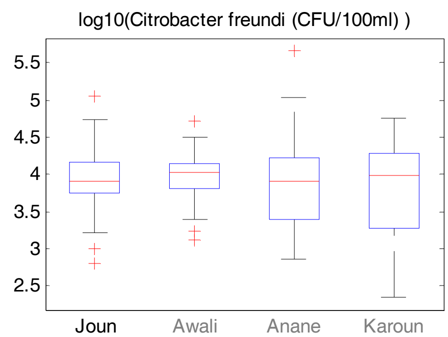
Box plot description: On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. Outliers are those points falling more than 1.5 times the difference between the 25th and 75th percentiles from either edge of the box. This corresponds to approximately 99.3 percentile coverage if the data are normally distributed.

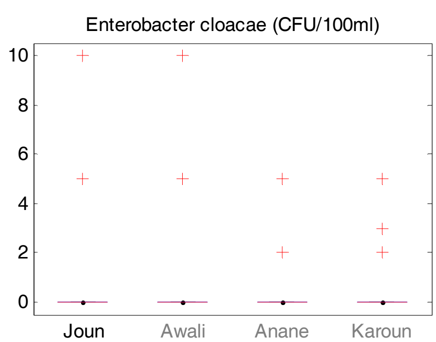


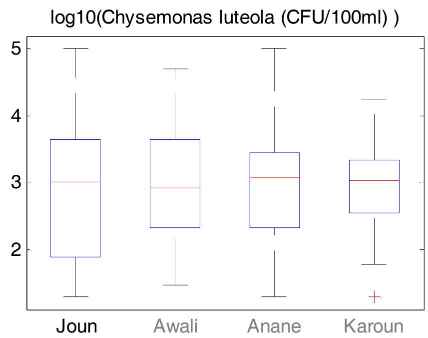

log10(Total coliform (CFU/100ml))
6
5.5
5
4.5
4
3.5
Joun
Awali
Anane
Karoun

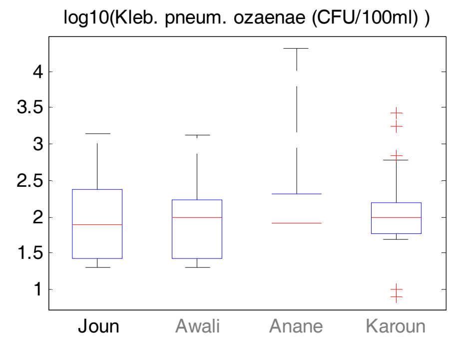

log10(Total thermal-tolerant coliforms (CFU/100ml))
5.5
5
4.5
4
3.5
3
2.5
Joun
Awali
Anane
Karoun

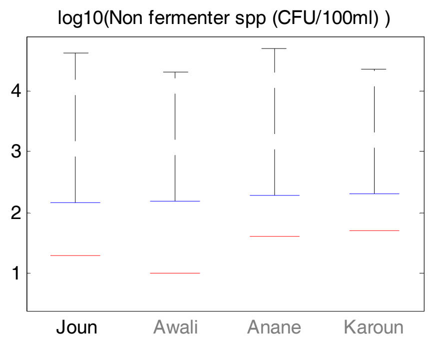

log10(Escherichia coli (CFU/100ml))
4
3
2
1
Joun
Awali
Anane
Karoun

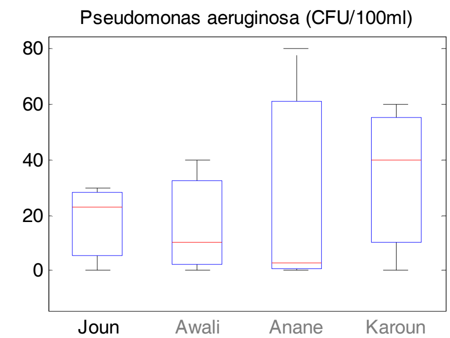

log10(Citrobacter freundi (CFU/100ml))
5.5
5
4.5
4
3.5
3
2.5
Joun
Awali
Anane
Karoun

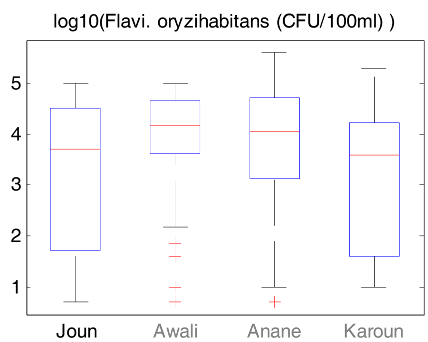

Enterobacter cloacae (CFU/100ml)
10
8
6
4
2
0
Joun
Awali
Anane
Karoun

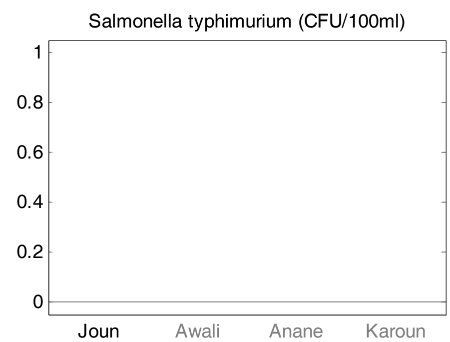

log10(Chysemonas luteola (CFU/100ml))
5
4
3
2
Joun
Awali
Anane
Karoun

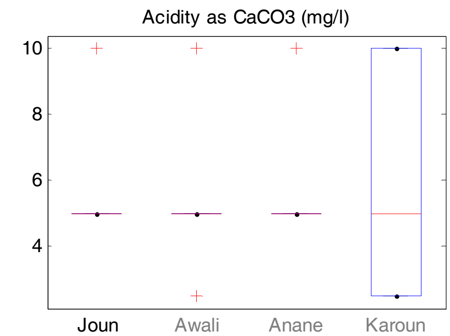

log10(Kleb. pneum. ozaenae (CFU/100ml))
4
3.5
3
2.5
2
1.5
1
Joun
Awali
Anane
Karoun

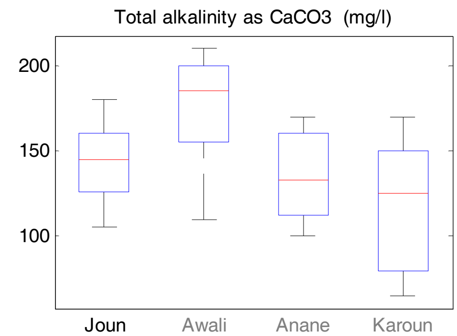

log10(Non fermenter spp (CFU/100ml))
4
3
2
1
Joun
Awali
Anane
Karoun

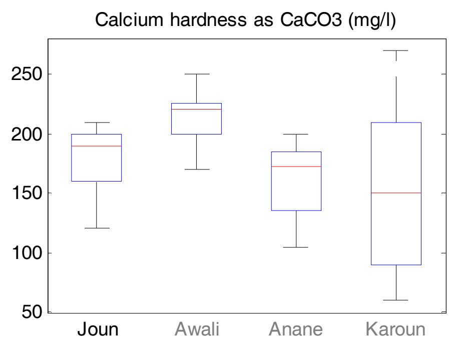

Pseudomonas aeruginosa (CFU/100ml)
80
60
40
20
0
Joun
Awali
Anane
Karoun

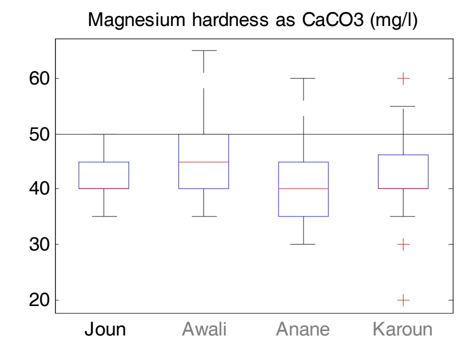

log10(Flavi. oryzihabitans (CFU/100ml))
5
4
3
2
1
Joun
Awali
Anane
Karoun

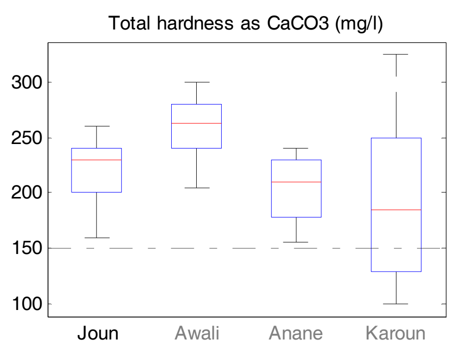

Salmonella typhimurium (CFU/100ml)
1
0.8
0.6
0.4
0.2
0
Joun
Awali
Anane
Karoun

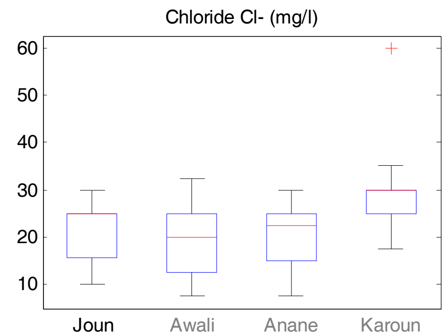

Acidity as CaCO3 (mg/l)
10
8
6
4
Joun
Awali
Anane
Karoun

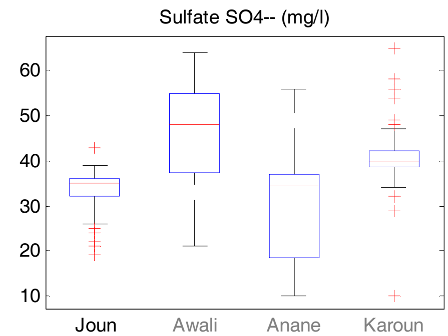

Total alkalinity as CaCO3 (mg/l)
200
150
100
Joun
Awali
Anane
Karoun

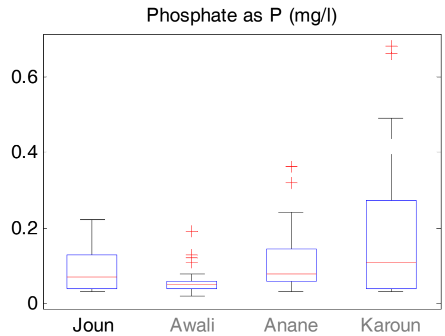

Calcium hardness as CaCO3 (mg/l)
250
200
150
100
50
Joun
Awali
Anane
Karoun

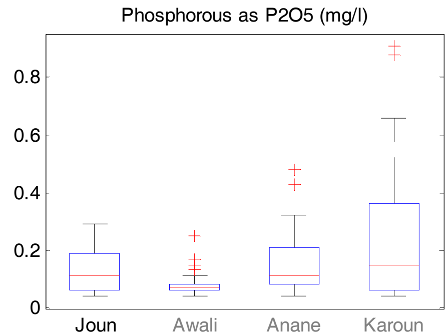

Magnesium hardness as CaCO3 (mg/l)
60
50
40
30
20
Joun
Awali
Anane
Karoun

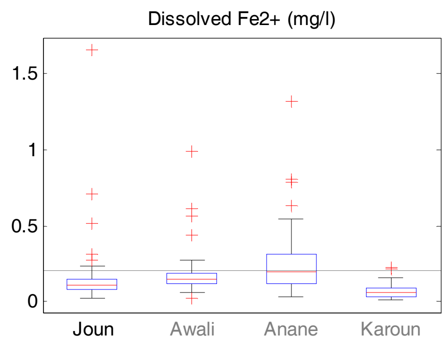

Total hardness as CaCO3 (mg/l)
300
250
200
150
100
Joun
Awali
Anane
Karoun

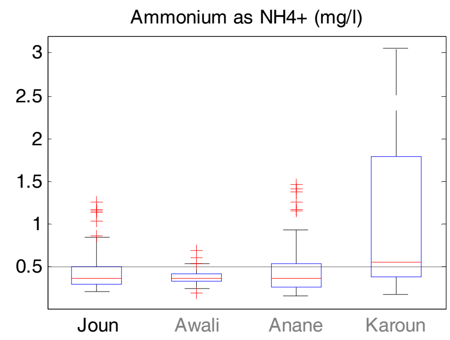

Chloride Cl- (mg/l)
60
50
40
30
20
10
Joun
Awali
Anane
Karoun

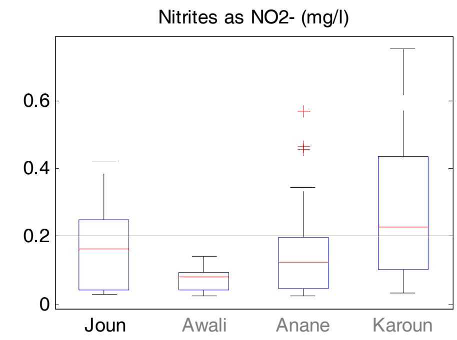

Sulfate SO4-- (mg/l)
60
50
40
30
20
10
Joun
Awali
Anane
Karoun

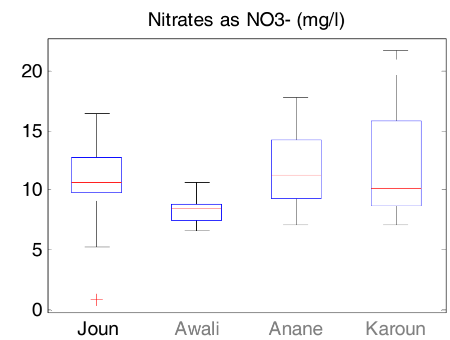

Phosphate as P (mg/l)
0.6
0.4
0.2
0
Joun
Awali
Anane
Karoun

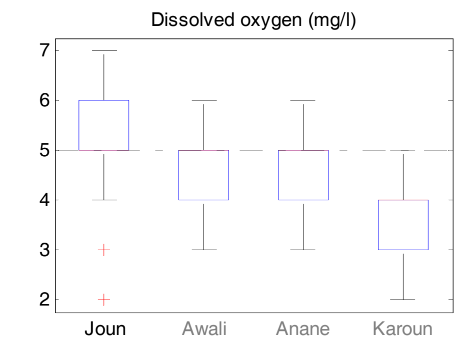

Phosphorous as P2O5 (mg/l)
0.8
0.6
0.4
0.2
0
Joun
Awali
Anane
Karoun

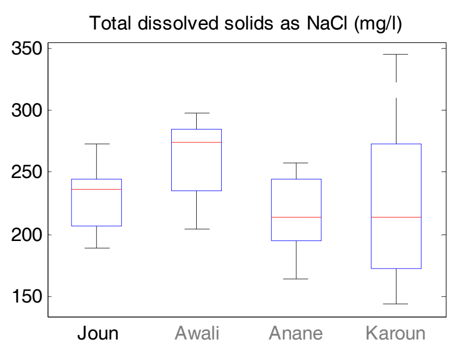

Dissolved Fe2+ (mg/l)
1.5
1
0.5
0
Joun
Awali
Anane
Karoun

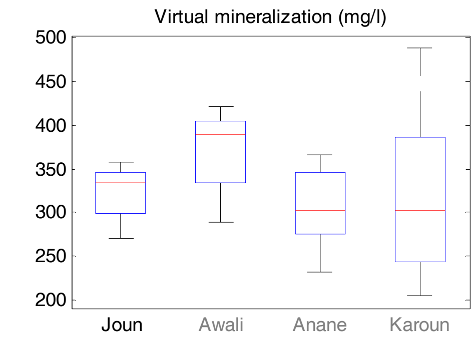

Ammonium as NH4+ (mg/l)
3
2.5
2
1.5
1
0.5
Joun
Awali
Anane
Karoun

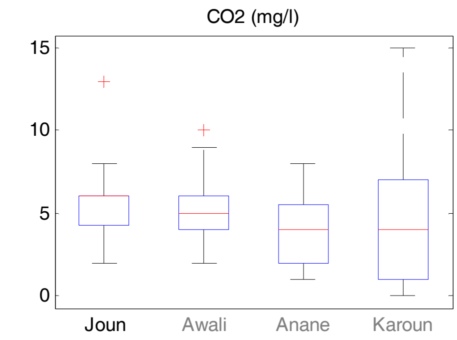

Nitrites as NO2- (mg/l)
0.6
0.4
0.2
0
Joun
Awali
Anane
Karoun

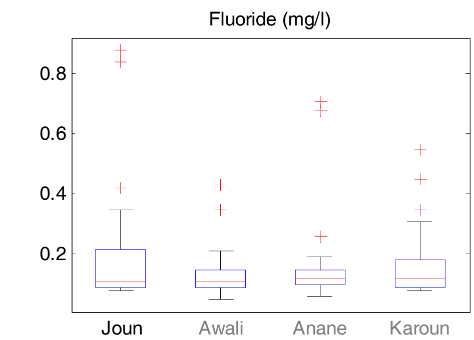

Nitrates as NO3- (mg/l)
20
15
10
5
0
Joun
Awali
Anane
Karoun

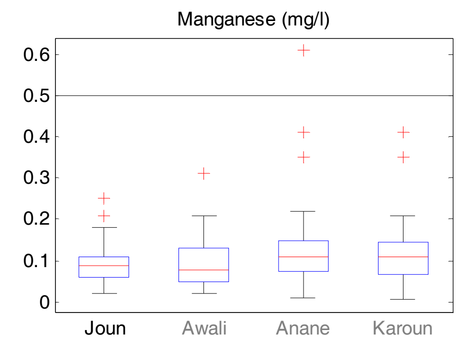

Dissolved oxygen (mg/l)
7
6
5
4
3
2
Joun
Awali
Anane
Karoun

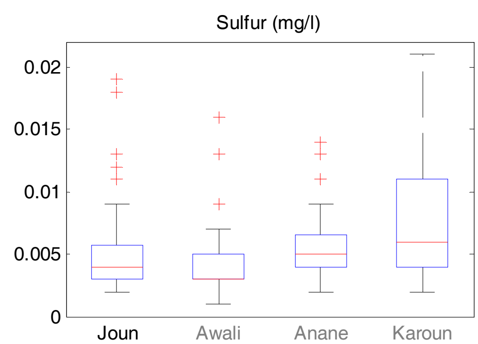

Total dissolved solids as NaCl (mg/l)
350
300
250
200
150
Joun
Awali
Anane
Karoun


Virtual mineralization (mg/l)
500
450
400
350
300
250
200
Joun
Awali
Anane
Karoun


CO2 (mg/l)
15
10
5
0
Joun
Awali
Anane
Karoun


Fluoride (mg/l)
0.8
0.6
0.4
0.2
Joun
Awali
Anane
Karoun


Manganese (mg/l)
0.6
0.5
0.4
0.3
0.2
0.1
0
Joun
Awali
Anane
Karoun


Sulfur (mg/l)
0.02
0.015
0.01
0.005
0
Joun
Awali
Anane
Karoun