NUTRIENT FILTER PILOT TRIAL
Ellen Brook Western Australia

A REPORT FOR THE SWAN RIVER TRUST

CHEMCENTRE Project T23601

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EXECUTIVE SUMMARY

Following a stakeholder workshop involving staff from the Swan River Trust, CSIRO, Government agencies, local catchment management groups and councils on 19 February 2010, it was recommended that a pilot-scale field study was required to determine the effectiveness of Neutralised Used Acid (NUA) blended with other materials at a field scale to inform the feasibility of an end of catchment treatment system. Two blends, containing either 25% or 40% NUA with granular activated carbon (GAC), calcined magnesia (MgO) and coarse river sand were recommended based on earlier laboratory trials conducted by CSIRO (Wendling *et al*, 2009a, Wendling *et al*, 2009b).

An initial pilot trial was established at the Bingham Road Creek (Figure 1) in winter/spring 2010, however design issues resulted in insufficient data collected to inform the feasibility study (Douglas *et al*, 2011). The report from the pilot trial recommended a second pilot trial, with modified design, be established to provide 'proof of concept' for an end of catchment treatment system. Information gained from the second pilot trial will be used to inform the feasibility study to ultimately influence a decision framework as to the cost and viability of using an end of catchment treatment system to remove nutrients from the Ellen Brook. The results of the second pilot trial are presented in this report.

Syrinx Environmental developed a design for the new treatment filter systems. The designs followed the recommendations and findings from the 2010 trial and involve both an actively pumped system and a passive gravity fed system.

The actively pumped system involved two replicate treatment systems, each incorporating three separate columns 2 metres in length and 0.5 metres in diameter (approximately 0.4 cubic metres volume). The three columns were set vertically and linked in series with water pumped in at the base of each column in an upward flow configuration.

The Passive or gravity fed filter system used four treatment systems, each incorporating tanks 1.86 metres diameter and 1.2 metres high (3.26 cubic metres in volume). The influent water enters the system from the top through slotted pipes and percolates through the NUA filter blend by gravity flow.

Laboratory analyses of the active constituents and both blends using deionised water as the leaching fluid indicated that the initial water quality from the systems would be moderately alkaline, moderately saline (with calcium and sulphate as the major ions) and contain very low concentrations of soluble metals and metalloids.

Particle size measurements of the 40% and 25% NUA blends indicated that hydraulic flow through the system would be in line with system design expectations. However, significant reductions in flow occurred after several days of operations for both Active and Passive systems. The reduced hydraulic conductivity was attributed to "blinding" of the base of the filter by very fine iron and manganese oxide particles produced by dissolution of gypsum ($CaSO_4.2H_2O$) from NUA.

Comparison of water quality for the inlet and outlet streams from replicated Passive and Active systems indicated effective reduction in concentrations of soluble phosphorus, nitrogen, organic carbon, aluminium, iron and barium.

The major elements released from the system were calcium and sulphate, most likely from dissolution of gypsum in NUA. Relatively low concentrations of magnesium were released by slow dissolution of the calcined magnesia component of the filter blend.

Low concentrations of fluoride, manganese, copper, cobalt, lead, nickel, chromium, uranium and strontium are released from both systems. Most of the released chromium is present in the hexavalent form and is associated with the alkaline MgO and NUA components. Almost all of the soluble chromium is released within several days of operation. The total amount released from one of the Passive systems was estimated to be 0.35 grams, which is considered minuscule when dilution by the inflow volume is taken into account.

The only metal released by the systems that resulted in a concentration increase from below a published environmental or health default trigger value was copper. Inlet concentrations of copper were slightly below the default ANZECC 2000 Trigger Value for protection of slightly to moderately disturbed freshwater aquatic ecosystems (0.0014 milligrams per litre). The highest recorded concentration in the outlet stream was 0.005 milligrams per litre for Passive System 3.

All outlet concentrations for other soluble metals, metalloids and fluoride were well below existing national guideline health limits for humans and livestock.

Provided existing issues with the fouling of the systems by fine particulate movement are resolved, the potential for significant removal of soluble nutrients and organic carbon is likely to be achieved.

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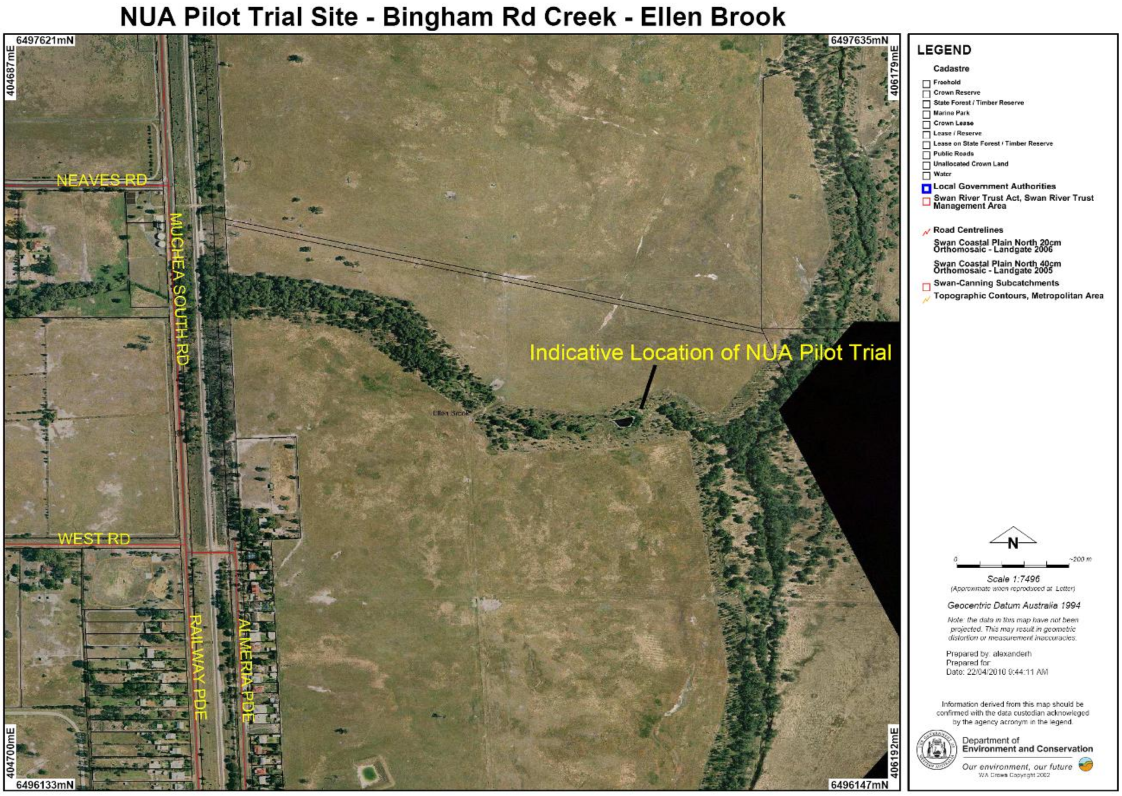
1. INTRODUCTION

Within Australia and around the world, eutrophication and the increasing occurrence of algal blooms in inland water systems are important water quality issues that have significant economic and environmental impacts (Barlow *et al*, 2009). In 2009 the Swan River Trust released the Swan Canning Water Quality Improvement Plan (SCWQIP) in order to manage nutrient loads entering the Swan Canning river system (Swan River Trust, 2009). The SCWQIP recommends that nutrient loads need to be halved in order to achieve the maximum acceptable loads to reduce algal blooms, subsequent low oxygen levels and fish kills. One of the management measures being investigated to reduce nutrient loads to the Swan Canning river system is the Ellen Brook end of catchment nutrient filter treatment system. This nutrient filter system aims to reduce nutrients flowing from the Ellen Brook into the Swan River.

Figure 1: Location of Pilot Trial on Department of Defence land near West Bullsbrook, access off Muchea South Rd



The Ellen Brook Catchment provides, on average, almost 27 gigalitres of water a year to the Swan River, approximately 7% of the annual flow. The Ellen Brook, on average, also contributes 10.04 tonnes of the annual phosphorus load and 71.4 tonnes of the annual nitrogen load (Swan River Trust, 2009). This equates to approximately 39% and 28% of the phosphorus and nitrogen loads respectively from the coastal catchments (Swan River Trust, 2009). The Ellen Brook Catchment has been identified as a priority catchment in which to reduce nutrients.

A stakeholder workshop including staff from the Swan River Trust, CSIRO, Government agencies, local catchment management groups and councils was held on 19 February 2010 to determine the best approach to conduct a feasibility study for an Ellen Brook end of catchment nutrient filter treatment system. This type of end-of-catchment approach has been consistently advocated by CSIRO for over a decade as a scientifically-robust and cost-effective approach to intercepting nutrients discharged by Ellen Brook into the upper Swan River. With the identification and characterisation of a suite of low-cost, large-volume, nutrient-adsorbent materials potential viability of an effective end-of-catchment nutrient intervention treatment system was considerably enhanced.

It was determined at the stakeholder workshop that a pilot trial field study was required to determine the effectiveness of Neutralised Used Acid (NUA) blended with other materials at a field scale to inform the feasibility of an end of catchment treatment system. An initial pilot trial was established at the Bingham Road Creek (Figure 1) in winter/spring 2010, however design issues resulted in insufficient data collected to inform the feasibility study. The report from the pilot trial recommended a second pilot trial, with modified design, be established to provide 'proof of concept' for an end of catchment treatment system. Information gained from the second pilot trial will inform the feasibility study to ultimately influence a decision framework as to the cost and viability of using an end of catchment treatment system to remove nutrients from the Ellen Brook.

The main objective of the pilot trial is to collect data that will help to measure the effectiveness of the media in reducing the concentrations of nutrients using flows in the Bingham Road Creek wetland (Figure 2). The results from this pilot trial will be used to inform partners of the cost and viability of using the material in an end of catchment treatment system to remove nutrients from the Ellen Brook.

Figure 2: Photograph of the Bingham Road Creek wetland, the source of the trials influent water

2. METHODS

2.1 DESIGN OF FILTER SYSTEM

Syrinx Environmental developed a design for the new treatment filter systems. The designs followed the recommendations and findings from the 2010 trial and involve both an actively pumped system and a passive gravity fed system. The filter blend, as recommended by CSIRO, differed slightly from that used in the 2010 trial. The recommended blend for the 2011 trial incorporated approximately 50% (by volume) coarse river sand, 42% NUA, 4% granular activated carbon (GAC) and 4% calcined magnesia (MgO).

2.2 TYPE OF SYSTEM

2.2.1 Active System

The Actively pumped system involved two replicate treatment systems, each incorporating three separate columns 2 metres in length and 0.5 metres in diameter (approximately 0.4 cubic metres volume). The three columns were set vertically and linked in series with water pumped in an upward flow configuration (as shown in Figure 3 and Figure 4). Total filter volume (including duplicate system) was 2.35 cubic metres, consisting of approximately 1.06 cubic metres of coarse river sand (45%), 0.85 cubic metres of NUA (36%), 0.11 cubic metres of MgO (4.5%), 0.11 cubic metres of GAC (4.5%) and 0.24 cubic metres of coarse aggregate (10 to 20 millimetres diameter) (10%).

Figure 3: Schematic of Active Treatment System

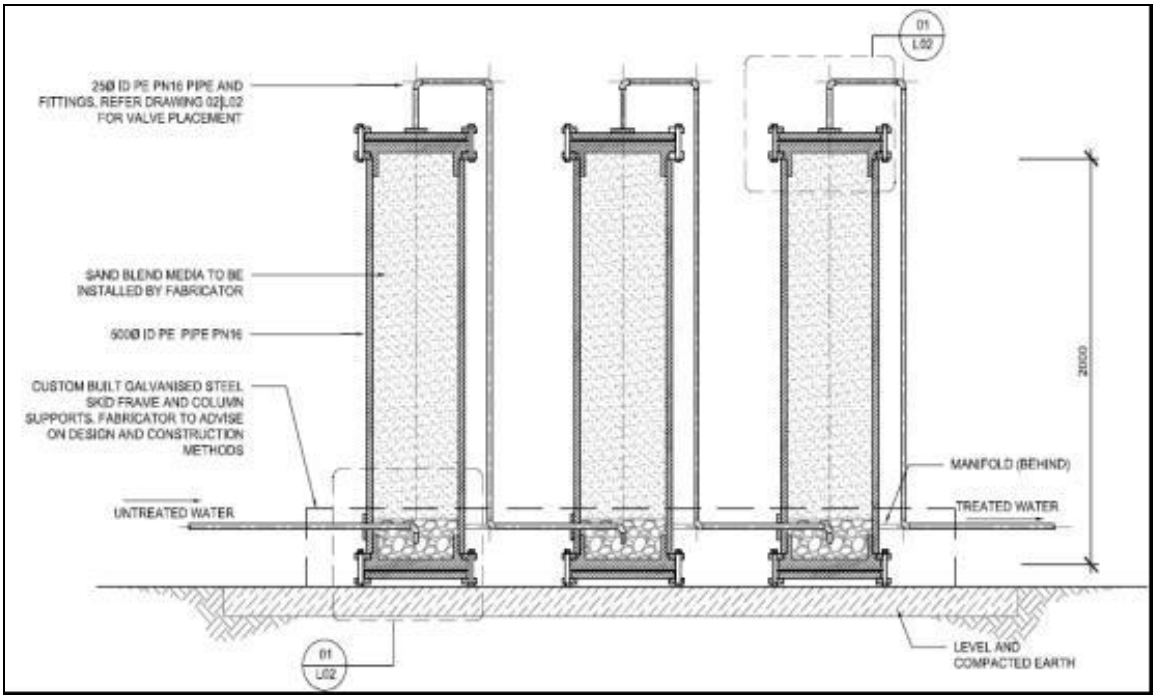


Figure 4: Photograph of Active Treatment System

2.2.2 Passive System

The Passive or gravity fed filter system will involve four treatment systems, each incorporating tanks 1.86 metres diameter and 1.2 metres high (3.26 cubic metres in volume). The influent water will enter from the top through slotted pipes and percolate through the NUA filter blend by gravity as shown in

Figure 5 and Figure 6. The containers were filled with 150 millimetres coarse aggregate (10 millimetre diameter) covering slotted drainage pipes, 100 millimetres coarse sand and 400 millimetres of the NUA filter blend. Two of the tanks contained 400 millimetres of a filter blend with 25% NUA whilst two tanks contained a filter blend with 40% NUA (the same as in the Active systems). Each of the blends used in the passive system had a duplicate to compare results. The containers maintained a minimum of 500 millimetres head of water above the NUA filter blend to provide downward flow pressure.

Figure 5: Schematic of Passive Treatment System

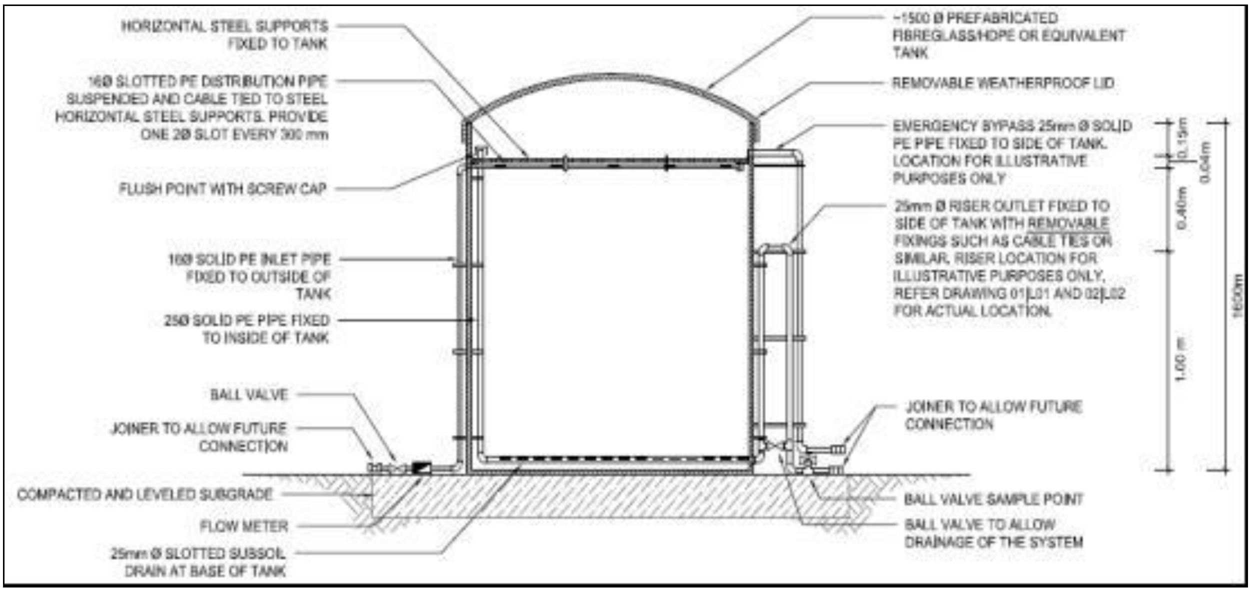


Figure 6: Photograph of Passive Treatment System prior to installation of inlet pipes

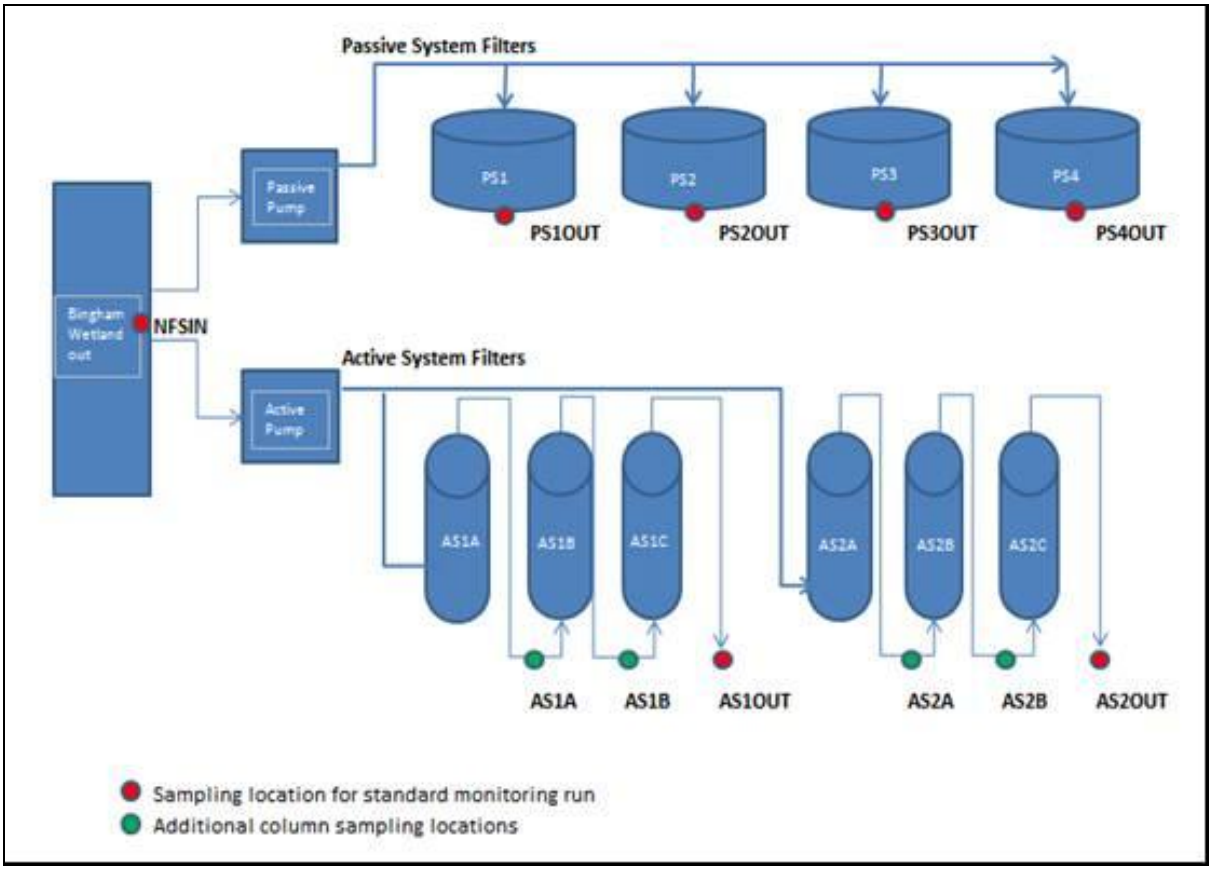
2.3 MONITORING

The Passive and Active nutrient filters were designed to accommodate flow rates equivalent to achieving a 1 hour contact time between the influent water and the filter medium. This flow rate was based on a calculated hydraulic conductivity of the finest material in the blend, NUA, of 0.54 centimetres per minute. This flow rate was equivalent to 0.28 litres per second or 1,000 litres per hour in each of the passive system filters and 0.2 litres per second or 720 litres per hour in each of the active system filters.

2.3.1 Active System

Water quality and flow data was collected at the pump inlet and outlet of each active treatment system to determine the efficacy of the NUA-blends to adsorb nutrients at varying flow rates. Samples were also collected at the outlet of each individual column periodically to assess the nutrient removal performance of each column and compare with the combined treatment system to allow for analysis of required filter length (Figure 7).

Figure 7: Schematic Monitoring Points in the Treatment Systems



2.3.2 Passive System

Water quality and flow data was collected at the inlet and outlet of each passive treatment system to determine the efficacy of the NUA-blends to adsorb nutrients under gravity fed flows (Figure 7).

2.4 SAMPLING AND ANALYSIS PROGRAM

2.4.1 Sampling Equipment

A Hydrolab Quanta (or similar field meter) was used to take the *in situ* physico-chemical measurements. Flow rates were measured by a stop watch and a one litre jug. All other samples were analysed at ChemCentre (NATA approved laboratory for analysis).

- Bottles for each sampling site (multiply by number of sites monitored on a particular day).
  a) 1 L plastic – green label - no preservative (TSS)
  b) 250 mL plastic – yellow label - preservative (sulphate)
  c) 250 mL plastic – black label - no preservative (total metals)
  d) 250 mL plastic – pink label - no preservative (soluble metals)
  e) 125 mL plastic – black label - no preservative (total nutrients)
  f) 125 mL plastic – purple label - no preservative (filtered nutrients)
  g) 60 mL plastic – blue label - preservative (Chromium VI)
  h) 40 mL glass – grey label - no preservative (TOC)
  i) 40 mL glass – grey label - no preservative (DOC)
- Quanta (calibrated), probe cover, protection cap, spare batteries etc.
- 1 L plastic beaker.
- Chain of Custody forms.
- Field Observation Forms.
- Sample numbers.
- 2 x Eskies with ice bricks.
- Extendable pole sampler.
- Filter tower and 0.45 µm filter papers.
- DI water and spray bottle.
- Gumboots.
- Nitrile gloves.
- Stop watch.
- Bags to carry bottles to and from vehicle.
- Copy of this Sampling and Analysis Plan (SAP).
- Permanent marker and pens.
- First aid kit.

- Mobile phone.
- QC bottles if required.

2.4.2 Labelling

Sample bottles were pre-ordered from the laboratory prior to sampling. Sample bottles for each site were clearly labelled with the following information:

- Unique sample reference number (e.g. 20045678).
- Site name (e.g. NFSIN).
- Date and time.
- Department taking the sample (e.g. SRT).
- Parameter to be analysed (e.g. Total metals, Filtered nutrients).
- Any treatment (i.e. filtration, preservative).

The unique sample reference number is printed on adhesive labels, which are available from DoW (Water Information Branch). All samples from a single site with the same sampling method must have the same unique sample reference number.

2.4.3 Collection Methods

All samples were collected, prepared and analysed at the laboratory in accordance with the methods described in AS/NZS 5667.1.1998. Flow through each of the outlet pipes for both the active and passive systems were recorded on the Field Observation Form.

***Grab sample collection methods*:**

- Wear disposable nitrile gloves while sampling with disposal at the end of sampling at each site to avoid cross contamination. Samplers must not handle the inside of the bottles or the lids.
- Water samples are to be taken with an extendable pole sampler when sampling influent water (NFSIN) or straight from the outlet pipe into sample bottles. Take care to avoid collecting floating debris and scum as this could contaminate the sample.
- The pole sampling container or bottle (unless it contains preservative) is rinsed 3 times with sample water and the rinseate is poured downstream.
- All sample bottles should be filled such that a small air space is left at the top, apart from the TOC and DOC vials which need to exclude air.
- Take care not to touch the opening of the sample container with any part of the grab pole container, the outlet pipe or your hands in order to avoid contamination of the sample. Do not put sample bottle caps on the ground as this increases the risk of contamination.

- Once samples are collected they should be stored upright at 4°C in an esky with ice bricks (i.e. cold and in the dark) until delivery the same day (or within 24 hours) to the laboratory.

2.4.4 Filtering of Samples

Filtering of samples was conducted in the field using a filter tower with 0.45 µm filter papers (Figure 8) purchased from an environmental equipment supplier. Filtering was conducted in accordance with DoW Field Sampling Guidelines (DoW, 2008). After rinsing with de-ionised water, all filtering equipment was rinsed with the sample water prior to collecting the filtered sample. The sample bottles were rinsed three times with filtered water (unless preservative is present) before filling.

Figure 8: Photograph of filed monitoring filtering equipment

2.4.5 Measurement of *in situ* Parameters

Physical parameters (pH, salinity, conductivity, temperature and dissolved oxygen were measured *in situ* with a multi-parameter water quality meter. The meter probe was submerged into the water at the site where the surface water grab sample was taken or in the 1 litre plastic beaker. *In situ* monitoring results were recorded on the Field Observation Form (Appendix 3).

2.4.6 Flow Measurements

The flow through the outlet pipes was calculated using a stop watch. Using the 1 litre plastic beaker, time how long it takes to fill the beaker to the one litre mark (Figure 9). Repeat a number of times and average. Record readings on the Field Observation Form (Appendix 3).

Figure 9: Flow collection point from an active system filter and 1 L beaker used for flow measurement

2.4.7 Sampling Regime

A SAP was developed prior to trial commencement. Monitoring data was analysed during the trial and monitoring was conducted by staff from the Trust and Ellen Brockman Integrated Catchment Group (EBICG). The primary purpose of the monitoring program is to evaluate the effectiveness of the material, to be used in the end of catchment wetland, in reducing the nutrient concentrations from flows in the Ellen Brook and determining if the effluent contained any contaminants. Monitoring was conducted at the nutrient filters positioned at the Bingham Road Creek wetland approximately 800 metres downstream of Muchea South Road.

The sampling commenced in early September 2011 and finished when flows through the site ceased in November 2011. The analytes that were measured are listed in Table 1.

Table 1: Sampling Locations

Site Code	Location	Components to be Sampled
NFSIN	Influent to filter systems. In wetland near pump intake pipes	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
PS1OUT	Passive system filter 1 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
PS2OUT	Passive system filter 2 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
PS3OUT	Passive system filter 3 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
PS4OUT	Passive system filter 4 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS1A	Active system filter 1 column A outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS1B	Active system filter 1 column B outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS1OUT	Active system filter 1 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS2A	Active system filter 2 column A outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS2B	Active system filter 2 column B outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC
AS2OUT	Active system filter 2 outlet	Nutrients, metals, TSS, sulphate, chromium VI, DOC and TOC

It was proposed that water quality testing be conducted three times per week for the first two weeks of the trial, and twice per week until flow rates are modified. At this point the monitoring was returned to three times per week in order to determine the effects of the increased flow rates. Samples collected from the pilot trial were tested for various analytes including nutrients, metals, physical parameters and others as shown in Table 1. The research primarily concentrated on some analytes such as total phosphorus (TP); total nitrogen (TN); filterable reactive phosphorus (FRP); total organic nitrogen; ammonium nitrogen; nitrate nitrogen; and total organic carbon. Physical parameters including pH, EC, temperature and dissolved oxygen were recorded in the field with verification of EC and pH taken in the laboratory.

2.5 METHODS OF ANALYSIS

Water samples were analysed using validated methods developed by the ChemCentre based on methods published by the APHA or USEPA.

- Alkalinity (as milligrams $CaCO_3$ per litre) and constituents by acid titration (APHA 2320B).
- Ammonia expressed as Nitrogen by FIA (APHA 4500NH3-H).
- Sulphate in water by Ion Chromatography (APHA 4110B).
- Chloride (Cl), Colorimetric analysis by discrete autoanalyser (APHA in house method).
- Chromium VI (Cr6), Colorimetric analysis by discrete autoanalyser (APHA in house method).
- Dissolved Organic Carbon (DOC) as NPOC (APHA 5310B).
- Total Organic Carbon (TOC) as NPOC or Total Carbon (TC) (APHA 5310B).
- Electrical Conductivity in water @ 25C (APHA 2510B).
- Fluoride in water by ion specific electrode (ISE) (APHA 4500F-C).
- Total Dissolved metals by ICP-AES (APHA 3120) Al, Ba, Be, B, Ca, Fe, Mg, Mn, Si, Na, Sr, and Zn.
- Total Dissolved metals by ICP-MS (APHA 3125) As, Cd, Cs, Cr, Co, Cu, Pb, Hg, Mo, Ni, Sb, Se, Ag, Th, Sn, V and U.
- Total Metals by digestion (USEPA 3015 modification) and ICP-AES (APHA 3120) Al, Ba, Be, B, Ca, Fe, Mg, Mn, Si, Na, Sr, and Zn.
- Total metals by digestion (USEPA 3015 modification) and ICP-MS (APHA 3125) As, Cd, Cs, Cr, Co, Cu, Pb, Hg, Mo, Ni, Sb, Se, Ag, Th, Sn, V and U.
- Organic Nitrogen as N calculated (TN-Ammonia-N, Nitrate/Nitrite_N).
- Total Nitrogen by persulphate digestion FIA (APHA 4500N-C,I).
- Nitrate-Nitrite expressed as Nitrogen by FIA (APHA 4500NO3-I).
- Phosphorus soluble reactive as P in water by FIA (APHA 4500P-G).
- pH in water by pH meter (APHA 4500H+).
- Total Phosphorus by persulphate digestion and FIA (APHA P-J,G).
- Sulphide in water by methylene blue colorimetry.
- Suspended solids (APHA 2540D) and volatile suspended solids (APHA 2540E).

Table 2: Analytes Measured, Limits of Reporting

		Analytes	Limits	Limits
	Physicals (field)	pH	0.1	
		EC	0.2 mS/m	
		Temp	na	
		DO	0.1%	
Nutrients	Total	TP	0.01 mg/L	
		TN	0.02 mg/L	
	Dissolved	NH3 - N	0.01 mg/L	
		NOx - N	0.01 mg/L	
		FRP	0.01 mg/L	
		Total Oxidised N	0.01 mg/L	
			In solution	**Totals**
Metals	Metals based on total dissolved solids to less than 30000mg/L	Al	0.005 mg/L	0.01 mg/L
		B	0.02 mg/L	0.02 mg/L
		Ba	0.002 mg/L	0.002 mg/L
		Be	0.001 mg/L	0.001 mg/L
		Ca	0.1 mg/L	0.5 mg/L
		Cr	0.001 mg/L	0.001 mg/L
		Fe	0.005 mg/L	0.01 mg/L
		K	0.1 mg/L	0.1 mg/L
		Mg	0.1 mg/L	0.1 mg/L
		Mn	0.001 mg/L	0.001 mg/L
		Zn	0.005 mg/L	0.01 mg/L
	Metals based on total dissolved solids to less than 3000mg/L	Ag	0.0001 mg/L	0.0001 mg/ L
		As	0.001 mg/L	0.001 mg/ L
		Cd	0.0001 mg/L	0.0001 mg/ L
		Co	0.0001 mg/L	0.0001 mg/ L
		Cr	0.0005 mg/L	0.001 mg/ L
		Cu	0.001 mg/L	0.001 mg/ L
		Pb	0.0001 mg/L	0.0005 mg/ L
		Mo	0.001 mg/L	0.001 mg/ L
		Ni	0.001 mg/L	0.001 mg/ L
		Sb	0.0001 mg/ L	0.0001 mg/ L
		Se	0.001 mg/L	0.001 mg/ L
		Sn	0.0001 mg/L	0.001 mg/ L
		U	0.0001 mg/L	0.0001 mg/ L
		V	0.0001 mg/L	0.0001 mg/ L
		Th	0.0001mg/L	0.0001mg/ L
		Hg	0.0001 mg/L	0.0001 mg/L
Others		Cr VI	0.005 mg/L	
		F	0.05 mg/L	
		SiO2 - Si	0.1 mg/L	
		SO4	0.1 mg/L	
		Cl	1 mg/L	
		Sulphide	0.01 mg/L	
		Alkalinity as CaCO3	1mg/L	
		TOC	1 mg/L	
		DOC	1 mg/L	
		TSS	1 mg/L	

3. FILTER BLEND CHARACTERISATION

3.1 COMPONENT PROPERTIES

The principal components, NUA, MgO and GAC have been characterised by CSIRO for a wide range of chemical and biological parameters in previous studies. A CSIRO report (CSIRO 2009) containing this data is attached as Appendix 4. Results for particle size distribution solute leachability (as measured by the Australian Standard Leaching Procedure (ASLP)) are presented in Sections 3.2 and 3.3.

Finely ground samples of MgO, NUA and both blends were analysed for elemental composition using strong acid digestion (USEPA 3051 modified) and hexavalent chromium. The results are presented in Table 3.

Table 3: Analysis of MgO, NUA and Filter Blends

Analyte	Units	MgO	NUA	25% Blend	40% Blend
Ag	mg/kg	<0.05	<0.05	<0.05	<0.05
Al	mg/kg	1280	1360	601	540
As	mg/kg	0.2	4	1.4	1.6
B	mg/kg	<5	9	<5	<5
Ba	mg/kg	15	22	5.1	4.7
Be	mg/kg	<0.05	0.21	0.05	<0.05
Ca	%	2.4	11.0	2.6	2.5
Cd	mg/kg	<0.05	<0.05	<0.05	<0.05
Co	mg/kg	8.6	150	30	36
Cr	mg/kg	19	59	14	15
CrVI	mg/kg	4	<1	<1	<1
Cs	mg/kg	<0.05	0.15	0.06	<0.05
Cu	mg/kg	15	21	5.5	5.3
Fe	%	0.14	12.0	2.3	2.4
K	mg/kg	25	80	110	110
Mg	mg/kg	52.0	1.0	4.0	2.4
Mn	mg/kg	130	21000	3900	4100
Mo	mg/kg	<0.05	2.3	0.62	0.63
Na	mg/kg	260	110	45	34
Ni	mg/kg	130	64	22	19
Pb	mg/kg	<0.5	22	3.3	4.1
SO4_S	mg/kg	0.015	22.0	5.0	5.2
Sb	mg/kg	<0.05	0.28	0.06	0.06

Analyte	Units	MgO	NUA	25% Blend	40% Blend
Se	mg/kg	0.06	0.13	<0.05	<0.05
Sr	mg/kg	58	840	150	150
U	mg/kg	0.02	4.2	0.87	0.91
V	mg/kg	2.2	40	8.5	9.3
Zn	mg/kg	8	47	8	7

3.2 PARTICLE SIZE DISTRIBUTION

Graphs showing the particle size distributions of NUA and both filter blends are presented in Charts 1 to 3.

Although the hydraulic conductivity (K) of porous media, including filter sands, is influenced by particle size distribution, other factors such as particle shape and compaction also influence hydraulic properties. The Hazen relationship (Equation 1) is the most widely used method to estimate permeability of sands through particle size distribution:

$K = 0.01\ d^2_{10}$ (metres per second) **Equation 1**

where d_{10} is 10th percentile effective particle diameter (in millimetres)

d_{10} and estimated K values for NUA and the filter blends are:

- NUA, d_{10} = 0.0009 millimetres (0.9 micrometres), K = 8.1 x 10^{-9} metres per second.
- 40% blend, d_{10} = 0.1 millimetres (100 micrometres), K = 1 x 10^{-4} metres per second.
- 25% blend, d_{10} = 0.06 millimetres (60 micrometres), K = 3.6 x 10^{-5} metres per second.

These calculated values for K confirm that very slow infiltration rates would be expected for pure NUA. Blending with coarse media such as river sand results in significant increases in K. Estimated values for the 25% and 40% NUA blends are considered suitable for the proposed filter system. However, if the fine particles segregate significant decreases in K, treated water throughout can be expected.

Chart 1: Particle Size Distribution of NUA

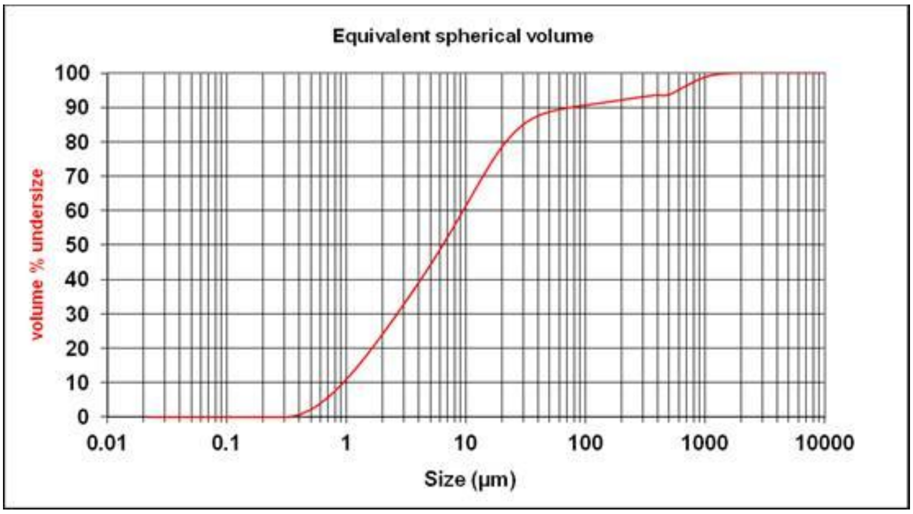


Chart 2: Particle Size Distribution of 40% Blend

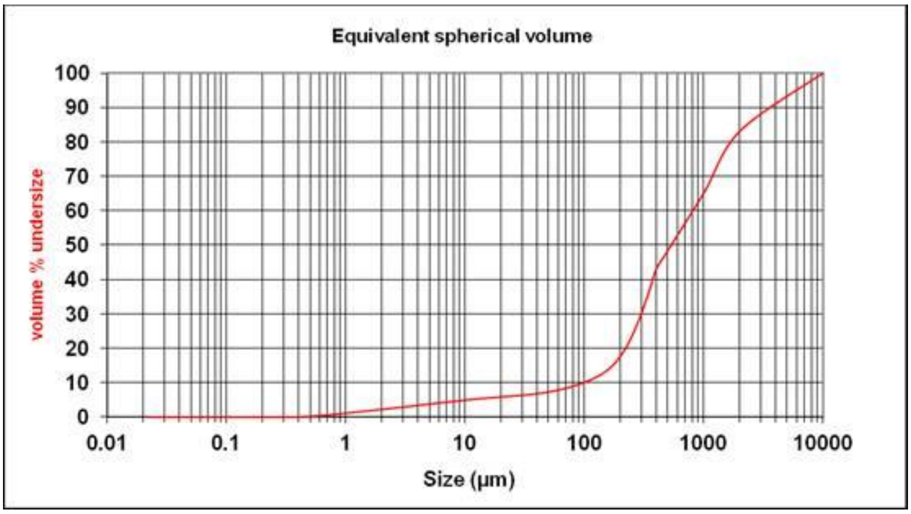
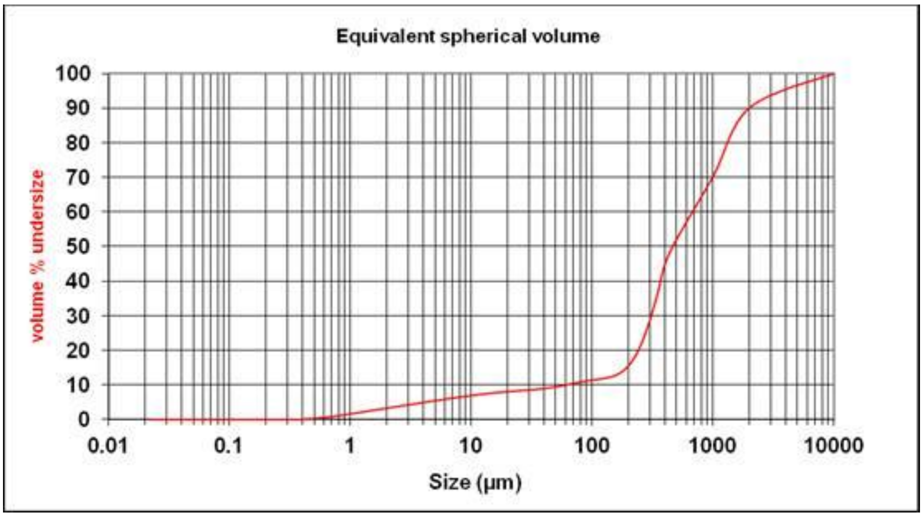


Chart 3: Particle Size Distribution of 25% Blend



3.3 ASLP ANALYSIS OF FILTER BLENDS

Results for analysis of MgO, NUA and both filter blends by the ASLP procedure using deionised water as the leaching solution are presented in Table 4. The samples were also analysed using a pH 5.0 leaching solution. Results from this procedure are presented in the complete laboratory report provided in Appendix 1.

These results indicate:

- NUA produces a slightly alkaline leachate. Calcined magnesia provides additional alkalinity to blend leachates. Leachate pH values from both blends are approximately 9.0. An increase in the leachate pH of blends could be due to MGO which has higher pH values (12) compared to NUA (7.8) and blends (9).
- The major ions in leachates of NUA and both blends are calcium and sulphur. The concentrations of these ions in NUA and filter blend leachates are similar in each case and correspond to the maximum solubility of the mineral gypsum ($CaSO_4.H_2O$).
- With the exception of chromium, concentrations of metals and metalloids in the leachates of all materials are very low.
- Concentrations of soluble chromium were 0.0086 and 0.0088 milligrams per litre in leachates of MgO and NUA, respectively. As concentrations of the more toxic hexavalent form were very low, most of the soluble chromium was present in the trivalent form.
- NUA contains a small amount of soluble nitrogen, most of which was present as nitrate-nitrogen. The concentration of nitrate-nitrogen in the water leachate of NUA was 0.62 milligrams per litre.
- *It was noted that the Cr(VI) result is higher than the Total Cr for NUA. The reaction of Cr(VI) and precipitation of Cr (III) is caused by the presence of high levels of organic acids in these samples. The high alkalinity however of the NUA blend extract which is then subsequently acidified, causes the Cr to drop out of solution, resulting in analytical bias's (low) total Chrome result. The results however are still within the method uncertainty at these low levels for this procedure.

Table 4: Analysis of ASLP Leachates (1:20 De-ionised water)

Analyte	Units	MgO	NUA	25% Blend	40% Blend
Al	mg/L	<0.005	<0.005	<0.005	<0.005
Alkalinity	mg/L	964	14	17	16
Ba	mg/L	0.12	0.009	0.005	0.013
Ca	mg/L	390	612	539	597
Cl	mg/L	1	<1	<1	<1
CrVI	mg/L	<0.005	0.020*	<0.005	<0.005
DOC	mg/L	1.3	<1.0	1	<1.0
ECond	mS/m	415	230	212	225
Fe	mg/L	<0.005	<0.005	<0.005	<0.005
K	mg/L	0.2	1.5	3.2	3.3
Mg	mg/L	<0.1	21.8	20.9	20.7
Mn	mg/L	<0.001	<0.001	<0.001	0.002
Na	mg/L	5.6	1.3	1	1.4
Ni	mg/L	<0.01	<0.01	<0.01	<0.01
SO_4_S	mg/L	4.1	1440	1300	1410
Sr	mg/L	1.1	6.2	2.7	3.9
pH of extract		12.2	7.8	9.2	8.8
Ag	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
As	mg/L	<0.001	<0.001	<0.001	<0.001
B	mg/L	<0.005	<0.005	<0.005	<0.005
Be	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Cd	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Co	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Cr	mg/L	0.0086	0.0088*	0.0007	0.0036
Cs	mg/L	0.0002	<0.0001	<0.0001	<0.0001
Cu	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Se	mg/L	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	0.0002	<0.0001	<0.0001	<0.0001
Th	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
U	mg/L	<0.0001	0.0001	<0.0001	0.0002
V	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Zn	mg/L	<0.001	<0.001	<0.001	0.002
N_NH_3	mg/L	0.02	<0.01	<0.01	<0.01
N_NO_x	mg/L	0.03	0.62	0.1	0.31
N_org	mg/L	0.1	<0.01	0.08	0.11
N_total	mg/L	0.15	0.62	0.18	0.42

4. LEACHATE RESULTS

Results for analysis of leachates from the passive and active systems for a comprehensive suite of physicochemical water quality parameters are presented in the following sections. Where relevant, results are compared with various human and environmental water quality indicators for waters that are listed in Table 5. These indicator values, which may be aesthetic limits, health limits or site investigation "trigger values", are sourced from the Australian Drinking Water Guidelines (ADWG), the ANZECC 2000 Water Quality Guidelines and the Government of Western Australia's Department of Health assessment levels for domestic non-potable groundwater use (DoH 2006). The other comparators used for this assessment are the minimum and maximum values for the background quality of Bingham Road Creek Wetland during the period of the trial. The minimum and maximum values are denoted by NFSIN (minimum) and NFSIN (maximum), respectively. Also results below detection limit assigned a value of 0 for clarity in viewing charts.

Table 5: Health and Environmental Water Quality Indicators

Parameter	Units	ADWG[1]	Livestock[2]	Irrigation[3]	Domestic non-potable groundwater use[7]	Aquatic Ecosystem Protection[4,5]		
						95%	90%	80%
pH		6.5 – 8.5[6]						
Aluminium	mg/L	(0.2)	5	5	2	0.055	0.08	0.15
Arsenic	mg/L	0.007	0.5	0.1	0.07			
Arsenic (III)	mg/L					0.024	0.094	0.36
Arsenic (V)	mg/L					0.013	0.042	0.14
Barium	mg/L	0.7			7			
Beryllium	mg/L			0.1				
Boron	mg/L	4	5	0.5	40	0.37	0.68	1.3
Cadmium	mg/L	0.002	0.01	0.01	0.02	0.0002	0.0004	0.0008
Chromium	mg/L		1	0.1				
Chromium (VI)	mg/L	0.05			0.5	0.001	0.006	0.04
Cobalt	mg/L		1	0.05				
Copper	mg/L	2 (1)	1	0.2	20	0.0014	0.0018	0.0025
Iron	mg/L	(0.3)		0.2	3			
Lead	mg/L	0.01	0.1	2	0.1	0.0034	0.0056	0.0094
Manganese	mg/L	0.5 (0.1)		0.2	5	1.9	2.5	3.6
Mercury	mg/L	0.001	0.002	0.002	0.01	0.0006	0.0019	0.0054
Molybdenum	mg/L	0.05	0.15	0.01	0.5			
Nickel	mg/L	0.02	1	0.2	0.2	0.011	0.013	0.017
Selenium	mg/L	0.01	0.02	0.02	0.1	0.011	0.018	0.034
Uranium	mg/L	0.02	0.2	0.01	0.2			
Vanadium	mg/L			0.1				
Zinc	mg/L	(3)	20	2	30	0.008	0.015	0.031
Ammonia as NH_3	mg/L	(0.5)			5	0.9	1.43	2.3
Nitrate as NO_3	mg/L	50	(400)		500	0.7	3.4	17
Nitrite as NO_2	mg/L	3	30		30			
Fluoride	mg/L	1.5	2	1	15			

Parameter	Units	ADWG[1]	Livestock[2]	Irrigation[3]	Domestic non-potable groundwater use[7]	Aquatic Ecosystem Protection[4,5]		
						95%	90%	80%
Sulphate as SO_4	mg/L	500 (250)	(1,000)		5,000			

Notes:

[1] ADWG human health limits are presented. Where available, aesthetic quality limits are presented in parentheses.

[2] Livestock drinking water quality limits relate to cattle (ANZECC 2000).

[3] Irrigation water quality limits are long term trigger values (up to 100 years) for irrigation of crops and pastures (ANZECC 2000). Higher values usually apply to some contaminants when used for irrigation over a shorter timeframe (up to 20 years).

[4] Trigger values for protection of freshwater aquatic ecosystems are taken from ANZECC 2000 for different levels of environmental value. 95% protection of species applies to slightly to moderately disturbed systems, such as that of existing rural land use within the Ellen Brook catchment. Lower levels of protection (80% to 90%) are considered relevant for areas impacted by industry and other potentially contaminating land use activities.

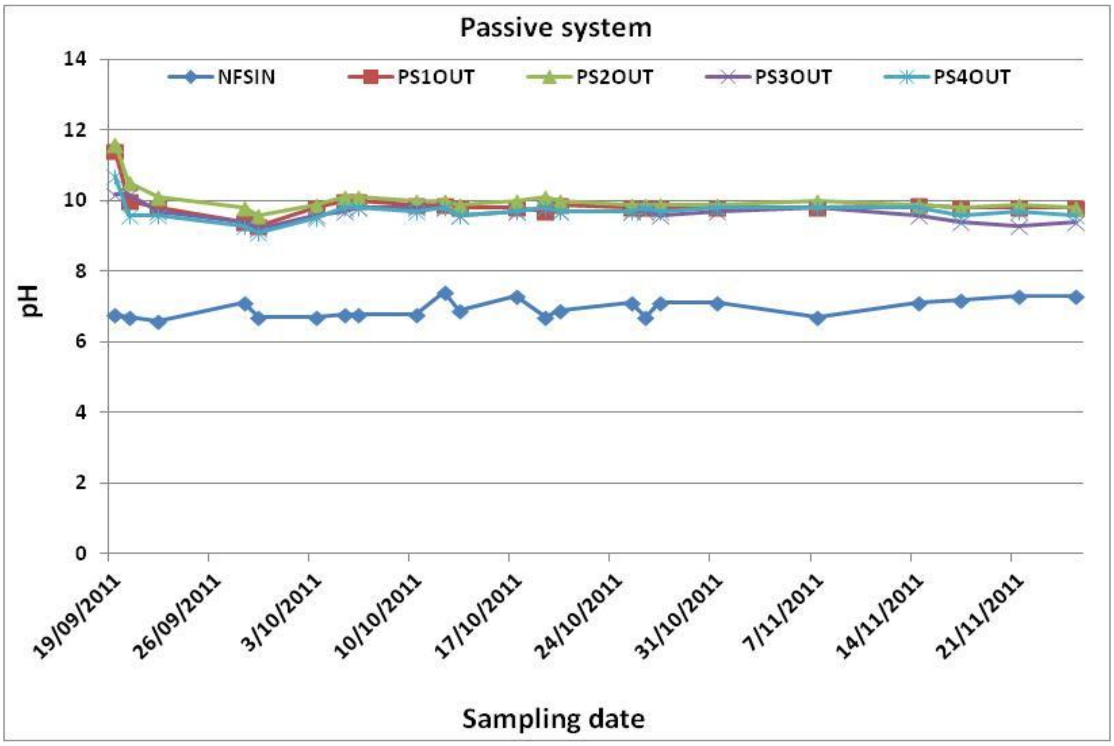
[5] Human, livestock and irrigation water quality indicators are usually “total” element concentrations, that is, the contaminant may be present in both soluble and particulate forms. Freshwater ecosystem protection “trigger values” refer to concentrations of soluble (filtered) species only.

[6] Aesthetic value.

[7] DoH has developed generic assessment criteria (DoH, 2006) to protect the public who may be using, or may be exposed to, groundwater containing chemical residues in a non-potable setting. The DoH (2006) guideline value is generally a factor of 10 times the corresponding ADWG Health value.

4.1 PH

Chart 4: Passive System, pH

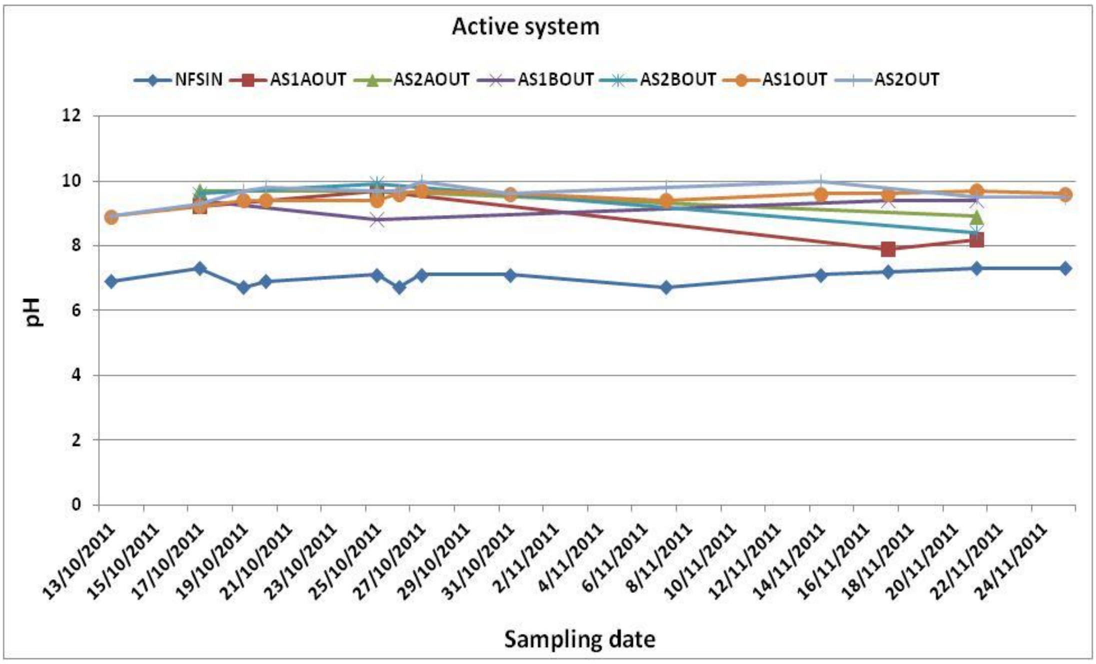


Comparators:

NFSIN (minimum)	6.6
NFSIN (maximum)	7.4
ADWG	6.5 to 8.5

Trends: pH values were initially as high as 11.5, then stabilized at approximately pH 10 after several days. Approximately three pH units higher than background.

Chart 5: Active System, pH



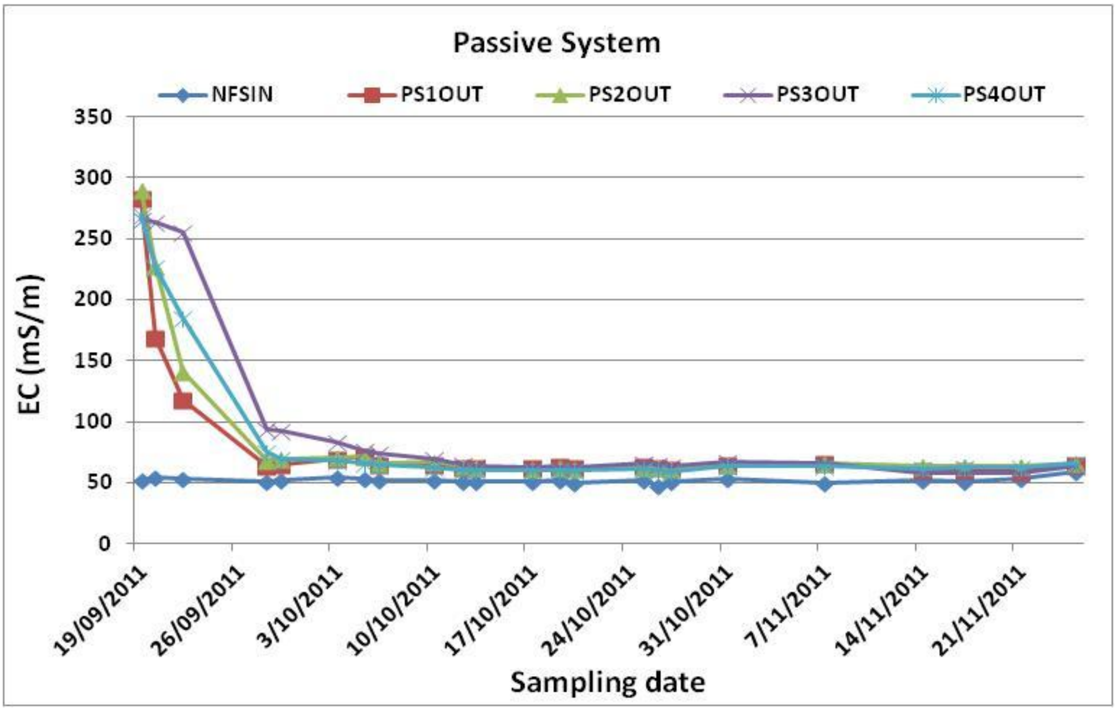
Comparators:

NFSIN (minimum)	6.6
NFSIN (maximum)	7.4
ADWG	6.5 to 8.5

Trends: pH values were significantly lower than the passive system, rarely exceeding 10.0. Treated water from the final cell had pH values of approximately 9.0-9.5 by the end of the trial, more than one and half pH unit above background. Some other cells (AS1AOUT and AS2BOUT) showed pH ≈ 8.0 at the end of trial which is less than one pH unit above background.

4.2 ELECTRICAL CONDUCTIVITY

Chart 6: Passive System, EC

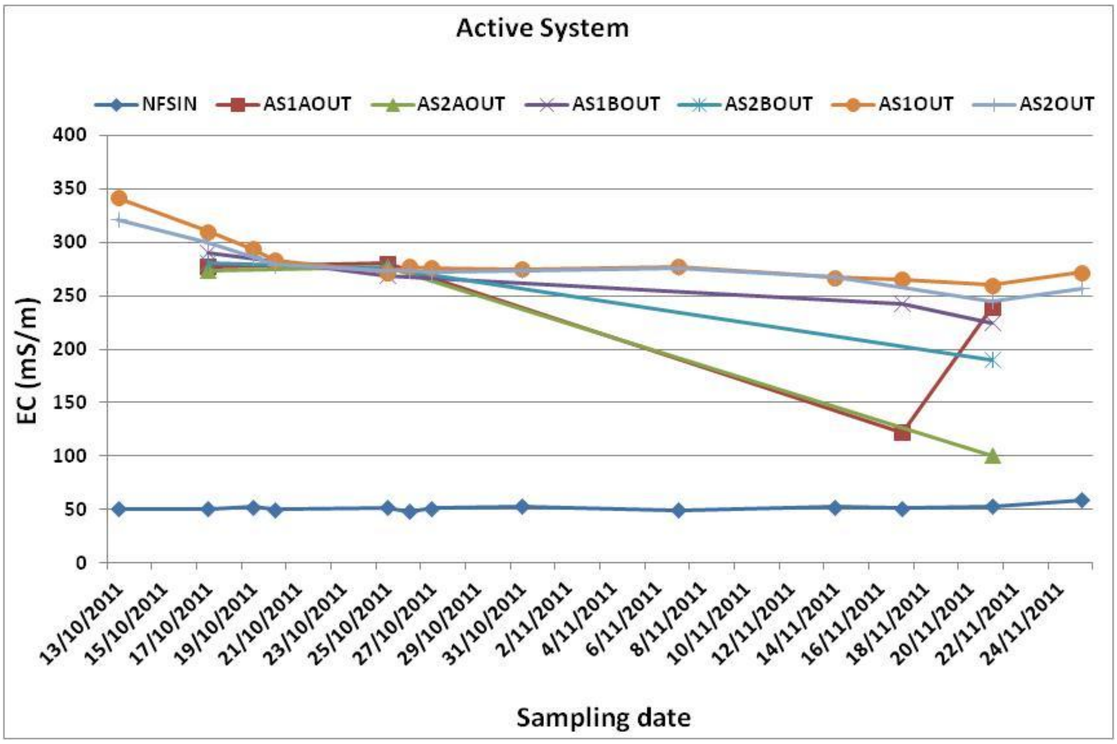


Comparators:

NFSIN (minimum)	48
NFSIN (maximum)	58.7

Trends: Initial EC levels approximately seven times higher than background, then decreased to just above background after approximately two weeks.

Chart 7: Active System, EC



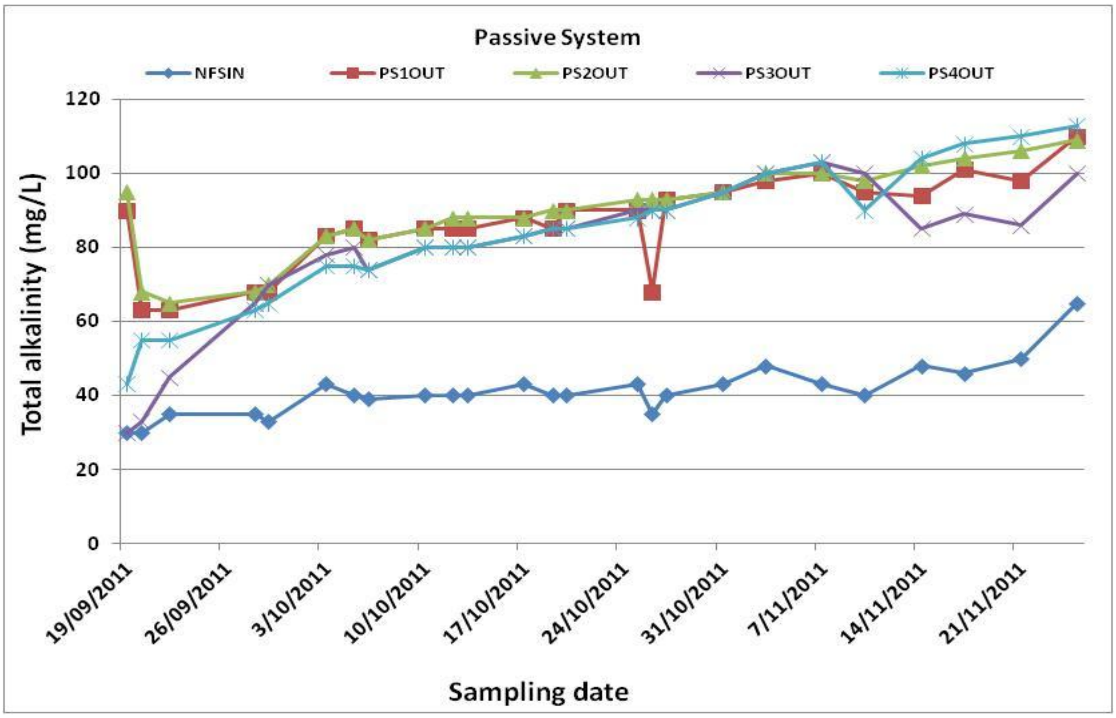
Comparators:

NFSIN (minimum)	48 milliSiemens per centimetre
NFSIN (maximum)	58.7 milliSiemens per centimetre

Trends: Initial EC levels were similar to those for the passive system, but decreased much more slowly throughout the period of the trial.

4.3 TOTAL ALKALINITY

Chart 8: Passive System, Alkalinity

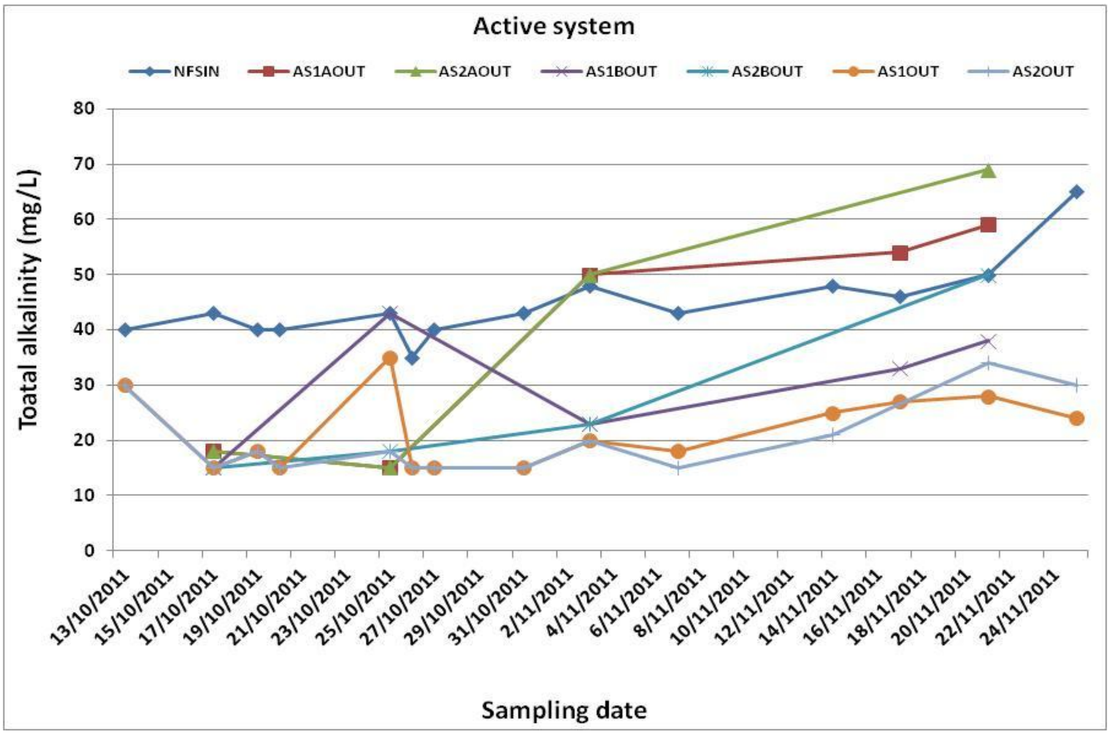


Comparators:

NFSIN (minimum)	30 milligrams per litre
NFSIN (maximum)	65 milligrams per litre

Trends: Constant increasing trend to levels more than twice as high as background.

Chart 9: Active System, Alkalinity



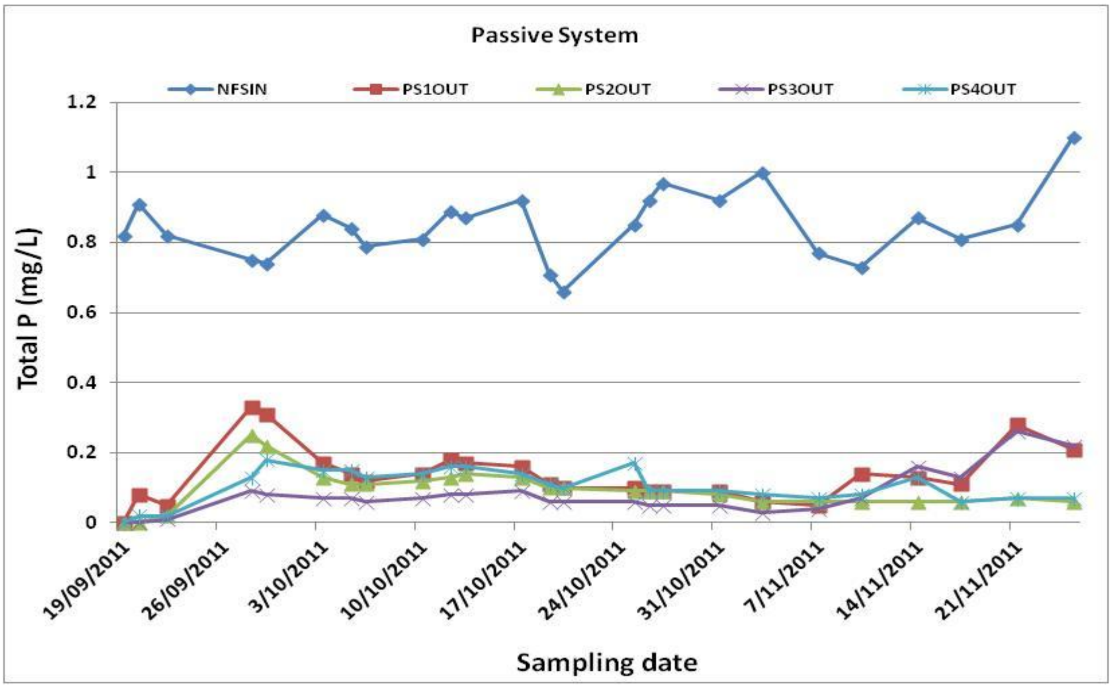
Comparators:

NFSIN (minimum)	30 milligrams per litre
NFSIN (maximum)	65 milligrams per litre

Trends: Initial values were less than that of the inlet water, then increased slowly over time. Final outlet alkalinity values were only slightly higher than the inlet values.

4.4 TOTAL PHOSPHORUS

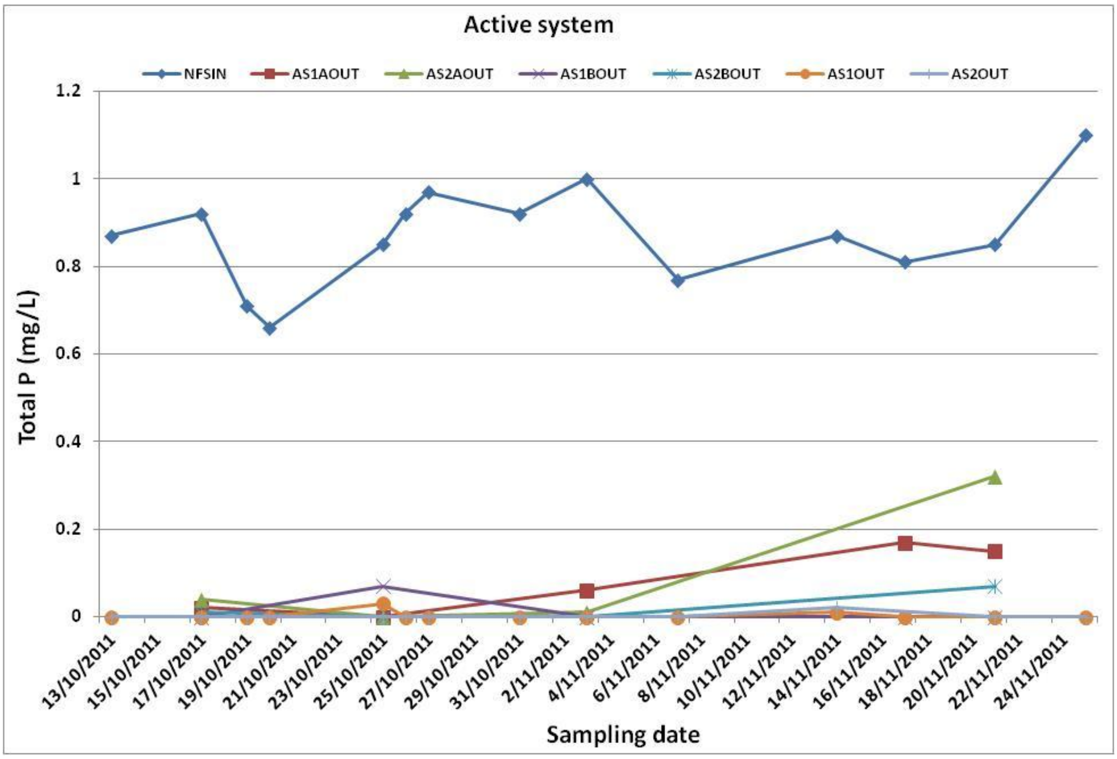
Chart 10: Passive System, Total Phosphorus



Comparators:
NFSIN (minimum) 0.66 milligrams per litre
NFSIN (maximum) 1.1 milligrams per litre

Trends: Removal of 80 to 90% of total phosphorus over the entire monitoring period.

Chart 11: Active System, Total Phosphorus



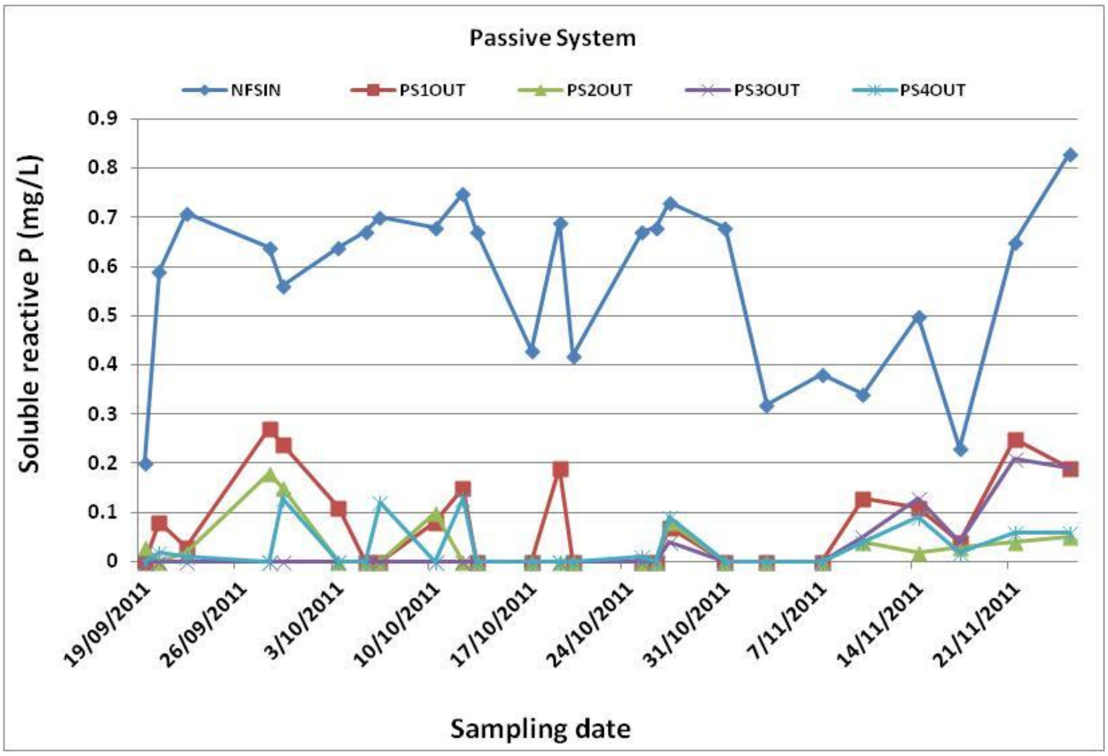
Comparators:

NFSIN (minimum) 0.66 milligrams per litre
NFSIN (maximum) 1.1 milligrams per litre

Trends: Removal of 80 to 90% of total phosphorus for most of entire monitoring period, with increasing concentrations of total phosphorus in the 1st and 2nd column water towards the end. The total phosphorus concentration in fully treated water decreased towards the end.

4.5 SOLUBLE REACTIVE PHOSPHORUS

Chart 12: Passive System, Soluble Reactive Phosphorus

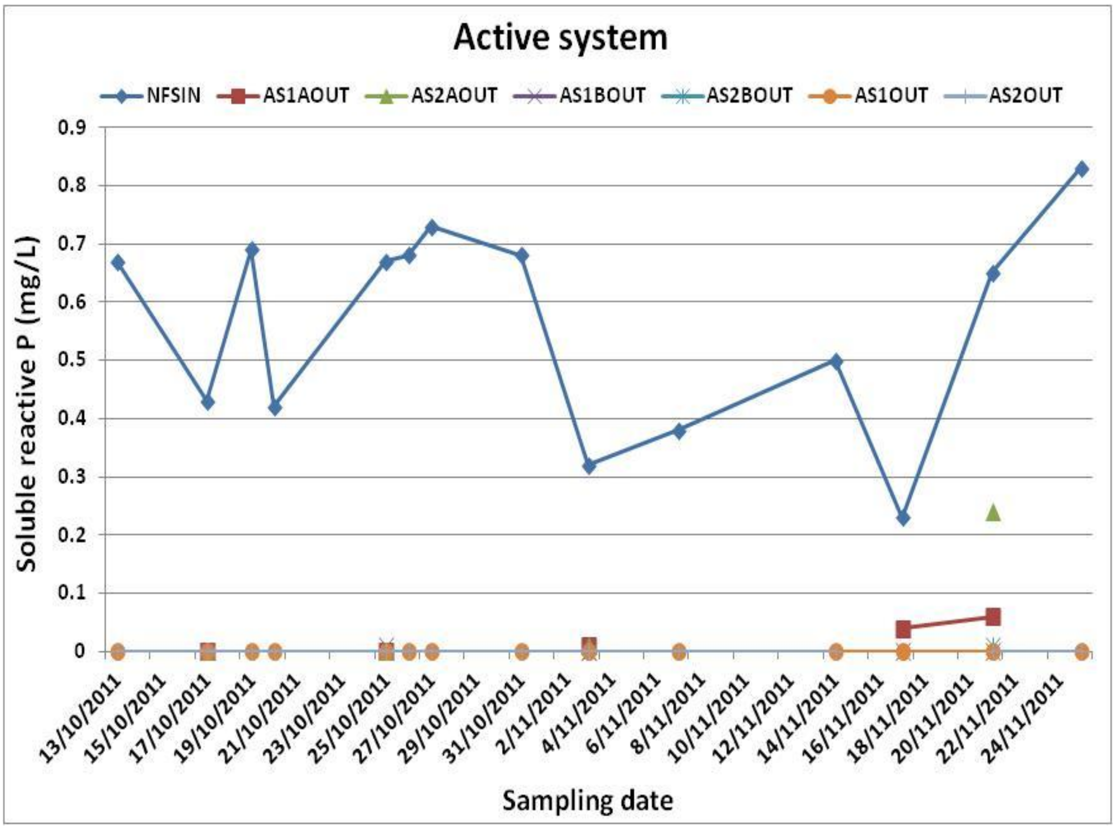


Comparators:

NFSIN (minimum) 0.2 milligrams per litre
NFSIN (maximum) 0.83 milligrams per litre

Trends: Reflects total phosphorus trends, with good removal efficiencies; PS1 least effective.

Chart 13: Active System, Soluble Reactive Phosphorus



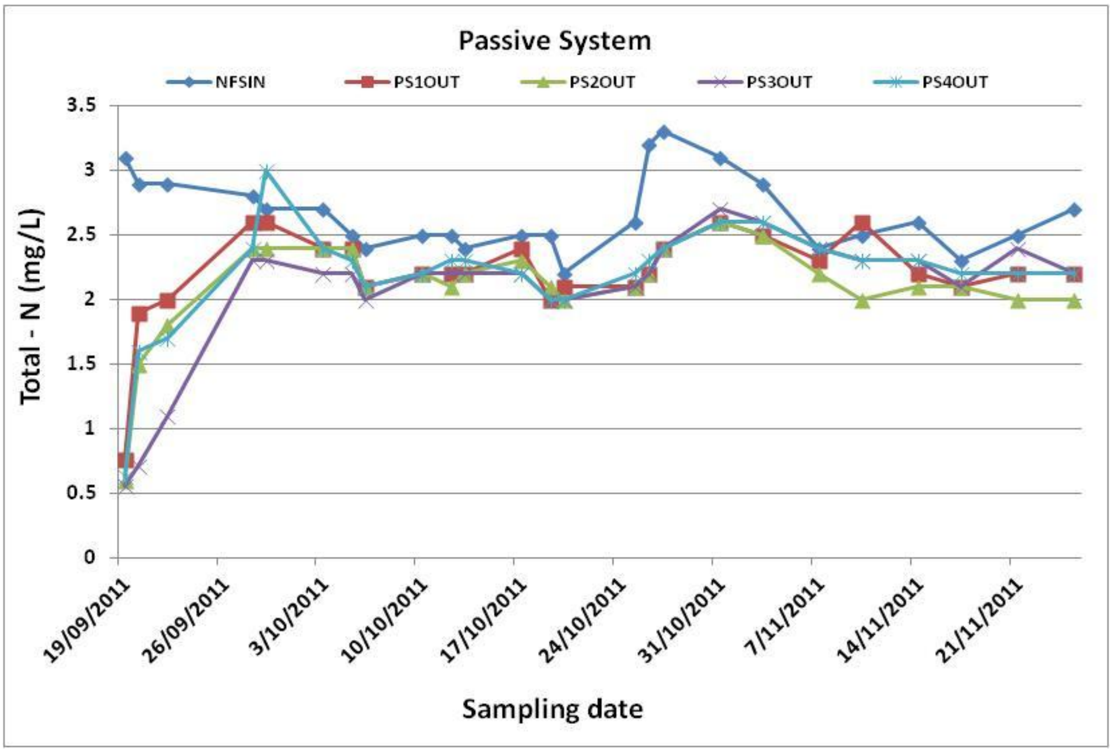
Comparators:

NFSIN (minimum)	0.23 milligrams per litre
NFSIN (maximum)	0.83 milligrams per litre

Trends: Reflects total phosphorus trends, with good removal efficiencies.

4.6 TOTAL NITROGEN

Chart 14: Passive System, Total Nitrogen

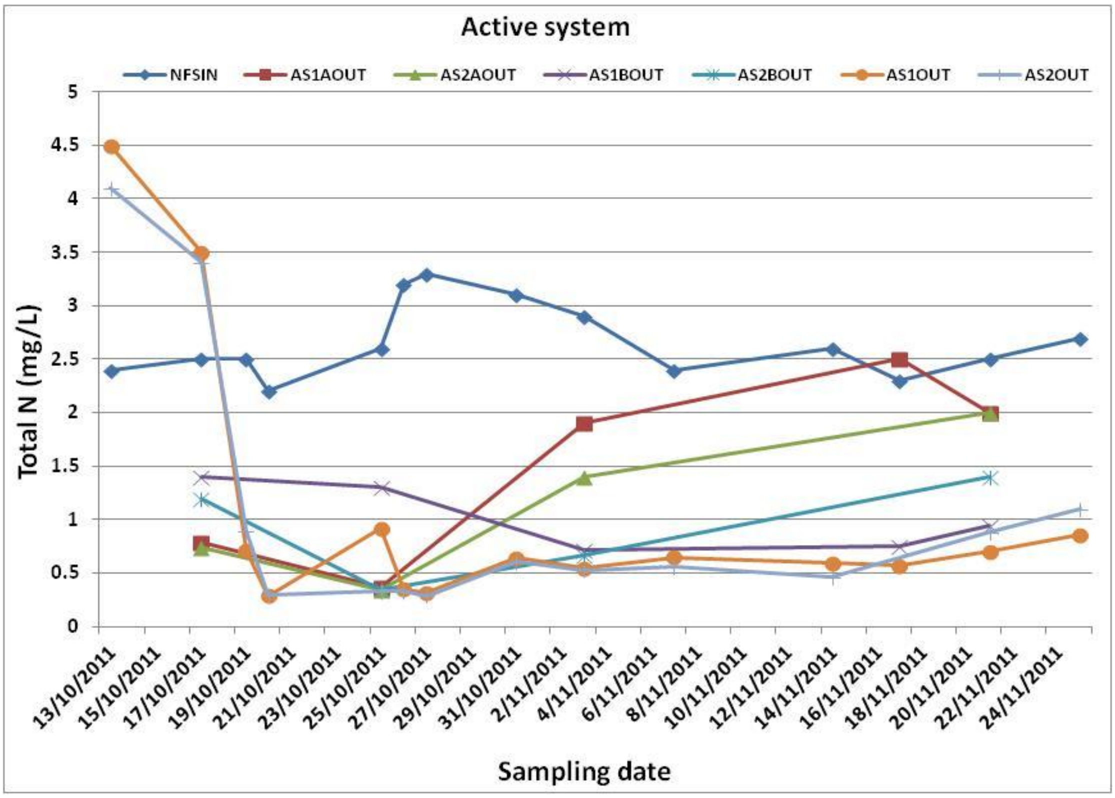


Comparators:

NFSIN (minimum)	2.0 milligrams per litre
NFSIN (maximum)	3.1 milligrams per litre

Trends: High removal efficiencies for the first 4 days, then efficiency decreased to approximately 20% removal.

Chart 15: Active System, Total Nitrogen



Comparators:

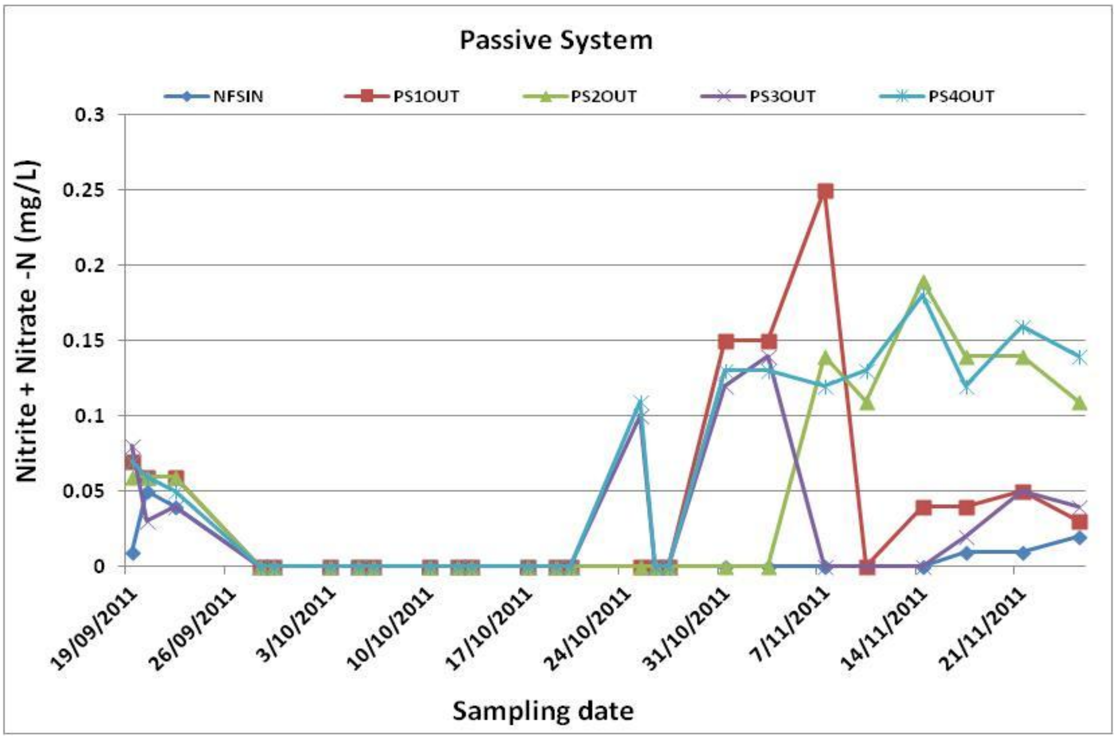
NFSIN (minimum) 2.2 milligrams per litre

NFSIN (maximum) 3.3 milligrams per litre

Trends: Initially released nitrogen, then high nitrogen removal efficiency (approximately 80%) after the first week.

4.7 NITRATE / NITRITE (NO_X) NITROGEN

Chart 16: Passive System, Nitrate / Nitrite (NO_x) Nitrogen

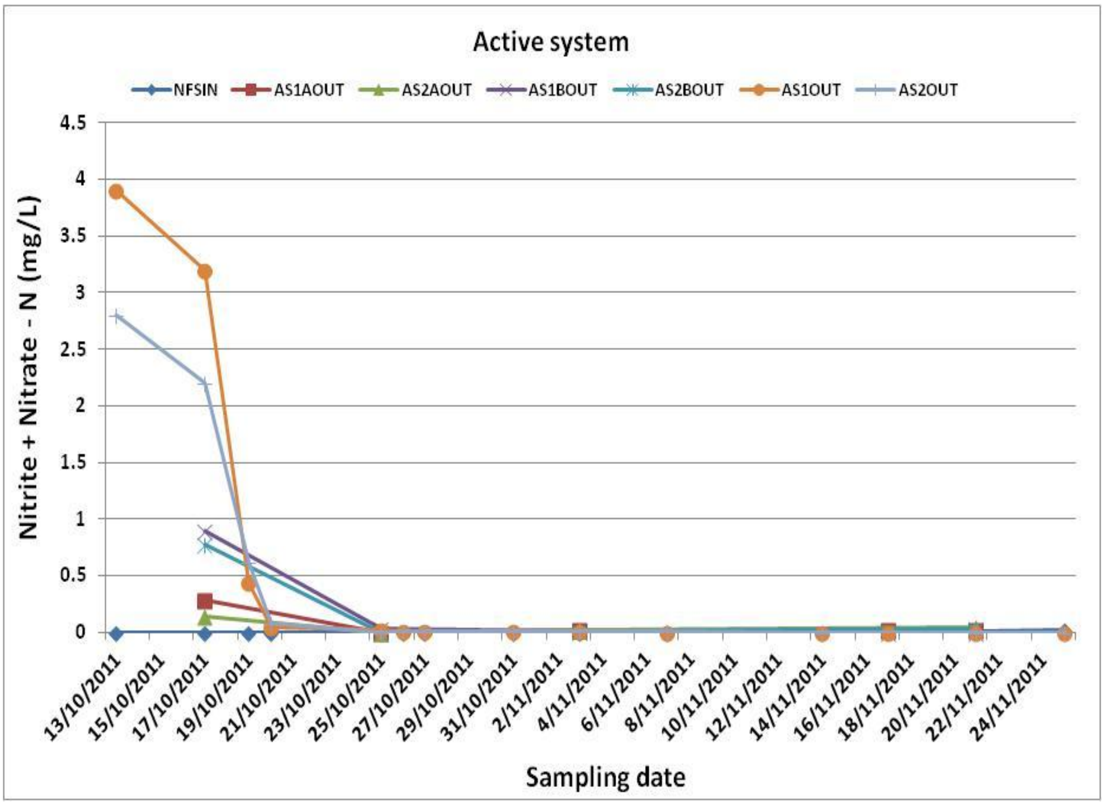


Comparators:

NFSIN (minimum)	<0.1 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
AEP (95%)	0.7 milligrams per litre
ADWG	50 milligrams per litre
Livestock	400 milligrams per litre

Trends: Minimal differences between inlet and outlet concentrations (both very low) for several weeks, followed by slow release of nitrate / nitrite nitrogen.

Chart 17: Active System, Nitrate / Nitrite (NO_x) Nitrogen



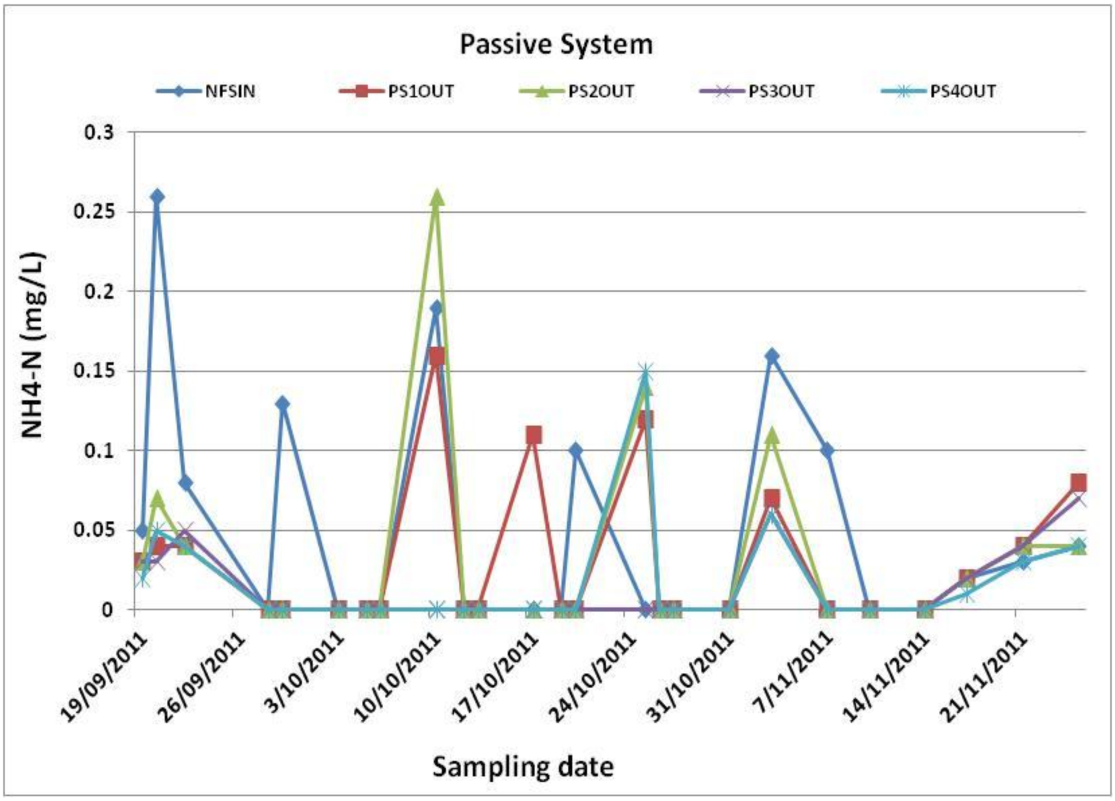
Comparators:

NFSIN (minimum)	<0.1 milligrams per litre
NFSIN (maximum)	0.02 milligrams per litre
AEP (95%)	0.7 milligrams per litre
ADWG	50 milligrams per litre
Livestock	400 milligrams per litre

Trends: Initial release of nitrate / nitrite nitrogen (up to 4 milligrams per litre) during the first week, followed by very low inlet and outlet concentrations. The initial release is consistent with the presence of low concentrations of nitrate / nitrite nitrogen present in NUA as discussed in Section 3.3.

4.8 AMMONIUM NITROGEN

Chart 18: Passive System, Ammonium Nitrogen

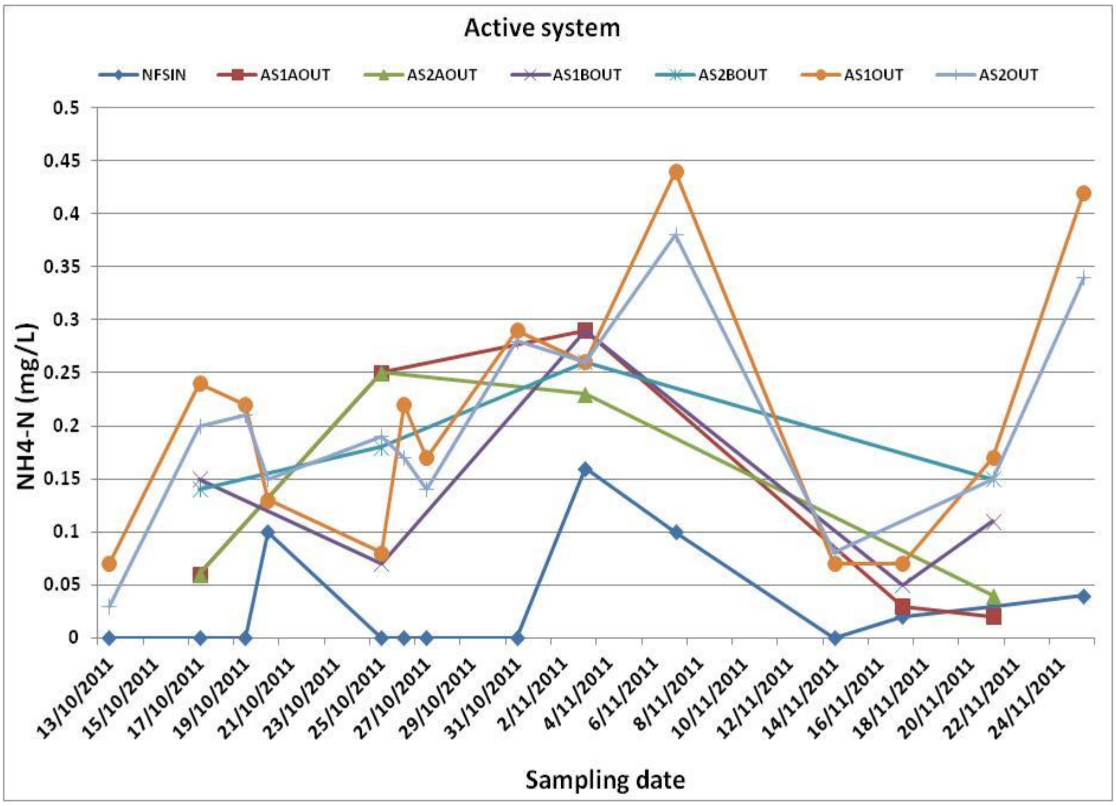


Comparators:

NFSIN (minimum)	<0.1 milligrams per litre
NFSIN (maximum)	0.26 milligrams per litre
AEP (95%)	0.9 milligrams per litre
ADWG	0.5 milligrams per litre

Trends: Highly variable; related to background quality. Removal efficiency decreases over time.

Chart 19: Active System, Ammonium Nitrogen



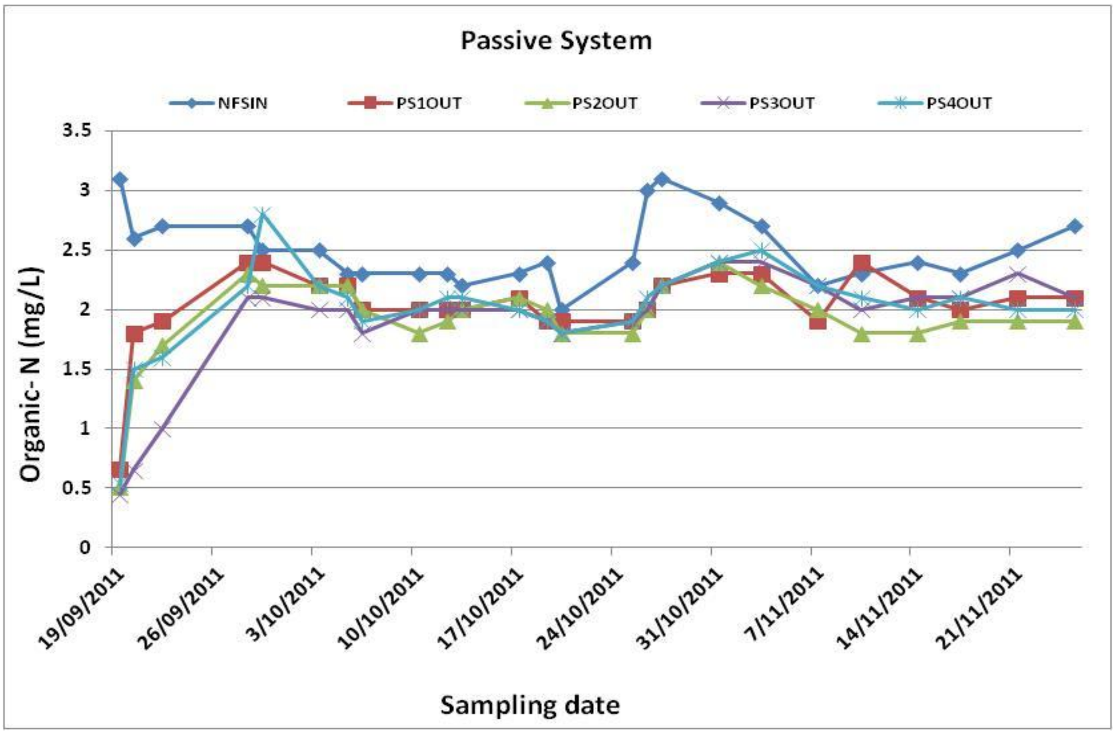
Comparators:

NFSIN (minimum)	<0.1 milligrams per litre
NFSIN (maximum)	0.16 milligrams per litre
AEP (95%)	0.9 milligrams per litre
ADWG	0.5 milligrams per litre

Trends: Highly variable, but typically releases 0.2 milligrams per litre of ammonium nitrogen.

4.9 ORGANIC NITROGEN

Chart 20: Passive System, Organic Nitrogen

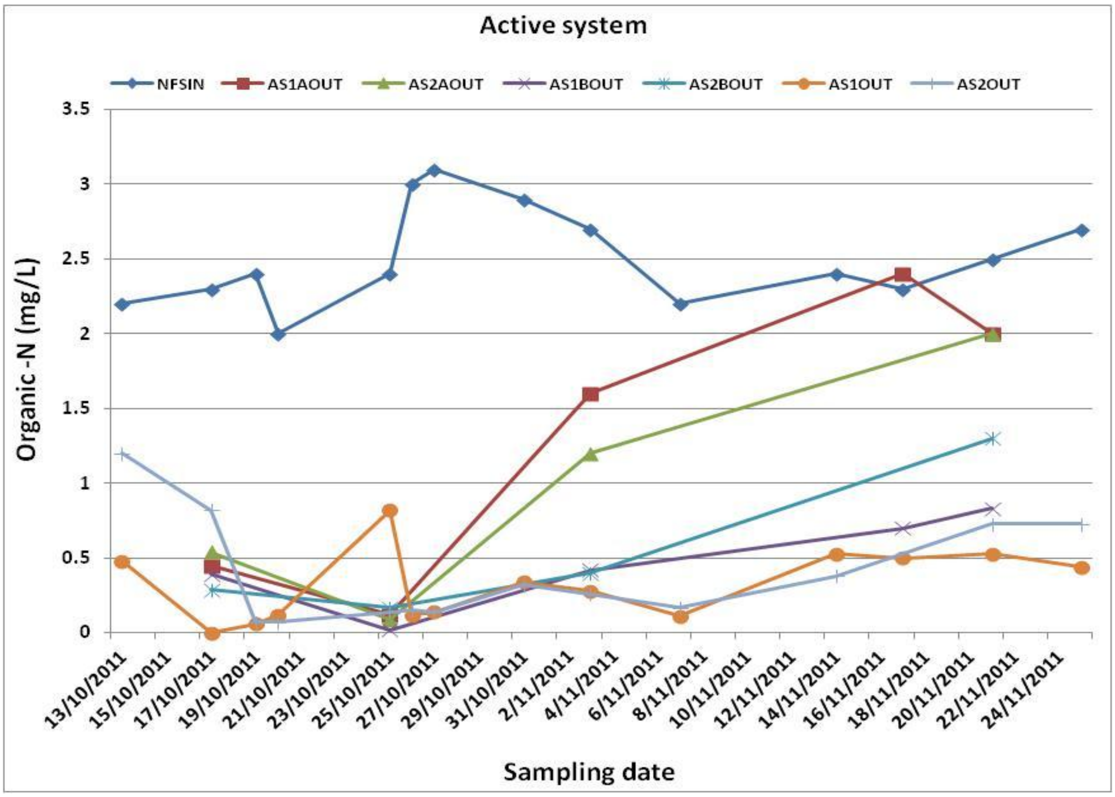


Comparators:

NFSIN (minimum)	2 milligrams per litre
NFSIN (maximum)	3.1 milligrams per litre

Trends: Very similar to total nitrogen trends. High removal efficiency for the first 4 days, then decreases to approximately 20% long term removal.

Chart 21: Active System, Organic Nitrogen



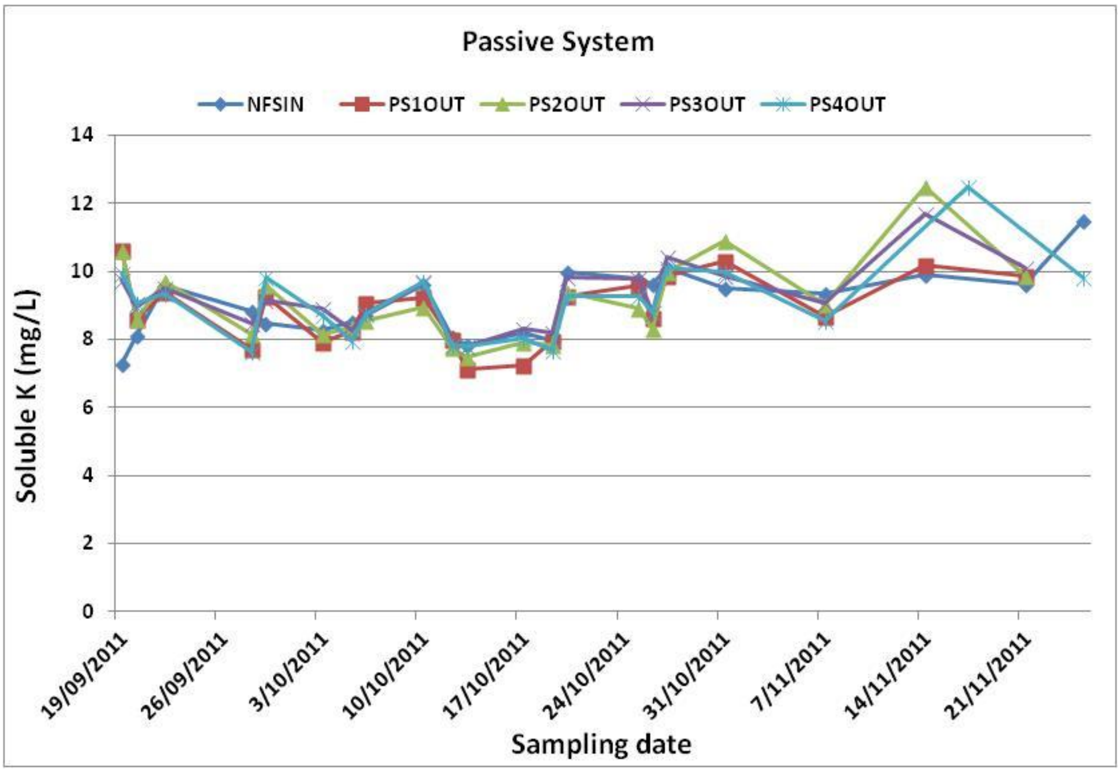
Comparators:

NFSIN (minimum)	2 milligrams per litre
NFSIN (maximum)	3.1 milligrams per litre

Trends: Very similar to total nitrogen trends, although there is no initial release of organic nitrogen.

4.10 POTASSIUM

Chart 22: Passive System, Soluble Potassium

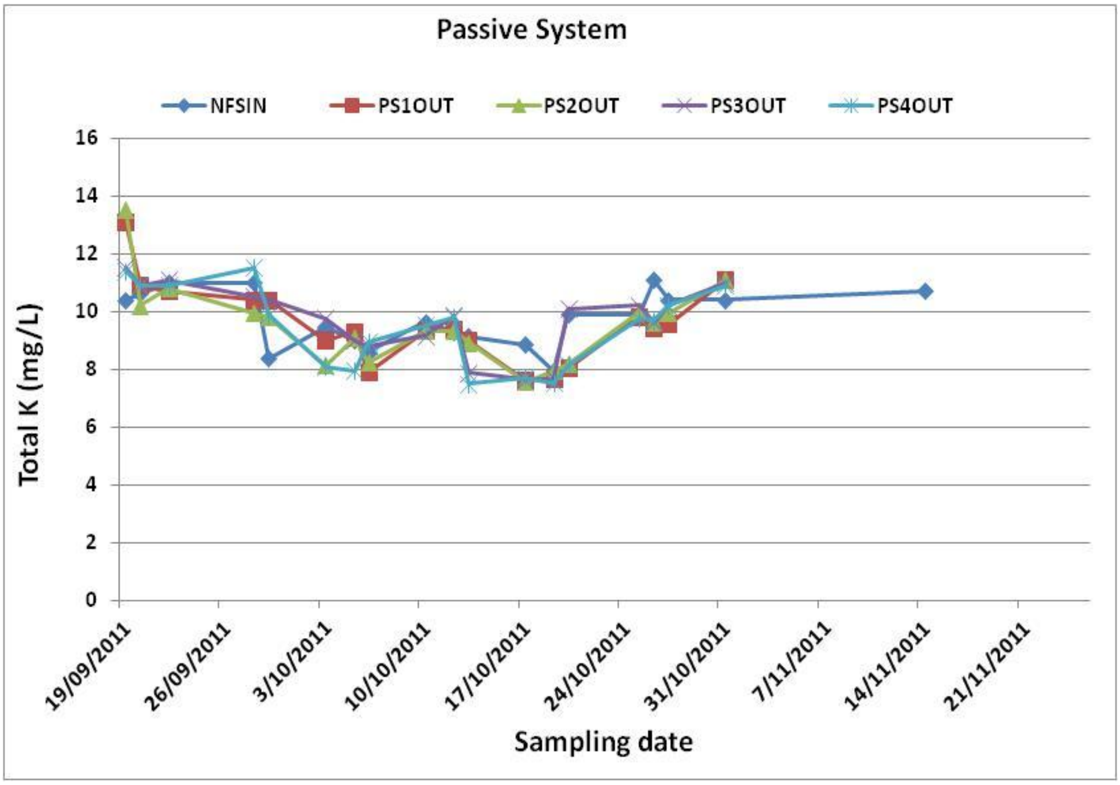


Comparators:

NFSIN (minimum)	7.8 milligrams per litre
NFSIN (maximum)	11.5 milligrams per litre

Trends: Initial release of potassium, followed by release of very small amounts of potassium.

Chart 23: Passive System, Total Potassium

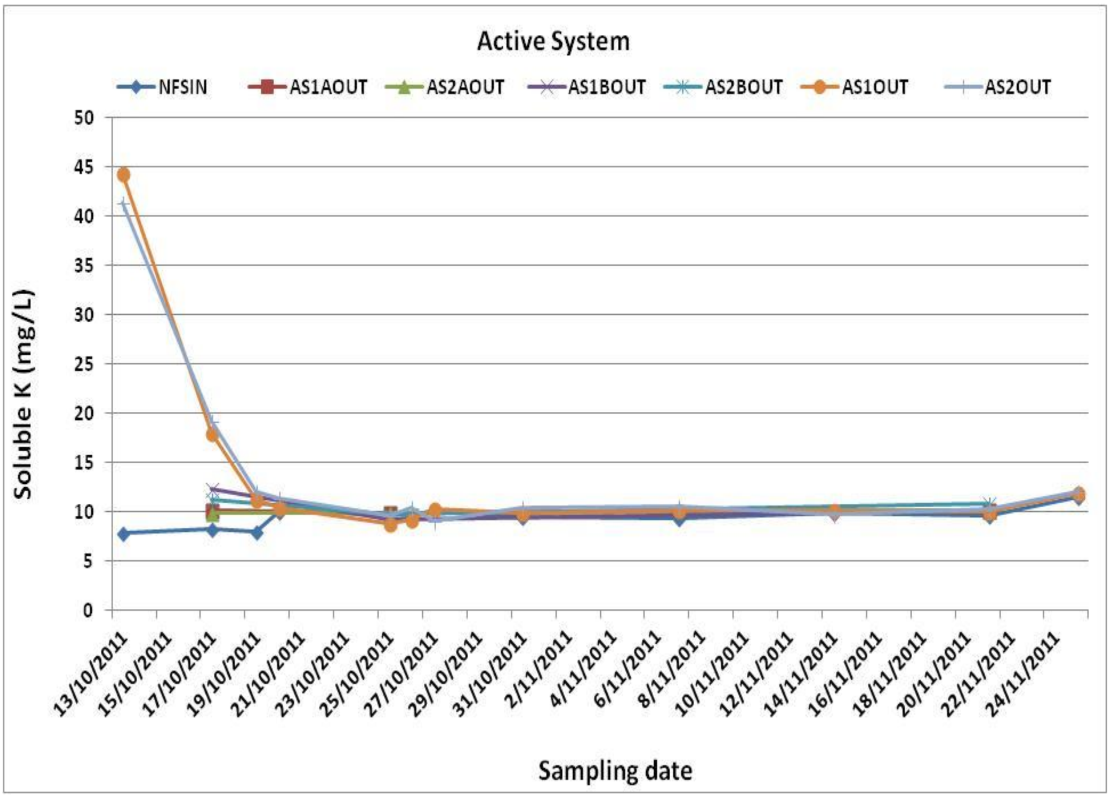


Comparators:

NFSIN (minimum)	7.9 milligrams per litre
NFSIN (maximum)	11.1 milligrams per litre

Trends: Almost identical to soluble potassium.

Chart 24: Active System, Soluble Potassium

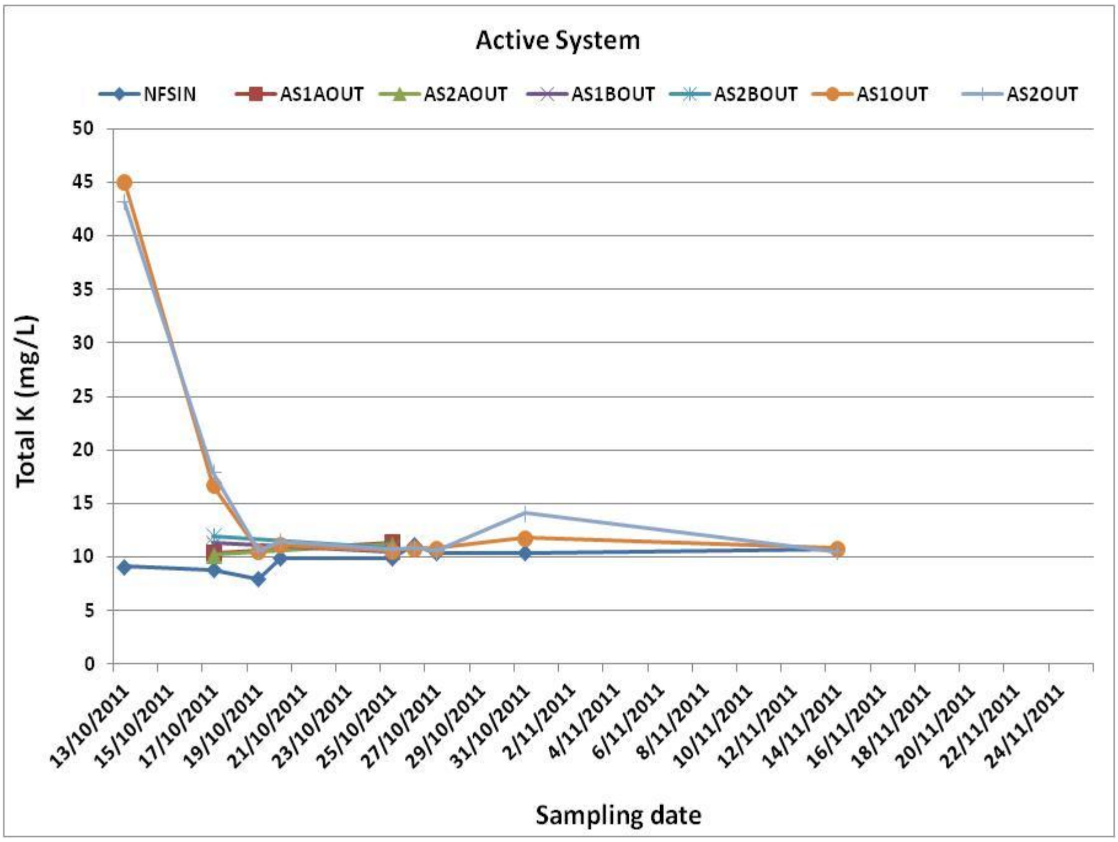


Comparators:

NFSIN (minimum)	7.8 milligrams per litre
NFSIN (maximum)	11.5 milligrams per litre

Trends: Initial release of up to approximately 35 milligrams per litre for the first week, followed by almost identical inlet and outlet concentrations.

Chart 25: Active System, Total Potassium



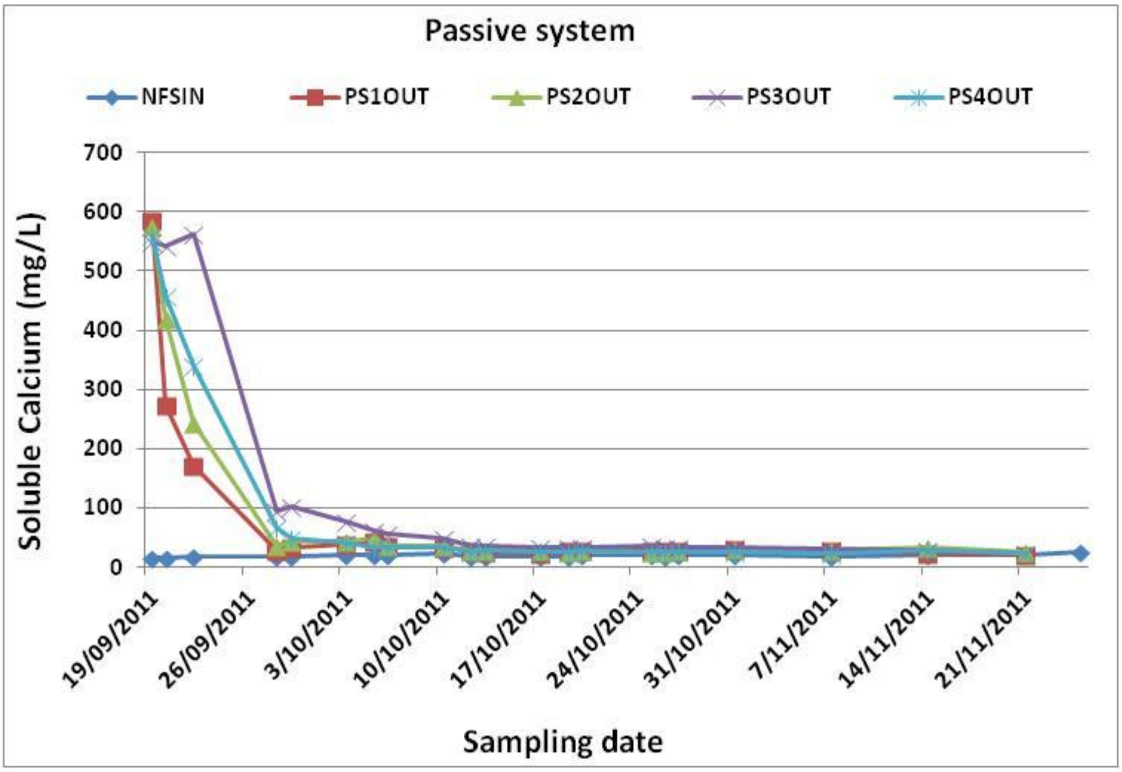
Comparators:

NFSIN (minimum)	7.9 milligrams per litre
NFSIN (maximum)	11.1 milligrams per litre

Trends: Almost identical to soluble potassium.

4.11 CALCIUM

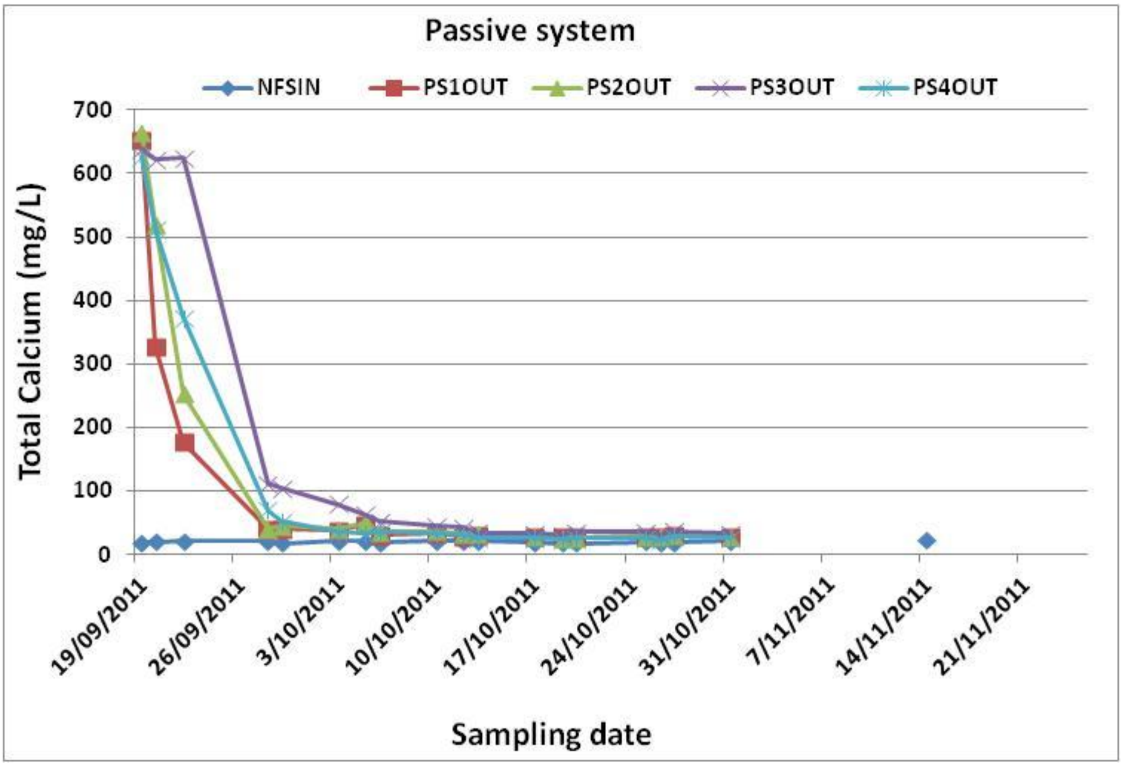
Chart 26: Passive System, Soluble Calcium



Comparators:
NFSIN (minimum) 15.5 milligrams per litre
NFSIN (maximum) 27.2 milligrams per litre

Trends: Initial release of soluble calcium for the first week, followed by release of very small amounts of calcium. Initial concentrations of up to 600 milligrams per litre are similar to that expected by dissolution of gypsum.

Chart 27: Passive System, Total Calcium

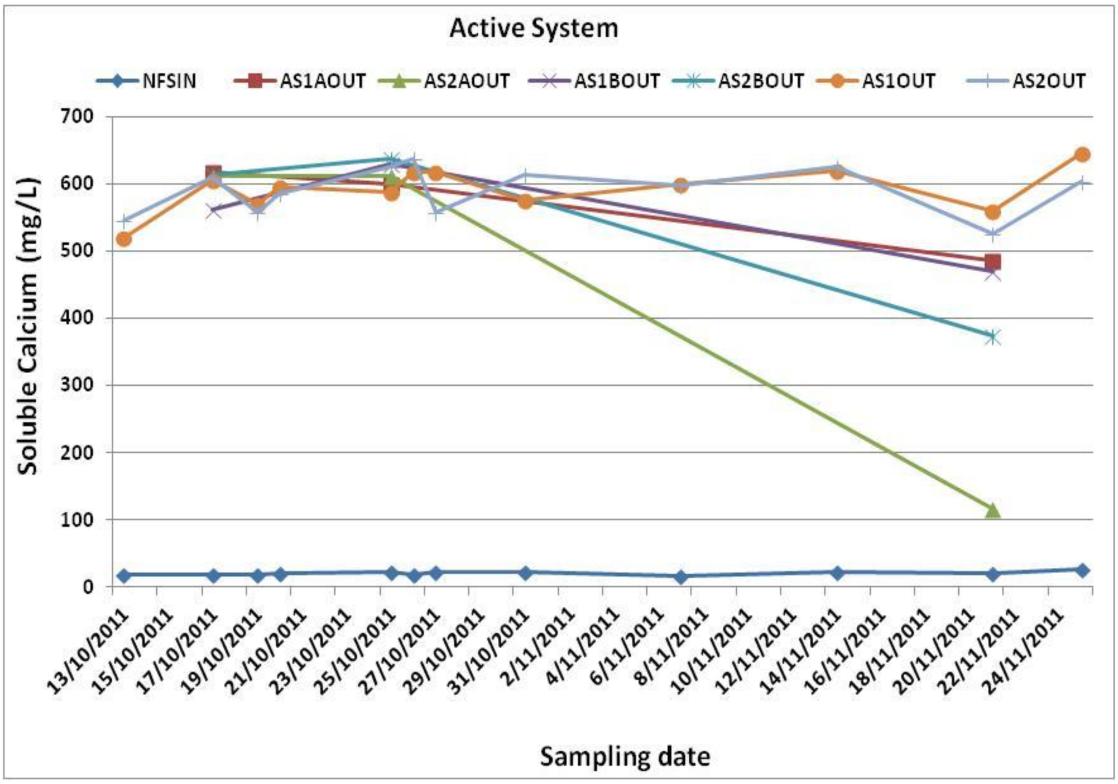


Comparators:

NFSIN (minimum)	18 milligrams per litre
NFSIN (maximum)	23.8 milligrams per litre

Trends: Almost identical to soluble calcium.

Chart 28: Active System, Soluble Calcium

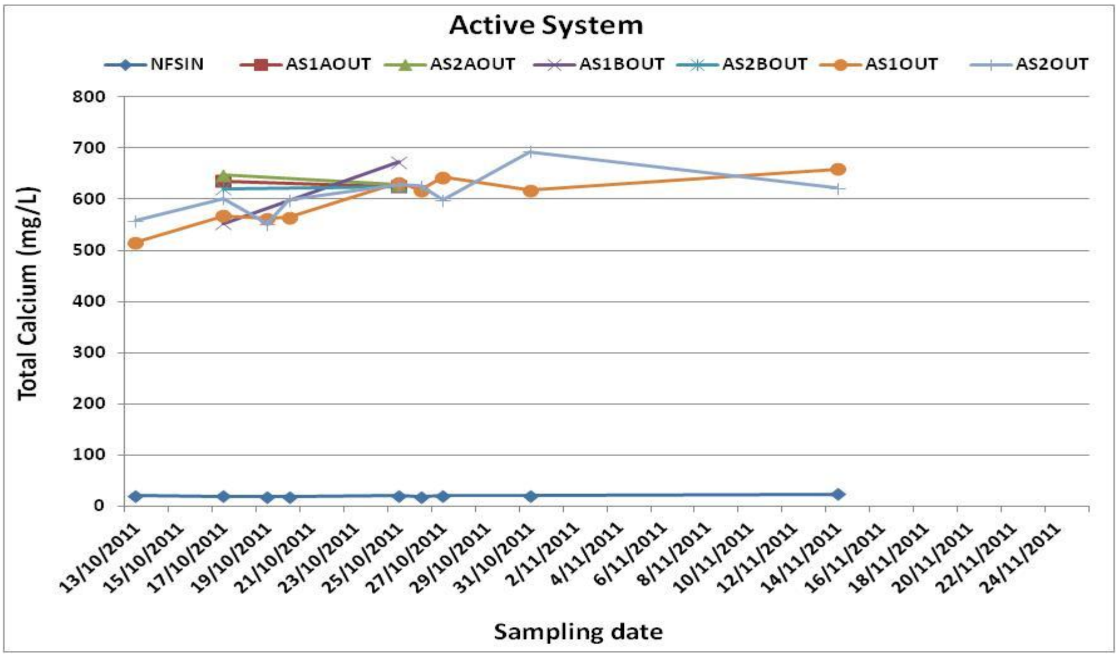


Comparators:

NFSIN (minimum)	15.5 milligrams per litre
NFSIN (maximum)	27.2 milligrams per litre

Trends: Final outlet concentration maintained at approximately 600 milligrams per litre, corresponding to the solubility of gypsum.

Chart 29: Active System, Total Calcium



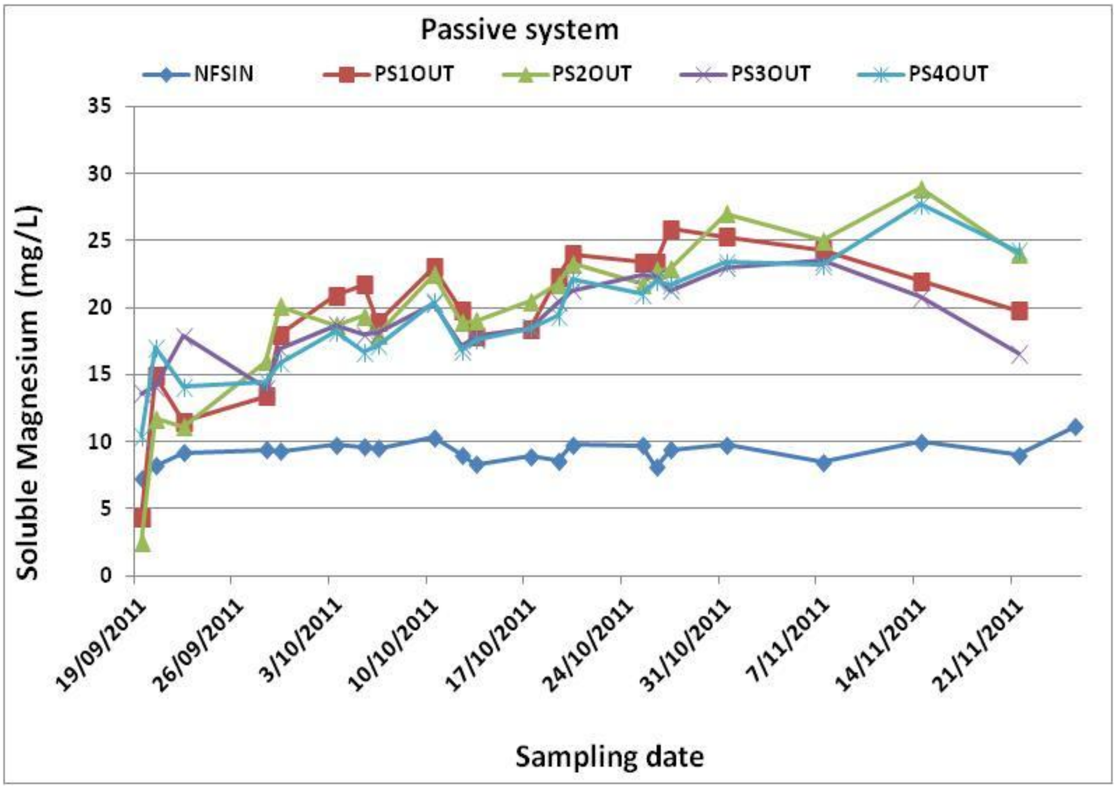
Comparators:

NFSIN (minimum)	17.9 milligrams per litre
NFSIN (maximum)	23.8 milligrams per litre

Trends: Almost identical to soluble calcium.

4.12 MAGNESIUM

Chart 30: Passive System, Soluble Magnesium

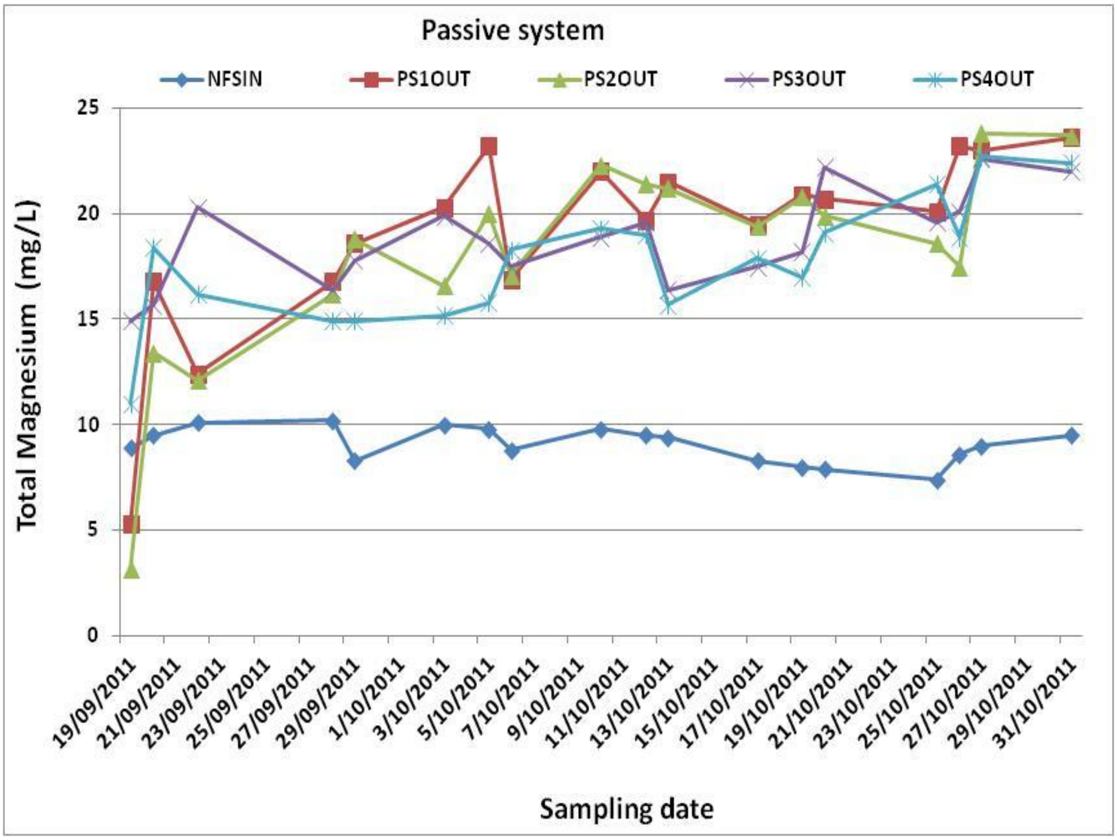


Comparators:

NFSIN (minimum)	7.3 milligrams per litre
NFSIN (maximum)	11.1 milligrams per litre

Trends: Initial decrease of soluble magnesium in PS1 and PS2 systems, followed by release of increasing concentrations of soluble magnesium for all systems.

Chart 31: Passive System, Total Magnesium

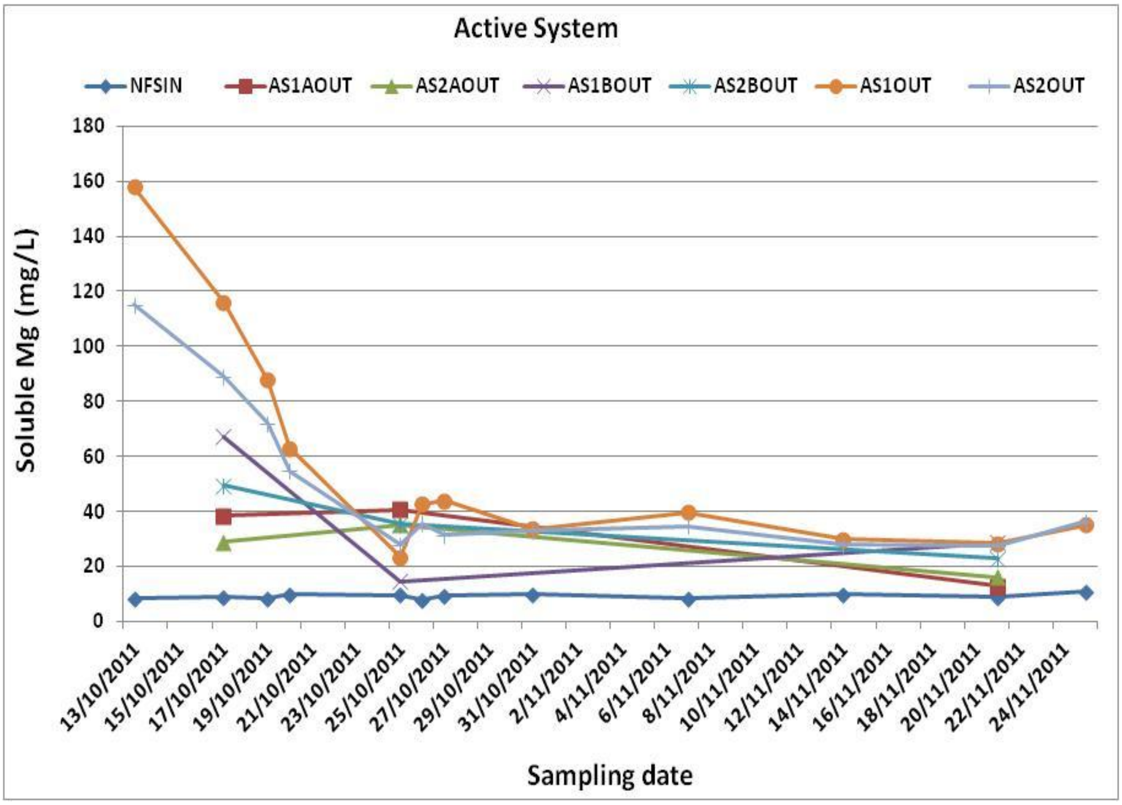


Comparators:

NFSIN (minimum)	7.4 milligrams per litre
NFSIN (maximum)	10.4 milligrams per litre

Trends: Similar to soluble magnesium.

Chart 32: Active System, Soluble Magnesium

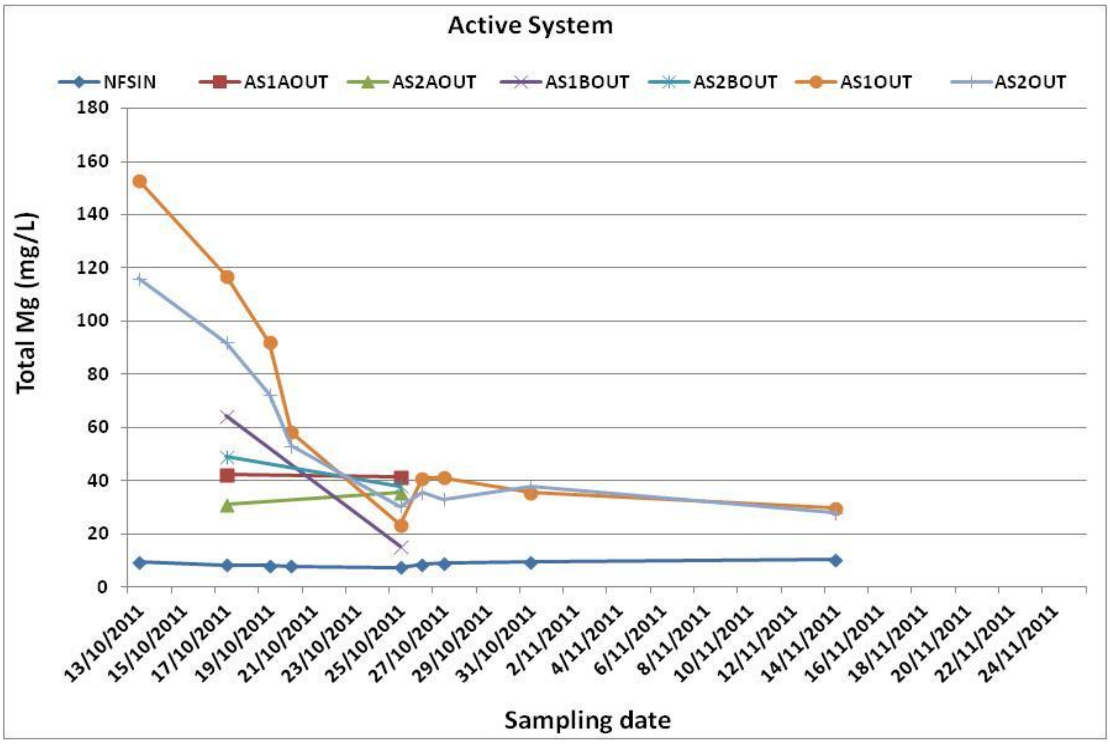


Comparators:

NFSIN (minimum)	7.3 milligrams per litre
NFSIN (maximum)	11.1 milligrams per litre

Trends: Initial release of magnesium in concentrations up to 150 milligrams per litre higher than background, following by a decreasing trend. Outlet concentrations at the end of the monitoring period were about 20 milligrams per litre higher than inlet concentrations.

Chart 33: Active System, Total Magnesium



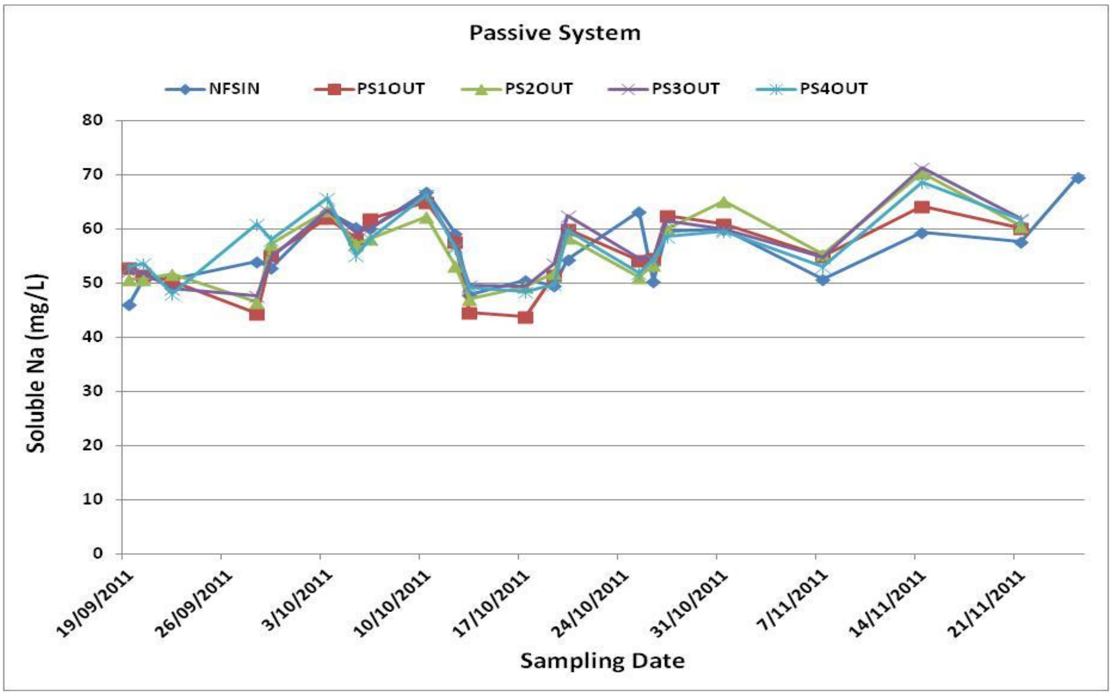
Comparators:

NFSIN (minimum)	7.4 milligrams per litre
NFSIN (maximum)	10.4 milligrams per litre

Trends: Similar to soluble magnesium.

4.13 SODIUM

Chart 34: Passive System, Soluble Sodium

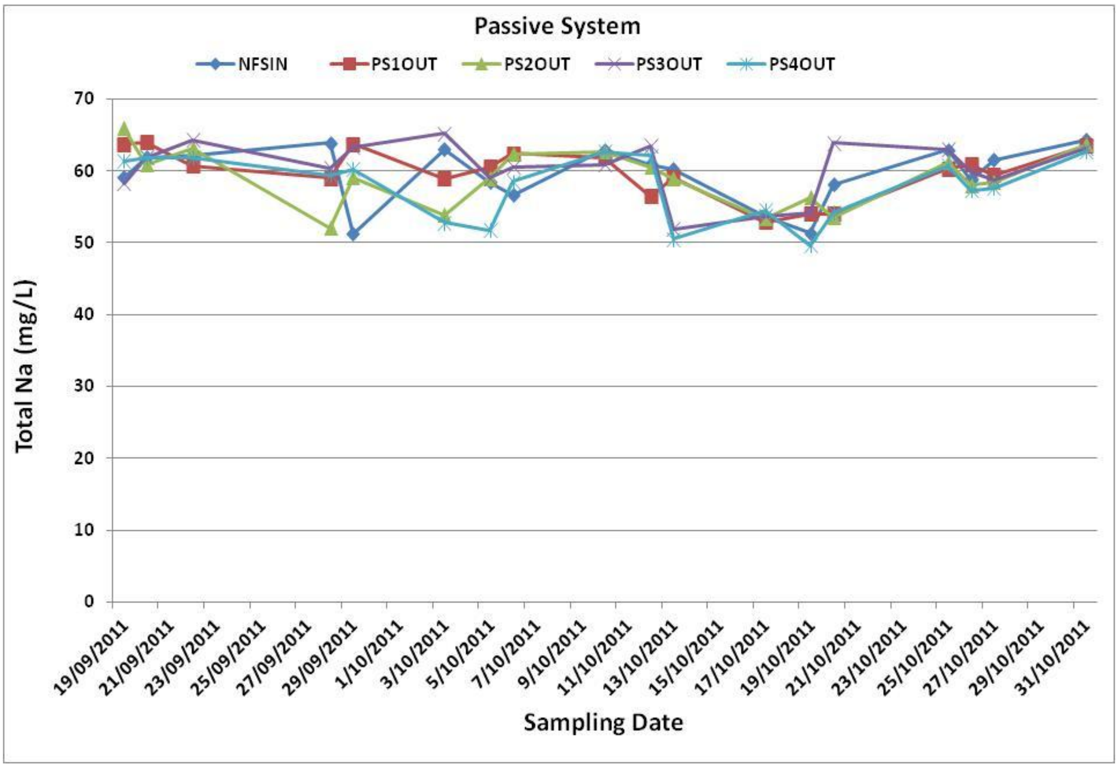


Comparators:

NFSIN (minimum) 46.1 milligrams per litre
NFSIN (maximum) 69.5 milligrams per litre

Trends: No significant difference between inlet and outlet concentrations.

Chart 35: Passive System, Total Sodium

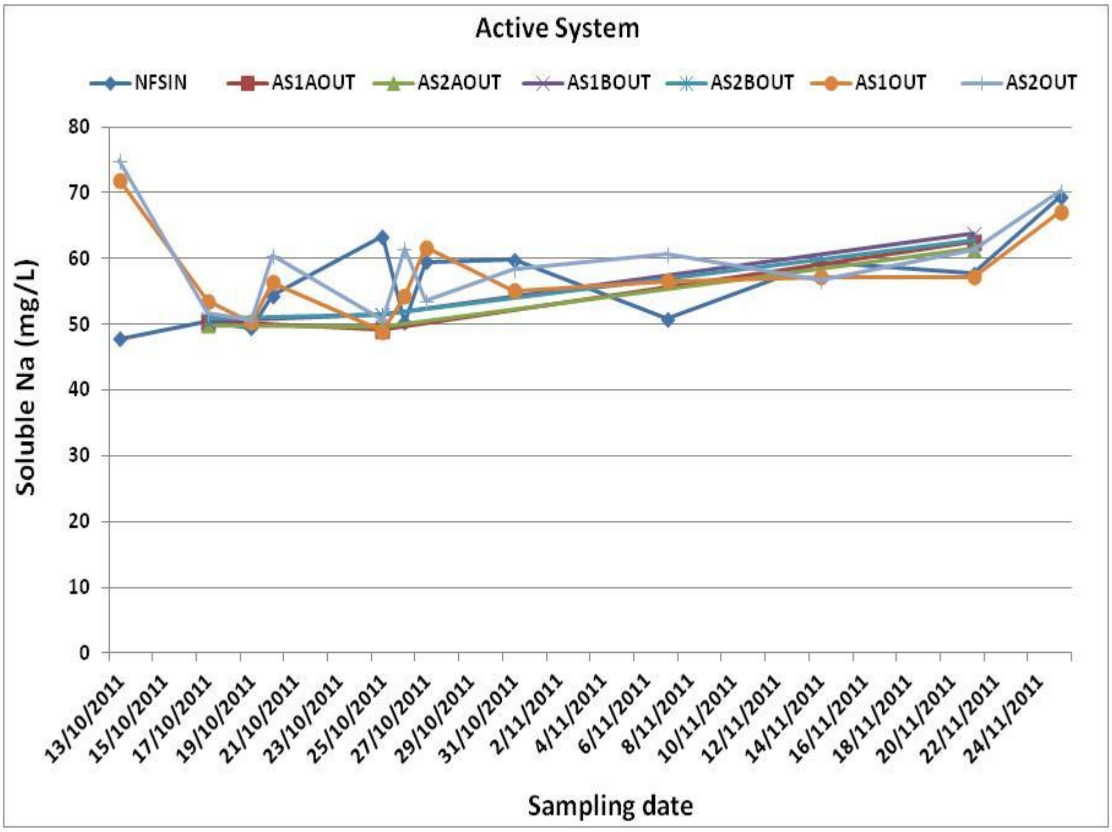


Comparators:

NFSIN (minimum)	51.2 milligrams per litre
NFSIN (maximum)	64.3 milligrams per litre

Trends: No significant difference between inlet and outlet concentrations.

Chart 36: Active System, Soluble Sodium

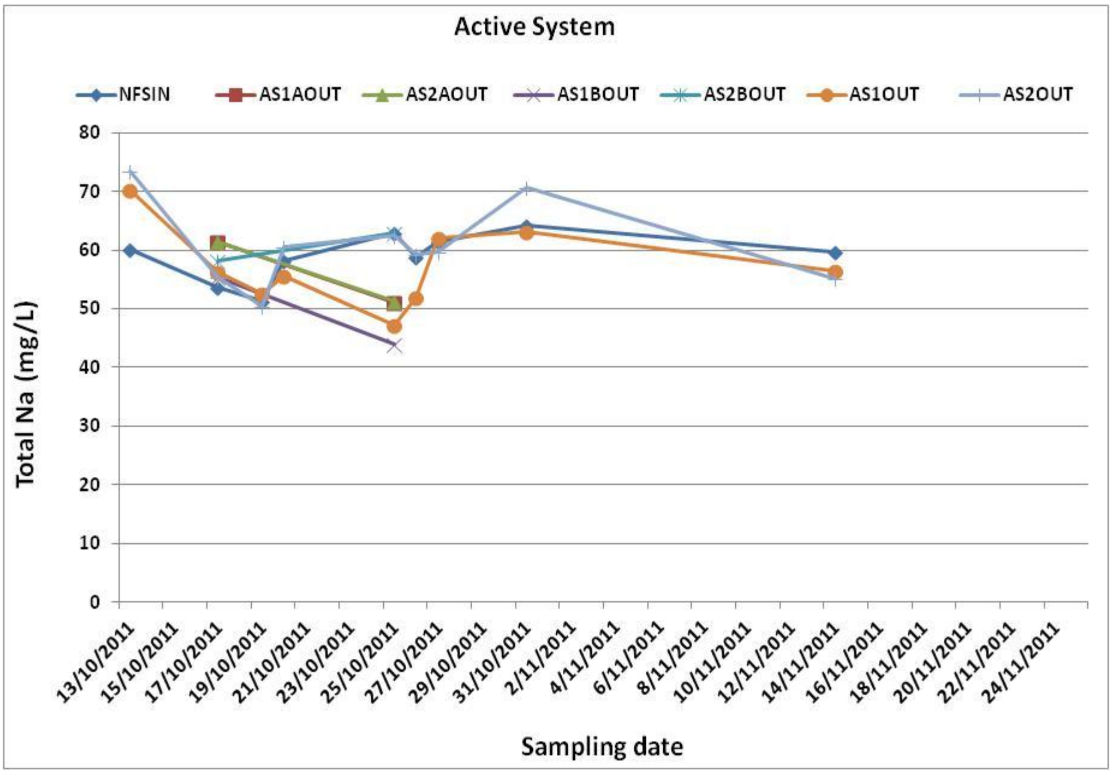


Comparators:

NFSIN (minimum)	46.1 milligrams per litre
NFSIN (maximum)	69.5 milligrams per litre

Trends: Initial release of approximately 20 milligrams per litre of soluble sodium, then no significant differences between inlet and outlet concentrations after the first week.

Chart 37: Active System, Total Sodium



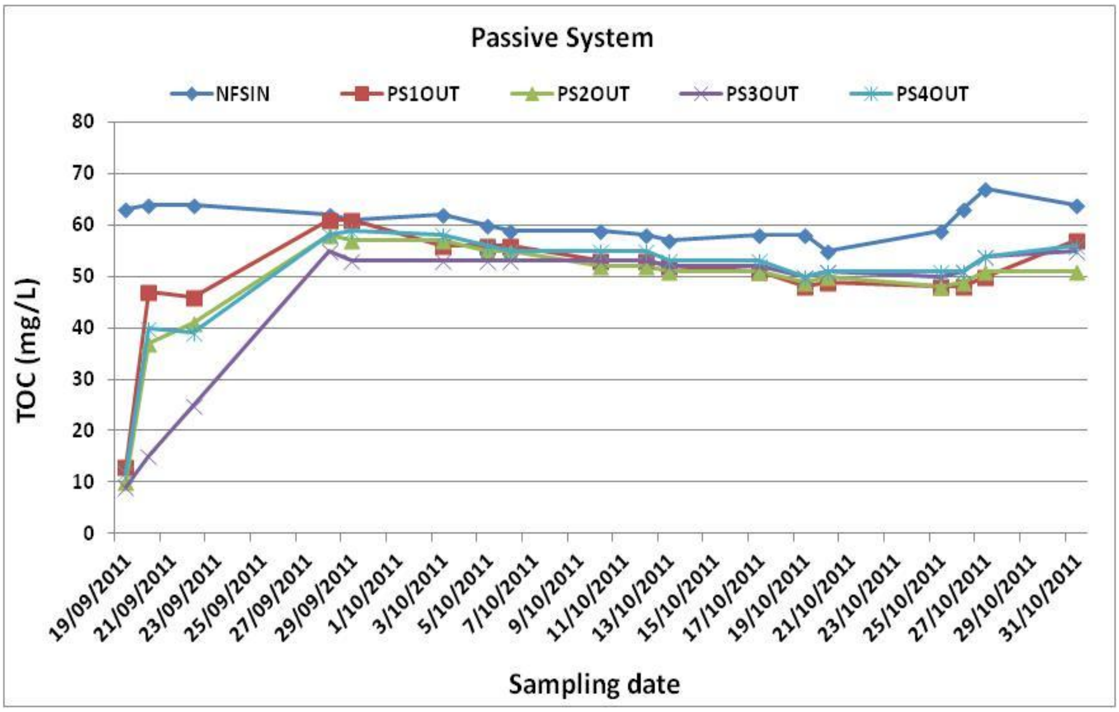
Comparators:

NFSIN (minimum)	51.2 milligrams per litre
NFSIN (maximum)	64.3 milligrams per litre

Trends: Similar to soluble sodium.

4.14 TOTAL ORGANIC CARBON

Chart 38: Passive System, Total Organic Carbon

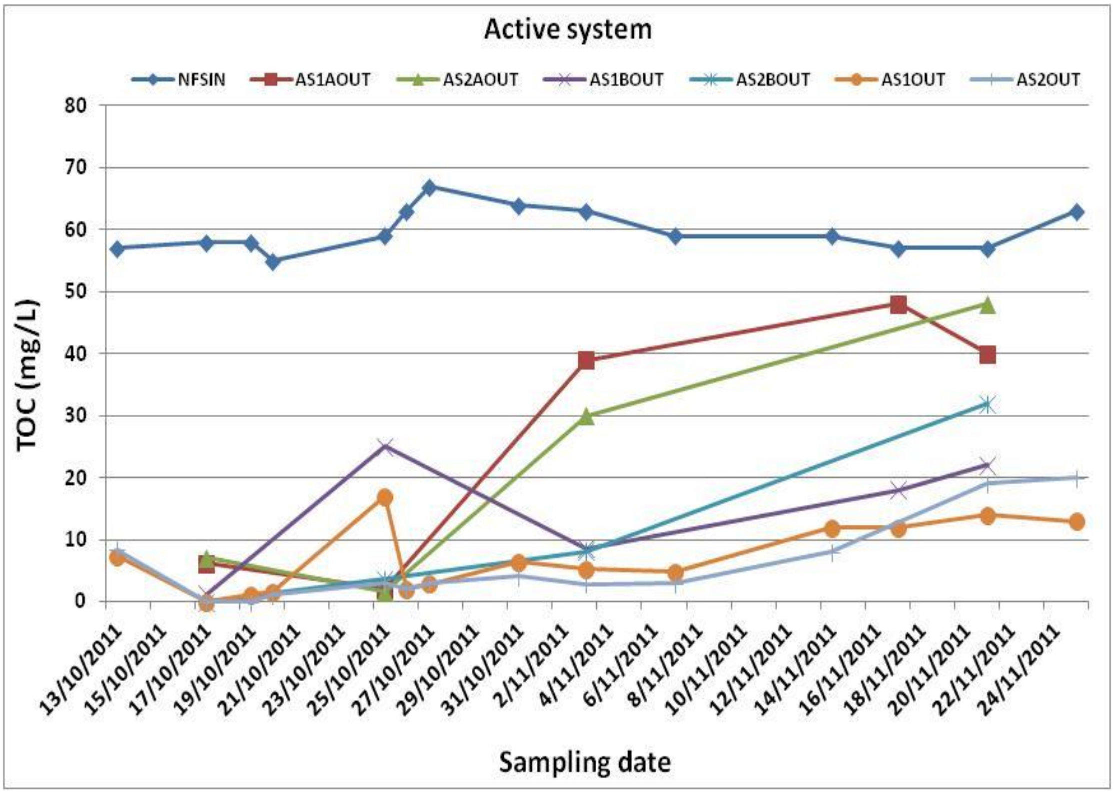


Comparators:

NFSIN (minimum)	55 milligrams per litre
NFSIN (maximum)	67 milligrams per litre

Trends: Very similar relationship to total nitrogen and organic nitrogen removal efficiencies - very effective for the first 4 days, then stabilises at approximately 15% removal.

Chart 39: Active System, Total Organic Carbon



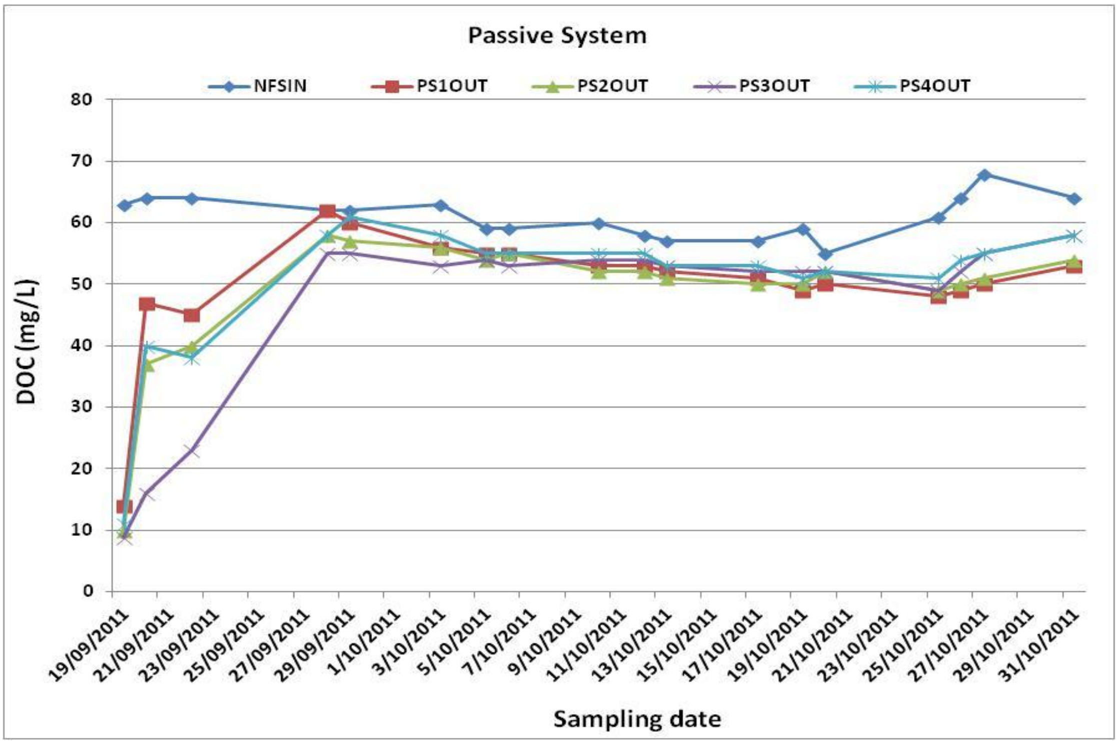
Comparators:

NFSIN (minimum)	55 milligrams per litre
NFSIN (maximum)	67 milligrams per litre

Trends: Very similar relationship to total nitrogen and organic nitrogen removal efficiencies.

4.15 DISSOLVED ORGANIC CARBON

Chart 40: Passive System, Dissolved Organic Carbon

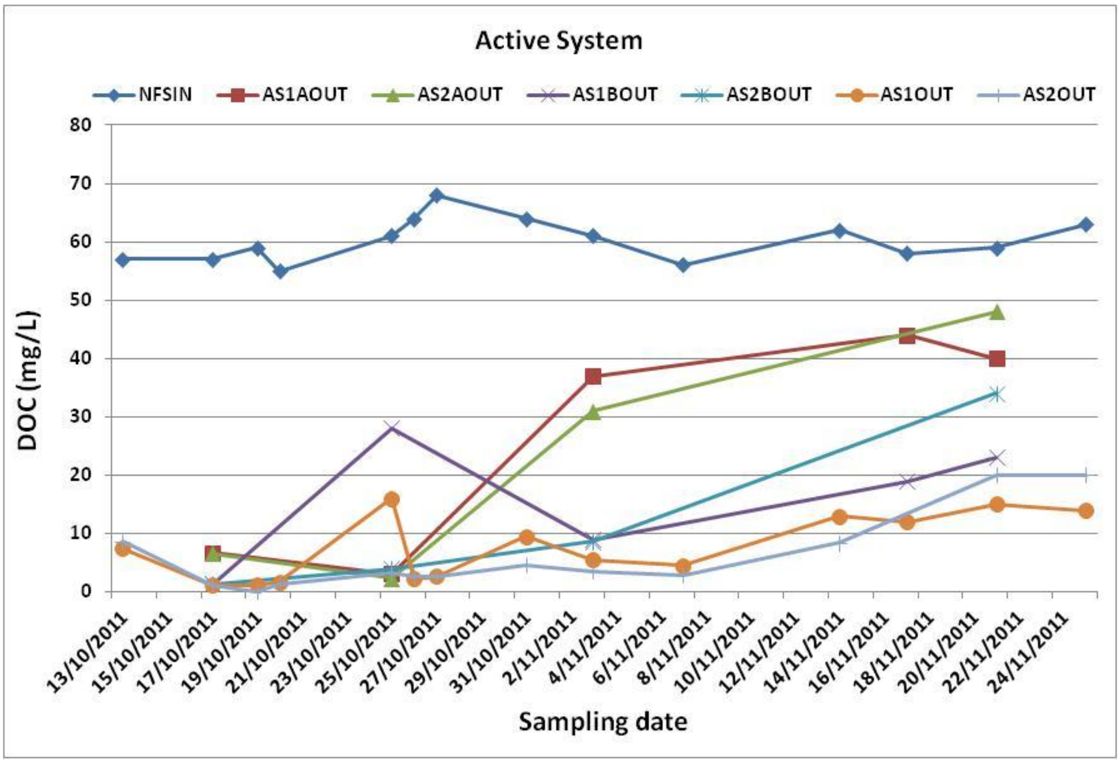


Comparators:

NFSIN (minimum)	55 milligrams per litre
NFSIN (maximum)	68 milligrams per litre

Trends: Very similar to Total Organic Carbon

Chart 41: Active System, Dissolved Organic Carbon



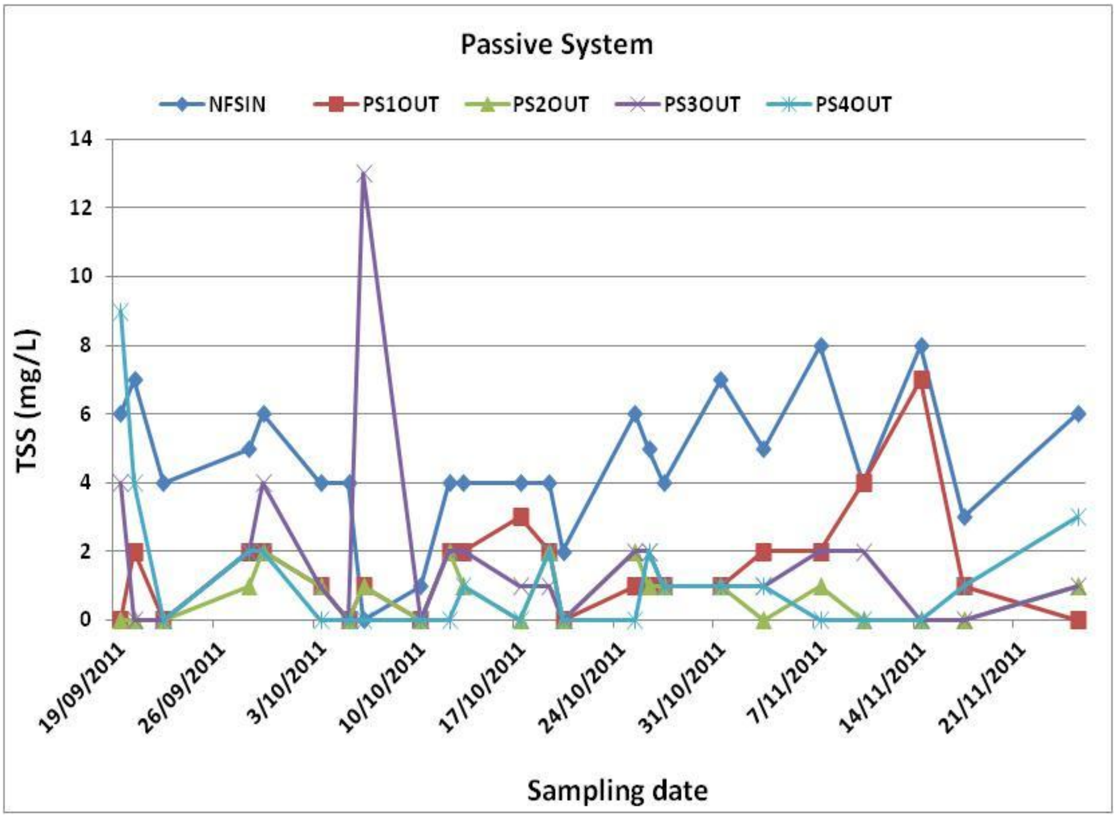
Comparators:

NFSIN (minimum) 55 milligrams per litre
NFSIN (maximum) 68 milligrams per litre

Trends: Very similar to Total Organic Carbon

4.16 TOTAL SUSPENDED SOLIDS

Chart 42: Passive System, Total Suspended Solids

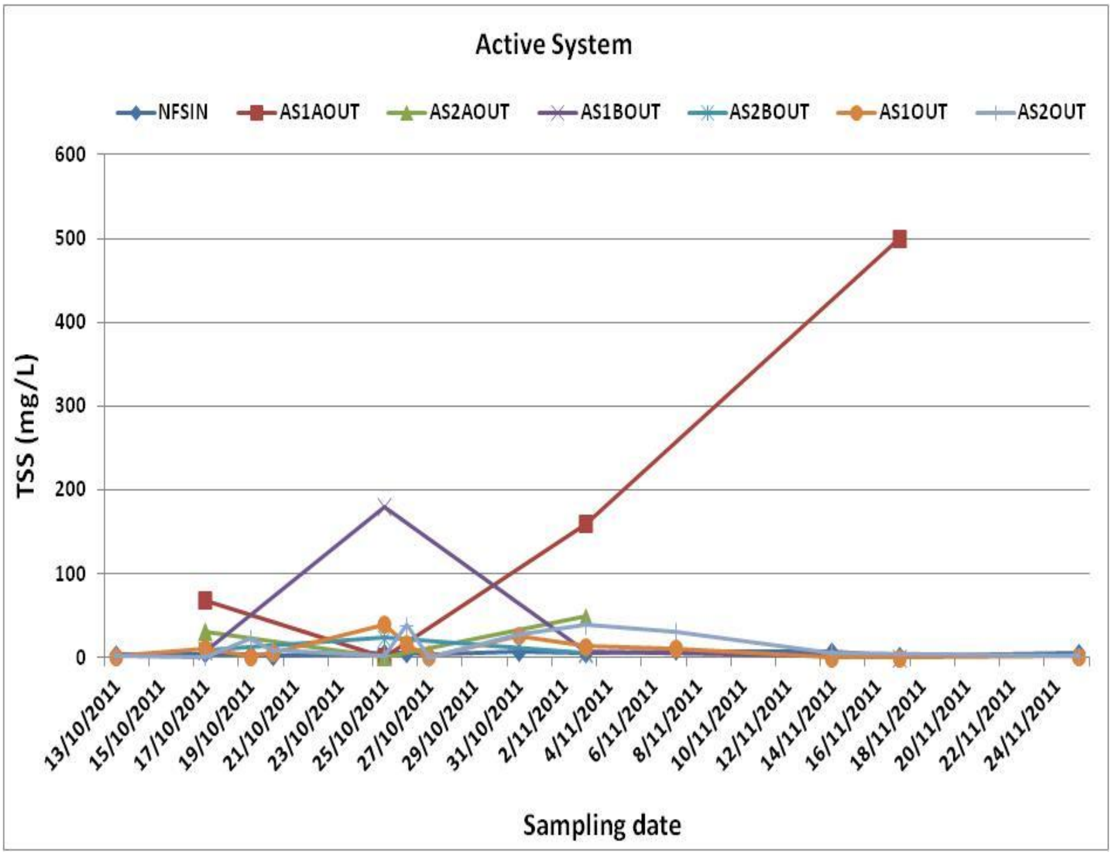


Comparators:

NFSIN (minimum)	<1 milligrams per litre
NFSIN (maximum)	8 milligrams per litre

Trends: Effective at removing suspended solids on most, but not all, occasions.

Chart 43: Active System, Total Suspended Solids



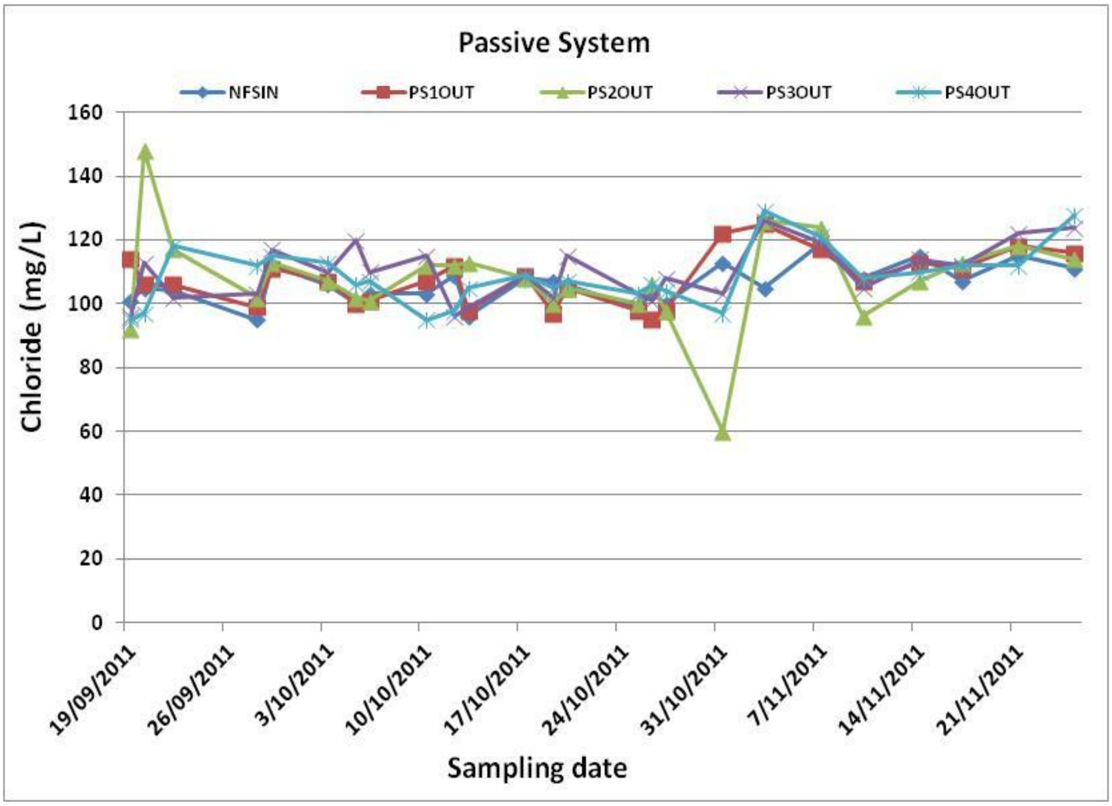
Comparators:

NFSIN (minimum)	2 milligrams per litre
NFSIN (maximum)	8 milligrams per litre

Trends: Very low concentrations of Total Suspended Solids in the final outlet stream of each system.

4.17 CHLORIDE

Chart 44: Passive System, Chloride

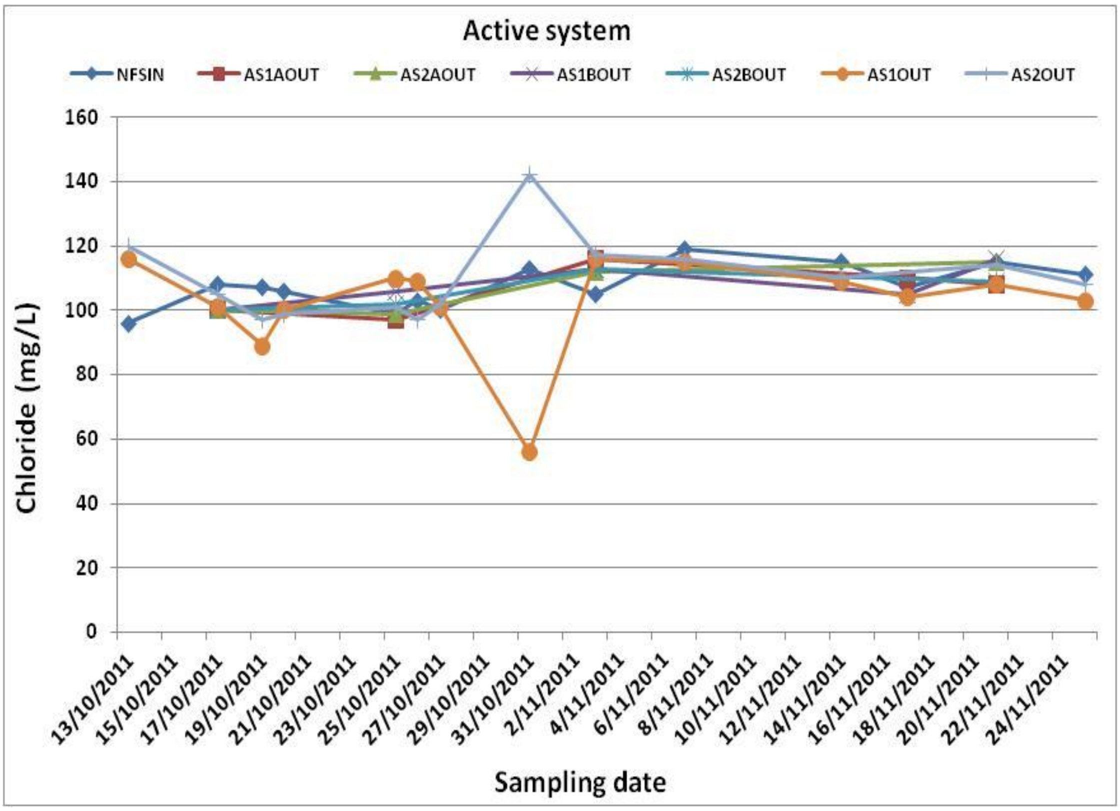


Comparators:

NFSIN (minimum)	95 milligrams per litre
NFSIN (maximum)	119 milligrams per litre

Trends: No evidence for reducing or increasing chloride concentrations.

Chart 45: Active System, Chloride



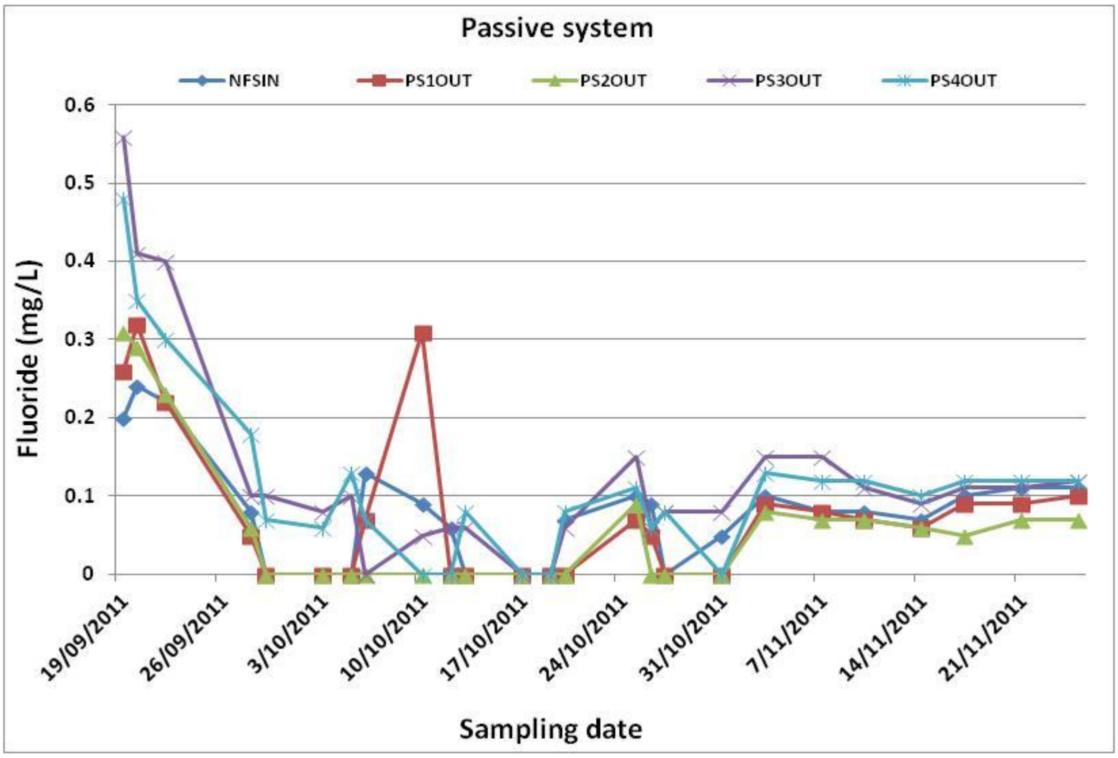
Comparators:

NFSIN (minimum)	96 milligrams per litre
NFSIN (maximum)	119 milligrams per litre

Trends: No evidence for reducing or increasing chloride concentrations.

4.18 FLUORIDE

Chart 46: Passive System, Fluoride

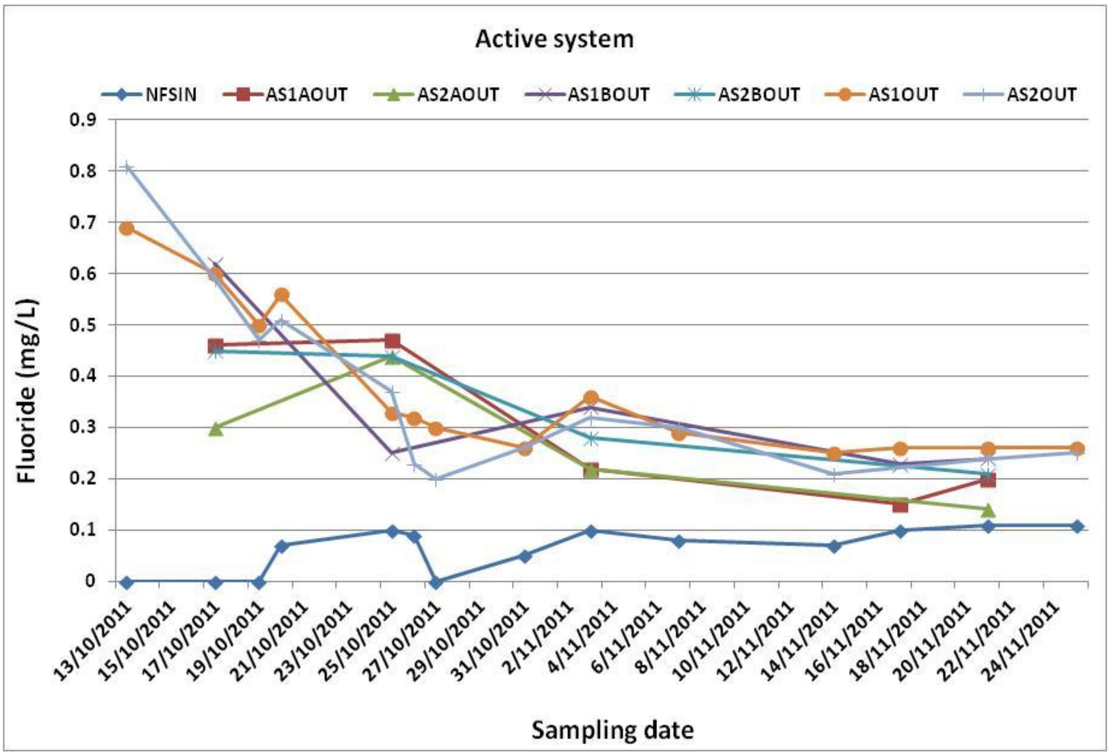


Comparators:

NFSIN (minimum)	<0.05 milligrams per litre
NFSIN (maximum)	0.24 milligrams per litre
ADWG	1.5 milligrams per litre
Livestock	2 milligrams per litre
Irrigation	1 milligrams per litre

Trends: Initial release of fluoride to levels approximately twice as high as background; mainly PS3 and PS4. PS1 and PS2 absorb some fluoride in the longer term. PS3 and PS4 release low levels of fluoride.

Chart 47: Active System, Fluoride



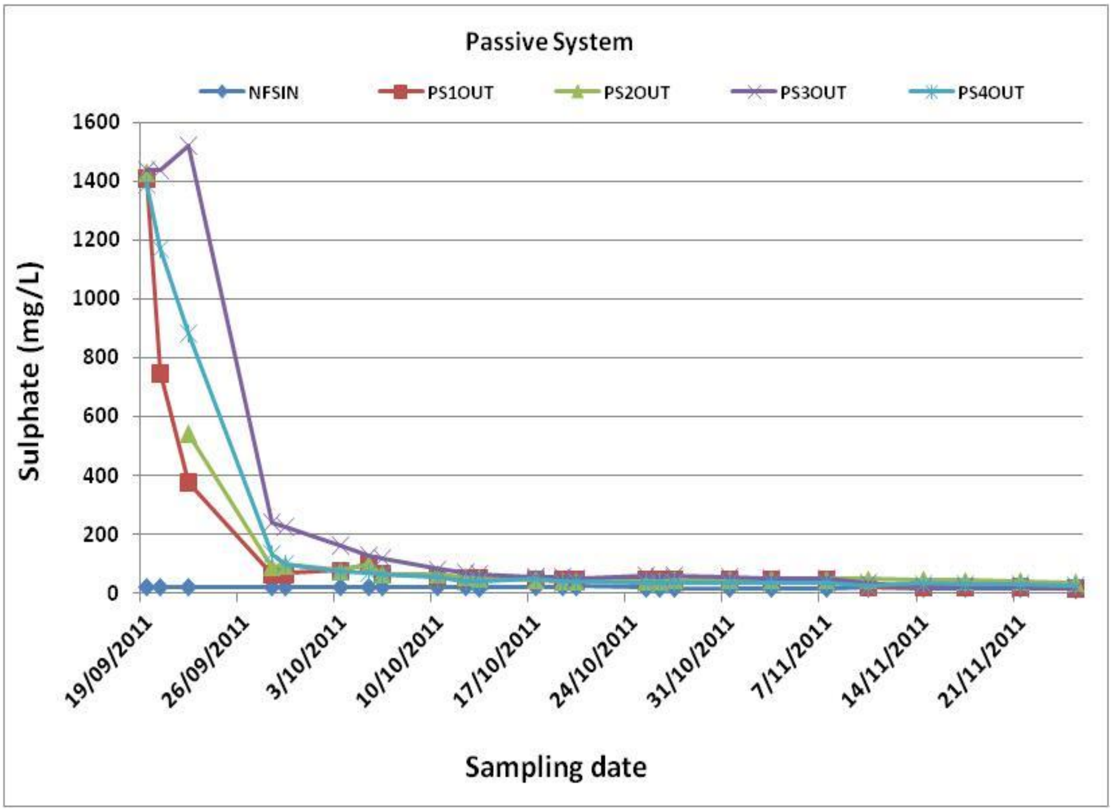
Comparators:

NFSIN (minimum)	<0.05 milligrams per litre
NFSIN (maximum)	0.11 milligrams per litre
ADWG	1.5 milligrams per litre
Livestock	2 milligrams per litre
Irrigation	1 milligrams per litre

Trends: Initially released concentrations up to approximately 0.8 milligrams per litre. Continued releasing fluoride throughout the monitoring period, although concentrations were less than 0.3 milligrams per litre after approximately four weeks.

4.19 SULPHATE

Chart 48: Passive System, Sulphate

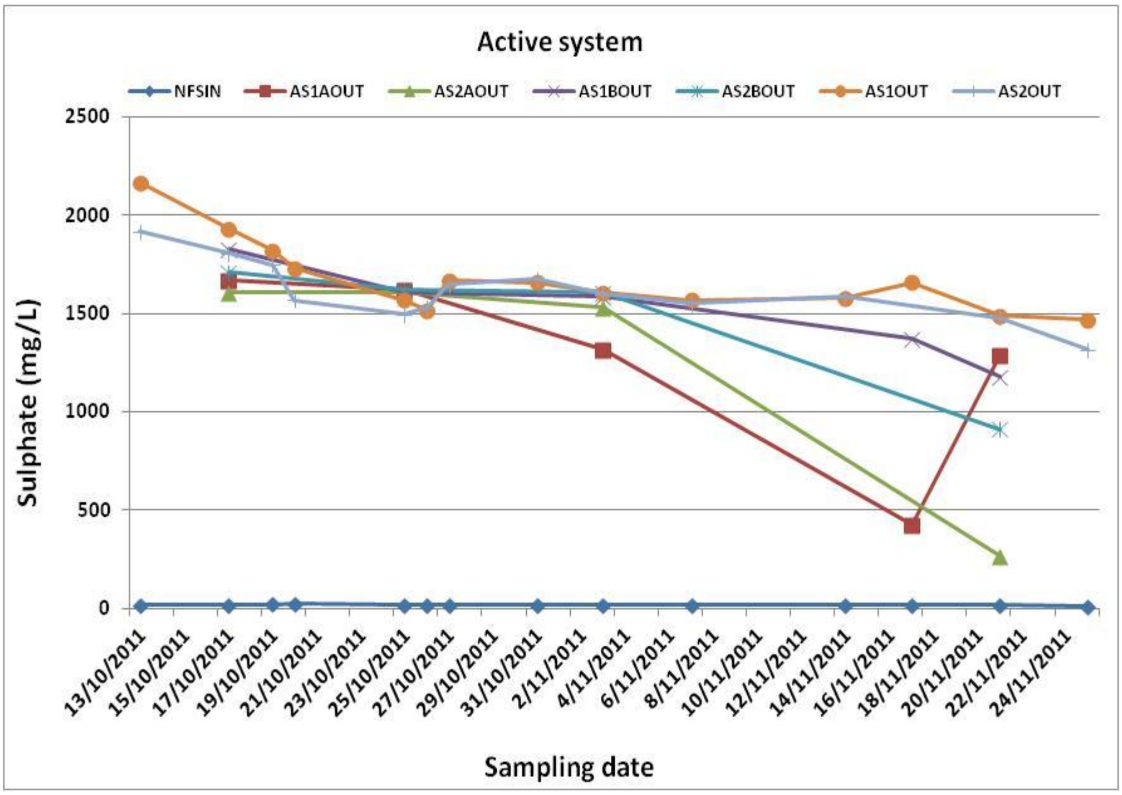


Comparators:

NFSIN (minimum)	13.6 milligrams per litre
NFSIN (maximum)	24.2 milligrams per litre
ADWG	250 milligrams per litre
Livestock	1,000 milligrams per litre

Trends: Very high release of sulphate for one week, then stabilises at levels slightly higher than background. Similar curves to calcium, suggesting rapid washout of gypsum.

Chart 49: Active System, Sulphate



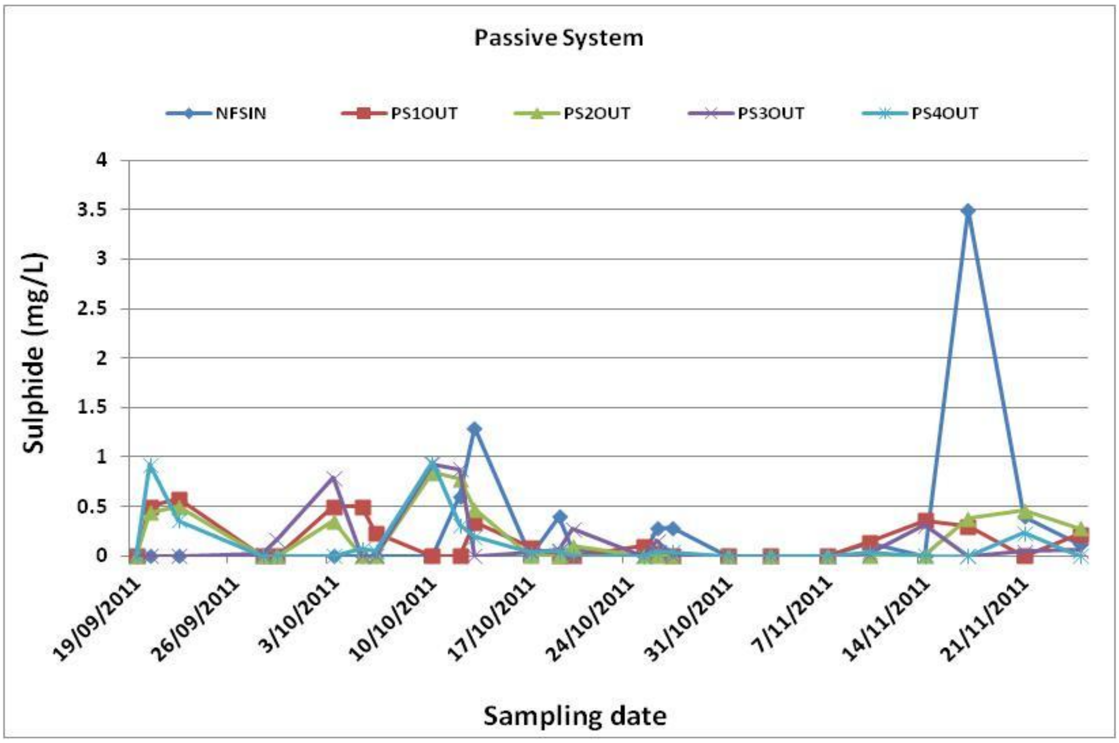
Comparators:

NFSIN (minimum)	13.6 milligrams per litre
NFSIN (maximum)	24.2 milligrams per litre
ADWG	250 milligrams per litre
Livestock	1,000 milligrams per litre

Trends: Similar curves to soluble calcium. After the first week of operation, concentrations of outlet streams are relatively stable at approximately 1,500 milligrams per litre.

4.20 SULPHIDE

Chart 50: Passive System, Sulphide

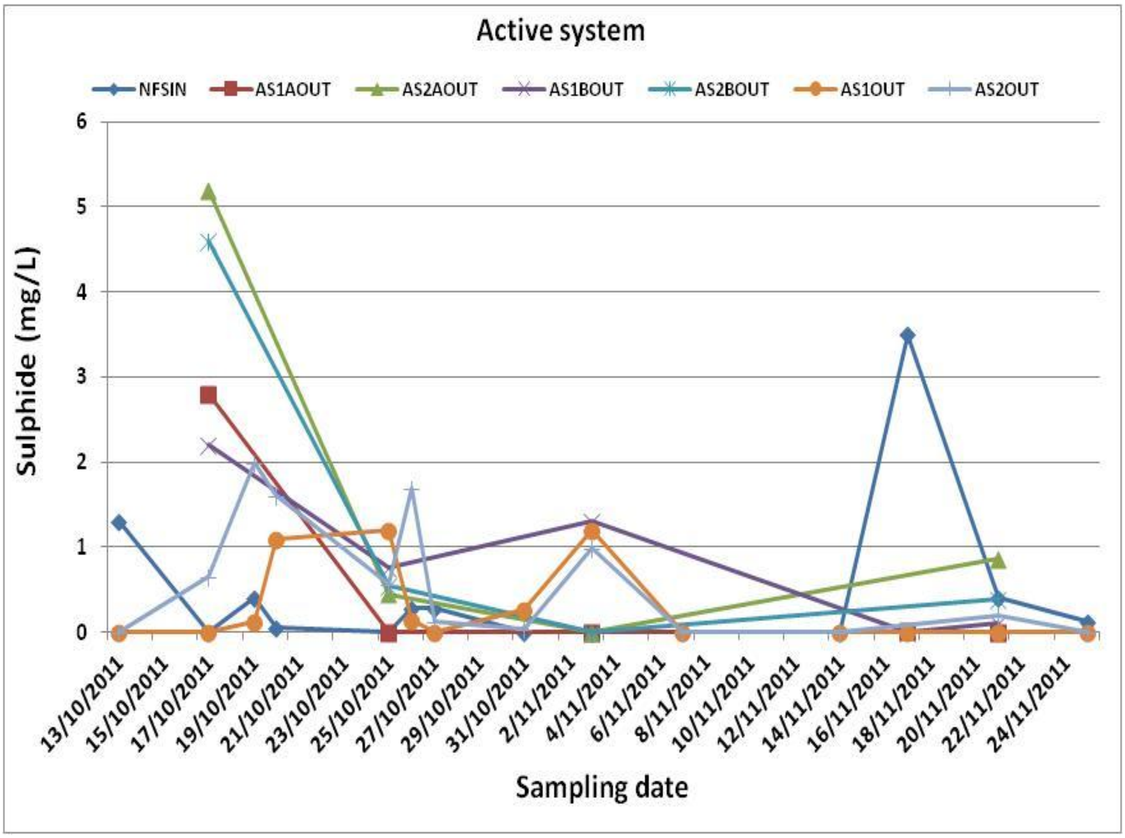


Comparators:

NFSIN (minimum)	<0.01 milligrams per litre
NFSIN (maximum)	3.5 milligrams per litre

Trends: Variable performance. Maintains relatively low levels despite occasional peaks in background water quality.

Chart 51: Active System, Sulphide



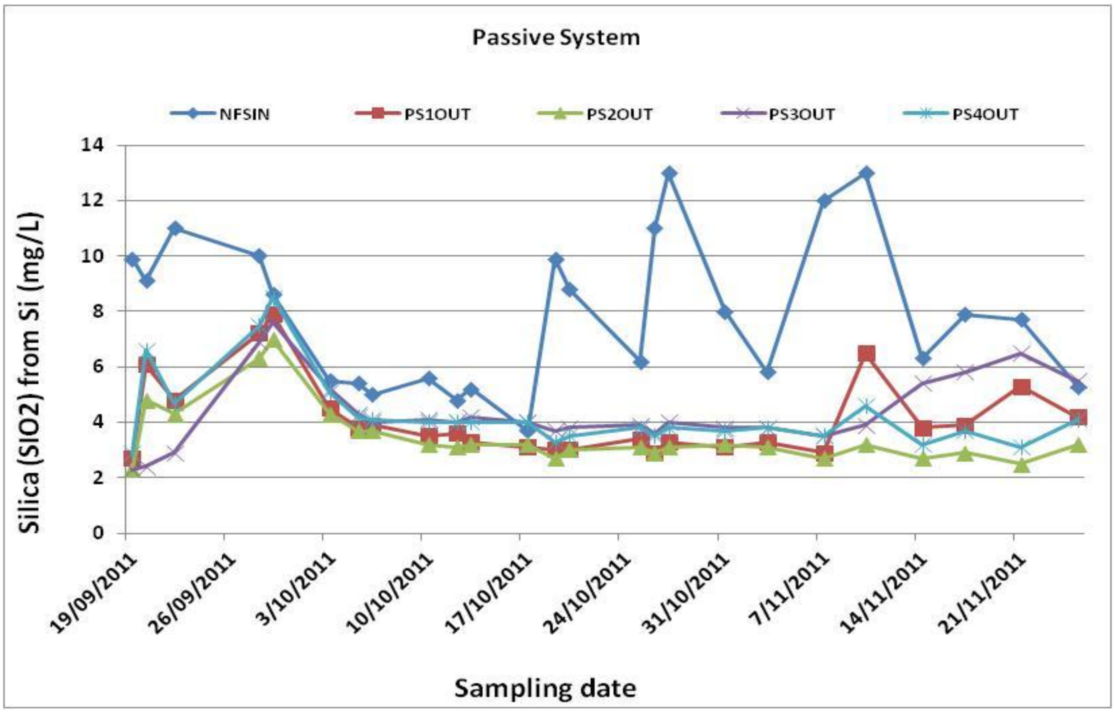
Comparators:

NFSIN (minimum)	<0.01 milligrams per litre
NFSIN (maximum)	3.5 milligrams per litre

Trends: Highly variable, especially intermediate sampling points. Highest concentration of approximately five milligrams per litre at intermediate sampling point AS2A out. Inlet concentration at that time was below LOR and final outlet stream concentration was approximately 0.6 milligrams per litre.

4.21 SILICA

Chart 52: Passive System, Soluble Silica

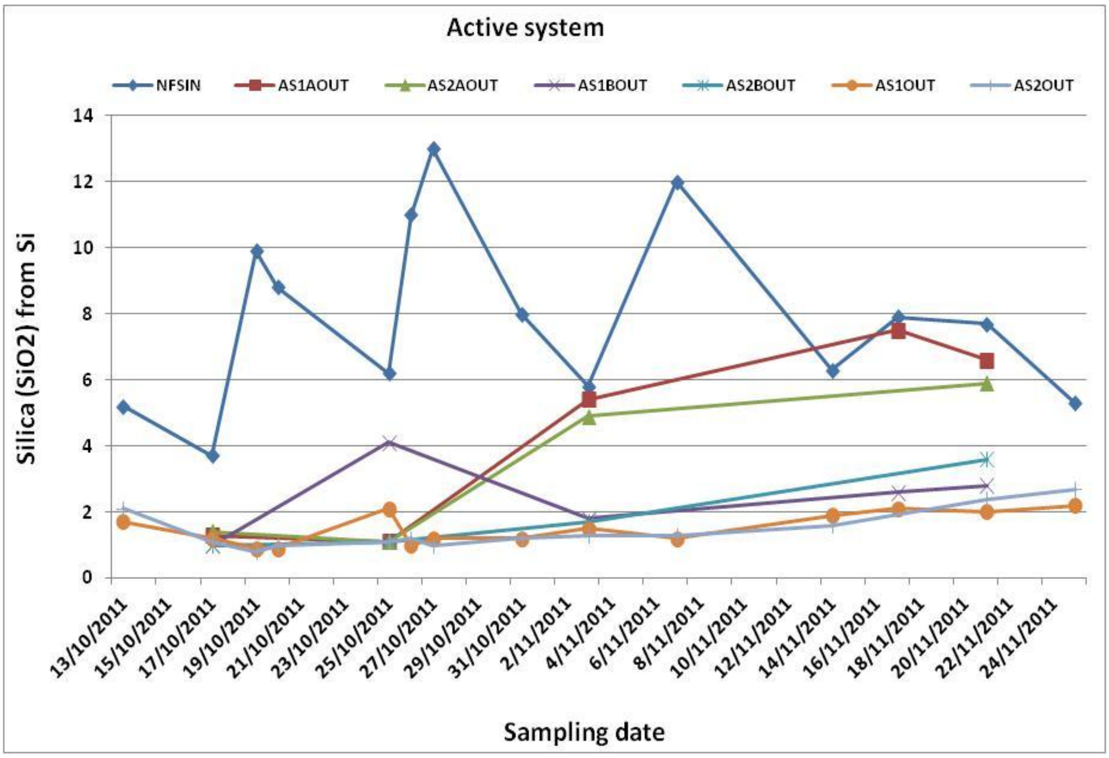


Comparators:

NFSIN (minimum)	3.7 milligrams per litre
NFSIN (maximum)	13 milligrams per litre

Trends: Moderately effective at removing silica, especially during the first week. Variable removal deficiency, decreasing towards the end of the monitoring period.

Chart 53: Active System, Silica



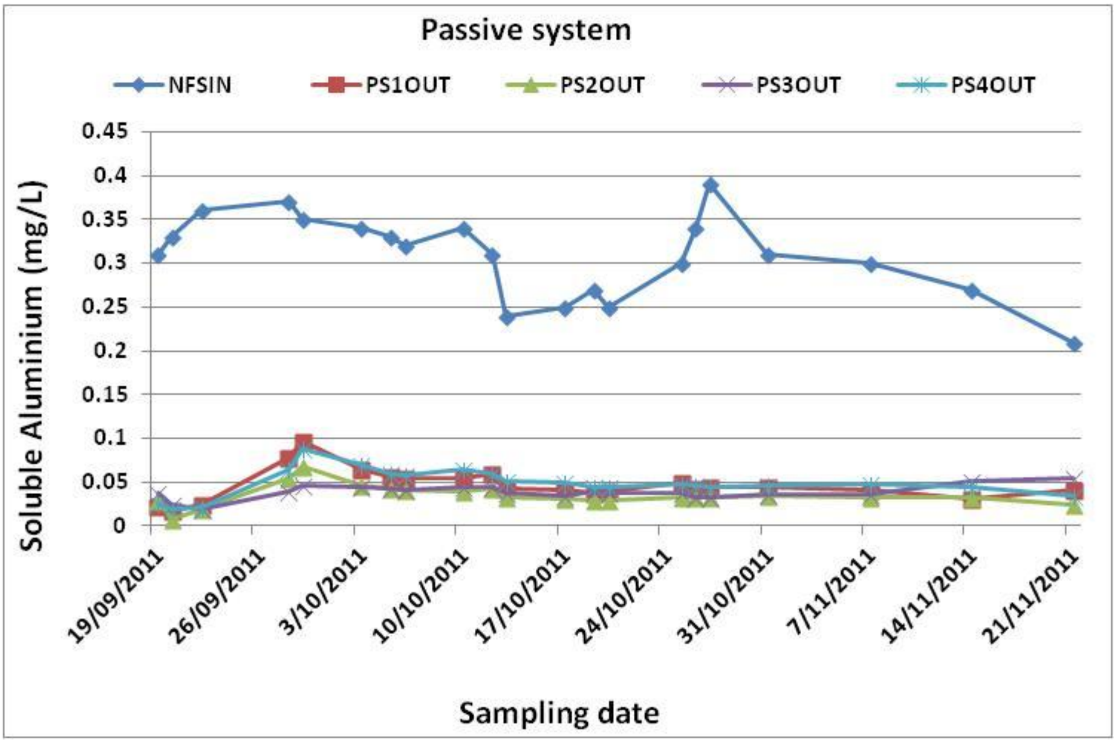
Comparators:

NFSIN (minimum)	3.7 milligrams per litre
NFSIN (maximum)	13 milligrams per litre

Trends: Inlet streams are highly variable. Significantly lower concentrations in final outlet streams.

4.22 ALUMINIUM

Chart 54: Passive System, Soluble Aluminium

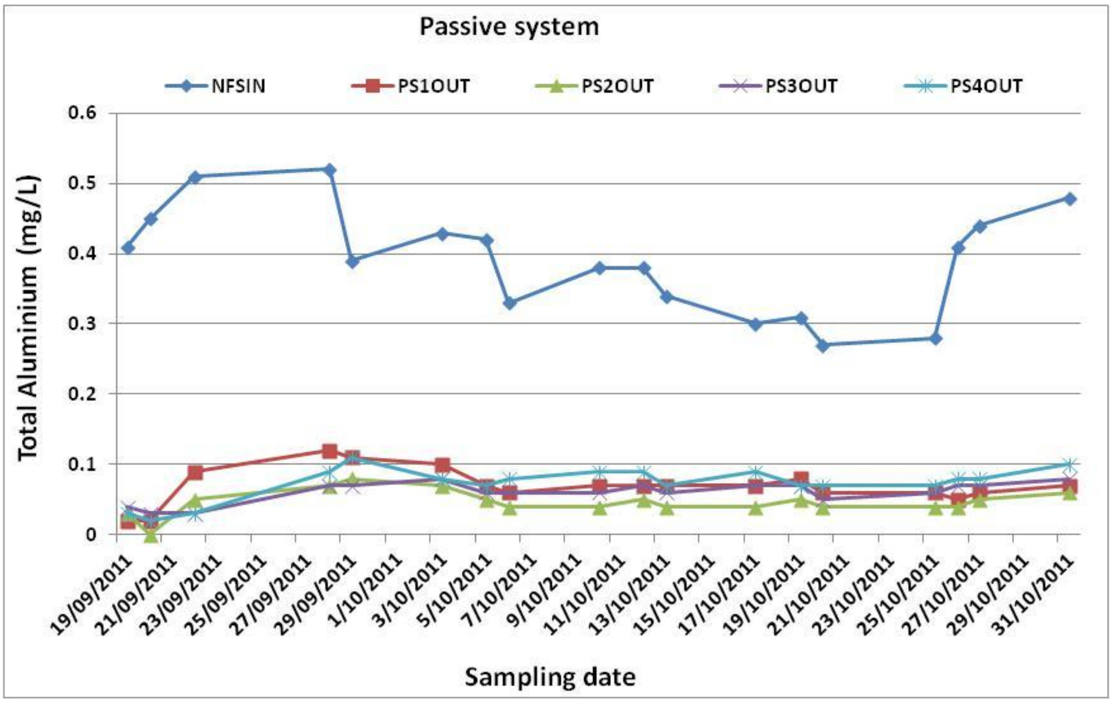


Comparators:

NFSIN (minimum)	0.20 milligrams per litre
NFSIN (maximum)	0.39 milligrams per litre
AEP (95%)	0.055 milligrams per litre

Trends: Inlet stream concentrations are consistently well above the 95% species protection level (ANZECC 2000). Outlet stream concentrations are below or close to the 95% species protection level.

Chart 55: Passive System, Total Aluminium

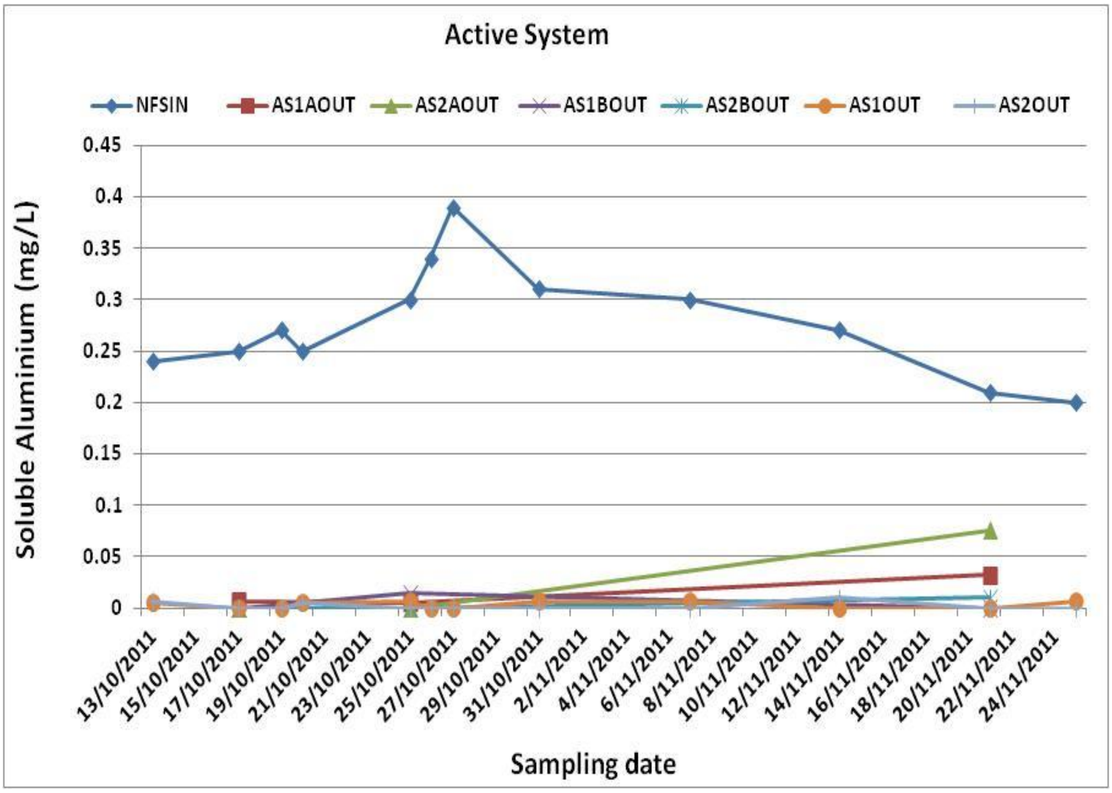


Comparators:

NFSIN (minimum)	0.27 milligrams per litre
NFSIN (maximum)	0.52 milligrams per litre
ADWG	0.2 milligrams per litre (aesthetic)
Livestock	5 milligrams per litre
Irrigation	5 milligrams per litre

Trends: Inlet stream concentrations are slightly higher than the corresponding soluble aluminium concentrations. Significant (approximately 80%) removal of total aluminium by all systems. Outlet stream concentrations are below guideline values for human and livestock drinking water.

Chart 56: Active System, Soluble Aluminium

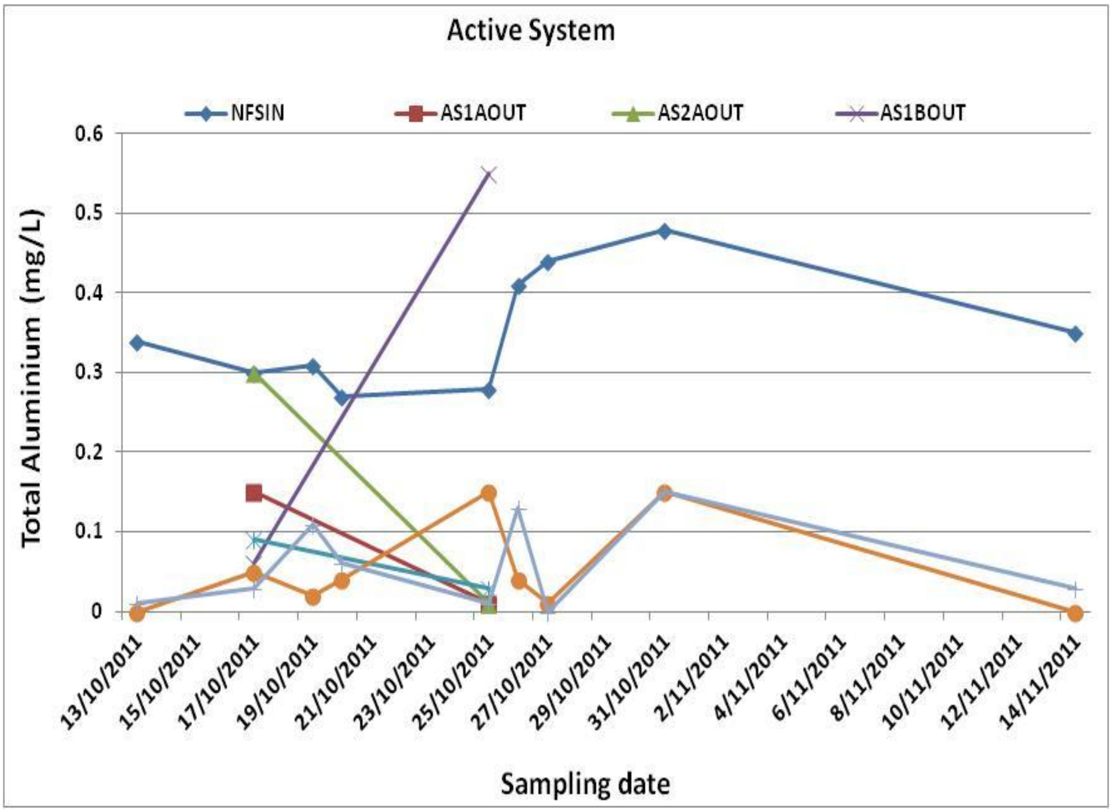


Comparators:

NFSIN (minimum)	0.20 milligrams per litre
NFSIN (maximum)	0.39 milligrams per litre
AEP (95%)	0.055 milligrams per litre

Trends: Very low concentrations consistently achieved in both final outlet streams (below 95% species protection level (ANZECC 2000)).

Chart 57: Active System, Total Aluminium



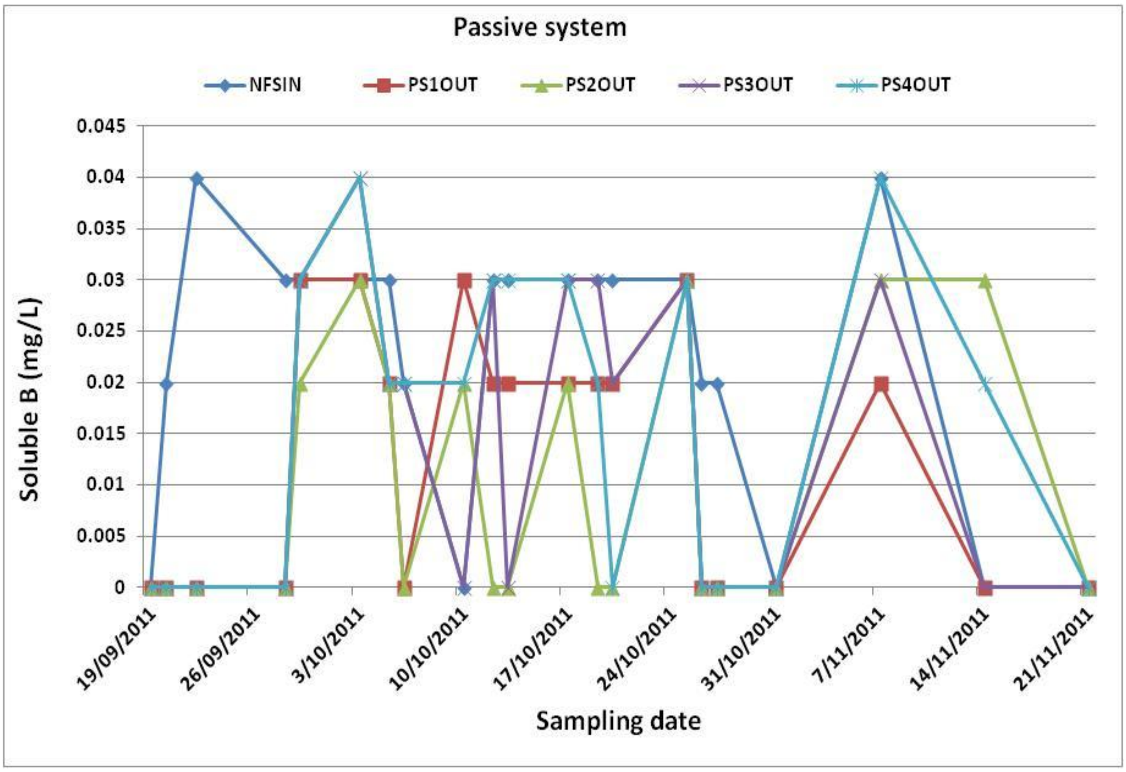
Comparators:

NFSIN (minimum)	0.27 milligrams per litre
NFSIN (maximum)	0.52 milligrams per litre
ADWG	0.2 milligrams per litre (aesthetic)
Livestock	5 milligrams per litre
Irrigation	5 milligrams per litre

Trends: Inlet stream concentrations are slightly higher than the corresponding soluble aluminium concentrations. Significant removal of total aluminium by both systems. Outlet stream concentrations are below guideline values for human and livestock drinking water.

4.23 BORON

Chart 58: Passive System, Soluble Boron

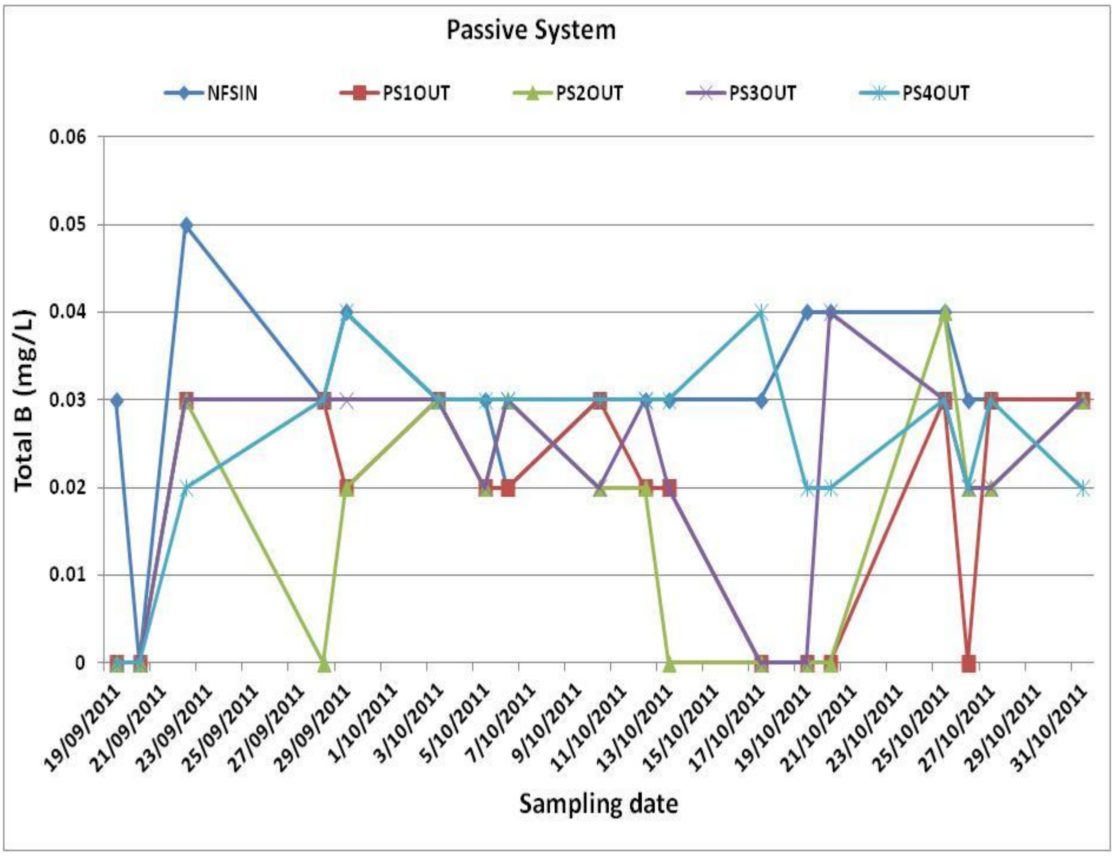


Comparators:

NFSIN (minimum)	<0.02 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
AEP (95%)	0.37 milligrams per litre

Trends: Soluble boron concentrations in all sample streams are well below the 95% species protection level (ANZECC 2000) at all times. No significant trends observed.

Chart 59: Passive System, Total Boron

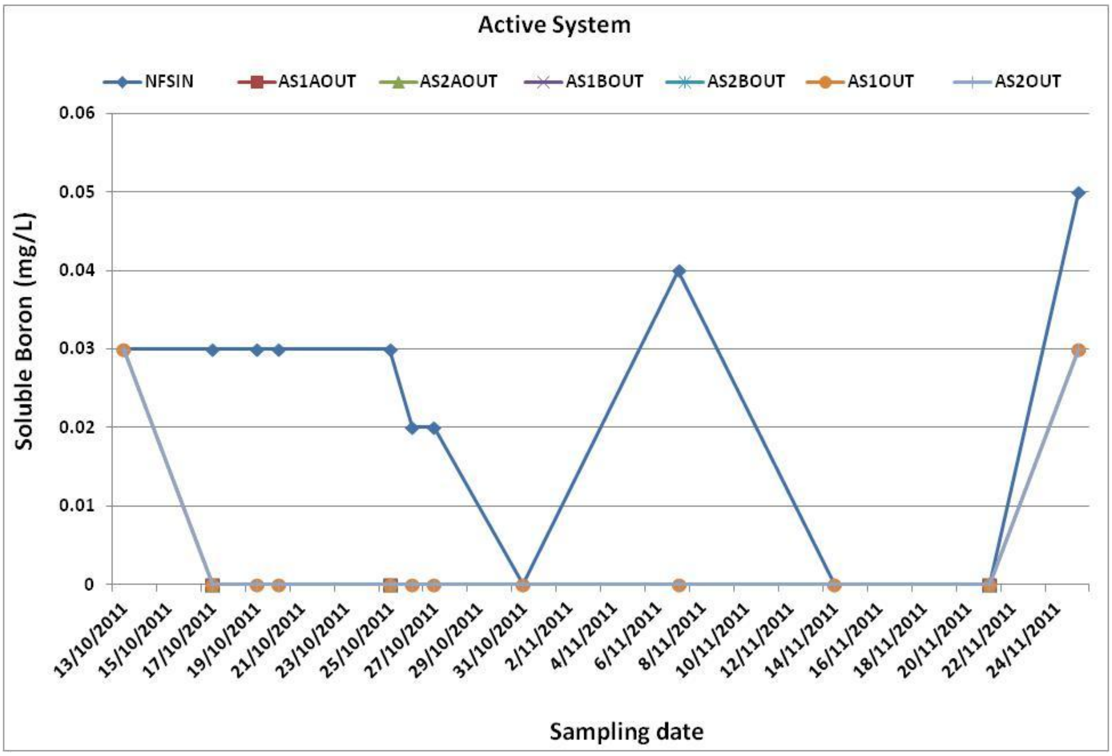


Comparators:

NFSIN (minimum)	<0.02 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
ADWG	4 milligrams per litre (aesthetic)
Livestock	5 milligrams per litre
Irrigation	0.5 milligrams per litre

Trends: Total boron concentrations in all sample streams are well below drinking and irrigation guideline values at all times. No significant trends observed.

Chart 60: Active System, Soluble Boron

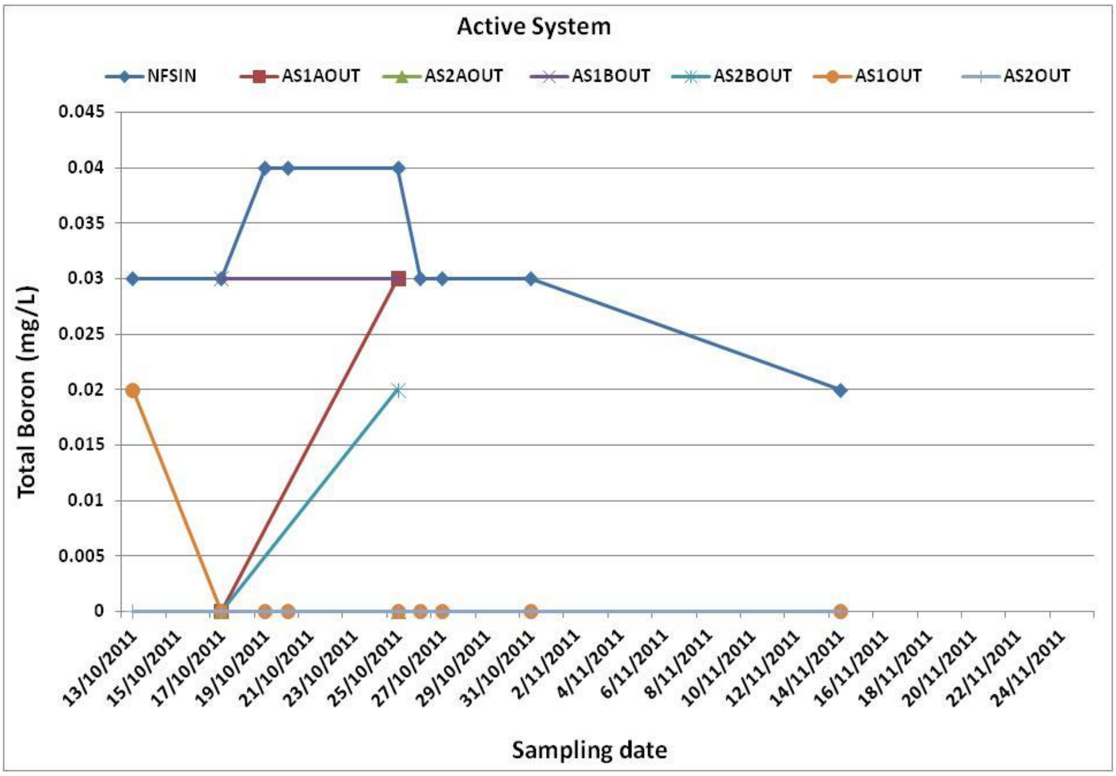


Comparators:

NFSIN (minimum)	<0.02 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
AEP (95%)	0.37 milligrams per litre

Trends: Soluble boron concentrations in all sample streams are well below the 95% species protection level (ANZECC 2000) at all times. Significant removal of soluble boron in all systems.

Chart 61: Active System, Total Boron



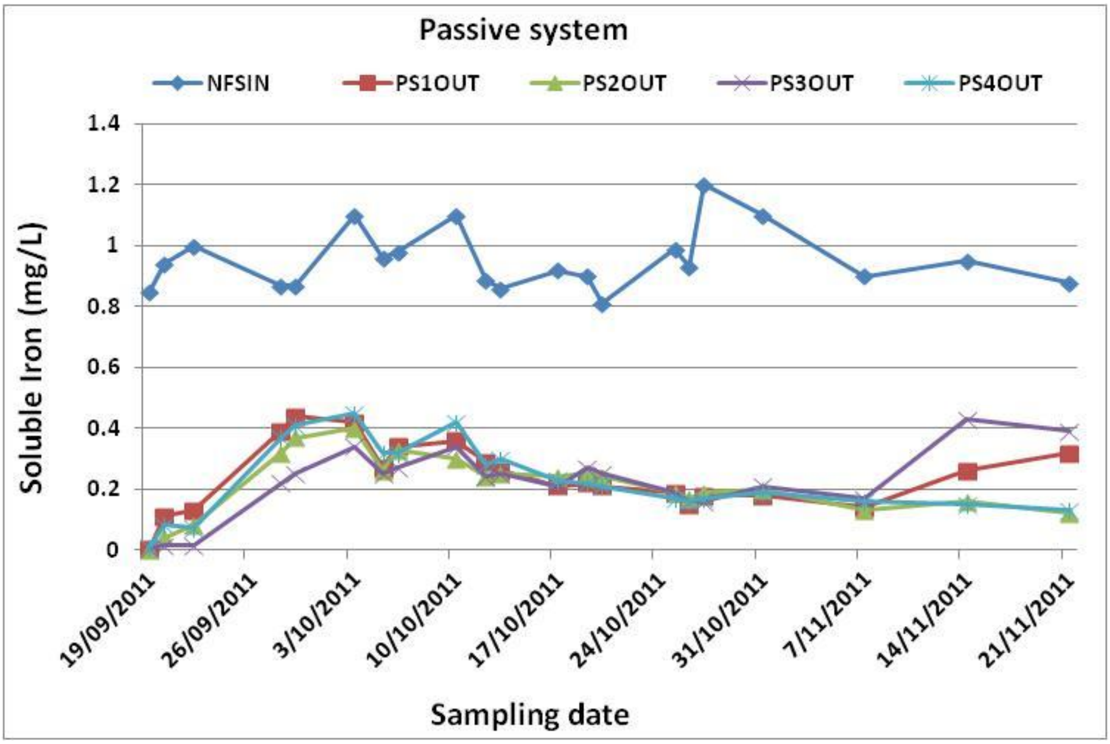
Comparators:

NFSIN (minimum)	<0.02 milligrams per litre
NFSIN (maximum)	0.04 milligrams per litre
ADWG	4 milligrams per litre (aesthetic)
Livestock	5 milligrams per litre
Irrigation	0.5 milligrams per litre

Trends: Total boron concentrations in all sample streams are well below drinking and irrigation guideline values at all times. Significant removal of total boron in all systems.

4.24 IRON

Chart 62: Passive System, Soluble Iron

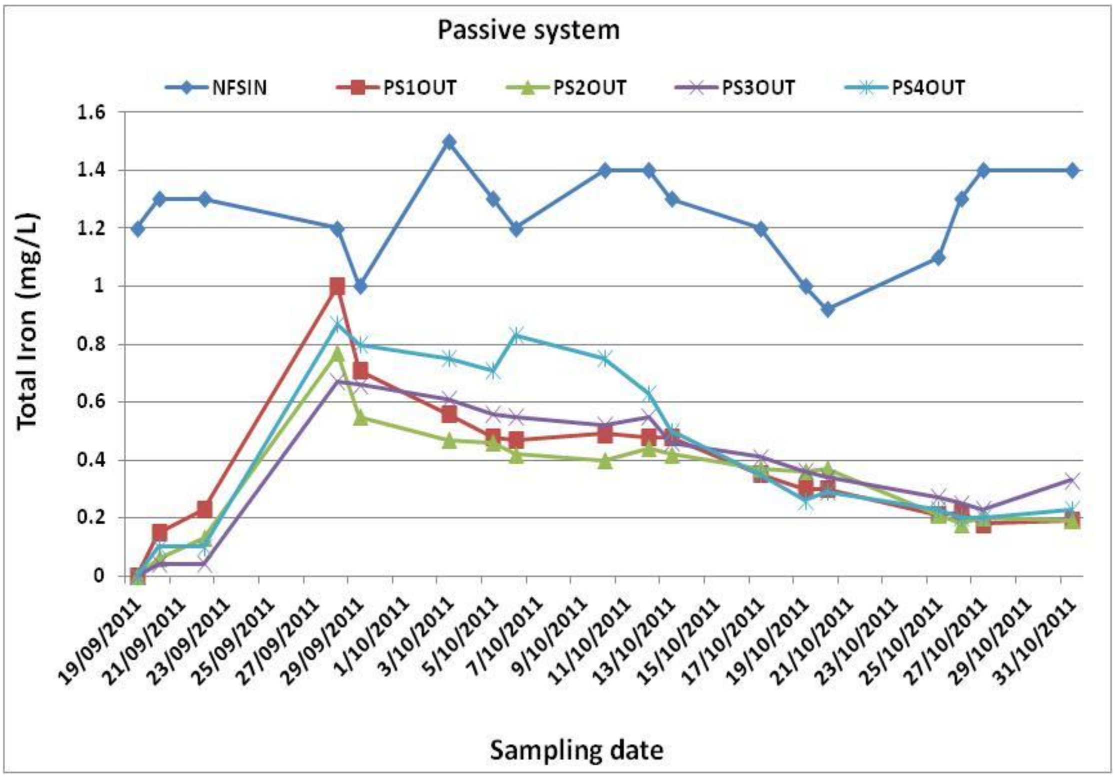


Comparators:

NFSIN (minimum) 0.85 milligrams per litre
NFSIN (maximum) 1.2 milligrams per litre

Trends: Inlet stream concentrations of soluble iron are moderately high, averaging approximately 1 milligram per litre. All systems achieved approximately 80% removal of soluble iron, with PS2 achieving the highest removal efficiencies.

Chart 63: Passive System, Total Iron

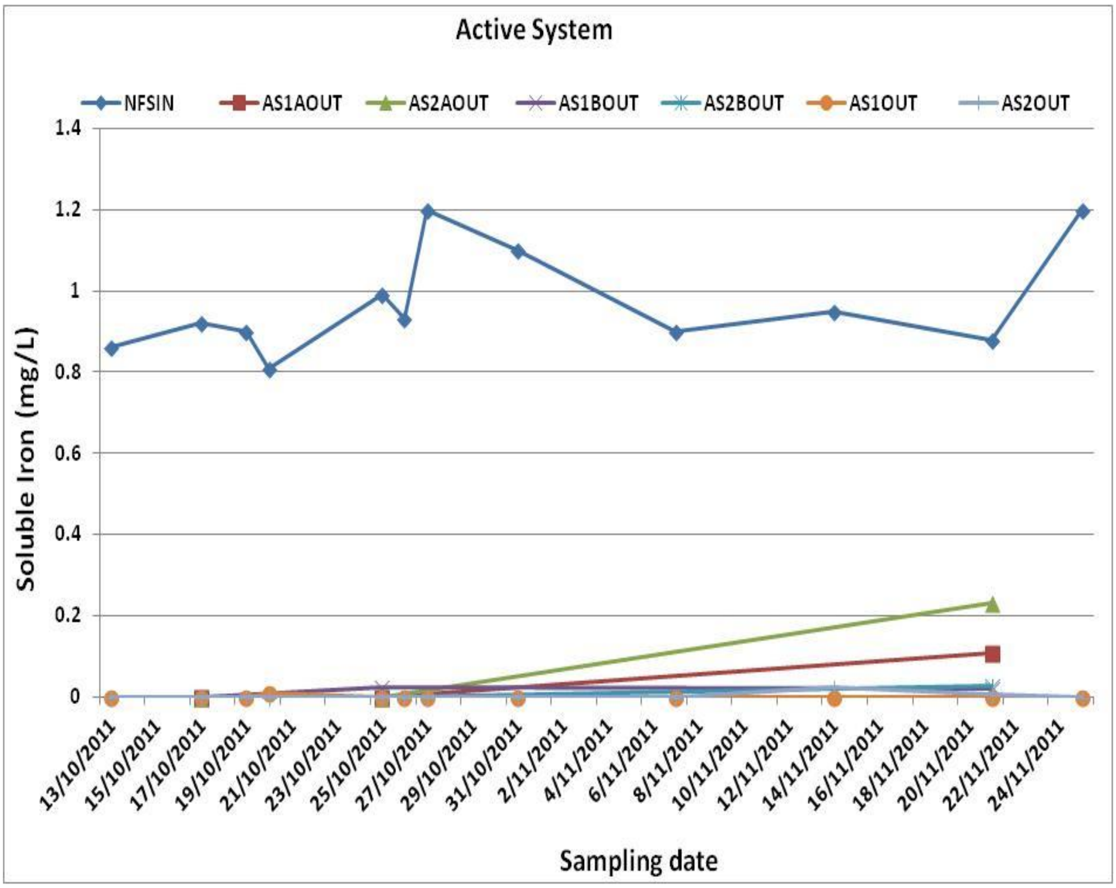


Comparators:

NFSIN (minimum)	0.92 milligrams per litre
NFSIN (maximum)	1.5 milligrams per litre
ADWG	0.3 milligrams per litre (aesthetic)
Irrigation	0.2 milligrams per litre

Trends: Inlet stream concentrations of total iron are slightly higher than the corresponding soluble iron concentrations. Significant removal of total iron, especially at the commencement of the trial and again at the end of the trial. Highest concentrations observed between weeks 1 and 3, during which time inlet and outlet streams for all passive systems exceeded the aesthetic human drinking guideline value and the irrigation guideline value.

Chart 64: Active System, Soluble Iron

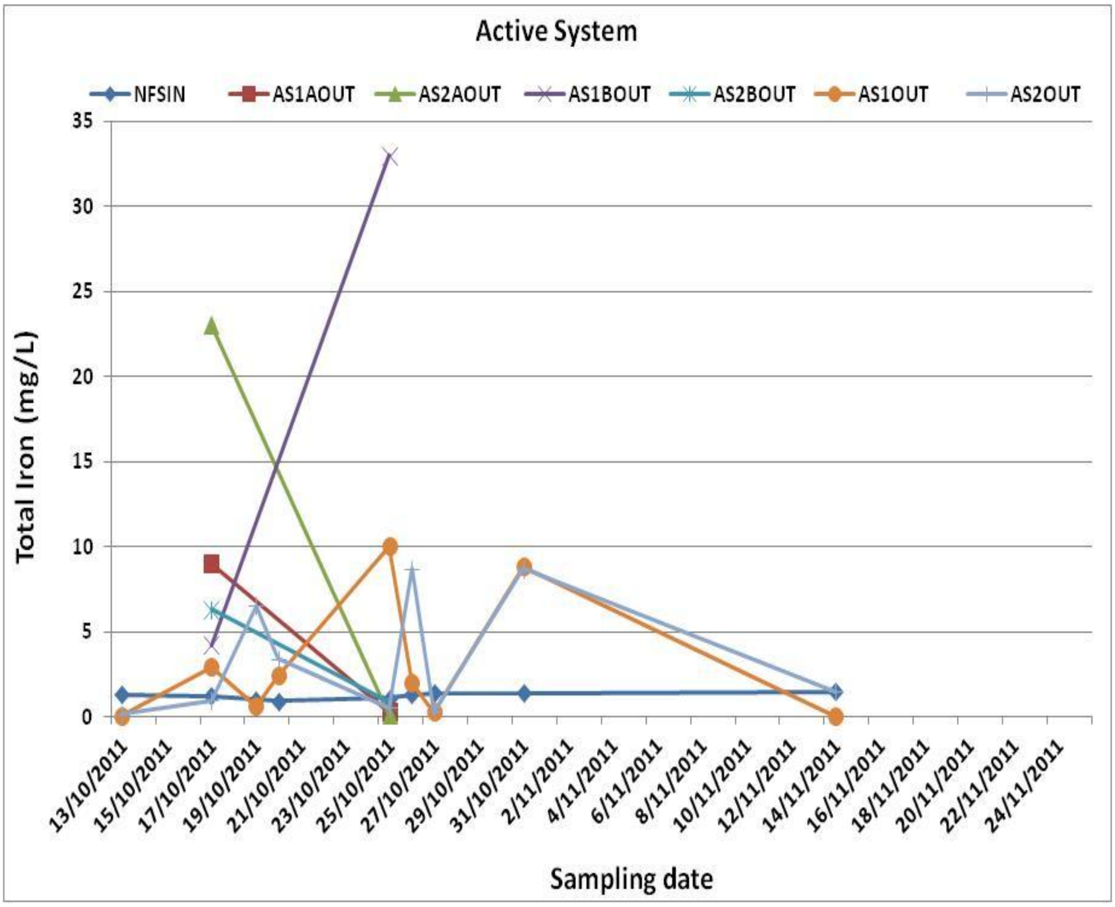


Comparators:

NFSIN (minimum)	0.8 milligrams per litre
NFSIN (maximum)	1.2 milligrams per litre

Trends: Very high removal efficiencies removed throughout the trial.

Chart 65: Active System, Total Iron



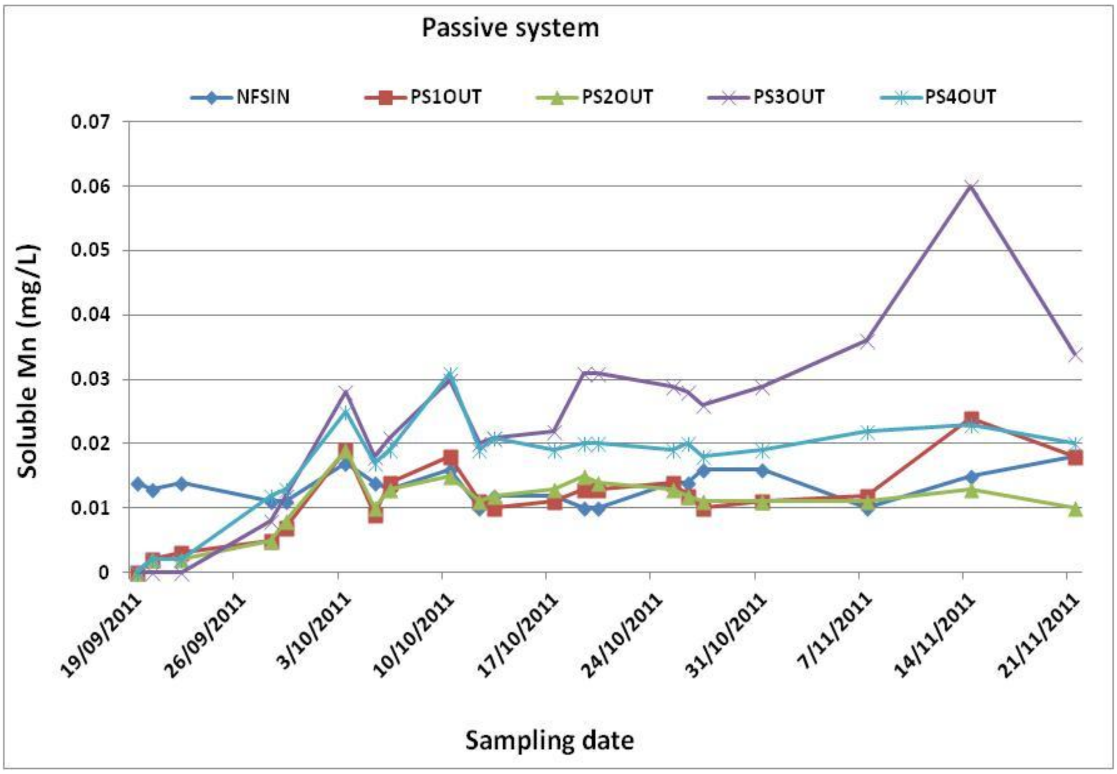
Comparators:

NFSIN (minimum)	0.92 milligrams per litre
NFSIN (maximum)	1.5 milligrams per litre
AWDG	0.3 milligrams per litre (aesthetic)
Irrigation	0.2 milligrams per litre

Trends: Variable, but final outlet concentrations from both systems are significantly higher than inlet concentrations and much higher than the soluble iron concentrations. This indicates there is some release of particulate iron from the system.

4.25 MANGANESE

Chart 66: Passive System, Soluble Manganese



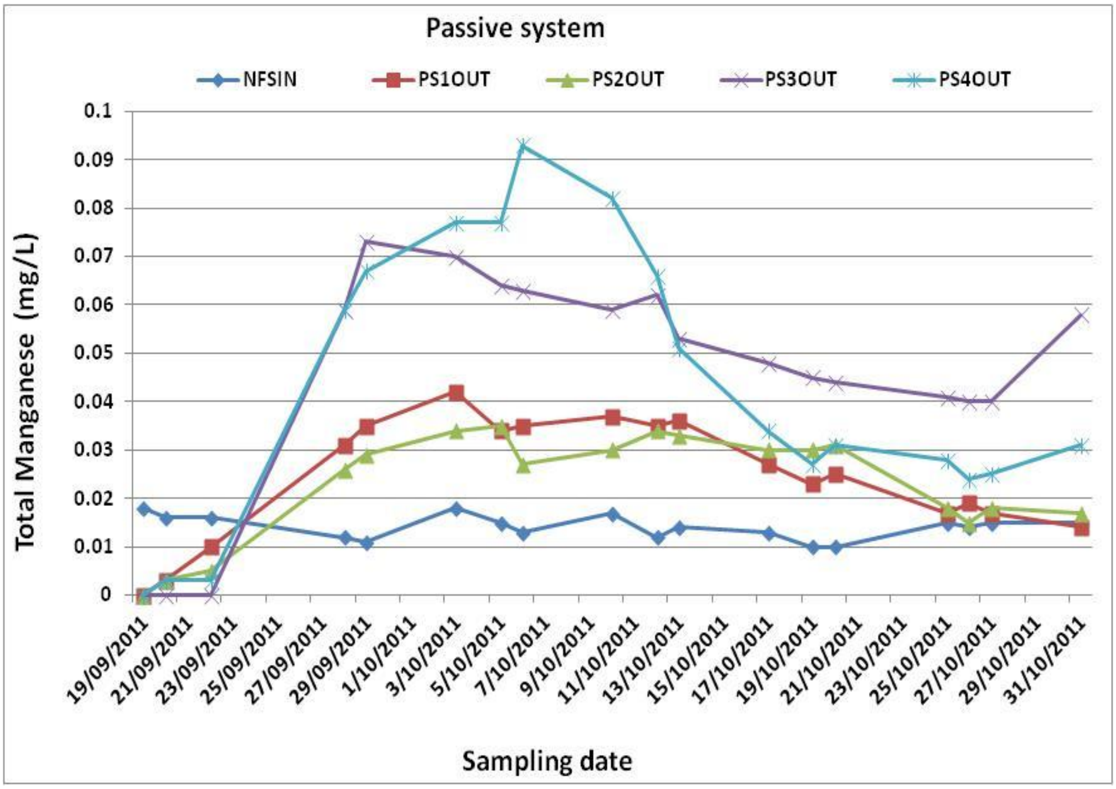
Comparators:

NFSIN (minimum)	0.01 milligrams per litre
NFSIN (maximum)	0.018 milligrams per litre
AEP (95%)	1.9 milligrams per litre

Trends: Effective removal of manganese for the first three sampling times. Systems PS3 and PS4 released soluble manganese after that time, reaching a maximum 0.06 milligrams per litre for PS3 on 14 November. Minimal differences between soluble manganese concentrations in inlet and outlet streams after the first five samplings for PS1 and PS2.

Concentrations of soluble manganese in all sample streams were well below the aquatic ecosystem trigger value of 1.9 milligrams per litre (95% protection of species).

Chart 67: Passive System, Total Manganese

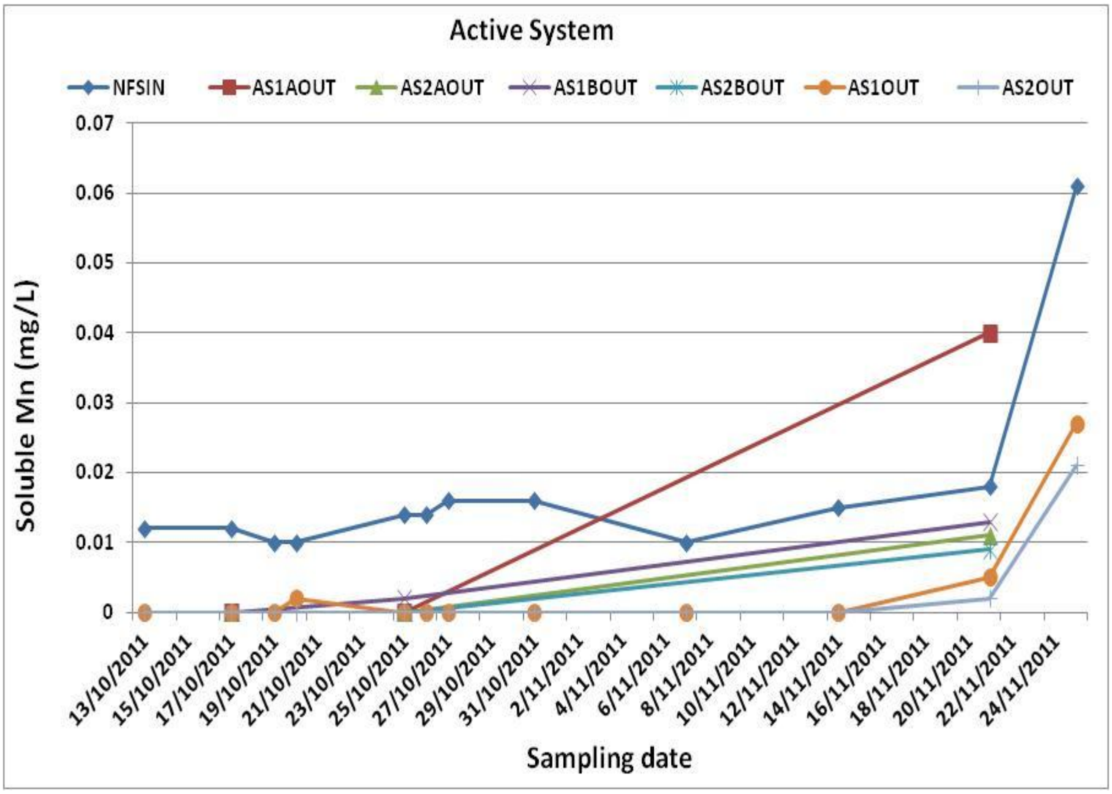


Comparators:

NFSIN (minimum)	0.01 milligrams per litre
NFSIN (maximum)	0.018 milligrams per litre
ADWG	0.5 milligrams per litre
Livestock	No limit
Irrigation	0.2 milligrams per litre

Trends: Effective removal of manganese for the first three sampling times. All systems released soluble manganese after that time, reaching a maximum of approximately 0.09 milligrams per litre in the outlet stream of system PS4 after two weeks. Declining trends thereafter. All samples well below guideline limits.

Chart 68: Active System, Soluble Manganese

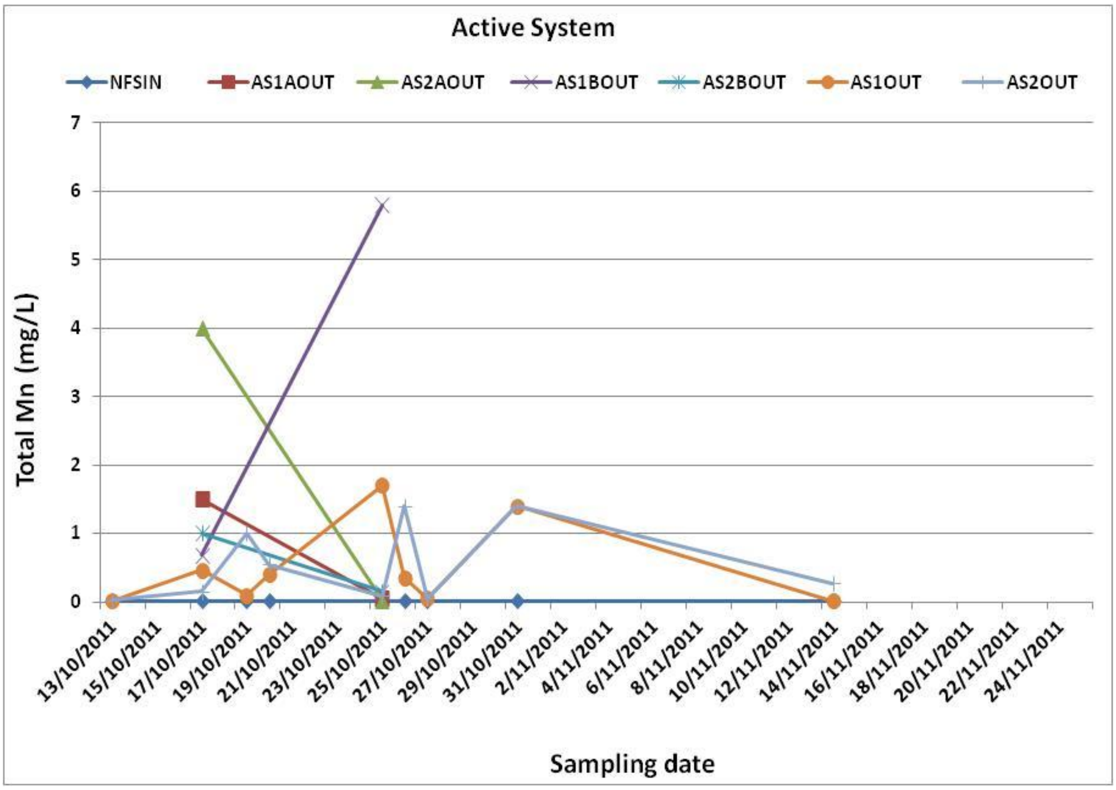


Comparators:

NFSIN (minimum)	0.01 milligrams per litre
NFSIN (maximum)	0.061 milligrams per litre
AEP (95%)	1.9 milligrams per litre

Trends: Effective removal of soluble manganese from all systems until 22 November 2011. All samples well below guideline limits. Results indicate > 90% of removal of soluble Mn until 14 November 2011, then between 40-60% removals thereafter. Only one sample contained significantly high levels of manganese *AS1AOUT*, however it was concluded it was more likely to be an outlier, caused by an sampling error.

Chart 69: Active System, Total Manganese



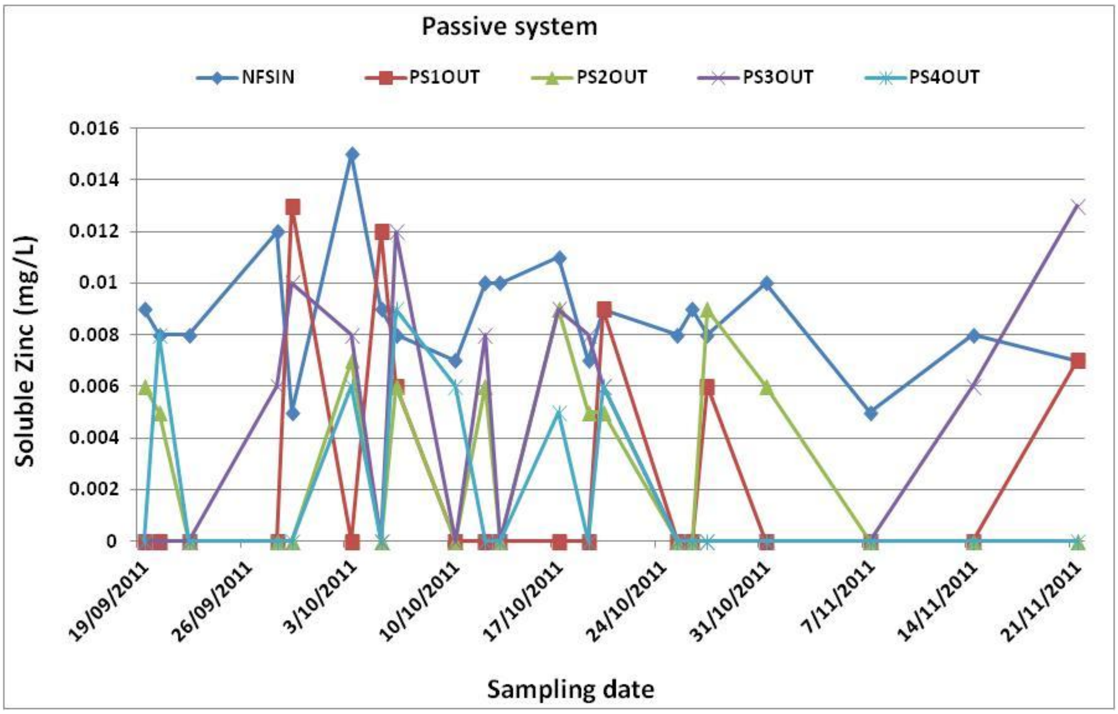
Comparators:

NFSIN (minimum)	0.01 milligrams per litre
NFSIN (maximum)	0.018 milligrams per litre
ADWG	0.5 milligrams per litre
Livestock	No limit
Irrigation	0.2 milligrams per litre

Trends: Concentrations in outlet streams are variable, but usually higher than the inlet stream and soluble manganese concentrations. This indicates the presence of some particulate manganese in the outlet streams.

4.26 ZINC

Chart 70: Passive System, Soluble Zinc

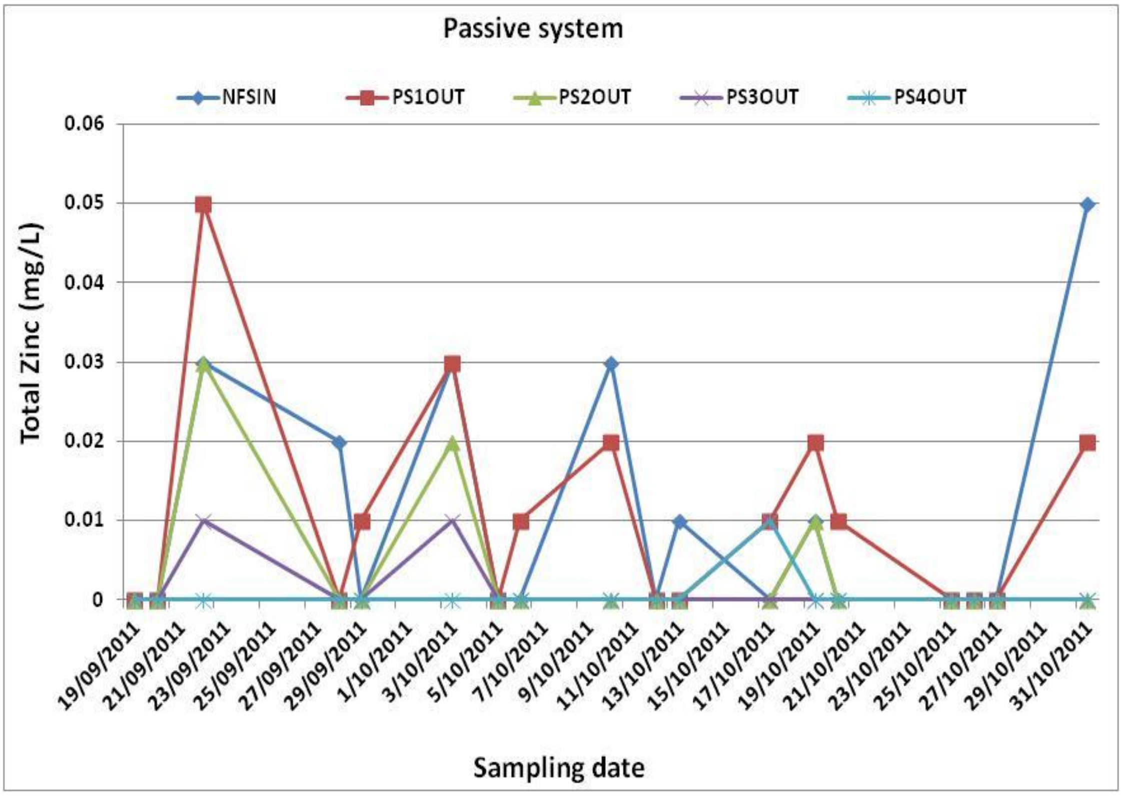


Comparators:

NFSIN (minimum)	0.005 milligrams per litre
NFSIN (maximum)	0.015 milligrams per litre
AEP (95%)	0.008 milligrams per litre

Trends: Variable performance, but generally effective removal of soluble zinc. Inlet stream concentrations occasionally exceed the aquatic ecosystem trigger value of 0.008 milligrams per litre (95% protection of species).

Chart 71: Passive System, Total Zinc

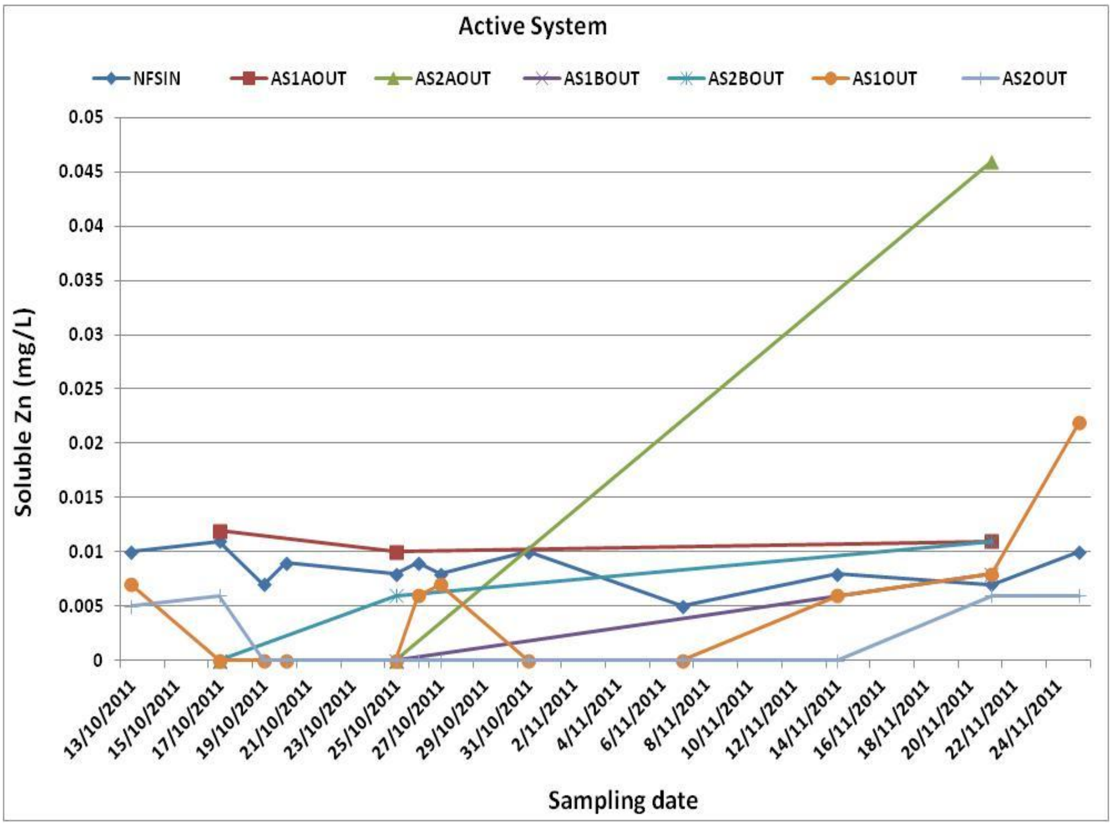


Comparators:

NFSIN (minimum)	<0.01 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
ADWG	3 milligrams per litre (aesthetic limit)
Livestock	20 milligrams per litre
Irrigation	2 milligrams per litre

Trends: Highly variable in all sample streams. All values well below human and livestock drinking water and irrigation water guidelines.

Chart 72: Active System, Soluble Zinc

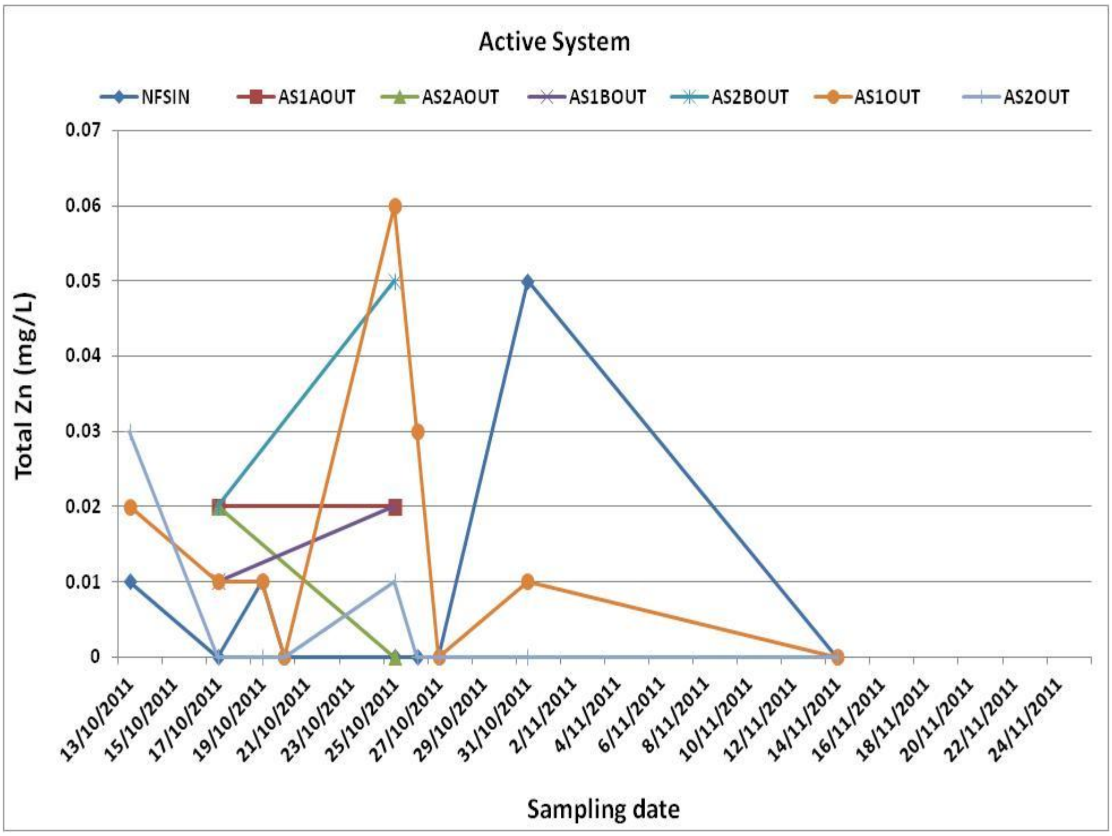


Comparators:

NFSIN (minimum)	0.005 milligrams per litre
NFSIN (maximum)	0.012 milligrams per litre
AEP (95%)	0.008 milligrams per litre

Trends: Variable performance, but generally effective in removing soluble zinc. Concentrations in final outlet streams are less than inlet stream concentrations for all but the final sample from system AS1.

Chart 73: Active System, Total Zinc



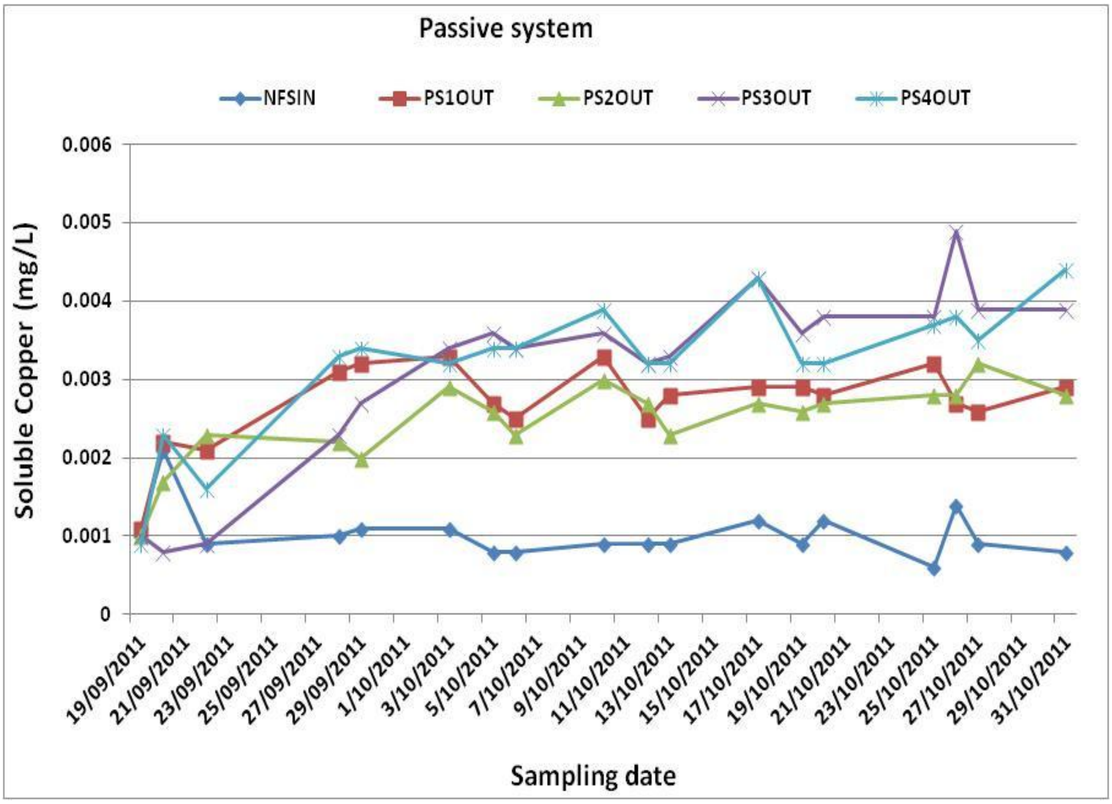
Comparators:

NFSIN (minimum)	<0.01 milligrams per litre
NFSIN (maximum)	0.05 milligrams per litre
AWDG	3 milligrams per litre (aesthetic limit)
Livestock	20 milligrams per litre
Irrigation	2 milligrams per litre

Trends: Highly variable in all sample streams. All values well below human and livestock drinking water and irrigation water guidelines.

4.27 COPPER

Chart 74: Passive System, Soluble Copper

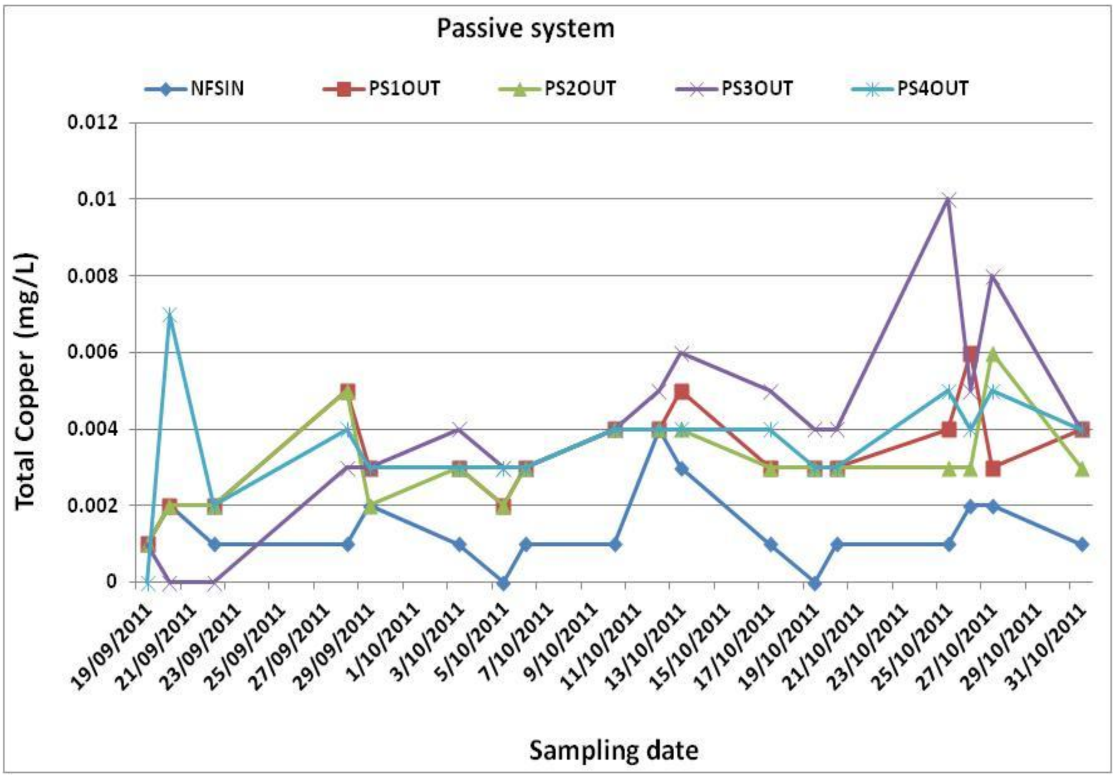


Comparators:

NFSIN (minimum)	0.0005 milligrams per litre
NFSIN (maximum)	0.0015 milligrams per litre
AEP (95%)	0.0014 milligrams per litre

Trends: Release of copper from all systems. Generally effluent concentrations exceed the aquatic ecosystem trigger value of 0.0014 milligrams per litre (95% protection of species). The concentration of releases seems to correlate closely to proportion of NUA in the blend, i.e. 40% blend effluent is higher than 25% blend.

Chart 75: Passive System, Total Copper

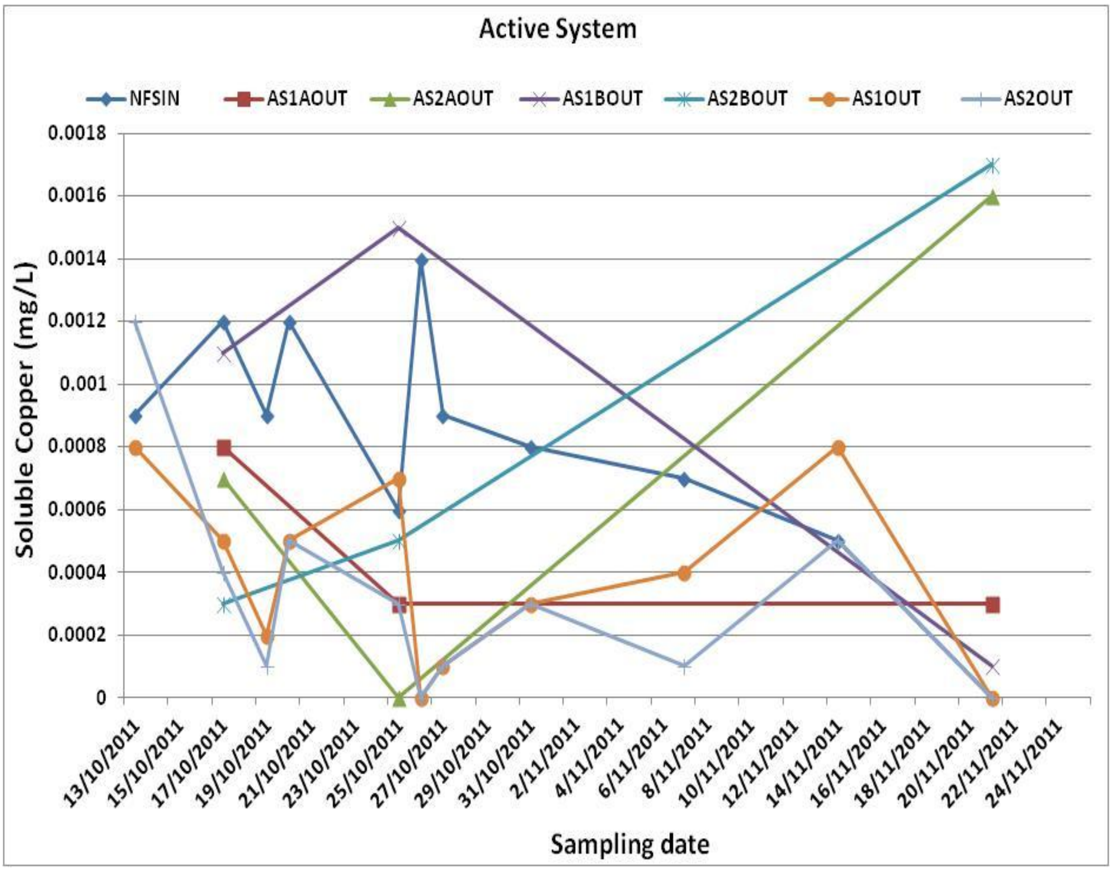


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.004 milligrams per litre
ADWG	3 milligrams per litre (aesthetic limit)
Livestock	20 milligrams per litre
Irrigation	2 milligrams per litre

Trends: Release of copper on most occasions, but all values well below human and livestock drinking water and irrigation water guidelines.

Chart 76: Active System, Soluble Copper

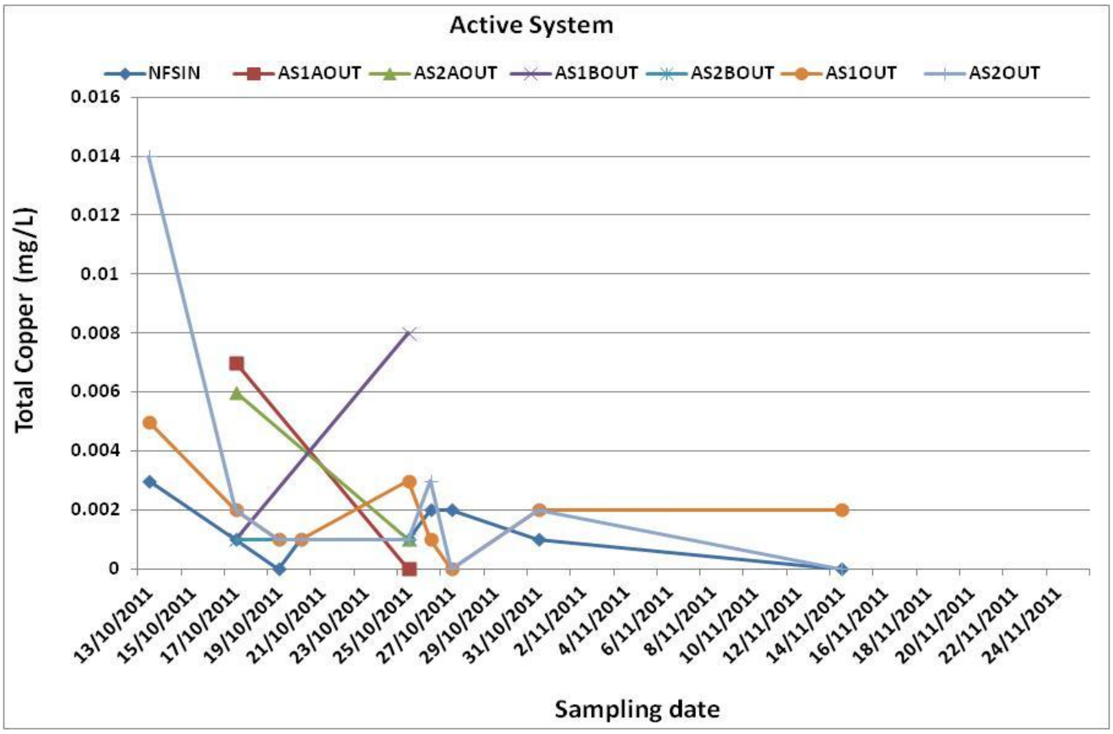


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0014 milligrams per litre
AEP (95%)	0.0014 milligrams per litre

Trends: Variable performance, but outlet stream concentrations are below the aquatic ecosystem protection trigger value (95% protection of species) of 0.0014 milligrams per litre on most occasions.

Chart 77: Active System, Total Copper



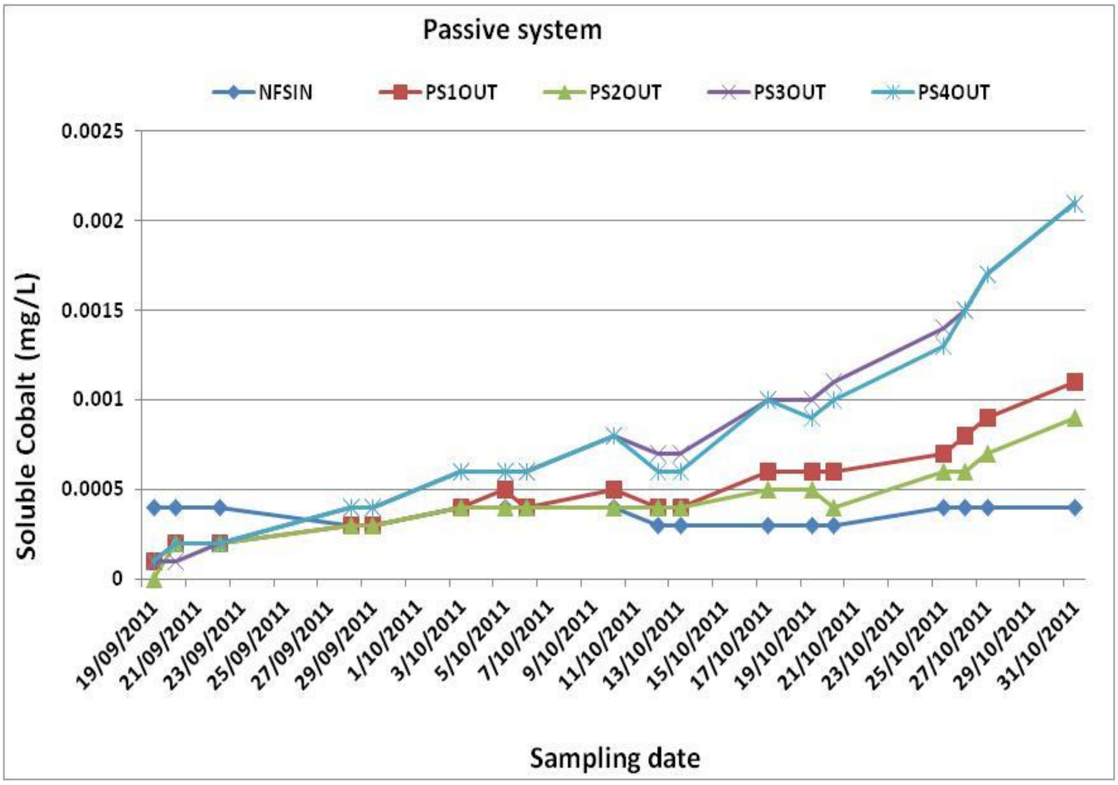
Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.003 milligrams per litre
ADWG	3 milligrams per litre (aesthetic limit)
Livestock	20 milligrams per litre
Irrigation	2 milligrams per litre

Trends: Release of copper on most occasions, but all values well below human and livestock drinking water and irrigation water guidelines.

4.28 COBALT

Chart 78: Passive System, Soluble Cobalt

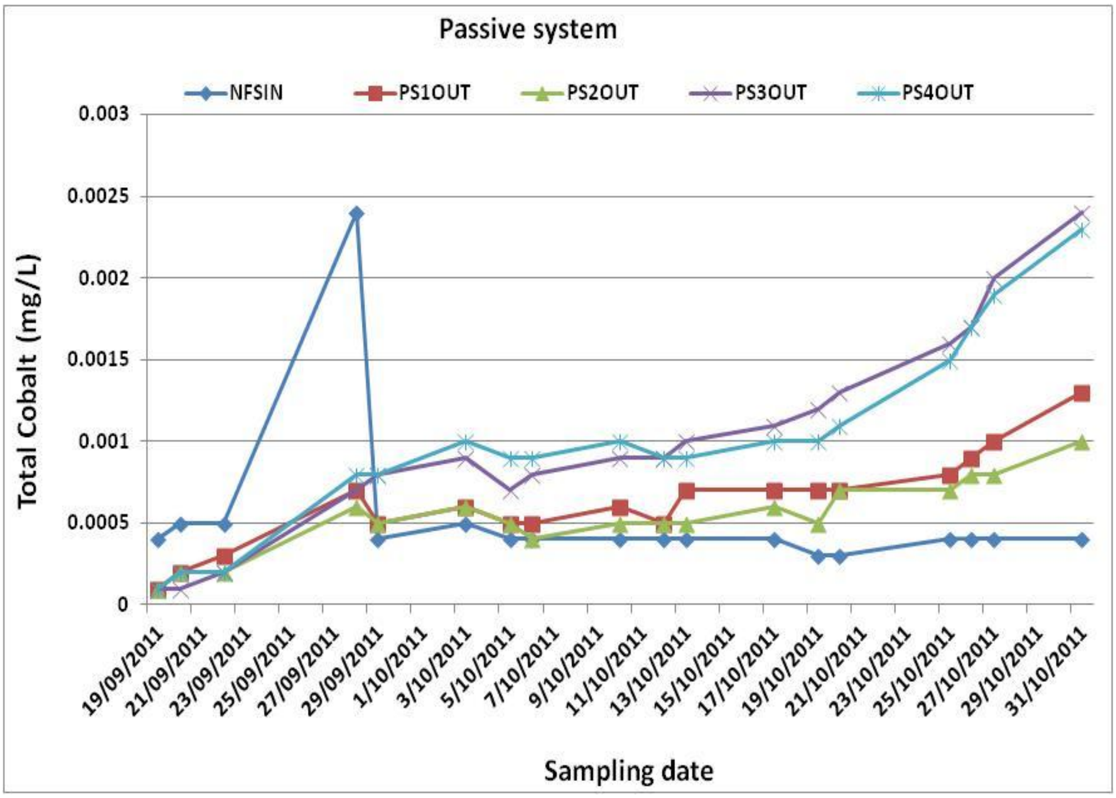


Comparators:

NFSIN (minimum)	0.0003 milligrams per litre
NFSIN (maximum)	0.0004 milligrams per litre

Trends: Significant removal of soluble cobalt for the first three samples, then a steady release of soluble cobalt from all systems, particularly PS3 and PS4. Cobalt release increases with increasing NUA blend content.

Chart 79: Passive System, Total Cobalt

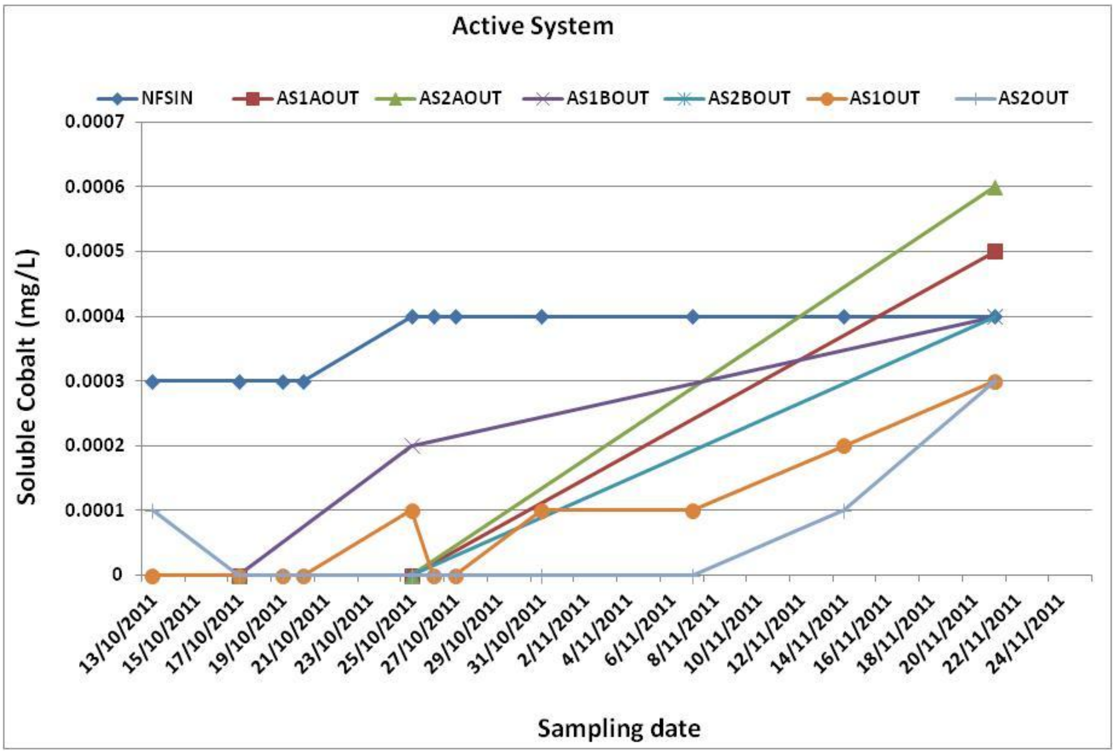


Comparators:

NFSIN (minimum)	0.0003 milligrams per litre
NFSIN (maximum)	0.0024 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.05 milligrams per litre

Trends: Similar behaviour to soluble cobalt; initial removal of cobalt followed by release in increasing concentrations (especially systems P3 and P4). Concentrations in all streams are well below the livestock drinking water and irrigation water guidelines.

Chart 80: Active System, Soluble Cobalt

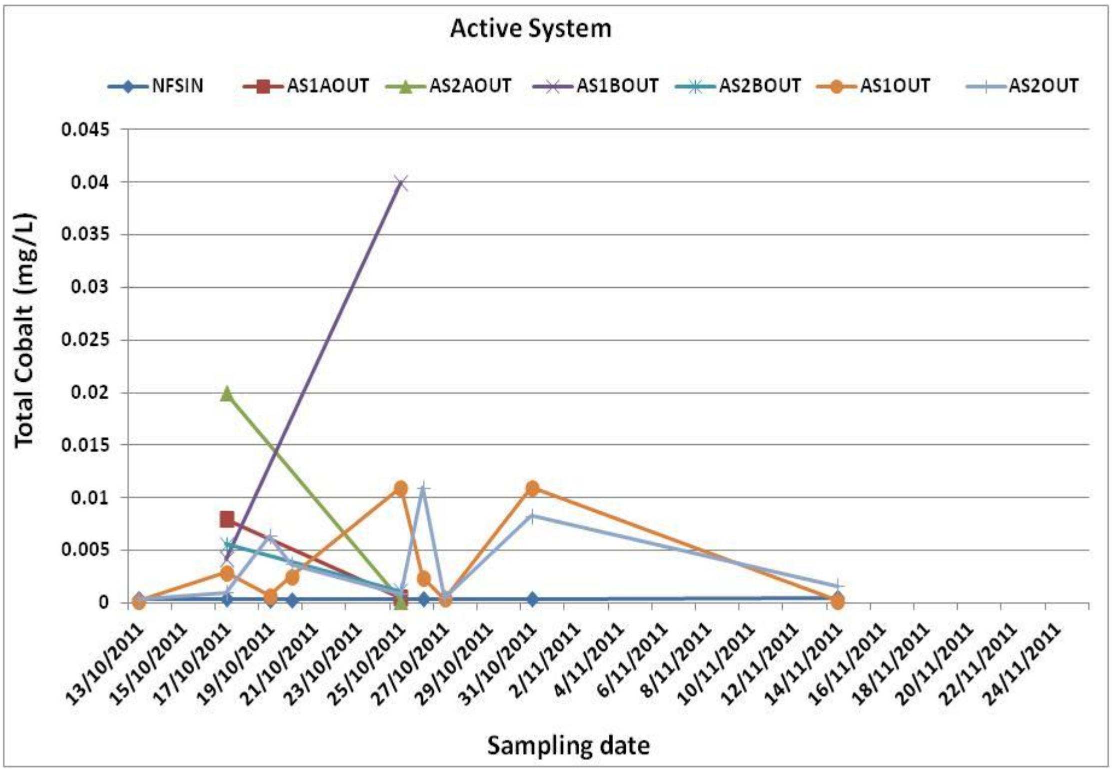


Comparators:

NFSIN (minimum)	0.0003 milligrams per litre
NFSIN (maximum)	0.0004 milligrams per litre

Trends: Significant removal of soluble cobalt in all systems for the first two weeks. Concentrations steadily increase, but final outlet streams' concentrations of soluble cobalt are less than inlet stream concentrations throughout the monitoring period.

Chart 81: Active System, Total Cobalt



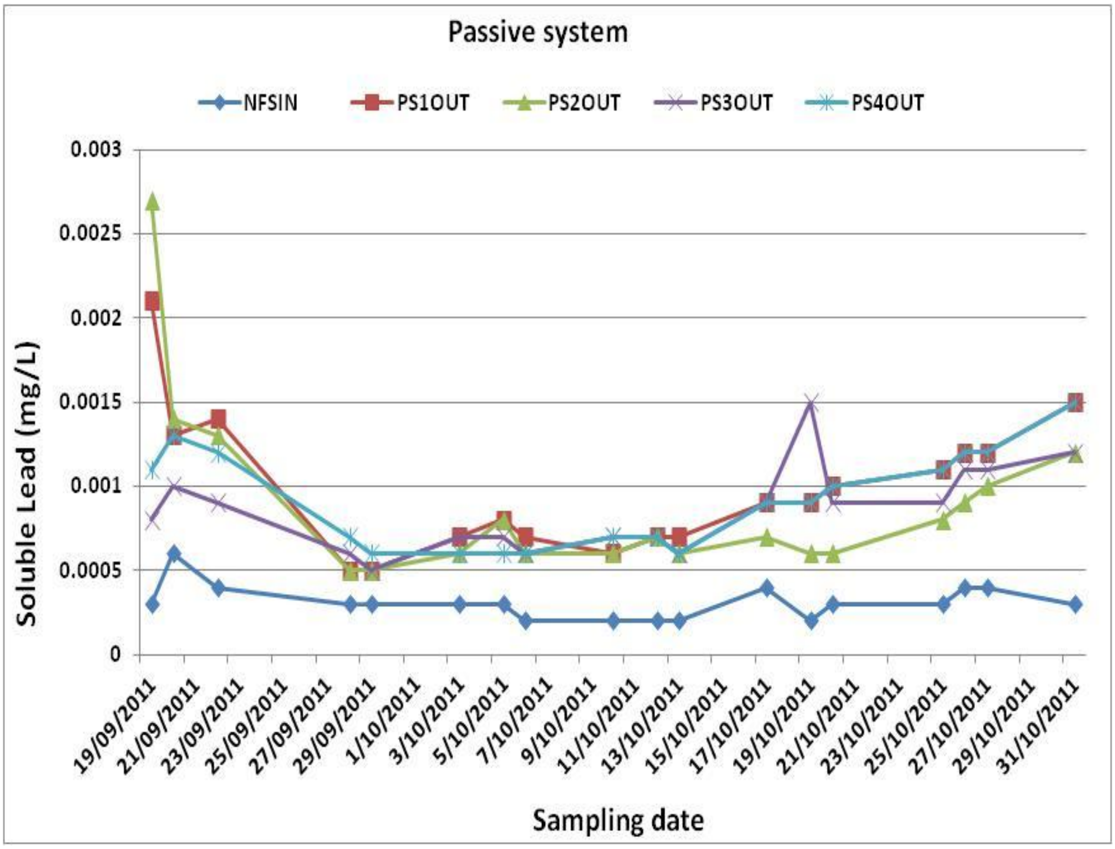
Comparators:

NFSIN (minimum)	0.0003 milligrams per litre
NFSIN (maximum)	0.0024 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.05 milligrams per litre

Trends: Final outlet streams from both systems contained higher total cobalt concentrations than the inlet streams. As the total cobalt concentrations are significantly higher than soluble cobalt concentrations, most of the released cobalt appears to be present in particulate form.

4.29 LEAD

Chart 82: Passive System, Soluble Lead

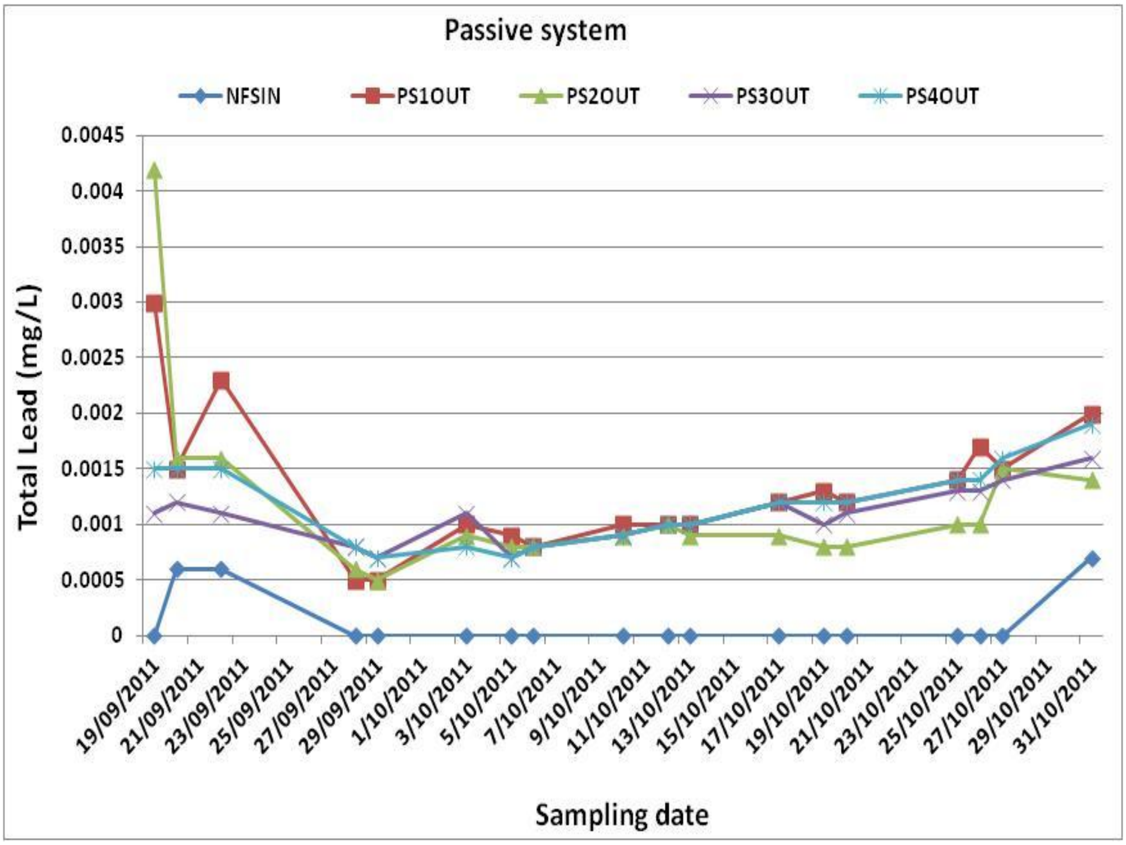


Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0006 milligrams per litre
AEP (95%)	0.0034 milligrams per litre

Trends: Release of soluble lead from all systems, especially the initial samples collected from systems PS1 and PS2. Increasing trend towards the end of the monitoring period. However, concentrations of soluble lead in all samples are well below the aquatic ecosystem protection trigger value (95% protection of species).

Chart 83: Passive System, Total Lead

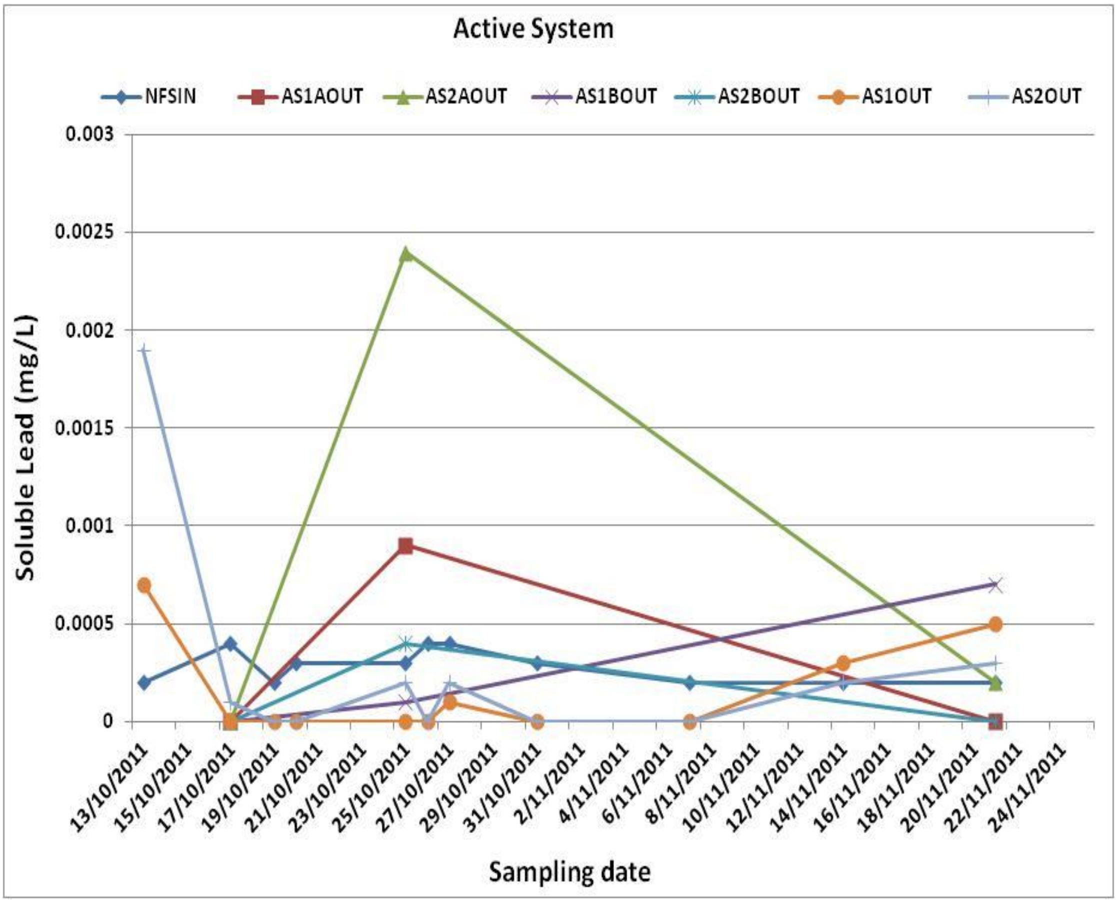


Comparators:

NFSIN (minimum)	<0.0005 milligrams per litre
NFSIN (maximum)	0.0007 milligrams per litre
ADWG	0.01 milligrams per litre
Livestock	0.1 milligram per litre
Irrigation	2 milligrams per litre

Trends: Release of lead from all systems, especially at the first sampling. Increasing trend towards the end of the monitoring period. Concentrations of total lead in all samples were well below the human and livestock drinking water and irrigation water guideline values.

Chart 84: Active System, Soluble Lead

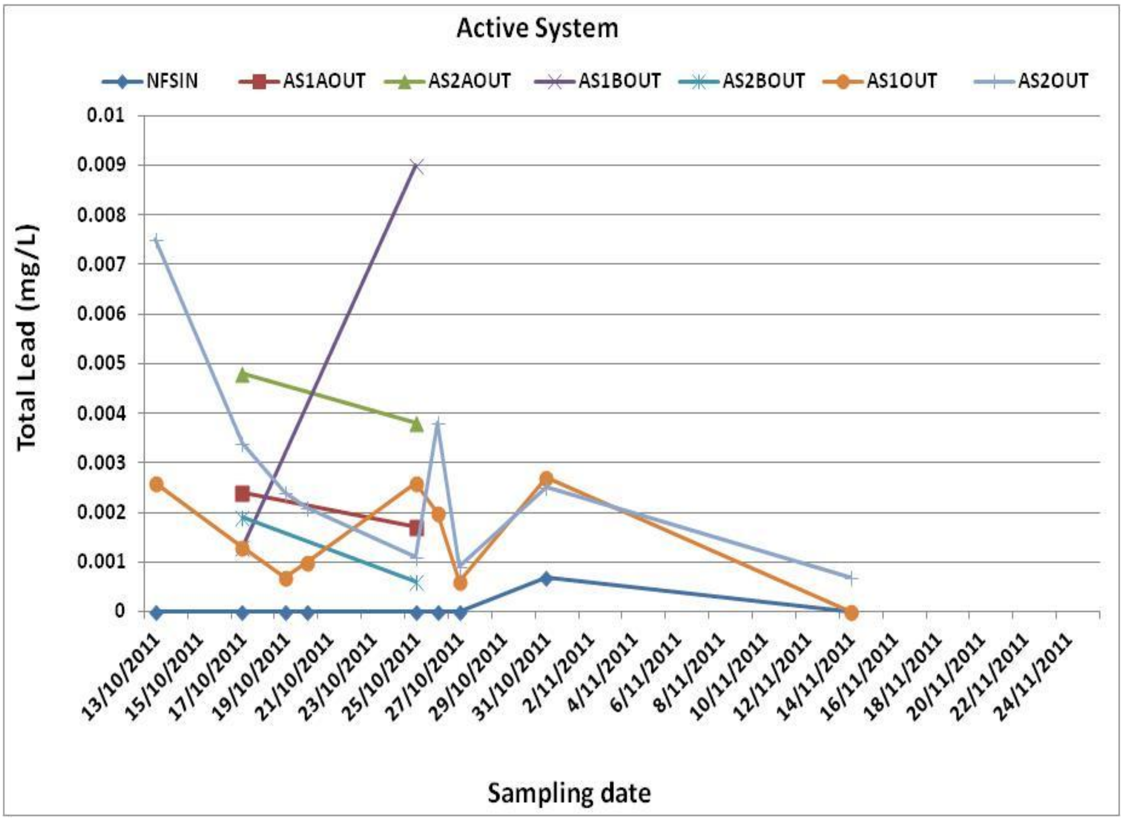


Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0004 milligrams per litre
AEP (95%)	0.0034 milligrams per litre

Trends: Variable performance. Concentrations of soluble lead in all samples are well below the aquatic ecosystem protection trigger value (95% protection of species).

Chart 85: Active System, Total Lead



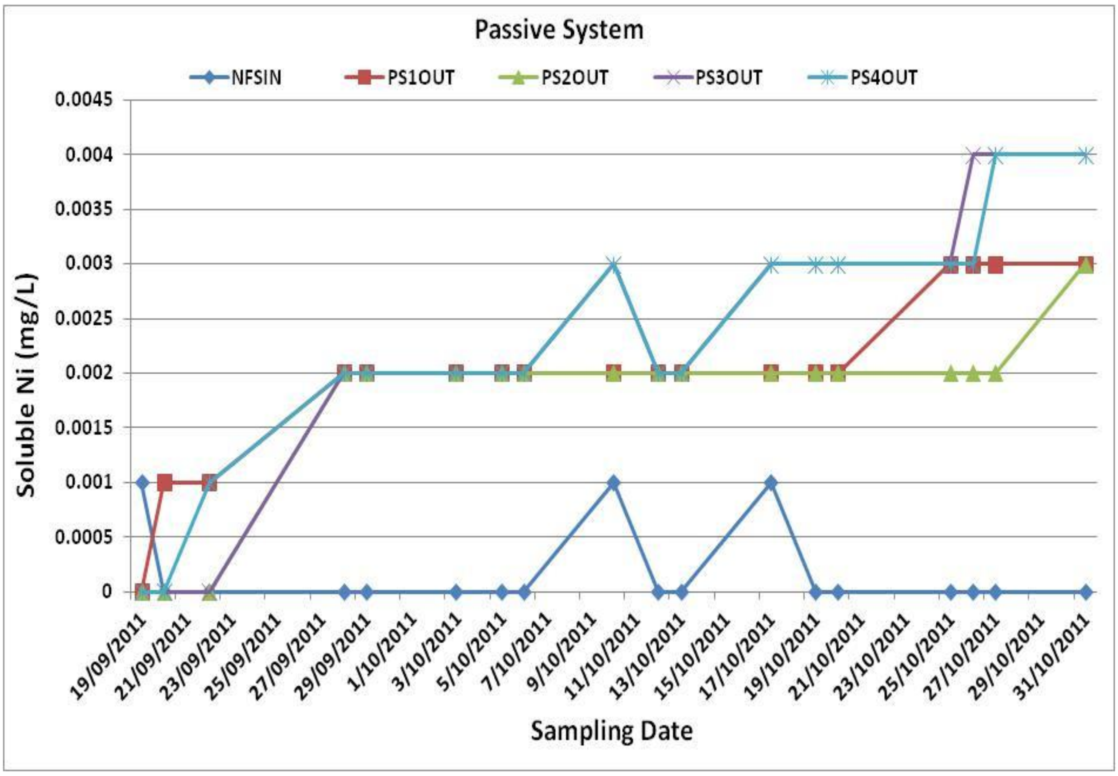
Comparators:

NFSIN (minimum)	<0.0005 milligrams per litre
NFSIN (maximum)	0.0007 milligrams per litre
ADWG	0.01 milligrams per litre
Livestock	0.1 milligram per litre
Irrigation	2 milligrams per litre

Trends: Release of lead from all systems, especially at the first sampling. Concentrations of total lead in all samples were well below the human and livestock drinking water and irrigation water guideline values.

4.30 NICKEL

Chart 86: Passive System, Soluble Nickel

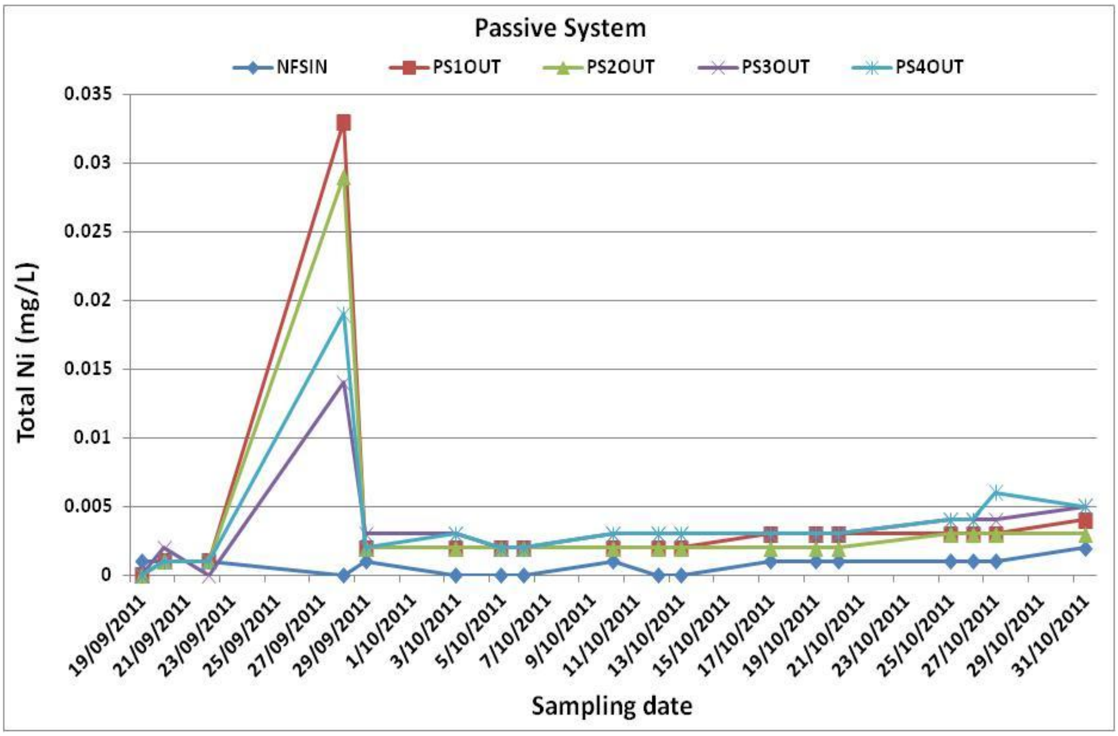


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.001 milligrams per litre
AEP (95%)	0.011 milligrams per litre

Trends: Release of nickel from all systems with an increasing trend. All nickel concentrations in all outlet streams were below the aquatic ecosystem trigger value (95% protection of species) of 0.011 milligrams per litre.

Chart 87: Passive System, Total Nickel

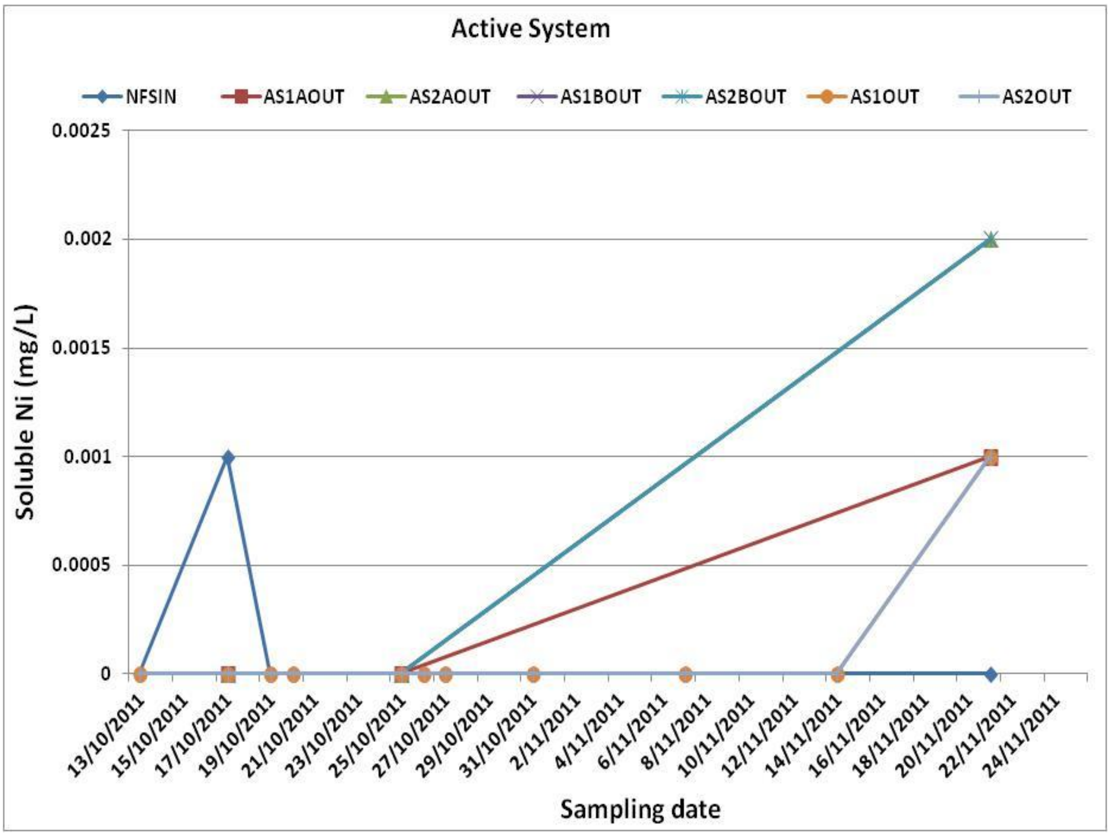


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.001 milligrams per litre
ADWG	0.02 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.2 milligrams per litre

Trends: Anomalous values for all four outlet streams in the samples collected on 27 September 2011. Otherwise, trends were similar to soluble nickel. Concentrations of total nickel in all samples were well below the human and livestock drinking water and irrigation water guideline values.

Chart 88: Active System, Soluble Nickel

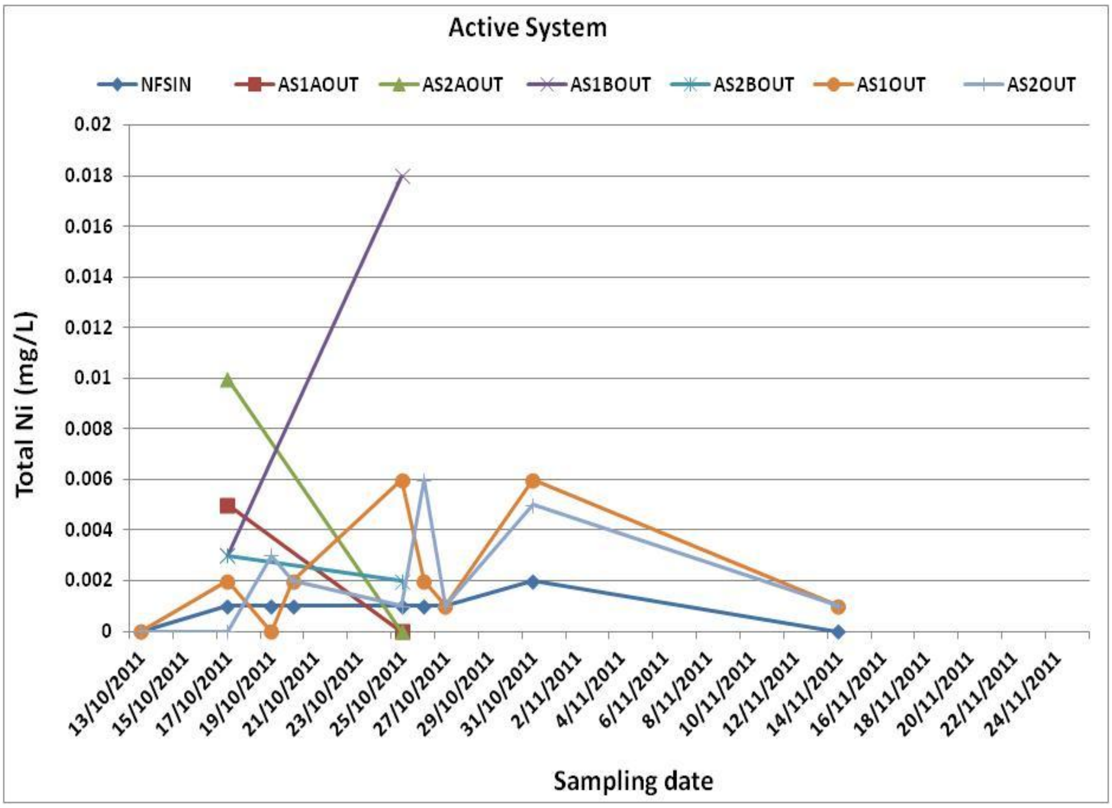


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.001 milligrams per litre
AEP (95%)	0.011 milligrams per litre

Trends: Very low concentrations in all samples.

Chart 89: Active System, Total Nickel



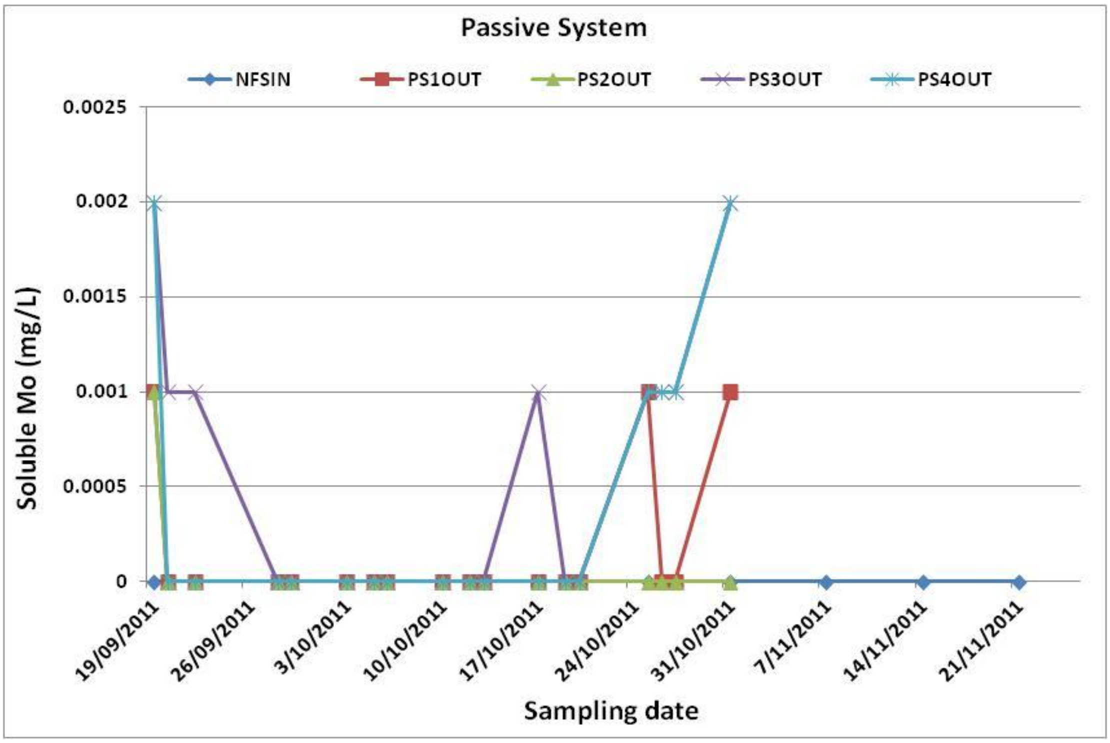
Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.002 milligrams per litre
ADWG	0.02 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.2 milligrams per litre

Trends: Release of nickel on most occasions, but concentrations are well below the human and livestock drinking water and irrigation water guideline values.

4.31 MOLYBDENUM

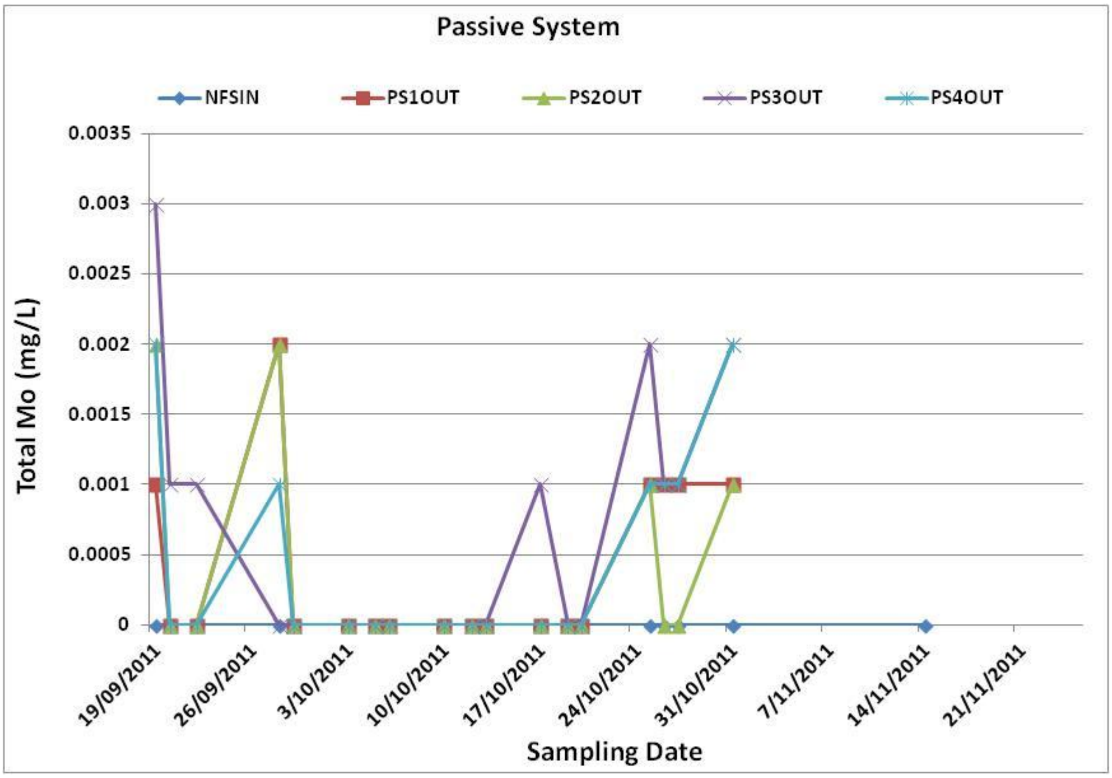
Chart 90: Passive System, Soluble Molybdenum



Comparators:
NFSIN (minimum) <0.001 milligrams per litre
NFSIN (maximum) <0.001 milligrams per litre

Trends: Release of small amounts of molybdenum from all systems, maximum value 0.002 milligrams per litre.

Chart 91: Passive System, Total Molybdenum

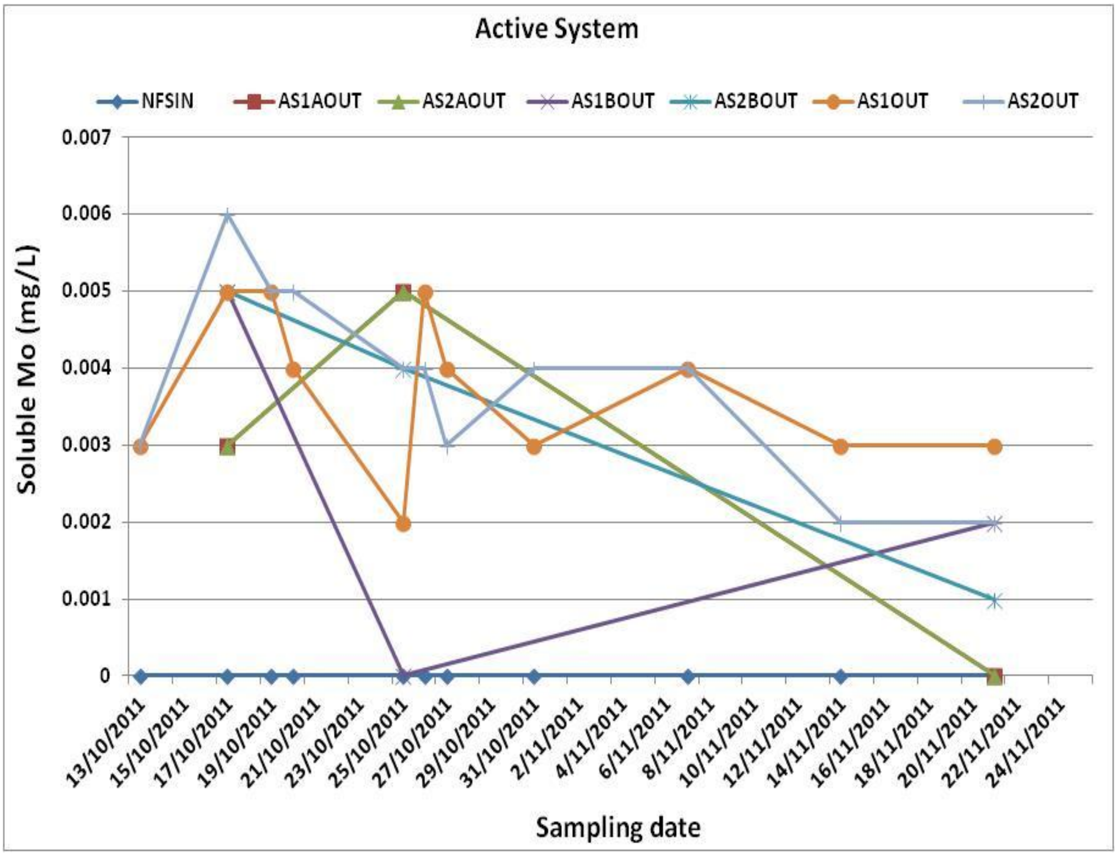


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	<0.001 milligrams per litre
ADWG	0.05 milligrams per litre
Livestock	0.15 milligrams per litre
Irrigation	0.01 milligrams per litre

Trends: Release of small amounts of molybdenum from all systems, maximum value 0.003 milligrams per litre. All concentrations are well below human and livestock drinking water and irrigation water guidelines.

Chart 92: Active System, Soluble Molybdenum

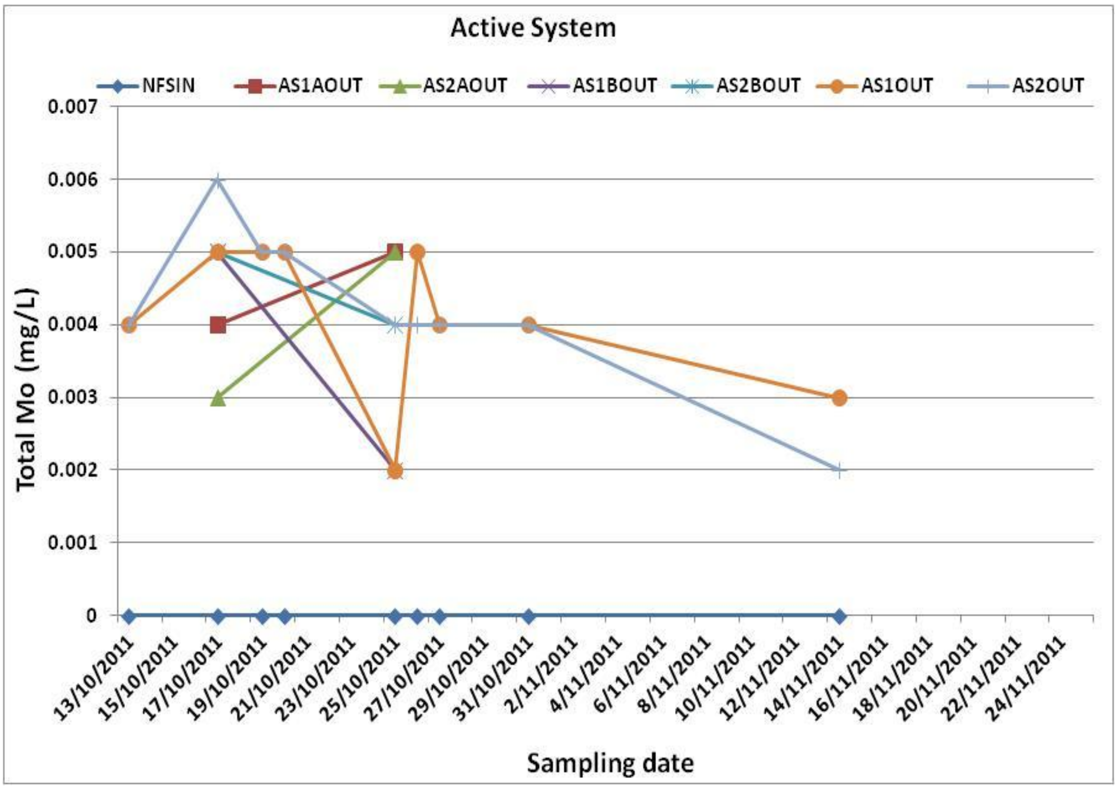


Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	<0.001 milligrams per litre

Trends: Release of small amounts of molybdenum from all systems, maximum value 0.006 milligrams per litre.

Chart 93: Active System, Total Molybdenum



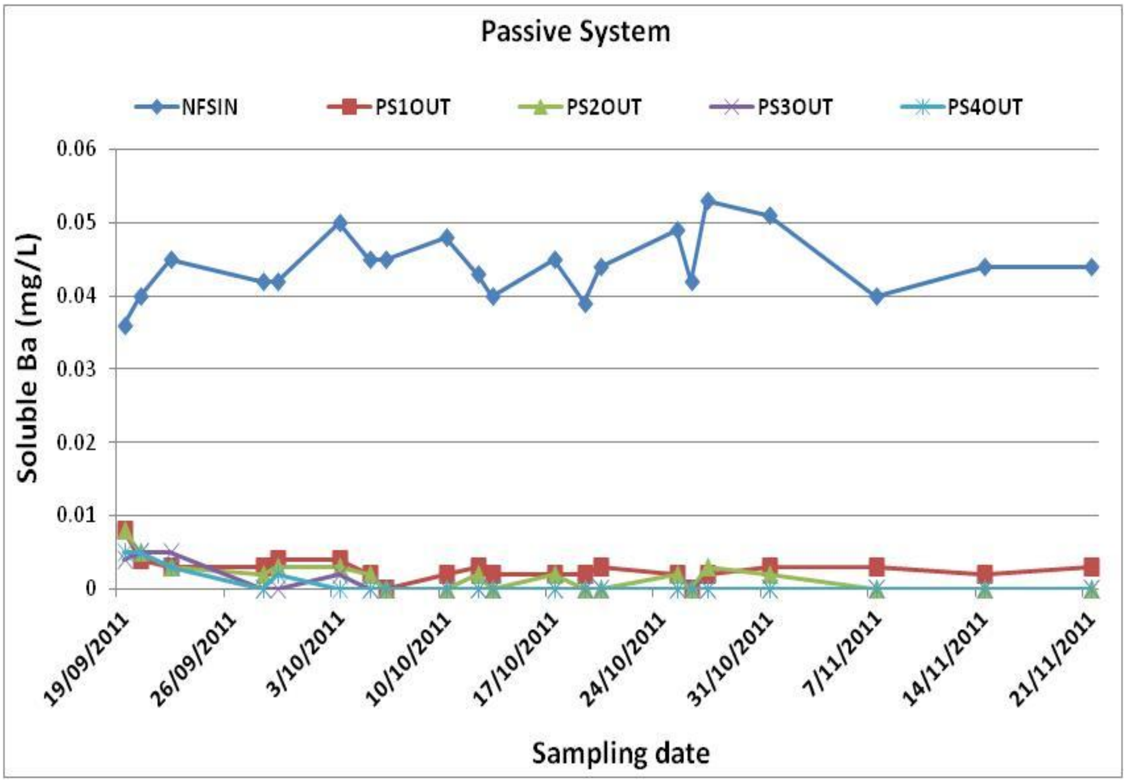
Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	<0.001 milligrams per litre
ADWG	0.05 milligrams per litre
Livestock	0.15 milligrams per litre
Irrigation	0.01 milligrams per litre

Trends: Release of small amounts of molybdenum from all systems, maximum value 0.006 milligrams per litre. All concentrations are well below human and livestock drinking water and irrigation water guidelines.

4.32 BARIUM

Chart 94: Passive System, Soluble Barium

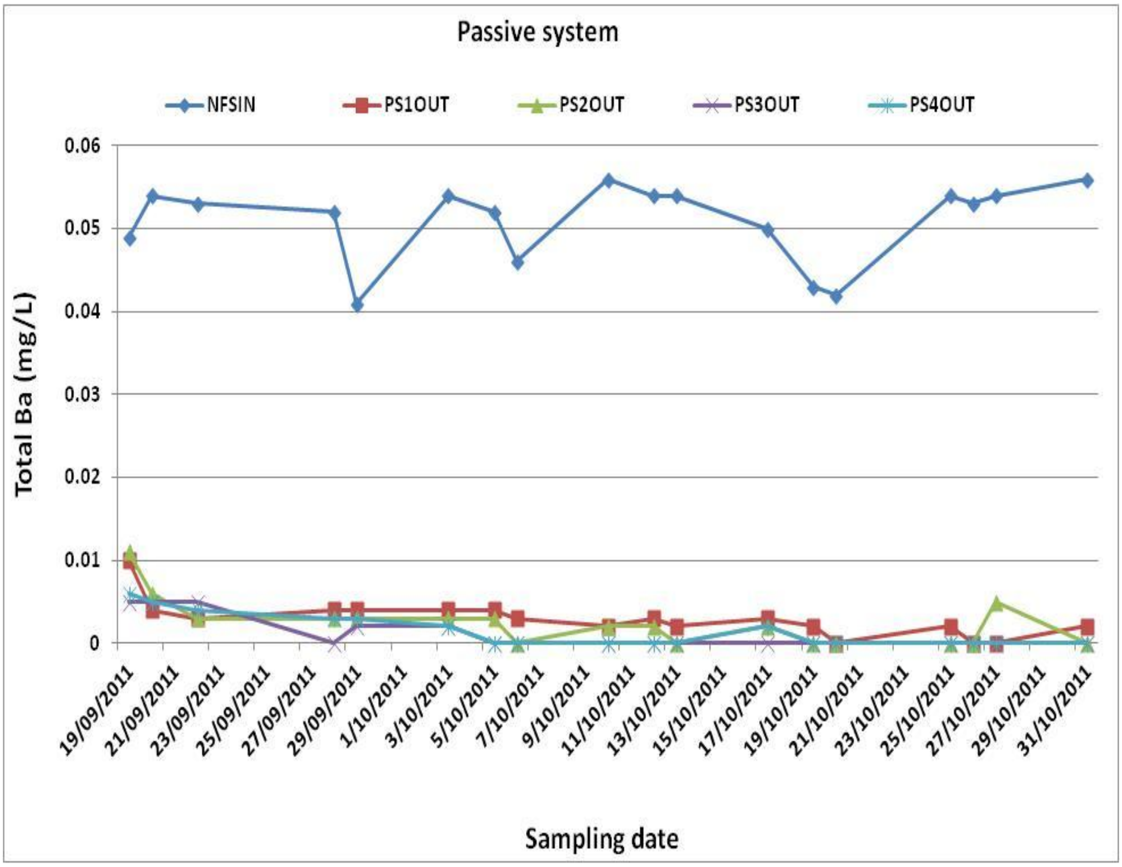


Comparators:

NFSIN (minimum)	0.036 milligrams per litre
NFSIN (maximum)	0.053 milligrams per litre

Trends: High removal efficiency of barium is all outlet sample streams.

Chart 95: Passive System, Total Barium

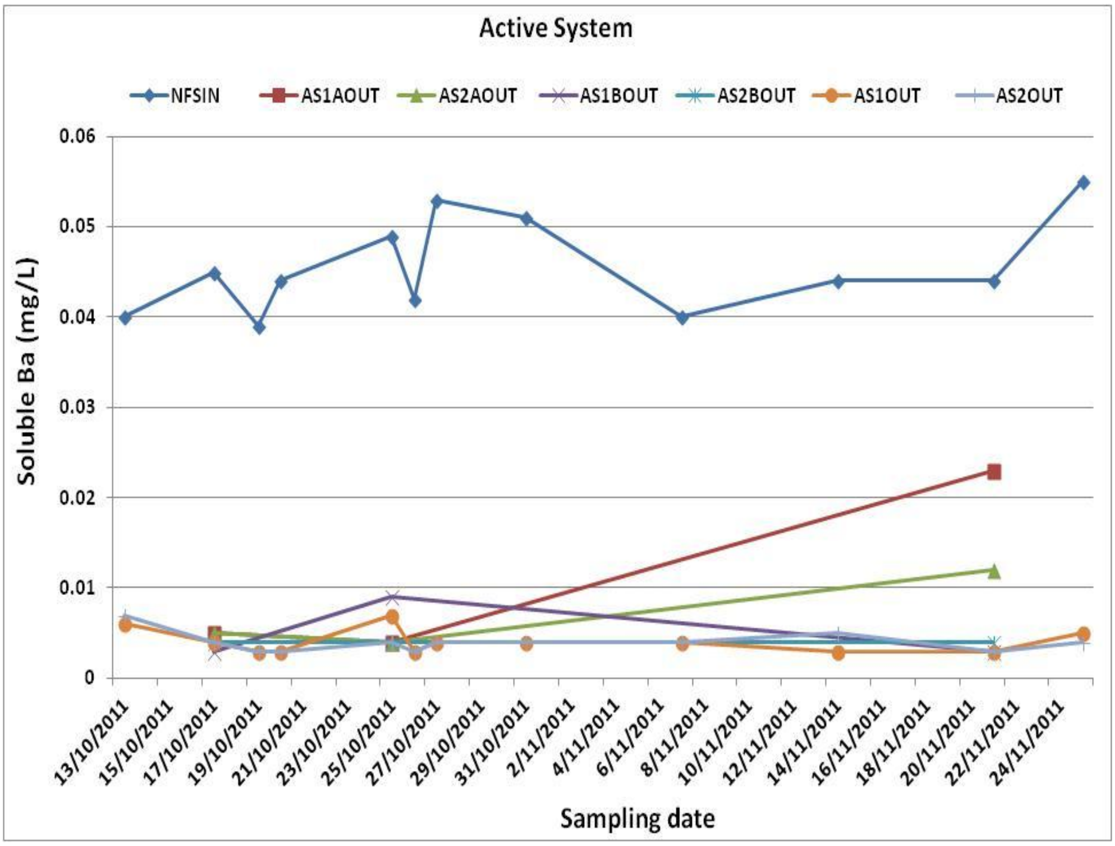


Comparators:

NFSIN (minimum)	0.041 milligrams per litre
NFSIN (maximum)	0.057 milligrams per litre
ADWG	0.7 milligrams per litre

Trends: High removal efficiency of barium is all outlet sample streams. Concentration in all stream are well below the ADWG guideline of 0.7 milligrams per litre.

Chart 96: Active System, Soluble Barium

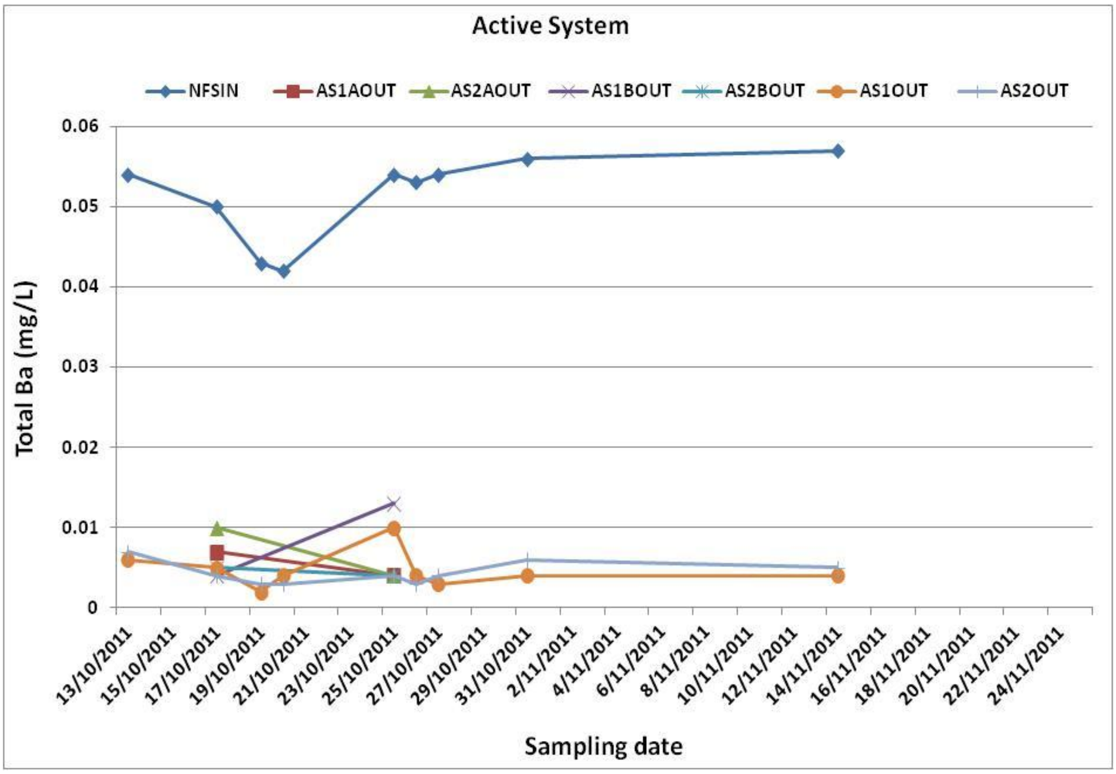


Comparators:

NFSIN (minimum)	0.036 milligrams per litre
NFSIN (maximum)	0.055 milligrams per litre

Trends: High removal efficiency of barium is all outlet sample streams.

Chart 97: Active System, Total Barium



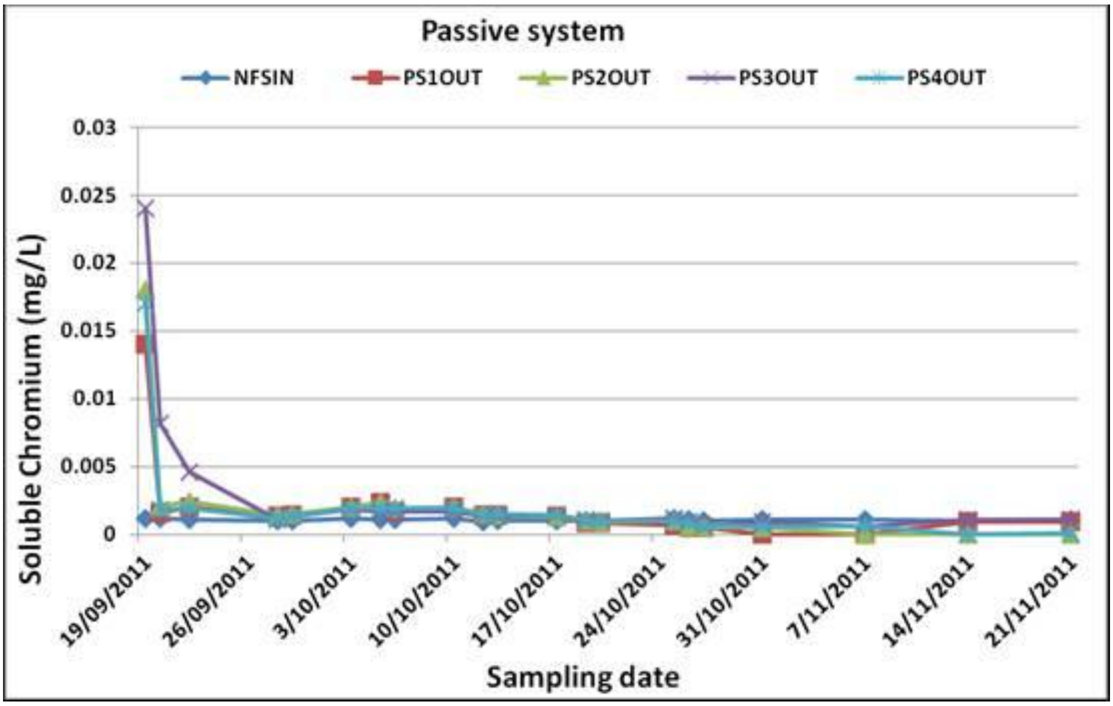
Comparators:

NFSIN (minimum)	0.041 milligrams per litre
NFSIN (maximum)	0.057 milligrams per litre
ADWG	0.7 milligrams per litre

Trends: High removal efficiency of barium is all outlet sample streams. Concentrations in all streams well below the ADWG guideline of 0.7 milligrams per litre.

4.33 CHROMIUM

Chart 98: Passive System, Soluble Chromium

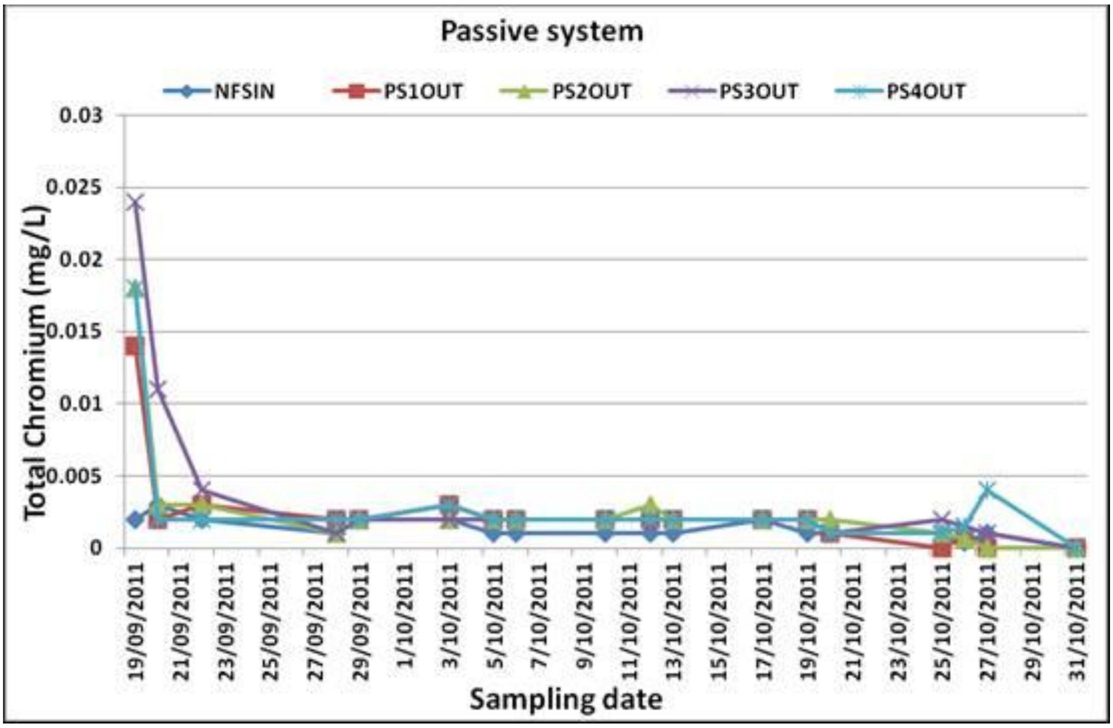


Comparators:

NFSIN (minimum)	0.0009 milligrams per litre
NFSIN (maximum)	0.0012 milligrams per litre

Trends: Rapid release of chromium in initial samplings. Very low thereafter.

Chart 99: Passive System, Total Chromium

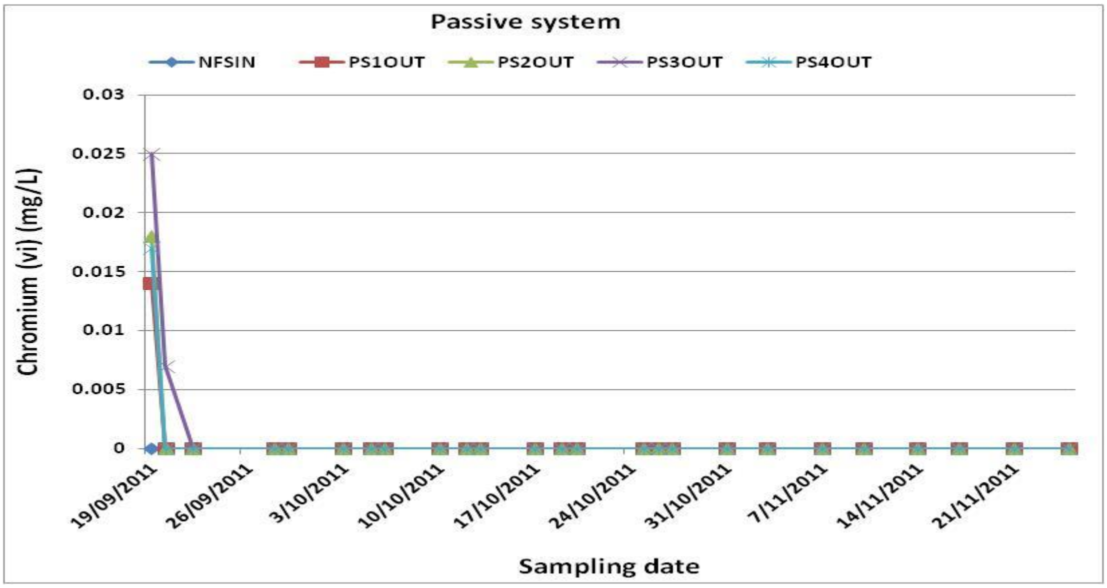


Comparators:

NFSIN (minimum)	0.0004 milligrams per litre
NFSIN (maximum)	0.003 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.1 milligrams per litre

Trends: Similar to soluble chromium results; initial rapid release of chromium from all systems.

Chart 100: Passive System, Hexavalent Chromium

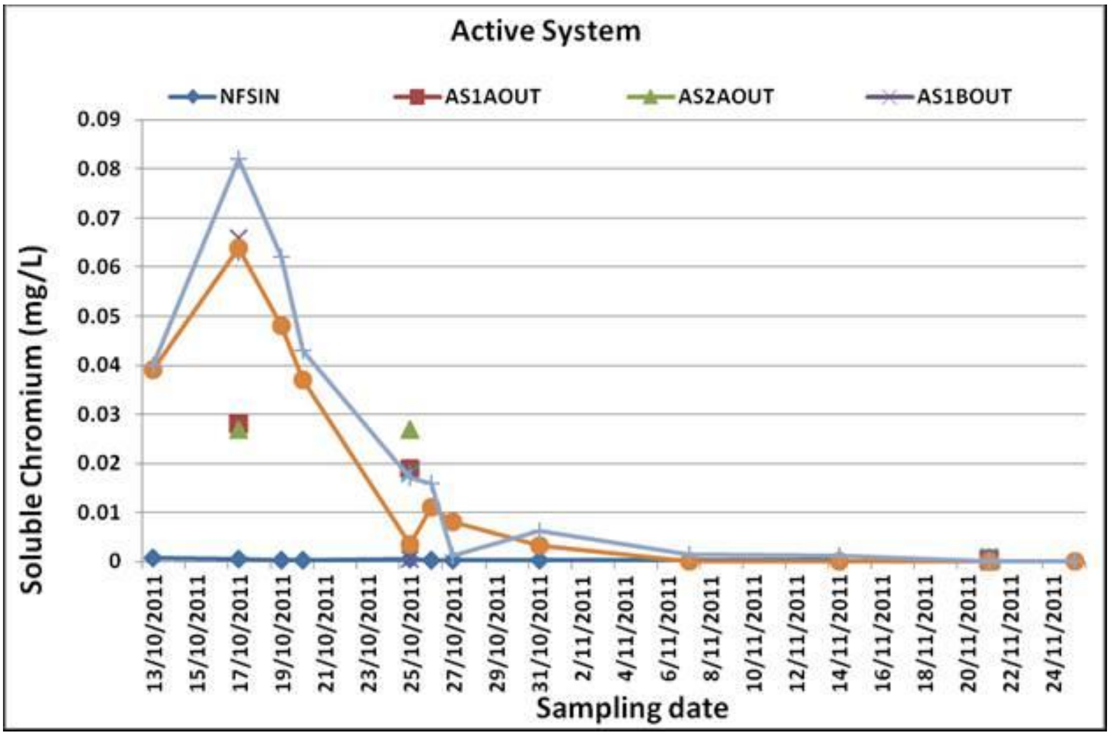


Comparators:

NFSIN (minimum)	<0.005 milligrams per litre
NFSIN (maximum)	<0.005 milligrams per litre
AEP (95%)	0.001 milligrams per litre
ADWG	0.05 milligrams per litre

Trends: Hexavalent chromium only detected in the initial samples from PS1, PS2 and PS4, and the first two samples from PS3. Concentrations are similar to total chromium concentrations.

Chart 101: Active System, Soluble Chromium

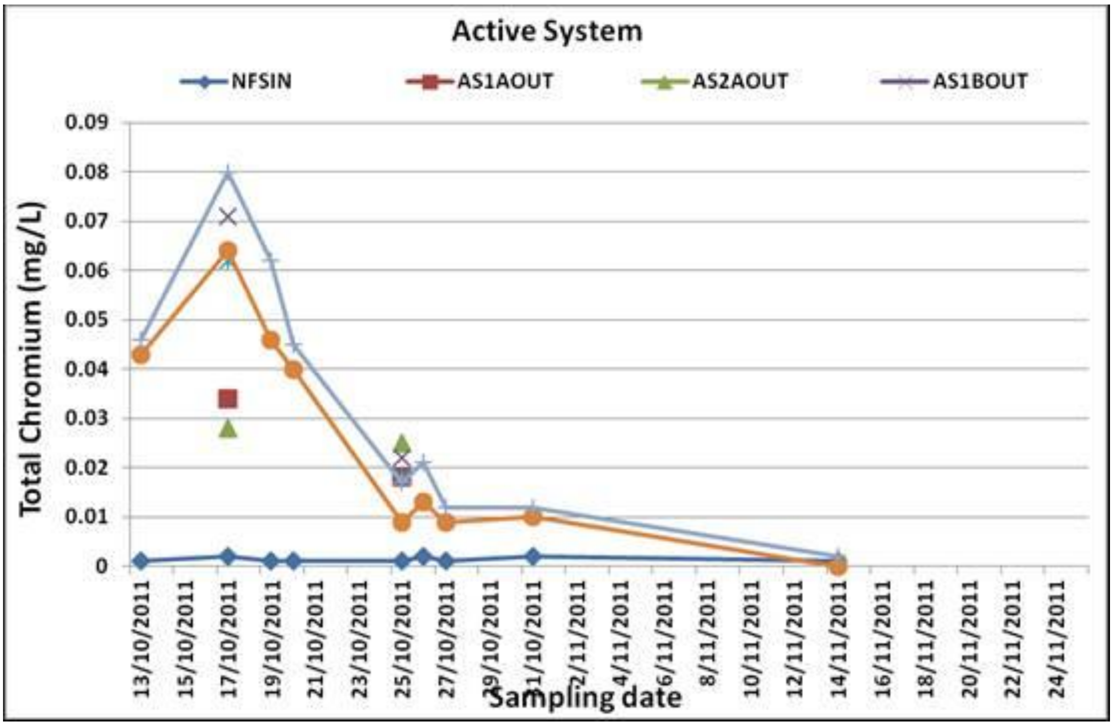


Comparators:

NFSIN (minimum)	0.0009 milligrams per litre
NFSIN (maximum)	0.0012 milligrams per litre

Trends: Rapid release of chromium in initial samplings. Maximum concentration (0.08 milligrams per litre significantly lower than passive system. Very low thereafter.

Chart 102: Active System, Total Chromium

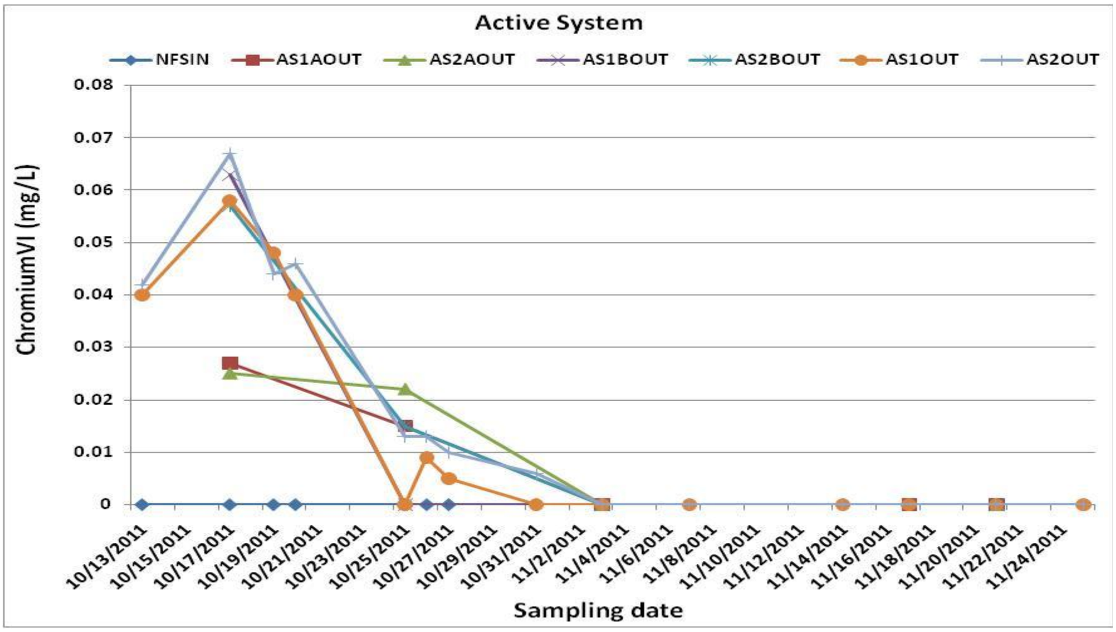


Comparators:

NFSIN (minimum)	0.0004 milligrams per litre
NFSIN (maximum)	0.003 milligrams per litre
Livestock	1 milligram per litre
Irrigation	0.1 milligrams per litre

Trends: Similar to soluble chromium results; initial rapid release of chromium from all systems. All samples below guideline levels.

Chart 103: Active System, Hexavalent Chromium



Comparators:

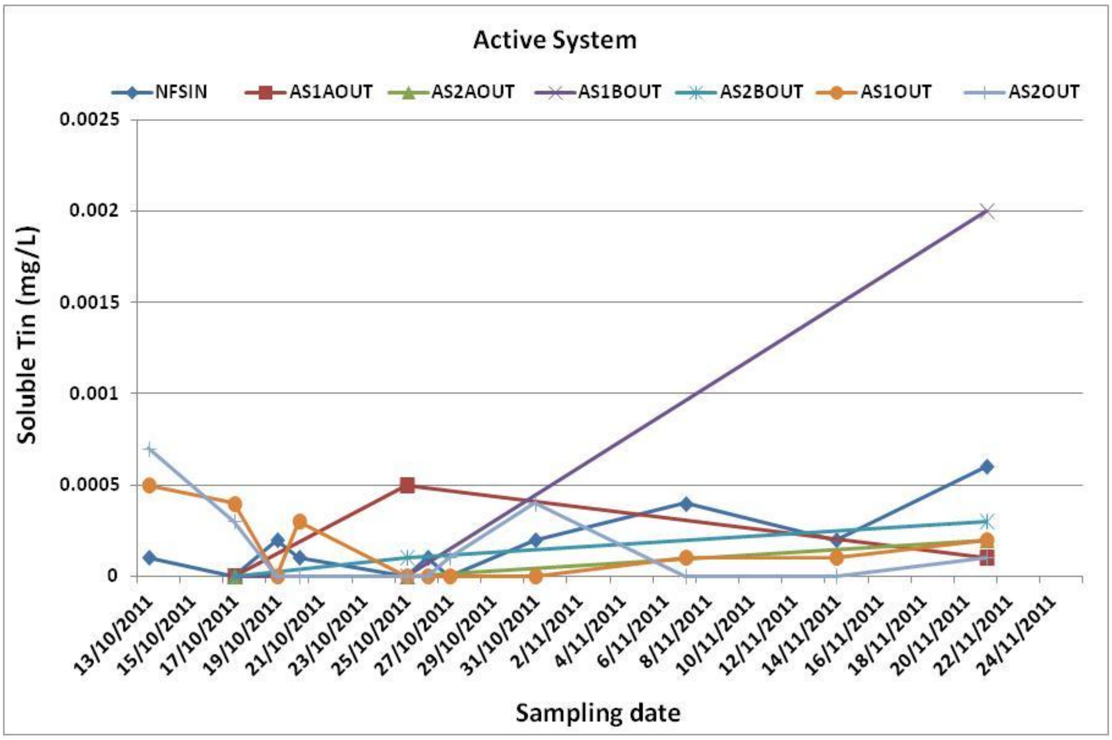
NFSIN (minimum)	<0.005 milligrams per litre
NFSIN (maximum)	<0.005 milligrams per litre
AEP (95%)	0.001 milligrams per litre
ADWG	0.05 milligrams per litre

Trends: Concentrations are similar to total chromium concentrations. "Wash out" of hexavalent chromium occurred over a longer timeframe than the passive systems.

4.34 TIN

Passive system: All values for soluble and total tin are less than 0.001 milligrams per litre.

Chart 104: Active System, Soluble Tin

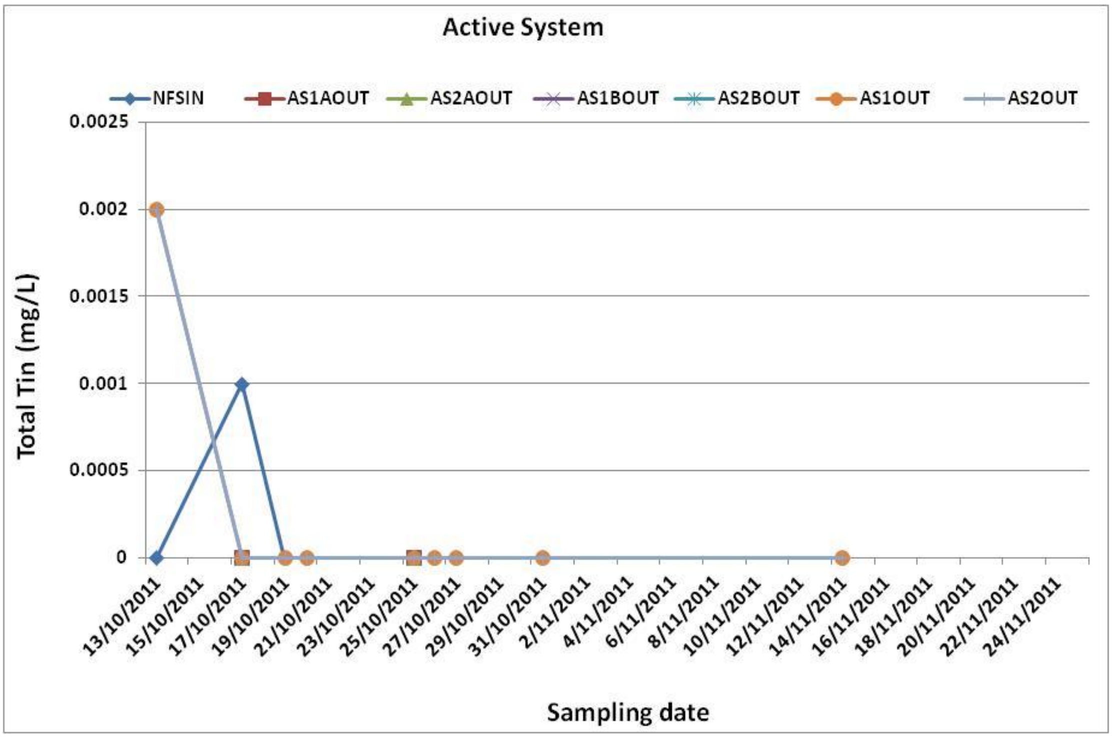


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0006 milligrams per litre

Trends: No significant trends.

Chart 105: Active System, Total Tin



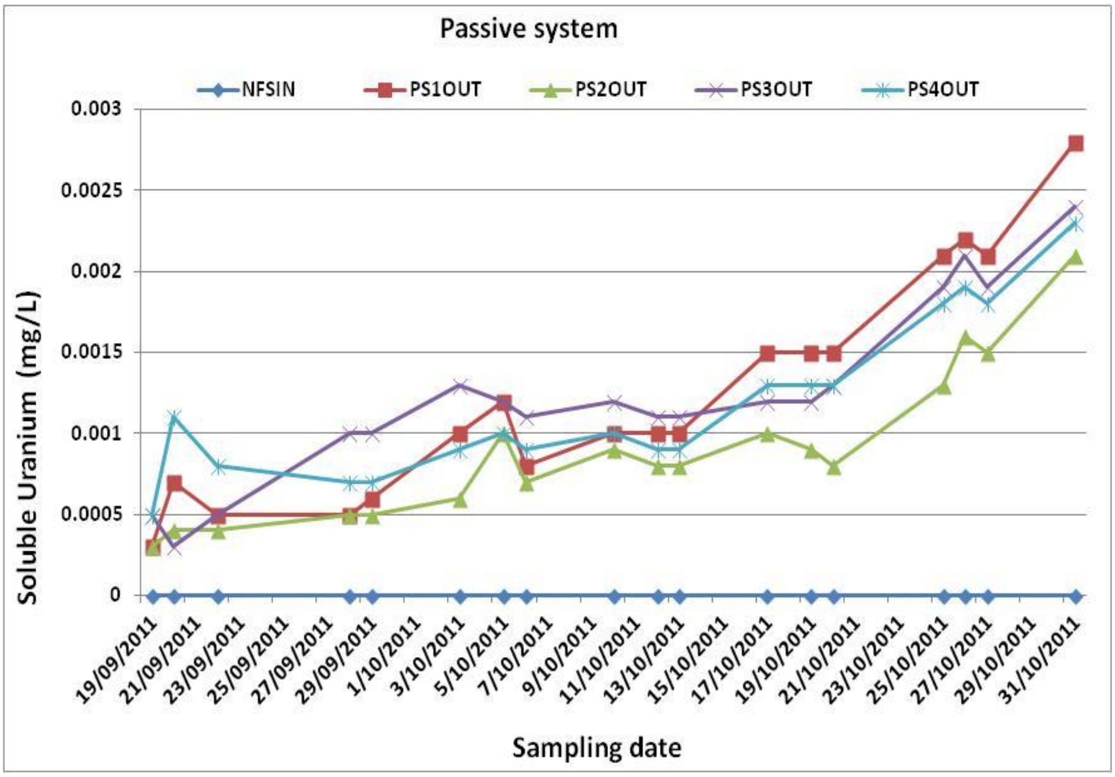
Comparators:

NFSIN (minimum)	<0.001 milligrams per litre
NFSIN (maximum)	0.001 milligrams per litre

Trends: No significant trends.

4.35 URANIUM

Chart 106: Passive System, Soluble Uranium

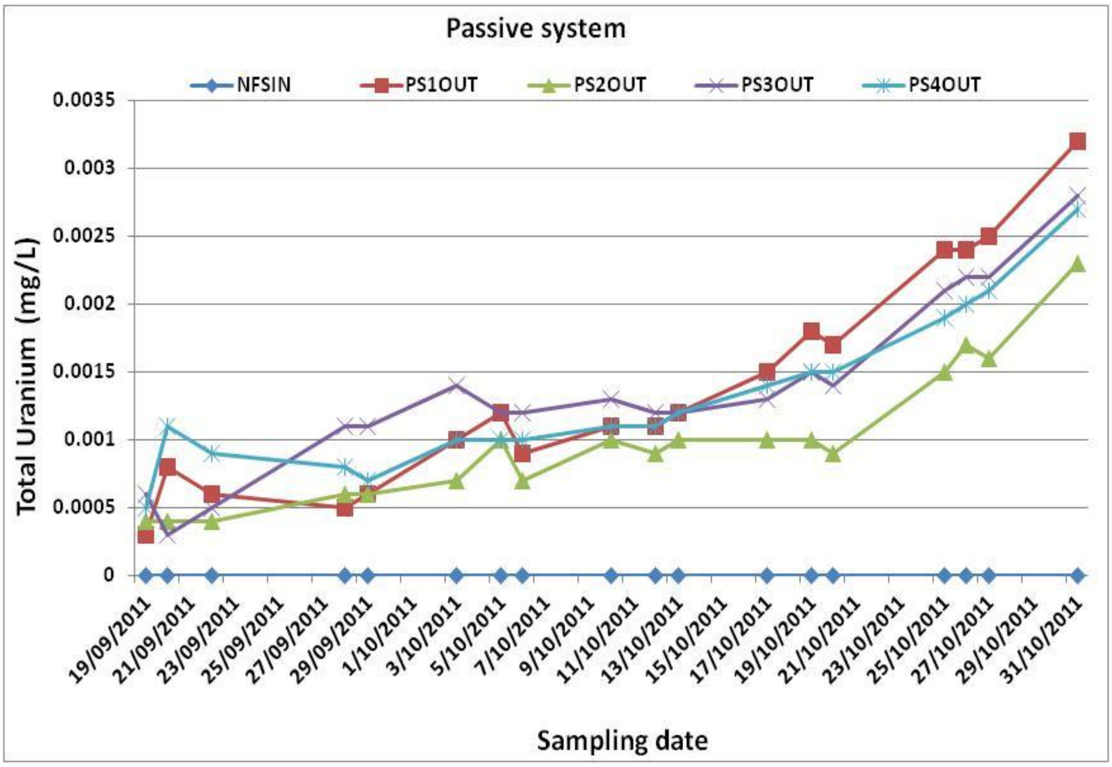


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	<0.0001 milligrams per litre

Trends: Increasing release of soluble uranium from all systems. There are no high reliability trigger values for uranium in ANZECC 2000 guidelines for freshwater aquatic ecosystems. A low reliability value of 0.0005 milligram was calculated using a conservative factor of 20 based on limited chronic toxicity data. The observed concentrations exceed this value, but are unlikely to result in significant toxicity issues. Very closely linked to flow values (ie as flows decreased, uranium concentrations increased).

Chart 107: Passive System, Total Uranium

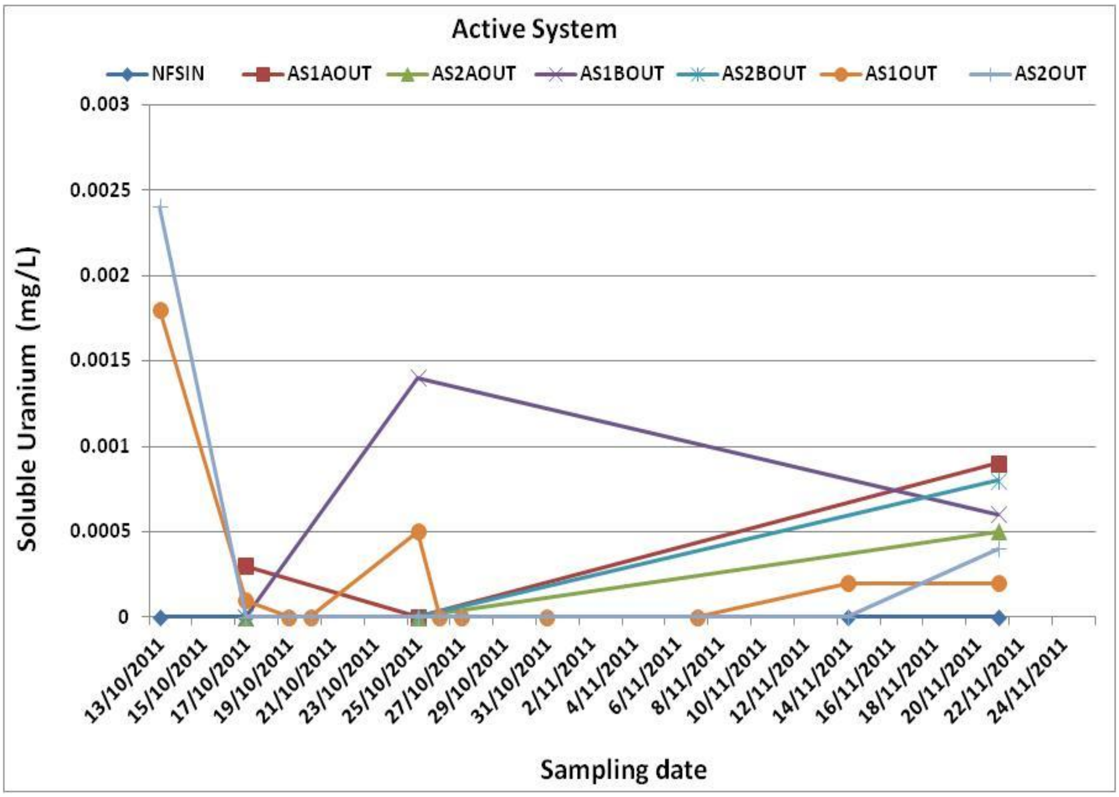


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	<0.0001 milligrams per litre

Trends: Increasing release of soluble uranium from all systems. Values and trends reflect soluble uranium data.

Chart 108: Active System, Soluble Uranium

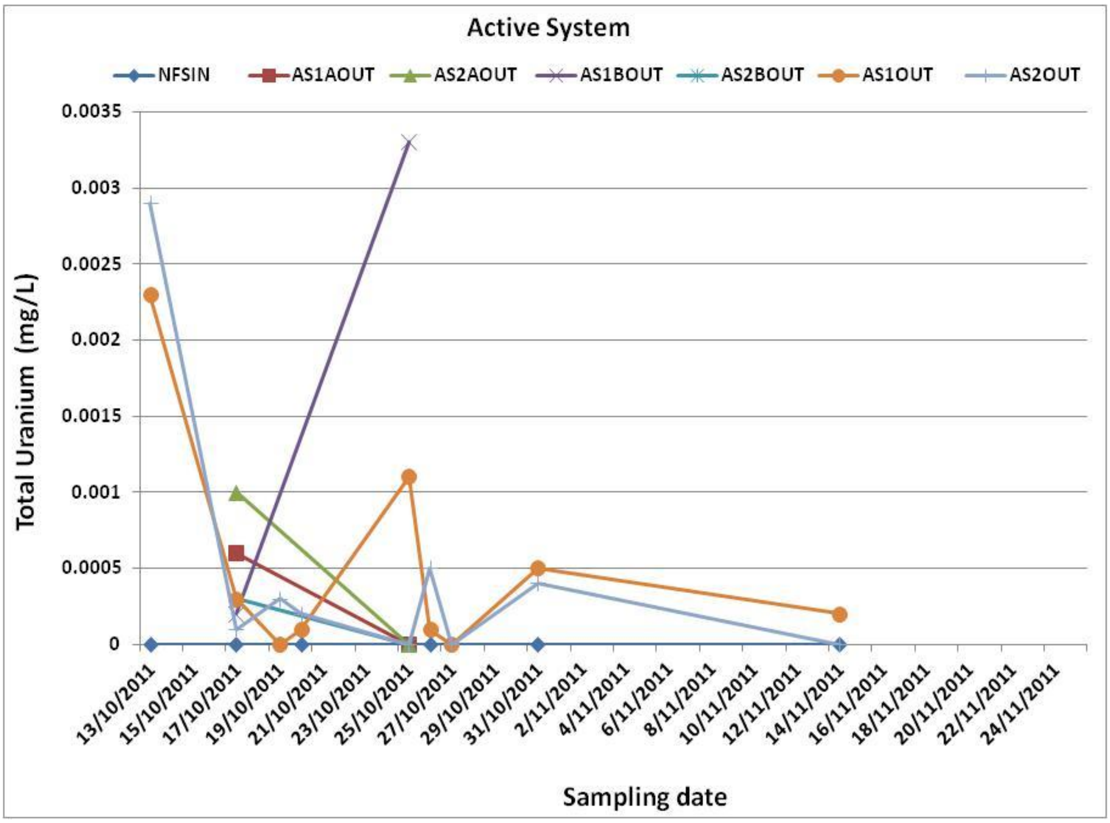


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	<0.0001 milligrams per litre

Trends: Release of uranium observed in all systems, but no significant trends are apparent.

Chart 109: Active System, Total Uranium



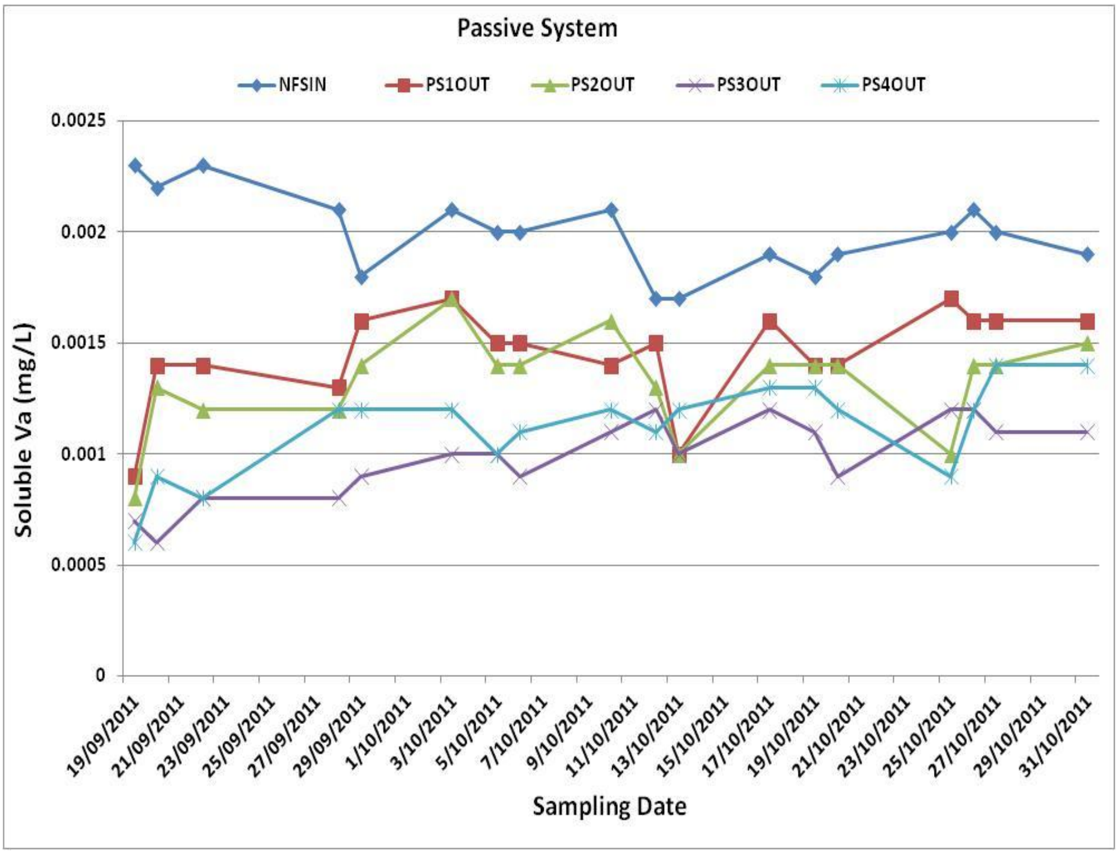
Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	<0.0001 milligrams per litre

Trends: Similar values to soluble uranium data.

4.36 VANADIUM

Chart 110: Passive System, Soluble Vanadium

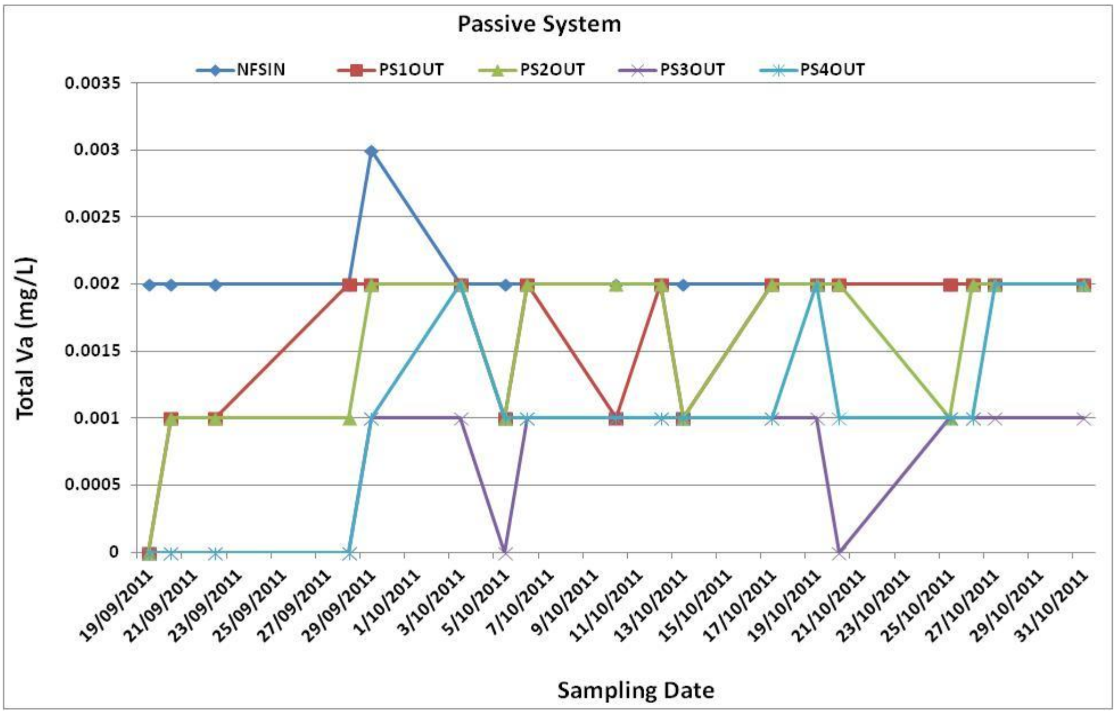


Comparators:

NFSIN (minimum)	0.0016 milligrams per litre
NFSIN (maximum)	0.0023 milligrams per litre

Trends: Removal of 20% to 50% of soluble vanadium from all systems.

Chart 111: Passive System, Total Vanadium

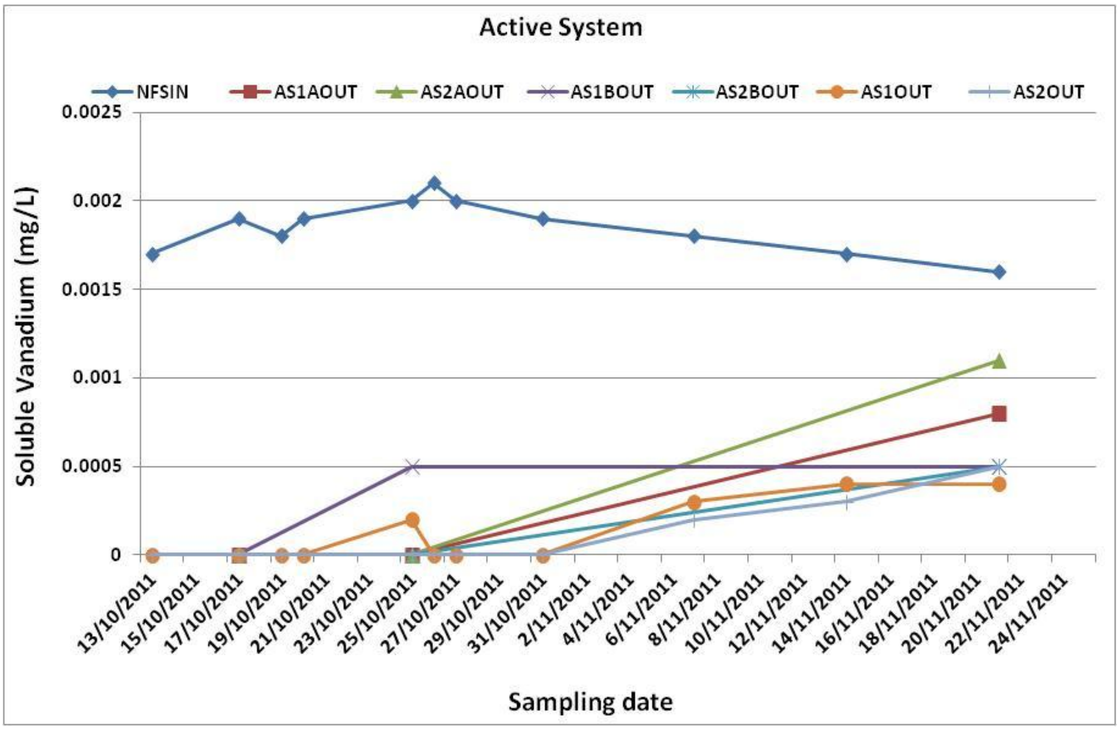


Comparators:

NFSIN (minimum)	0.002 milligrams per litre
NFSIN (maximum)	0.003 milligrams per litre
Irrigation	0.1 milligrams per litre

Trends: Removal of vanadium indicated, although the results were measured by a less sensitive technique compared to soluble vanadium measurements.

Chart 112: Active System, Soluble Vanadium

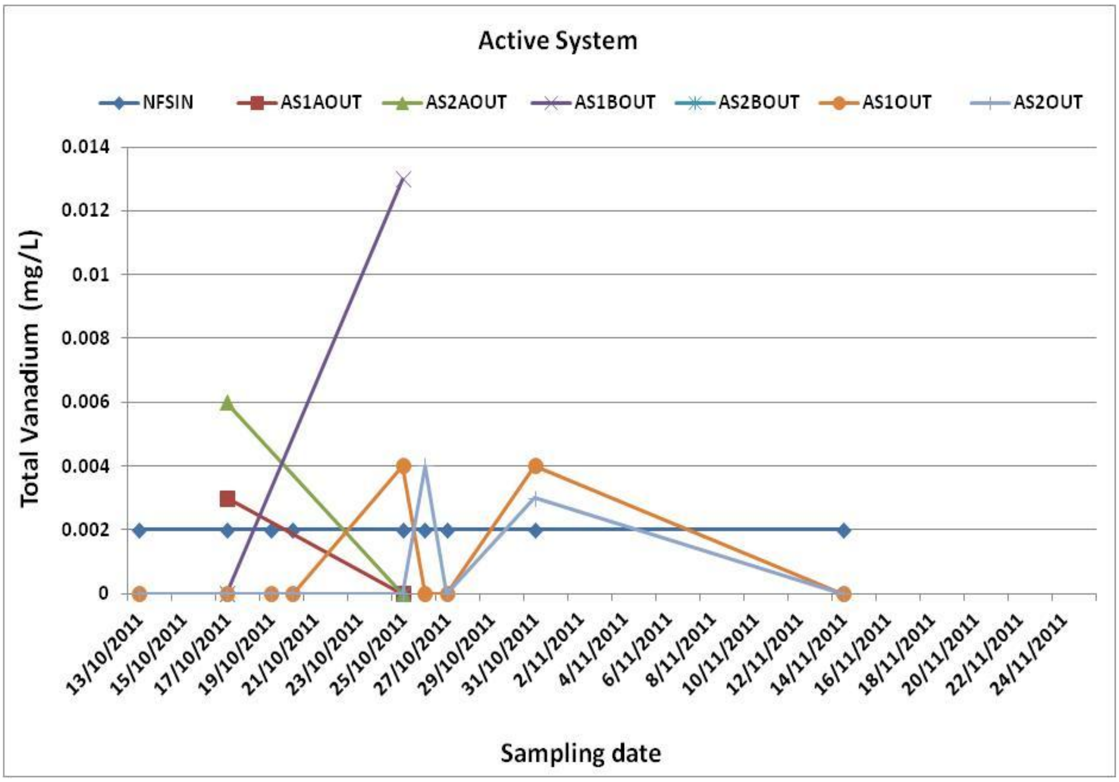


Comparators:

NFSIN (minimum)	0.0016 milligrams per litre
NFSIN (maximum)	0.0021 milligrams per litre

Trends: Effective removal of vanadium, with decreasing efficiencies over time.

Chart 113: Active System, Total Vanadium



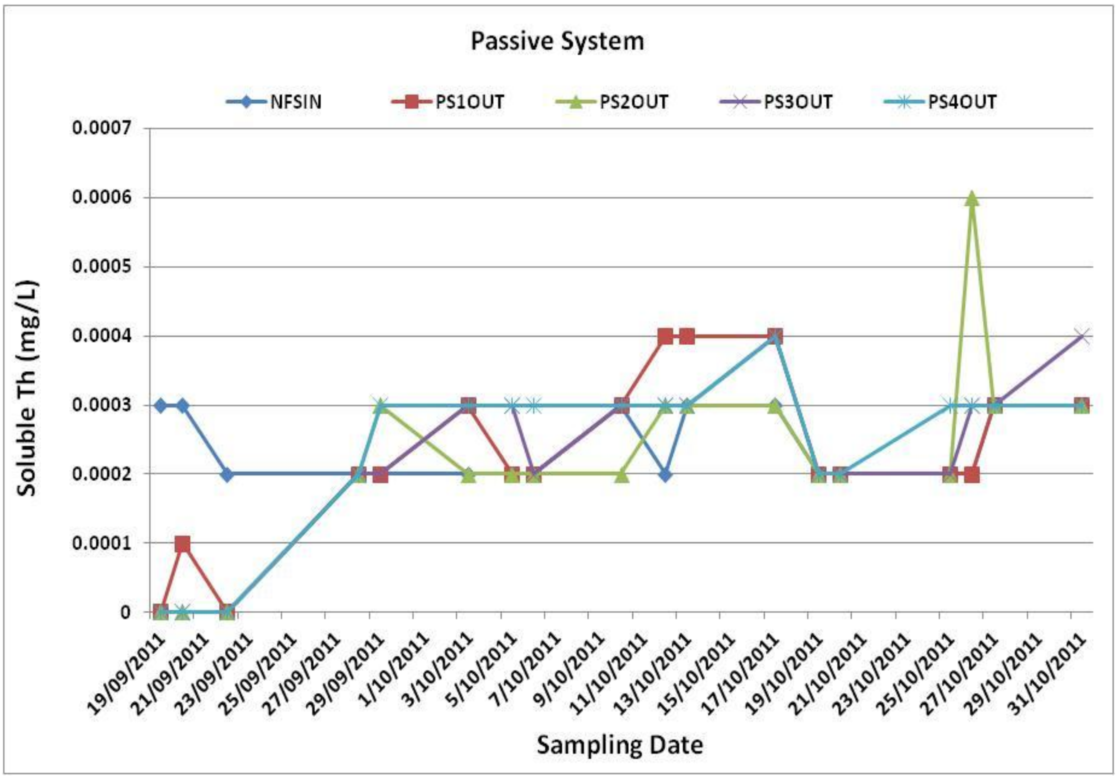
Comparators:

NFSIN (minimum)	0.002 milligrams per litre
NFSIN (maximum)	0.002 milligrams per litre
Irrigation	0.1 milligrams per litre

Trends: No significant trends.

4.37 THORIUM

Chart 114: Passive System, Soluble Thorium

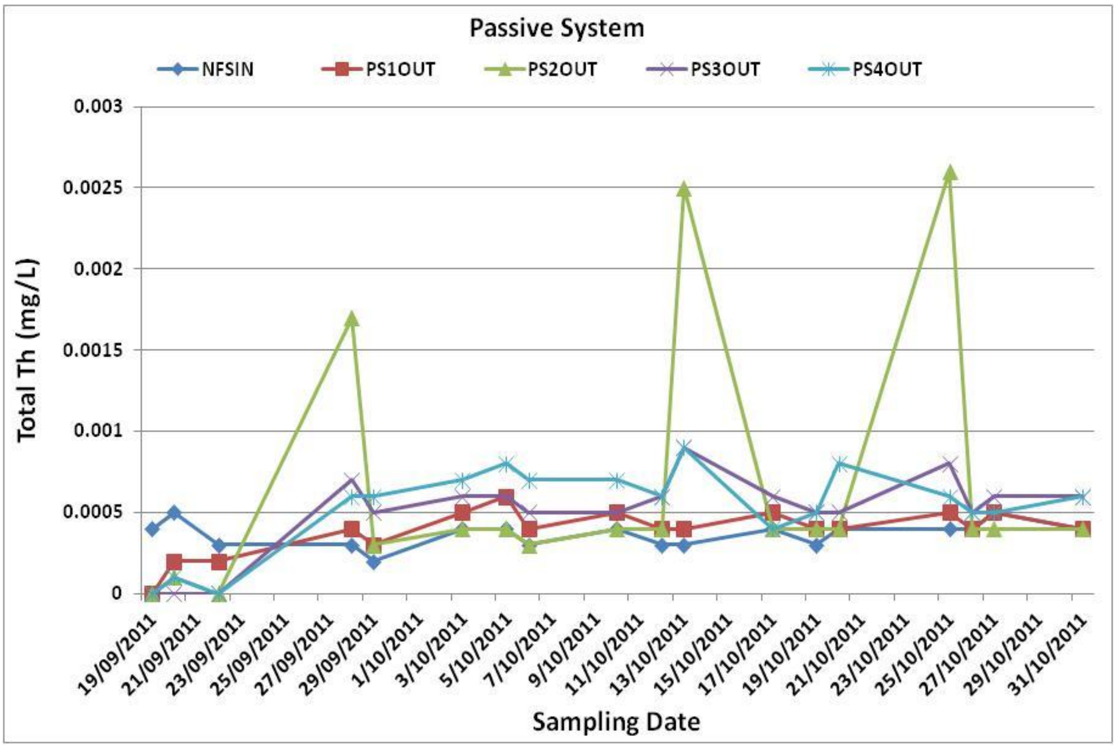


Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0003 milligrams per litre

Trends: Evidence of removal of thorium for the first four days of operation.

Chart 115: Passive System, Total Thorium

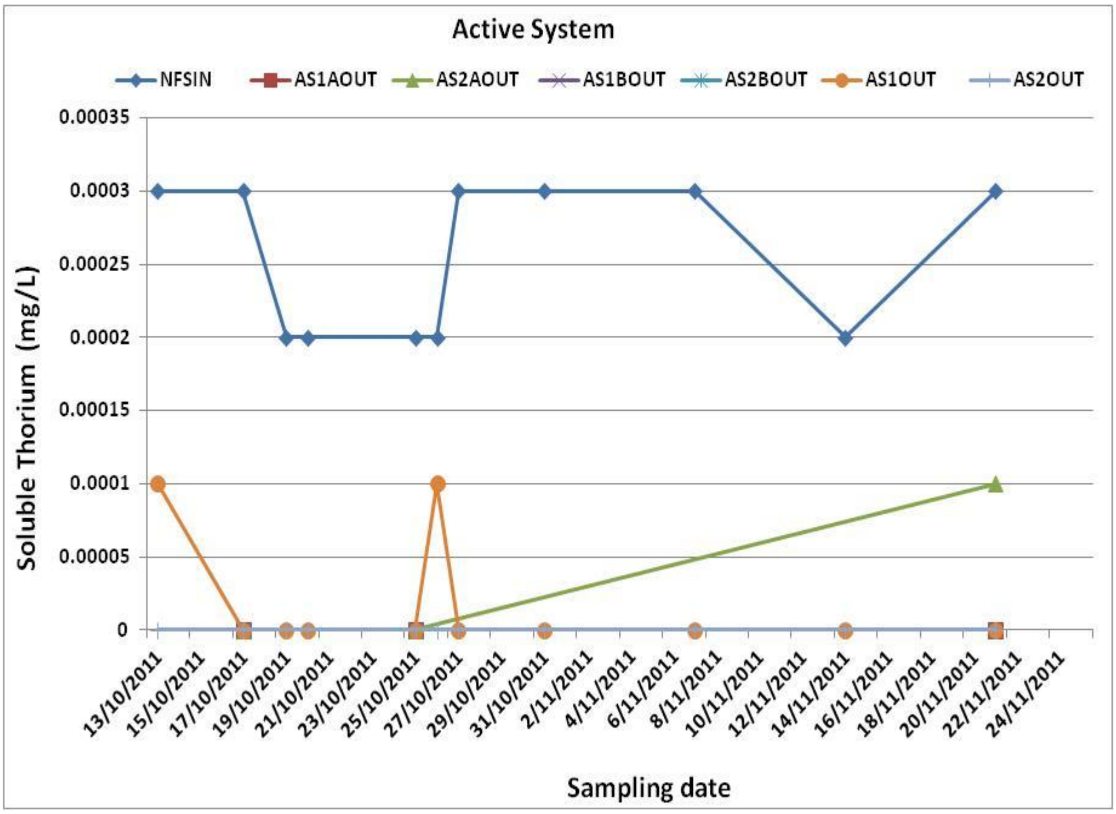


Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0005 milligrams per litre

Trends: Evidence for removal of thorium during the first four days of operation, followed by release of thorium, particularly from system PS2.

Chart 116: Active System, Soluble Thorium

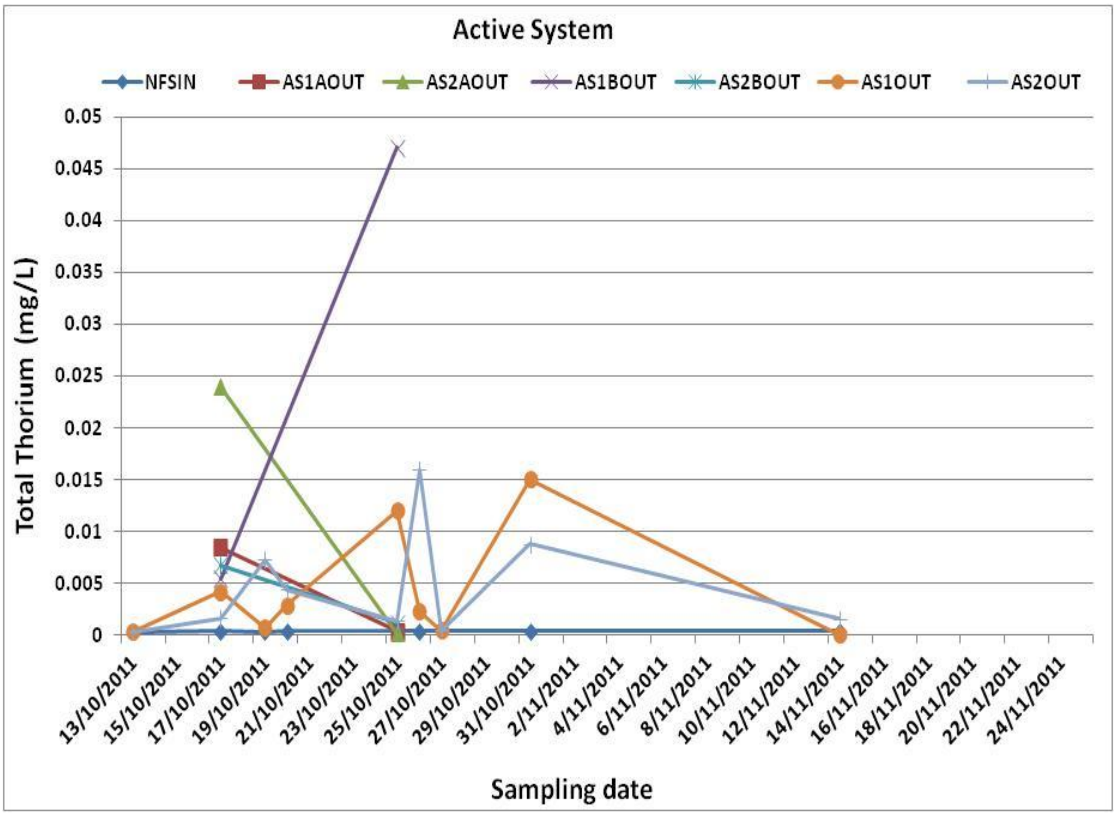


Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0003 milligrams per litre

Trends: Significant removal of thorium for all systems.

Chart 117: Active System, Total Thorium



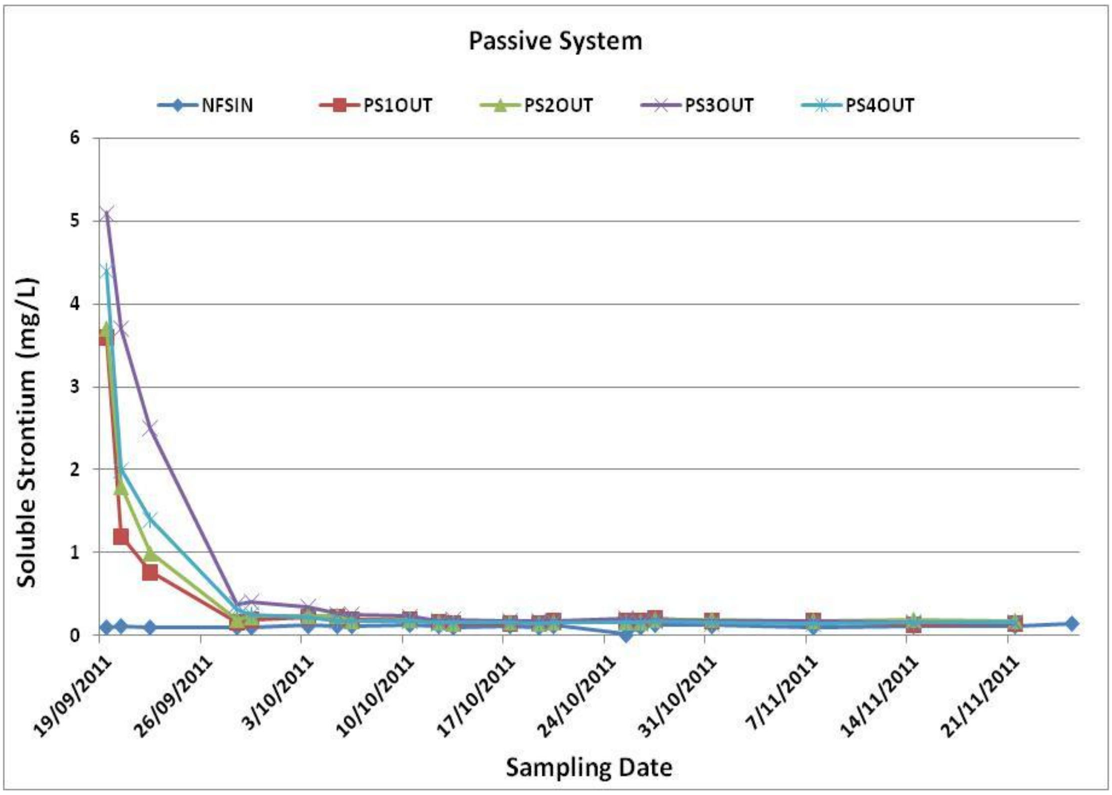
Comparators:

NFSIN (minimum)	0.0002 milligrams per litre
NFSIN (maximum)	0.0005 milligrams per litre

Trends: Suggests thorium is being released from all systems. The detection however of thorium in *AS1BOUT*, suggests it is present in particulate forms.

4.38 STRONTIUM

Chart 118: Passive System, Soluble Strontium

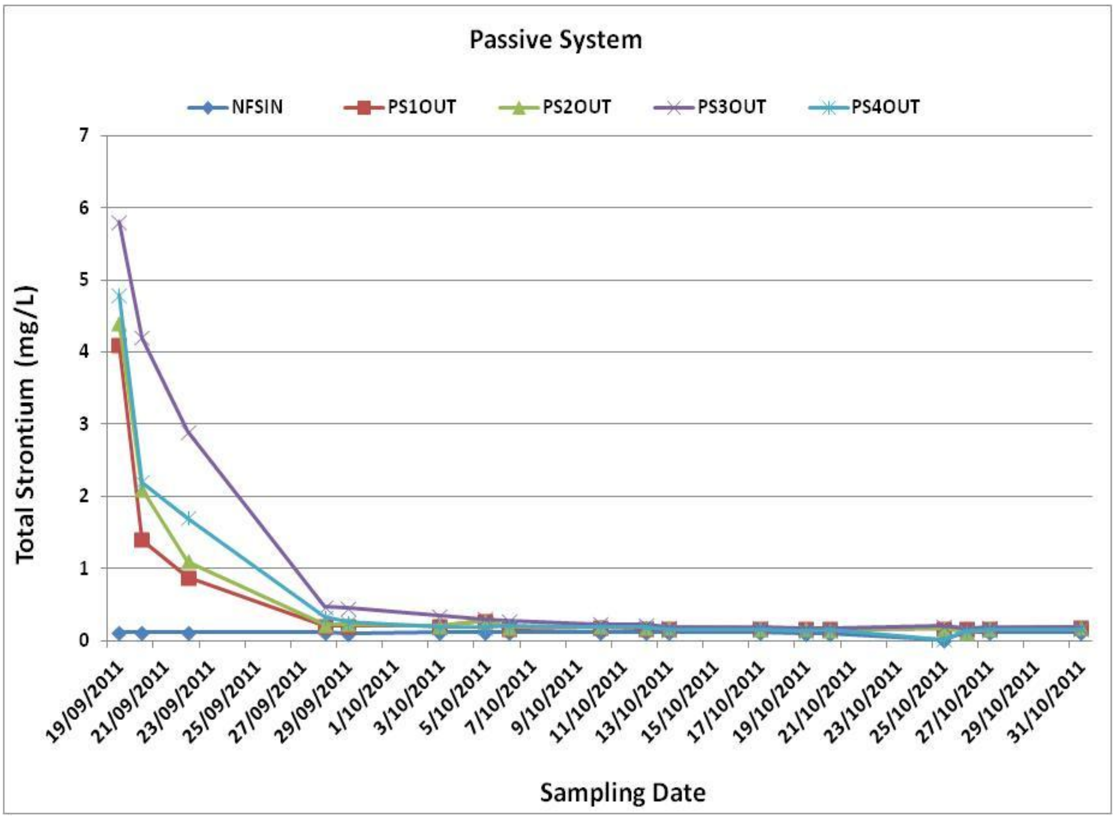


Comparators:

NFSIN (minimum)	0.012 milligrams per litre
NFSIN (maximum)	0.13 milligrams per litre

Trends: Evidence for release of strontium for the first four days of operation. Release curves are similar to those of calcium and sulphate.

Chart 119: Passive System, Total Strontium

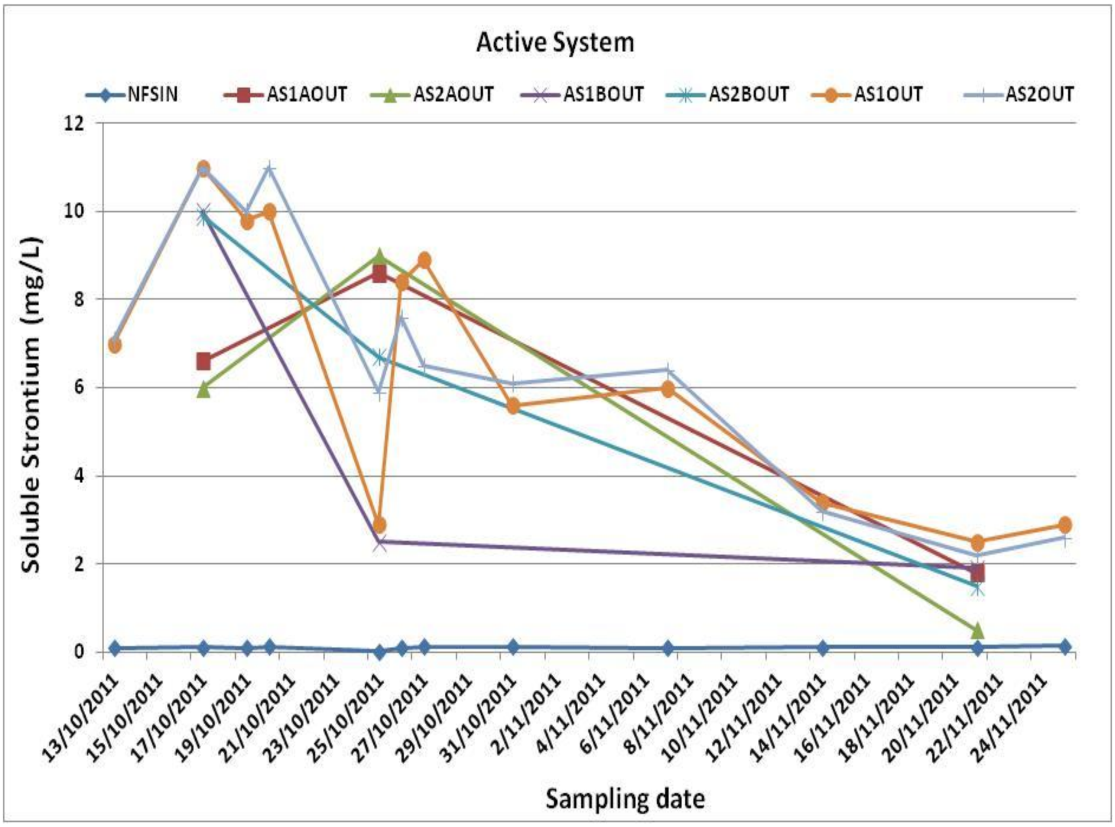


Comparators:

NFSIN (minimum)	0.098 milligrams per litre
NFSIN (maximum)	0.14 milligrams per litre

Trends: Similar trends to soluble strontium.

Chart 120: Active System, Soluble Strontium

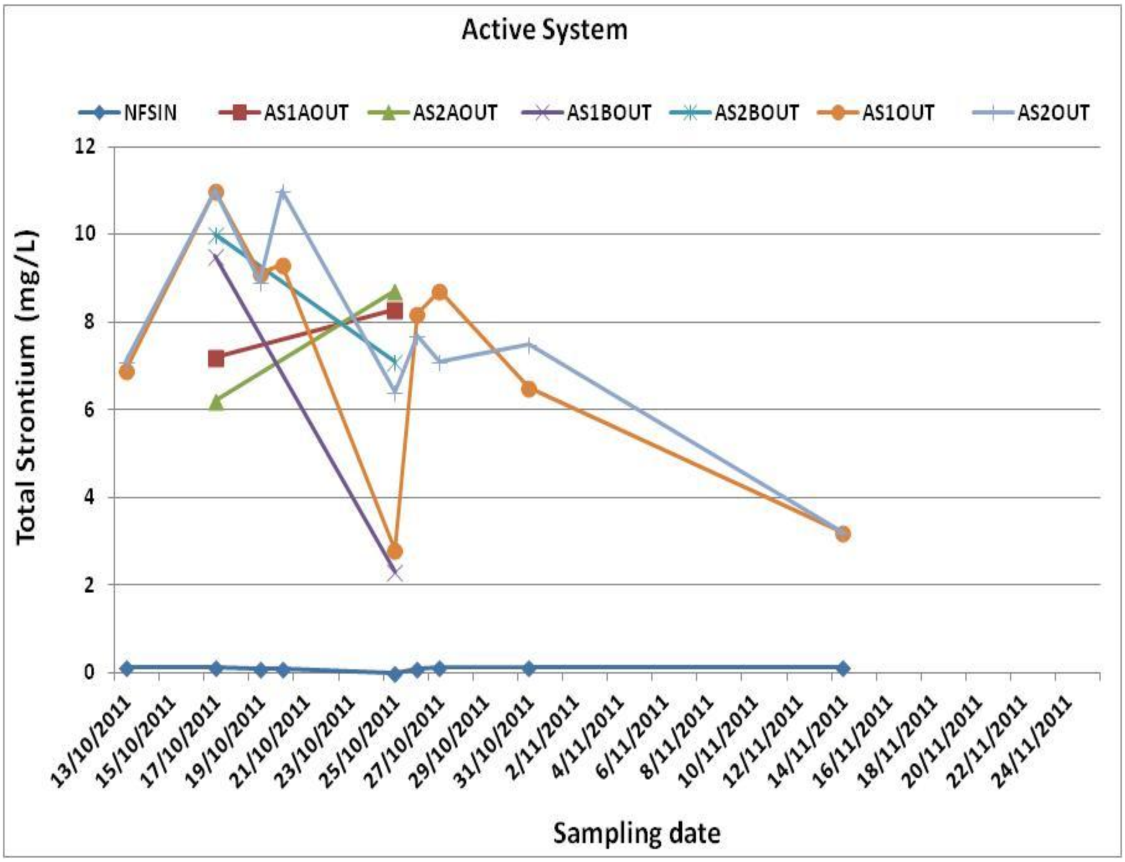


Comparators:

NFSIN (minimum)	0.096 milligrams per litre
NFSIN (maximum)	0.13 milligrams per litre

Trends: Release of soluble strontium occurs at maximum concentrations twice as high as those from the passive systems and over a significantly longer timeframe.

Chart 121: Active System, Total Strontium



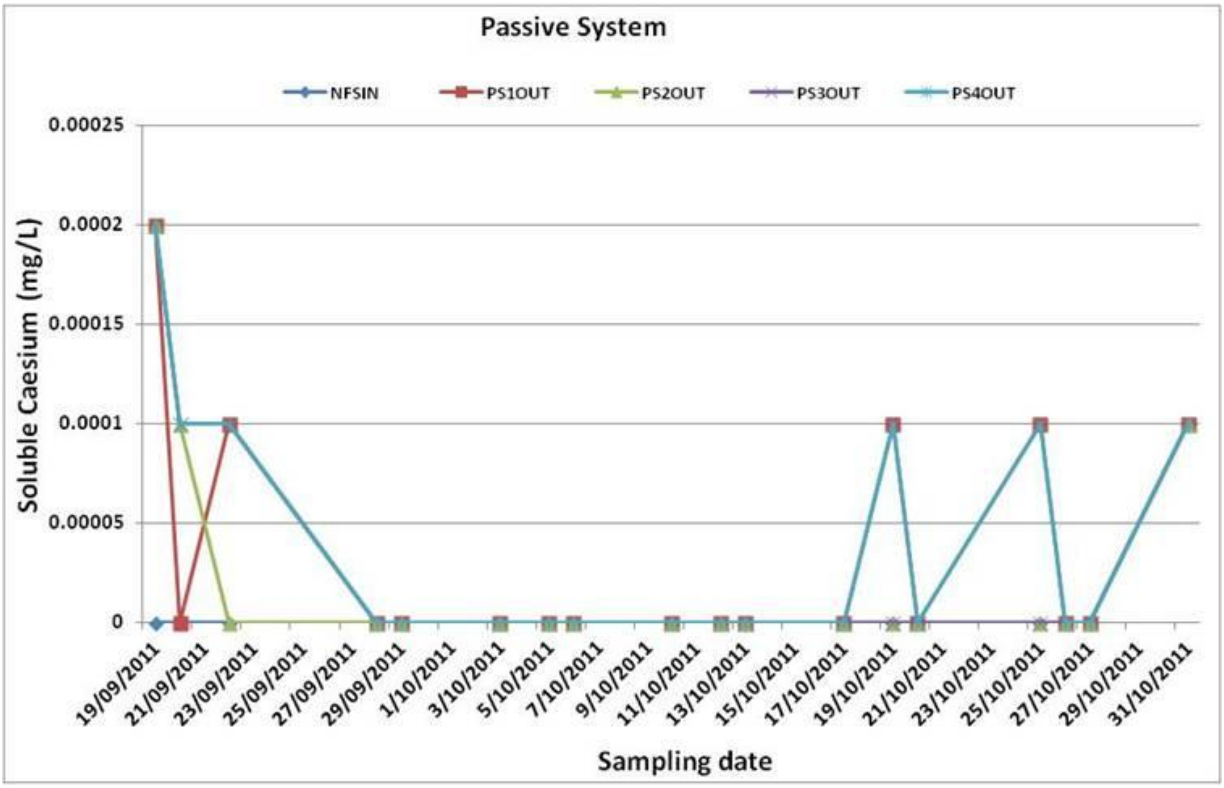
Comparators:

NFSIN (minimum)	0.098 milligrams per litre
NFSIN (maximum)	0.14 milligrams per litre

Trends: Similar to soluble strontium release curves.

4.39 CAESIUM

Chart 122: Passive System, Soluble Caesium

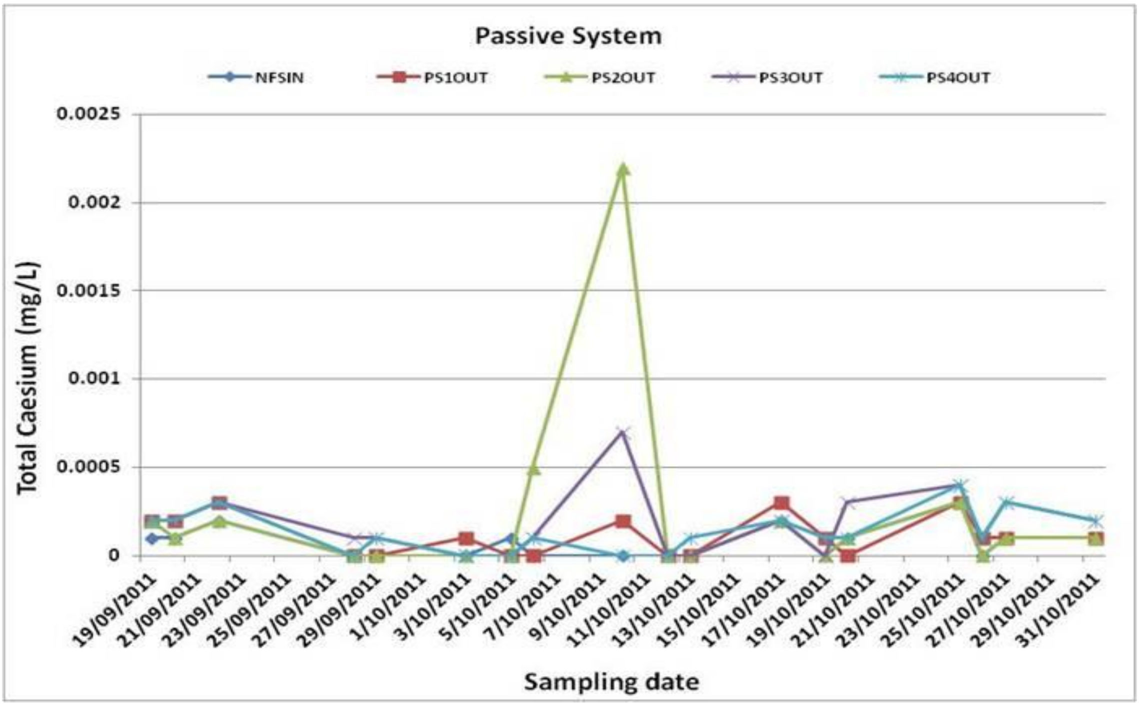


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0001 milligrams per litre

Trends: Concentrations are extremely low and of no environmental significance.

Chart 123: Passive System, Total Caesium

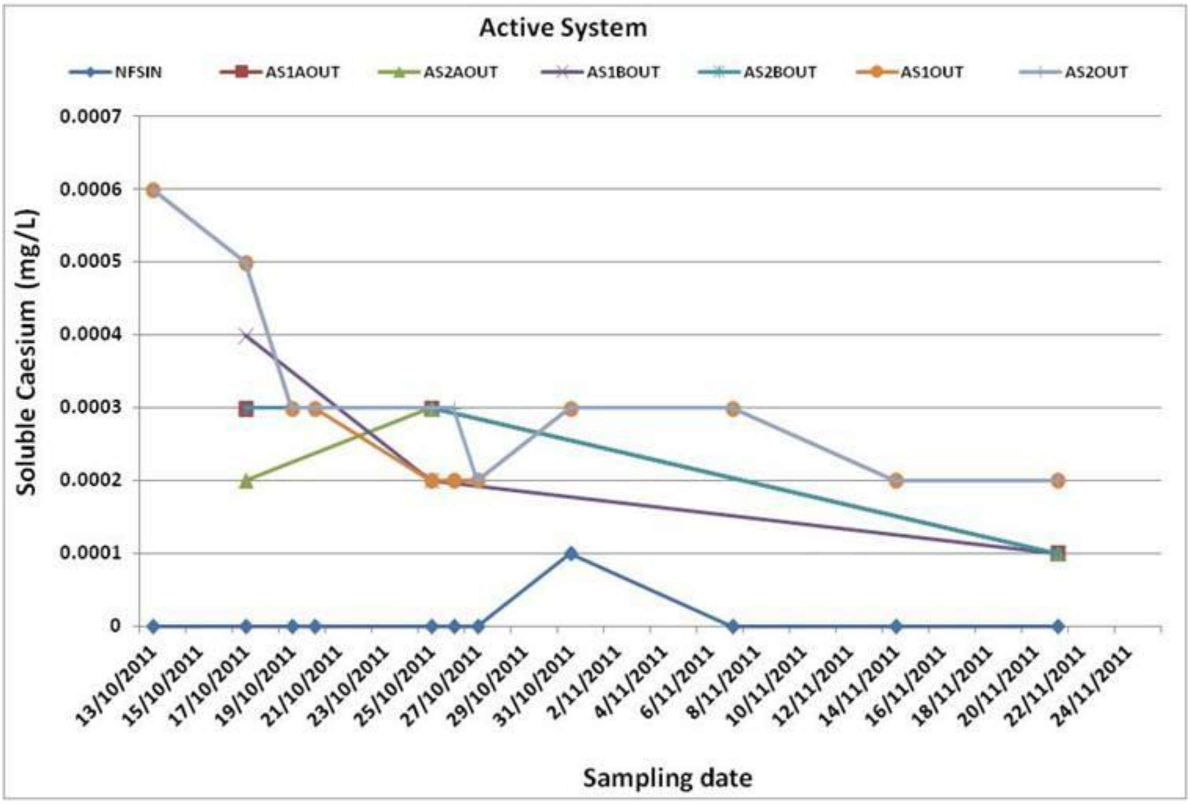


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0003 milligrams per litre

Trends: Concentrations are extremely low and of no environmental significance.

Chart 124: Active System, Soluble Caesium

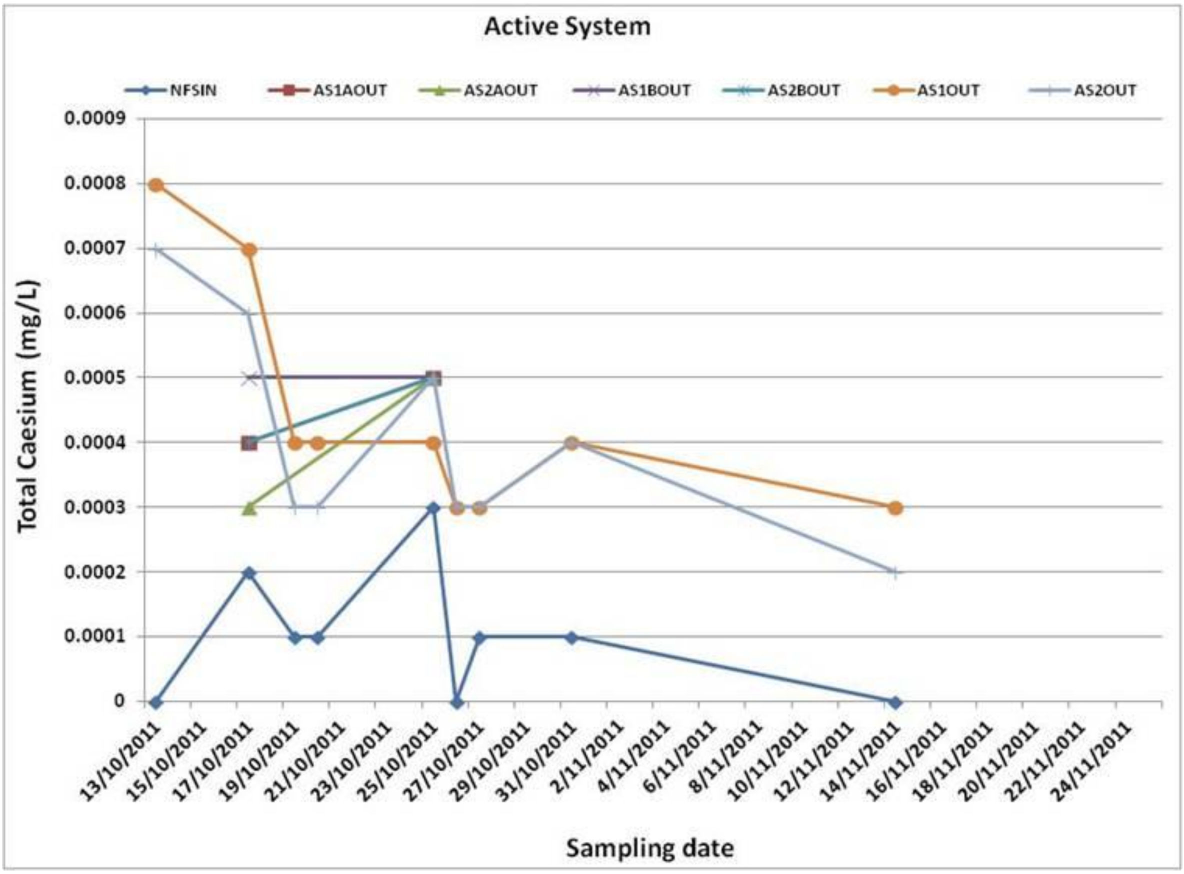


Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0001 milligrams per litre

Trends: Concentrations are extremely low and of no environmental significance.

Chart 125: Active System, Total Caesium



Comparators:

NFSIN (minimum)	<0.0001 milligrams per litre
NFSIN (maximum)	0.0003 milligrams per litre

Trends: Concentrations are extremely low and of no environmental significance.

4.40 MERCURY

Passive system, Mercury:
All values for soluble and total mercury are below the reporting limit (<0.0001 milligrams per litre).

Active system, Mercury:
All values for soluble and total mercury are below the reporting limit (<0.0001 milligrams per litre).

4.41 SILVER

Passive system, Silver:
All values for soluble and total silver are below the reporting limit (<0.0001 milligrams per litre).

Active system, Silver:
All values for soluble and total silver are below the reporting limit (<0.0001 milligrams per litre).

4.42 BERYLLIUM

Passive system, Beryllium:
All values for soluble and total beryllium are below the reporting limit (<0.001 milligrams per litre).

Active system, Beryllium:
All values for soluble and total beryllium are below the reporting limit (<0.001 milligrams per litre).

4.43 ARSENIC

Passive system, Arsenic:
All values for soluble and total arsenic are below the reporting limit (<0.001 milligrams per litre).

Active system, Arsenic:
All values for soluble and total arsenic are below the reporting limit (<0.001 milligrams per litre).

4.44 CADMIUM

Passive system, Cadmium:
All values for soluble and total cadmium are below the reporting limit (<0.0001 milligrams per litre).

Active system, Cadmium:
All values for soluble and total cadmium are below the reporting limit (<0.0001 milligrams per litre).

4.45 ANTIMONY

Passive system, Antimony:
All values for soluble and total antimony are below the reporting limit (<0.0001 milligrams per litre).

Active system, Antimony:
All values for soluble and total antimony are below the reporting limit (<0.0001 milligrams per litre).

4.46 SELENIUM

Passive system, Selenium:
All values for soluble and total selenium are below the reporting limit (<0.0001 milligrams per litre).

Active system, Selenium:
All values for soluble and total selenium are below the reporting limit (<0.0001 milligrams per litre).

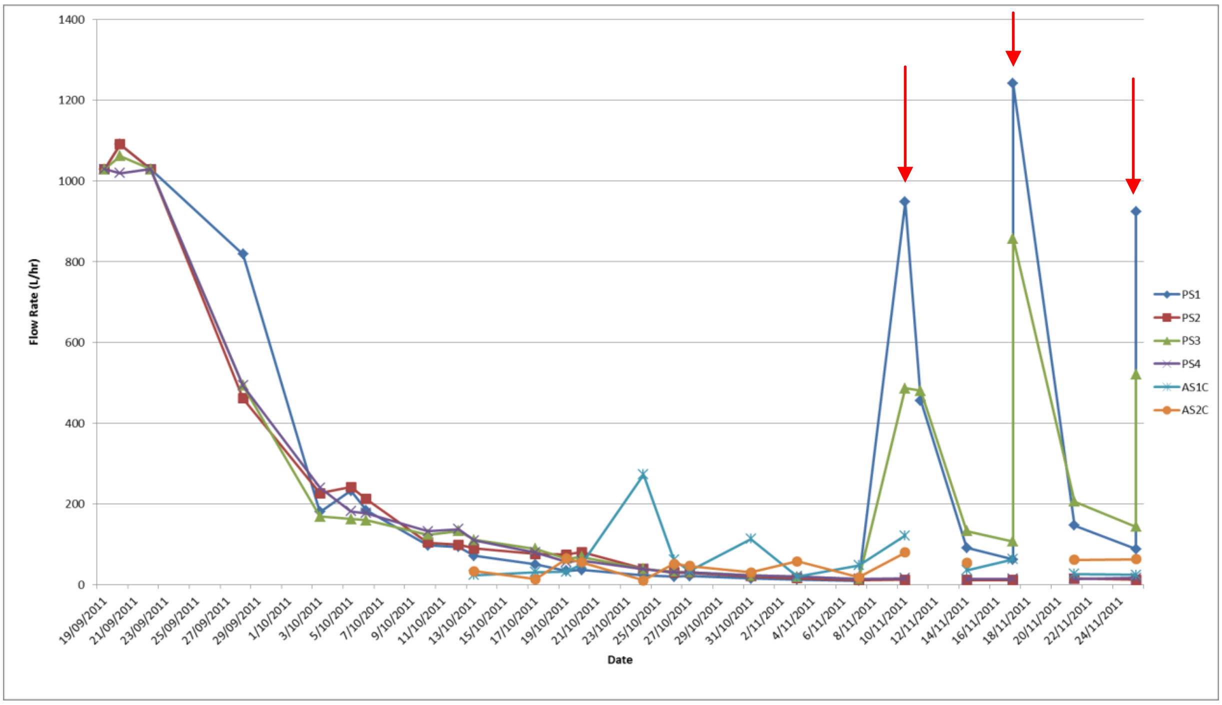
4.47 FLOW RATES AND FLUXES

4.47.1 Flow Rates

Initial flow rates through each passive system exceeded the design specification of 1,000 litres per hour. However, there were significant decreases in flow rates through all systems, decreasing to less than 100 litres per hour after four weeks (as presented in Chart 126). Flows in each of the active systems was well below the desired flow rate of 720 litres per hour in all samples collected.

On three occasions towards the end of the trial, systems the filter blend materials in PS1 and PS3 were probed approximately 250 times with a 15 millimetre steel stake and then flows re-commissioned. A significant improvement in flow rates was recorded, denoted by the red arrows in Chart 126. However, the flows decreased again within several days. These observations indicate that there is likely to be movement of fine particles through the filter bed, which results in clogging at the base of the filter.

Chart 126: Flow Rates (L/hr) Through Each Filter System

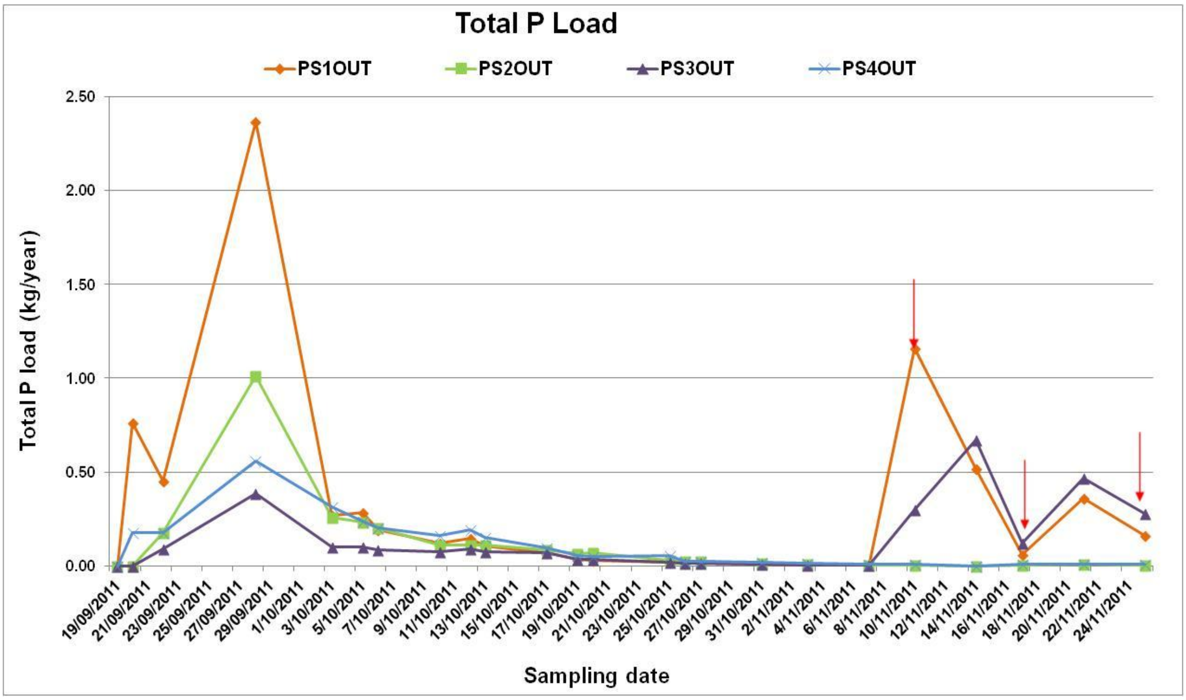


As the nutrient removal efficiency is expected to vary in response to flow rates, the nutrient concentration data presented in earlier Sections of this report were recalculated and presented as nutrient fluxes in the following Sections.

4.47.2 Total Phosphorus Flux

The total phosphorus fluxes, calculated as kilograms per year, through the four passive systems, are presented in Chart 127.

Chart 127: Total Phosphorus Flux



4.48 NUTRIENT AND METAL FLUXES IN PS1& PS3

Fluxes of individual nutrients and selected metals were calculated for the passive system PS1 and PS3 and the concentrations data for the period 19 September to 31 October 2011, the last date before the column were manipulated by probing. Results for the calculated masses of nutrients and metals entering the system and exiting the system are presented in Table 6.

Table 6: Nutrient and Metal Fluxes through PS1 & PS3

Parameter	Units	PS1			PS3		
		Inlet load	Outlet load	Difference	Inlet load	Outlet load	Difference
Total Phosphorus	g	222	52	170 grams removed	222	15	207 grams removed
Total Nitrogen	g	780	610	170 grams removed	780	485	295 grams removed
Total Organic Carbon	kg	17.2	14.2	4 kilograms removed	17.2	11.4	5.8 grams removed
Calcium	kg	5.7	40.2	34.5 kilograms released	5.7	70.0	64.3 grams released
Sulphate	kg	6.2	84.6	78.4 kilograms released	6.2	183	177 grams released
Magnesium	kg	2.7	4.4	1.7 kilograms released	2.7	4.82	2.12 grams released
Fluoride	g	33.4	34.8	1.5 grams released	33.4	56.6	23.2 grams released
Aluminium	g	131	24	107 grams removed	131	15.5	116 grams removed
Iron	g	348	161	187 grams removed	348	113	235 grams removed
Manganese	g	4.0	6.3	2.3 grams released	4.0	10.5	6.5 grams released

Parameter	Units	PS1			PS3		
		Inlet load	Outlet load	Difference	Inlet load	Outlet load	Difference
Copper	g	0.31	0.95	0.64 grams released	0.31	0.61	0.3 grams released
Cobalt	g	0.36	0.14	0.22 grams released	0.36	0.15	0.21 grams released
Lead	g	0.09	0.26	0.15 grams released	0.09	0.26	0.17 grams released
Nickel	g	0.12	4.1	4.0 grams released	0.12	1.87	1.75 grams released
Barium	g	14.4	1.2	13.2 grams removed	14.4	0.54	13.9 grams removed
Chromium	g	0.42	0.91	0.49 grams released	0.42	1.03	0.61 grams released
Hexavalent Chromium	g	<0.1	0.35	0.35 grams released	<0.1	<0.1	<0.1 grams released
Uranium	g	<0.1	0.19	0.19 grams released	<0.1	0.26	0.26 grams released
Strontium	g	32.3	218	186 grams released	32.8	468	435 grams released

4.49 PASSIVE SYSTEM MODIFICATIONS

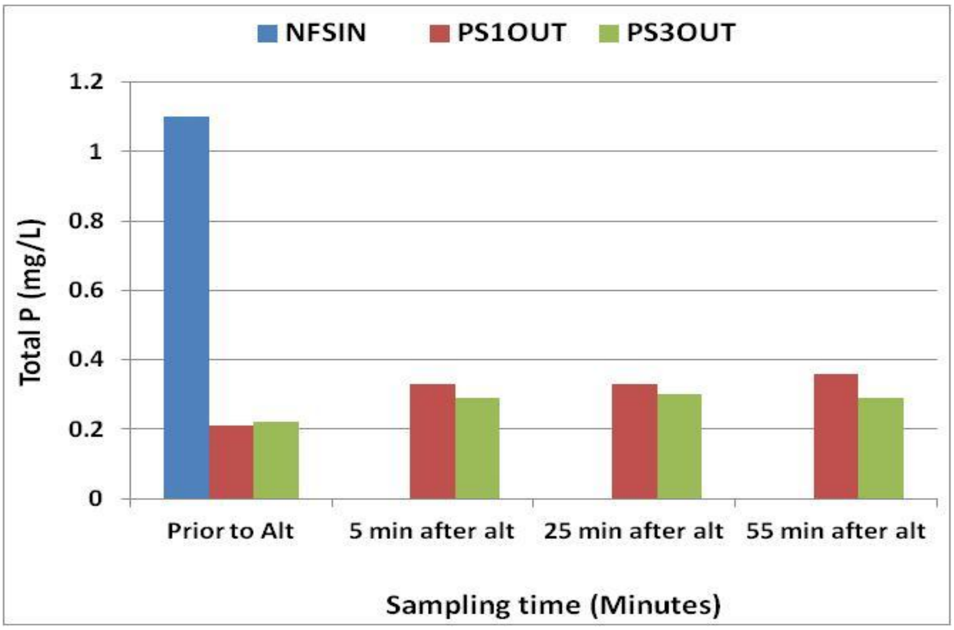
In order to measure the effects on nutrient removal efficiencies following probing of the PS1 and PS3 passive systems as described in Section 4.47.1, samples of the outlet streams were collecting immediately before the probing and again at 5, 25 and 55 minutes after re-commissioning the systems. These samples and a sample of the inlet stream prior to re-mixing the filter blends were analysed for nutrients. The results are presented in the following Sections.

4.49.1 Total Phosphorus

Results for total phosphorus concentrations are presented in

Chart 128. Phosphorus removal efficiencies of the two systems were approximately 80% prior to probing the filter beds, then decreased slightly to approximately 70% after re-commissioning the systems.

Chart 128: Total Phosphorus Concentrations after Probing Filter Beds in PS1 & PS3

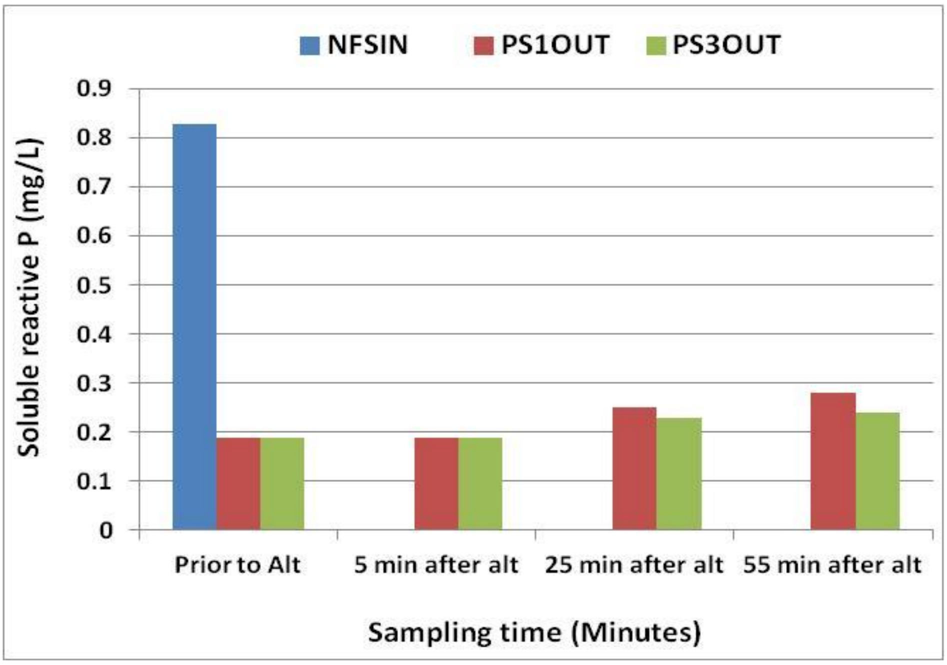


4.49.2 Soluble Reactive Phosphorus

Results for soluble reactive phosphorus concentrations after presented in

Chart 129. As was observed with the total phosphorus results discussed in Section 4.49.1, a slight reduction in soluble reactive phosphorus removal efficiency was observed after re-commissioning the systems, however the removal efficiencies were still greater than 70%.

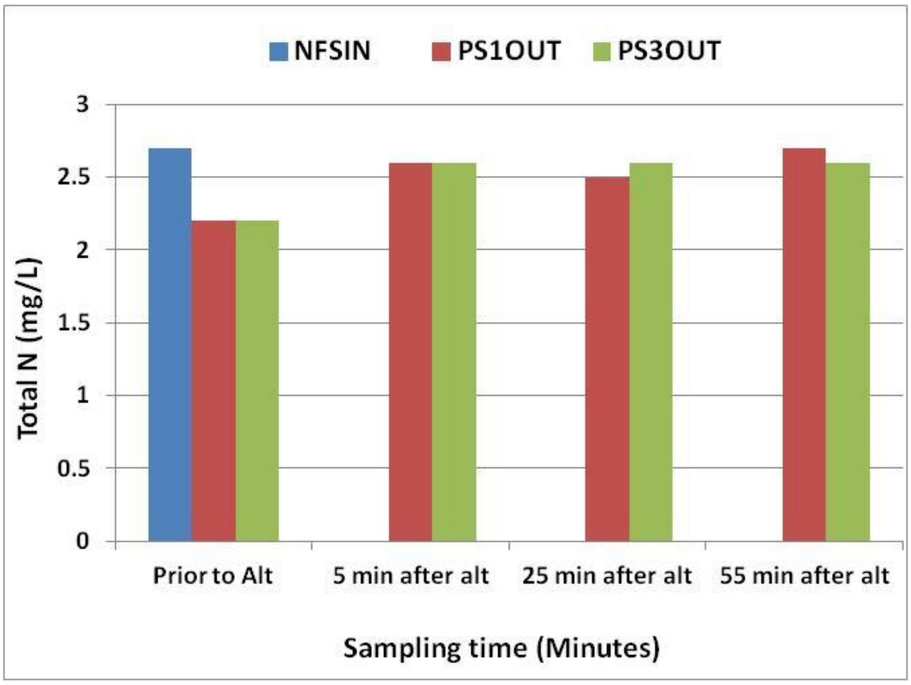
Chart 129: Soluble Reactive Phosphorus Concentrations After Probing Filter Beds in PS1 and PS3



4.49.3 Total Nitrogen

Results for total nitrogen concentrations after presented in Chart 130. Prior to re-mixing the filter blends, both systems were achieving approximately 20% total nitrogen removal efficiencies. After recommissioning the systems, there was insignificant nitrogen removal.

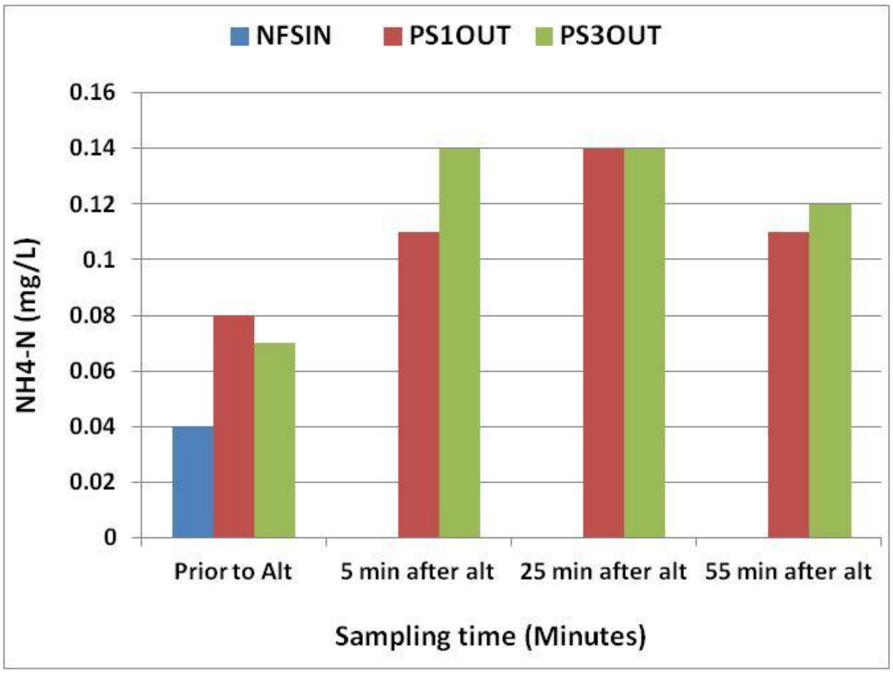
Chart 130: Total Nitrogen Concentrations After Probing Filter Beds in PS1 and PS3



4.49.4 Ammonium Nitrogen

Results for total ammonium nitrogen concentrations are presented in Chart 131. Both systems were releasing ammonium nitrogen prior to mixing the filter blends. After re-commissioning the systems, a further increase in ammonium nitrogen concentrations was observed.

Chart 131: Ammonium Nitrogen Concentrations After Probing Filter Beds in PS1 and PS3

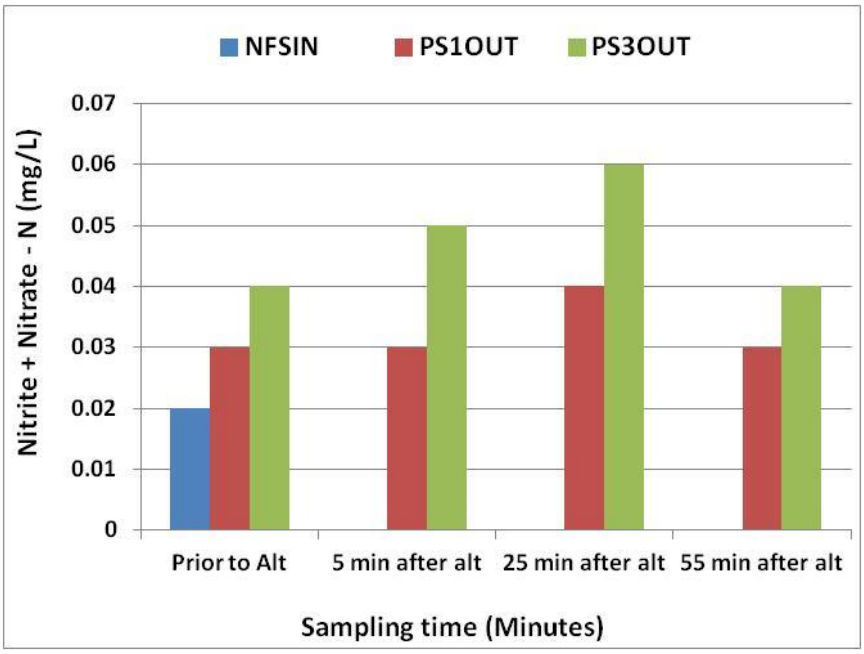


4.49.5 Nitrate / Nitrite (NO_x) Nitrogen

Results for total nitrate / nitrite (NO_x) nitrogen concentrations are presented in

Chart 132. Both systems were releasing NOx nitrogen prior to mixing the filter blends. After re-commissioning the systems, a further increase in NOx nitrogen concentrations was observed for the first two sampling before returning to similar levels to those recorded prior to re-mixing the filter bed.

Chart 132: Nitrate / Nitrite Nitrogen Concentrations After Probing Filter Beds in PS1 and PS3

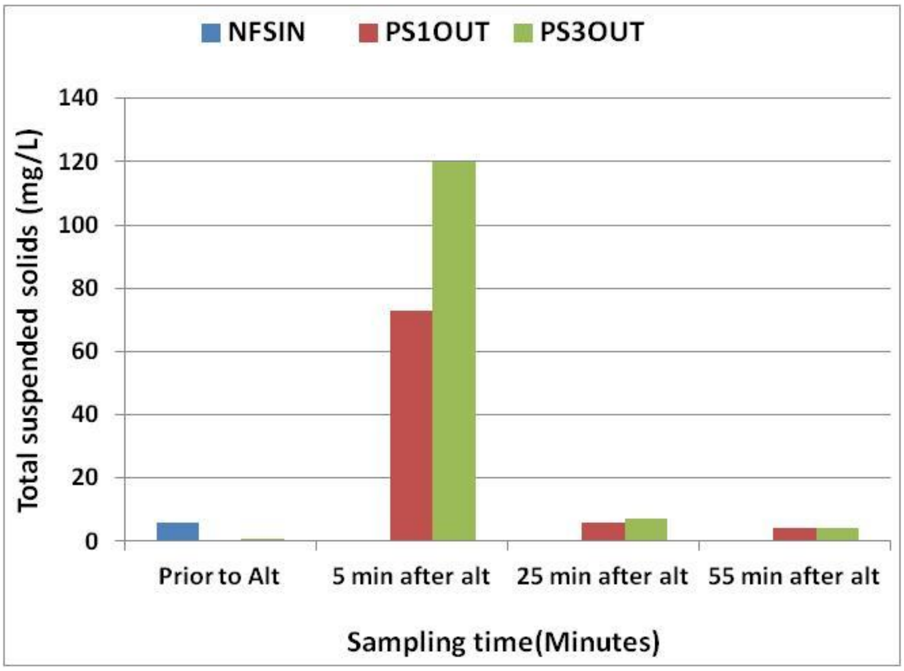


4.49.6 Total Suspended Solids

Results for total ammonium nitrogen concentrations are presented in

Chart 133. Both systems were effective at removing the small amount of suspended solids in the inlet stream, then there was an immediate significant increase in Total Suspended Solids in both systems (up to 120 milligrams per litre) after recommissioning the system before returning to inlet stream concentrations within 25 minutes.

Chart 133: Total Suspended Solids Concentrations After Probing Filter Beds in PS1 and PS3



5. DISCUSSION

The initial performance of the passive and active systems was consistent with expectations. Reasonable flow of water was recorded through each system and was associated with effective reductions in concentrations of major nutrients, suspended solids, organic matter and some heavy metals.

During the initial phase, the outlet streams had salinity levels significant higher than that of the corresponding inlet streams. The major ions in the outlet streams of each system were calcium and sulphate, in concentrations that were consistent with dissolution of the sparingly soluble mineral gypsum ($CaSO_4.2H_2O$).

The performance of the systems in terms of flow rates decreased dramatically after the initial period (approximately four days for the passive systems). This was attributed to fouling of the base of the filters by migration of fine particulate material (Figure 10), most likely iron and manganese oxides following dissolution of gypsum from the NUA particles.

Figure 10: Active System Filter, pre filtration (left) and post "fouled" (right)

During the initial phase, the performance of the system in terms of nutrient removal and release of soluble ions was consistent with earlier studies by CSIRO (Wendling *et al*, 2009) and the results of characterisation of the raw materials and blends by the ASLP test (Section 3.3). Slightly elevated concentrations of chromium were released by the systems, with most of the soluble chromium present in the hexavalent form. The ASLP test results indicated some chromium may be released, but not in the hexavalent form.

Slightly elevated concentrations of other metals including cobalt, nickel, copper, lead, manganese and uranium were also recorded in the outlet streams. With the exception of manganese, the total mass of each metal released by the system was less than one gram and the consequent impact on the receiving quality of the outlet stream was minimal (certainly in terms of suitability for human and livestock drinking and irrigation water. The only metal for which the amount released from the system resulted in an increase above the ANZECC 2000

Trigger Value for protection of freshwater aquatic ecosystems (95% protection, soft water) was copper.

Significant reductions in concentrations of soluble iron, aluminium and silica were recorded, although the environmental benefits following reduction in concentrations of these elements are expected to be minimal.

A moderate amount of strontium (218 grams from system PS1) was leached from the filter blends during the trial. The observed concentrations were considered to be environmentally insignificant. The source of strontium was considered to be a minor constituent of gypsum in the NUA component. Strontium sulphate ($SrSO_4$ or celestite) is less soluble than gypsum and commonly associated with calcium in materials such as limestone and natural gypsum. The release curves of strontium were similar to those of calcium and sulphate, which indicates that it most likely comes from a common source.

Another alkaline earth metal, barium, was not released by the system. Barium concentrations in the outlet streams were significantly less than those in the inlet stream. Effective reduction of barium concentrations is attributed to precipitation of the highly insoluble barium sulphate ($BaSO_4$, barite) in the system.

6. CONCLUSIONS

6.1 PASSIVE SYSTEM

Although the initial performance of the passive and active systems trialled at Ellen Brook were consistent with expectations from earlier laboratory scale experiments, the overall performance was significantly compromised by very low flow rates through the system after several days of operation. The flow reduction was attributed to migration of very fine particles to the base of the filter, most likely iron and manganese oxides released by dissolution of gypsum from the NUA.

If the clogging issues can be resolved, the passive system has potential to remove significant amounts of phosphorus, suspended solids, organic forms of nitrogen and organic matter. Small amounts of heavy metals such as copper, uranium, manganese, cobalt, lead and nickel will be released by such a system, but the resulting concentrations are unlikely to compromise water quality in the receiving environment.

An attempt to restore hydraulic performance of passive systems PS1 and PS2 resulted in short term increases in flow rates and effective nutrient removal.

6.2 ACTIVE SYSTEM

Water quality data in outlets from the active systems were more variable than that from the passive systems, but the trends for nutrient removal and solute release were similar.

7. REFERENCES

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Wendling, L. A., Douglas, G. and Coleman, S. (2009b). *"Characterisation of mining and industrial by-products with potential for use as environmental amendments. Report for the Water Foundation, Western Australian Department of Water."* Perth, CSIRO Water for a Healthy Country National Research Flagship.

APPENDICES

APPENDIX 1:
LABORATORY REPORTS

APPENDIX 2:
FIELD NOTES

APPENDIX 3:
FIELD OBSERVATION FORMS

APPENDIX 4:
CSIRO REPORTS