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REMEDICATION TECHNOLOGIES

**TREATMENT OF GROUNDWATER FROM THE ARKEMA FACILITY IN
PORTLAND, OREGON:
BENCH-SCALE TREATABILITY STUDY**

FINAL REPORT

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EXECUTIVE SUMMARY

Legacy Site Services LLC (LSS) is preparing to implement a Groundwater Source Control Interim Remedial Measure (IRM) at the Arkema Inc. property located in Portland, Oregon (the Site). The intent of the Groundwater Source Control IRM is to prevent migration of constituents of potential concern (COPCs) present in groundwater to the Willamette River, and groundwater extraction and ex situ treatment are essential parts of the proposed IRM. Due to the variety of constituents present in Site groundwater, multiple technologies are required to treat the groundwater. As such, a groundwater treatability study was conducted to support the design of the Groundwater Source Control IRM. The goal of this study was to evaluate the feasibility of several treatment technologies and develop design parameters and cost information for full-scale implementation of potentially feasible technologies.

Adventus was contracted by LSS to conduct the bench-scale treatability study in support of designing the ex situ groundwater treatment system for the Site. The scope of the study was to: a) evaluate chemical pre-treatment of the Site groundwater for chlorate and metals; b) evaluate two anaerobic biological technologies (fluidized bed and packed bed reactors) for the treatment of perchlorate; and c) evaluate alternate treatment processes (i.e., EHC and AQUAMEND reactors in series) for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides in groundwater.

The groundwater and soil samples for the treatability study were collected by Environmental Resources Management (ERM) from the Site as outlined in the Groundwater Treatability Study Work Plan submitted to the Oregon Department of Environmental Protection (ODEQ) on April 10, 2007. The initial characterization revealed that the groundwater samples received by Adventus had lower concentrations of the COPC than expected. The lower concentrations of COPC may be due to the large volume of groundwater collected for the treatability study and the locations selected for collection of the blended sample. The samples collected in April 2007 may be more representative of the current Site groundwater conditions and thus the study was conducted with the “as received” groundwater samples.

Chemical reduction via zero-valent iron (ZVI) treatment was evaluated to reduce the concentration of chlorate. The objective of the ZVI pretreatment was to reduce the chlorate load to the anaerobic biological systems. The ZVI batch test showed that all three ZVI samples evaluated supported treatment of chlorate, however, ATOMET 414 supported the greatest removal (67%). Due to limited chlorate removal, pre-treatment with ZVI was not carried forward in the study.

Chemical precipitation was evaluated for the removal of metals from groundwater. Based on the results of the initial characterization, iron was the only target metal that was present at concentrations that required treatment. The main objective of the chemical precipitation testing was to remove the iron prior to the anaerobic biological systems. The chemical precipitation jar testing identified the most effective treatment process for the removal of iron from the groundwater. Chemical pre-treatment consisted of aeration; pH adjustment to pH 8 with sodium hydroxide; polymer addition and settling.

Anaerobic biological treatment is a recognized technology for the treatment of perchlorate and chlorate in groundwater. Fluidized bed reactors, packed bed reactors and an alternate treatment

system were evaluated for the treatment of perchlorate and chlorate in the Site groundwater. In addition, the alternate treatment system was evaluated for the treatment of metals, VOC, SVOC, and pesticides via anaerobic and aerobic biological treatment.

Two fluidized bed reactors systems were set up: one system was operated with the chemically pre-treated low chloride groundwater and the second system was operated with the chemically pre-treated high chloride groundwater. Each system contained two reactors set up in series, with the first reactor containing sand and the second containing GAC. The FBR systems were operated in batch mode for 32 days and under continuous feed mode for 111 days. Complete reduction of chlorate and perchlorate were supported in the first FBR column (Sand) which suggested that a two-stage FBR system was not required. Gradual increases in the feed flow rate to achieve the target HRT of 3 hours had no effect on the treatment of chlorate and perchlorate. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

Two packed bed reactors systems were set up: one system was operated with the chemically pre-treated low chloride groundwater and the second system was operated with the chemically pre-treated high chloride groundwater. Each system consisted of one reactor which contained AQUAMEND, an inorganic biocarrier, as the media. The PBR systems were operated in batch mode for 32 days and under continuous feed mode for 114 days. Complete reduction of chlorate and perchlorate were supported in the PBR systems. Gradual increases in the feed flow rate to achieve the target HRT of approximately 3 hours had no effect on the treatment of chlorate and perchlorate. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

After the target HRT was met for the PBR systems, perchlorate and chlorate were spiked into the feeds. Both PBR systems showed complete removal of 6-7 mg/L perchlorate at an HRT of 3.5 hours. A reduction in the perchlorate removal efficiency was observed when the chlorate concentration increased; however further removal of both perchlorate and chlorate was supported when additional carbon was added to the systems.

Two alternate treatment systems were set up: one system was operated with the low chloride groundwater and the second system was operated with the high chloride groundwater. Each system consisted of an EHC reactor and sand reactor set up in series. The effluent from the sand reactor was divided in half such that aerobic AQUAMEND and anaerobic AQUAMEND treatment could be evaluated. The EHC-Sand-AQUAMEND systems were operated under continuous feed mode for 117 days. The Alternate Treatment systems showed little to no treatment of perchlorate during the initial 28 days of testing. With more time, and with use of the blended groundwater, complete removal of perchlorate and chlorate were supported. Marginal treatment of VOCs and SVOCs was observed in the EHC columns and the AQUAMEND columns supported some removal of chlorobenzene and 2-chlorophenol. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

Each of the three biological treatment processes (FBR, PBR, and EHC-AQUAMEND treatment systems) effectively treat perchlorate and chlorate without being highly sensitive to chloride concentrations and slight pH changes. An economic evaluation will be conducted to determine the preferred treatment process.

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1. INTRODUCTION AND OBJECTIVES

1.1. Project Background

Legacy Site Services LLC (LSS) is preparing to implement a Groundwater Source Control Interim Remedial Measure (IRM) at the Arkema Inc. property located in Portland, Oregon (the Site). The intent of the Groundwater Source Control IRM is to prevent migration of constituents of potential concern (COPCs) present in groundwater to the Willamette River, and groundwater extraction and ex situ treatment are an essential part of the proposed IRM. Due to the variety of constituents present in Site groundwater, multiple technologies are required to treat the groundwater. As such, a groundwater treatability study was conducted to support the design of the Groundwater Source Control IRM. The goal of this study was to evaluate the feasibility of several treatment technologies and develop design parameters and cost information for full-scale implementation of potentially feasible technologies.

Adventus was contracted by LSS to conduct the bench-scale treatability study in support of designing the ex situ groundwater treatment system for the Site. The scope of the study was to: a) evaluate chemical pre-treatment of the Site groundwater for chlorate and metals; b) evaluate two anaerobic biological technologies (fluidized bed and packed bed reactors) for the treatment of perchlorate; and c) evaluate alternate treatment processes (i.e., EHC and AQUAMEND reactors in series) for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides in groundwater. The groundwater and soil samples for the treatability study were collected by Environmental Resources Management (ERM) from the Site as outlined in the Groundwater Treatability Study Work Plan submitted to the Oregon Department of Environmental Protection (ODEQ) on April 10, 2007.

The COPCs included: perchlorate, SVOCs, VOCs, metals, and pesticides. In addition to evaluating the selected technologies for the treatment of the COPCs, the effect of chloride concentration on biological treatment was also evaluated. This report presents the results and data interpretation of the bench-scale treatability study completed between April 2007 and February 2008 at the Adventus facility in Mississauga, Ontario, Canada.

ERM and KC Environmental Inc. provided guidance on the set-up of the fluidized bed reactors and operation of the systems. LSS, ERM, and KC Environmental provided insight for the interpretation of the data throughout the study.

1.2. Technology Background

Fluidized Bed Reactors

Fluidized bed reactors (FBRs) were introduced in the 1970s for the treatment of municipal wastewater (Tyagi & Vembu, 1990). Since then the FBR technology has been used for various other processes including the treatment of high strength industrial wastewater, contaminated groundwater and hazardous wastes (Tyagi & Vembu, 1990). FBRs can be used to support aerobic, anaerobic, nitrification and denitrification processes. FBR systems consist of one (or more) reactors filled with media (i.e. sand or carbon) to support the growth of microorganisms (EPA, 2006). Fluidization of the media is achieved by maintaining a high influent flow rate (EPA, 2006). Some advantages of FBR systems include: increased surface area available for microbial growth; increase in efficiency of

treatment yielding a smaller footprint; and continuous control of microbial growth reducing clogging and channeling (EPA, 2006). Some disadvantages of FBR systems include: more expensive to build and operate than packed bed reactors, higher pumping capital and electrical costs; and operational problems such as media loss; bed height control and loss of biomass in the effluent (EPA, 2006).

For this study, two FBRs were used in series, with sand and GAC, respectively, selected as the fluidized media.

References:

EPA. 2006. Perchlorate (ClO₄⁻) Treatment Technologies Literature Review Operable Unit 1 Expanded Treatability Study, National Aeronautics and Space Administration Jet Propulsion Laboratory Pasadena, CA EPA ID# CA9800013030
<http://jplwater.nasa.gov/nmoweb/Docs/ROD/Perchlorate-Lit-Review.pdf>

Tyagi, R.D. and K. Vembu. 1990. CRC Wastewater Treatment by Immobilized Cells. CRC Press, Boca Raton, FL. Pg. 254

Packed Bed Reactors

Packed bed reactors (PBRs) contain media which support the growth of microorganisms. In contrast to the FBRs where the media is fluidized, the media of a packed bed reactor is fixed in place (EPA, 2006). Various media (sand, GAC, plastic rings or spheres) can be used in a PBR and for this study, AQUAMEND was selected. AQUAMEND media (or “biocarriers”) are biocompatible, engineered, inorganic surfaces that provide surface area for the development of immobilized biofilms. AQUAMEND biocarriers exhibit high surface area, high porosity, very high mechanical and dimensional stability, and excellent resistance to attrition. Because of these properties, bioreactors equipped with AQUAMEND media can respond to system upsets including acid and base shocks, surges of toxic organics, nutrient starvation, oxygen limitation, and heavy metal contamination. These characteristics provide several advantages over traditional suspended-growth systems such as improved system productivity, high-concentration chemical loading without washout, reduced sludge production, and reduced susceptibility to hydraulic and process upsets (Adventus, 2008).

The main advantage of PBR systems is the lower pumping requirements and costs compared to FBR systems (EPA, 2006). PBR systems are more prone to channeling and clogging and thus require backwashing to prevent excessive head losses. After backwashing the system may show a reduction in removal efficiency (EPA, 2006).

References:

EPA. 2006. Perchlorate (ClO₄⁻) Treatment Technologies Literature Review Operable Unit 1 Expanded Treatability Study, National Aeronautics and Space Administration Jet Propulsion Laboratory Pasadena, CA EPA ID# CA9800013030
<http://jplwater.nasa.gov/nmoweb/Docs/ROD/Perchlorate-Lit-Review.pdf>

Adventus. 2008. <http://www.adventusgroup.com/>

Alternate Treatment Processes

The alternate treatment process was designed as a stand alone system to treat the various COPCs present in the Site groundwater. The alternate treatment system consisted of three distinct units set up in series. The first unit contained EHC which was designed to supported reductive treatment of perchlorate, SVOCs, VOCs, and pesticides. Adventus has adapted its patented combination of controlled-release solid carbon and zero-valent iron (ZVI) particles to yield a material (EHC™) for stimulating reductive dechlorination of persistent organic solvents in groundwater and source zones (Adventus, 2008). Effluent from the EHC unit flowed into a Sand reactor which was designed to support further removal of perchlorate, SVOCs, VOCs, and pesticides under reducing conditions. The effluent from the sand reactor was divided in half to allow for the evaluation of both aerobic and anaerobic packed bed reactors. Half the effluent flowed into a unit containing a Waterloo Emitter which was designed to provide oxygen to the groundwater while reducing the production of off-gases. The effluent from the Waterloo Emitter flowed into the final unit containing AQUAMEND which was designed to support aerobic treatment of SVOCs. The other half of the Sand effluent flowed into an anaerobic AQUAMEND unit which evaluated reductive treatment of SVOCs.

For this study, EHC™, sand, and AQUAMEND were used in a series of PBRs

References:

Adventus. 2008. <http://www.adventusgroup.com/>

1.3. Project Objectives

The aim of this bench-scale feasibility study was to aid in the design of an ex situ groundwater treatment system by evaluating the effectiveness of several technologies for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides in the impacted Site groundwater. The effect of chloride concentration on biological treatment of the Site groundwater was also evaluated. Specific objectives included:

- evaluation of ZVI for the treatment of chlorate in batch tests;
- evaluation of chemical precipitation for the treatment of metals present at concentrations exceeding potential discharge limits in batch tests (however, only iron was detected at concentrations sufficient to warrant treatment);
- evaluation of a two-stage fluidized bed reactor system for the treatment of perchlorate at two chloride concentrations;
- evaluation of a packed bed reactor system for the treatment of perchlorate at two chloride concentrations;
- evaluation of an EHC-AQUAMEND system for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides at two chloride concentrations;
- evaluation of ion exchange as a polishing step for perchlorate if biological treatment was not able to achieve potential discharge limits (however, this evaluation was not completed since biological treatment proved effective for perchlorate); and
- recommendations for potential field implementation.

2. ANALYTICAL AND INITIAL CHARACTERIZATION

2.1. ANALYTICAL

All samples were submitted to TestAmerica for analysis. Chlorate samples were submitted to TestAmerica-Houston and the remaining samples were submitted to TestAmerica-Denver. Two perchlorate analytical methods are listed in Table 1 based on ERM's findings from a separate study that evaluated the potential interference of anions on the perchlorate concentrations of groundwater from the Site. ERM concluded that at perchlorate concentrations greater than 2 mg/L, the concentrations of anions (chloride, chlorate, sulfate) are unlikely to interfere with perchlorate analyses by either ion chromatography with conductivity detection (Method 314) or ion chromatography with tandem mass spectrometry (IC/MS-MS). However, at perchlorate concentrations below 2 mg/L, high concentrations of anions (chloride, chlorate, sulfate) are likely to cause a matrix interference especially when analyzed by Method 314. Based on these findings, Method 314 was used for routine analyses and IC-MS/MS analyses were conducted as confirmation analyses and when low concentrations of perchlorate were expected (Report on Determination of Anion Interference in Perchlorate Analyses, 2006, ERM-West, Inc.). The majority of the samples were submitted with RUSH turn-around-times, which are summarized in Appendix A. A summary of analyses and methods is included as Table 1.

All samples were shipped on ice via FedEx priority overnight service.

2.2. RECEIPT OF GROUNDWATER AND SOIL SAMPLES

Groundwater samples were collected by ERM for the treatability study from several locations: MWA-30, MWA-17Si, MWA-23 and blended (of equal parts from MWA-5, MWA-14i, MWA-34i, MWA-43, MWA-44, MWA-52i, MWA-66i, and MWA-68si) at the Site and were received by Adventus on April 4, 2007. The blended sample was collected from locations considered to be representative of the groundwater to be treated as part of the Groundwater Source IRM. Adventus received the following:

- Nine (55-gallon) and one (10-gallon) metal drums of the blended groundwater
- Four (55-gallon) metal drums of groundwater from MWA-23
- One (55-gallon) metal drum of groundwater from MWA-17Si
- One (55-gallon) metal drum of groundwater from MWA-30

All drums were placed into cold room storage (4°C) upon receipt. Soil (B-122 36-38' 4/11/07) was also collected by ERM and was received by Adventus on April 16, 2007. The soil sample, which was used as a source of native microorganisms for the biological treatment portions of the study, was placed into cold room storage upon receipt.

Samples of groundwater from the MWA-23, MWA-17Si, MWA-30 and blended drums were submitted for total phosphate, total organic carbon, total suspended solids, total volatile solids, hexavalent chromium, alkalinity, chloride, sulfate, nitrate, calcium, manganese, magnesium, target metals (As, Cd, total Cr, Cu, Fe, Pb, Ni, Se, Ag, and Zn), semivolatile organic compounds, pesticides, volatile organic compounds, total Kjeldahl nitrogen (TKN), ammonium, and perchlorate. Additional samples were filtered with 0.45 micron filters and submitted for dissolved hexavalent chromium and dissolved target metals. All samples were submitted to TestAmerica as outlined in Section 2.1. The

following laboratory parameters were measured at Adventus: pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), specific conductivity (SC), perchlorate (probe method), and temperature.

2.3. RESULTS AND DISCUSSION

The results of the initial characterization of the four groundwater samples are presented in Tables 2 – 7.

The perchlorate, chlorate, and chloride concentrations in the blended groundwater sample were 3.2 mg/L, 45.5 mg/L, and 1,600 mg/L, respectively. Perchlorate and chlorate were not detected in the MWA-30 and MWA-23 groundwater samples and the chloride concentrations were 46,000 mg/L and 29 mg/L, respectively. The perchlorate, chlorate, and chloride concentrations in the MWA-17Si groundwater sample were 4.8 mg/L, 24.5 mg/L, and 1,500 mg/L, respectively (Table 2).

Iron was the predominant metal detected in the groundwater samples (Table 3). The iron concentrations in the blended, MWA-30, MWA-17Si, and MWA-23 groundwater samples were 140 mg/L, 58 mg/L, 190 mg/L, and 40 mg/L, respectively. The dissolved iron concentration for the blended groundwater was 110 mg/L which indicated that the majority of the iron was present in the soluble form. Chromium and nickel were also detected in the MWA-30 and MWA-17Si groundwater samples (Table 3). Other target metals (cadmium and zinc) were present at either non-detectable or trace concentrations, and removal of these other target metals could not be evaluated as part of the treatability study.

The groundwater collected for the treatability study was placed into metal drums and thus some of the iron detected in the groundwater samples may have been contributed from the drum.

Trace concentrations of total cadmium (3.5 – 5.6 µg/L) and zinc (8.9 – 720 µg/L) were also detected in the groundwater samples.

The predominant VOC detected in the blended and MWA-17Si groundwater samples was chlorobenzene at concentrations of 1,700 µg/L and 38,000 µg/L, respectively (Table 4). Lower concentrations of chloroethane (24 µg/L) and chloroform (9.9 µg/L) were detected in the blended groundwater. Trace concentrations of chloroform (3.2 µg/L) and toluene (0.39 µg/L) were detected in the MWA-30 groundwater and toluene (48 µg/L) was detected in the MWA-23 groundwater.

The blended groundwater contained low concentrations of bis-(2-Ethylhexyl)phthalate (3.1 µg/L) and 2-Chlorophenol (43 µg/L). Trace concentrations of bis-(2-Ethylhexyl)phthalate were present in the MWA-30 (3.2 µg/L) and MWA-23 (2.9 µg/L) groundwater samples. The MWA-17Si groundwater sample contained 2-chlorophenol (450 µg/L), 1,2-Dichlorobenzene (5.9 µg/L), 1,4-Dichlorobenzene (18 µg/L), 2,4-Dichlorophenol (6.0 µg/L) and Naphthalene (1.6 µg/L) (Table 5).

Trace concentrations (<0.16 ug/L) of DDD, DDE, DDT, Aldrin, and BHC were detected in all four groundwater samples (Table 6).

The lab parameter data are summarized in Table 7. The blended, MWA-30, and MWA-23 groundwater samples exhibited neutral pH (6.5 to 7.2) while the groundwater sample from MWA-17Si was acidic (4.8). Slightly reducing conditions were measured in the blended, MWA-30, and

MWA-23 groundwater samples. The highest conductivity was measured in the MWA-30 groundwater sample. Nitrate concentrations from the probe readings did not correlate well with the analytical concentrations. Perchlorate concentrations from the probe readings were higher than the analytical concentrations.

2.4. SUMMARY AND CONCLUSIONS

The results of the baseline sampling showed that the groundwater was impacted with perchlorate, chlorate, SVOCs, VOCs, metals, and pesticides. Concentrations of the COPC were lower than historic Site data, which may be due to the large volume of groundwater collected for the treatability study and the locations selected for collection of the blended groundwater sample. The samples collected in April 2007 may be more representative of the current Site groundwater conditions and thus the study was conducted with the “as received” groundwater samples.

3. CHEMICAL PRE-TREATMENT

Chemical reduction via zero-valent iron treatment was evaluated to reduce the concentration of chlorate. The objective of the ZVI pretreatment was to reduce the chlorate load to the anaerobic biological systems. Chemical precipitation was evaluated for the removal of metals from groundwater. Based on the results of the initial characterization, iron was the only target metal that was present at concentrations that required treatment. The main objective of the chemical precipitation testing was to remove the iron prior to the anaerobic biological systems.

3.1. METHODS

3.1.1 Chemical Reduction for Chlorate Treatment

Three zero-valent iron samples (Quebec Metal Powders) with different grain sizes were evaluated in the batch tests. The three samples selected were: ATOMET 414, H2OMet 57-C, and H2OMet 56. The grain size distribution curves of the three products are shown in Figure 1.

Sixteen jars were prepared consisting of reactive samples and blank samples. The reactive samples consisted of a 250-mL jar containing approximately 50 grams of iron material and were filled with blended groundwater, providing an iron to water ratio of about 1:5. The blank jars contained only blended groundwater. The jars were placed on an orbital shaker to provided mixing without agitation. At time zero, 2 hours (hrs), 7 hrs, and 23 hrs, the jars were inverted manually. The jars were maintained at room temperature (approximately 21°C; 70°F).

One set of jars was sacrificed for each sampling time. Groundwater samples for chlorate and perchlorate analyses were collected from each jar, along with samples for oxidation-reduction potential (ORP), pH and perchlorate (probe method) at sampling times of 1, 3, 8, and 24 hours.

The chlorate (TestAmerica-Houston) and perchlorate (TestAmerica-Denver) samples were shipped on ice via FedEx priority. ORP, pH, and perchlorate (probe method) were determined using reference electrodes.

3.1.2 Chemical Precipitation for Treatment of Iron and Other Metals

pH Titration

The blended groundwater was titrated with sodium hydroxide (NaOH) to a pH of 11. After each addition of caustic, the groundwater was stirred for 1 minute. After five minutes, the turbidity and pH were measured. The pH titration was repeated with calcium hydroxide (Ca(OH)₂).

The pH titrations were completed with:

- 1 % (wt/v) NaOH and 1 % (wt/v) Ca(OH)₂ solutions
- 4 % (wt/v) NaOH and 3.7 % (wt/v) Ca(OH)₂ solutions
- 20 % (wt/v) NaOH and 20 % (wt/v) Ca(OH)₂ solutions

Titrations completed with the 1 % and 4 % solutions were done as screening tests and the 20% solutions were used for subsequent testing.

Jar Test I

A jar test was completed to evaluate the effect of caustic (NaOH and Ca(OH)₂), pH (8, 9, 10, and 11), and aeration (aerated vs. non-aerated) on metals removal in the blended groundwater. A total of eighteen jars were set up with the blended Site groundwater (Table 8).

On May 14th, 1L of the blended groundwater was poured into 9 – 2L jars. The pH in four of the jars was adjusted to 8, 9, 10, and 11 with 20% (wt/v) NaOH (200 g/L). An air diffuser was placed into each of the NaOH adjusted jars and into the control (no pH adjustment). The air pump was turned on and operated for 20 minutes. The air pump was then turned off and the jars were left stagnant for 15 minutes. The supernatant in each jar was sampled for selected parameters in the following order:

- 1) Turbidity (Adventus – HACH Turbidity Meter – Cole Parmer Cat. No. 99511-00)
- 2) Total suspended solids (TestAmerica)
- 3) Target metals (TestAmerica)
- 4) Dissolved target metals (TestAmerica) – sample was filtered through a 0.45 micron filter prior to analysis
- 5) Lab parameters (ORP, DO, pH, conductivity, temperature, perchlorate) (Adventus)

The pH of the remaining four jars was adjusted to 8, 9, 10, and 11 with 20% (wt/v) Ca(OH)₂ (200 g/L) and the same protocol was followed as outlined above. The samples for TestAmerica were stored at 4°C overnight.

On May 15th, 1L of the blended groundwater was poured into 9 – 2L jars. The pH in four of the jars was adjusted to 8, 9, 10, and 11 with 20% (wt/v) NaOH (200 g/L). The jars were left stagnant for 15 minutes. The supernatant in each jar was sampled for selected parameters as outlined above.

The pH of the remaining four jars was adjusted to 8, 9, 10, and 11 with 20% (wt/v) Ca(OH)₂ (200 g/L) and the same protocol was followed as outlined above.

The samples collected on May 14th and 15th were shipped on ice via FedEx to TestAmerica-Denver.

Polymer Evaluation

The polymer jar test evaluated the effect of different polymers on solids removal from the blended groundwater. A total of 21 polymer samples were evaluated from three vendors as outlined in Table 9.

The following procedure was followed for each polymer sample:

- 1) 0.1% solution of the polymer was prepared by dissolving 0.100 g of polymer in 100 mL of distilled water.
- 2) 500 mL of the blended Site groundwater was transferred into a 1L glass beaker
- 3) The pH of the GW was adjusted to 8 with 20% (wt/v) caustic (NaOH or Ca(OH)₂) solution
- 4) The jars were allowed to sit for 15 minutes following pH adjustment and then the turbidity was recorded. The turbidity of the control jar (no pH adjustment) was also recorded.
- 5) 0.5 mL of the 0.1% polymer solution was added to the beaker
- 6) The jar testing apparatus was turned on and the speed was set at approximately 30 rpm for 30 seconds.
- 7) The speed was reduced to approximately 10 rpm for 30 seconds and then the jar testing apparatus was turned off.
- 8) After 15 minutes, a sample of the supernatant was collected and the turbidity was recorded.
- 9) Steps 5-8 were repeated two more times for the CSC polymers, and one more time for the NALCO and GE polymers.

The procedure (Steps 5-7) outlined above was recommended by CSC Technology, a polymer supplier.

The testing was completed as outlined below:

CSC - June 6 (NaOH); June 7 (Ca(OH)₂)

NALCO - June 8 (NaOH); June 11 (Ca(OH)₂)

GE - June 13 (NaOH); June 14 (Ca(OH)₂)

CSC Repeat with lower concentrations - June 15 (NaOH); June 18 (Ca(OH)₂)

The best performing polymer from each vendor was selected for further evaluation.

Jar Test II

During the polymer testing, the blended Site groundwater turned a blue/green color after the addition of caustic solution which indicated the presence of soluble ferrous iron. This color change was not observed during Jar Test I. Although the first jar testing showed that aeration did not enhance iron removal, an additional jar test was set up to evaluate the effect of aeration on iron removal in the blended Site groundwater.

A total of four jars were set up with the blended Site groundwater as outlined in Table 10.

One liter of the blended groundwater was placed into each 2L jar. Jar #3 was aerated for 15 minutes and then the pH of jars 2, 3, and 4 was adjusted to 8 with 20% NaOH. Jars 1, 2, and 3 were allowed to settle while jar 4 was aerated for 15 minutes. The supernatant of each jar was sampled for turbidity, target metals, dissolved target metals and TSS. The dissolved target metals sample was

filtered through a 0.45 micron filter prior to analysis. Turbidity was monitored at Adventus and the remaining samples were shipped on ice to TestAmerica-Denver via FedEx.

Jar Test III

The results of Jar Test II indicated that in addition to aeration and pH adjustment, further treatment (i.e. polymer addition and/or filtration) was required to remove the iron present in the blended groundwater to targeted levels.

A total of five jars were set up with the blended Site groundwater as outlined in Table 11.

Blended site groundwater (750 mL) was placed into each 1L beaker. All jars were aerated for 20 minutes and then the pH of jars C2, 1, 2, and 3 was adjusted to 8 with 20% NaOH. Immediately following the pH adjustment, 1 mL of the 0.1% polymer solution was added to Jars 1, 2, and 3. The jar testing apparatus was turned on and the speed was set at approximately 30 rpm for 30 seconds. The speed was reduced to approximately 10 rpm for 30 seconds and then the jar testing apparatus was turned off. The jars were allowed to settle for 15 minutes and the supernatant of each jar was sampled for turbidity. After an additional 15 minutes, the supernatant in each jar was sampled for turbidity. ORP, temperature, and perchlorate readings were also taken.

The supernatant of the jar with the lowest turbidity reading was sampled for metals. The supernatant was then filtered with a Whatman 41 filter (20-25 µm particle retention) and the filtrate was sampled for metals. Metal samples were submitted to TestAmerica-Denver on ice via FedEx.

Jar Test IV

A final jar test was conducted to determine the polymer dosage for 4816P (Table 12).

Blended site groundwater (500 mL) was placed into each 1L beaker. All jars were aerated for 20 minutes and then the pH was adjusted to 8 with 20% NaOH. Immediately following the pH adjustment, different volumes of the 0.1% 4816P polymer solution were added to each jar. The jar testing apparatus was turned on and the speed was set at approximately 30 rpm for 30 seconds. The speed was reduced to approximately 10 rpm for 30 seconds and then the jar testing apparatus was turned off. The jars were allowed to settle for 15 minutes and the supernatant of each jar was sampled for turbidity.

3.2. RESULTS AND DISCUSSION

3.2.1 Chemical Reduction for Chlorate Treatment

Figure 2 shows the chlorate results for all samples treated with the ZVI materials plotted as concentration in mg/L versus time in hours. The blanks vials showed a consistent chlorate concentration over time. The chlorate concentration for the ATOMET 414 material declined continuously from 37.1 mg/L to 12.4 mg/L at the end of the test (24 hrs). The chlorate concentrations for the H2OMET 57-C and H2OMET 56 materials showed a slow decline and had final values of 31.4 mg/L and 29.4 mg/L, respectively. The ATOMET 414 showed the greatest

removal of chlorate (67%) when compared with the H2OMET 56 and H2OMET 57-C irons (21 % and 15%, respectively).

The perchlorate concentrations trends are shown in Figure 3. The perchlorate concentrations in the blanks and the reactive jars were similar. These data indicate that chemical reduction using the various ZVI materials is an ineffective treatment technology for perchlorate.

Figure 4 shows that slightly reducing conditions (-63 to -83 mV) were maintained throughout the test in the blank samples. The three iron samples showed a decline in ORP to a range of -238 to -290 mV for the ATOMET 414 material, -87 to -144 mV for the H2OMET 57-C material and -85 to -177 mV for the H2OMET 56 material. Figure 5 shows the initial pH value of 6.6 in the blank sample decreased slightly over time, while the pH in the reactive jars increased gradually to values of about 7.8 for the ATOMET 414 material, 6.7 for the H2OMET 57-C material and 6.9 for the H2OMET 57-C material.

First-order reaction rates and half lives for chlorate were calculated for each iron sample (Table 13). The Atomet 414 had a reaction rate of $0.0475 \text{ mg/L}\cdot\text{hr}^{-1}$ while the H2OMET 56 and H2OMET 57-C samples had reaction rates of $0.0106 \text{ mg/L}\cdot\text{hr}^{-1}$ and $0.0076 \text{ mg/L}\cdot\text{hr}^{-1}$, respectively. The chlorate half lives for the ATOMET 414, H2OMET 56 and H2OMET 57-C samples were, 14.6 hrs, 65.4 hrs, and 91.4 hrs, respectively.

3.2.2 Chemical Precipitation for Treatment of Iron and Other Metals

pH titration

The pH titrations showed that 3.8 mL of 20% NaOH or 3.8 mL of 20% $\text{Ca}(\text{OH})_2$ were required to increase the pH of 1 L of the blended groundwater to 11 (Figures 6 and 7).

Jar Test I

The volume of 20% (wt/v) NaOH and 20% (wt/v) $\text{Ca}(\text{OH})_2$ required to adjust the pH of the blended groundwater to the pre-determined endpoints is presented in Table 14. Comparing these values with those from the pH titrations shows that less caustic was required to reach the target pH values.

Without any pH adjustment (controls), 72% and 73% removal of Fe was observed in the non-aerated and aerated controls, respectively, as a result of settling (Figure 8). These observations are not consistent with the result of the initial characterization where the total and dissolved iron concentrations in the blended groundwater were $140,000 \mu\text{g/L}$ and $110,000 \mu\text{g/L}$, respectively. This indicates that some aeration or agitation of the groundwater may have taken place during the set up of the jar test. Aeration of the groundwater enhanced the removal of dissolved iron. Dissolved iron concentrations were reduced by 22% and 76% in the non-aerated and aerated controls, respectively.

Dissolved iron was not detected in any of the pH-adjusted test jars (detection limit of $100 \mu\text{g/L}$) (Figures 9 through 12) which suggested that the process chemistry was good.

Comparison of aerated and non-aerated jars prior to filtration indicates differences in settling performance or possible floc shear caused by aeration. In the jars that were pH-adjusted, the non-aerated jars generally showed the greater reduction in total iron concentrations. However, in the jars that were adjusted with NaOH to a pH of 9 or 11, the aerated jars showed a greater reduction in total iron than the non-aerated jars.

With the exception of the jars adjusted to pH 8 or 9, lower TSS concentrations were obtained for the aerated NaOH treatments. With the exception of pH 11, the aerated $\text{Ca}(\text{OH})_2$ treatments had higher TSS values than the non-aerated. The non-aerated NaOH and $\text{Ca}(\text{OH})_2$ treatments showed an increase in TSS as the pH increased (Figure 13).

Polymer Testing

The data from the jar testing indicated that further testing was required to enhance solids removal during settling. The jar tests completed on June 6th and 7th with the CSC Technology polymers showed that as the polymer dosage increased, the turbidity increased (Figure 14). Brent Cowan (CSC Technology) indicated that too much polymer may have been added and suggested repeating the testing with lower polymer concentrations.

On June 15th (NaOH) and June 18th ($\text{Ca}(\text{OH})_2$) the CSC polymers were evaluated again but the polymer was added in 0.1 mL increments. For the NaOH jars, it appears that 0.1 mL of polymer (0.2 mg/L) was the ideal dosage for the 4816P, 4807, and 4809 since higher dosages resulted in an increase in turbidity (Figure 17). For the 4814-P and 4818-P polymers even the 0.1 mL addition resulted in an increase in turbidity (Figure 17). The repeat of the $\text{Ca}(\text{OH})_2$ jars showed a decrease in turbidity after the first two 0.1 mL additions of the polymer solution (Figure 17).

The 4816P and 4818P polymers showed the greatest reductions in turbidity in the NaOH and $\text{Ca}(\text{OH})_2$ jar tests, respectively.

Of the six NALCO polymers evaluated, ULTRION 7157 and NALCLEAR 7768 showed the greatest reductions in turbidity in the NaOH and $\text{Ca}(\text{OH})_2$ jar tests, respectively (Figure 15).

Of the ten GE polymer samples evaluated, POLYFLOC AS1002 and KLARAID CDP 1314C showed the greatest reductions in turbidity in the NaOH and $\text{Ca}(\text{OH})_2$ jar tests, respectively (Figure 17).

Jar Test II

The results of the first jar test (data summarized above) showed that aeration did not improve iron removal at the four pH values evaluated; however, the unadjusted (ambient pH) controls indicated that aeration was helpful in reducing the soluble fraction of iron. Following the observation that the iron may have shifted to the reduced state during storage, the jar test was repeated and the results of jar test II showed that aeration improved iron removal. After pH adjustment and settling, 58% removal of Fe was observed (Jar #2) while the aerated jars showed 93% (Jar #3) and 89% (Jar #4) removals (Figure 18). Aeration prior to pH adjustment showed a significant improvement of turbidity and iron removal compared to the reverse order of pH adjustment followed by aeration (Table 15).

Jar Test III

Based on visual observations and turbidity readings (Table 16), the best removal of iron was observed in Jar 3 where the groundwater was aerated, pH adjusted with 20% (wt/v) NaOH, and 1 mL of 0.1% 4816P polymer solution were added. The targeted pH value was 8, however the final pH of the test jars was approximately 9.

The data from jar test III showed that almost 50% of iron in the blended groundwater sample was soluble, however, during the initial characterization, 79% of the iron in the blended groundwater sample was soluble. The groundwater used for the jar test may have been aerated or agitated in preparation of the batch jar which would result in the oxidation of iron and settling of the oxides. Sampling the supernatant of jar 3 showed that 99.4% removal of iron was achieved. After filtering the supernatant from jar 3, 99.9% removal of iron was achieved (Table 17).

Total and dissolved zinc were also detected in the blended groundwater sample at concentrations of 31 µg/L and 19 µg/L, respectively. Sampling the supernatant of jar 3 showed that 72.5% removal of zinc was achieved and after filtering the supernatant from jar 3, an additional 0.7% removal of zinc was supported (Table 17).

Jar Test IV

The results of the final jar test showed that the greatest removal of solids was achieved when 100 µL of 0.1% 4816(P) polymer solution was added to 500 mL of blended groundwater (Table 18).

3.3. SUMMARY AND CONCLUSIONS

3.3.1 Chemical Reduction for Chlorate Treatment

All three ZVI samples evaluated showed treatment of chlorate in the 24 hour batch test. The ATOMET 414 ZVI sample showed the greatest removal of chlorate (67%) and had the fastest reaction rate ($0.0475 \text{ mg/L}\cdot\text{hr}^{-1}$) and shortest half life (14.6 hours). No removal of perchlorate was observed in any of the ZVI batch tests.

Due to the limited removal of chlorate, pre-treatment by ZVI was not carried forward in this study.

3.3.2 Chemical Precipitation for Treatment of Iron and Other Metals

The jar testing identified the most effective treatment process for the removal of iron from the blended groundwater. The major mechanism for iron removal after pH adjustment to 8 was settling. pH adjustment above 8 didn't precipitate more iron it only made the iron precipitate settle better. Thus a combination of chemical (pH adjustment to 8) and physical (settling) processes were used to treat the iron present in the groundwater sample.

The following chemical treatment protocol reduced the iron concentration to below 1 mg/L (the target value for iron in the feed to the FBR and PBR biological systems) in the blended groundwater sample:

- 1) Aeration for 20 minutes
- 2) pH adjustment to pH 8 with NaOH (approximately 30 μ L 20% (wt/v) NaOH per liter of groundwater)
- 3) Polymer addition (CSC Technology 4816P) (200 μ L of 0.1% 4816(P) solution per liter of groundwater)
- 4) Settling for a minimum of 15 minutes.

4. ANAEROBIC BIOLOGICAL TREATMENT STUDIES

Anaerobic biological treatment is a recognized technology for the treatment of perchlorate and chlorate in groundwater. FBRs, PBRs, and an alternate treatment system were evaluated for the treatment of perchlorate and chlorate in the Site groundwater. In addition, the alternate treatment system was evaluated for the treatment of metals, VOC, SVOC, and pesticides via anaerobic and aerobic biological treatment. Schematic diagrams of each biological treatment system are provided in Appendix B.

4.1. METHODS

4.1.1 Chemical Pre-Treatment of Groundwater

The blended groundwater was used for the low chloride (1,600 mg/L) testing. A mixture of six parts blended groundwater and one part MWA-30 groundwater was prepared for the high chloride (8,000 mg/L) testing.

Based on the results of the jar testing, the groundwater was chemically pre-treated as follows:

- 1) groundwater (14 L) was transferred into a 20 L pail and aerated for 20 minutes
- 2) pH was adjusted to 8 with 20% or 40% NaOH
- 3) 3 mL of 0.1% 4816P polymer solution was added and the groundwater was stirred rapidly for 30 seconds and then slowly for 30 to 60 seconds
- 4) solids were allowed to settle for at least 15 minutes
- 5) supernatant was siphoned into a clean pail and stored at 4°C until required for testing.

The groundwater was chemically pre-treated in 14L batches throughout the study. Prior to initiation of the reactor tests, one groundwater sample before and one after chemical pre-treatment was sampled for VOCs, SVOCs, pesticides, target metals, perchlorate, chlorate, TOC, nitrate, sulfate, ammonium, TKN and phosphate. Laboratory parameters were also analyzed in the groundwater samples before and after chemical pre-treatment.

Preparation of the FBR and PBR feeds throughout the study showed that additional NaOH was required to adjust the pH of the groundwater to 8 over time. The jar testing showed that 30 μ L of 20% (wt/v) NaOH was required to adjust the pH of one liter of blended groundwater to 8 and during the FBR and PBR batch test period, between 140 and 600 μ L of 20% (wt/v) NaOH were required per liter. Towards the end of the FBR and PBR continuous feed mode testing, between 350 and 500 μ L of 40% (wt/v) NaOH were required per liter to adjust the pH to 8.

4.1.2 Fluidized Bed Reactors

Two parallel fluidized bed reactor systems were set up to evaluate chlorate and perchlorate treatment. One system (FBR System 1) was operated with the chemically pre-treated low chloride (1,600 mg/L) groundwater and the second system (FBR System 2) was operated with the chemically pre-treated high chloride (8,000 mg/L) groundwater.

Glass columns (2" ID x 18" L) with Teflon end fittings (Kontes Glass; Vineland, NJ) were used for the FBR testing. A two-stage FBR system was set up with the first reactor (i.e. column) containing sand (VWR - Fine Silica Sand 40 mesh; Cat. No. 57457-265) and the second reactor containing granular activated carbon (GAC) (Sigma - DARCO 12-20 mesh, granular; Cat. No. 24224-1). Each reactor was filled with 9" of packing material and the remaining 9" of the column remained void to allow for expansion of the bed. The bottom of the column had a T-connector such that the feed and recycle were simultaneously pumped into the column at the required flow rates. The feed lines also contained a T-connector to allow for the addition of high fructose corn syrup (HFCS), which was added as electron donor. Check valves were placed on the influent, electron donor, and recycle lines.

The recycle reservoir for each system contained 91 g of the Site soil to provide a source of native microorganisms, and three liters of the chemically pre-treated groundwater. Each recycle reservoir was amended with 0.24 g ammonium phosphate and 300 μ L of HFCS. On August 31st, 2007 the recycle pump (Cole Parmer Economy Drive; Cat. No. 07554-80) was turned on and the groundwater in the recycle reservoir was continuously recirculated through the system.

Laboratory parameters (pH, ORP, DO, conductivity, temperature, perchlorate, nitrate, and phosphate) were monitored in the recycle reservoir daily (Table 19). An aliquot of the recycle water was sampled on days 10, 18, and 31 for perchlorate, chlorate, sulfate, nitrate, ammonium, TKN, TOC, and phosphate. All samples for all analytes, except for chlorate, were shipped on ice to TestAmerica-Denver via FedEx. Chlorate samples were shipped to TestAmerica-Houston on ice via FedEx. On days 11, 18, and 28 additional chemically pre-treated groundwater amended with HFCS was added to the recycle reservoir.

Following the 32-days of batch mode operation, the FBR systems were switched to continuous feed mode. The chemically pre-treated groundwater was amended with ammonium hydroxide (NH_4OH) and phosphoric acid (H_3PO_4) and pumped (Cole Parmer Console Drive; Cat No. 77521-50) from an influent feed reservoir into the sand column in an up-flow manner. The GAC column recycle pump (Cole Parmer Economy Drive; Cat No. 07554-90) and the HFCS feed pump (Cole Parmer Console Drive; Cat. No. 775121-50) were turned on. Due to the high viscosity of the HFCS, it could not be pumped directly into the column and thus a solution was prepared. A given volume of HFCS was diluted with distilled water and pumped into the column at a set flow rate.

Laboratory parameters (pH, ORP, DO, conductivity, temperature, perchlorate, ammonium, and phosphate) were monitored in the recycle reservoir daily (Table 19).

The FBR operating conditions during continuous feed mode operation are summarized in Table 20.

The flow rate of the FBR system was increased intermittently throughout the study to obtain a targeted hydraulic retention time (HRT) of 3 hours. After each increase in the feed flow rate, the system was sampled for perchlorate, chlorate, sulfate, ammonium, phosphate, chloride, TSS, and

TVSS. Progress samples were collected in thirteen sampling events over a period of 111 days (Table 21). During each sampling event, samples were collected from the feed, sand column effluent, and GAC column effluent. A detailed list of samples submitted is provided in Appendix A.

Data obtained from the sampling events was reviewed and additions of HFCS and nutrients were adjusted, as required.

Once the FBR systems reached the targeted HRT, a comprehensive sampling of the feeds and effluents was conducted. Samples were collected for SVOC, VOC, pesticides, target metals, dissolved target metals, hexavalent chromium, and dissolved hexavalent chromium. All samples were submitted on ice to TestAmerica-Denver via FedEx.

Throughout the study, the final effluents from each system were transferred into 5-gallon pails and stored at 4°C.

4.1.3 Packed Bed Reactors

Two parallel packed bed reactor systems were set up to evaluate chlorate and perchlorate treatment. One system was operated with the chemically pre-treated low chloride (1,600 mg/L) groundwater and the second system was operated with the chemically pre-treated high chloride (8,000 mg/L) groundwater.

Glass columns (2" ID x 12" L) with Teflon end fittings (Kontes Glass; Vineland, NJ) were used for the PBR testing. Each system consisted of one reactor (i.e. column). Each column was filled with 400 mL of the AQUAMEND biocarrier. The bottom of the column had a T-connector such that the feed and recycle were simultaneously pumped into the column at the required flow rates. The feed lines also contained a T-connector to allow for the addition of the electron donor, HFCS. Check valves were placed on the influent, electron donor, and recycle lines.

The recycle reservoir for each system contained 91 g of the Site soil, to provide a source of native microorganisms, and three liters of the chemically pre-treated groundwater. Each recycle reservoir was amended with 0.24 g ammonium phosphate and 300 uL of HFCS. On August 31st, 2007 the recycle pump was turned on and the groundwater in the recycle reservoir was continuously recirculated through the system.

Laboratory parameters (pH, ORP, DO, SC, temperature, perchlorate, nitrate, and phosphate) were monitored in the recycle reservoir daily (Table 19). An aliquot of the recycle water was sampled on days 10, 18, and 31 for perchlorate, chlorate, sulfate, nitrate, ammonium, TKN, TOC, and phosphate. Samples for all analytes, except chlorate, were shipped on ice to TestAmerica-Denver via FedEx. Chlorate samples were shipped to TestAmerica-Houston on ice via FedEx. On days 11, 18, and 28 additional pre-treated groundwater amended with HFCS was added to the recycle reservoir.

Following the 32-days of batch mode operation, the PBR systems were switched to continuous feed mode. The chemically pre-treated groundwater was amended with ammonium (NH₄OH) and phosphate (H₃PO₄) and pumped (Cole Parmer Console Drive; Cat. No.77521-50) from an influent reservoir into the column in an up-flow manner. Due to the high viscosity of the HFCS, it could not be pumped directly into the column and thus a solution was prepared. A given volume of HFCS was

diluted and pumped (Cole Parmer Console Drive; Cat. No. 77521-50) into the column at a set flow rate.

Monitoring of the columns was completed daily as outlined above for the FBR systems (Table 19). Progress samples were collected in fourteen sampling events over a period of 114 days. During each sampling event, samples were collected from the feed and final column effluent. A detailed list of samples submitted is provided in Appendix A.

The flow rate of the system was increased throughout the study to obtain the targeted hydraulic retention time (HRT) of 3 hours. After each increase in the feed flow rate, the system was sampled for perchlorate, chlorate, sulfate, ammonium, phosphate, chloride, TSS, and TVSS.

The PBR operating conditions during continuous feed mode operation are summarized in Table 22.

Once the PBR systems reached the targeted HRT, a comprehensive sampling of the feeds and effluents was conducted. Samples were collected for SVOC, VOC, pesticides, target metals, dissolved target metals, hexavalent chromium, and dissolved hexavalent chromium. All samples were submitted on ice to TestAmerica-Denver via FedEx.

Data obtained from the sampling events was reviewed and additions of HFCS and nutrients were adjusted, as required.

During the final 22 days of continuous feed mode operation the concentrations of perchlorate and chlorate were increased in the feeds of the PBR systems (Table 23) to stress the PBR systems and evaluate the resulting performance.

Throughout the study, the final effluents from each system were transferred into 5-gallon pails and stored at 4°C.

4.1.4 EHC-AQUAMEND Reactors

On August 29th, 2007 two alternate treatment systems were started; one for low chloride (1,600 mg/L) and the other for high chloride (8,000 mg/L) Site groundwater.

Each system consisted of an EHC column followed by a sand column to allow for continued utilization of the dissolved organic carbon released by the EHC. The effluent from the sand column was split between two AQUAMEND column systems. One stream went to an oxygenation column followed by an aerobic AQUAMEND column, while the other stream went straight to an anaerobic AQUAMEND system. For the oxygenation step, the water passed through a column containing a Waterloo Emitter, which diffused air into the column while limiting off-gas production. Effluent from the oxygenation column flowed into the aerobic AQUAMEND column. The anaerobic AQUAMEND system consisted of two columns in series. Each AQUAMEND system was also set up with a recycle loop.

Recycle mode

On August 29th, 2007 six AQUAMEND columns were set up, two anaerobic and one aerobic for each system. Glass columns (2" ID x 12" L) with Teflon end fittings (Kontes Glass; New Jersey)

were used for the AQUAMEND testing. Each column was filled with 400ml of AQUAMEND biocarrier. A two liter recycle jar was set up for each of the AQUAMEND systems. Each recycle reservoir contained 50 g of Site soil, to provide a source of native microorganisms, and was filled with the appropriate groundwater.

The feeds were prepared by transferring the appropriate groundwater into Tedlar® bags to eliminate volatile loss of VOCs and SVOCs. From August 29, 2007 (Day 1) to October 25, 2007 (Day 36), the high chlorobenzene groundwater (MWA-17Si) was used for the alternate treatment systems. The MWA-17Si groundwater (high chlorobenzene concentration – 38 mg/L) was used for the low chloride (1,600 mg/L) testing. A groundwater mixture of 12 L MWA-17Si plus 2.1 L MWA-30 was used for the high chloride (8,000 mg/L) testing. On October 26th, 2007 (Day 37) new Tedlar bags were set up and filled with the blended groundwater for the low chloride (1,600 mg/L) testing, and a mixture of six parts blended groundwater with one part MWA-30 groundwater for the high chloride (8,000 mg/L) testing. These groundwater samples were used for the remainder of the study.

Using a peristaltic pump, the AQUAMEND columns were filled with feed in an up flow manner and the effluent of the column was collected into the recycle reservoirs. Once the column and recycle reservoirs were filled, the recycle pump was turned on and the groundwater was recirculated through each system at a flow rate of 625 ml per hour for 21 days. Aeration of the aerobic AQUAMEND reactors was achieved by inserting air stones attached to a pump directly into the aerobic recycle reservoirs.

Continuous feed mode

Plexiglass columns (20" x 2.5"ID) were used for the EHC and sand testing. On August 30th, 2007 two EHC reactors (i.e. columns) were set up by transferring a well blended mixture containing 187 g EHCFe20 (20% wt/wt), 173 g Site soil (18% wt/wt) and 576 g concrete sand (62% wt/wt) to each column. The sand columns were packed with 1,290 g concrete sand (100%).

The feed flow rate for each system was set at 125 ml per hour to yield an empty-bed contact time of 8 hours. The Tedlar bags containing each of the feeds were connected to the base of the appropriate EHC reactor, and using a peristaltic pump the Site groundwater was pumped in an up-flow manner into the EHC reactors only. The effluents from the EHC reactors were collected in five liter pails. Over the next 7 days the EHC reactors were gently tapped to remove trapped gas pockets. Due to the ongoing production of gases in the EHC reactors, the contents of each reactor were transferred to five liter pails on September 7th, 2007 and allowed to degas for three days.

On September 11th, 2007 the effluents collected from the EHC reactors were pumped in an up-flow manner into their respective sand columns followed by the Waterloo Emitter columns at a flow rate of 125 ml per hour. On the following day, the 20% EHC reactors were repacked, and on September 13th, 2007 feed was once again passed through the EHC reactors.

By September 19th, 2007 the entire system was filled with feed. A compressed air cylinder was connected to the Waterloo Emitter and the regulator was set to deliver 20 PSI. Both systems were then started in continuous feed mode mode. Throughout the study, the AQUAMEND columns continued in the recycle mode at 625 ml per hour and recirculated the final effluent from the recycle reservoirs through the AQUAMEND columns while simultaneously receiving the continuous feed mode effluent from the appropriate Sand column.

On October 25th, 2007 the EHC reservoirs were repacked as previous repacking of the columns led to a concentration of the EHC at the top (effluent) end of the column. The new packing distributed the EHC uniformly through the column.

Internal bi-weekly lab parameter monitoring was started on October 1, 2007. On November 8, 2007 the monitoring of phosphate and ammonium was started. The laboratory parameters (pH, ORP, DO, conductivity, temperature, perchlorate, phosphate, and ammonium) were measured in the feed, after the sand column and in the aerobic and anaerobic AQUAMEND recycle reservoirs (Table 24).

Progress sampling occurred after 4, 7, 10 and 16 weeks of continuous feed mode operation (Table 24). Samples were collected from the feeds, after the sand columns, and final effluents from the aerobic and anaerobic AQUAMEND systems. Samples were submitted for perchlorate, VOC, SVOC, metal, pesticide, chlorate, TOC, anions, ammonium, TKN, TSS and TVSS analysis. All samples (except chlorate) were submitted to Test America-Denver on ice via FedEx. Chlorate samples were submitted to Test America-Houston on ice via FedEx.

4.2. RESULTS AND DISCUSSION

4.2.1 Chemical Pre-Treatment of Groundwater

Based on the results of the jar tests, the chemical pretreatment of the groundwater consisted of aeration, pH adjustment with NaOH to 8, flocculation with 4816 polymer and settling followed by extraction of the supernatant. The results from before and after the chemical pre-treatment of the low and high chloride groundwater samples used for the FBR and PBR testing are summarized in Tables 25 through 30.

Chemical pre-treatment of the Site groundwater showed small reduction in phosphate and TOC and no effect on perchlorate and chlorate (Table 25).

Reductions in the concentrations of several metals (Cr, Fe, Ni, and Zn) were observed in the chemically pre-treated groundwater. As expected, significant iron removal occurred in both the low chloride (97%) and high chloride (94%) groundwater samples (Table 26). The iron concentrations in the chemically treated feeds were above the upper limit of 1 mg/L. This was likely due to transferring some of the floc while siphoning the supernatant from the chemically treated groundwater.

Since the chemical pre-treatment involved aeration, reductions in VOCs and SVOCs was observed in the chemically pre-treated groundwater (Tables 27 and 28).

No pesticides were detected in the groundwater samples either before or after chemical pre-treatment (Table 29).

The pH of the chemically treated samples increased due to the addition of NaOH. The ORP and DO of the chemically treated samples also increased since the pre-treatment procedure involved aerating the groundwater for 20 minutes (Table 30).

The chemical pre-treatment procedure had no effect on the conductivity, perchlorate, phosphate or chloride concentrations.

Nitrate concentrations as measured by the analytical tests conducted by TestAmerica and by spectrometer were the same before and after chemical pre-treatment. The nitrate concentration measured with the probe showed an increase in nitrate in the chemically pre-treated groundwater

4.2.2 Fluidized Bed Reactors

Batch Mode

The fluidized bed reactor systems were operated in batch mode for 31 days. The purpose of the batch mode was to allow the native microorganisms present in the Site groundwater and soil to colonize the media. The laboratory parameter data collected from the recycle reservoir of each system are presented in Figures 19 through 21. The pH remained neutral throughout the batch mode and showed a slight decrease towards the end of the batch testing period (Figure 19). The oxidation-reduction potential remained positive throughout most of the batch mode operation. On day 28 reducing conditions were detected in both the recycle reservoirs (Figure 20). Dissolved oxygen concentrations in the recycle reservoirs decreased gradually over time (Figure 21). A significant drop in DO was observed towards the end of the batch mode operation when the HFCS concentrations increased.

The analytical data collected during the batch mode operation is presented in Figures 22 through 27. FBR System 1 showed a decrease in both perchlorate and chlorate during the batch mode operation (Figure 22). Initially when TOC was limited (day 10 and 18), the ammonium-N and phosphate-P concentrations remained high (Figures 23 and 24). Once additional HFCS was added to the recycle reservoirs, both ammonium-N and phosphate-P concentrations decreased. The sulfate concentration remained constant throughout the batch testing. FBR System 2 also supported treatment of perchlorate and chlorate; however, on day 31, an increase in perchlorate was observed when compared to the day 10 and 18 data (Figure 25). Both ammonium-N and phosphate-P concentrations decreased overtime and the greatest reductions were observed on day 31 when excess TOC was present (Figures 26 and 27).

Continuous feed mode

The fluidized bed reactor systems were operated in continuous feed mode for 112 days.

The laboratory parameter data collected from the FBR feed reservoirs are presented in Figures 28 through 32. The pH values in both feeds ranged between 7.6 and 8.9 with the average values being 8.3 and 8.5 for systems 1 and 2, respectively (Figure 28). Oxic conditions were observed in both feeds throughout the study (Figure 29). Dissolved oxygen was consumed in the System 1 feed over time. Spikes in the dissolved oxygen concentration in the System 1 feed corresponded with addition of new chemically pre-treated groundwater to the feed reservoir. The consumption of oxygen in the System 1 feed was greatest at the beginning of the study when the HRT was longer and the feed lasted for a longer period of time. At the end of the study when the systems were operating with a reduced HRT, the DO concentrations remained high (Figure 30). The targeted phosphate-P concentration was 0.5 mg/L during the initial 14 days of the continuous feed mode operation and

was then increased to 1.0 mg/L (Figure 31). The targeted ammonium-N concentration was 13 mg/L during the initial phase of the testing and then decreased to 10 mg/L on day 85. The decrease in the ammonium concentration observed in the feed for system 1 during the initial 60 days of continuous feed mode operation was likely due to the activity on native microorganisms present in the groundwater (Figure 32).

The laboratory parameter data collected from the four FBR recycle reservoirs (System 1 Sand and GAC; System 2 Sand and GAC) during continuous feed mode operation are presented in Figures 33 through 39. The pH remained neutral in the Sand recycle reservoirs and the pH of the GAC recycle reservoirs were generally lower than that of the Sand recycle reservoirs (Figure 33). The adjustment of pH with sodium bicarbonate was required in the GAC recycle reservoirs to maintain a neutral pH. The ORP values in the Sand recycle reservoirs were initially positive and on day two reducing conditions were established (Figure 34). Over time stronger reducing conditions were created and maintained throughout the test period. The ORP values in the GAC recycle reservoirs remained positive during the first 30 days of continuous feed mode operation. On October 30, 2007 (day 27) 600 μ L of HFCS was added to each GAC recycle reservoir and a drop in ORP was observed in each system. Daily additions of phosphate-P, ammonium-N, and HFCS to the GAC recycle reservoirs assisted in maintaining reducing conditions throughout the study. A comparison of dissolved oxygen concentrations in the feeds and the sand recycle reservoirs shows that oxygen was quickly consumed in the sand FBRs. Trace concentrations of dissolved oxygen were detected in both the sand and GAC recycle reservoirs during the initial 48 days of the study (Figures 35 – 38). Nutrients (N and P) were detected in the sand and GAC recycle reservoirs of each system which indicated that they were not limited throughout the study (Figures 35 - 39).

The analytical data collected during the FBR continuous feed mode operation are presented in Figures 40 through 55.

Figures 40 through 47 summarize the data for FBR System 1. A decrease in the perchlorate concentration was observed in the FBR System 1 feed during the initial 67 days of the study. This reduction in perchlorate may have been due to the activity of the native microorganisms present in the Site groundwater. Towards the end of the study when new feed was being prepared more frequently, the perchlorate concentration approached the value observed during the baseline sampling (Figure 40). The sand reactor supported >97% removal of perchlorate during the initial 43 days of the continuous feed mode operation. Analysis of the Sand reactor effluents with Method 6860 on days 29 and 43 revealed that perchlorate concentrations were lower than those reported with Method 314. Perchlorate was non-detect (detection limits varied between 0.1 and 1.0 μ g/L) in the FBR System 1 sand reactor throughout the remaining test period. During the initial 43 days of continuous feed mode operation, the GAC reactor supported additional removal of perchlorate. The perchlorate concentration remained non-detect in the GAC reactor through the remaining test period (Figure 41).

Chlorate concentrations in the FBR System 1 feed ranged between 2.2 and 17.6 mg/L. Complete removal (detection limit of 0.8 mg/L) of chlorate was supported in the FBR System 1 Sand column (Figure 42). Ammonium-N concentrations in the feed ranged between 4.9 mg/L and 16 mg/L. During the initial 43 days of continuous feed mode operation, a decrease in the ammonium concentration in the feed was observed over time. This trend correlated with the reduction in perchlorate concentration discussed above. On day 110, the Sand and GAC reactors consumed 4.5 mg/L and 2.8 mg/L of ammonium-N, respectively (Figure 43). Phosphate-P concentrations in the

feed ranged between 2.6 mg/L and 3.7 mg/L. On day 110, the Sand and GAC reactors consumed 1.7 mg/L and 0.8 mg/L of phosphate-P, respectively (Figure 44). The TOC concentrations in the effluent increased gradually during the first 56 days of continuous feed mode operation. The higher TOC concentrations may be due to a less efficient use of the carbon substrate (HFCS) or an increase in the biomass in the effluents. The higher TSS concentrations in effluents suggested that the increase in TOC may be due to the presence of biomass. In order to distinguish between the soluble TOC due to HFCS and biomass, TOC samples collected during sampling events 7-13 were filtered with a 0.45 micron filter and thus the data presented for day 72 through 110 is soluble TOC. The soluble TOC concentrations in the Sand reactor ranged between 16 and 24 mg/L while the soluble TOC concentrations in the GAC reactor ranged between 77 and 3.3 mg/L (Figure 45). As described previously, the GAC reservoirs were amended daily with HFCS between day 27 and 89. Between days 91-103, HFCS was not added to the GAC reservoir and on day 104 daily additions of HFCS were initiated again. On day 110, 32 mg/L of TOC were consumed in the Sand reactor and 80 mg/L of TOC were consumed in the GAC reactor. TSS and TVSS concentrations were similar which indicated that the TSS was composed primarily of biomass (Figures 46 and 47).

The analytical data collected for FBR System 2 during the continuous feed mode are presented in Figures 48 through 55. As observed with the low chloride feed, a decrease in the perchlorate concentration was observed in the FBR System 2 feed during the initial 67 days of the study (Figure 48). Towards the end of the study when new feed was being prepared more frequently, the perchlorate concentration approached the value observed during the baseline sampling. The sand reactor supported >97% removal of perchlorate during the initial 43 days of the continuous feed mode operation. Analysis of the sand reactor effluents with Method 6860 on days 29 and 43 revealed that perchlorate concentrations were lower than those reported with Method 314. Perchlorate was non-detect (detection limits varied between 0.1 and 2.0 µg/L) in the FBR System 2 sand reactor throughout the remaining test period (Figure 49). On day 8, the perchlorate concentration of the GAC reactor was greater than that of the Sand reactor, possibly due to a flushing effect of the porous GAC substrate before biological treatment had been established. On days 20 and 29, the GAC reactor supported further removal of perchlorate and on day 43, perchlorate was not detected (detection limit 20 µg/L). The perchlorate concentration remained non-detect in the GAC reactor through the remaining test period.

Chlorate concentrations in the FBR System 2 feed ranged between non-detect (4 mg/L) and 13.1 mg/L. Chlorate was not detected in the effluents of the FBR System 2 Sand and GAC columns (Figure 50). Ammonium-N concentrations in the feed ranged between 7.4 mg/L and 21 mg/L. As observed with the low chloride feed, a decrease in the feed ammonium concentration was observed during the initial 72 days of the study. On day 110, the Sand and GAC reactors consumed 4.0 mg/L and 3.4 mg/L of ammonium-N, respectively (Figure 51). Phosphate-P concentrations in the feed ranged between 2.4 mg/L and 3.9 mg/L. During the initial 56 days of continuous feed mode operation, the phosphate-P concentration in the GAC reactor effluent was greater than that of the Sand reactor. The high P concentrations observed in the GAC reactor on days 8 and 20 were unexpected since the Sand feed was the only source of P during the initial 28 days of continuous feed mode operation. As described previously, on day 28, daily additions of P were made to the GAC reservoir and likely account for the high P concentrations observed. On day 110, the Sand and GAC reactors consumed 1.6 mg/L and 1.2 mg/L of phosphate-P, respectively (Figure 52). The TOC concentrations in the effluents increased gradually during the initial 56 days for the Sand reactor and 72 days for the GAC reactor of continuous feed mode operation. As described above for system 1, the TOC samples were filtered with a 0.45 micron filter starting on day 72. The soluble TOC

concentrations in the Sand reactor decreased over time. Even after filtration with a 0.45 micron filter, the TOC remained high in the GAC reactor for days 72 and 78. On day 82, the GAC reactor TOC concentration decreased and remained low throughout the remainder of the study. The soluble TOC concentrations in the Sand reactor ranged between 21 and 29 mg/L while the soluble TOC concentrations in the GAC reactor ranged between 4.5 and 89 mg/L. On day 110, 26 mg/L of TOC were consumed in the Sand reactor and 104 mg/L of TOC were consumed in the GAC reactor (Figure 53). TSS and TVSS concentrations were similar which indicated that the TSS was composed primarily of biomass (Figures 54 and 55).

Comprehensive Final Sampling

The results from the comprehensive final sampling of the FBR feeds and effluents are summarized in Tables 31 through 35.

The total iron concentrations in the FBR System 1 feed, Sand, and GAC effluents were 450 µg/L, 130 µg/L, and 87 µg/L, respectively. The total iron concentrations in the FBR System 2 feed, sand and GAC effluents were 290 µg/L, 79 µg/L, and 82 µg/L, respectively. The iron concentrations in both feeds were below the targeted value of 1 mg/L and each FBR reactor showed some reduction of iron. Given the excellent removal rates of perchlorate, low levels of iron did not affect the biological treatment process. A trace concentration of selenium (5.2 µg/L) was also detected in the FBR System 2 sand effluent (Table 31).

No dissolved metals were detected in the FBR System 1 feed, however 50 µg/L of iron were detected in the Sand column effluent. The FBR System 2 feed showed a trace concentration (4.9 µg/L) of zinc, however, no zinc was detected (< 20 µg/L) in the sand or GAC effluents. Dissolved iron and arsenic were not detected in the FBR System 2 feed; however, 39 µg/L of iron and 4.9 µg/L of arsenic were detected in the Sand effluent (Table 32).

Low concentrations of chloroethane, chloroform, and methylene chloride were detected in the FBR feeds. The same three parameters were detected in the sand effluents at slightly lower concentrations than observed in the feeds. Although chlorobenzene was not detected in the feeds, it was detected in the both sand column effluents. Methylene chloride was the only VOC detected in the GAC effluents (0.55 µg/L in System 1 and 0.40 µg/L in System 2) (Table 33).

Trace concentrations of bis(2-Ethylhexyl)phthalate and 2-chlorophenol were detected in the System 1 feed. FBR System 1 sand effluent showed a trace concentration of 2-chlorophenol while System 1 GAC effluent had a trace concentration of bis(2-Ethylhexyl)phthalate (Table 34).

Pesticides were not detected in the FBR feeds or the GAC column effluents. Trace concentrations of delta-BHC (0.013 µg/L) and heptachlor (11 µg/L) were detected in the System 1 sand effluent. Trace concentrations of delta-BHC (0.012 µg/L), gamma-BHC (0.0086 µg/L) and heptachlor (0.0091 µg/L) were detected in the System 1 sand effluent (Table 35).

4.2.3 Packed Bed Reactors

Batch Mode

The packed bed reactor systems containing AQUAMEND media were operated in batch mode for 31 days. The purpose of the batch mode was to allow the native microorganisms present in the groundwater and soil to colonize the AQUAMEND media.

The laboratory parameter data collected from the recycle reservoir of each PBR system are presented in Figures 56 through 58.

The pH remained neutral throughout the period of batch mode operation but showed a slight decrease towards the end of the testing period (Figure 56). ORP remained positive throughout most of the batch mode operation. On day 27 a drop in ORP was observed and on day 28 reducing conditions were detected in both the recycle reservoirs (Figure 57). DO concentrations in the recycle reservoirs remained above 5 mg/L during the initial 19 days of batch mode operation. On day 20, both systems showed a drop in DO in response to the additional HFCS added to each recycle reservoir (Figure 58).

The analytical data collected during the batch mode operation is presented in Figures 59 through 64. Initially when TOC was limited (day 10 and 18), the perchlorate and chlorate concentrations remained high (Figures 59 and 62). Once additional HFCS was added to the recycle reservoirs, complete removal of perchlorate and chlorate was supported and reductions in ammonium-N and phosphate-P concentrations were observed (Figures 60, 61, 63, and 64).

Continuous feed mode

The packed bed reactor systems were operated in continuous feed mode for 114 days.

The laboratory parameter data collected from the feed reservoirs are presented in Figures 65 through 69. The pH values in the system 1 feed ranged between 7.43 and 8.60 and the average value was 8.18. The pH in PBR system 2 ranged between 8.05 and 8.91 and the average value was 8.45 (Figure 65). Oxic conditions were observed in both feeds throughout the study (Figure 66). As observed in the low chloride feed for the FBR, oxygen was being consumed in the PBR System 1 feed over time. Spikes in the dissolved oxygen concentration in the System 1 feed corresponded with addition of new groundwater to the feed reservoir. The dissolved oxygen concentrations in the PBR System 2 feed remained high and ranged between 6.7 and 8.9 mg/L (Figure 67). The targeted phosphate-P concentrations was 0.5 mg/L during the initial 14 days of the continuous feed mode operation and was then increased to 1.0 mg/L (Figure 68). The targeted ammonium-N concentrations was 13 mg/L during the initial phase of the testing and then decreased to 10 mg/L on day 85 (Figure 69).

The laboratory parameter data collected from the PBR recycle reservoirs are presented in Figures 70 through 74.

The pH in the PRB recycle reservoirs was maintained between 6.5 and 7 (Figure 70). On days when the pH dropped below 6.5, sodium bicarbonate was added to increase the pH to 7. Reducing conditions were maintained in both PBR systems and as the feed flow rate increased, greater reducing

conditions were created (Figure 71). Towards the end of the study the ORP values increased due to the higher perchlorate and chlorate concentrations in the feeds. A comparison of dissolved oxygen concentrations in the feeds and the PBR recycle reservoirs shows that oxygen was quickly consumed in the PBRs. Trace concentrations of dissolved oxygen were detected in both PBR recycle reservoirs during the initial 46 days of the study (Figures 72 and 73). Nutrients (N and P) were detected in the recycle reservoirs of each PRB system which indicated that they were not limited throughout the study (Figures 72, 73, and 74). On day 68, the phosphate-P concentrations in both recycle reservoirs were greater than the feed concentrations (1 mg/L). Changes in the sample color were noted for the PBR samples analyzed with the HACH Phosphate-P kit. Thus the phosphate concentrations reported between days 68 and 100 are higher than expected due to an interference with the colorimetric method. The source of the interference was not identified during the column testing.

The analytical data collected for the PBRs during continuous feed mode operation are presented in Figures 75 through 81.

A decrease in the perchlorate concentration was observed in both PBR feeds during the initial 78 days of the study. On days 86 and 92, when new feeds were being prepared more frequently, the perchlorate concentration approached the value observed during the baseline sampling. On days 98, 105 and 110 the perchlorate concentrations in the PBR System 1 feed were increased to 7,600 µg/L, 7,800 µg/L and 23,000 µg/L, respectively. The perchlorate concentrations in PBR System 2 feed were increased to 6,700 µg/L, 7,400µg/L and 24,000 µg/L on days 98, 105 and 110, respectively (Figure 75). Analysis of the PBR effluents with Method 6860 on days 29 and 43 revealed that perchlorate concentrations were lower than those reported with Method 314.

During the initial 20 days of continuous feed mode operation, PBR System 1 supported >97% removal of perchlorate. On day 29, the perchlorate concentration was reduced from 2,300 µg/L in the feed to non-detect (detection limit of 0.10 µg/L) in the PBR System 1 effluent. On day 43 a trace concentration (0.079 µg/L) of perchlorate was detected in the effluent of PBR System 1. Complete removal of perchlorate was supported in PBR System 1 effluent on days 56 through 98. On day 105, the perchlorate concentration was reduced from 7,800 µg/L in the feed to 2,700 µg/L in the PBR System 1 effluent (65% removal). On day 110, the perchlorate concentration was reduced from 23,000 µg/L in the feed to 21,000 µg/L in the PBR System 1 effluent (9% removal). On day 114, the perchlorate concentration in the PBR System 1 effluent was 15,000 µg/L, assuming the influent concentration remained the same as on day 110, 35% removal was supported (Figure 76).

During the initial 20 days of continuous feed mode operation, PBR System 2 supported >97% removal of perchlorate. On day 29, the perchlorate concentration was reduced from 2,100 µg/L in the feed to non-detect (detection limit of 0.10 µg/L) in the PBR System 2 effluent. Complete removal of perchlorate (detection limits varied between 0.1 and 2 µg/L) was supported in PBR System 2 on days 43 through 98. On day 105, the perchlorate concentration was reduced from 7,400 µg/L in the feed to 3,800 µg/L in the PBR System 1 effluent (49% removal). On day 110, the perchlorate concentration was reduced from 24,000 µg/L in the feed to 21,000 µg/L in the PBR System 2 effluent (13% removal). On day 114, the perchlorate concentration in the PBR System 2 effluent was 21,000 µg/L, assuming the influent concentration remained the same as on day 110, 17% removal was supported (Figure 76).

The reduction in perchlorate removal efficiency observed on day 105 was due to an increase in the chlorate concentration in the feeds. On day 110 the removal efficiency declined further due to an

additional increase in the chlorate feed concentrations. Additional removal of perchlorate was supported on day 114 once the PBR recycle reservoirs were amended with additional HFCS.

Prior to spiking, chlorate concentrations in the PBR feeds ranged between 2 and 18 mg/L for system 1 and between non-detect (detection limit of 4 mg/L) and 13 mg/L for System 2. On days 100 and 105 the chlorate concentrations in both PBR System feeds were increased to 72 mg/L and 271 mg/L, respectively (Figure 77). Chlorate was not detected in the effluents of the PBR Systems during the initial 98 days of continuous feed mode operation. On day 105, the chlorate concentration was reduced from 72 mg/L in the feeds to 11.7 mg/L in the PBR System 1 effluent (84% removal) and 11 mg/L in the PBR System 2 effluents (85% removal). On day 110, the chlorate concentrations were reduced from 271 mg/L in the feeds to 132 mg/L in the PBR System 1 effluent (51% removal) and 186 mg/L in the PBR System 2 effluent (31% removal). After increasing the HFCS dosage, additional removal of chlorate was supported in each system. On day 114, the chlorate concentrations in the PBR System 1 and 2 effluents were 16.2 mg/L (94% removal) and 88.2 mg/L (67%), respectively (Figure 78).

Ammonium-N concentrations in the PBR System 1 feed ranged between 3.8 mg/L and 21 mg/L. During the initial 72 days of continuous feed mode operation, a decrease in the ammonium concentration in the feed was observed over time. Phosphate-P concentrations in the feed ranged between 2.3 mg/L and 3.9 mg/L. On day 92, the PBR System 1 consumed 6.3 mg/L of ammonium-N and 1.8 mg/L of phosphate-P (Figure 79).

Ammonium-N concentrations in the PBR System 2 feed ranged between 7.4 mg/L and 19 mg/L. Phosphate-P concentrations in the feed ranged between 2.3 mg/L and 3.9 mg/L. On day 92, the PBR System 2 consumed 7.2 mg/L of ammonium-N and 1.7 mg/L of phosphate-P (Figure 80).

The TOC concentrations in both PBR effluents fluctuated during the continuous feed mode operation (Figure 79 and 80). Comparing the data from samples collected on day 67 (total TOC) and day 72 (soluble TOC) indicated that greater than 50% of the TOC was due to solids (i.e. biomass). On day 92 the PBR System 1 and 2 consumed 43 mg/L and 40 mg/L of soluble TOC, respectively. As the perchlorate and chlorate concentrations in the feeds increased, additional soluble TOC was consumed. On day 110 the PBR System 1 and 2 consumed 60 mg/L and 53 mg/L of soluble TOC, respectively.

TSS and TVSS concentrations were similar which suggested that the TSS was composed primarily of biomass (Figure 81 and 82).

Comprehensive Final Sampling

The results from the comprehensive final sampling of the PBR feeds and effluents are summarized in Tables 36 through 40.

The total iron concentrations in the PBR System 1 feed and effluent were 230 µg/L and 160 µg/L, respectively. The total iron concentrations in the PBR System 2 feed and effluent were 170 µg/L and 130 µg/L, respectively (Table 36). The iron concentrations in the feeds were below the targeted value of 1 mg/L and each PBR reactor showed some reduction of iron. These low levels of iron did not affect the treatment of perchlorate and chlorate in the blended groundwater.

Trace concentrations of silver and zinc were detected in the PRB System 1 feed. The PRB System 1 effluent also showed a trace concentration of zinc (6.1 µg/L), and chromium (4.1 µg/L), however silver was not detected (detection limit of 10 µg/L).

A trace concentration of silver (4.0 µg/L) was detected in the PRB System 2 feed and zinc (6.8 µg/L) was detected in the PRB System 2 effluent.

No dissolved metals were detected in the PBR feeds or effluents (Table 37).

No VOCs were detected in the PBR feeds and trace concentrations of chlorobenzene were detected in the System 1 (0.25 µg/L) and System 2 (0.59 µg/L) effluents (Table 38).

Trace concentrations of bis(2-Ethylhexyl)phthalate and 2,4,6-trichlorophenol were detected in the System 1 feed. Trace concentrations of bis(2-Ethylhexyl)phthalate and 2-chlorophenol were detected in the System 2 feed. PBR System 1 and 2 effluents showed a trace concentrations of 2-chlorophenol (Table 39).

Trace concentrations of endrin were detected in the PBR feeds. Trace concentrations of beta-BHC and delta-BHC were detected in the PBR effluents (Table 40).

4.2.4 EHC-AQUAMEND Reactors

The alternate treatment systems were operated in continuous feed mode for 114 days.

The laboratory parameter data collected from the feeds in the Tedlar[®] bags is presented in Figures 83 through 86.

During the initial 37 days of the study, the pH values in the feeds for each system ranged between 4.3 and 6.4 with the average values being 5.2 and 6.0 for systems 1 and 2, respectively (Figure 86). As noted previously the high chlorobenzene (MWA-17Si) and high chloride (MWA-30) groundwaters were used to prepare the feeds during the initial 37 days. Oxidic conditions were maintained in the system 1 feed until day 37 when it became slightly anoxic. The system 2 feed became anoxic by day 30 (Figure 84).

The feeds for the remainder of the study (days 37 to 114) were prepared with the blended and high chloride (MWA-30) groundwaters. The pH values in the system 1 and 2 feeds ranged between 6.3 and 7.1 with the average values being 6.6 for both systems (Figure 86). The system 1 feed remained anoxic for the rest of the study. Except for day 68 when the system 2 feed went slightly oxidic, the system 2 feed maintained an anoxic state (Figure 84).

Throughout the study, dissolved oxygen was being consumed in both feeds over time (Figure 85). The monitoring of ammonium-N in the feeds was initiated on day 50. The ammonium-N values remained steady for both systems, ranging between 4.0 mg/L and 5.6 mg/L (Figure 86).

The laboratory parameter data collected from after the sand columns and from the aerobic and anaerobic recycle reservoirs are presented in Figures 87 through 94. The pH remained neutral after the sand columns and in the AQUAMEND recycle reservoirs for both systems, ranging between 6.1

and 7.5. During the initial 16 days of the study, low pH values (<6.5) were detected in the AQUAMEND aerobic reservoirs for both systems (Figure 87 and 88). Reducing conditions were maintained in System 1 throughout the study (Figure 89). Barring one reading on day 99 for the AQUAMEND recycle reservoirs, the reducing conditions were also maintained in System 2 (Figure 90). A comparison of dissolved oxygen concentrations in the feeds and after the sand columns shows that oxygen was almost completely consumed in the EHC-sand column treatment step (Figures 91 and 92). Low levels (< 1 mg/L) of dissolved oxygen were maintained in the sand column effluents and in each of the AQUAMEND recycle reservoirs. The higher DO readings on day 22 and 26 were due to a pump problem on day 20 which resulted in air entering the EHC and sand columns for both systems. An increase in dissolved oxygen was not observed in the aerobic AQUAMEND columns. Thus the use of a Waterloo Emitter to oxygenate the groundwater was not successful. Relative to the feeds, the ammonium-N concentrations did not decrease after the sand columns and the AQUAMEND columns of both systems (Figure 93 and 94). Between day 50 and 65 ammonium-N concentrations increased in the System 2 effluent from the sand column and the recycle reservoirs of the AQUAMEND columns. During this same time period, the ammonium-N concentration in the System 2 feed remained constant (between 4 and 6 mg/L).

The analytical data collected for the Alternate Treatment Systems are presented in Figures 95 through 104.

A decrease in the perchlorate concentration was observed in the Alternate Treatment feeds over time. The high perchlorate concentration on day 28 was due to the use of the MWA-17si groundwater during the initial 37 days of the study. The variability in the perchlorate concentration in the feed for sampling events 2 through 4 may be due to differences in perchlorate concentrations in the drums over time or due to the activity on native microorganisms (Figures 95 and 96).

Alternate Treatment System 1 EHC column showed no perchlorate treatment on day 28; however, 98% removal of perchlorate was observed on day 49 and complete removal (detection limit of 0.1 µg/L) of perchlorate was supported on days 70 and 112. The System 1 AQUAMEND aerobic and anaerobic columns showed 52% and 11% reductions in perchlorate on day 28 when compared to the EHC effluent. On day 49, no further treatment of perchlorate was supported in the AQUAMEND columns (Figure 95). Alternate Treatment System 2 supported 91% removal of perchlorate in the EHC column and complete removal of perchlorate was observed on day 49 (detection limit of 20 µg/L), 70 (detection limit of 0.1 µg/L), and 112 (detection limit of 0.1 µg/L). The System 2 AQUAMEND aerobic and anaerobic columns showed 20% and 16% reductions in perchlorate on day 28 when compared to the EHC effluent. On days 49, 70 and 112 no perchlorate was detected in the final effluents (Figure 96).

The high chlorate concentration in the Alternate Treatment feeds on day 28 was due to the use of the MWA-17si groundwater during the initial 37 days of the study (Figures 97 and 98). Chlorate concentrations in both feeds decreased over time and no chlorate was detected (detection limit 0.8 mg/L for System 1 and 4 mg/L for System 2). Chlorate was only detected in the System 2 EHC column effluent on day 28 (Figure 98).

Chlorobenzene was the main VOC detected in the Alternate Treatment feeds. The chlorobenzene concentrations were higher in the Alternate Treatment feeds on day 28, due to the use of the MWA-17Si groundwater, and lower on days 49, 70, and 112 when the blended groundwater was used. On day 28, the EHC columns supported up to 19% removal of chlorobenzenes while the AQUAMEND

systems supported between 75% and 90% removal in Alternate Treatment Systems. On day 49, the chlorobenzene concentrations in the feeds were lower than the effluent concentrations due to the high chlorobenzene groundwater that was still present in the columns from the initial 37 days of the study. On day 70 the chlorobenzene concentrations in the EHC and AQUAMEND Aerobic columns continued to be greater than the feed however reduction in chlorobenzenes were observed in the AQUAMEND Anaerobic columns. On day 112, reductions in chlorobenzenes were observed in the AQUAMEND columns. The aerobic and anaerobic AQUAMEND columns of System 1 supported 35% and 38% removal of chlorobenzenes, respectively (Figure 99). The aerobic and anaerobic AQUAMEND columns of System 2 supported 58% and 49% removal of chlorobenzenes, respectively (Figure 100).

2-Chlorophenol was the main SVOC detected in the Alternate Treatment feeds. The 2-chlorophenol concentrations were higher in the Alternate Treatment feeds on day 28, due to the use of the MWA-17Si groundwater, and lower on days 49, 70, and 112 when the blended groundwater was used (Figures 101 and 102). Some removal (34%) of CP was observed on day 70 in the EHC column effluent of System 2.

The iron concentrations in Alternate Treatment System 1 feed was 250 mg/L on day 28 and ranged between 120 mg/L and 160 mg/L on days 49-112 (Figure 103). The iron concentrations in Alternate Treatment System 2 feed was 210 mg/L on day 28 and ranged between 56 mg/L and 120 mg/L on days 49-112 (Figure 104). Reductions in the iron concentration of the System 1 EHC column effluent were observed on 28, 49, and 112. The System 2 EHC column effluent also showed reductions in iron on days 28 and 49. This is contrary to what was expected since EHC contains iron and soluble iron is released from EHC over time. On day 70, an increase in iron was observed in the System 1 EHC column effluent. An increase in the iron concentration was observed in the System 2 EHC column effluent on days 70 and 112. Comparing the iron concentrations in the EHC effluents and the AQUAMEND column effluents on days 70 and 112 suggests that iron was precipitated out in the AQUAMEND columns. Visual observation of the columns showed that solids were present in the AQUAMEND columns.

Comprehensive Final Sampling

The results from the comprehensive final sampling of the Alternate Treatment System feeds and effluents are summarized in Tables 41 through 50.

Iron was the main metal detected in the Alternate Treatment System 1 feed and effluents (Table 41 and Figure 103). Trace concentrations of arsenic, chromium, copper, lead, zinc and hexavalent chromium were also detected in the System 1 feed. The System 1 EHC-sand, aerobic-AQUAMEND and anaerobic-AQUAMEND effluents showed trace concentrations of zinc (4.9 µg/L, 6.6 µg/L and 5.5 µg/L, respectively), while the remaining metals were not detected (detection limits ranged from 0.020 µg/L to 40 µg/L).

The dissolved iron concentrations in the System 1 feed, EHC-sand, aerobic-AQUAMEND and anaerobic-AQUAMEND effluents were 110 mg/L, 50 mg/L, 6.3 mg/L and 6.5 mg/L respectively (Table 42). Trace concentrations of dissolved zinc (5.3 µg/L) and hexavalent chromium (0.0070 µg/L) were detected in the System 1 feed. A trace concentration of dissolved zinc (4.7 µg/L) was detected in the System 1 EHC-sand effluent.

Chlorobenzene was the main VOC detected in the Alternate Treatment System 1 feed and effluents (Figure 99 and Table 43). Trace concentrations of chloroethane (32 µg/L) and chloroform (8.1 µg/L) were also detected in the System 1 feed. The System 1 EHC-sand, aerobic-AQUAMEND and anaerobic-AQUAMEND effluents contained trace amounts of chloroethane (<28 µg/L), cis-1,2-dichloroethene (<9.9 µg/L) and methylene chloride (<15 µg/L). The System 1 aerobic-AQUAMEND effluent also contained a trace amount of chloroform (4.6 µg/L) (Table 43).

In addition to 2-chlorophenol (Figure 101 and Table 44), trace concentrations of phenol were detected in the System 1 feed (1.3 µg/L) and the anaerobic-AQUAMEND effluent (1.1 µg/L). The System 1 EHC-sand effluent contained a trace amount of 2,4,6-Trichlorophenol (1.0 µg/L). A trace amount of bis(2-Ethylhexyl)phthalate (1.4 µg/L) was detected in the System 1 aerobic-AQUAMEND effluent (Table 44).

Pesticides were not detected in the Alternate Treatment System 1 feed and effluents (Table 45)

In addition to iron (Figure 104), lower concentrations of chromium (54 µg/L), zinc (12 µg/L), copper (4.8 µg/L), and cadmium (1.3 µg/L) were detected in the Alternate Treatment System 2 feed (Table 46). Complete removal of chromium was supported in the EHC-Sand effluent (detection limit of 10 µg/L) and no chromium was detected in the AQUAMEND effluents (detection limit 10 µg/L). Trace concentrations of cadmium (1.5 µg/L) and zinc (10 µg/L) were detected in the EHC-Sand effluent. Trace concentrations of cadmium (0.45 µg/L), copper (9.4 µg/L), and zinc (7.7 µg/L) were detected in the aerobic AQUAMEND effluent and trace concentrations of copper (6.8 µg/L), zinc (7.6 µg/L) and hexavalent chromium (0.026 µg/L) were detected in the anaerobic AQUAMEND effluent (Table 46).

The dissolved iron concentrations in the Alternate Treatment System 2 feed, EHC-sand, aerobic-AQUAMEND and anaerobic-AQUAMEND effluents were 83 mg/L, 24 mg/L, 1.8 mg/L and 2.3 mg/L respectively (Table 47). Trace concentrations of dissolved cadmium (0.65 µg/L), copper (12 µg/L) and zinc (23 µg/L) were detected in the System 2 feed. A trace concentration of dissolved zinc (8 µg/L) was detected in the System 1 EHC-sand effluent. Trace concentrations of dissolved copper (4.6 µg/L) and nickel (9.0 µg/L) were detected in the System 2 anaerobic AQUAMEND effluent.

Chlorobenzene was the main VOC detected in the Alternate Treatment System 2 feed and effluents (Figure 100 and Table 48). The System 2 feed also contained trace concentrations of chloroethane (32 µg/L) and chloroform (7.1 µg/L). Trace concentrations of chloroethane (<25 µg/L), chloroform (<4.6 µg/L), cis-1,2-dichloroethene (<13 µg/L) and methylene chloride (<13 µg/L) were detected in the aerobic and anaerobic AQUAMEND effluents (Table 48).

In addition to 2-chlorophenol (Figure 102 and Table 49), trace concentrations of bis(2-Ethylhexyl)phthalate (1.1 µg/L) and phenol (0.97 µg/L) were detected in the System 2 feed. A trace concentration of bis(2-Ethylhexyl)phthalate (1.3 µg/L) was also detected in the aerobic AQUAMEND effluent (Table 49).

Pesticides were not detected in the Alternate Treatment System 2 feed and effluents (Table 50).

4.3. SUMMARY AND CONCLUSIONS

4.3.1 *Chemical Pre-Treatment of Groundwater*

Chemical pre-treatment of the groundwater (aeration, pH adjustment to 8 with NaOH, flocculation with 4816 polymer, and settling) provided effective treatment of iron in the groundwater sample. Aeration of the groundwater produced off gases which will be considered during pilot testing and/or design if the ex situ groundwater treatment systems. Neutralization of the chemically treated groundwater was not required for the bench study. Low concentrations of TOC, phosphate and nitrogen indicated that an electron donor and nutrients were required for the anaerobic biological systems.

The increase in volume of NaOH required to adjust the pH of the blended groundwater to 8 over time was likely due to the ageing of the groundwater as it was stored. Considering that the groundwater at the Site will be continuously extracted and treated, it is unlikely that the same effect would be observed on Site.

Perchlorate and nitrate concentrations monitored with ion selective probes did not correlate well with the analytical data. The sensitivity of the perchlorate probe at low concentrations (<1 mg/L) was poor and thus the data was not included in this report. The presence of other anions (for example perchlorate, chloride) interfered with the nitrate probe readings and thus the data was also not included in this report.

4.3.2 *Fluidized Bed Reactors*

Reducing conditions were maintained in the Sand and GAC reactors of both FBRs (high and low chloride concentrations) throughout the continuous feed mode operations. Addition of nutrients (ammonium hydroxide and phosphoric acid) and an electron donor (HFCS) to the Sand reactor feed and to the GAC recycle reservoir were required to support biological treatment.

On day 110, the HRT for the FBR System 1 Sand reactor was 3 hours and complete removal of chlorate and perchlorate were supported. The TOC concentration in the FBR feed was maintained at 50 mg/L and the nutrient dosages were 1.0 mg/L of phosphate-P and 10 mg/L of ammonium-N. On day 110, the HRT for the FBR System 1 GAC reactor was 2.8 hours and as expected no chlorate and perchlorate were detected since complete removal was supported in the Sand reactor.

On day 110, the HRT for the FBR System 2 Sand reactor was 2.7 hours and complete removal of chlorate and perchlorate were supported. The TOC concentration in the FBR feed was maintained at 50 mg/L and the nutrient dosages were 1.0 mg/L of phosphate-P and 10 mg/L of ammonium-N.

On day 110, the HRT for the FBR System 2 GAC reactor was 3.0 hours and as expected no chlorate and perchlorate were detected since complete removal was supported in the Sand reactor.

A single FBR (Sand) was capable of treating chlorate and perchlorate to non-detectable concentrations, suggesting that the use of a two-stage FBRs system (i.e. Sand-GAC) is not required.

Chloride concentrations (1,600 and 8,000 mg/L) did not have an effect on reactor performance

4.3.3 Packed Bed Reactors

On day 92, the HRT for both PBR Systems (high and low chloride concentrations) was 3.5 hours and complete removal of chlorate and perchlorate were supported. The TOC concentration in both PBR feeds was maintained at 75 mg/L and the nutrient dosages were 1.0 mg/L of phosphate-P and 10 mg/L of ammonium-N.

On day 98 Both PBR systems showed complete removal of 6 to 7 mg/L perchlorate to below the detection limit ($<0.5 \mu\text{g/L}$) in the presence of chlorate at 4 to 5 mg/L at an HRT of 3.5 hours.

A reduction in the perchlorate removal efficiency was observed when the chlorate concentrations were increased (72 mg/L on day 105 and 271 mg/L on day 110); however further removal of both perchlorate and chlorate were supported when the TOC concentration was increased (day 114).

As observed with the FBRs systems, chloride concentrations (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

4.3.4 EHC-AQUAMEND Reactors

Both systems supported perchlorate and chlorate reduction in the blended Site groundwater

Marginal treatment of VOCs and SVOCs was observed in the EHC columns and the AQUAMEND columns supported some removal of chlorobenzene and 2-chlorophenol.

5. TREATABILITY STUDY SUMMARY AND CONCLUSIONS

The purpose of this bench-scale treatability study was to evaluate the effectiveness of several technologies for the treatment of site groundwater containing, metals, perchlorate, chlorate, SVOCs, and VOCs. In addition, the bench scale study evaluated an alternate treatment system primarily for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides. The effect of chloride concentration on biological treatment of the Site groundwater was also evaluated. Specific objectives included:

- chemical characterization of the groundwater samples;
- evaluation of ZVI for the treatment of chlorate in batch tests;
- evaluation of chemical precipitation for the treatment of iron in batch tests;
- evaluation of a two-stage fluidized bed reactor system for the treatment of perchlorate at two chloride concentrations;
- evaluation of a packed bed reactor system for the treatment of perchlorate at two chloride concentrations; and
- evaluation of an EHC-AQUAMEND system for the treatment of perchlorate, SVOCs, VOCs, metals, and pesticides at two chloride concentrations.

The following summary is provided based on the results:

Chemical reduction via zero-valent iron (ZVI) treatment was evaluated to reduce the concentration of chlorate. The ZVI batch test showed that all three ZVI samples evaluated supported treatment of chlorate, however, ATOMET 414 supported the greatest removal (67%). Due to limited chlorate removal, pre-treatment with ZVI was not carried forward in the study.

Chemical precipitation was evaluated for the removal of metals from groundwater. The main objective of the chemical precipitation testing was to remove the iron prior to the FBR and PBR anaerobic biological systems. The chemical precipitation jar testing identified the most effective treatment process for the removal of iron from the groundwater. Chemical pre-treatment consisted of aeration; pH adjustment to pH 8 with sodium hydroxide; polymer addition and settling.

Fluidized bed reactors, packed bed reactors and an alternate treatment system were evaluated for the treatment of perchlorate and chlorate in the Site groundwater. In addition, the alternate treatment system was evaluated for the treatment of metals, VOC, SVOC, and pesticides via anaerobic and aerobic biological treatment.

Complete reduction of chlorate and perchlorate were supported in the first FBR column (Sand) of each system which suggested that a two-stage FBR system was not required. Gradual increases in the feed flow rate to achieve the target HRT of 3 hours had no effect on the treatment of chlorate and perchlorate. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

Complete reduction of chlorate and perchlorate were also supported in the PBR systems. Gradual increases in the feed flow rate to achieve the target HRT of approximately 3 hours had no effect on the treatment of chlorate and perchlorate. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

After the target HRT was met for the PBR systems, perchlorate and chlorate were spiked into the feeds. Both PBR systems showed complete removal of 6-7 mg/L perchlorate at an HRT of 3.5 hours. A reduction in the perchlorate removal efficiency was observed when the chlorate concentration increased; however further removal of both perchlorate and chlorate was supported when additional carbon was added to the systems.

The Alternate Treatment systems showed little to no treatment of perchlorate during the initial 28 days of testing. With more time, and with use of the blended groundwater, complete removal of perchlorate and chlorate were supported. Marginal treatment of VOCs and SVOCs was observed in the EHC columns and the AQUAMEND columns supported some removal of chlorobenzene and 2-chlorophenol. The chloride concentration (1,600 and 8,000 mg/L) did not have an effect on reactor performance.

Each of the three biological treatment processes (FBR, PBR, and EHC-AQUAMEND treatment systems) effectively treat perchlorate and chlorate without being highly sensitive to chloride concentrations and slight pH changes. An economic evaluation will be conducted to determine the preferred treatment process.

AAI7-062.1 FINAL REPORT TABLES

ANALYTICAL

Table 1 - Summary of analyses and methods

Parameter	EPA Method
Phosphate, Total	365.1
TOC	415.1
TSS	160.2
TVS	160.4
Hexavalent Chromium	7195
Dissolved Hexavalent Chromium	7195
Alkalinity	310.1
Chloride	300.0
Sulfate	300.0
Nitrate	300.0
Ammonium	350.1
Total Kjeldahl Nitrogen	351
Calcium	6010B
Manganese	6010B
Magnesium	6010B
Arsenic, Cadmium, Total Chromium, Copper, Iron, Lead, Nickel, Selenium, Silver, Zinc	6010B
Dissolved Metals (Arsenic, Cadmium, Total Chromium, Copper, Iron, Lead, Nickel, Selenium, Silver, Zinc)	6010B
PPL SVOCs	8270C
PPL VOCs	8260B
Pesticides, Organochlorine	8081A
Perchlorate – Routine	314.0
Perchlorate – IC/MS-MS	6860
Chlorate	300.0

INITIAL CHARACTERIZATION

Table 2 – Initial characterization of the Site groundwater samples

Parameter	Units	Blended	MWA-30	MWA-17Si	MWA-23
Alkalinity	mg/L	200	560	nd (5)	200
Hexavalent Chromium	mg/L	nd (0.020)	nd (0.020)	nd (0.020)	nd (0.020)
Dissolved Hexavalent Chromium	mg/L	nd (0.020)	nd (0.020)	nd (0.020)	nd (0.020)
Chloride	mg/L	1,600 Q	46,000 Q	1,500 Q	29
Perchlorate	ug/L	3,200 Q	nd (50) G	4,800 Q	nd (1)
Chlorate	mg/L	45.5	nd (10)	24.5	nd (0.4)
Nitrate an N	mg/L	nd (2.5) G	nd (25) G	1.2 B,G	nd (0.5)
Sulfate	mg/L	1,300 Q	540 Q	3,900 Q	25
Nitrogen, Ammonium	mg/L	5.2	1.4 G	8.6 Q	1.3
Total Phosphate (as P)	mg/L	0.18	0.2	0.037 B	0.73 V
Total Kjeldahl Nitrogen	mg/L	6.1	1.7	10 Q	2
Total Organic Carbon	mg/L	10	36 Q	32	7.2
TSS	mg/L	220 Q	140 Q	43 G	43 G
TVS	mg/L	48 Q	34 Q	14 G	10 G
Calcium	ug/L	73,000	77,000	580,000	70,000

Notes:

nd = non detect

Q = Elevated reporting limit. The reporting limit is elevated due to high analyte levels.

G = Elevated reporting limit. The reporting limit is elevated due to matrix interference.

B = Estimated result. Result is less than RL.

V = Elevated reporting limit. The reporting limit is elevated due to limited sample volume.

Table 3 – Total and dissolved metal concentrations in the Site groundwater samples

Parameter	Units	Blended	MWA-30	MWA-17Si	MWA-23
Arsenic	µg/L	nd (15)	nd (75)	nd (15)	7.5 B
Cadmium	µg/L	5.6	2.7 B	3.5 B	nd (5)
Chromium	µg/L	nd (10)	1,400	1,100	3.4 B
Copper	µg/L	nd (15)	nd (75)	29	nd (15)
Iron	µg/L	140,000	58,000	190,000	40,000
Lead	µg/L	nd (9)	nd (45)	nd (9)	nd (9)
Nickel	µg/L	nd (40)	90 B	1,800	nd (40)
Selenium	µg/L	nd (15)	nd (75)	nd (15)	nd (15)
Silver	µg/L	nd (10)	nd (50)	nd (10)	nd (10)
Zinc	µg/L	63	36 B	720	8.9 B
Dissolved Arsenic	µg/L	nd (15)	nd (15)	nd (15)	nd (15)
Dissolved Cadmium	µg/L	4 B	2.4 B	2.4 B	nd (5)
Dissolved Chromium	µg/L	nd (10)	15	830	nd (10)
Dissolved Copper	µg/L	nd (15)	nd (15)	30	nd (15)
Dissolved Iron	µg/L	110,000	34,000	260,000	140
Dissolved Lead	µg/L	nd (9)	nd (9)	nd (9)	nd (9)
Dissolved Nickel	µg/L	nd (40)	83	1,700	nd (40)
Dissolved Selenium	µg/L	nd (15)	nd (15)	nd (15)	nd (15)
Dissolved Silver	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Dissolved Zinc	µg/L	49	61	690	nd (20)

Notes:

nd = non detect

B = Estimated result. Result is less than RL.

Table 4 – VOC concentrations in the Site groundwater samples

Parameters	Units	Blended	MWA-30	MWA-17Si	MWA-23
Xylenes (total)	µg/L	nd (80)	nd (2)	nd (4000)	nd (2)
Acrolein	µg/L	nd (800)	nd (20)	nd (40000)	nd (20)
Acrylonitrile	µg/L	nd (800)	nd (20)	nd (40000)	nd (20)
Benzene	µg/L	nd (40)	nd(1)	nd (2000)	nd(1)
Bromodichloromethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Bromoform	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Bromomethane	µg/L	nd (80)	nd (2)	nd (4000)	nd (2)
Carbon Tetrachloride	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Chlorobenzene	µg/L	1,700	0.78 J	38,000	nd (1)
Dibromochloromethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Chloroethane	µg/L	24 J	nd (2)	nd (4000)	nd (2)
2-Chloroethyl vinyl ether	µg/L	nd (120)	nd (3)	nd (6000)	nd (3)
Chloroform	µg/L	9.9 J	3.2	nd (2000)	nd (1)
Chloromethane	µg/L	nd (80)	nd (2)	nd (4000)	nd (2)
1,2-Dichlorobenzene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
1,3-Dichlorobenzene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
1,4-Dichlorobenzene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Dichlorodifluoromethane	µg/L	nd (80)	nd (2)	nd (4000)	nd (2)
1,1-Dichloroethane	µg/L	nd (40)	nd (1)	nd (2000)	0.27 J
1,2-Dichloroethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
cis-1,2-Dichloroethene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
trans-1,2-Dichloroethene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
1,1-Dichloroethene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
1,2-Dichloropropane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
cis-1,3-Dichloropropene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
trans-1,3-Dichloropropene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Ethylbenzene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Methylene Chloride	µg/L	nd (200)	nd (5)	nd (10000)	nd (5)
1,1,2,2-Tetrachloroethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Tetrachloroethene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Toluene	µg/L	nd (40)	0.39 J	nd (2000)	48
1,1,1-Trichloroethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
1,1,2-Trichloroethane	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Trichloroethene	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)
Trichlorofluoromethane	µg/L	nd (80)	nd (2)	nd (4000)	nd (2)
Vinyl chloride	µg/L	nd (40)	nd (1)	nd (2000)	nd (1)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

Table 5 – SVOC concentrations in the Site groundwater samples

Parameter	Units	Blended	MWA-30	MWA-17Si	MWA-23
Acenaphthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Acenaphthylene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzidine	µg/L	nd (150)	nd (150)	nd (150)	nd (150)
Benzo(a)anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(b)Fluoranthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(k)Fluoranthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(g,h,i)perylene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(a)pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroethoxy)methane	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroethyl)ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroisopropyl)ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Ethylhexyl)phthalate	µg/L	3.1 J	3.2 J	nd (10)	2.9 J
4-bromophenyl phenyl ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Butyl benzyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Chloroaniline	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Chloro-3-methylphenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2-Chloronaphthalene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
2-Chlorophenol	µg/L	43	nd (10)	450	nd (10)
4-Chlorophenyl phenyl ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Chrysene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Dibenzo(a,h)anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Di-n-butyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
1,2-Dichlorobenzene	µg/L	nd (10)	nd (10)	5.9 J	nd (10)
1,3-Dichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
1,4-Dichlorobenzene	µg/L	nd (10)	nd (10)	18	nd (10)
3,3'-Dichlorobenzidine	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,4-Dichlorophenol	µg/L	nd (10)	nd (10)	6.0 J	nd (10)
Diethyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,4-Dimethylphenol	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Dimethyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4,6-Dinitro-2-methylphenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
2,4-Dinitrophenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
2,4-Dinitrotoluene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,6-Dinitrotoluene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
Di-n-octyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
1,2-Diphenylhydrazine (as Azobenzene)	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Fluoranthene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
Fluorene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorobutadiene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorocyclopentadiene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachloroethane	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Indeno(1,2,3-cd)pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Isophorone	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Naphthalene	µg/L	nd (10)	nd (10)	1.6 J	nd (10)

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LSS LLC

April 2008

Tables

Nitrobenzene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2-Nitrophenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Nitrophenol	µg/L	nd (50)	nd (50)	nd (50)	nd (50)
N-Nitrosodimethylamine	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
N-Nitrosodiphenylamine	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
N-Nitrosodi-n-propylamine	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
Pentachlorophenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
Phenanthrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Phenol	µg/L	nd (10)	nd (10)	10	nd (10)
Pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
1,2,4-Trichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
2,4,6-Trichlorophenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

Table 6 – Pesticide concentrations in the Site groundwater samples

Parameter	Units	Blended	MWA-30	MWA-17Si	MWA-23
4,4'-DDD	µg/L	0.027 J, COL	nd (0.11)	nd (1.1)	nd (0.11)
4,4'-DDE	µg/L	nd (0.040)	nd (0.040)	0.090 J, COL	nd (0.040)
4,4'-DDT	µg/L	0.015 J, COL	nd (0.12)	nd (1.2)	nd (0.12)
Aldrin	µg/L	nd (0.040)	nd (0.040)	0.063 J, COL	nd (0.040)
alpha-BHC	µg/L	nd (0.030)	nd (0.030)	nd (0.30)	nd (0.030)
beta-BHC	µg/L	0.035 J, COL	nd (0.060)	nd (0.60)	nd (0.060)
Chlordane (technical)	µg/L	nd (0.14)	nd (0.14)	nd (1.4)	nd (0.14)
delta-BHC	µg/L	nd (0.090)	0.017 J, COL	0.10 J, COL	nd (0.090)
Dieldrin	µg/L	nd (0.020)	nd (0.020)	nd (0.2)	nd (0.020)
Endosulfan I	µg/L	nd (0.020)	nd (0.020)	nd (0.2)	nd (0.020)
Endosulfan II	µg/L	nd (0.040)	nd (0.040)	nd (0.4)	nd (0.040)
Endosulfan sulfate	µg/L	nd (0.66)	nd (0.66)	nd (6.6)	nd (0.66)
Endrin	µg/L	nd (0.060)	nd (0.060)	nd (0.60)	nd (0.060)
Endrin aldehyde	µg/L	nd (0.23)	nd (0.23)	nd (2.3)	nd (0.23)
Endrin ketone	µg/L	nd (0.10)	nd (0.10)	nd (1)	nd (0.10)
gamma-BHC (Lindane)	µg/L	nd (0.040)	nd (0.040)	0.16 J, COL	nd (0.040)
Heptachlor	µg/L	nd (0.030)	nd (0.030)	nd (0.30)	nd (0.030)
Heptachlor epoxide	µg/L	nd (0.080)	nd (0.080)	nd (0.80)	nd (0.080)
Methoxychlor	µg/L	0.059 J	nd (1.8)	nd (18)	nd (1.8)
Toxaphene	µg/L	nd (2.5)	nd (2.5)	nd (25)	nd (2.5)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

V = Elevated reporting limit. The reporting limit is elevated due to limited sample volume.

COL = More than 40% RPD between primary and confirmation column results. The lower of the two results is reported.

Table 7 – Laboratory parameters in the Site groundwater samples

Parameter	Units	Blended	MWA-30	MWA-17Si	MWA-23
pH	pH units	6.54	6.58	4.81	7.17
ORP	mV	-45	-57	146	-19
DO	%	58.2	95.7	93.1	83.4
SC	mS	7.38	100.5	9.647	0.542
Perchlorate	mg/L	3.9	1	11	1
Nitrate	mg/L	17	39	7.3	0.51
Temperature*	C	19.5	19.3	19.4	19.6

Notes:

*samples were brought to room temperature prior to measuring the laboratory parameters

CHEMICAL PRECIPITATION - METHODS

Table 8 - Summary of hydroxide precipitation jar test

Jar #	Caustic	pH	Aeration?
1	NaOH	8	Yes
2	NaOH	9	Yes
3	NaOH	10	Yes
4	NaOH	11	Yes
5	Ca(OH) ₂	8	Yes
6	Ca(OH) ₂	9	Yes
7	Ca(OH) ₂	10	Yes
8	Ca(OH) ₂	11	Yes
17	Control	as is	Yes
9	NaOH	8	No
10	NaOH	9	No
11	NaOH	10	No
12	NaOH	11	No
13	Ca(OH) ₂	8	No
14	Ca(OH) ₂	9	No
15	Ca(OH) ₂	10	No
16	Ca(OH) ₂	11	No
18	Control	as is	No

Table 9 - Summary of polymer samples evaluated

Vendor	Polymer Name	Type
CSC Technology	4816P	anionic emulsion
	4807	anionic emulsion
	4809	anionic emulsion
	4814-P	anionic emulsion
	4818-P	anionic emulsion
NALCO	ULTRION 7157	cationic coagulant
	NALCOLYTE 8105	organic cationic coagulant
	NALCO 8190	organic cationic coagulant
	NALCLEAR 7763	anionic flocculant - medium weight
	CAT-FLOC 8103	organic cationic coagulant
	NALCLEAR 7768	anionic high molecular weight flocculant
GE	KLARAID PC 2700	Tannin based – cationic
	KLARAID PC 2705	Tannin based – cationic
	KLARAID PC 2706	Tannin based – cationic
	KLARAID CDP 1305	Coagulant blend
	KLARAID CDP 1314C	Coagulant blend
	POLYFLOC AS1002	Anionic
	POLYFLOC AS1001	Anionic
	METCLEAR MR 2404	Anionic
	METCLEAR MR 2405	Anionic
	METCLEAR MR 2406	Anionic

Table 10 - Summary of jar test II

Jar #	Caustic	pH	Aeration?
1	None	as is	No
2	NaOH	8	No
3	NaOH	8	Yes, before pH adjustment
4	NaOH	8	Yes, after pH adjustment

Table 11 - Summary of jar test III

Jar #	Caustic	Aeration	pH	Polymer
C1	None	Yes	as is	None
C2	NaOH	Yes	8	None
1	NaOH	Yes	8	Ultrion 7157
2	NaOH	Yes	8	Polyfloc AS1002
3	NaOH	Yes	8	4816P

Table 12 - Summary of jar test IV

Jar #	Caustic	Aeration	pH	Polymer Volume (uL)
1	NaOH	Yes	8	100
2	NaOH	Yes	8	200
3	NaOH	Yes	8	300
4	NaOH	Yes	8	400
5	NaOH	Yes	8	500

ZVI BATCH TEST RESULTS

Table 13 – Summary of chlorate reaction rates and half lives

Treatment	Rate (hr ⁻¹)	Half Life (hr)
Atomet 414	0.0475	14.6
H2OMet 56	0.0106	65.4
H2OMet57-C	0.0076	91.4

CHEMICAL PRECIPITAION RESULTS

Table 14 - Summary of pH values at the start of the testing and volumes of caustic required to adjust the pH

pH	NaOH					
	Aerated			Non-aerated		
	Initial pH	Final pH	Vol. (uL) 20% NaOH added	Initial pH	Final pH	Vol. (uL) 20% NaOH added
8	6.53	8.03	700	6.34	8.02	700
9	6.48	8.97	945	6.47	8.96	945
10	6.57	9.96	1,580	6.45	9.96	1,630
11	6.55	10.98	2,380	6.43	10.94	2,445
pH	Ca(OH) ₂					
	Aerated			Non-aerated		
	Initial pH	Final pH	Vol. (uL) 20% Ca(OH) ₂ added	Initial pH	Final pH	Vol. (uL) 20% Ca(OH) ₂ added
8	6.53	7.98	700	6.39	8.03	700
9	6.56	8.99	1,245	NR	9.06	1,350
10	6.53	10.15	1,700	6.50	10.10	1,900
11	6.52	10.99	2,500	NR	11.03	2,500

Notes:

NR = not recorded

Table 15 - Summary of pH and turbidity values for jar test II

Jar #	Description	Initial pH	Final pH (after NaOH addition)	Turbidity (NTU)
1	Control	6.42	6.44	443
2	pH 8	6.47	8.06	38
3	Aeration & pH 8	6.45	8.92	32
4	pH 8 & aeration	6.49	7.91	80

Table 16 - Summary of pH and turbidity values for jar test III

ID	Description	Initial pH	Final pH (after NaOH addition)	Turbidity (NTU)	
				After 15 mins	After 30 mins
C1	Control, Aeration	6.76	6.84	179	192
C2	Control aeration, pH 8	6.93	9.27	54.3	68.1
1	Aeration, pH 8, polymer (Ultrion 7157)	6.95	9.32	78.5	49.9
2	Aeration, pH 8, polymer (Polyfloc AS1002)	6.96	9.22	71.4	37.4
3	Aeration, pH 8, polymer (4816P)	6.88	9.26	10.9	10.1

Table 17 – Influence of chemical pre-treatment on metal concentrations

Parameter	Units	Blended GW	Blended GW Filtered	Jar 3 after aeration/pH adj/polymer/settling	Jar 3 after aeration/pH adj/polymer/settling/ 25µm filtering
Silver	µg/L	nd (10)	Nd (10)	nd (10)	nd (10)
Arsenic	µg/L	nd (15)	Nd (15)	nd (15)	nd (15)
Cadmium	µg/L	nd (5)	Nd (5)	nd (5)	nd (5)
Chromium	µg/L	nd (10)	Nd (10)	nd (10)	nd (10)
Copper	µg/L	nd (15)	5.5 B	nd (15)	nd (15)
Iron	µg/L	170,000	79,000 L	940	140
Nickel	µg/L	nd (40)	Nd (40)	nd (40)	nd (40)
Lead	µg/L	nd (9)	Nd (9)	nd (9)	nd (9)
Selenium	µg/L	nd (15)	Nd (15)	nd (15)	nd (15)
Zinc	µg/L	31 J	19 B,J	8.5 B,J	8.3 B,J

Notes:

nd = non detect

J = Method blank contamination. The associated method blank contains the target analyte at a reportable level

B = Estimated result. Result is less than RL

L = Serial dilution of digestate in the analytical batch indicates that physical and chemical interferences are present

Table 18 - Summary of pH, polymer addition, and turbidity values for jar test IV

Jar #	Initial pH	pH after aeration	Vol (uL) of 20% NaOH added	Final pH	Volume (uL) of 0.1% 4816(P)	Turbidity (NTU)
1	6.38	7.81	15	8.20	100	15.3
2	6.38	7.78	15	8.16	200	15.8
3	6.38	7.74	15	8.16	300	18.7
4	6.38	7.73	15	8.15	400	22.1
5	6.38	7.88	15	8.29	500	26.9

ANAEROBIC BIOLOGICAL TREATMENT SYSTEMS – METHODS

Table 19 - Summary of equipment used to monitor laboratory parameters

Parameter	Probe		Meter	
	Supplier	Cat. No.	Supplier	Cat. No.
pH	Cole Parmer	05718-55	Cole Parmer	35614-22
ORP	VWR	14002-856	Cole Parmer	35614-22
DO	Cole Parmer	35640-50	Cole Parmer	35433-02
Conductivity	Cole Parmer	35408-52	Cole Parmer	35433-02
Perchlorate	Cole Parmer	27504-24	Cole Parmer	35614-22
Nitrate	Cole Parmer	27502-31	Cole Parmer	35614-22
HACH test kits	Supplier		Cat. No.	
Nitrate	Clear Tech		99565-16	
Ammonium	Clear Tech		26680-00	
Phosphate	Clear Tech		58700-06	

Table 20 – FBR column details and flow rates

Parameter	FBR SYS 1		FBR SYS 2	
	SAND	GAC	SAND	GAC
Column Height (inches)	18	18	18	18
Column ID (inches)	2	2	2	2
Volume of media (mL)	464	464	464	464
Mass of media (g)	567	147	567	147
Stationary bed height (inches)	9	9	9	9
Operating bed height (inches)	10 ³ / ₄	10 1/8	9 7/8	10 ¹ / ₄
Recycle reservoir working volume (L)	2.5	2	2.5	2
Recycle Flow Rate (mL/min)	83	413	83	545
HFCS Flow Rate (mL/d)	110	NA ¹	100	NA ¹
Feed Flow Rate (L/d) Oct 03 – Nov 20/07	1.1	1.2	1.2	1.2
Feed Flow Rate (L/d) Nov 21 – Dec 03/07	1.3	1.3	1.3	1.3
Feed Flow Rate (L/d) Dec 04 – Dec 9/07	1.4	1.4	1.5	1.4
Feed Flow Rate (L/d) Dec 10 – Dec 14/07	1.7	1.6	1.7	1.6
Feed Flow Rate (L/d) Dec 15 – Dec 21/07	1.9	1.9	1.9	1.9
Feed Flow Rate (L/d) Dec 22 – Dec 28/07	2.4	2.3	2.4	2.3
Feed Flow Rate (L/d) Dec 29/07 – Jan 03/08	2.6	2.6	2.6	2.5
Feed Flow Rate (L/d) Jan 04 – Jan 09/08	3.1	3.1	3.1	3.0
Feed Flow Rate (L/d) Jan 10 – Jan 14/08	3.6	3.5	3.6	3.5
Feed Flow Rate (L/d) Jan 15 – Jan 23/08	4.4	4.5	4.5	4.2

¹HFCS was manually added to the GAC recycle reservoirs once per day on days 27 through 91, and 104 through 111

Table 21 - Summary of FBR column sampling events and flow rate changes

Mode	Time (days)	Description
Batch	0	Started recycle pump
	10	Sampling #1
	18	Sampling #2
	31	Sampling #3
Continuous feed mode	0	Started GAC recycle, feed, and HFCS pumps
	8	Continuous feed mode Sampling #1
	20	Continuous feed mode Sampling #2
	27	Daily additions of C, N and P to the GAC recycle started
	29	Continuous feed mode Sampling #3
	43	Continuous feed mode Sampling #4; Increased feed flow rate by 10%
	56	Continuous feed mode Sampling #5
	61	Increased flow rate by 15%
	67	Continuous feed mode Sampling #6; Increased flow rate by 15%
	72	Continuous feed mode Sampling #7; Increased flow rate by 15%
	78	Continuous feed mode Sampling #8; Increased flow rate by 15%
	86	Continuous feed mode Sampling #9; Increased flow rate by 15%
	91	Additions of C, N, and P to the GAC recycle were discontinued
	92	Continuous feed mode Sampling #10; Increased flow rate by 15%
	98	Continuous feed mode Sampling #11; Increased flow rate by 20%
	103	Continuous feed mode Sampling #12; Increased flow rate by 20%
	104	Daily additions of HFCS were made to the GAC recycle
110	Continuous feed mode Sampling #13	
111	Final Comprehensive Sampling	

Table 22 – PBR column details and flow rates

Parameter	PBR SYS 1	PBR SYS 2
Column Height (inches)	12	12
Column ID (inches)	2	2
Volume of media (mL)	400	400
Mass of media (g)	320	320
Media height (inches)	8 ¼	8 ¼
Recycle reservoir working volume (L)	2	2
Recycle Flow Rate (mL/min)	42	42
HFCS Flow Rate (mL/d) Oct 03 – Dec 06/07	194	191
HFCS Flow Rate (mL/d) Dec 07 – Jan 23/07	100	100
Feed Flow Rate (L/d) Oct 03 – Nov 20/07	1.3	1.3
Feed Flow Rate (L/d) Nov 21 – Dec 03/07	1.4	1.4
Feed Flow Rate (L/d) Dec 04 – Dec 09/07	1.6	1.6
Feed Flow Rate (L/d) Dec 10 – Dec 14/07	1.9	1.9
Feed Flow Rate (L/d) Dec 15 – Dec 21/07	2.2	2.2
Feed Flow Rate (L/d) Dec 22 – Dec 28/07	2.5	2.5
Feed Flow Rate (L/d) Dec 29/07 – Jan 25/08	2.9	2.9

Table 23 - Summary of PBR column sampling events and flow rate changes

Mode	Time (days)	Description
Batch	0	Started recycle pump
	10	Sampling #1
	18	Sampling #2
	31	Sampling #3
Continuous feed mode	0	Started feed and HFCS pumps
	8	Continuous feed mode Sampling #1
	20	Continuous feed mode Sampling #2
	29	Continuous feed mode Sampling #3
	43	Continuous feed mode Sampling #4
	49	Increased feed flow rate by 10%
	56	Continuous feed mode Sampling #5
	61	Increased feed flow rate by 15%
	68	Continuous feed mode Sampling #6; Increased flow rate by 15%
	72	Continuous feed mode Sampling #7; Increased flow rate by 15%
	78	Continuous feed mode Sampling #8; Increased flow rate by 15%
	86	Continuous feed mode Sampling #9; Increased flow rate by 15%
	92	Continuous feed mode Sampling #10; Increased feed perchlorate concentration to 3.5 mg/L
	98	Continuous feed mode Sampling #11
	100	Final Comprehensive Sampling; Increased feed chlorate concentration to 45 mg/L
105	Continuous feed mode Sampling #12; Increased feed perchlorate and chlorate concentrations to 24 mg/L and 180 mg/L, respectively	
111	Continuous feed mode Sampling #13	
115	Collected final effluent samples and stored at 4°C	
127	Submitted effluent samples collected on Jan. 25/08	

Table 24 - Description of major operational changes and column sampling events for the alternate treatment systems

Event	Time (days)	Description
Recycle	21	AQUAMEND Recycle
Continuous feed mode	0	Started Continuous feed mode
	12	Started bi-weekly lab parameter measurements
	28	Started Continuous feed mode Sampling #1
	33	Finished Continuous feed mode Sampling #1
	37	Switched to Blended groundwater feed
	49	Started Continuous feed mode Sampling #2
	54	Finished Continuous feed mode Sampling #2
	70	Started Continuous feed mode Sampling #3
	75	Finished Continuous feed mode Sampling #3
	112	Started Continuous feed mode Final Sampling
117	Finished Continuous feed mode Final Sampling	

ANAEROBIC BIOLOGICAL TREATMENT SYSTEMS - RESULTS

Table 25 – Comparison of inorganic parameters before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
Perchlorate	µg/L	2900 Q	2500 Q	3000 Q	2600 Q
Chlorate	mg/L	18.8	15	19.2	14.8
Nitrate an N	mg/L	nd (2.5) G	nd (5) G	nd (2.5) G	nd (5) G
Sulfate	mg/L	1300 Q	1200 Q	1300 Q	1200 Q
Nitrogen, Ammonium	mg/L	4.3	3.9	5	4.5
Total Phosphate (as P)	mg/L	0.59	0.99	nd (0.045)	0.034 B
Total Kjeldahl Nitrogen	mg/L	5.7	5.4	5.4	5.3
Total Organic Carbon	mg/L	11	15	9.6	12

Notes:

nd = non detect

Q = Elevated reporting limit. The reporting limit is elevated due to high analyte levels.

G = Elevated reporting limit. The reporting limit is elevated due to matrix interference.

B = Estimated result. Result is less than RL.

Table 26 – Comparison of metal concentrations before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
Arsenic	µg/L	nd (15)	nd (15)	nd (15)	10 B
Cadmium	µg/L	nd (5)	nd (5)	nd (5)	nd (5)
Chromium	µg/L	2.9 B	97	nd (10)	6.7 B
Copper	µg/L	nd (15)	nd (15)	nd (15)	nd (15)
Iron	µg/L	150,000	130,000	4,600	7,800
Lead	µg/L	nd (9)	nd (9)	nd (9)	nd (9)
Nickel	µg/L	nd (40)	8.4 B	nd (40)	nd (40)
Selenium	µg/L	nd (15)	nd (15)	nd (15)	nd (15)
Silver	µg/L	nd (10)	nd (10)	nd (10)	2.9 B
Zinc	µg/L	16 B,J	15 B,J	5.8 B,J	8.1 B, J

Notes:

nd = non detect

B = Estimated result. Result is less than RL.

J = Estimated result. Result is less than RL.

Table 27 – Comparison of VOC concentrations before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
Acrolein	µg/L	ND (800)	ND (800)	ND (200)	ND (200)
Acrylonitrile	µg/L	ND (800)	ND (800)	ND (200)	ND (200)
Benzene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Bromodichloromethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Bromoform	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Bromomethane	µg/L	ND (80)	ND (80)	ND (20)	ND (20)
Carbon Tetrachloride	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Chlorobenzene	µg/L	950	640	280	300
Dibromochloromethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Chloroethane	µg/L	33 J	25 J	6.3 J	6.5 J
2-Chloroethyl vinyl ether	µg/L	ND (120)	ND (120)	ND (30)	ND (30)
Chloroform	µg/L	11 J	8.3 J	3.3 J	3.6 J
Chloromethane	µg/L	ND (80)	ND (80)	ND (20)	ND (20)
1,2-Dichlorobenzene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,3-Dichlorobenzene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,4-Dichlorobenzene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Dichlorodifluoromethane	µg/L	ND (80)	ND (80)	ND (20)	ND (20)
1,1-Dichloroethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,2-Dichloroethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
cis-1,2-Dichloroethene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
trans-1,2-Dichloroethene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,1-Dichloroethene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,2-Dichloropropane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
cis-1,3-Dichloropropene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
trans-1,3-Dichloropropene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Ethylbenzene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Trichlorofluoromethane	µg/L	ND (80)	ND (80)	ND (20)	ND (20)
Methylene Chloride	µg/L	ND (200)	ND (200)	ND (50)	ND (50)
1,1,2,2-Tetrachloroethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Tetrachloroethene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Toluene	µg/L	32 J	21 J	7.8 J	8.2 J
1,1,1-Trichloroethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
1,1,2-Trichloroethane	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Trichloroethene	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Vinyl chloride	µg/L	ND (40)	ND (40)	ND (10)	ND (10)
Xylenes (total)	µg/L	ND (80)	ND (80)	ND (20)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 28 – Comparison of SVOC concentrations before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
Acenaphthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Acenaphthylene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzdine	µg/L	nd (150)	nd (150)	nd (150)	nd (150)
Benzo(a)anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(b)Fluoranthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(k)Fluoranthene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(g,h,i)perylene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Benzo(a)pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroethoxy)methane	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroethyl)ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Chloroisopropyl)ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
bis(2-Ethylhexyl)phthalate	µg/L	nd (10)	nd (10)	2.4 J	1.7 J
4-bromophenyl phenyl ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Butyl benzyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Chloroaniline	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Chloro-3-methylphenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2-Chloronaphthalene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
2-Chlorophenol	µg/L	45	34	27	35
4-Chlorophenyl phenyl ether	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Chrysene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Dibenzo(a,h)anthracene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Di-n-butyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
1,2-Dichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
1,3-Dichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
1,4-Dichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
3,3'-Dichlorobenzidine	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,4-Dichlorophenol	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Diethyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,4-Dimethylphenol	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Dimethyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4,6-Dinitro-2-methylphenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
2,4-Dinitrophenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
2,4-Dinitrotoluene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2,6-Dinitrotoluene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
Di-n-octyl phthalate	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
1,2-Diphenylhydrazine (as Azobenzene)	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Fluoranthene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
Fluorene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorobutadiene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachlorocyclopentadiene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Hexachloroethane	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Indeno(1,2,3-cd)pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)

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Isophorone	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Naphthalene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Nitrobenzene	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
2-Nitrophenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)
4-Nitrophenol	µg/L	nd (50)	nd (50)	nd (50)	nd (50)
N-Nitrosodimethylamine	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
N-Nitrosodiphenylamine	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
N-Nitrosodi-n-propylamine	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Pentachlorophenol	µg/L	nd (60)	nd (60)	nd (60)	nd (60)
Phenanthrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Phenol	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
Pyrene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
1,2,4-Trichlorobenzene	µg/L	nd (10)	nd (10)	nd (10)	nd (10)
2,4,6-Trichlorophenol	µg/L	nd (20)	nd (20)	nd (20)	nd (20)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

Table 29 – Comparison of pesticide concentrations before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
4,4'-DDD	µg/L	nd (0.11)	nd (0.11)	nd (0.11)	nd (0.11)
4,4'-DDE	µg/L	nd (0.040)	nd (0.040)	nd (0.040)	nd (0.040)
4,4'-DDT	µg/L	nd (0.12)	nd (0.12)	nd (0.12)	nd (0.12)
Aldrin	µg/L	nd (0.040)	nd (0.040)	nd (0.040)	nd (0.040)
alpha-BHC	µg/L	nd (0.030)	nd (0.030)	nd (0.030)	nd (0.030)
beta-BHC	µg/L	nd (0.060)	nd (0.060)	nd (0.060)	nd (0.060)
Chlordane (technical)	µg/L	nd (0.14)	nd (0.14)	nd (0.14)	nd (0.14)
delta-BHC	µg/L	nd (0.090)	nd (0.090)	nd (0.090)	nd (0.090)
Dieldrin	µg/L	nd (0.020)	nd (0.020)	nd (0.020)	nd (0.020)
Endosulfan I	µg/L	nd (0.020)	nd (0.020)	nd (0.020)	nd (0.020)
Endosulfan II	µg/L	nd (0.040)	nd (0.040)	nd (0.040)	nd (0.040)
Endosulfan sulfate	µg/L	nd (0.66)	nd (0.66)	nd (0.66)	nd (0.66)
Endrin	µg/L	nd (0.060)	nd (0.060)	nd (0.060)	nd (0.060)
Endrin aldehyde	µg/L	nd (0.23)	nd (0.23)	nd (0.23)	nd (0.23)
Endrin ketone	µg/L	nd (0.10)	nd (0.10)	nd (0.10)	nd (0.10)
gamma-BHC (Lindane)	µg/L	nd (0.040)	nd (0.040)	nd (0.040)	nd (0.040)
Heptachlor	µg/L	nd (0.030)	nd (0.030)	nd (0.030)	nd (0.030)
Heptachlor epoxide	µg/L	nd (0.080)	nd (0.080)	nd (0.080)	nd (0.080)
Methoxychlor	µg/L	nd (1.8)	nd (1.8)	nd (1.8)	nd (1.8)
Toxaphene	µg/L	nd (2.5)	nd (2.5)	nd (2.5)	nd (2.5)

Notes:

nd = non detect

Table 30 – Comparison of laboratory parameters before and after chemical pre-treatment

Parameter	Units	As received GW		Chemically Treated GW	
		1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻	1,600 mg/L Cl ⁻	8,000 mg/L Cl ⁻
pH	pH units	6.48	6.44	7.93	7.89
ORP	mV	-54.2	-45.2	160.2	140.6
DO	%	2.61	2.59	8.33	8.17
SC	mS	7.659	23.27	7.747	23.51
Perchlorate	mg/L	3.245	1.909	3.521	2.756
Nitrate ¹	mg/L	16	115	200	176
Nitrate ²	mg/L	0.3	0.0	0.0	0.8
Phosphate-P	mg/L	0.03	0.05	0.03	0.04
Chloride	mg/L	1754	8054	1894	8088

¹probe readings²spectrophotometer method**Table 31** – Comparison of total target metal concentrations in the FBR feeds and effluents

Parameter	Units	FEED		EFFLUENT			
		FBR SYS 1	FBR SYS 2	FBR SYS 1 SAND	FBR SYS 1 GAC	FBR SYS 2 SAND	FBR SYS 2 GAC
Silver	µg/L	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	µg/L	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Chromium	µg/L	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)
Copper	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)
Iron	µg/L	450	290	130	87 B	79 B	82 B
Nickel	µg/L	ND (40)	ND (40)	ND (40)	ND (40)	ND (40)	ND (40)
Lead	µg/L	ND (9)	ND (9)	ND (9)	ND (9)	ND (9)	ND (9)
Selenium	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	5.2 B	ND (15)
Zinc	µg/L	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)
Hexavalent Chromium	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 32 – Comparison of dissolved target metal concentrations in the FBR feeds and effluents

Parameter	Units	FEED		EFFLUENT			
		FBR SYS 1	FBR SYS 2	FBR SYS 1 SAND	FBR SYS 1 GAC	FBR SYS 2 SAND	FBR SYS 2 GAC
Silver	µg/L	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	4.9 B	ND (15)
Cadmium	µg/L	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
Chromium	µg/L	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)
Copper	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)
Iron	µg/L	ND (100)	ND (100)	50 B	ND (100)	39 B	ND (100)
Nickel	µg/L	ND (40)	ND (40)	ND (40)	ND (40)	ND (40)	ND (40)
Lead	µg/L	ND (9)	ND (9)	ND (9)	ND (9)	ND (9)	ND (9)
Selenium	µg/L	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	µg/L	ND (20)	4.9 B	ND (20)	ND (20)	ND (20)	ND (20)
Hexavalent Chromium	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	0.0053 B

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 33 – Comparison of VOC concentrations in the FBR feeds and effluents

Parameter	Units	FBR FEEDS		FBR EFFLUENTS			
		SYS 1	SYS 2	FBR SYS 1		FBR SYS 2	
				SAND	GAC	SAND	GAC
Xylenes (total)	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Acrolein	µg/L	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)
Acrylonitrile	µg/L	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)	ND (20)
Benzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromodichloromethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromoform	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromomethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Carbon Tetrachloride	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Chlorobenzene	µg/L	ND (1.0)	ND (1.0)	23	ND (1.0)	3.1	ND (1.0)
Dibromochloromethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Chloroethane	µg/L	1.9 J	0.91 J	1.1 J	ND (2.0)	0.60 J	ND (2.0)
2-Chloroethyl vinyl ether	µg/L	ND (3.0)	ND (3.0)	ND (3.0)	ND (3.0)	ND (3.0)	ND (3.0)
Chloroform	ug/L	1.0	0.56 J	0.44 J	ND (1.0)	0.34 J	ND (1.0)
Chloromethane	ug/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
1,2-Dichlorobenzene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,3-Dichlorobenzene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,4-Dichlorobenzene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Dichlorodifluoromethane	ug/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
1,1-Dichloroethane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,2-Dichloroethane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
cis-1,2-Dichloroethene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trans-1,2-Dichloroethene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1-Dichloroethene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,2-Dichloropropane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
cis-1,3-Dichloropropene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trans-1,3-Dichloropropene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Ethylbenzene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Methylene Chloride	ug/L	1.0 J	0.75 J	0.92 J	0.55 J	0.75 J	0.40 J
1,1,2,2-Tetrachloroethane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Tetrachloroethene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Toluene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1,1-Trichloroethane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1,2-Trichloroethane	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trichloroethene	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trichlorofluoromethane	ug/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Vinyl chloride	ug/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

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Indeno(1,2,3-cd)pyrene	µg/L	ND (10)					
Isophorone	µg/L	ND (10)					
Naphthalene	µg/L	ND (10)					
Nitrobenzene	µg/L	ND (20)					
2-Nitrophenol	µg/L	ND (20)					
4-Nitrophenol	µg/L	ND (50)					
N-Nitrosodimethylamine	µg/L	ND (10)					
N-Nitrosodiphenylamine	µg/L	ND (10)					
N-Nitrosodi-n-propylamine	µg/L	ND (20)					
Pentachlorophenol	µg/L	ND (60)					
Phenanthrene	µg/L	ND (10)					
Phenol	µg/L	ND (10)					
Pyrene	µg/L	ND (10)					
1,2,4-Trichlorobenzene	µg/L	ND (10)					
2,4,6-Trichlorophenol	µg/L	1.2 J	1.1 J	1.1 J	ND (20)	1.0 J	ND (20)

Notes:

nd = non detect

J = Estimated result. Result is less than RL

Table 35 – Comparison of pesticide concentrations in the FBR feeds and effluents

Parameter	Units	FBR FEEDS		FBR EFFLUENTS			
				FBR SYS 1		FBR SYS 2	
		SYS 1	SYS 2	SAND	GAC	SAND	GAC
4,4'-DDD	µg/L	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)
4,4'-DDE	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
4,4'-DDT	µg/L	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)
Aldrin	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
alpha-BHC	µg/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
beta-BHC	µg/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)	0.026 J	ND (0.060)
Chlordane (technical)	µg/L	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)
Delta-BHC	µg/L	ND (0.090)	ND (0.090)	0.013 J,COL	ND (0.090)	0.012 J,COL	ND (0.090)
Dieldrin	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan I	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan II	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Endosulfan sulfate	µg/L	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)
Endrin	µg/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)
Endrin aldehyde	µg/L	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)
Endrin ketone	µg/L	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)
gamma-BHC (Lindane)	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)	0.0086 J,COL	ND (0.040)
Heptachlor	µg/L	ND (0.030)	ND (0.030)	0.011 J	ND (0.030)	0.0091 J,COL	ND (0.030)
Heptachlor epoxide	µg/L	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)
Methoxychlor	µg/L	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)
Toxaphene	µg/L	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

COL = More than 40% RPD between primary and confirmation column results. The lower of the two results is reported.

Table 36 – Comparison of total target metal concentrations in the PBR feeds and effluents

Parameter	Units	FEED		EFFLUENT	
		PBR SYS 1	PBR SYS 2	PBR SYS 1	PBR SYS 2
Silver	µg/L	3.0 B	4.0 B	ND (10)	ND (10)
Arsenic	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	µg/L	ND (5.0)	ND (5.0)	ND (5.0)	ND (5.0)
Chromium	µg/L	ND (10)	ND (10)	4.1 B	ND (10)
Copper	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Iron	µg/L	230	170	160	130
Nickel	µg/L	ND (40)	ND (40)	ND (40)	ND (40)
Lead	µg/L	ND (9.0)	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	µg/L	5.3 B	ND (20)	6.1 B	6.8 B
Hexavalent Chromium	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 37 – Comparison of dissolved target metal concentrations in the PBR feeds and effluents

Parameter	Units	FEED		EFFLUENT	
		PBR SYS 1	PBR SYS 2	PBR SYS 1	PBR SYS 2
Silver	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	µg/L	ND (5.0)	ND (5.0)	ND (5.0)	ND (5.0)
Chromium	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Copper	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Iron	µg/L	ND (100)	ND (100)	ND (100)	ND (100)
Nickel	µg/L	ND (40)	ND (40)	ND (40)	ND (40)
Lead	µg/L	ND (9.0)	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	µg/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Hexavalent Chromium	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

Table 38 – Comparison of VOC concentrations in the PBR feeds and effluents

Parameter	Units	FEED		EFFLUENT	
		PBR SYS 1	PBR SYS 2	PBR SYS 1	PBR SYS 2
Xylenes (total)	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Acrolein	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Acrylonitrile	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Benzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromodichloromethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromoform	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Bromomethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Carbon Tetrachloride	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Chlorobenzene	µg/L	ND (1.0)	ND (1.0)	0.25 J	0.59 J
Dibromochloromethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Chloroethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
2-Chloroethyl vinyl ether	µg/L	ND (3.0)	ND (3.0)	ND (3.0)	ND (3.0)
Chloroform	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Chloromethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
1,2-Dichlorobenzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,3-Dichlorobenzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,4-Dichlorobenzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Dichlorodifluoromethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
1,1-Dichloroethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,2-Dichloroethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
cis-1,2-Dichloroethene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
trans-1,2-Dichloroethene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1-Dichloroethene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,2-Dichloropropane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
cis-1,3-Dichloropropene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
trans-1,3-Dichloropropene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Ethylbenzene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Methylene Chloride	µg/L	ND (5.0)	ND (5.0)	ND (5.0)	ND (5.0)
1,1,2,2-Tetrachloroethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Tetrachloroethene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Toluene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1,1-Trichloroethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
1,1,2-Trichloroethane	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trichloroethene	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
Trichlorofluoromethane	µg/L	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
Vinyl chloride	µg/L	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 39 – Comparison of SVOC concentrations in the PBR feeds and effluents

Parameter	Units	FEED		EFFLUENT	
		PBR SYS 1	PBR SYS 2	PBR SYS 1	PBR SYS 2
Acenaphthene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Acenaphthylene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Anthracene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzidine	µg/L	ND (150)	ND (150)	ND (150)	ND (150)
Benzo(a)anthracene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(b)Fluoranthene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(k)Fluoranthene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(g,h,i)perylene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(a)pyrene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethoxy)methane	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethyl)ether	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroisopropyl)ether	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Ethylhexyl)phthalate	µg/L	1.8 J	2.5 J	ND (10)	ND (10)
4-bromophenyl phenyl ether	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Butyl benzyl phthalate	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloroaniline	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloro-3-methylphenol	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Chloronaphthalene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
2-Chlorophenol	µg/L	ND (10)	11	11	7.0 J
4-Chlorophenyl phenyl ether	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Chrysene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Dibenzo(a,h)anthracene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Di-n-butyl phthalate	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Dichlorobenzene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
1,3-Dichlorobenzene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
1,4-Dichlorobenzene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
3,3'-Dichlorobenzidine	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dichlorophenol	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Diethyl phthalate	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dimethylphenol	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Dimethyl phthalate	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
4,6-Dinitro-2-methylphenol	µg/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrophenol	µg/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrotoluene	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
2,6-Dinitrotoluene	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Di-n-octyl phthalate	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Diphenylhydrazine (as Azobenzene)	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Fluoranthene	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Fluorene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorobenzene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorobutadiene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorocyclopentadiene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachloroethane	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Indeno(1,2,3-cd)pyrene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Isophorone	µg/L	ND (10)	ND (10)	ND (10)	ND (10)

Naphthalene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Nitrobenzene	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Nitrophenol	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Nitrophenol	µg/L	ND (50)	ND (50)	ND (50)	ND (50)
N-Nitrosodimethylamine	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodiphenylamine	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodi-n-propylamine	µg/L	ND (20)	ND (20)	ND (20)	ND (20)
Pentachlorophenol	µg/L	ND (60)	ND (60)	ND (60)	ND (60)
Phenanthrene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Phenol	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
Pyrene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
1,2,4-Trichlorobenzene	µg/L	ND (10)	ND (10)	ND (10)	ND (10)
2,4,6-Trichlorophenol	µg/L	1.1 J	ND (20)	ND (20)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 40 – Comparison of pesticide concentrations in the PBR feeds and effluents

Parameter	Units	FEED		EFFLUENT	
		PBR SYS 1	PBR SYS 2	PBR SYS 1	PBR SYS 2
4,4'-DDD	µg/L	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)
4,4'-DDE	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
4,4'-DDT	µg/L	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)
Aldrin	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Alpha-BHC	µg/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
beta-BHC	µg/L	ND (0.060)	ND (0.060)	0.012 J	0.0093 J, COL
Chlordane (technical)	µg/L	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)
Delta-BHC	µg/L	ND (0.090)	ND (0.090)	0.018 J, COL	0.010 J, COL
Dieldrin	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan I	µg/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan II	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Endosulfan sulfate	µg/L	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)
Endrin	µg/L	0.013 J	0.0081 J	ND (0.060)	ND (0.060)
Endrin aldehyde	µg/L	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)
Endrin ketone	µg/L	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)
gamma-BHC (Lindane)	µg/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Heptachlor	µg/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
Heptachlor epoxide	µg/L	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)
Methoxychlor	µg/L	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)
Toxaphene	µg/L	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

COL = More than 40% RPD between primary and confirmation column results. The lower of the two results is reported.

Table 41 – Comparison of total target metal concentrations in the EHC-AQUAMEND System 1 feed and effluents

Parameter	Units	EHC SYS 1 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Silver	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	ug/L	4.7 B	ND (15)	ND (15)	ND (15)
Cadmium	ug/L	ND (5.0)	ND (5.0)	ND (5.0)	ND (5.0)
Chromium	ug/L	4.4 B	ND (10)	ND (10)	ND (10)
Copper	ug/L	5.9 B	ND (15)	ND (15)	ND (15)
Iron	ug/L	160,000	110,000	35,000	63,000
Nickel	ug/L	ND (40)	ND (40)	ND (40)	ND (40)
Lead	ug/L	2.7 B	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	ug/L	14 B	4.9 B	6.6 B	5.5 B
Hexavalent Chromium	ug/L	0.0070 B	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 42 – Comparison of dissolved target metal concentrations in the EHC-AQUAMEND System 1 feed and effluents

Parameter	Units	EHC SYS 1 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Silver	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	ug/L	ND (5.0)	ND (5.0)	ND (5.0)	ND (5.0)
Chromium	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Copper	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Iron	ug/L	110,000	50,000	6,300	6,500
Nickel	ug/L	ND (40)	ND (40)	ND (40)	ND (40)
Lead	ug/L	ND (9.0)	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	ug/L	5.3 B	4.7 B	ND (20)	ND (20)
Hexavalent Chromium	ug/L	0.0070 B	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 43 – Comparison of VOC concentrations in the EHC-AQUAMEND System 1 feed and effluents

Parameter	Units	EHC SYS 1 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Xylenes (total)	ug/L	ND (53)	ND (53)	ND (53)	ND (40)
Acrolein	ug/L	ND (530)	ND (530)	ND (530)	ND (400)
Acrylonitrile	ug/L	ND (530)	ND (530)	ND (530)	ND (400)
Benzene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Bromodichloromethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Bromoform	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Bromomethane	ug/L	ND (53)	ND (53)	ND (53)	ND (40)
Carbon Tetrachloride	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Chlorobenzene	ug/L	1,100	1,100	720	680
Dibromochloromethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Chloroethane	ug/L	32 J	28 J	25 J	27 J
2-Chloroethyl vinyl ether	ug/L	ND (80)	ND (80)	ND (80)	ND (60)
Chloroform	ug/L	8.1 J	ND (27)	4.6 J	ND (20)
Chloromethane	ug/L	ND (53)	ND (53)	ND (53)	ND (40)
1,2-Dichlorobenzene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,3-Dichlorobenzene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,4-Dichlorobenzene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Dichlorodifluoromethane	ug/L	ND (53)	ND (53)	ND (53)	ND (40)
1,1-Dichloroethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,2-Dichloroethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
cis-1,2-Dichloroethene	ug/L	ND (27)	9.9 J	7.5 J	7.5 J
trans-1,2-Dichloroethene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,1-Dichloroethene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,2-Dichloropropane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
cis-1,3-Dichloropropene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
trans-1,3-Dichloropropene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Ethylbenzene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Methylene Chloride	ug/L	ND (130)	15 J	13 J	12 J
1,1,2,2-Tetrachloroethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Tetrachloroethene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Toluene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,1,1-Trichloroethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
1,1,2-Trichloroethane	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Trichloroethene	ug/L	ND (27)	ND (27)	ND (27)	ND (20)
Trichlorofluoromethane	ug/L	ND (53)	ND (53)	ND (53)	ND (40)
Vinyl chloride	ug/L	ND (27)	ND (27)	ND (27)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 44 – Comparison of SVOC concentrations in the EHC-AQUAMEND System 1 feed and effluents

Parameter	Units	EHC SYS 1 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Acenaphthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Acenaphthylene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzidine	ug/L	ND (150)	ND (150)	ND (150)	ND (150)
Benzo(a)anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(b)Fluoranthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(k)Fluoranthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(g,h,i)perylene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(a)pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethoxy)methane	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethyl)ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroisopropyl)ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Ethylhexyl)phthalate	ug/L	ND (10)	ND (10)	1.4 J	ND (10)
4-bromophenyl phenyl ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Butyl benzyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloroaniline	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloro-3-methylphenol	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Chloronaphthalene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
2-Chlorophenol	ug/L	27	28	31	38
4-Chlorophenyl phenyl ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Chrysene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Dibenzo(a,h)anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Di-n-butyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,3-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,4-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
3,3'-Dichlorobenzidine	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dichlorophenol	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Diethyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dimethylphenol	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Dimethyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4,6-Dinitro-2-methylphenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrophenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrotoluene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,6-Dinitrotoluene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Di-n-octyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Diphenylhydrazine (as Azobenzene)	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Fluoranthene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Fluorene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)

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Hexachlorobutadiene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorocyclopentadiene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachloroethane	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Indeno(1,2,3-cd)pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Isophorone	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Naphthalene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Nitrobenzene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Nitrophenol	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Nitrophenol	ug/L	ND (50)	ND (50)	ND (50)	ND (50)
N-Nitrosodimethylamine	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodiphenylamine	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodi-n-propylamine	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Pentachlorophenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
Phenanthrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Phenol	ug/L	1.3 J	ND (10)	ND (10)	1.1 J
Pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,2,4-Trichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
2,4,6-Trichlorophenol	ug/L	ND (20)	1.0 J	ND (20)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 45 – Comparison of pesticide concentrations in the EHC-AQUAMEND System 1 feed and effluents

Parameter	Units	EHC SYS 1 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
4,4'-DDD	ug/L	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)
4,4'-DDE	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
4,4'-DDT	ug/L	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)
Aldrin	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
alpha-BHC	ug/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
beta-BHC	ug/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)
Chlordane (technical)	ug/L	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)
delta-BHC	ug/L	ND (0.090)	ND (0.090)	ND (0.090)	ND (0.090)
Dieldrin	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan I	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan II	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Endosulfan sulfate	ug/L	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)
Endrin	ug/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)
Endrin aldehyde	ug/L	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)
Endrin ketone	ug/L	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)
gamma-BHC (Lindane)	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Heptachlor	ug/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
Heptachlor epoxide	ug/L	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)
Methoxychlor	ug/L	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)
Toxaphene	ug/L	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)

Notes:

ND = non detect

Table 46 – Comparison of total target metal concentrations in the EHC-AQUAMEND System 2 feed and effluents

Parameter	Units	EHC SYS 2 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Silver	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	ug/L	1.3 B	1.5 B	0.45 B	ND (5.0)
Chromium	ug/L	54	ND (10)	ND (10)	ND (10)
Copper	ug/L	4.8 B	ND (15)	9.4 B	6.8 B
Iron	ug/L	120,000	120,000	34,000	40,000
Nickel	ug/L	ND (40)	ND (40)	ND (40)	11 B
Lead	ug/L	ND (9.0)	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	ug/L	12 B	10 B	7.7 B	7.6 B
Hexavalent Chromium	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	0.026

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 47 – Comparison of dissolved target metal concentrations in the EHC-AQUAMEND System 2 feed and effluents

Parameter	Units	EHC SYS 2 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Silver	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Arsenic	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Cadmium	ug/L	0.65 B	ND (5.0)	ND (5.0)	ND (5.0)
Chromium	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Copper	ug/L	12 B	ND (15)	ND (15)	4.6 B
Iron	ug/L	83,000	24,000	1,800	2,300
Nickel	ug/L	ND (40)	ND (40)	ND (40)	9.0 B
Lead	ug/L	ND (9.0)	ND (9.0)	ND (9.0)	ND (9.0)
Selenium	ug/L	ND (15)	ND (15)	ND (15)	ND (15)
Zinc	ug/L	23	8.0 B	ND (20)	ND (20)
Hexavalent Chromium	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)

Notes:

ND = non detect

B = Estimated result. Result is less than RL.

Table 48 – Comparison of VOC concentrations in the EHC-AQUAMEND System 2 feed and effluents

Parameter	Units	EHC SYS 2 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Xylenes (total)	ug/L	ND (53)	ND (40)	ND (40)	ND (40)
Acrolein	ug/L	ND (530)	ND (400)	ND (400)	ND (400)
Acrylonitrile	ug/L	ND (530)	ND (400)	ND (400)	ND (400)
Benzene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Bromodichloromethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Bromoform	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Bromomethane	ug/L	ND (53)	ND (40)	ND (40)	ND (40)
Carbon Tetrachloride	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Chlorobenzene	ug/L	1,100	1,100	460	560
Dibromochloromethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Chloroethane	ug/L	32 J	25 J	23 J	24 J
2-Chloroethyl vinyl ether	ug/L	ND (80)	ND (60)	ND (60)	ND (60)
Chloroform	ug/L	7.1 J	4.6 J	3.7 J	4.0 J
Chloromethane	ug/L	ND (53)	ND (40)	ND (40)	ND (40)
1,2-Dichlorobenzene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,3-Dichlorobenzene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,4-Dichlorobenzene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Dichlorodifluoromethane	ug/L	ND (53)	ND (40)	ND (40)	ND (40)
1,1-Dichloroethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,2-Dichloroethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
cis-1,2-Dichloroethene	ug/L	ND (27)	13 J	8.5 J	9.0 J
trans-1,2-Dichloroethene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,1-Dichloroethene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,2-Dichloropropane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
cis-1,3-Dichloropropene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
trans-1,3-Dichloropropene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Ethylbenzene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Methylene Chloride	ug/L	ND (130)	13 J	12 J	12 J
1,1,2,2-Tetrachloroethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Tetrachloroethene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Toluene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,1,1-Trichloroethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
1,1,2-Trichloroethane	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Trichloroethene	ug/L	ND (27)	ND (20)	ND (20)	ND (20)
Trichlorofluoromethane	ug/L	ND (53)	ND (40)	ND (40)	ND (40)
Vinyl chloride	ug/L	ND (27)	ND (20)	ND (20)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 49 – Comparison of SVOC concentrations in the EHC-AQUAMEND System 2 feed and effluents

Parameter	Units	EHC SYS 2 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
Acenaphthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Acenaphthylene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzidine	ug/L	ND (150)	ND (150)	ND (150)	ND (150)
Benzo(a)anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(b)Fluoranthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(k)Fluoranthene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(g,h,i)perylene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Benzo(a)pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethoxy)methane	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroethyl)ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Chloroisopropyl)ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
bis(2-Ethylhexyl)phthalate	ug/L	1.1 J	ND (10)	1.3 J	ND (10)
4-bromophenyl phenyl ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Butyl benzyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloroaniline	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Chloro-3-methylphenol	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Chloronaphthalene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
2-Chlorophenol	ug/L	31	30	28	31
4-Chlorophenyl phenyl ether	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Chrysene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Dibenzo(a,h)anthracene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Di-n-butyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,3-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,4-Dichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
3,3'-Dichlorobenzidine	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dichlorophenol	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Diethyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,4-Dimethylphenol	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Dimethyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4,6-Dinitro-2-methylphenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrophenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
2,4-Dinitrotoluene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2,6-Dinitrotoluene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Di-n-octyl phthalate	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
1,2-Diphenylhydrazine (as Azobenzene)	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Fluoranthene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Fluorene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)

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Hexachlorobutadiene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachlorocyclopentadiene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Hexachloroethane	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Indeno(1,2,3-cd)pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Isophorone	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Naphthalene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Nitrobenzene	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
2-Nitrophenol	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
4-Nitrophenol	ug/L	ND (50)	ND (50)	ND (50)	ND (50)
N-Nitrosodimethylamine	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodiphenylamine	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
N-Nitrosodi-n-propylamine	ug/L	ND (20)	ND (20)	ND (20)	ND (20)
Pentachlorophenol	ug/L	ND (60)	ND (60)	ND (60)	ND (60)
Phenanthrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
Phenol	ug/L	0.97 J	ND (10)	ND (10)	ND (10)
Pyrene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
1,2,4-Trichlorobenzene	ug/L	ND (10)	ND (10)	ND (10)	ND (10)
2,4,6-Trichlorophenol	ug/L	ND (20)	ND (20)	ND (20)	ND (20)

Notes:

ND = non detect

J = Estimated result. Result is less than RL

Table 50 – Comparison of pesticide concentrations in the EHC-AQUAMEND System 2 feed and effluents

Parameter	Units	EHC SYS 2 FEED	EHC-SAND EFFLUENT	AEROBIC AQUAMEND EFFLUENT	ANAEROBIC AQUAMEND EFFLUENT
4,4'-DDD	ug/L	ND (0.11)	ND (0.11)	ND (0.11)	ND (0.11)
4,4'-DDE	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
4,4'-DDT	ug/L	ND (0.12)	ND (0.12)	ND (0.12)	ND (0.12)
Aldrin	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
alpha-BHC	ug/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
beta-BHC	ug/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)
Chlordane (technical)	ug/L	ND (0.14)	ND (0.14)	ND (0.14)	ND (0.14)
delta-BHC	ug/L	ND (0.090)	ND (0.090)	ND (0.090)	ND (0.090)
Dieldrin	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan I	ug/L	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
Endosulfan II	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Endosulfan sulfate	ug/L	ND (0.66)	ND (0.66)	ND (0.66)	ND (0.66)
Endrin	ug/L	ND (0.060)	ND (0.060)	ND (0.060)	ND (0.060)
Endrin aldehyde	ug/L	ND (0.23)	ND (0.23)	ND (0.23)	ND (0.23)
Endrin ketone	ug/L	ND (0.10)	ND (0.10)	ND (0.10)	ND (0.10)
gamma-BHC (Lindane)	ug/L	ND (0.040)	ND (0.040)	ND (0.040)	ND (0.040)
Heptachlor	ug/L	ND (0.030)	ND (0.030)	ND (0.030)	ND (0.030)
Heptachlor epoxide	ug/L	ND (0.080)	ND (0.080)	ND (0.080)	ND (0.080)
Methoxychlor	ug/L	ND (1.8)	ND (1.8)	ND (1.8)	ND (1.8)
Toxaphene	ug/L	ND (2.5)	ND (2.5)	ND (2.5)	ND (2.5)

Notes:

ND = non detect

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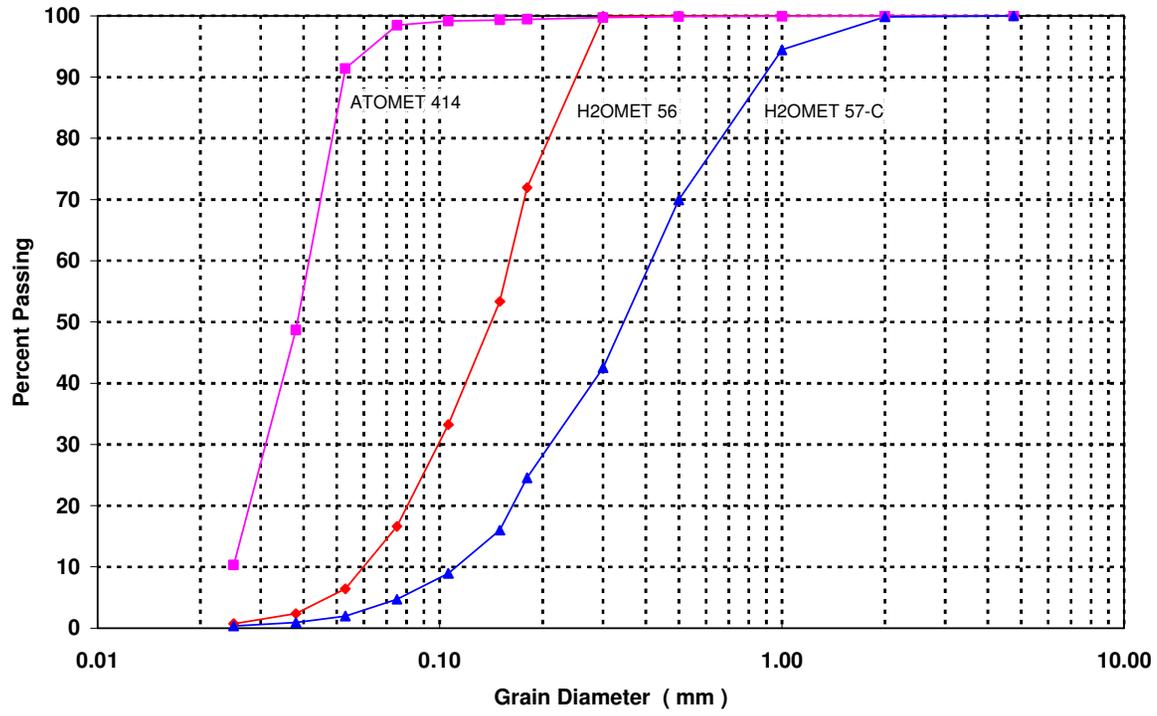


Figure 1 – Grain size distribution curves

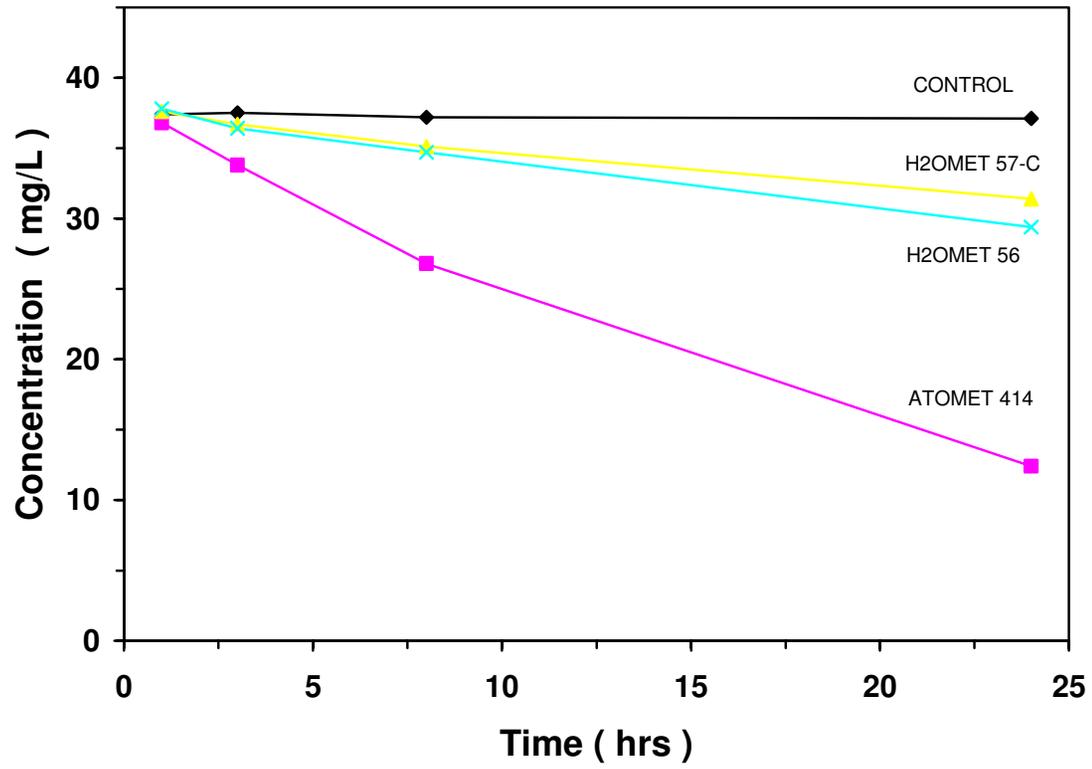


Figure 2 – ZVI Batch Test: Chlorate concentration versus time

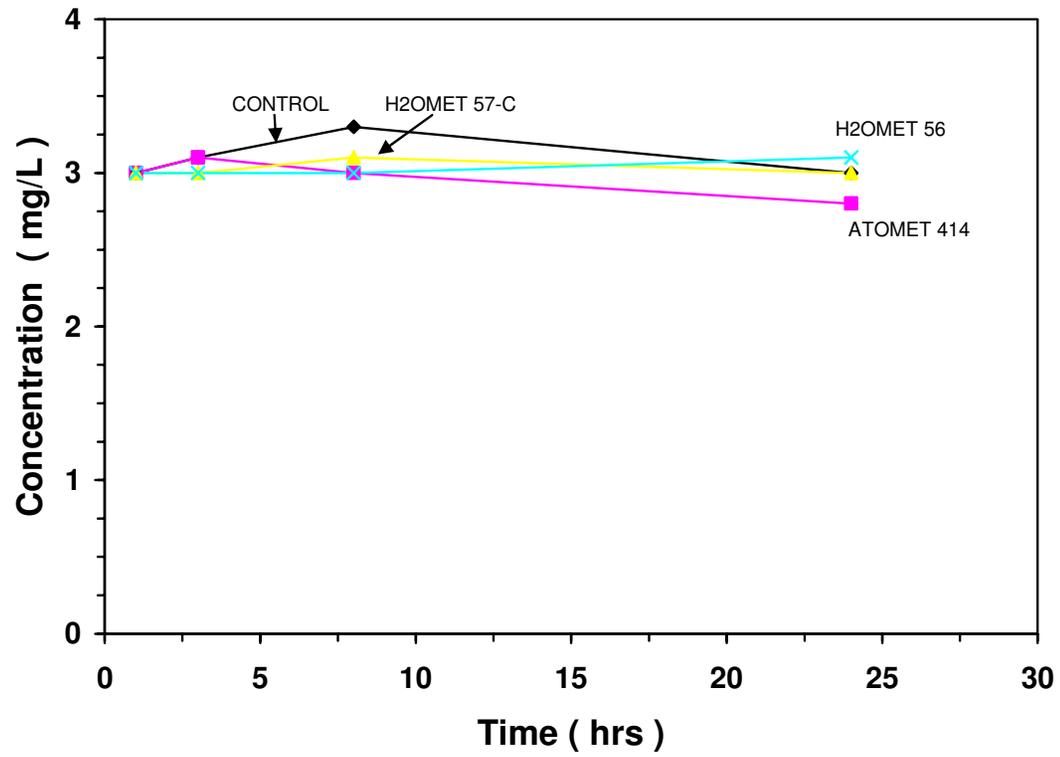


Figure 3 - ZVI Batch Test: Perchlorate concentration versus time

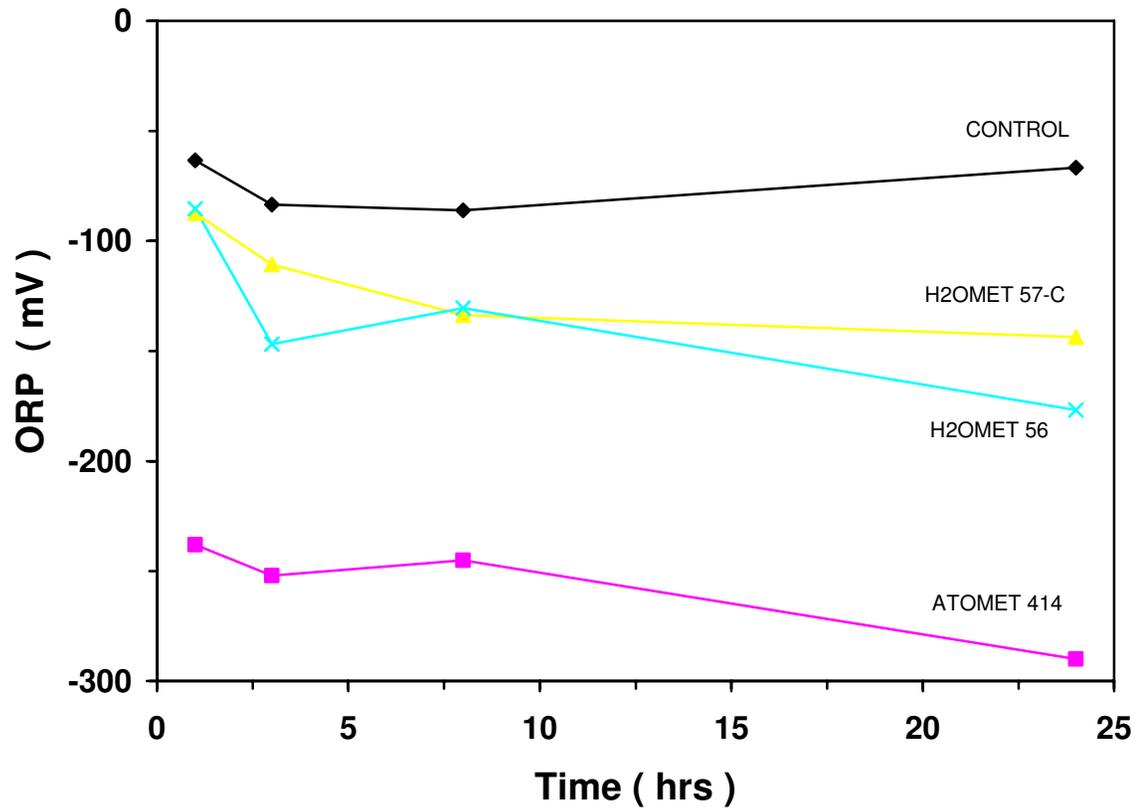


Figure 4 - ZVI Batch Test: Redox potential (Eh) versus time

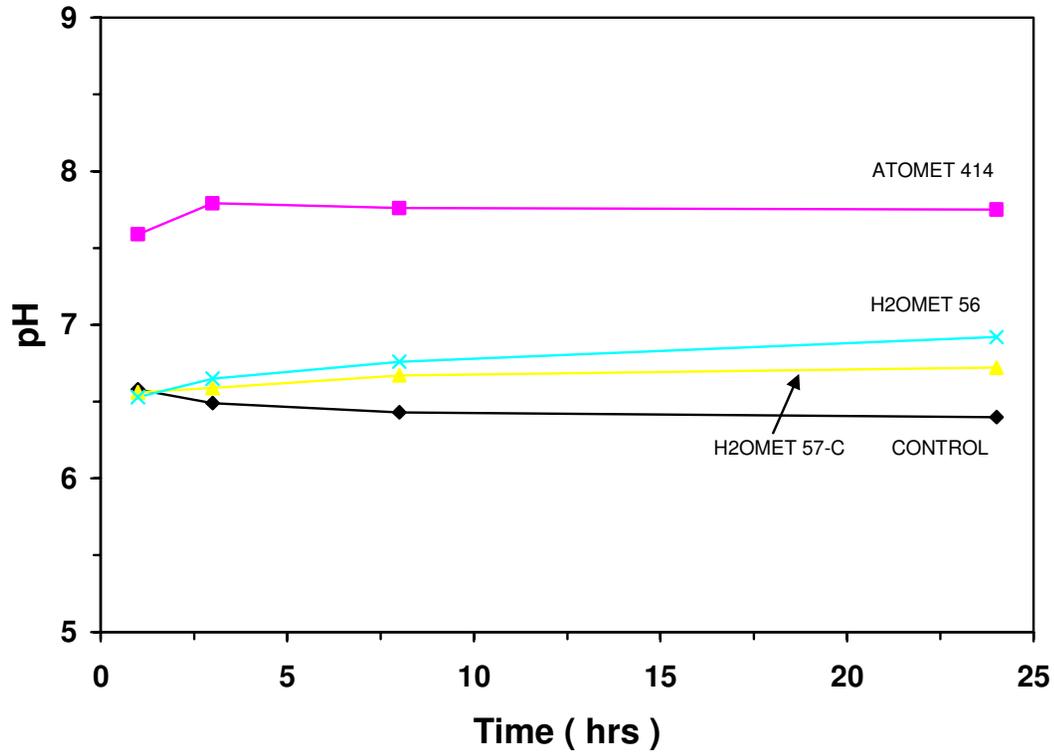


Figure 5 - ZVI Batch Test: pH versus time

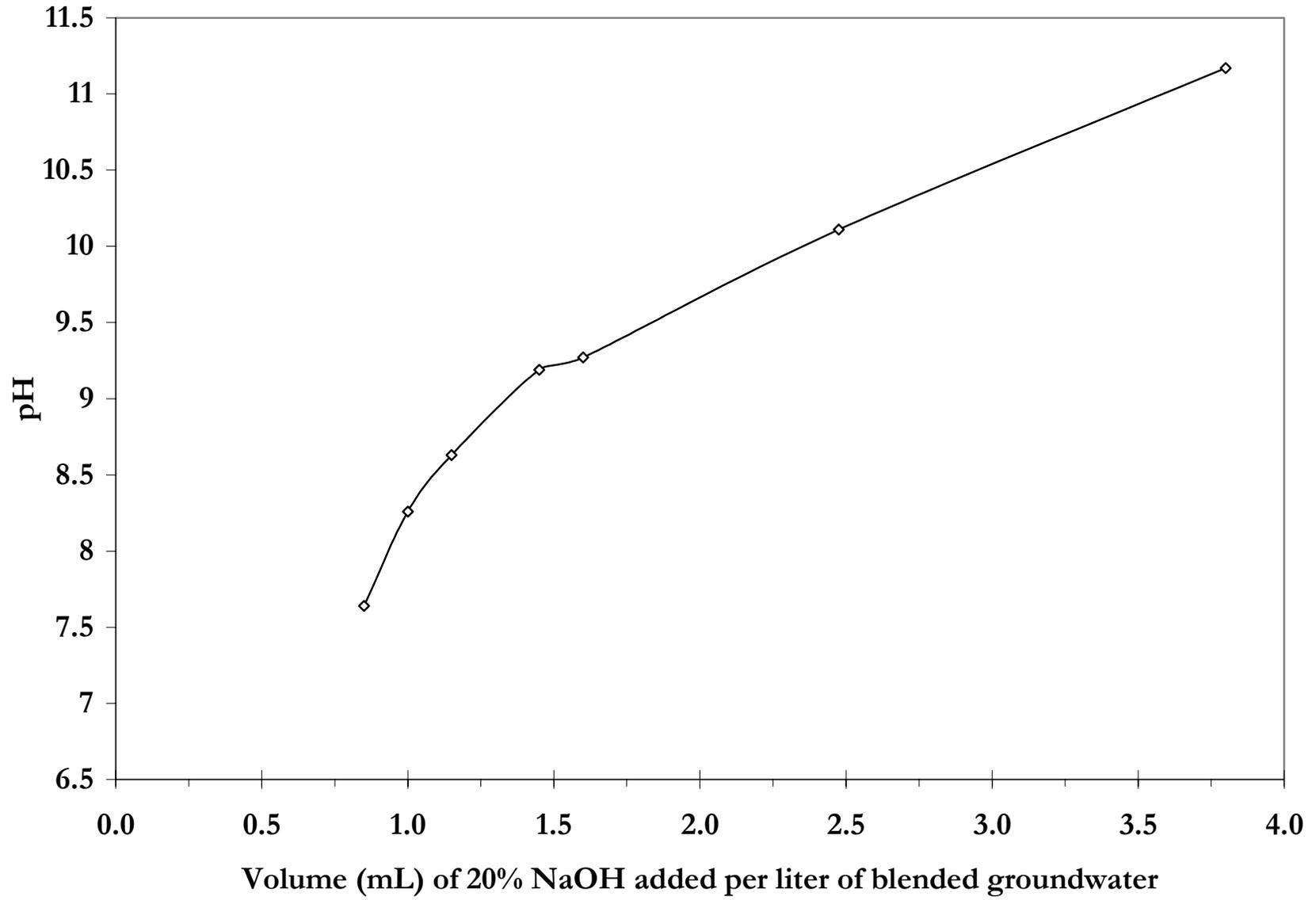


Figure 6 – Titration curve with sodium hydroxide

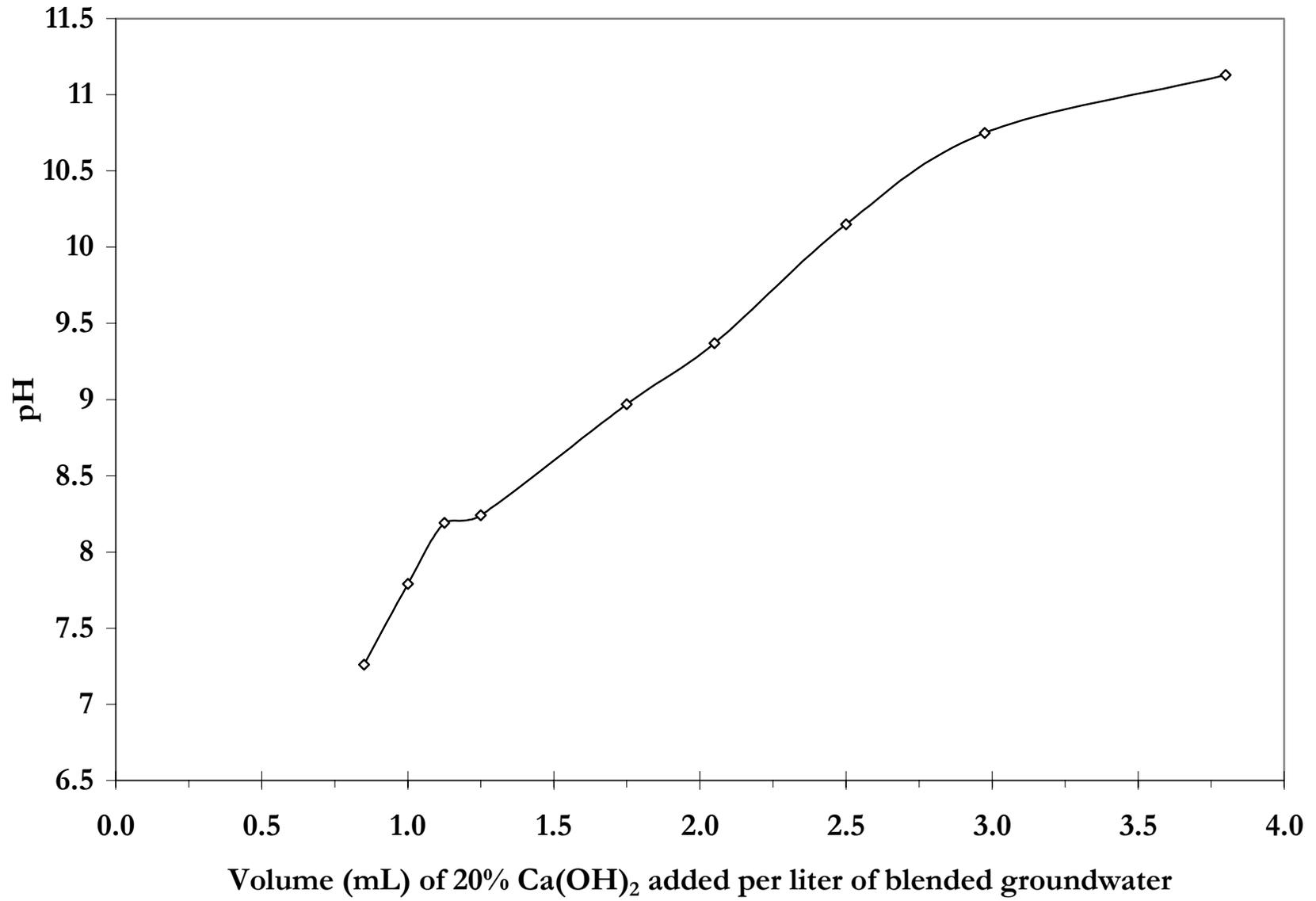


Figure 7 – Titration curve with calcium hydroxide

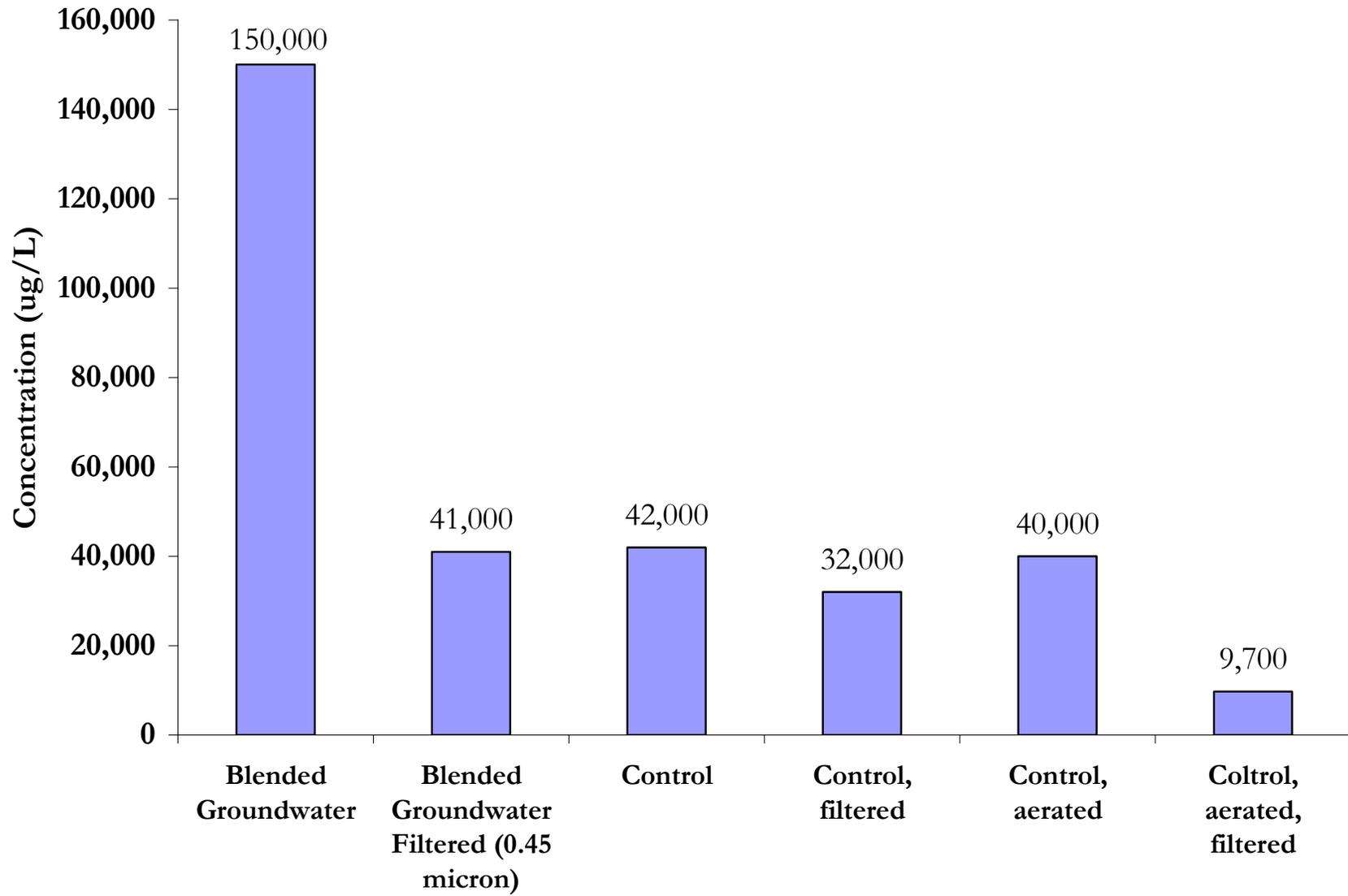


Figure 8 – Iron concentrations in the control jars

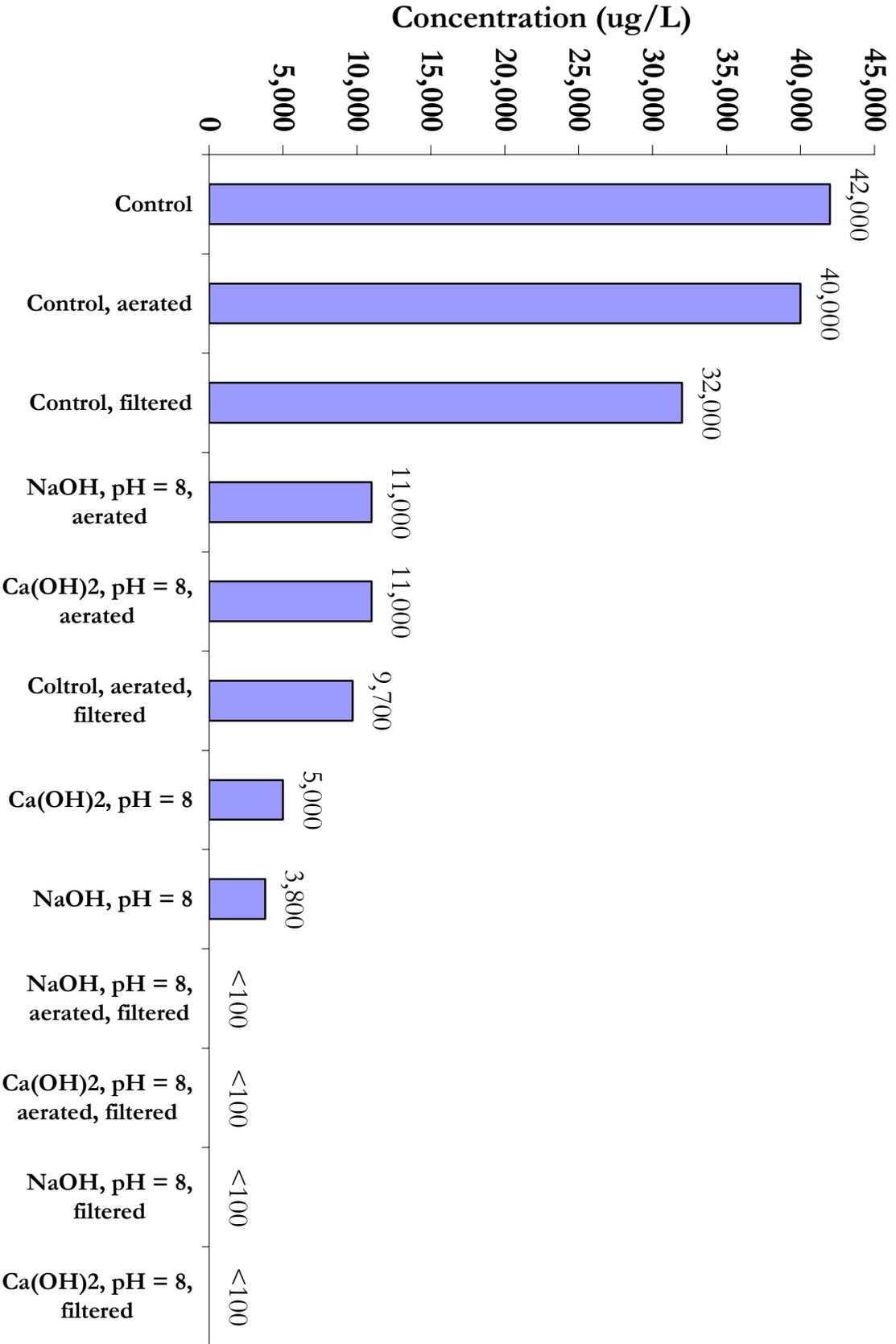


Figure 9 – Iron concentrations in the pH 8 jars

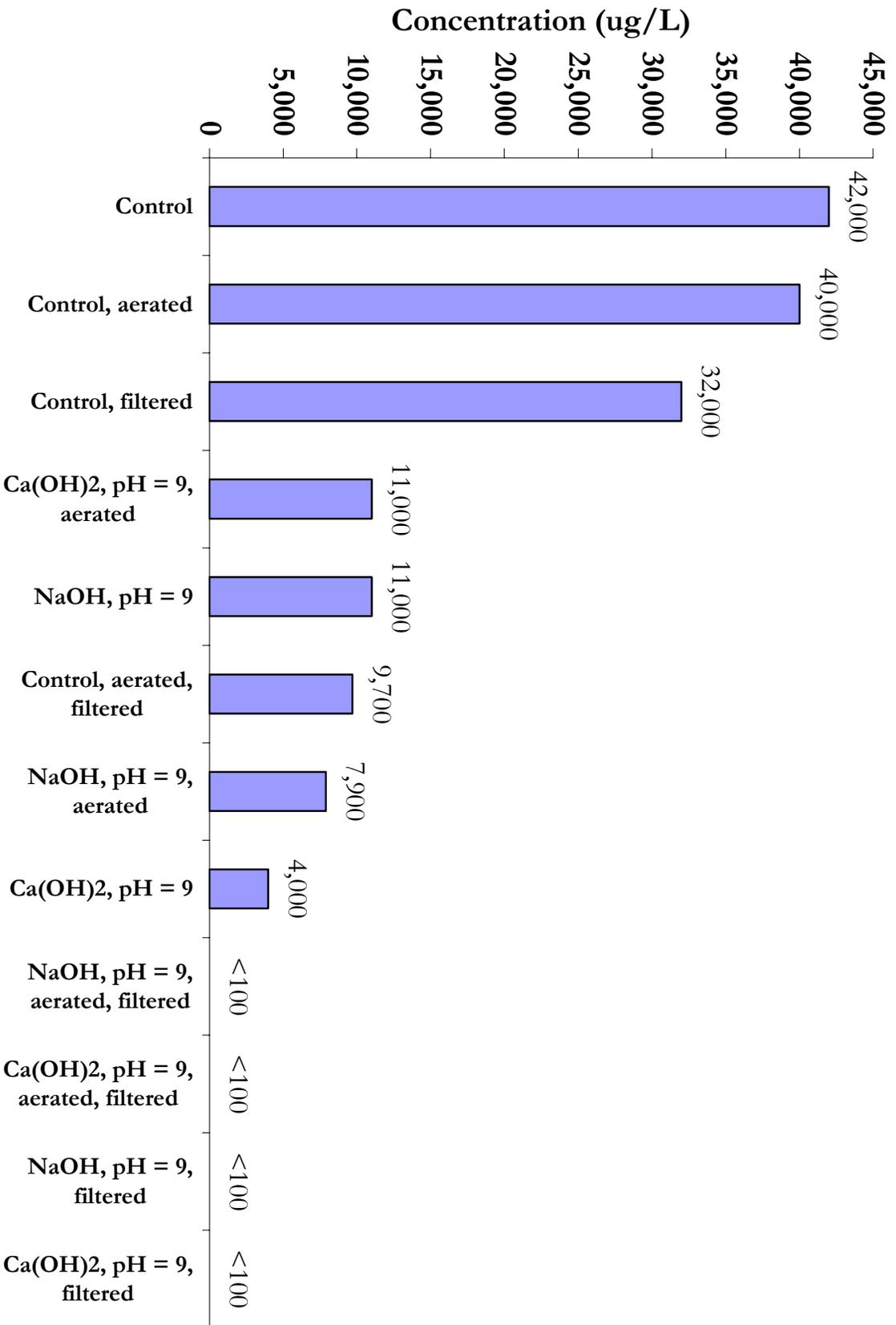


Figure 10 – Iron concentrations in the pH 9 jars

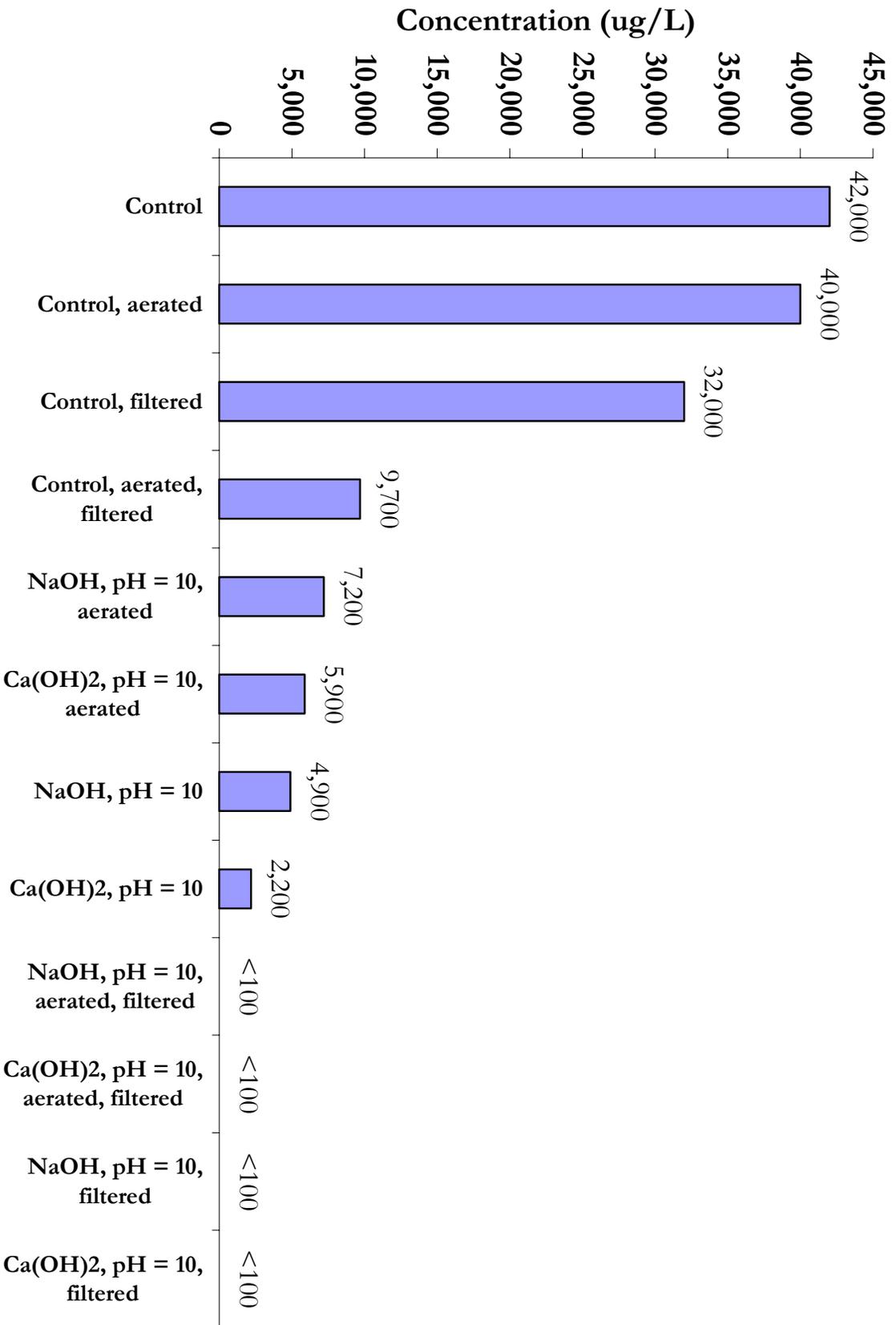


Figure 11 – Iron concentrations in the pH 10 jars

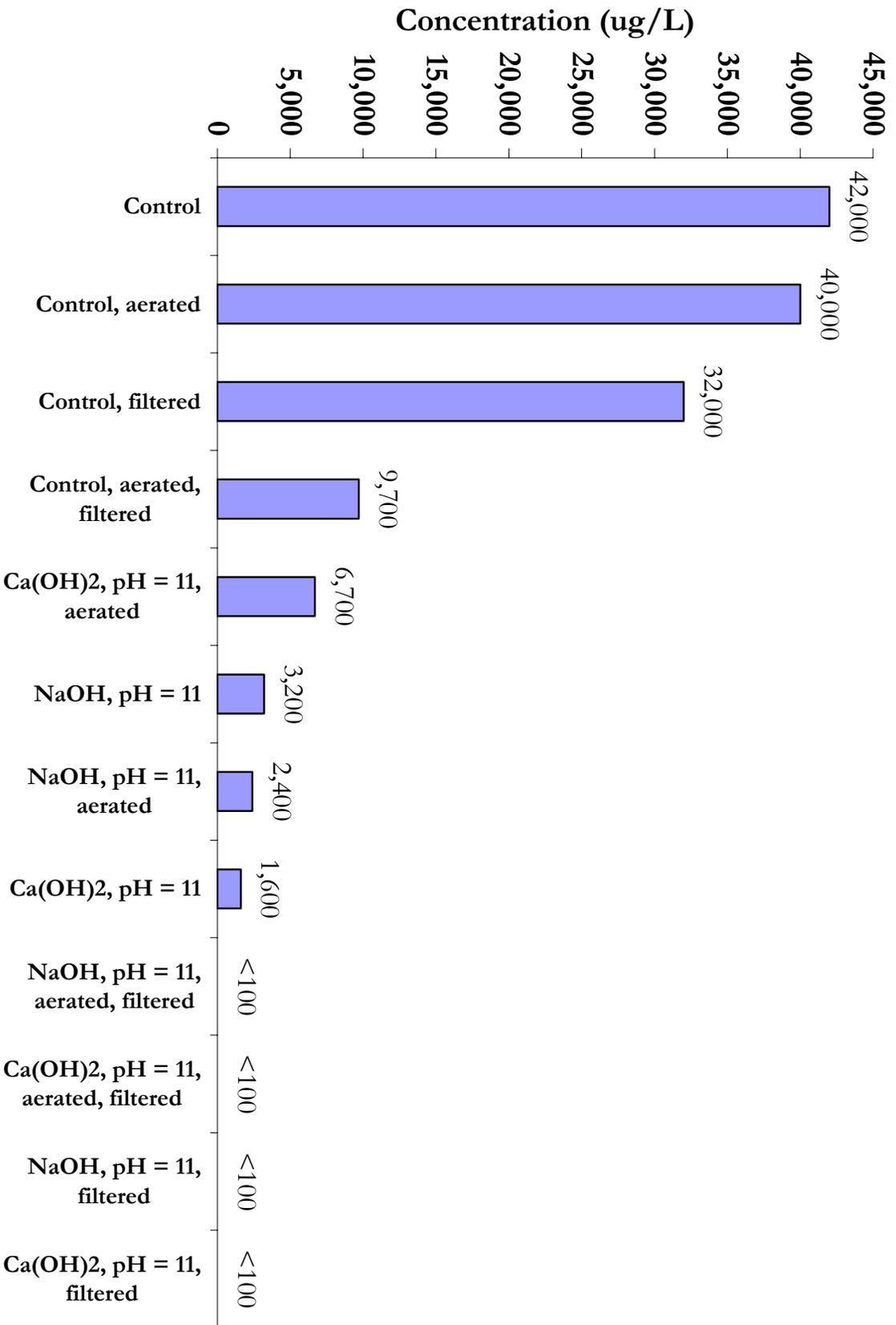


Figure 12 – Iron concentrations in the pH 11 jars

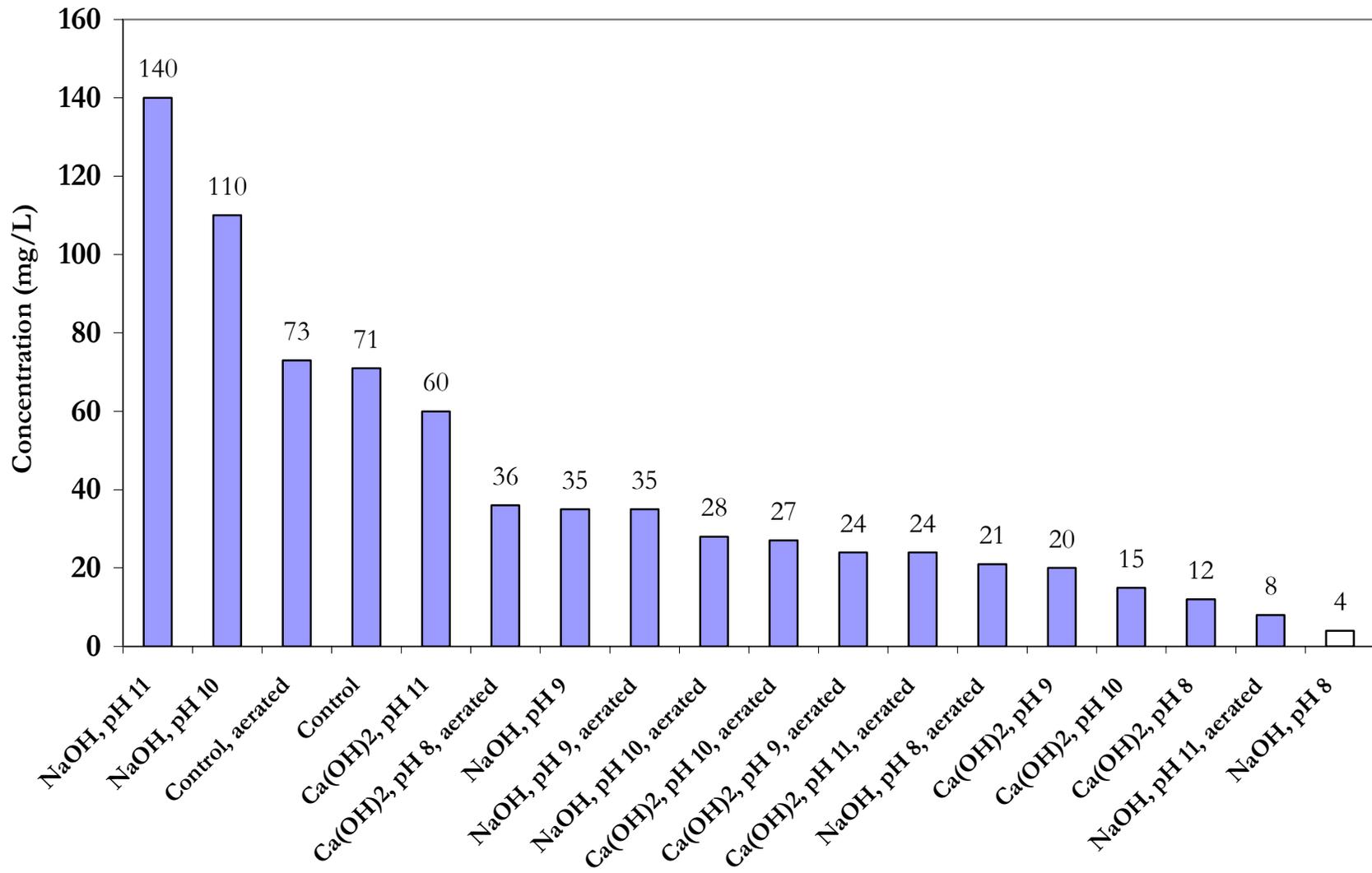


Figure 13 – TSS concentrations

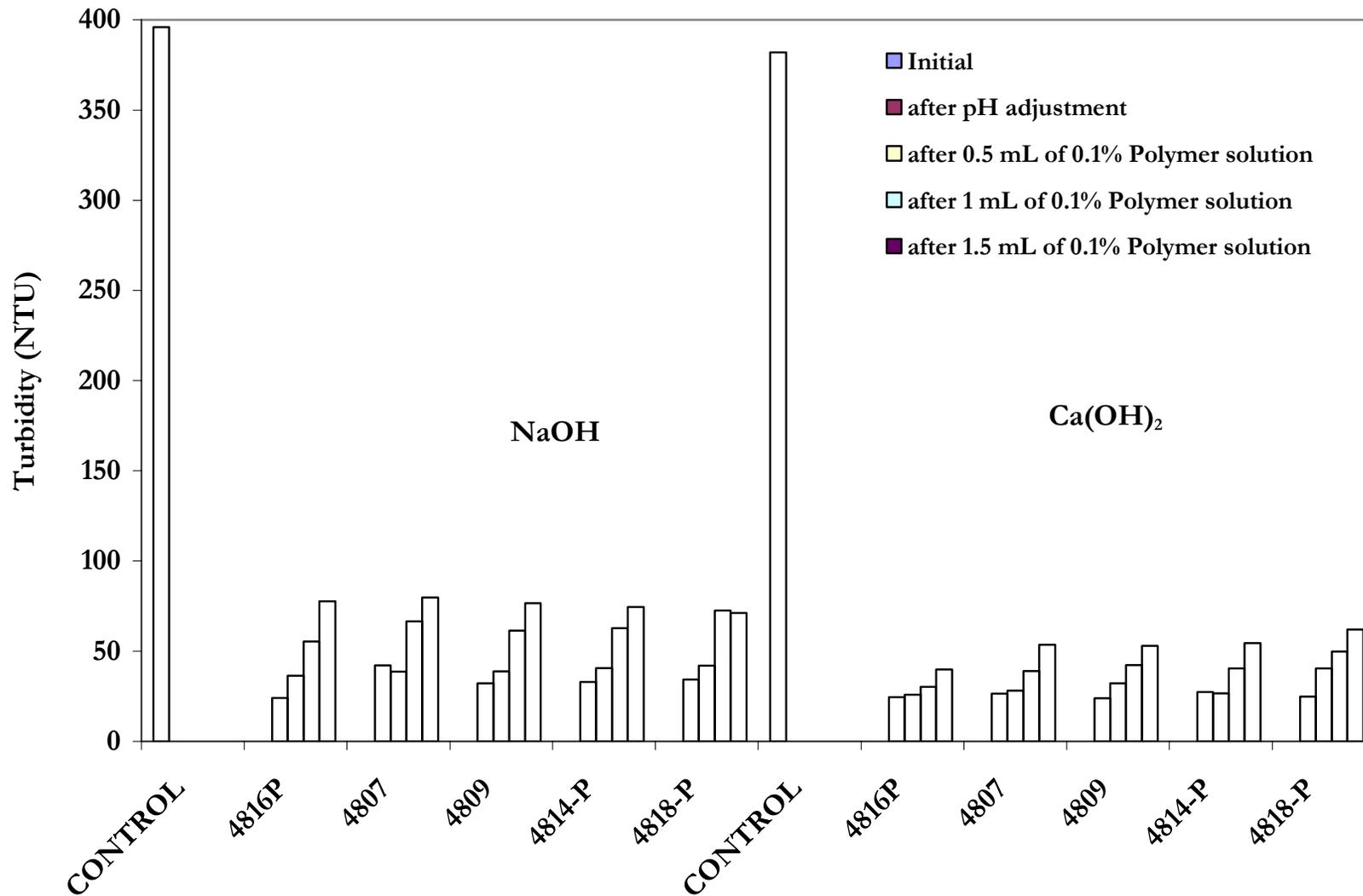


Figure 14 – Influence of CSC polymers on turbidity

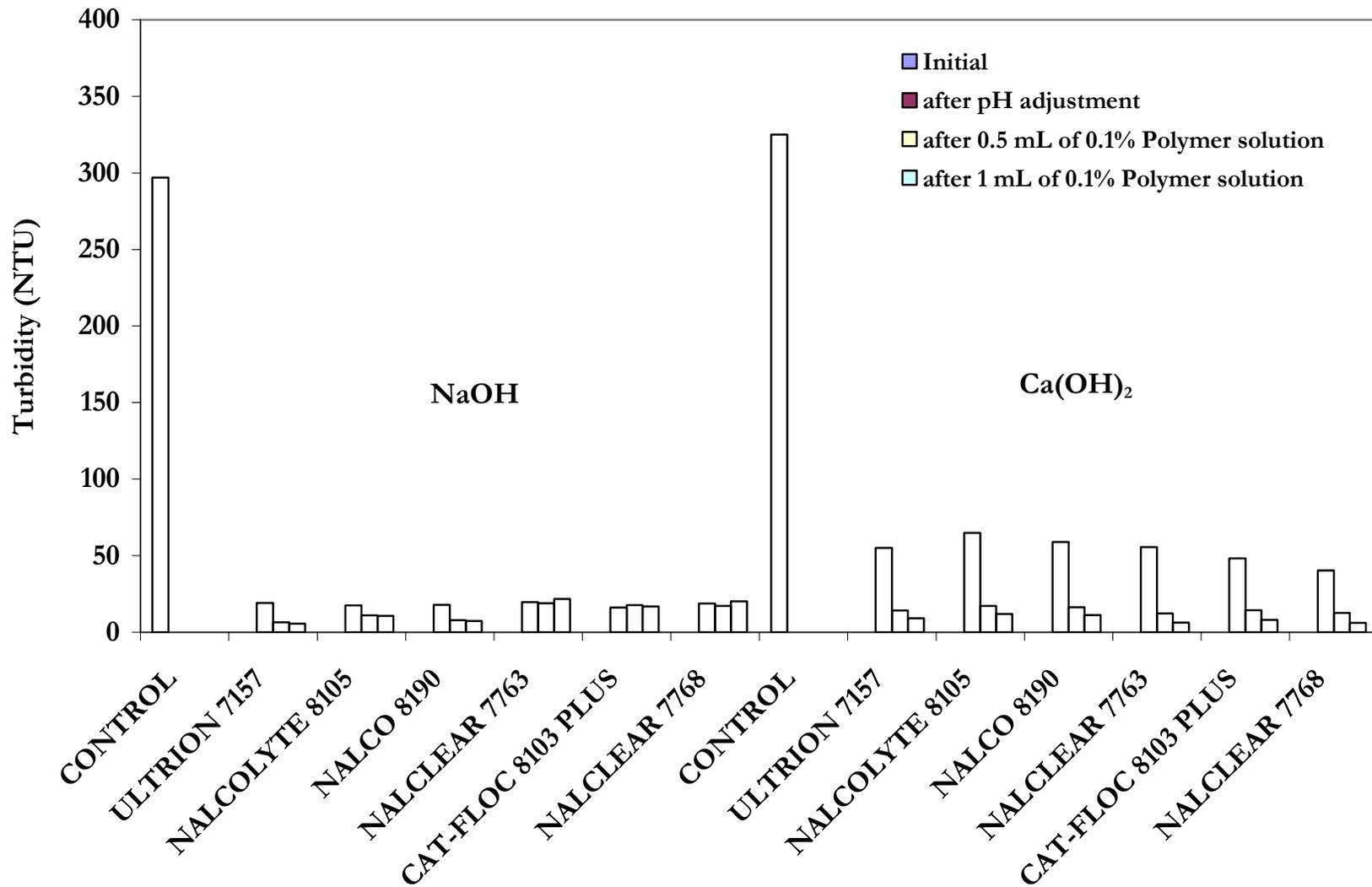


Figure 15 – Influence of NALCO polymers on turbidity

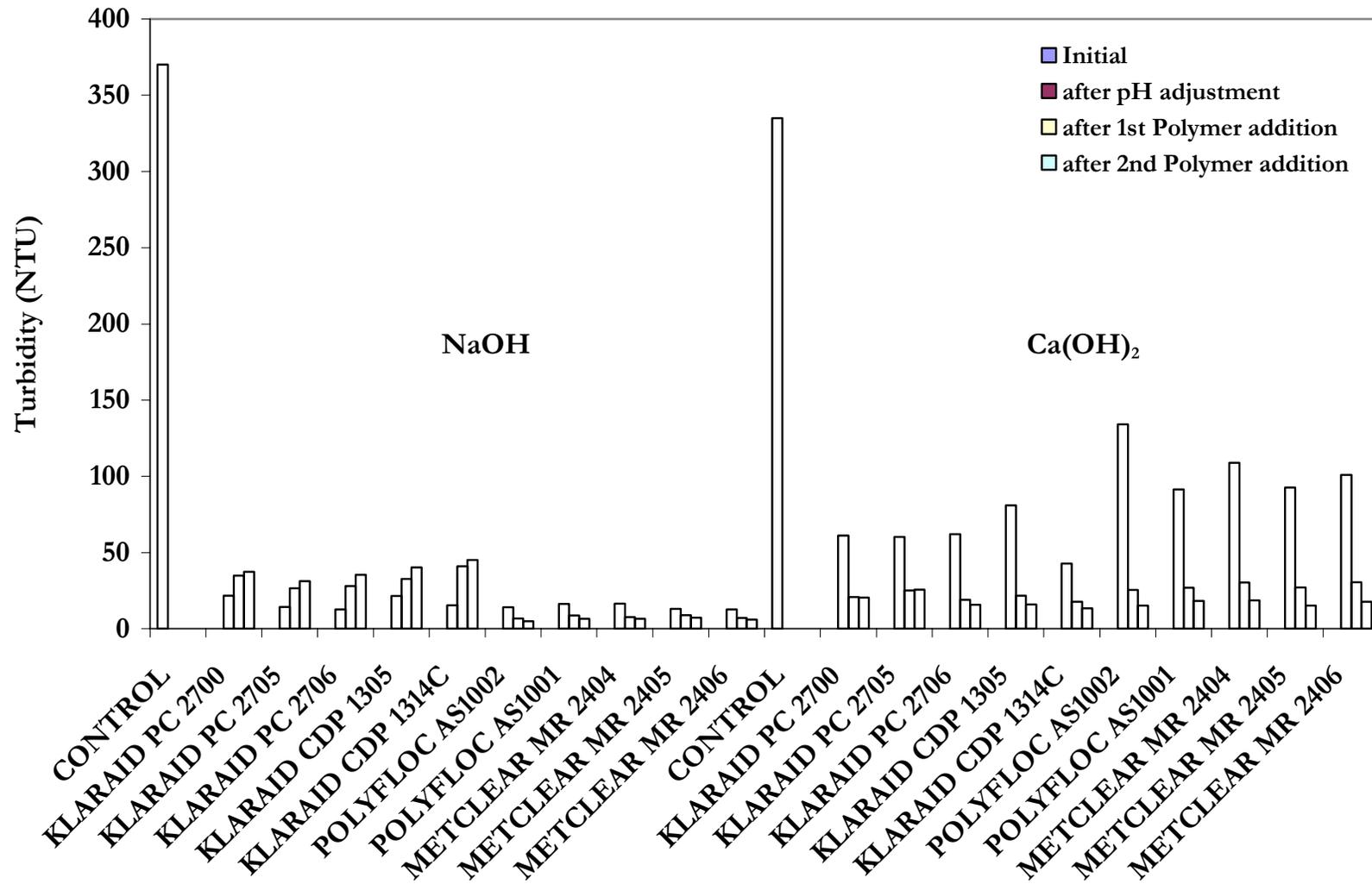


Figure 16 – Influence of GE polymers on turbidity

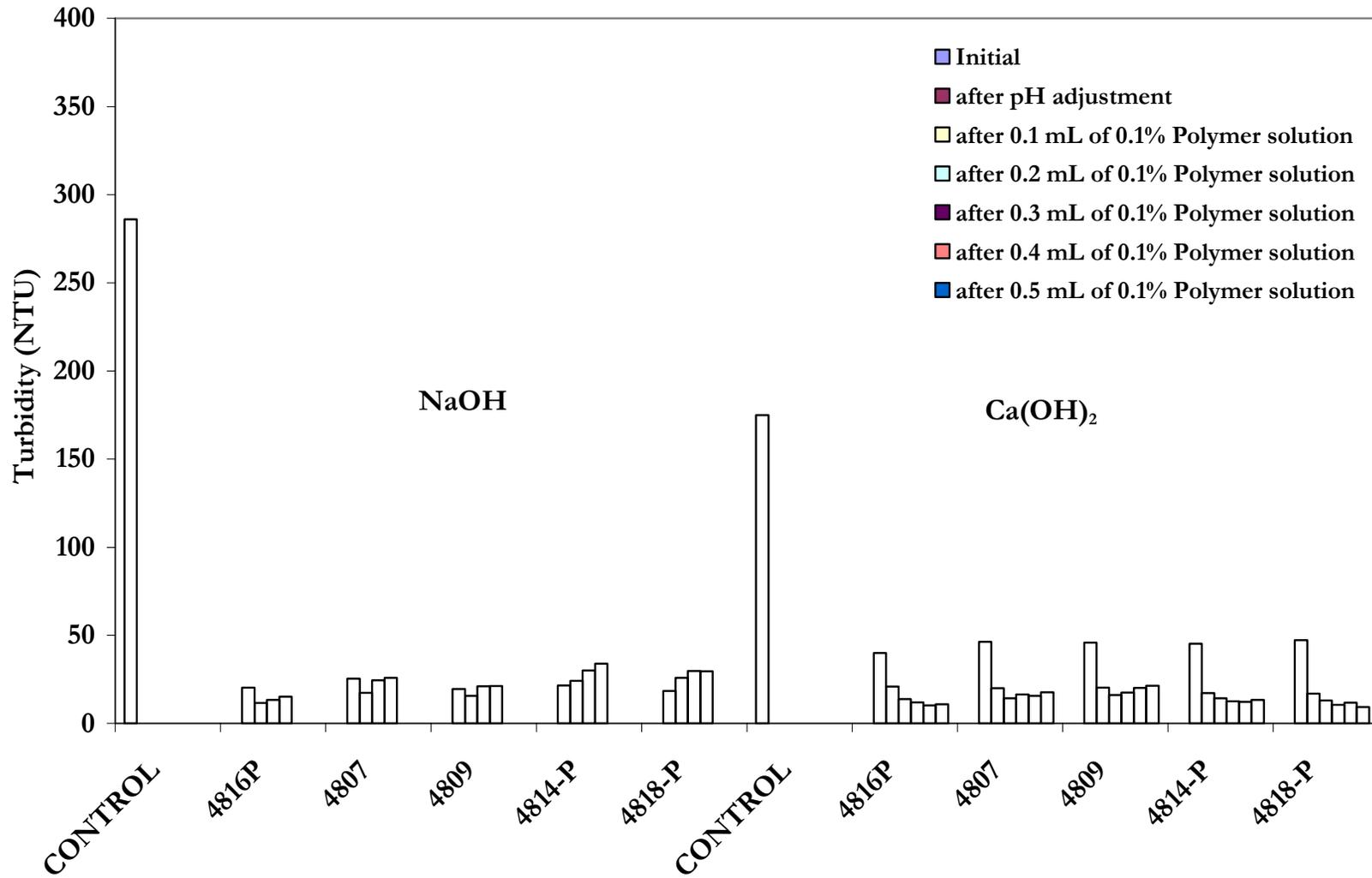


Figure 17 – Influence of CSC polymers (lower dosages) on turbidity

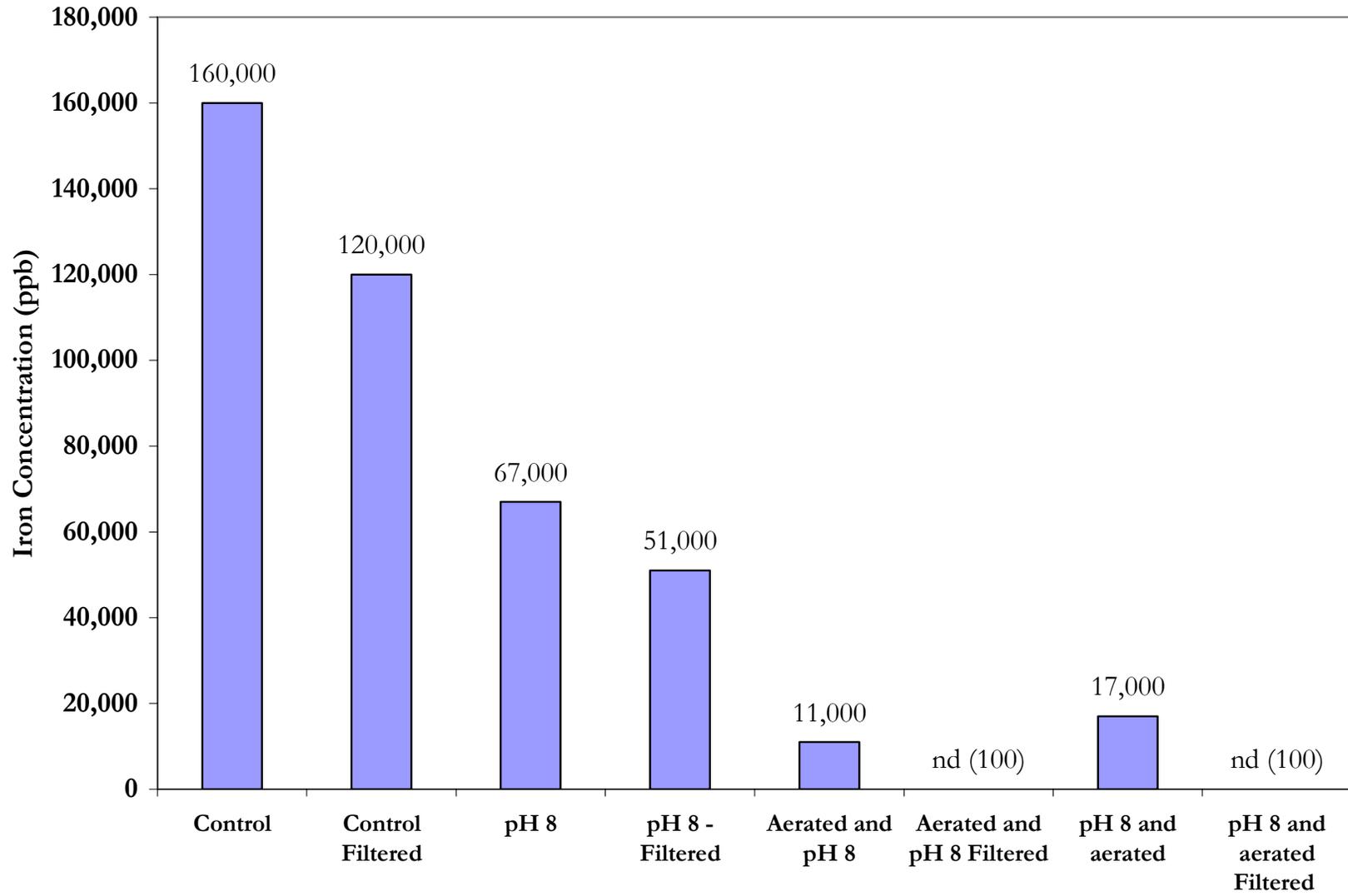


Figure 18 – Iron concentrations in jar test II

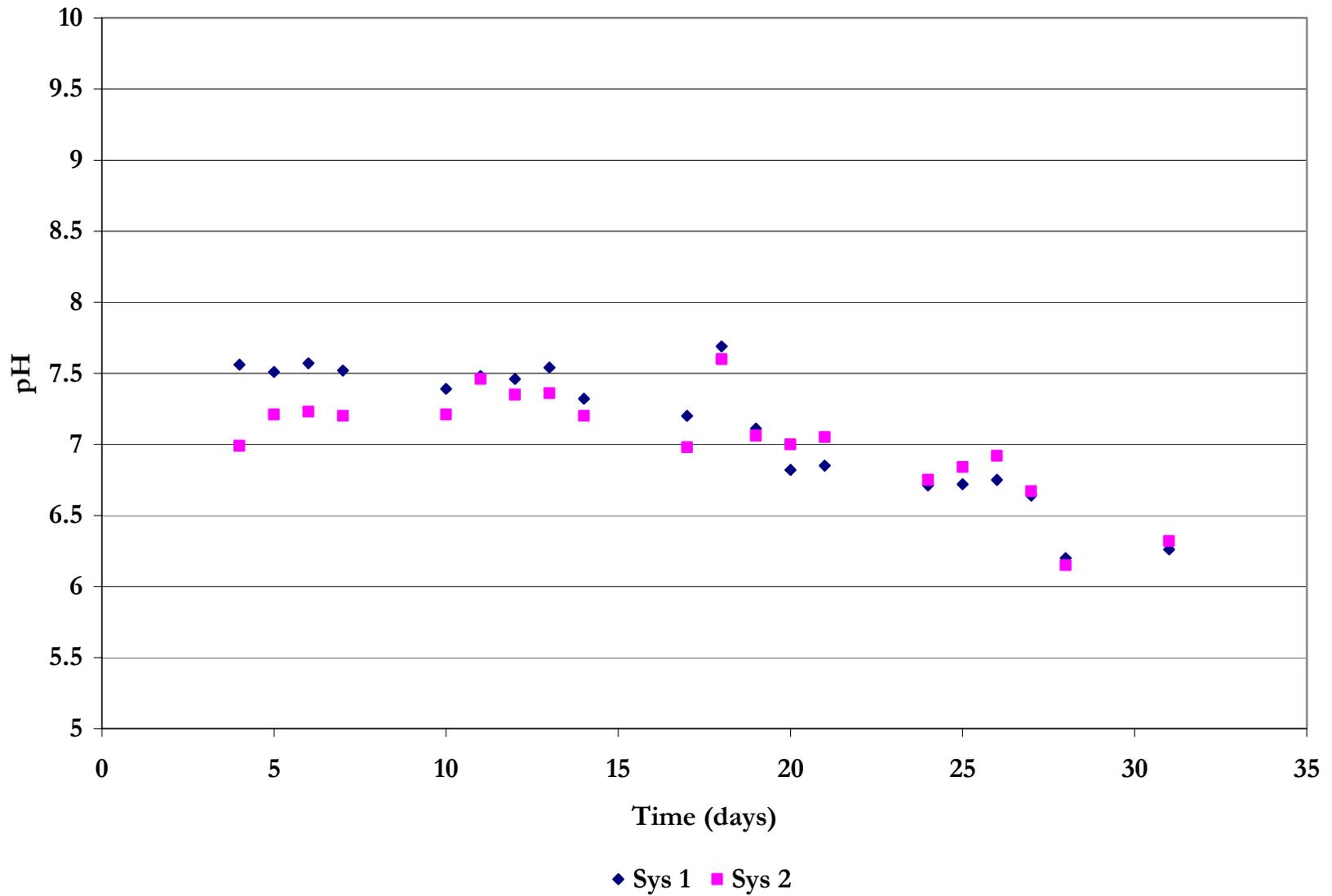


Figure 19 – pH values in the FBR recycle reservoirs during batch mode operation

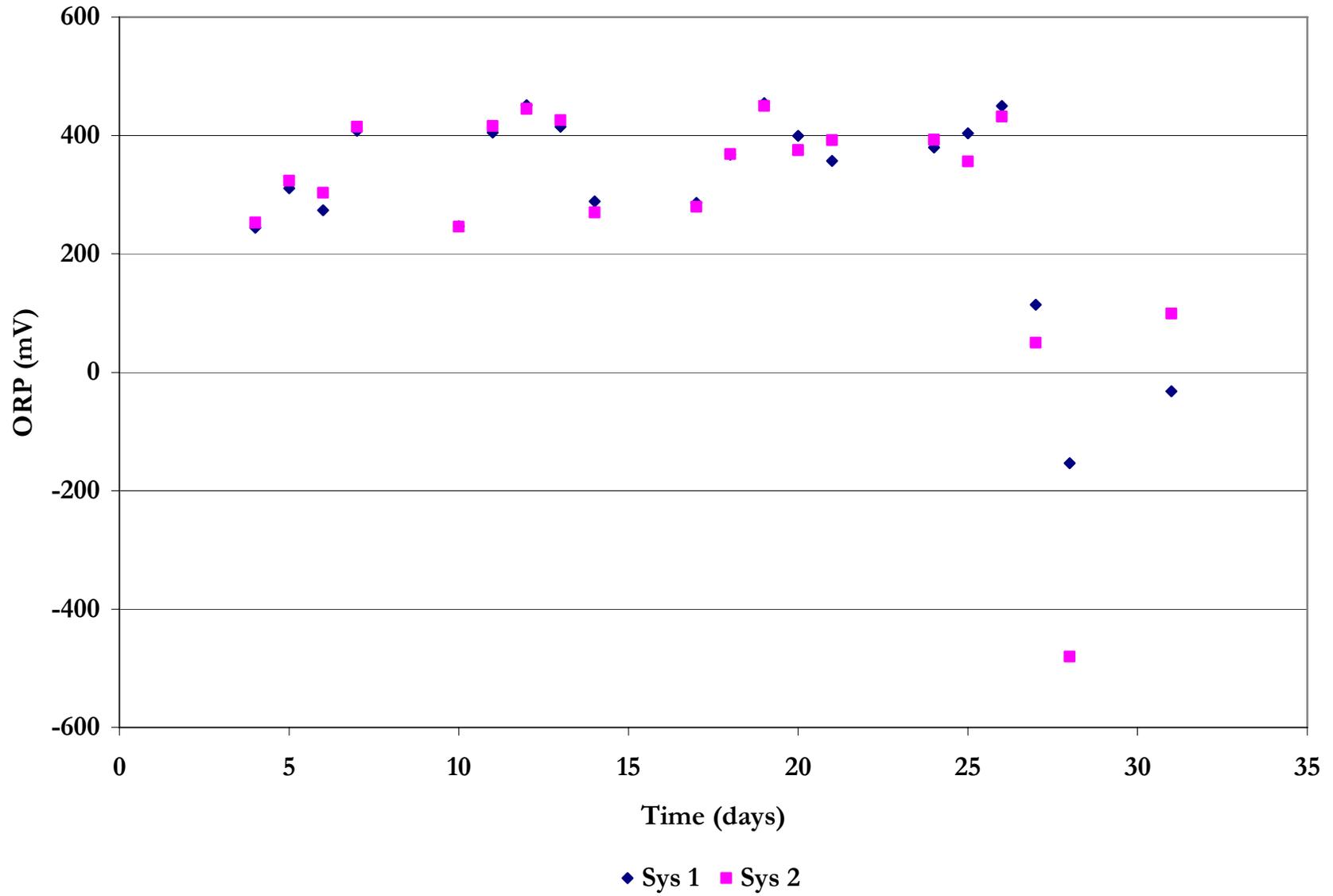


Figure 20 – ORP values in the FBR recycle reservoirs during batch mode operation

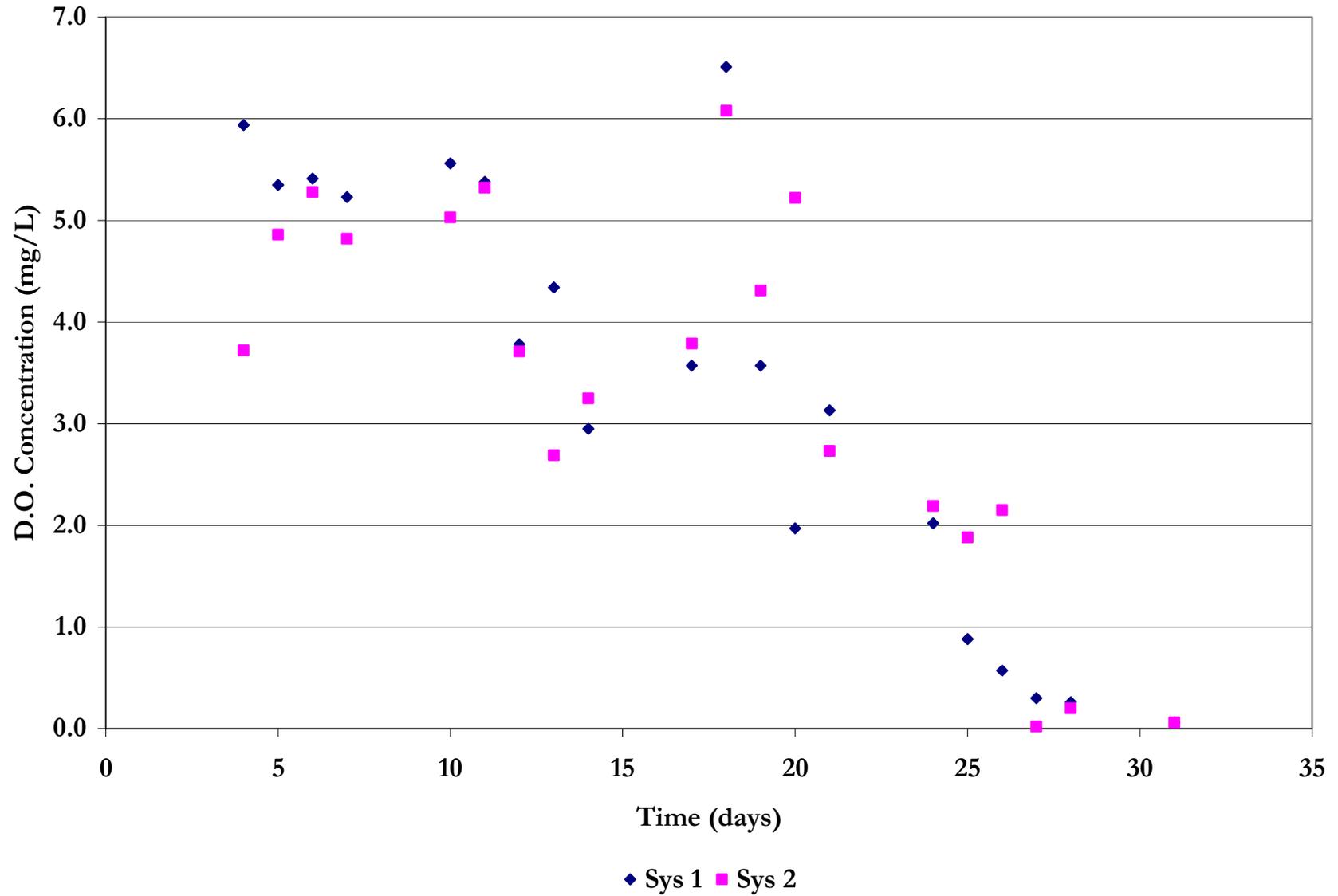


Figure 21 – Dissolved oxygen concentrations in the FBR recycle reservoirs during batch mode operation

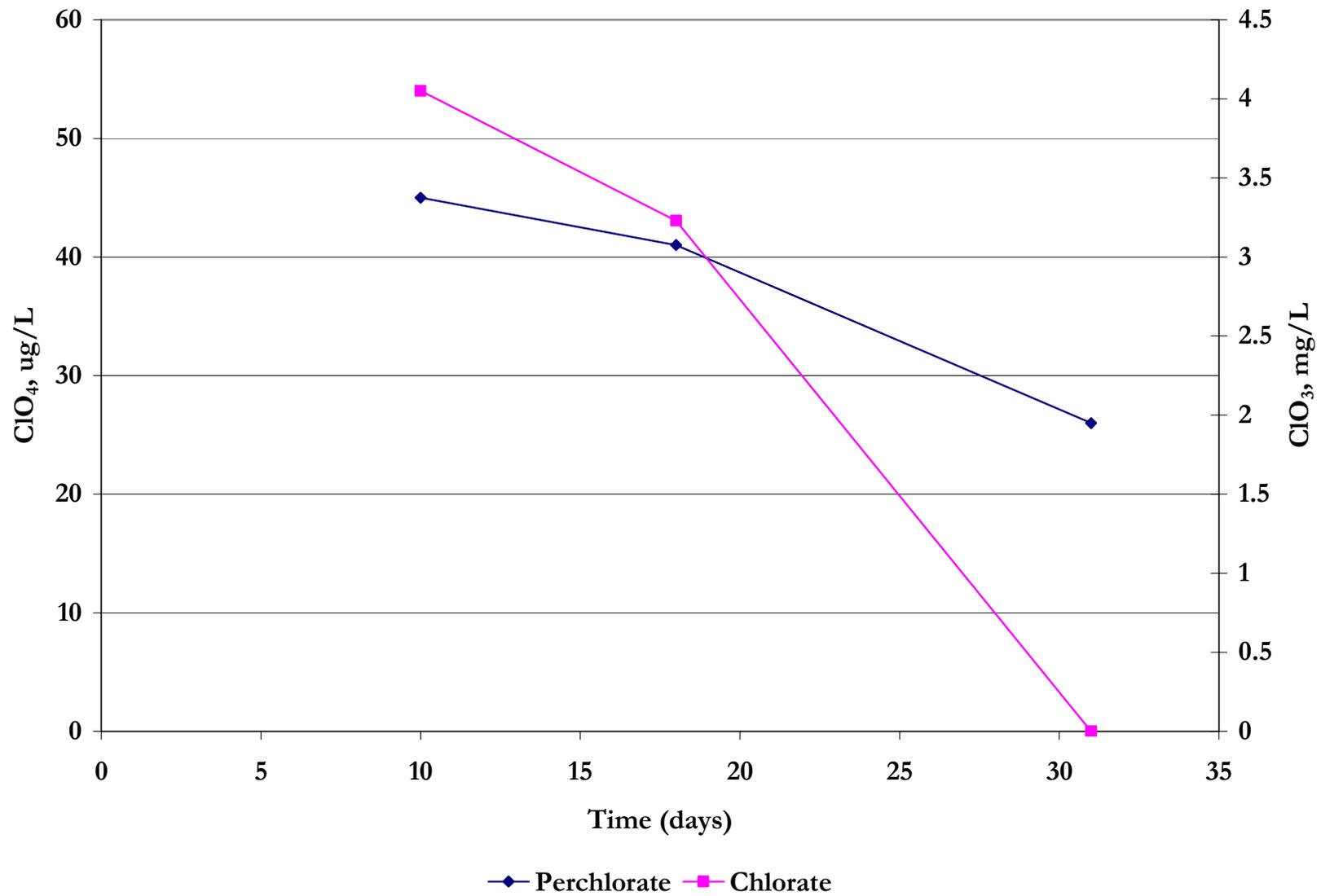


Figure 22 – Influence of FBR System 1 on perchlorate and chlorate concentrations during batch mode operation

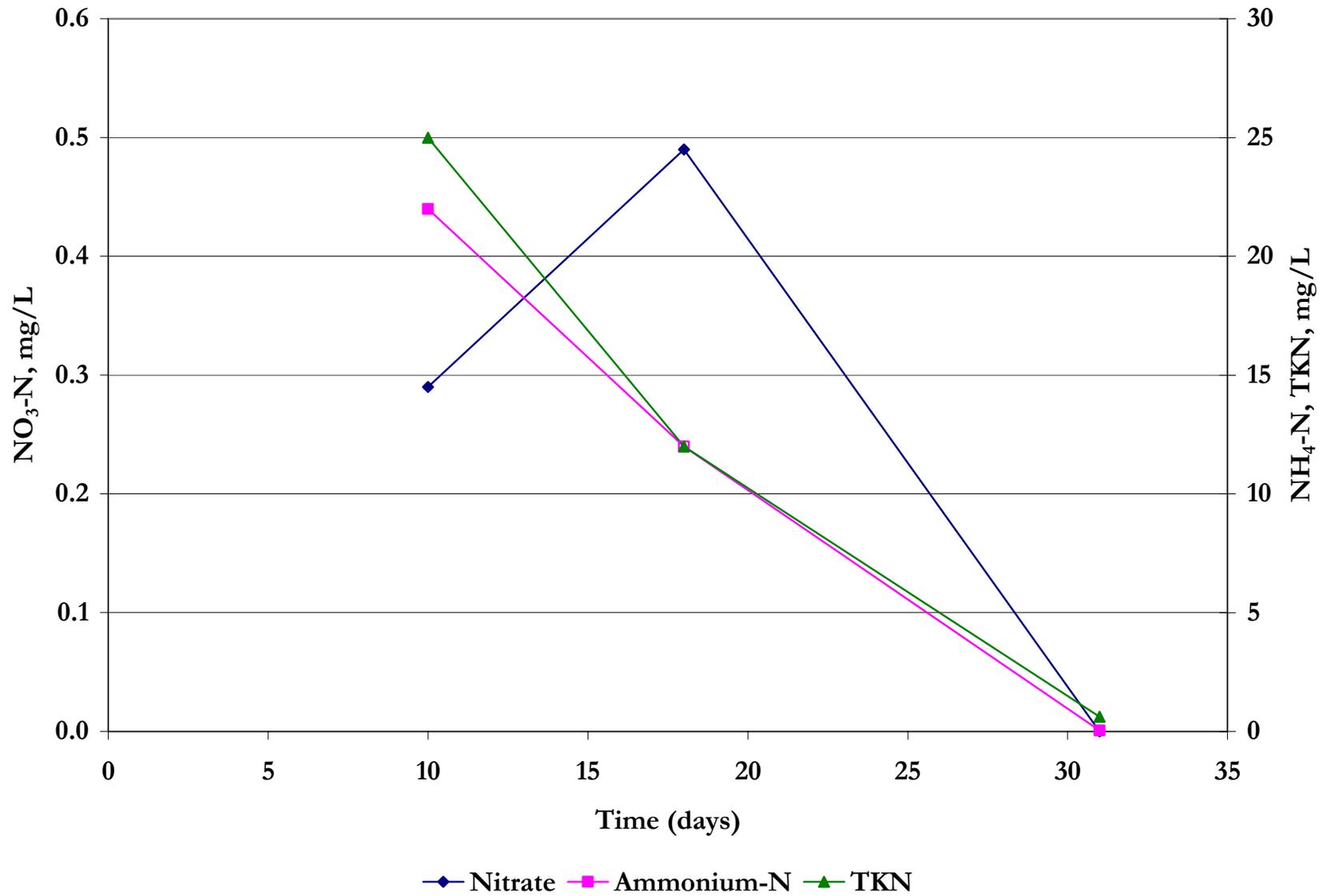


Figure 23 – Influence of FBR System 1 on ammonium, nitrate, and TKN concentrations during batch mode operation

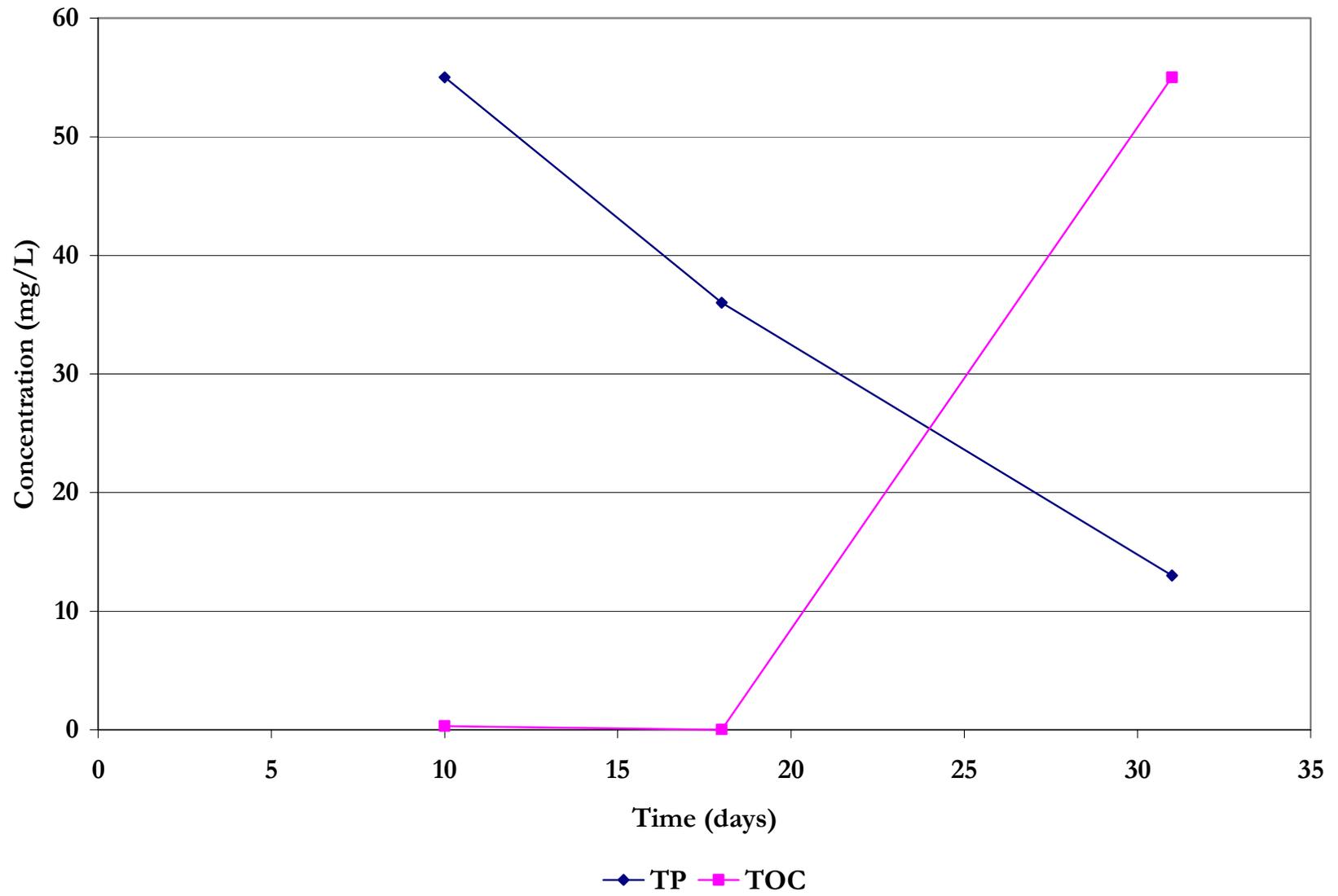


Figure 24 – Influence of FBR System 1 on total phosphate and total organic carbon concentrations during batch mode operation

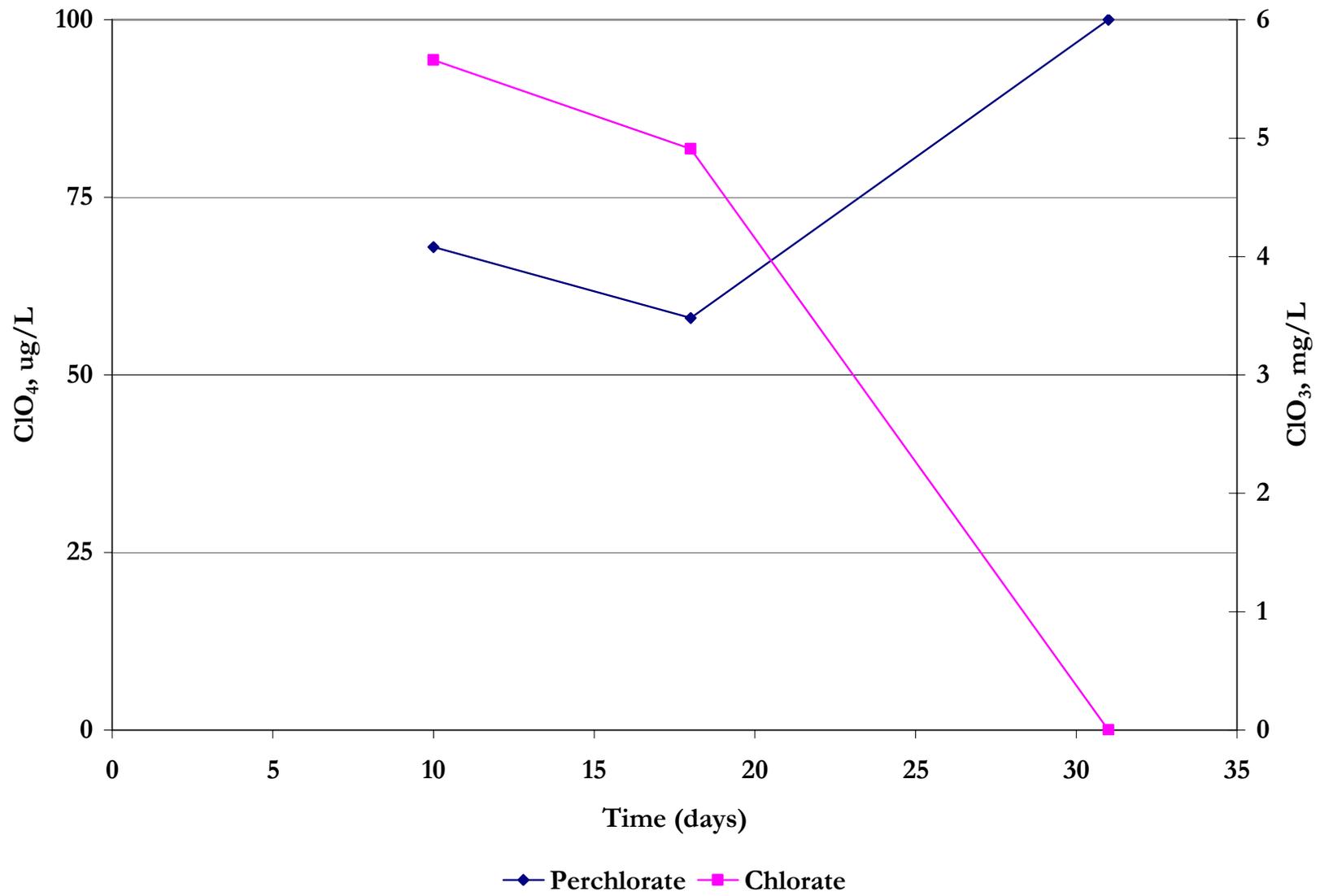


Figure 25 – Influence of FBR System 2 on perchlorate and chlorate concentrations during batch mode operation

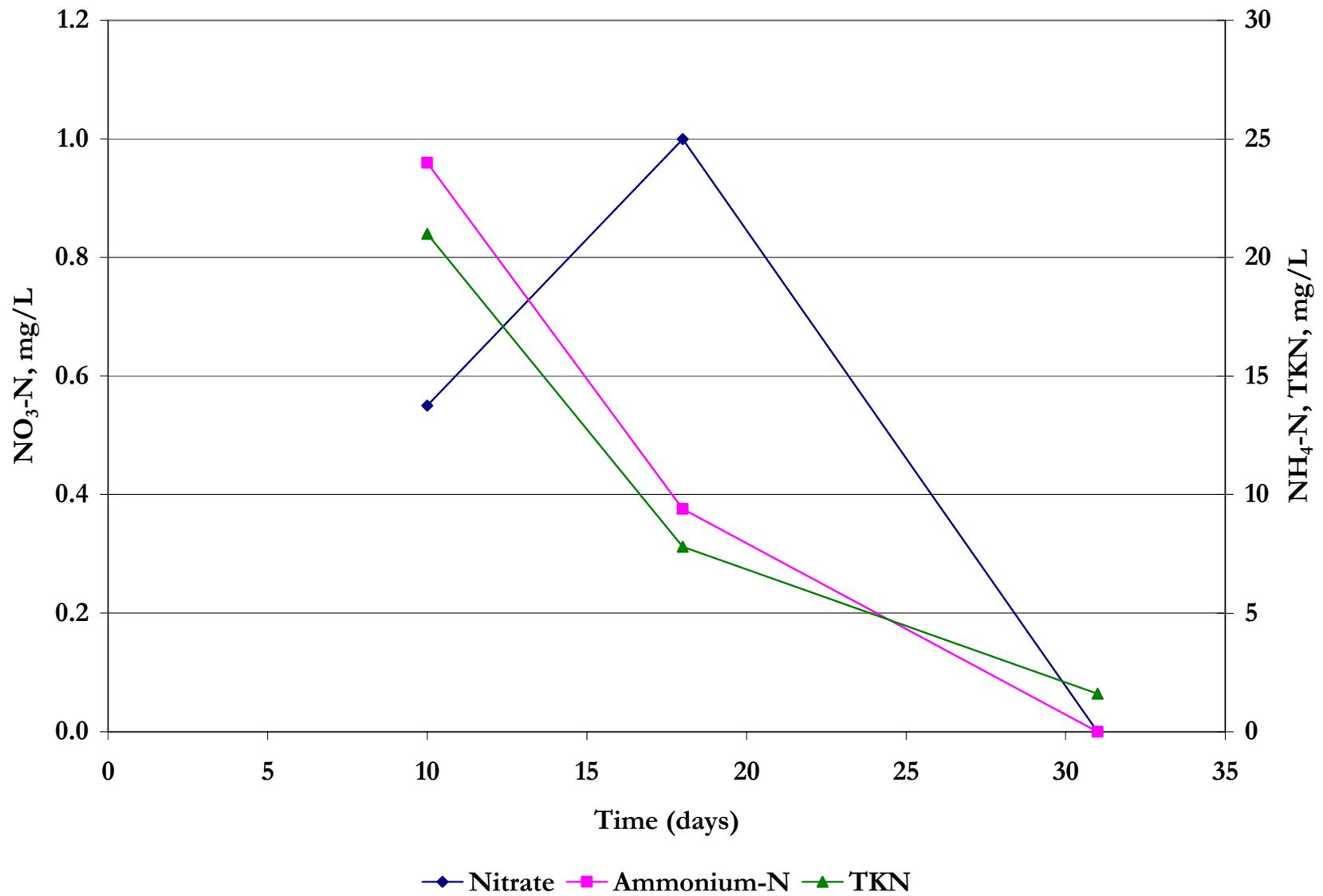


Figure 26 – Influence of FBR System 2 on ammonium, nitrate, and TKN concentrations during batch mode operation

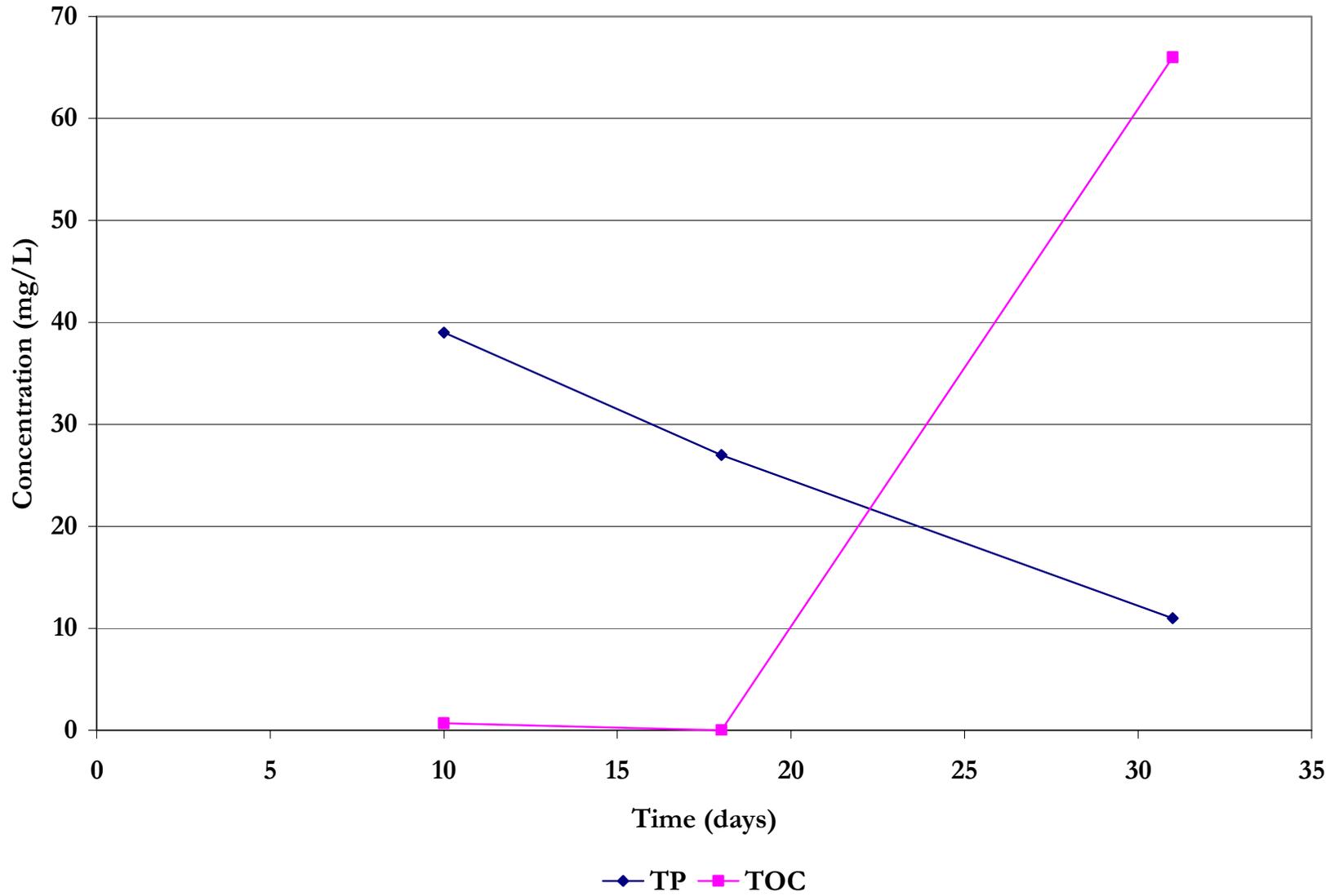


Figure 27 – Influence of FBR System 2 on total phosphate and total organic carbon concentrations during batch mode operation

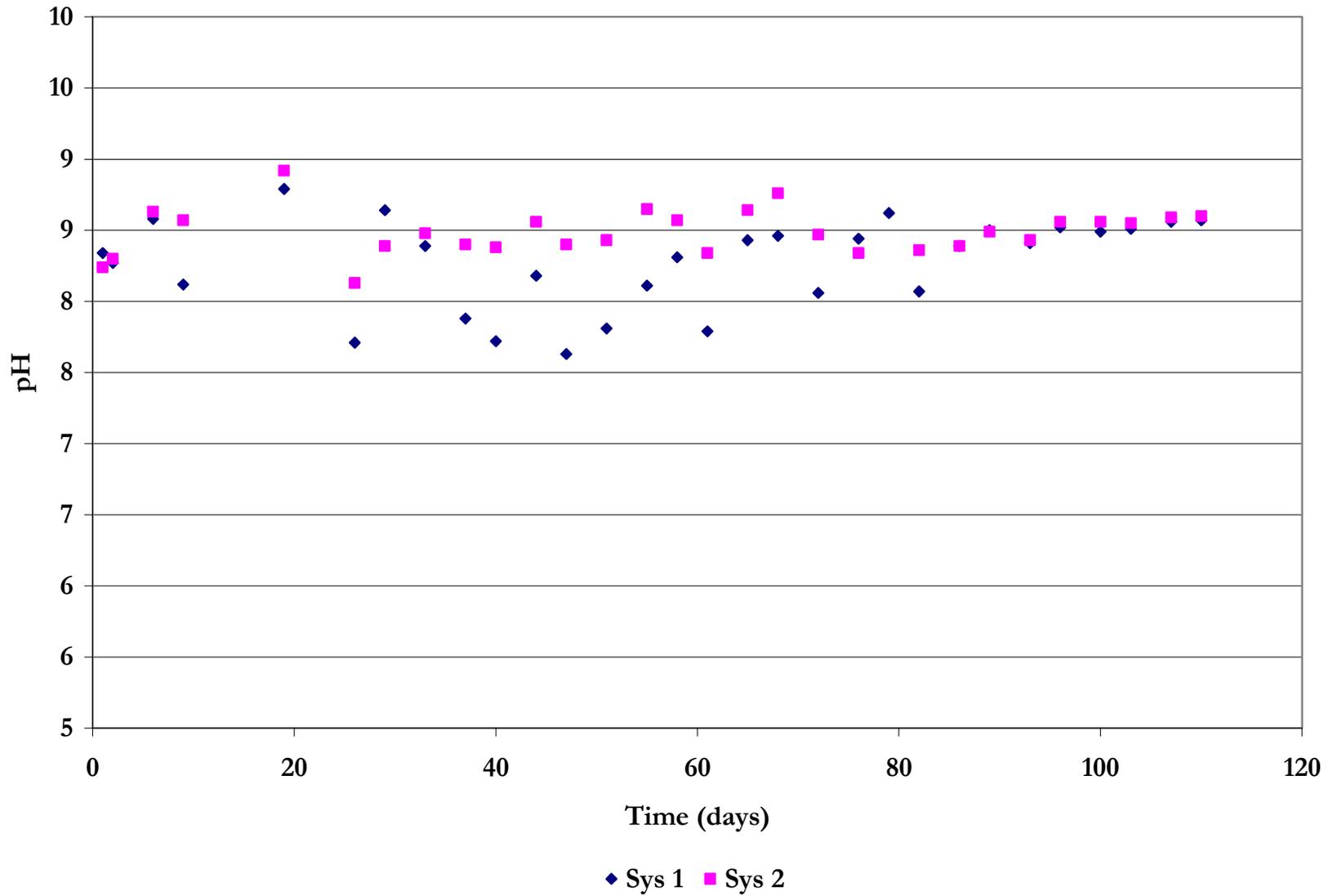


Figure 28 – pH trends in the FBR feed reservoirs during continuous feed mode operation

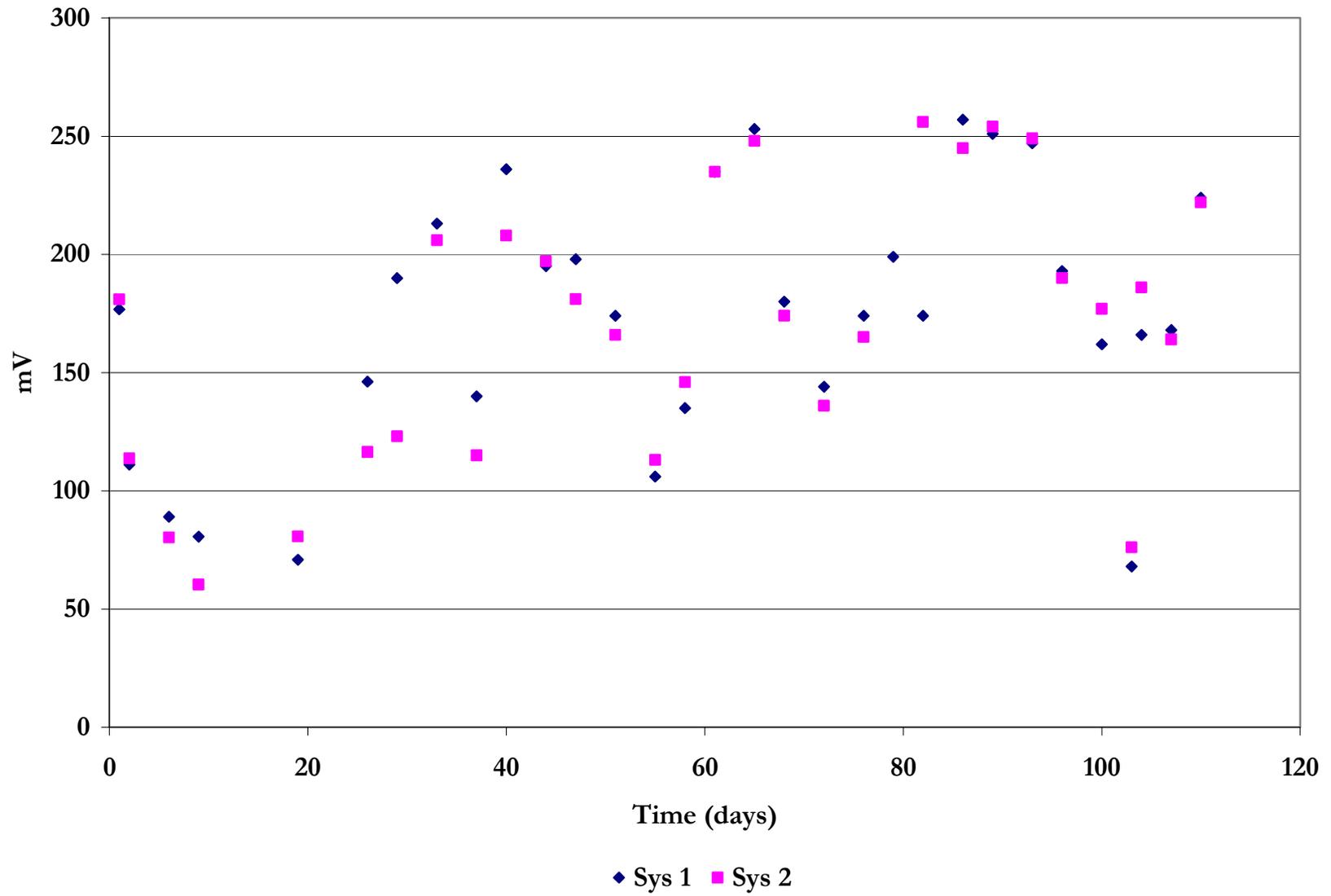


Figure 29 – ORP trends in the FBR feed reservoirs during continuous feed mode operation

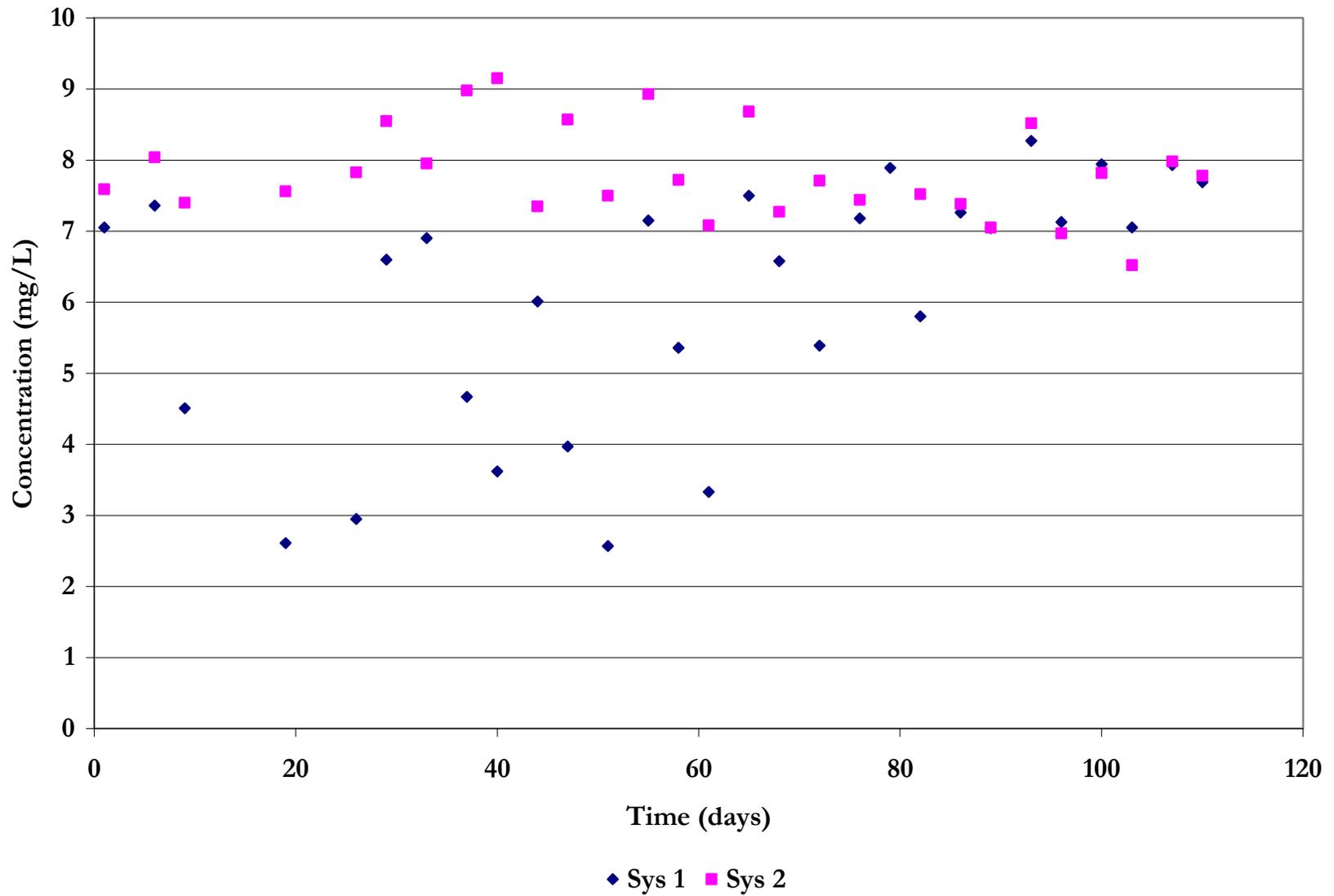


Figure 30 – D.O. trends in the FBR feed reservoirs during continuous feed mode operation

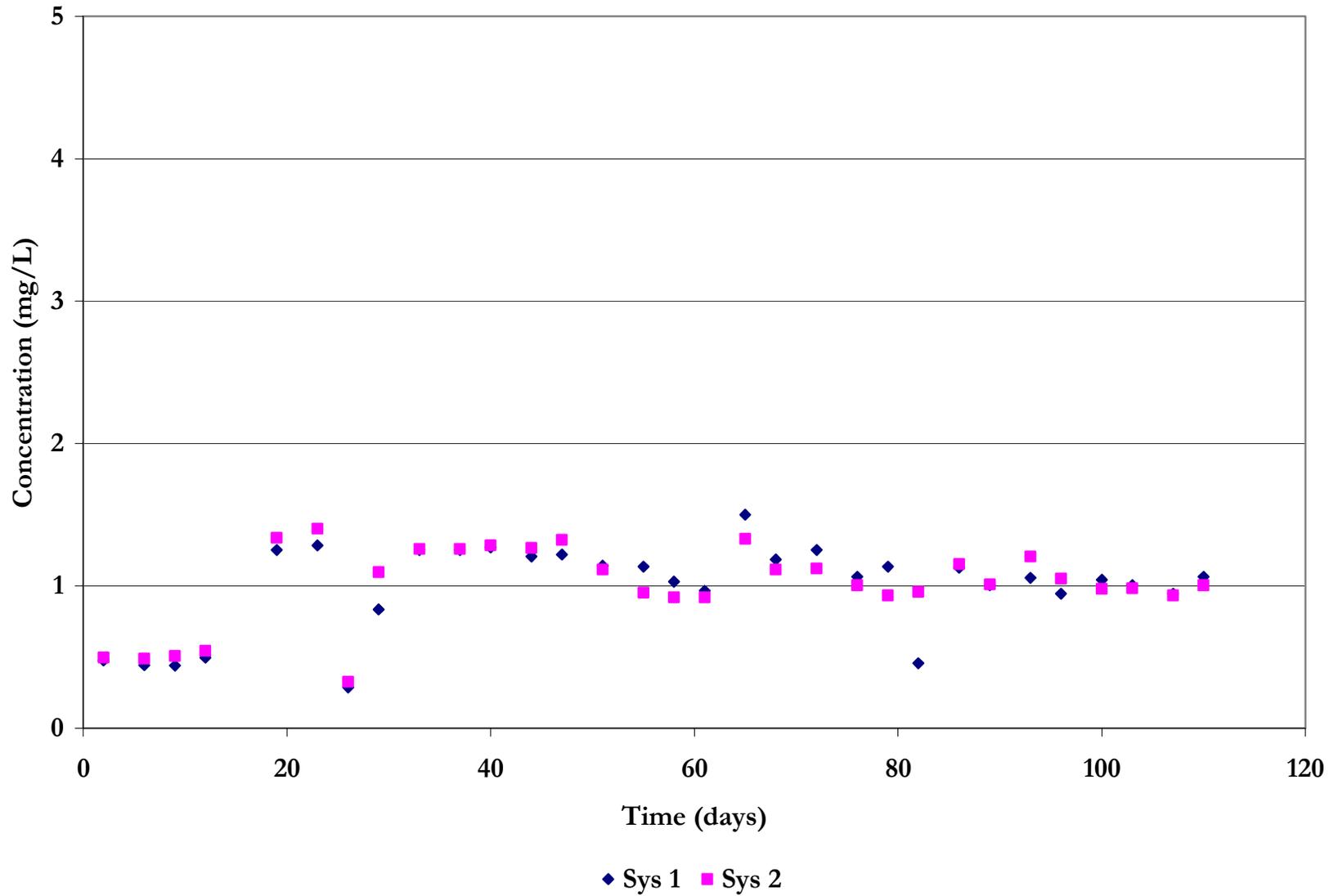


Figure 31 – Phosphate-P concentrations in the FBR feed reservoirs during continuous feed mode operation

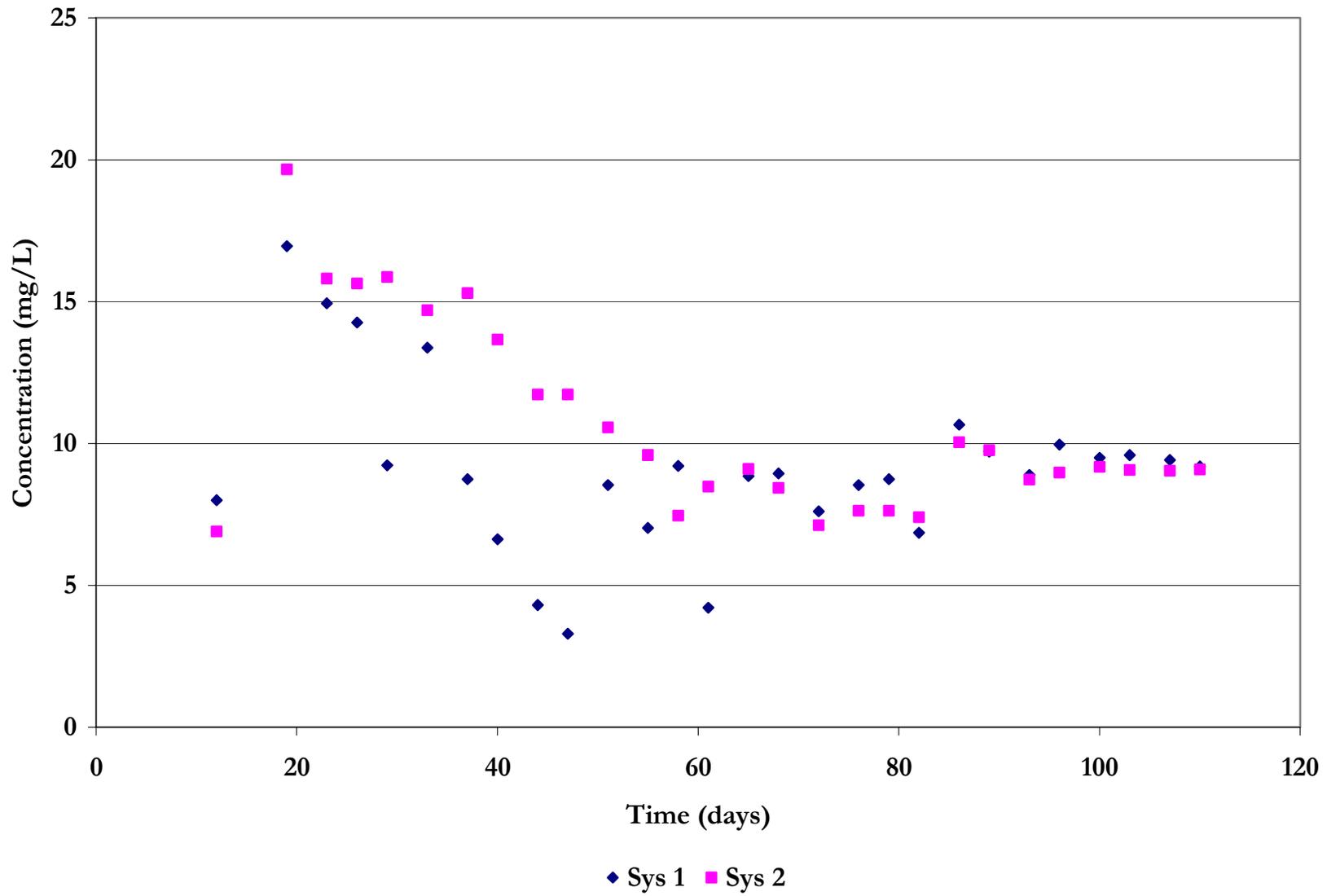


Figure 32 – Ammonium-N concentrations in the FBR feed reservoirs during continuous feed mode operation

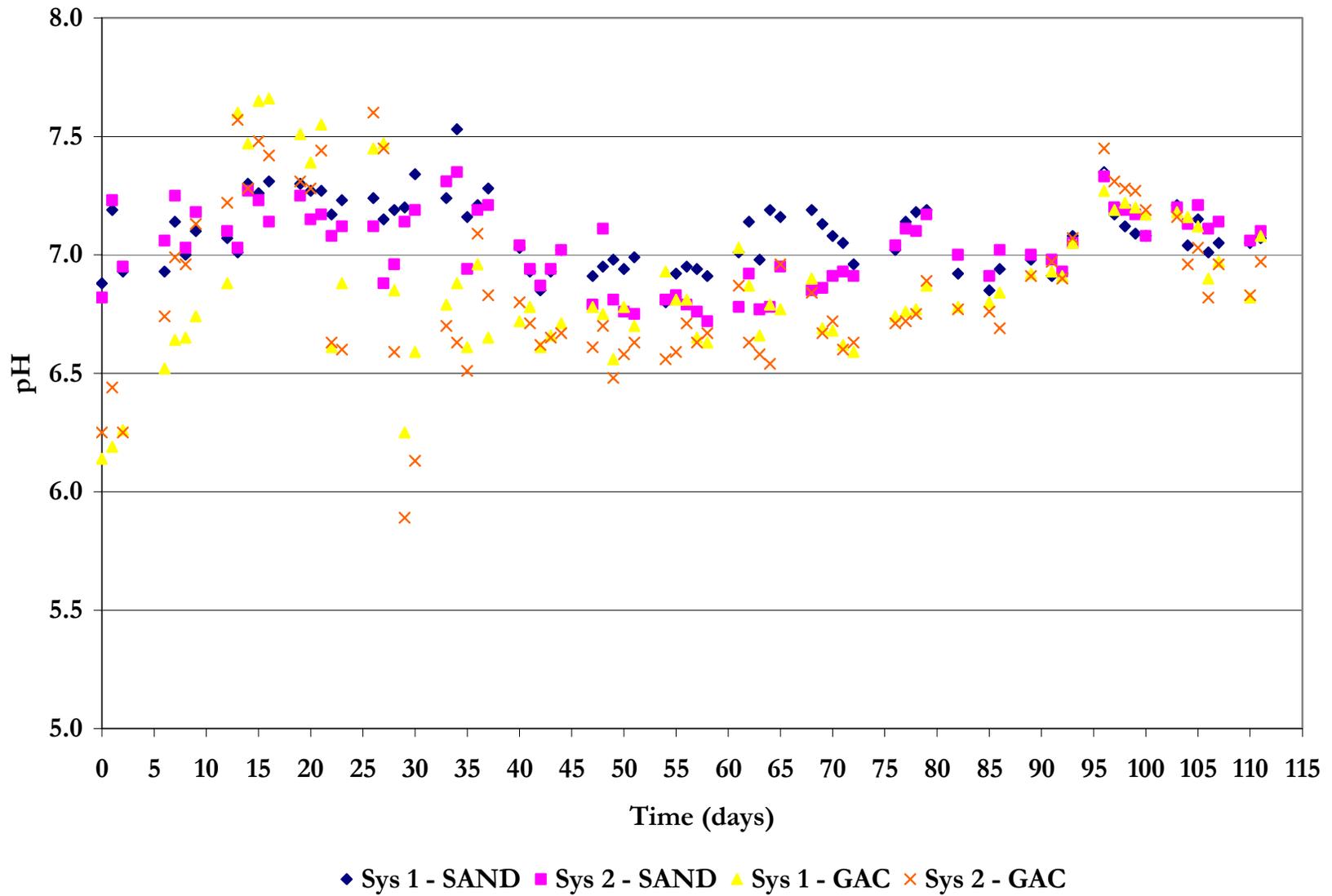


Figure 33 – pH trends in the FBR recycle reservoirs during continuous feed mode operation

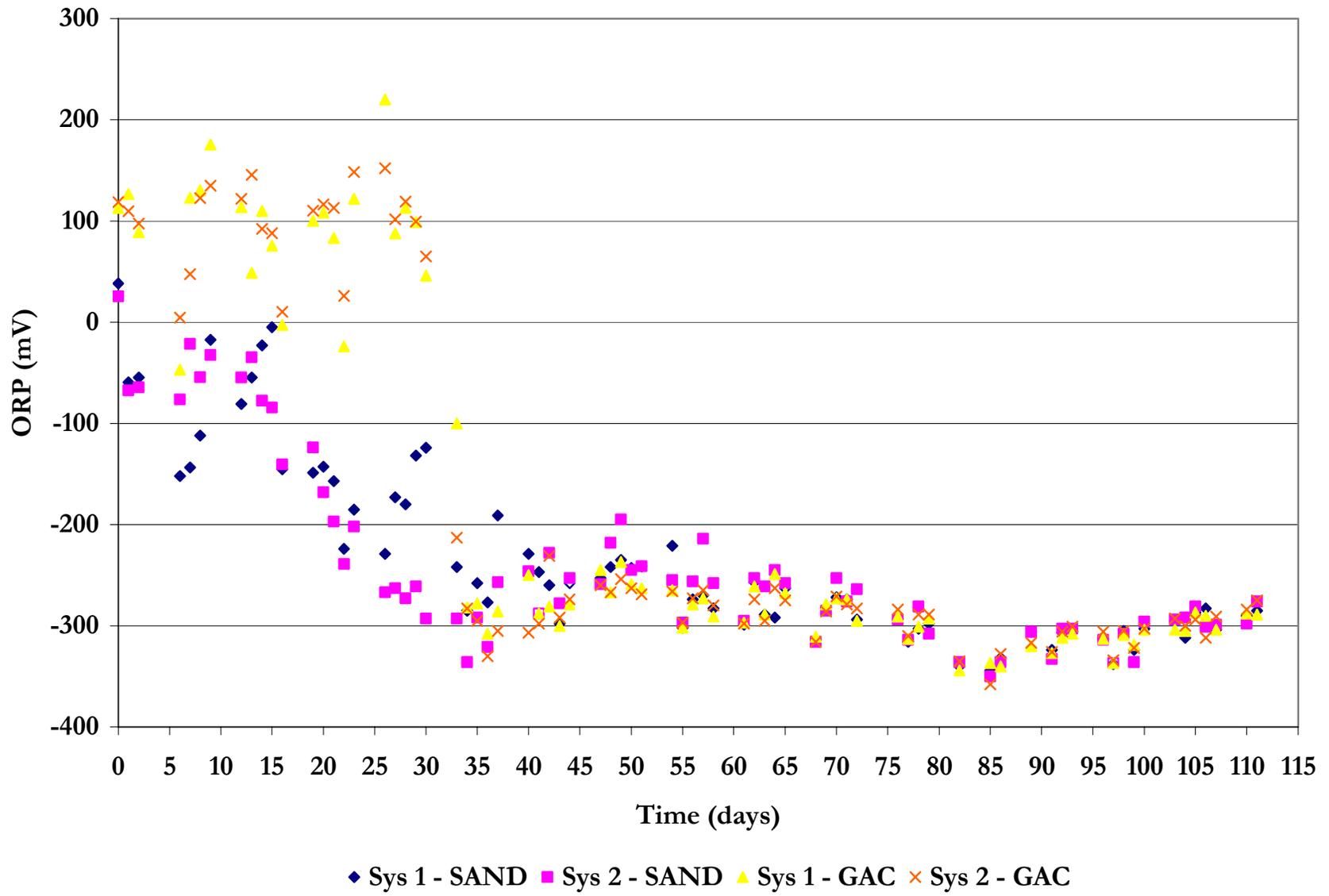


Figure 34 – ORP trends in the FBR recycle reservoirs during continuous feed mode operation

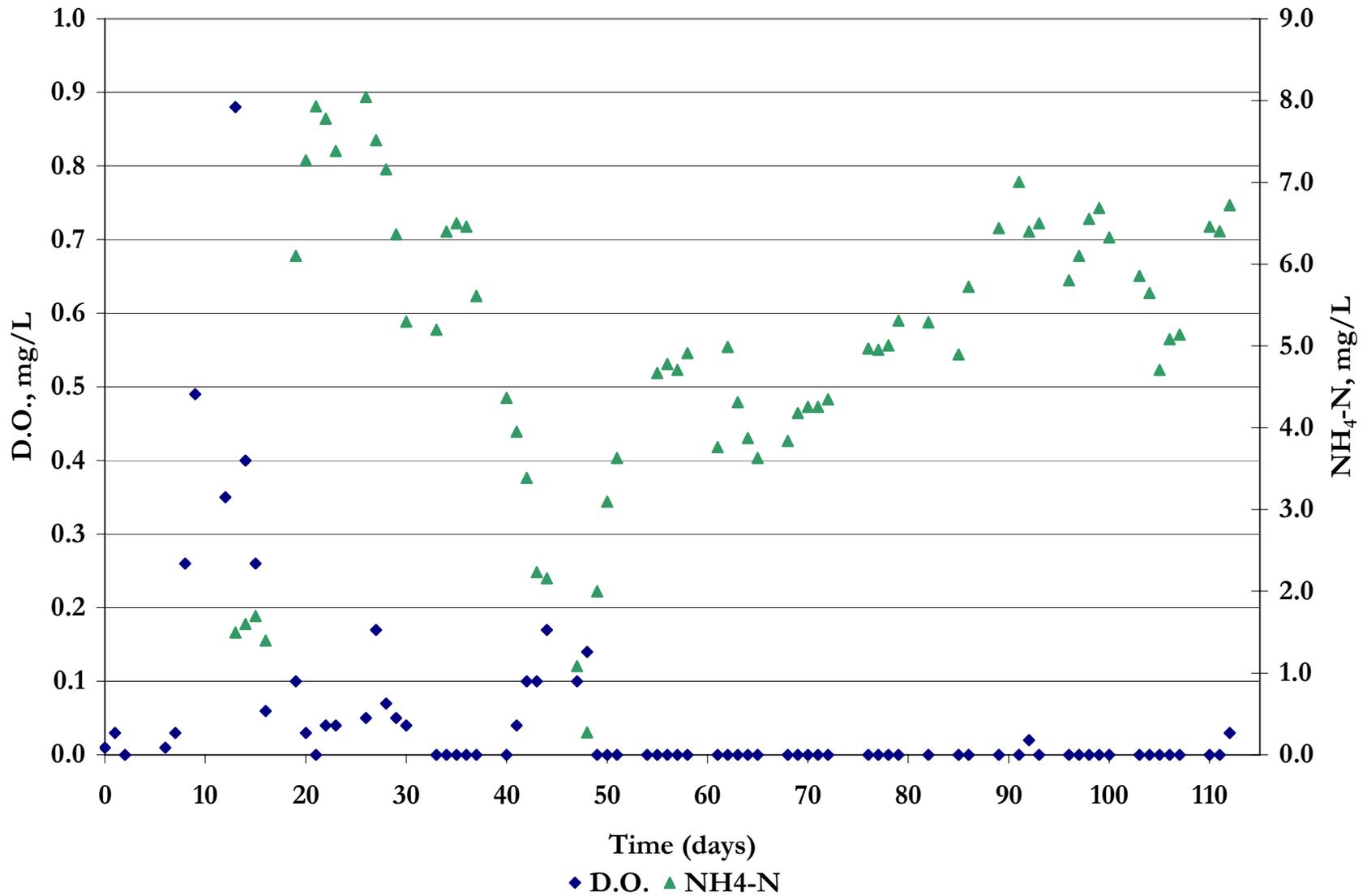


Figure 35 – Influence of FBR System 1 SAND on dissolved oxygen and ammonium concentrations during continuous feed mode operation

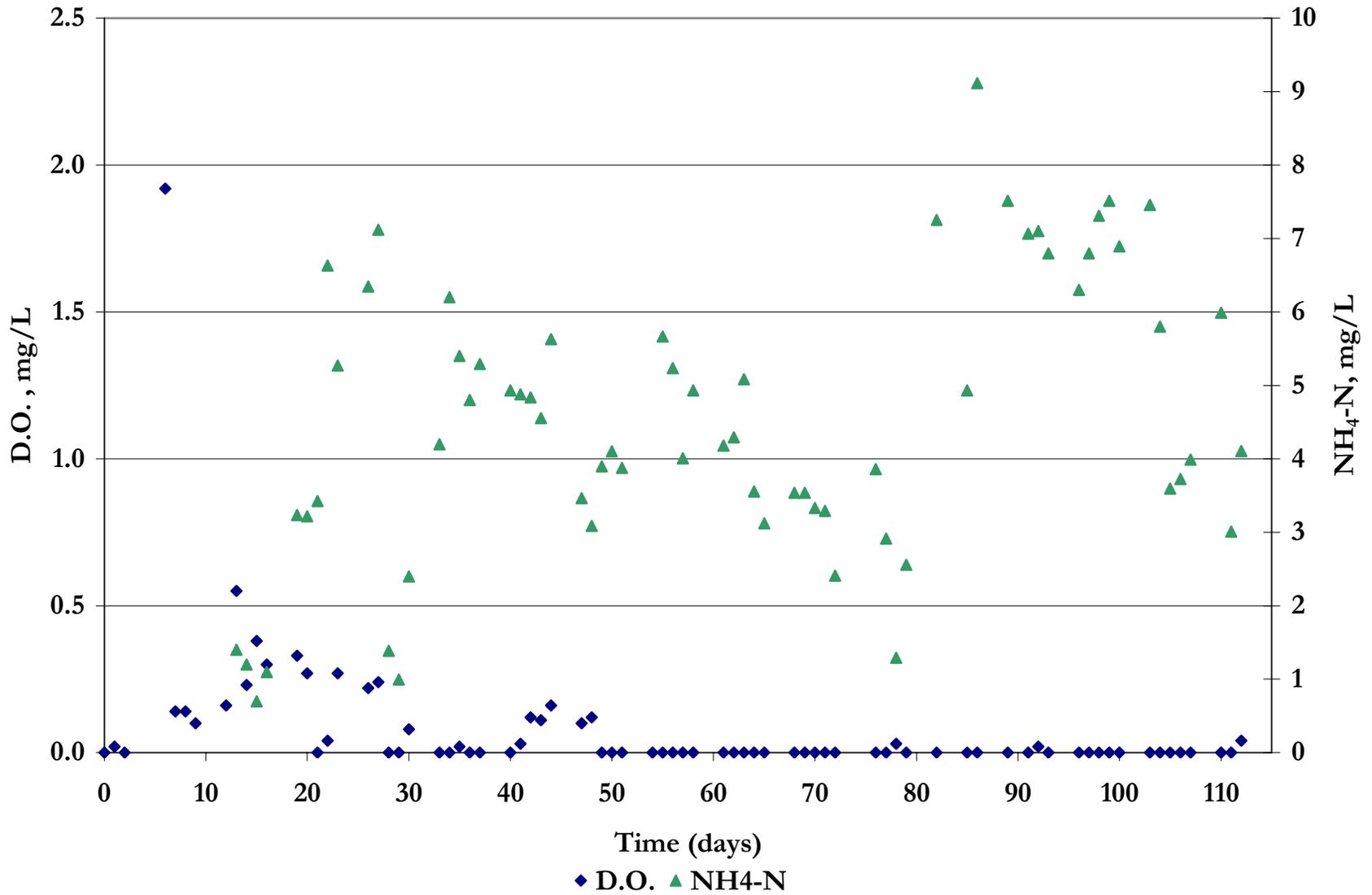


Figure 36 – Influence of FBR System 1 GAC on dissolved oxygen and ammonium concentrations during continuous feed mode operation

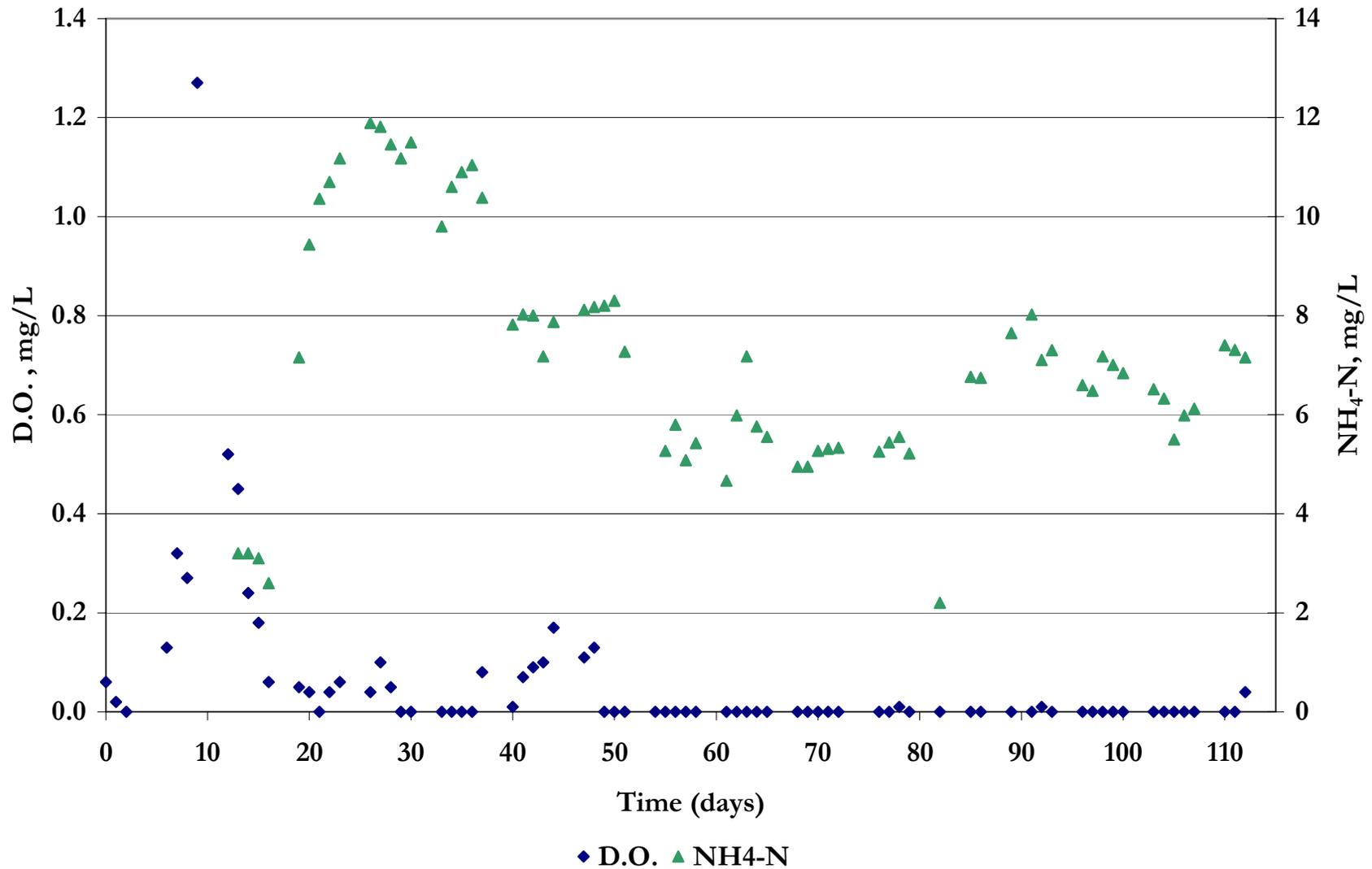


Figure 37 – Influence of FBR System 2 SAND on dissolved oxygen and ammonium concentrations during continuous feed mode operation

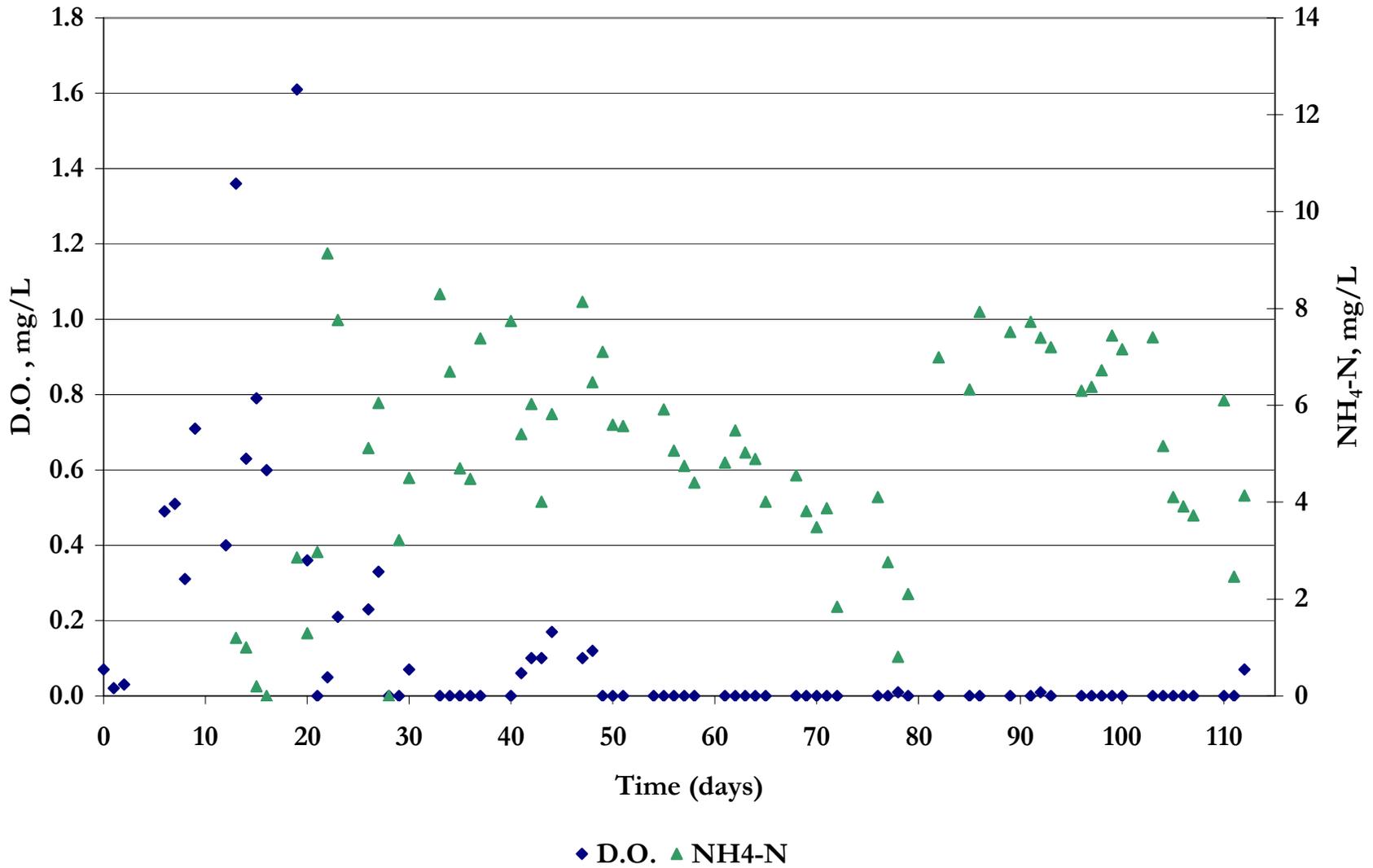


Figure 38 – Influence of FBR System 2 GAC on dissolved oxygen and ammonium concentrations during continuous feed mode operation

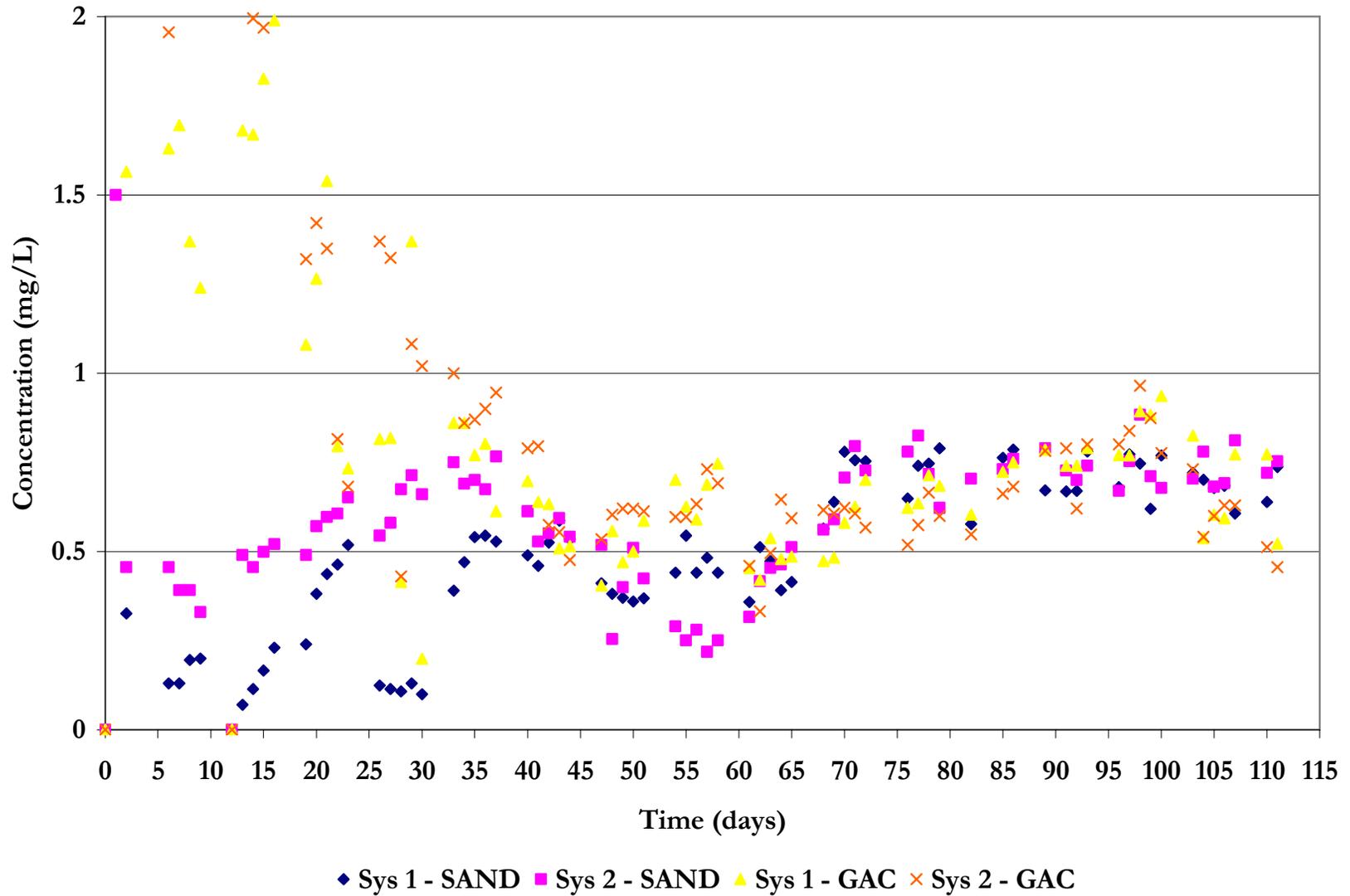


Figure 39 – Influence of FBR Systems 1 and 2 on phosphate concentrations

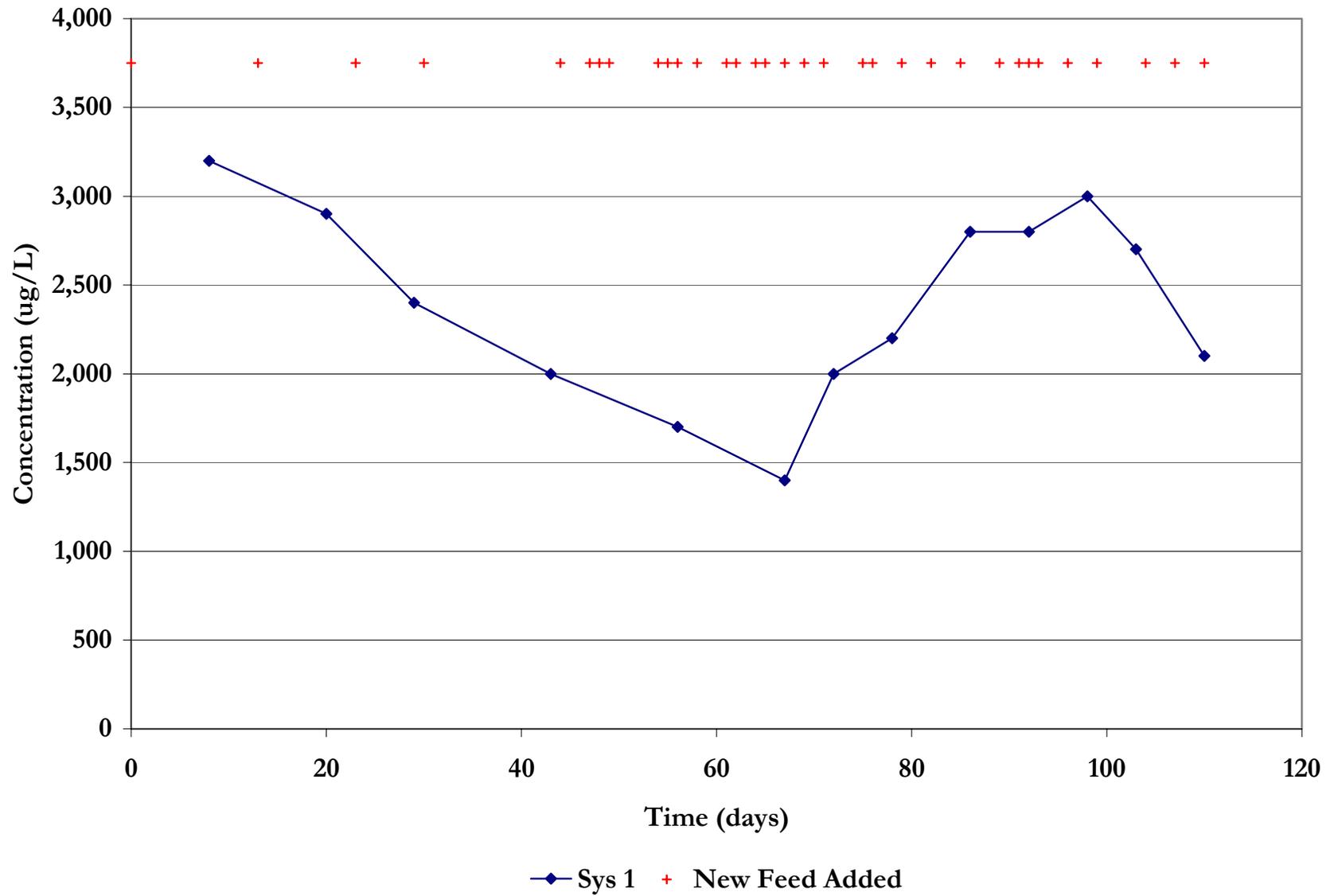


Figure 40 – FBR System 1 feed perchlorate concentrations

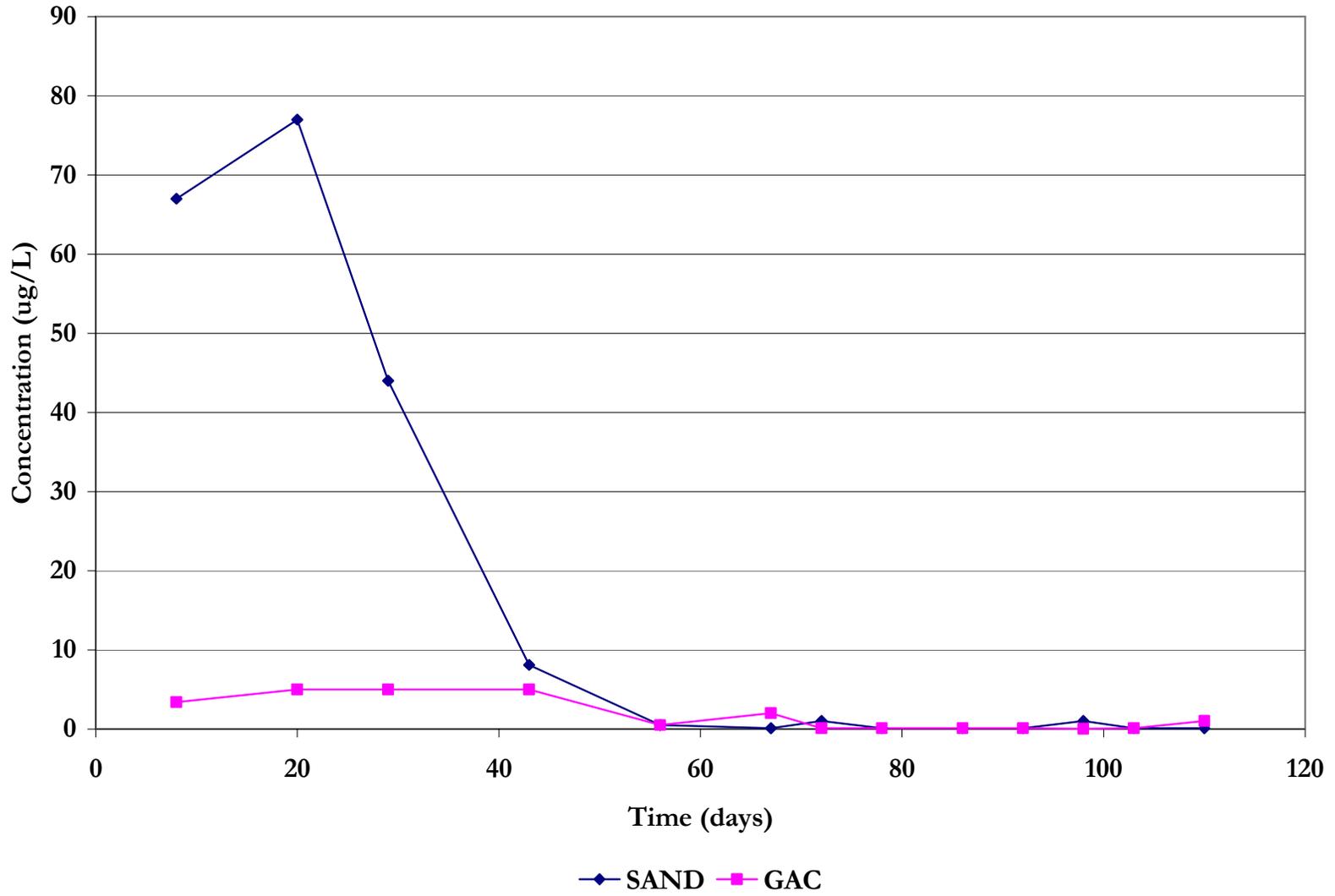


Figure 41 – Influence of FBR System 1 on perchlorate concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

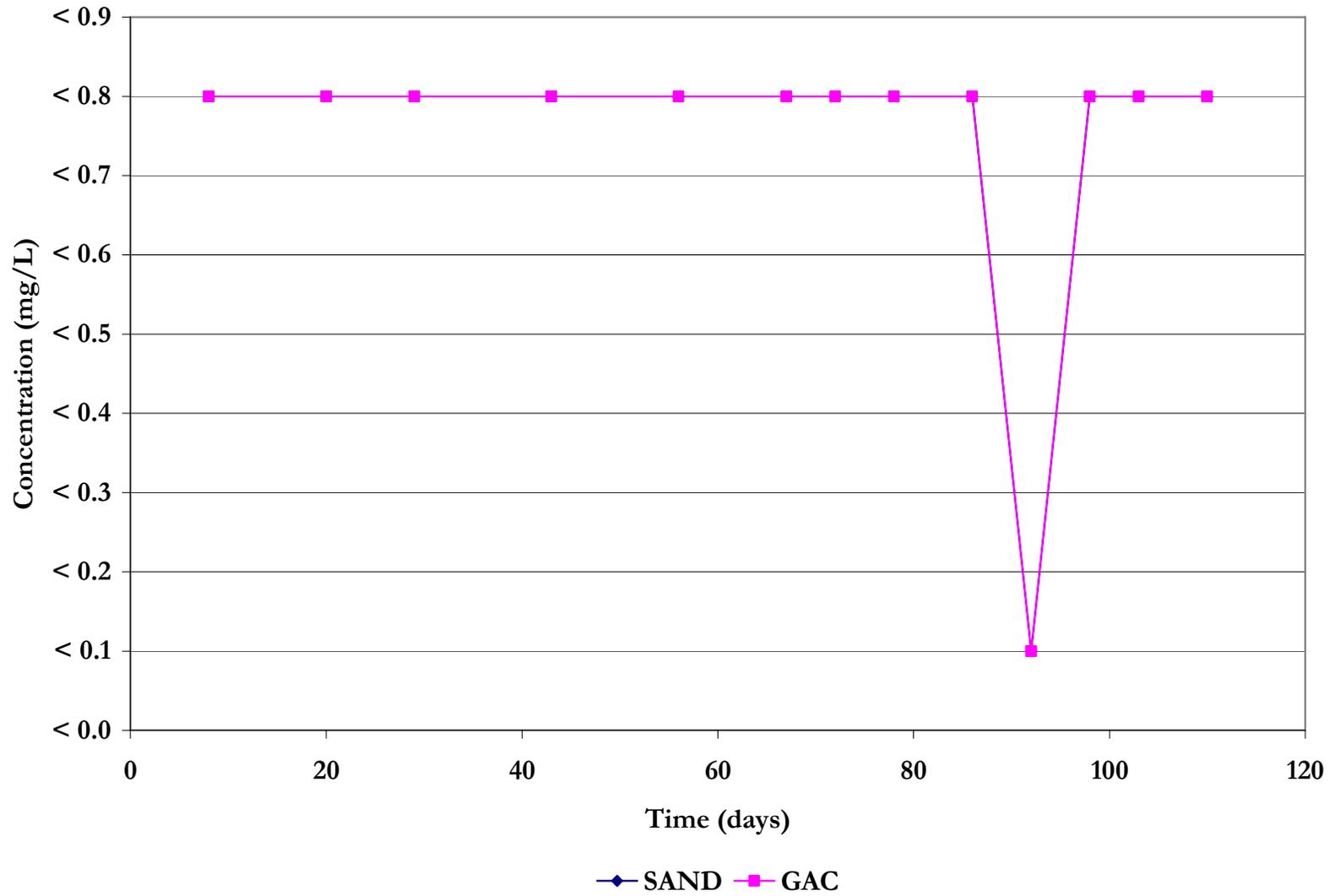


Figure 42 – Influence of FBR System 1 on chlorate concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

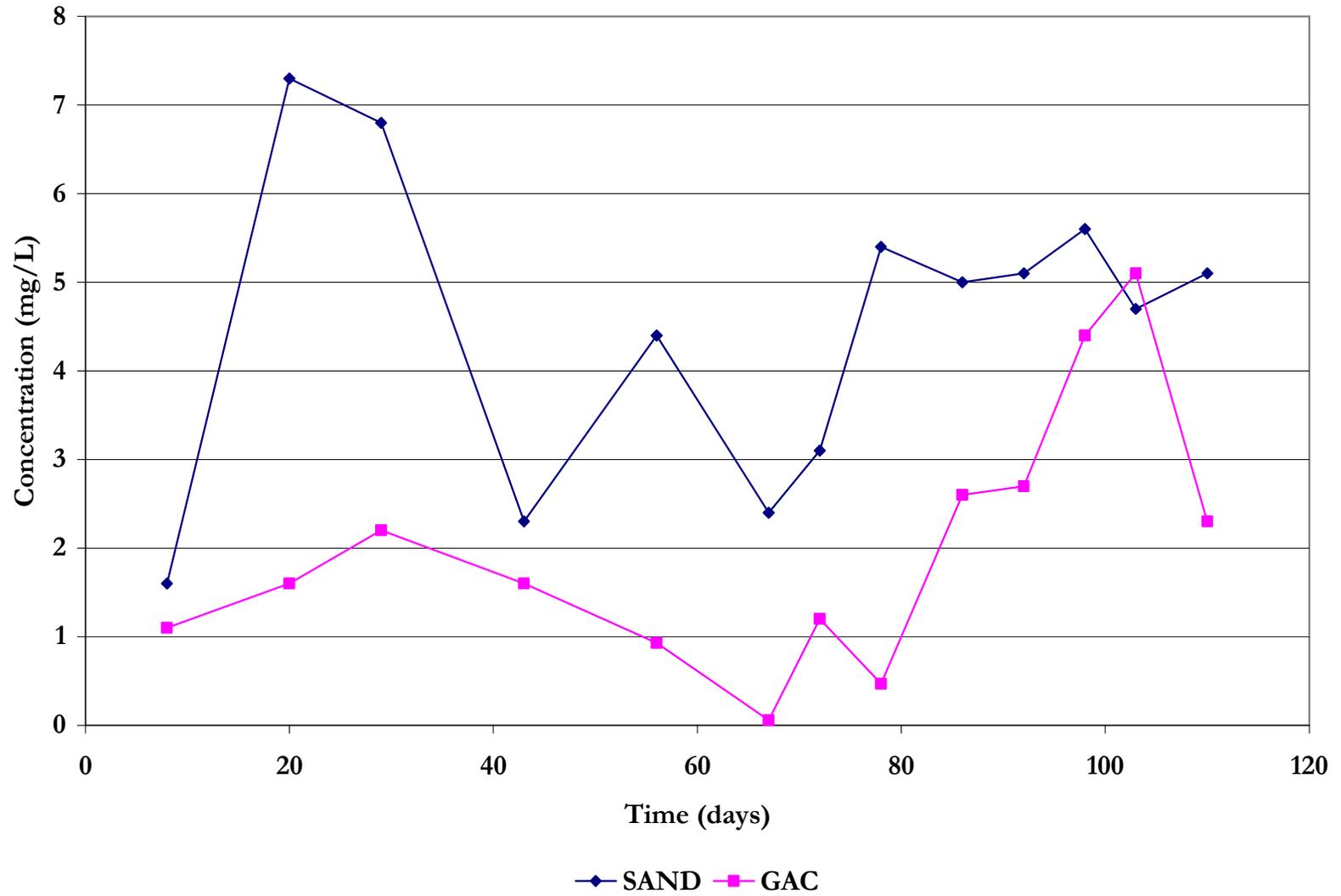


Figure 43 – Influence of FBR System 1 on ammonium-N concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

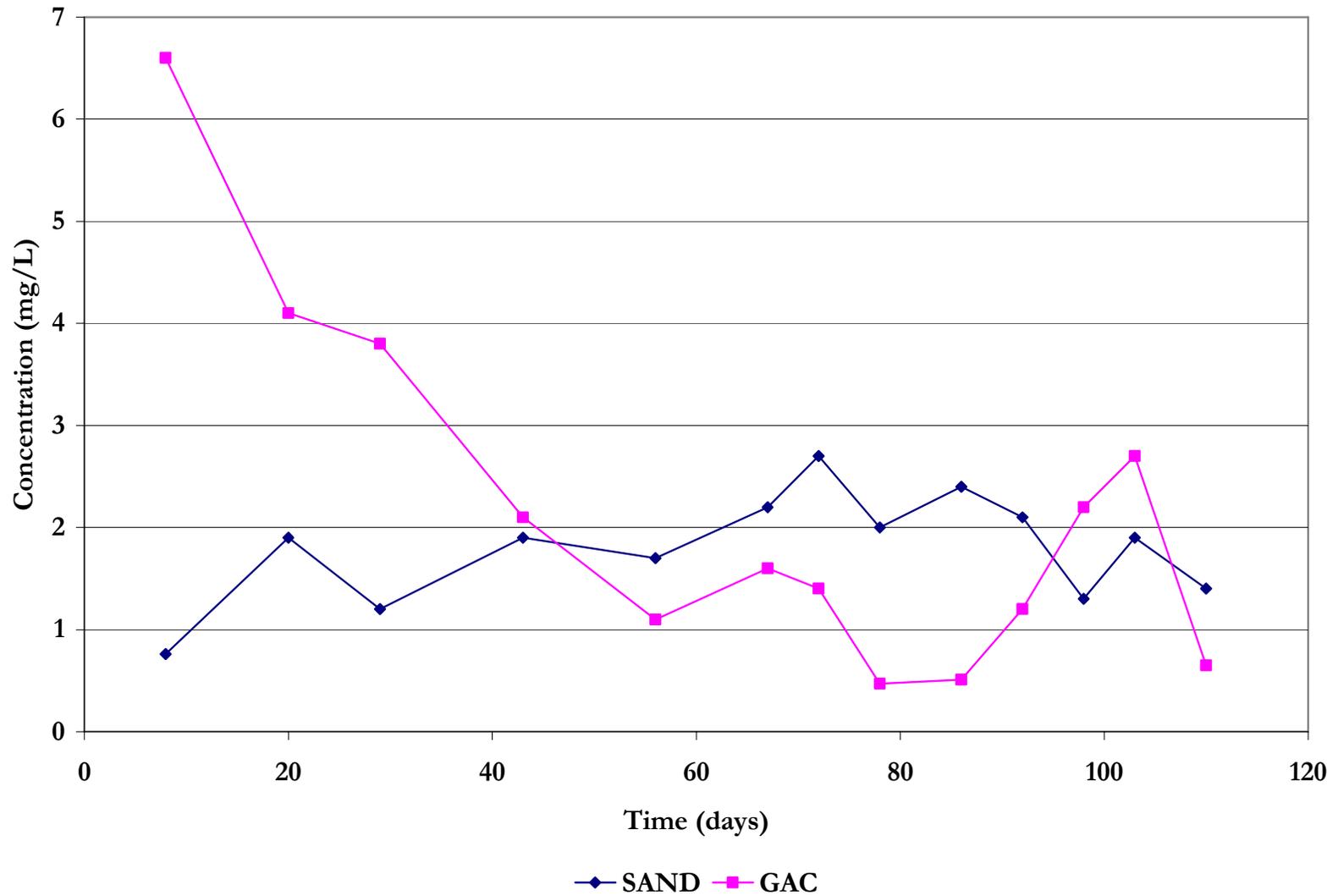


Figure 44 – Influence of FBR System 1 on phosphate-P concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

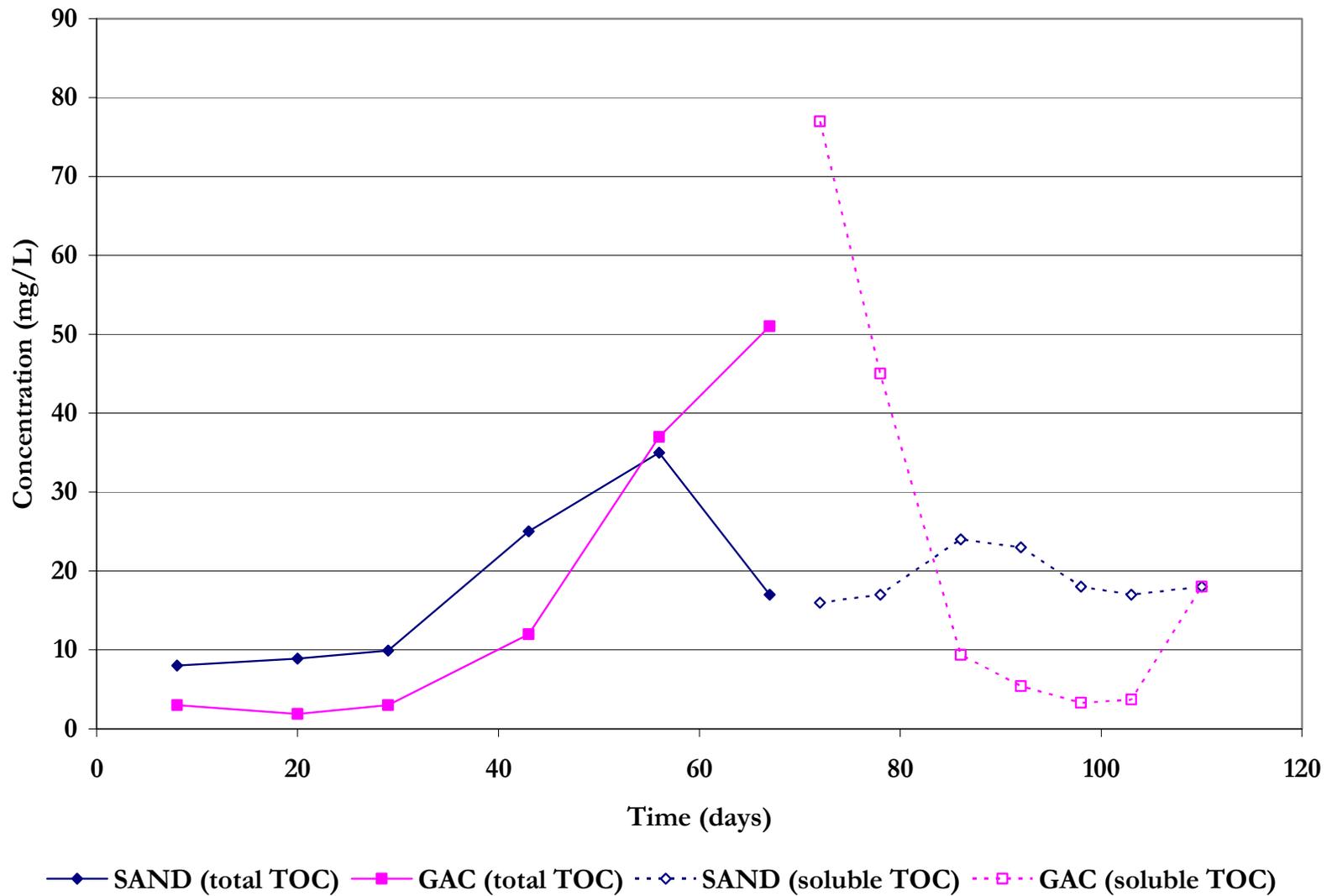


Figure 45 – Influence of FBR System 1 on TOC concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

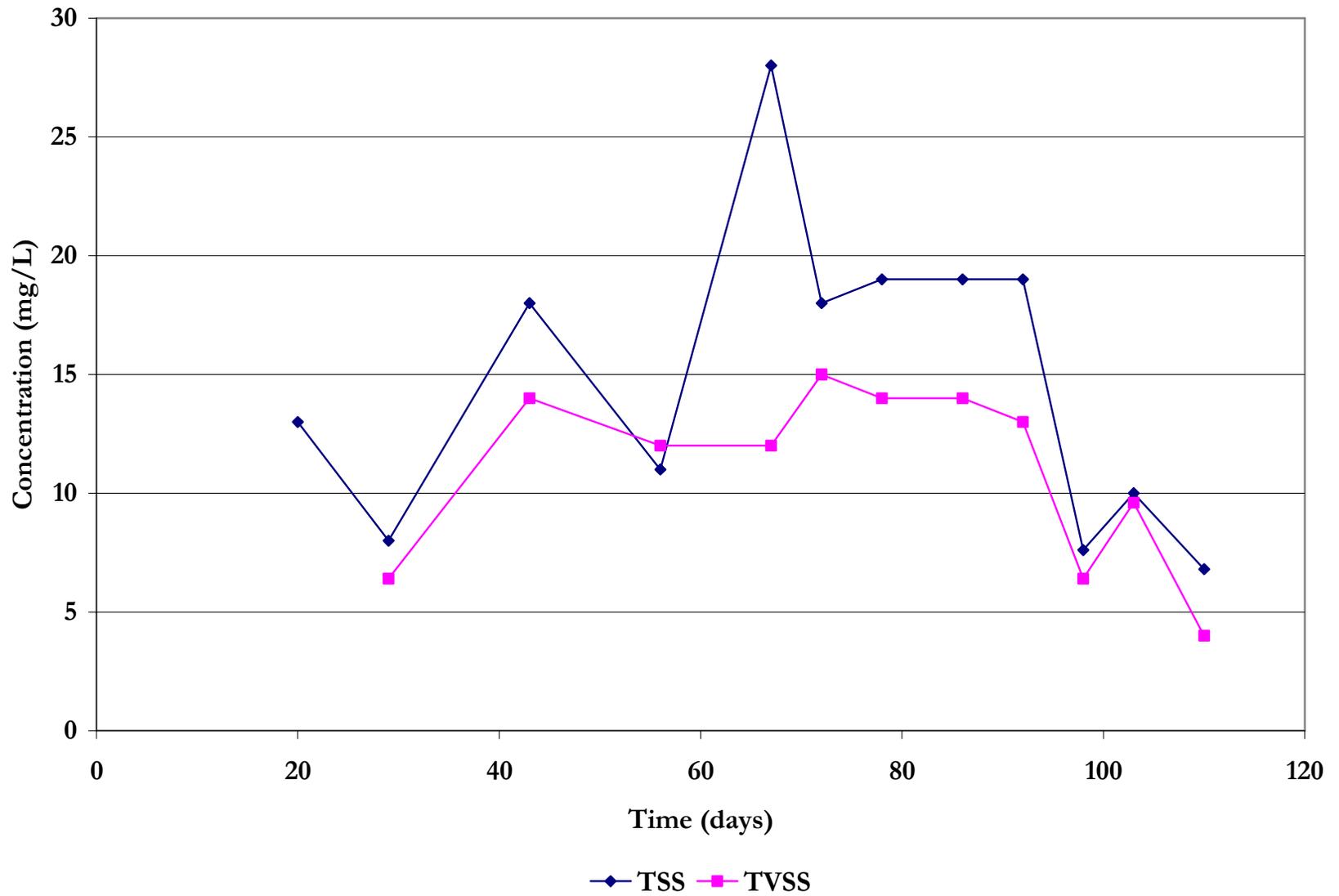


Figure 46 – Influence of FBR System 1 SAND on TSS and TVSS concentrations during continuous feed mode operation

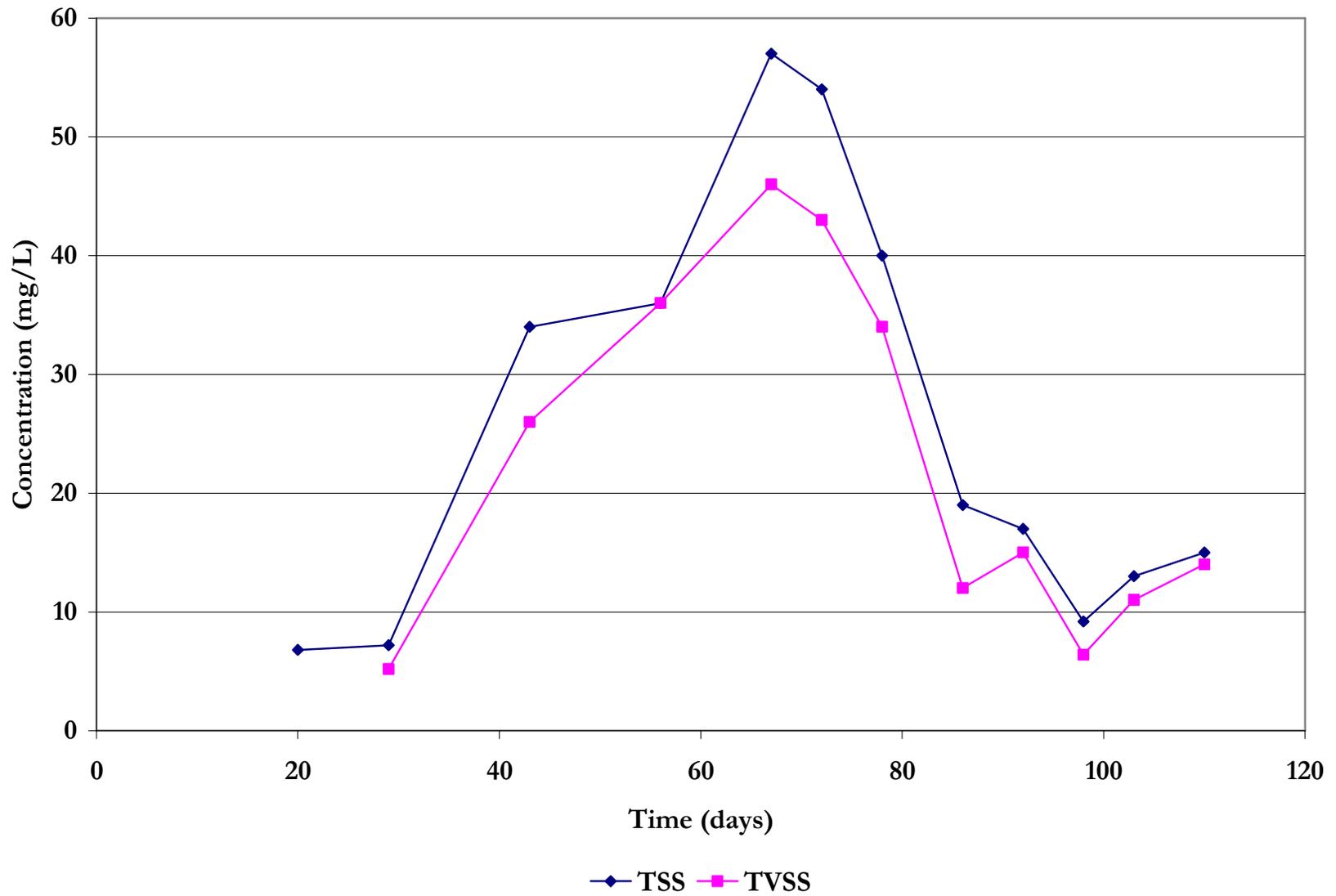


Figure 47 – Influence of FBR System 1 GAC on TSS and TVSS concentrations during continuous feed mode operation

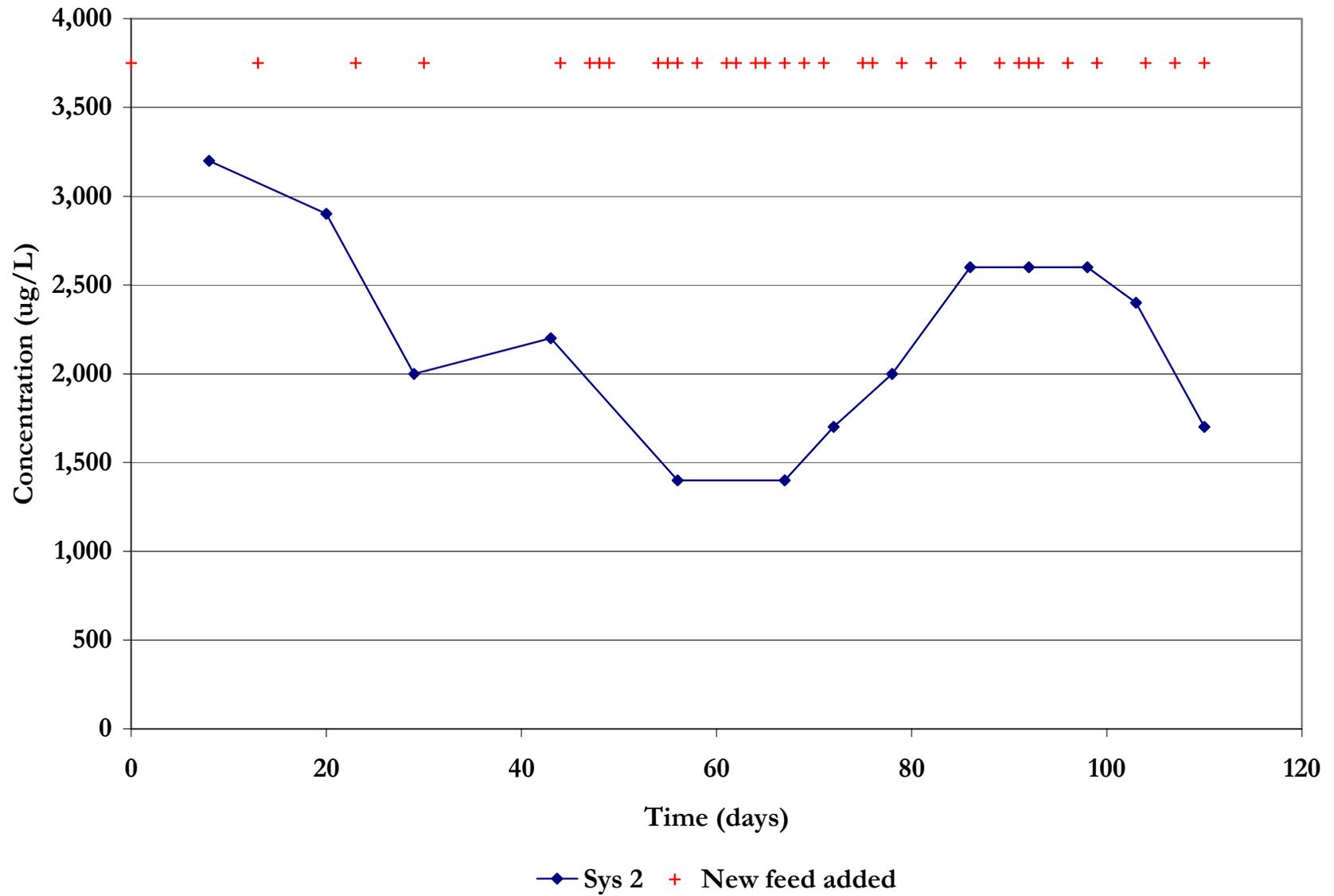


Figure 48 – FBR System 2 feed perchlorate concentrations

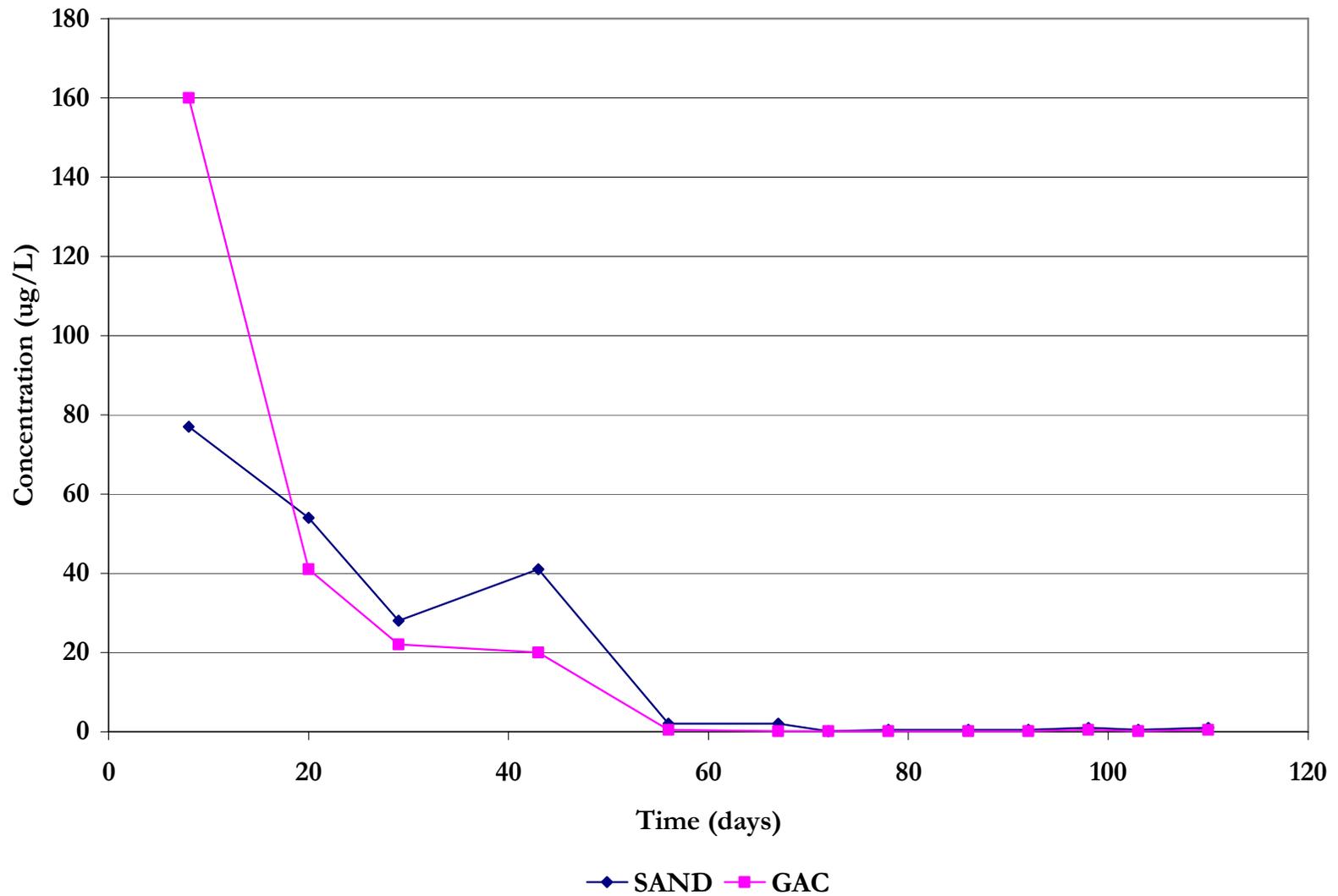


Figure 49 – Influence of FBR System 2 on perchlorate concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

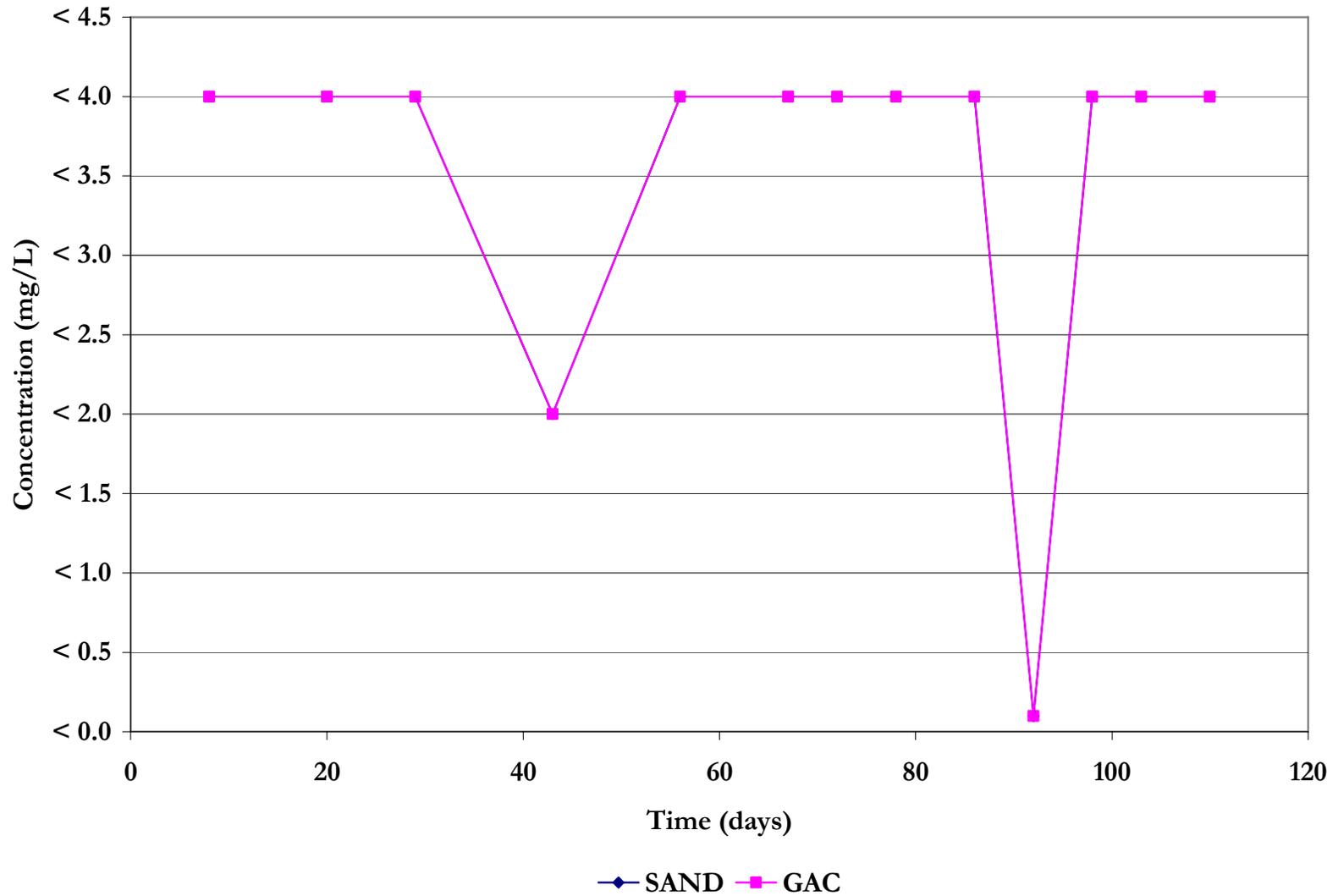


Figure 50 – Influence of FBR System 2 on chlorate concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

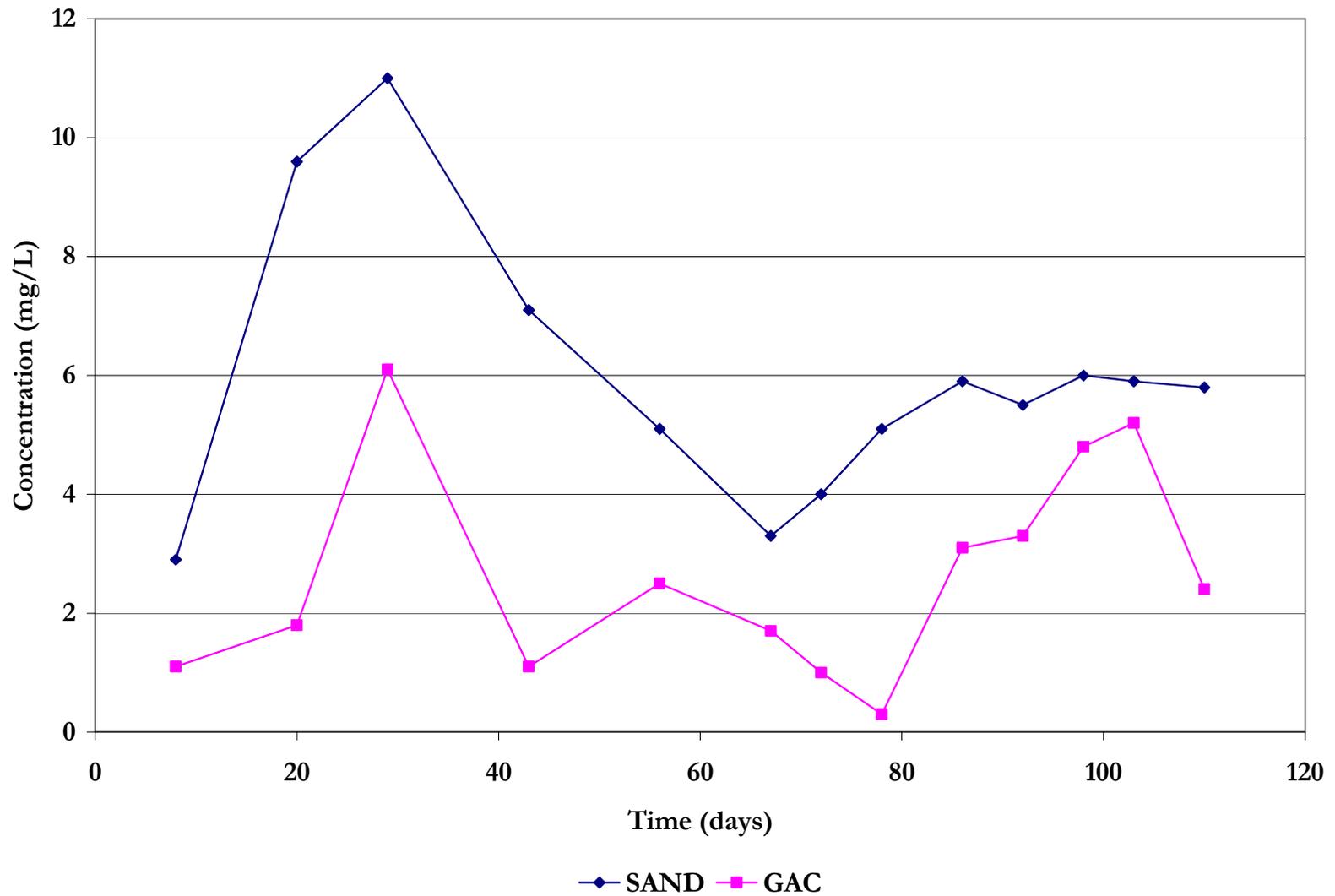


Figure 51 – Influence of FBR System 2 on ammonium-N concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

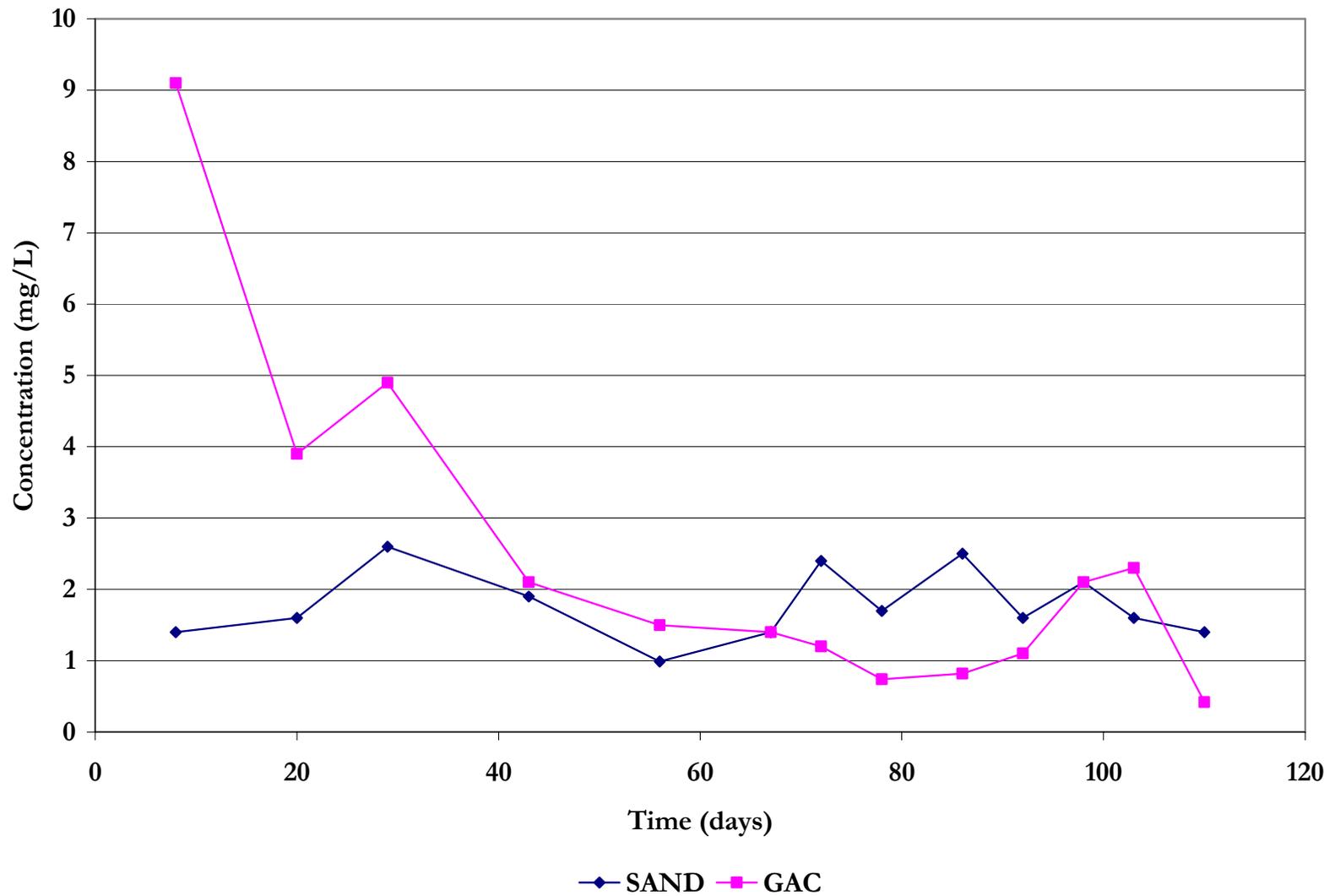


Figure 52 – Influence of FBR System 2 on phosphate-P concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

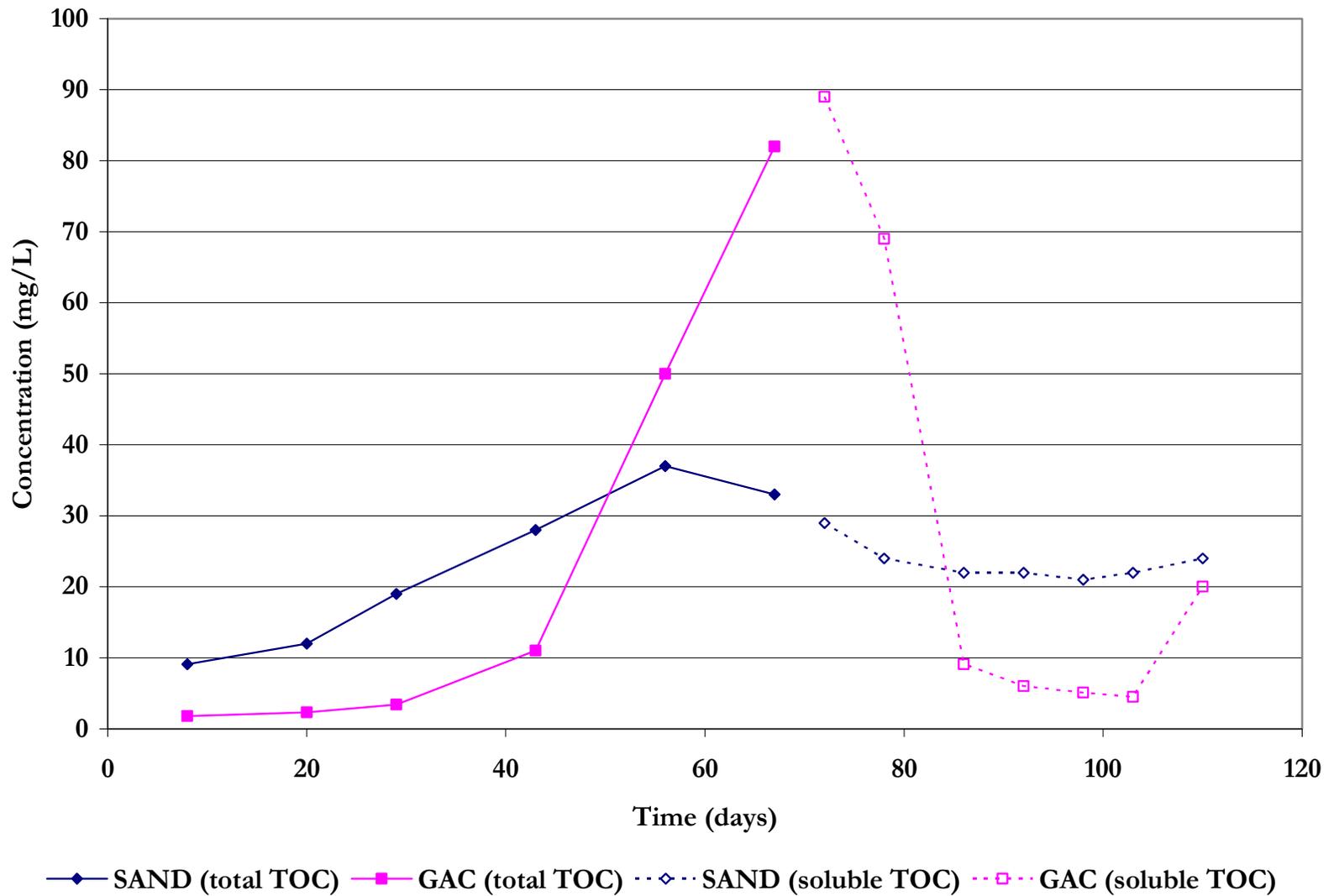


Figure 53 – Influence of FBR System 2 on TOC concentrations during continuous feed mode operation
Note: Sand and GAC reactors operated in series

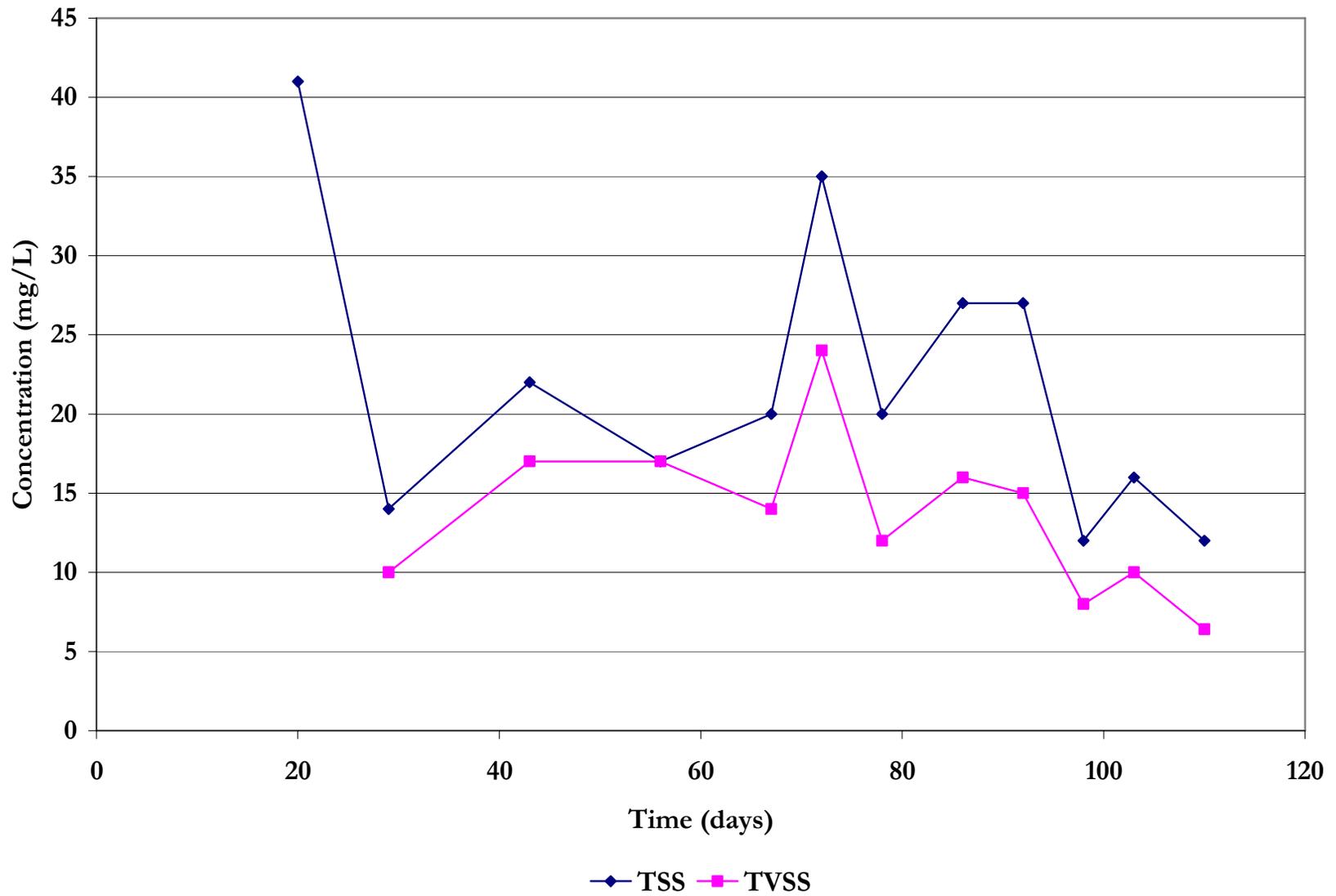


Figure 54 – Influence of FBR System 2 SAND on TSS and TVSS concentrations during continuous feed mode operation

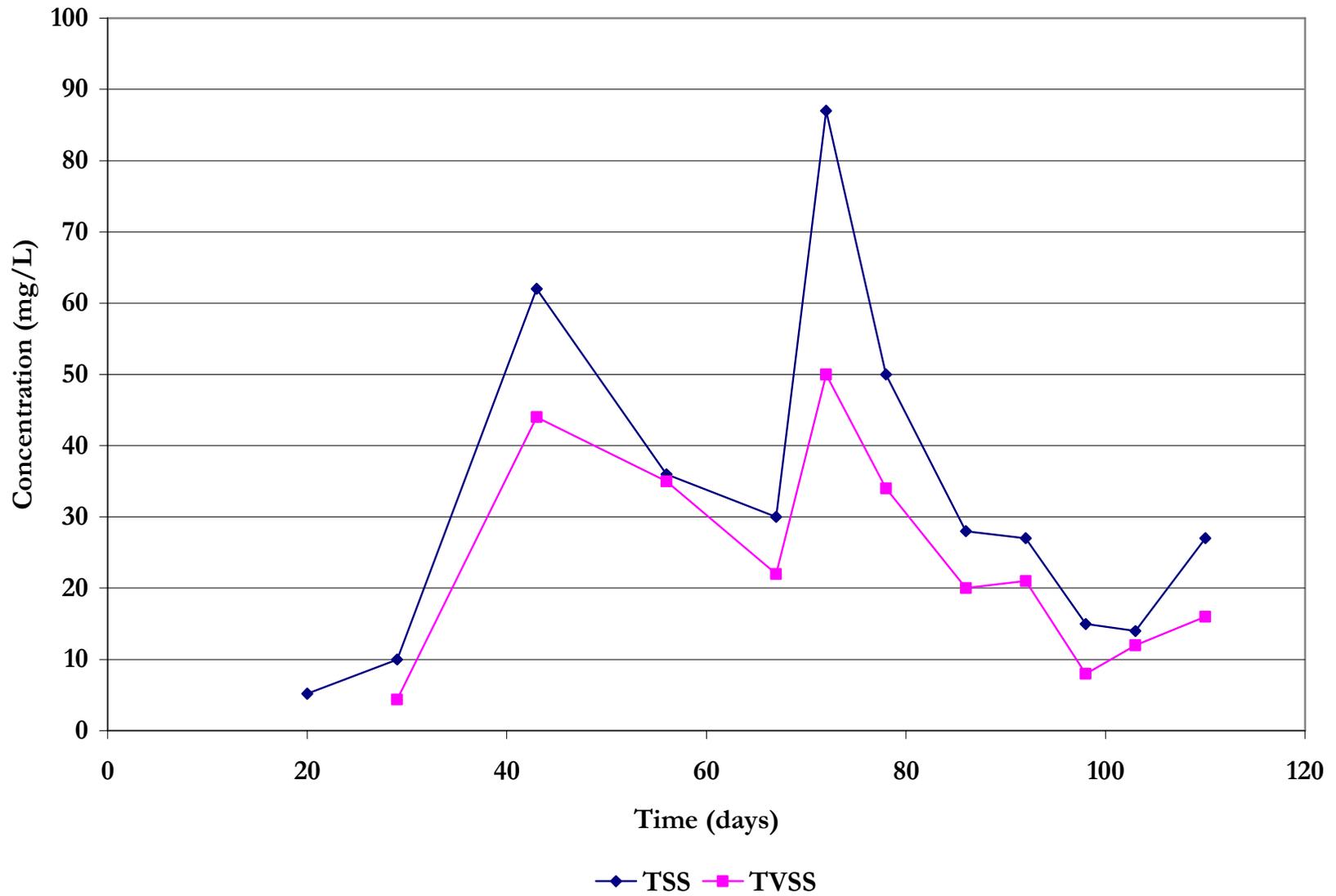


Figure 55 – Influence of FBR System 2 GAC on TSS and TVSS concentrations during continuous feed mode operation

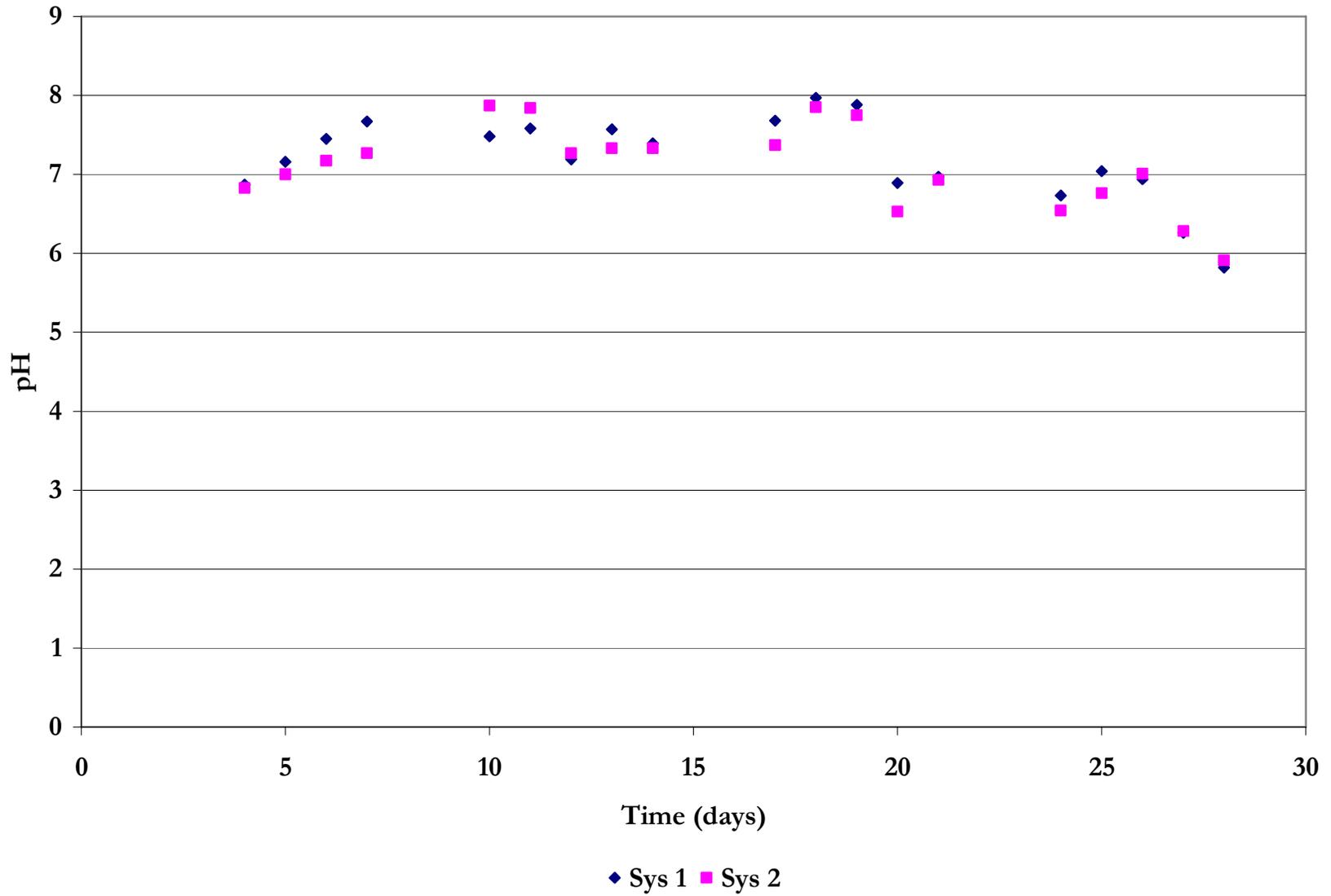


Figure 56 - pH trends in the PBR recycle reservoirs during batch mode operation

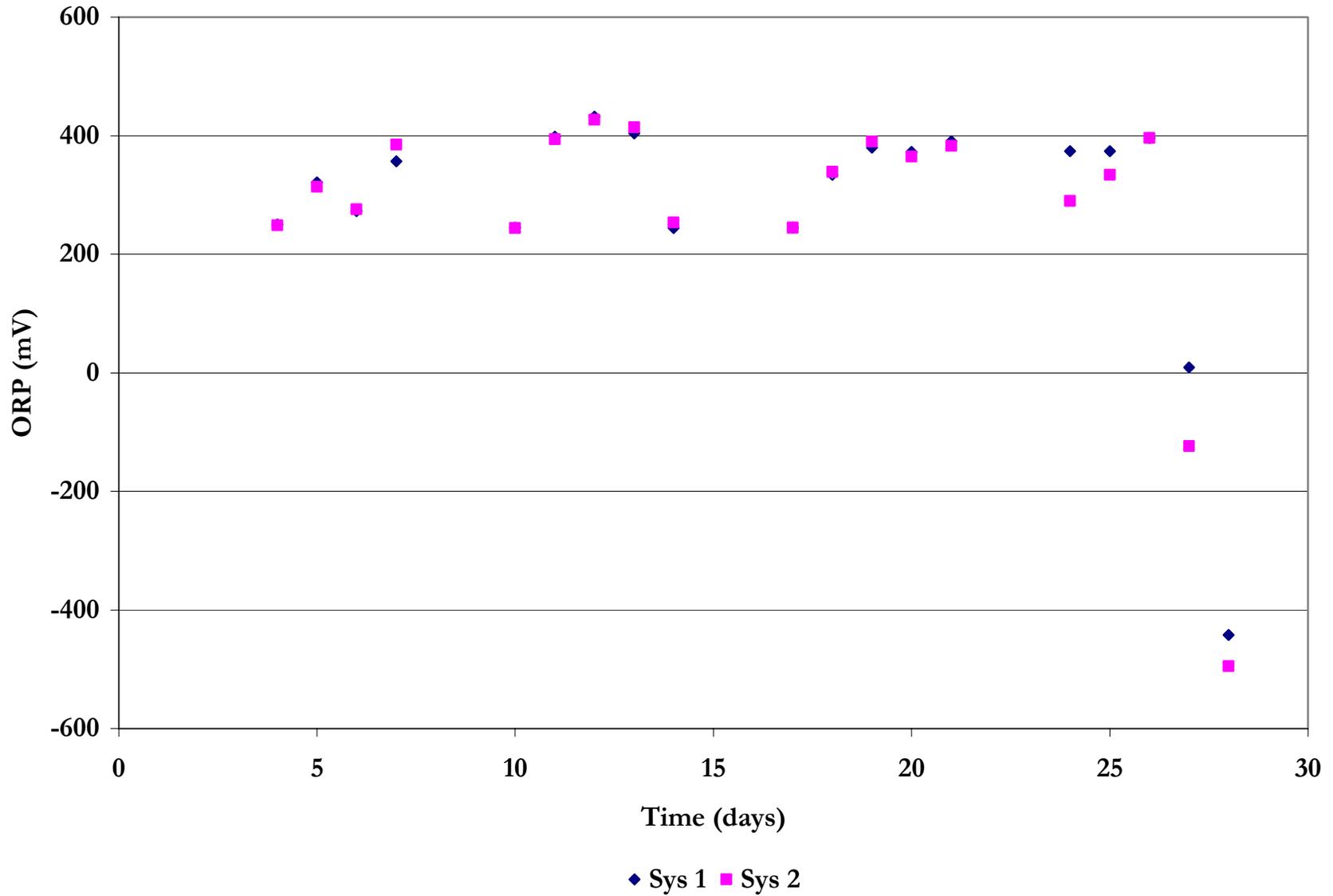


Figure 57 – ORP trends in the PBR recycle reservoirs during batch mode operation

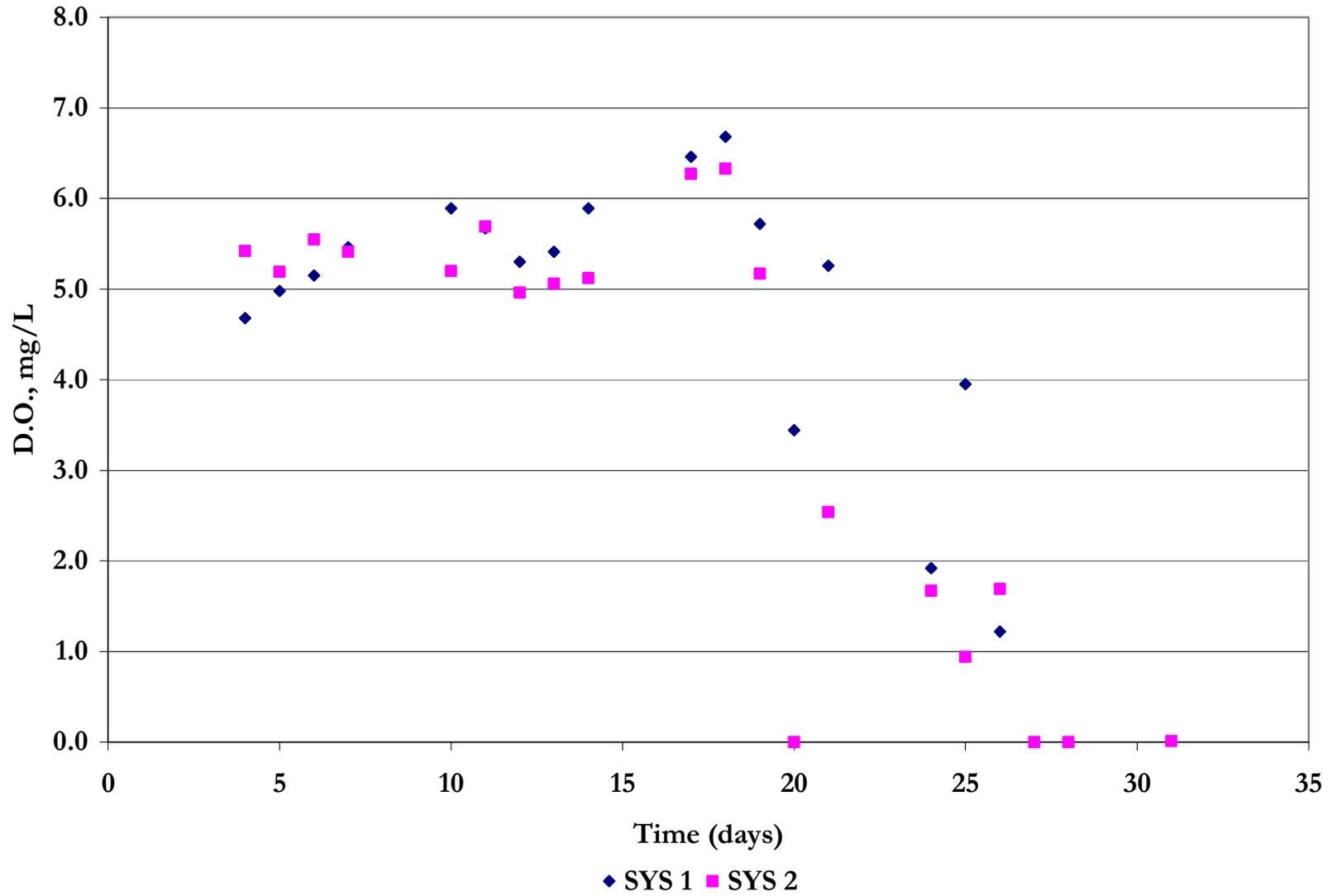


Figure 58 – Dissolved oxygen concentrations in the PBR recycle reservoirs during batch mode operation

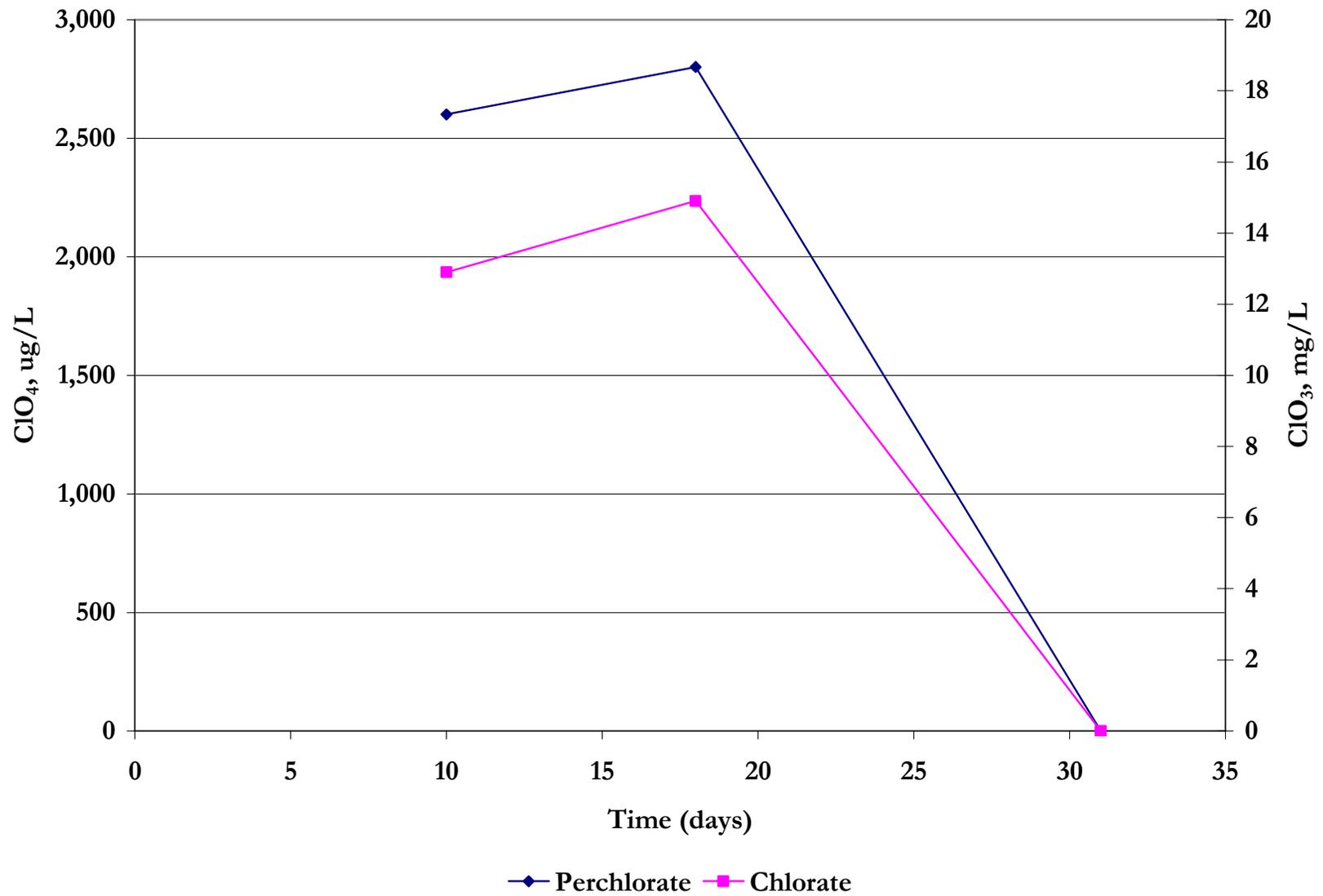


Figure 59 – Influence of PBR System 1 on perchlorate and chlorate concentrations during batch mode operation

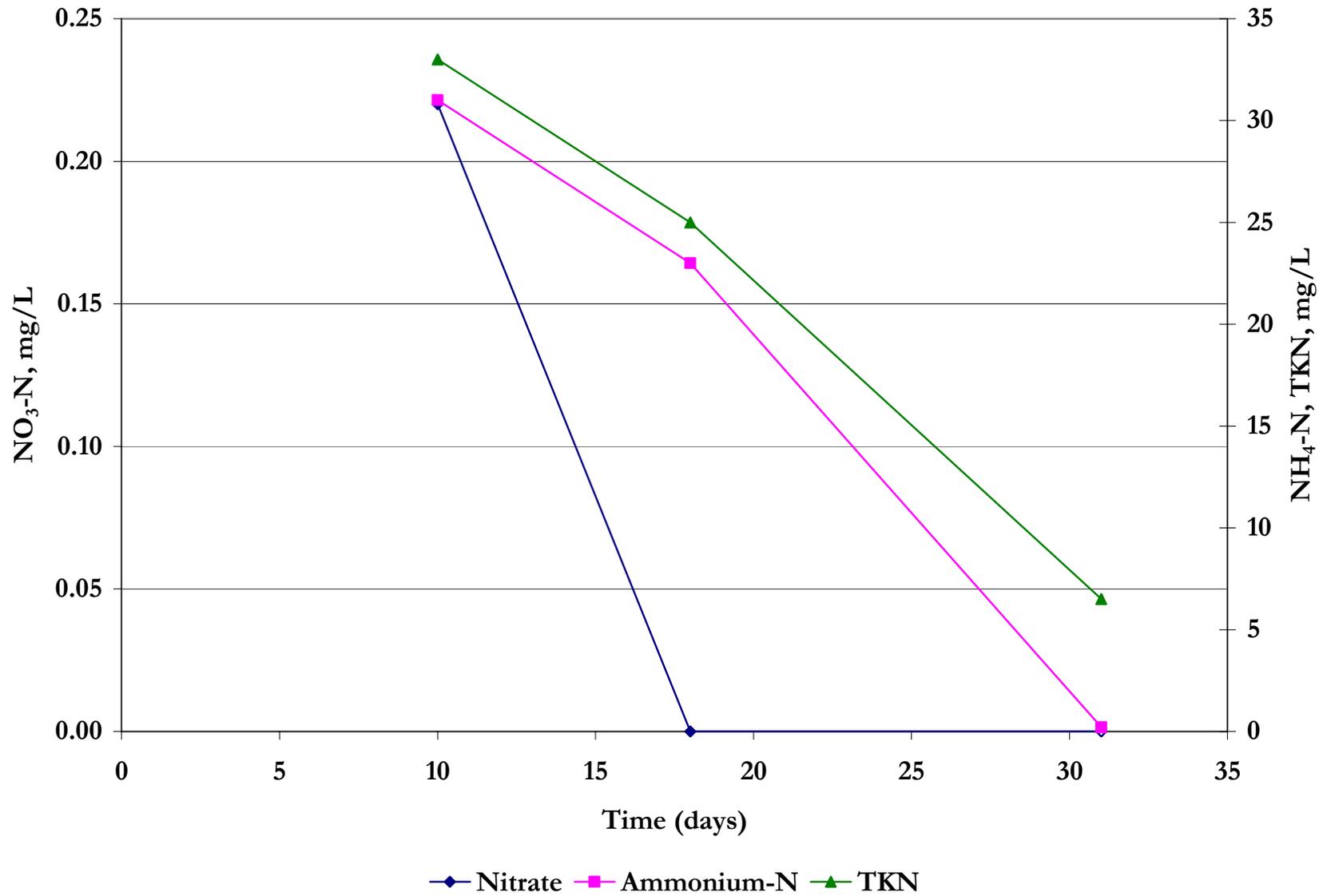


Figure 60 – Influence of PBR System 1 on ammonium, nitrate, and TKN concentrations during batch mode operation

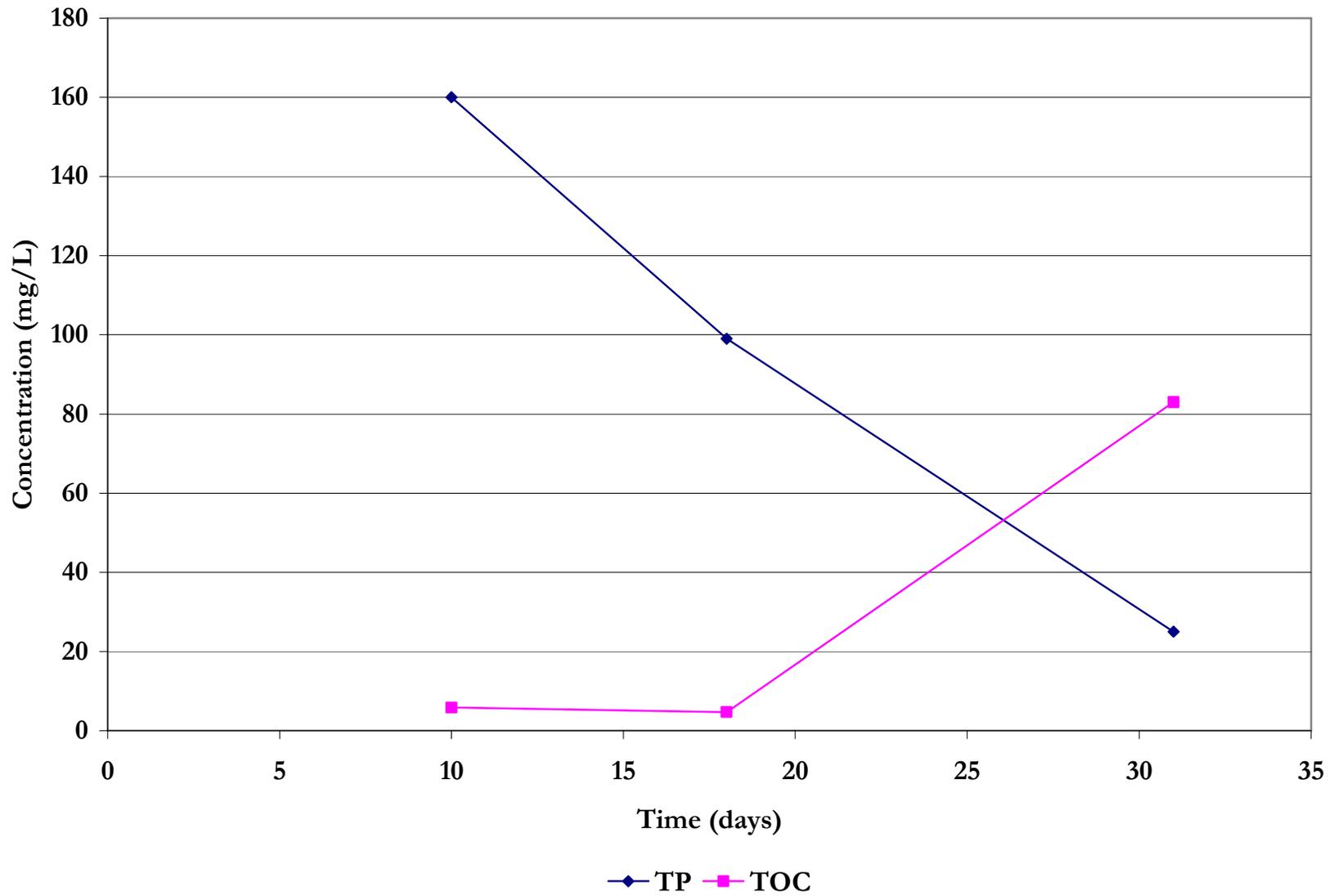


Figure 61 – Influence of PBR System 1 on phosphate and TOC concentrations during batch mode operation

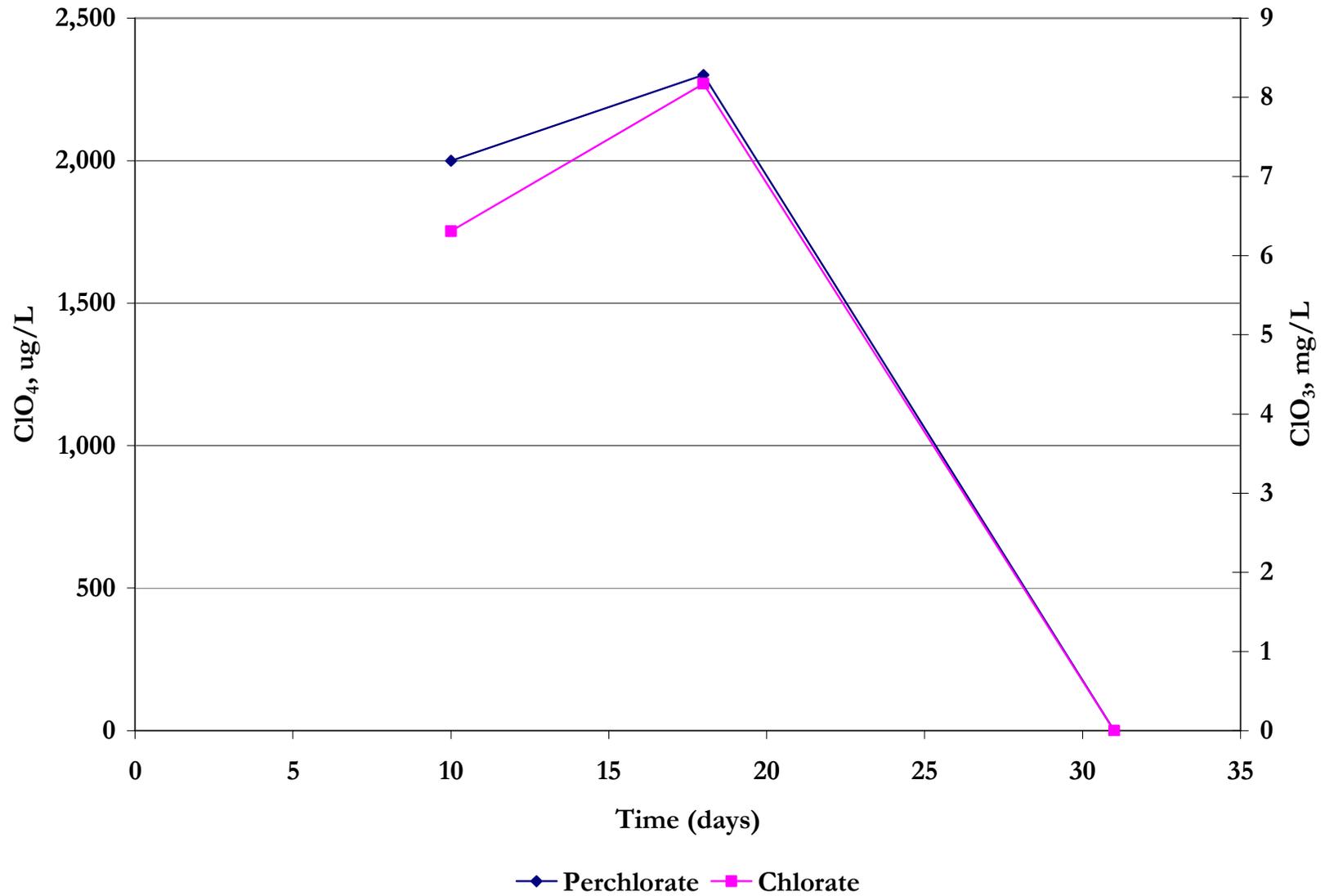


Figure 62 – Influence of PBR System 2 on perchlorate and chlorate concentrations during batch mode operation

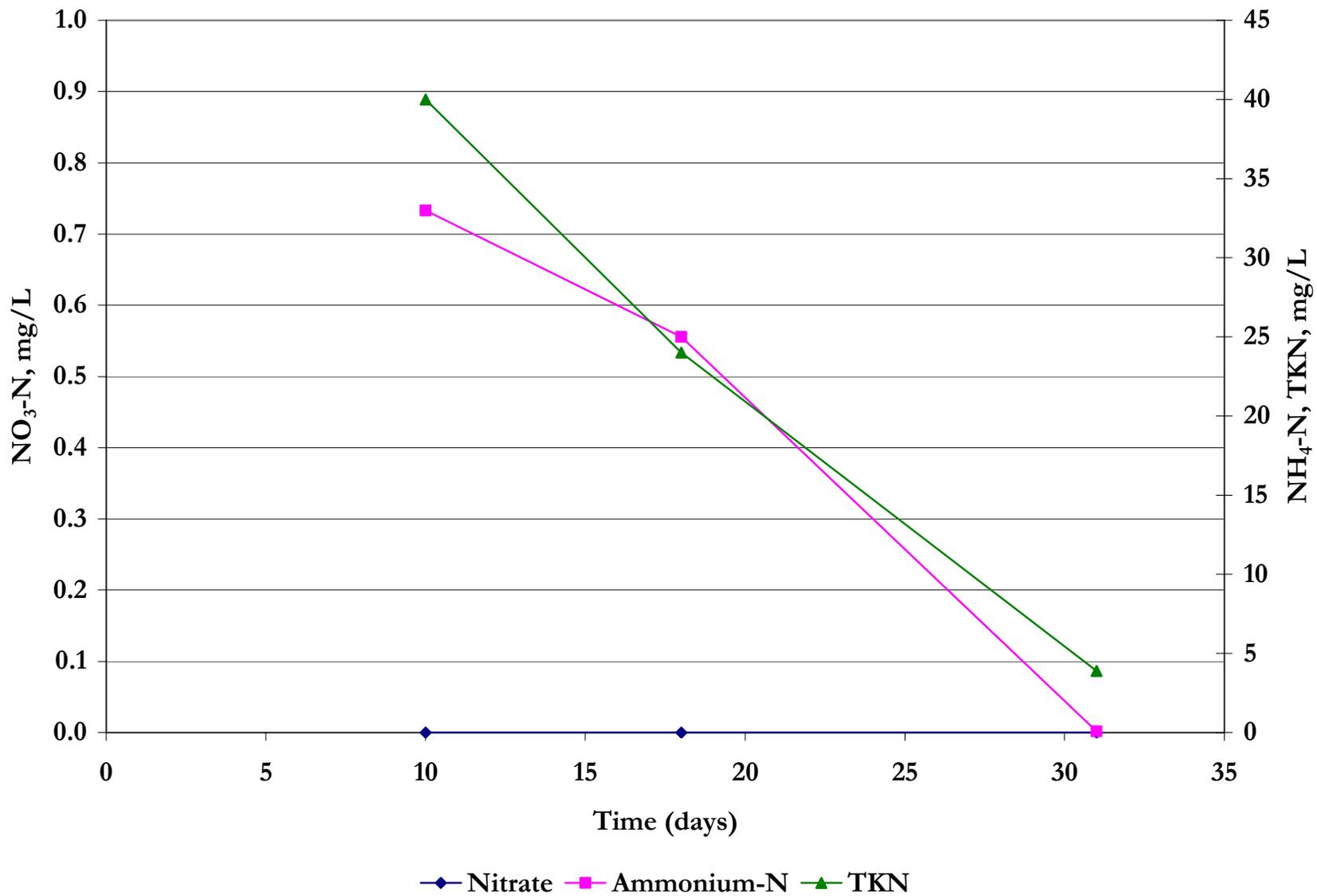


Figure 63 – Influence of PBR System 2 on ammonium, nitrate, and TKN concentrations during batch mode operation

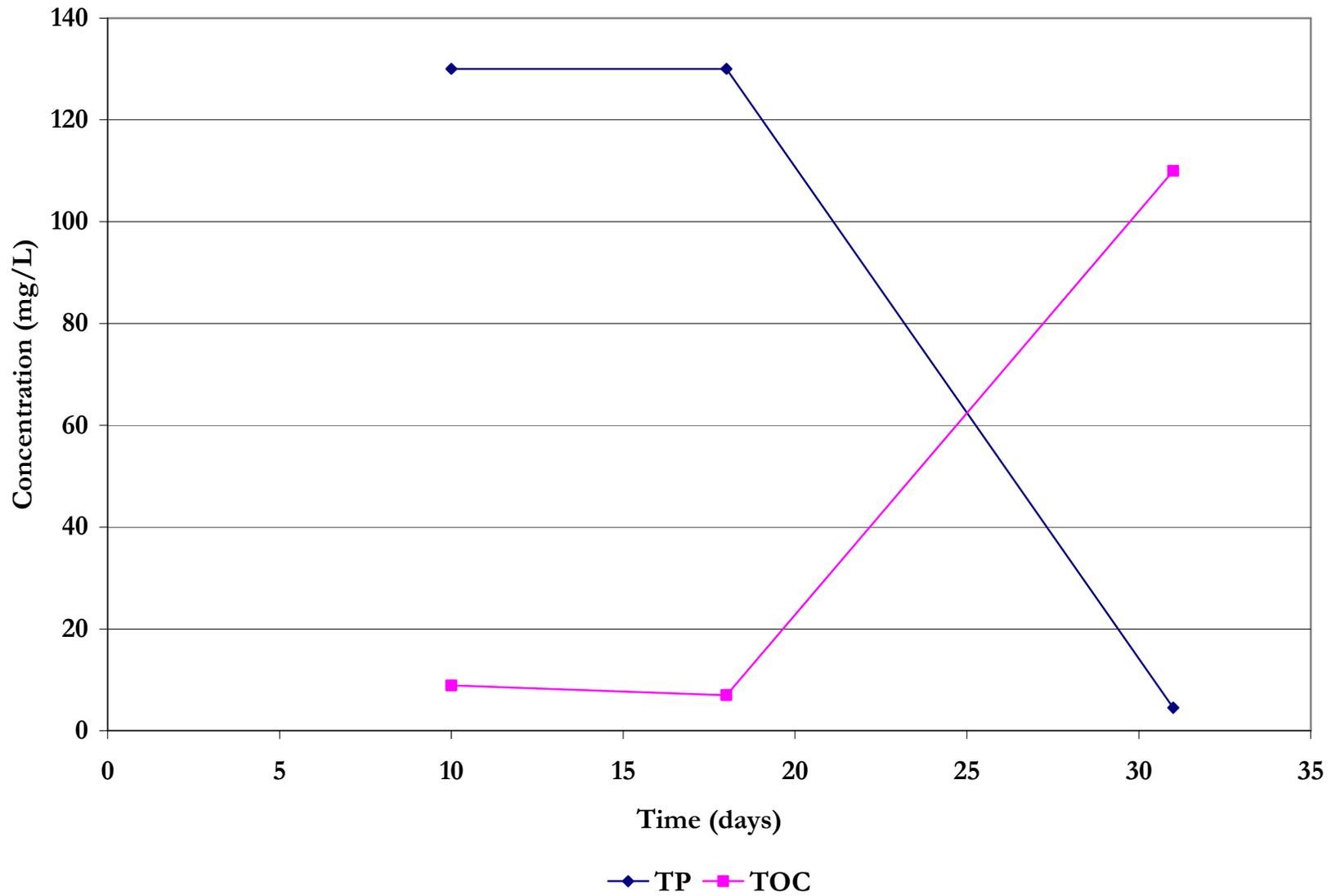


Figure 64 – Influence of PBR System 2 on phosphate and TOC concentrations during batch mode operation

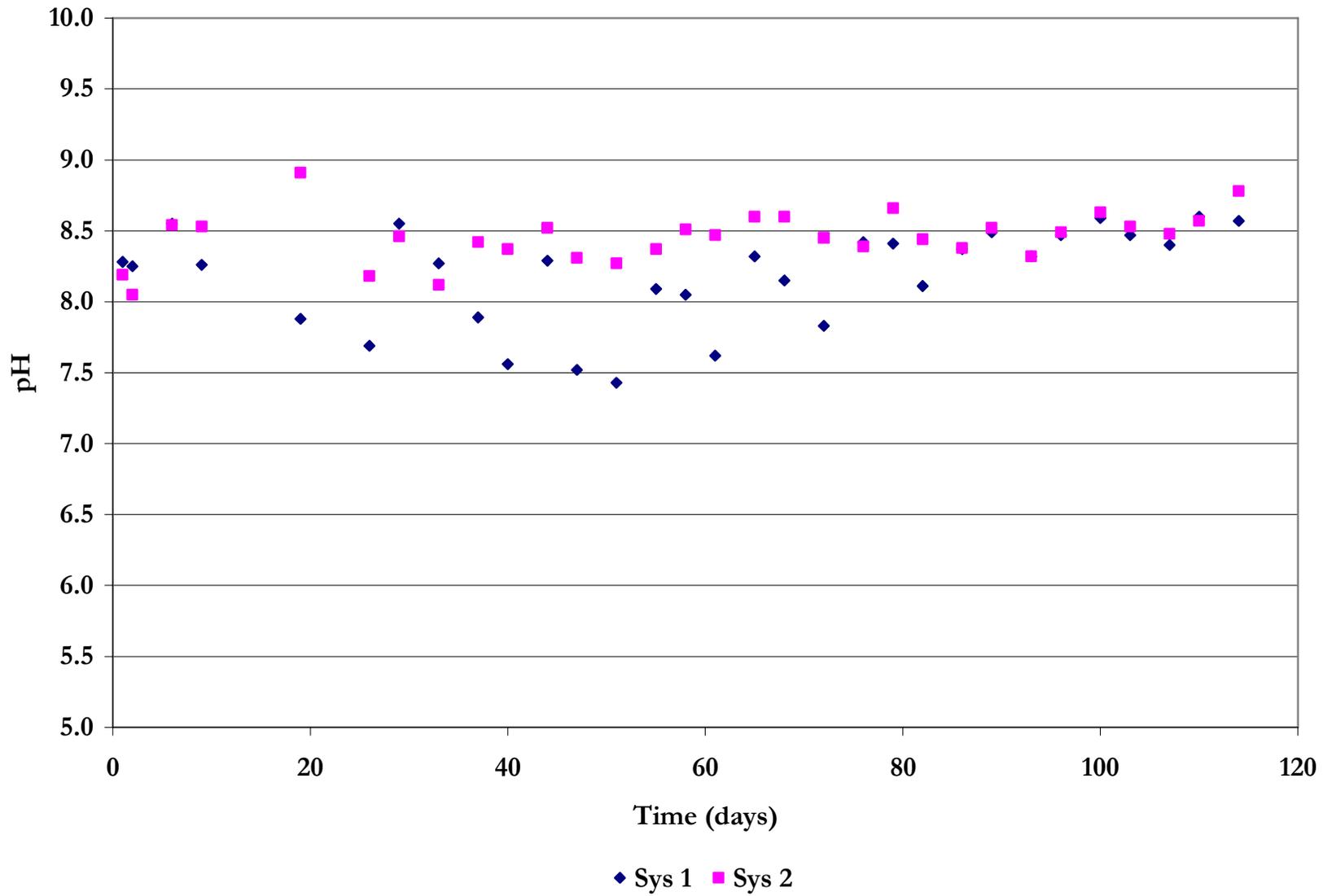


Figure 65 – pH trends in the PBR feed reservoirs during continuous feed mode operation

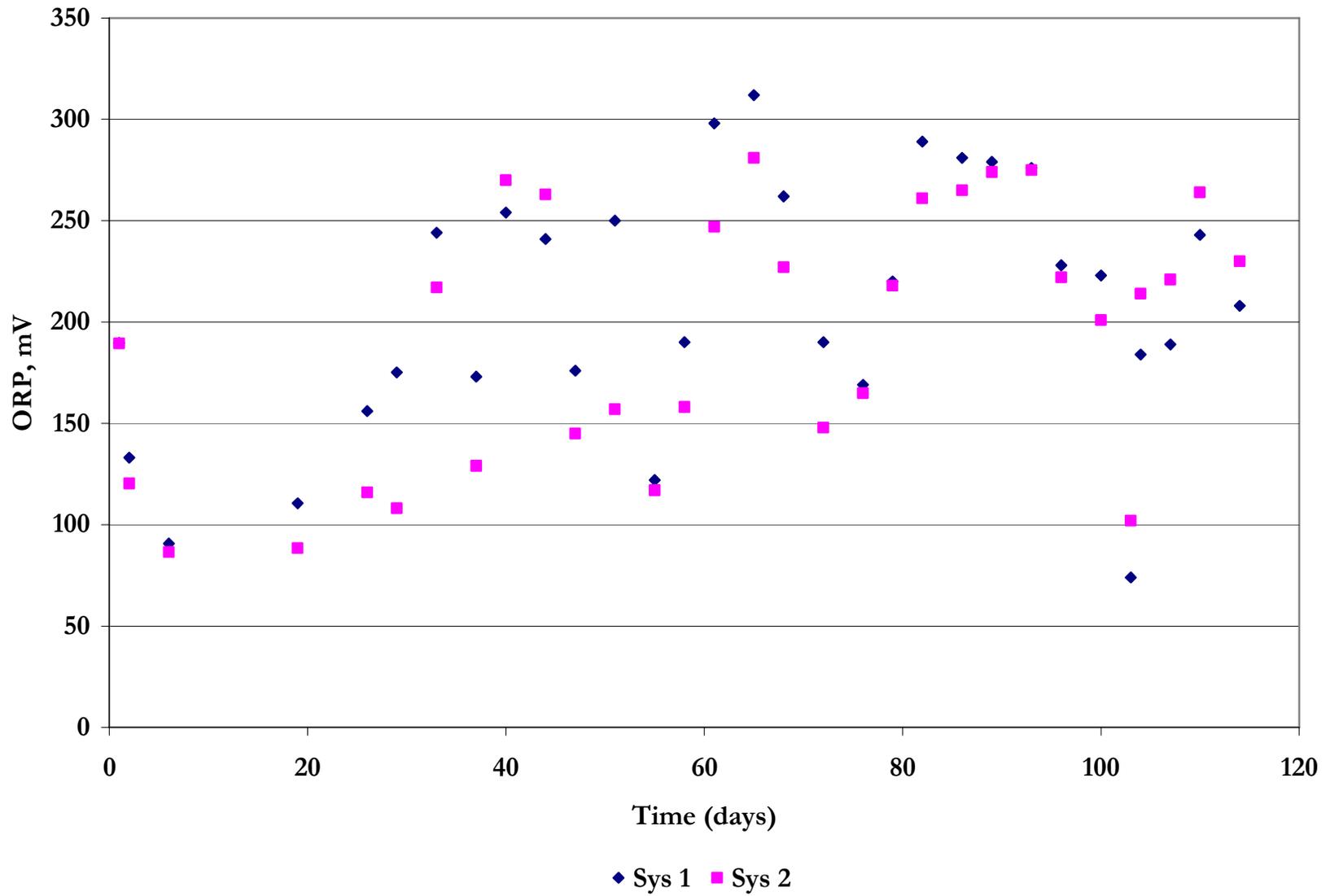


Figure 66 – ORP trends in the PBR feed reservoirs during continuous feed mode operation

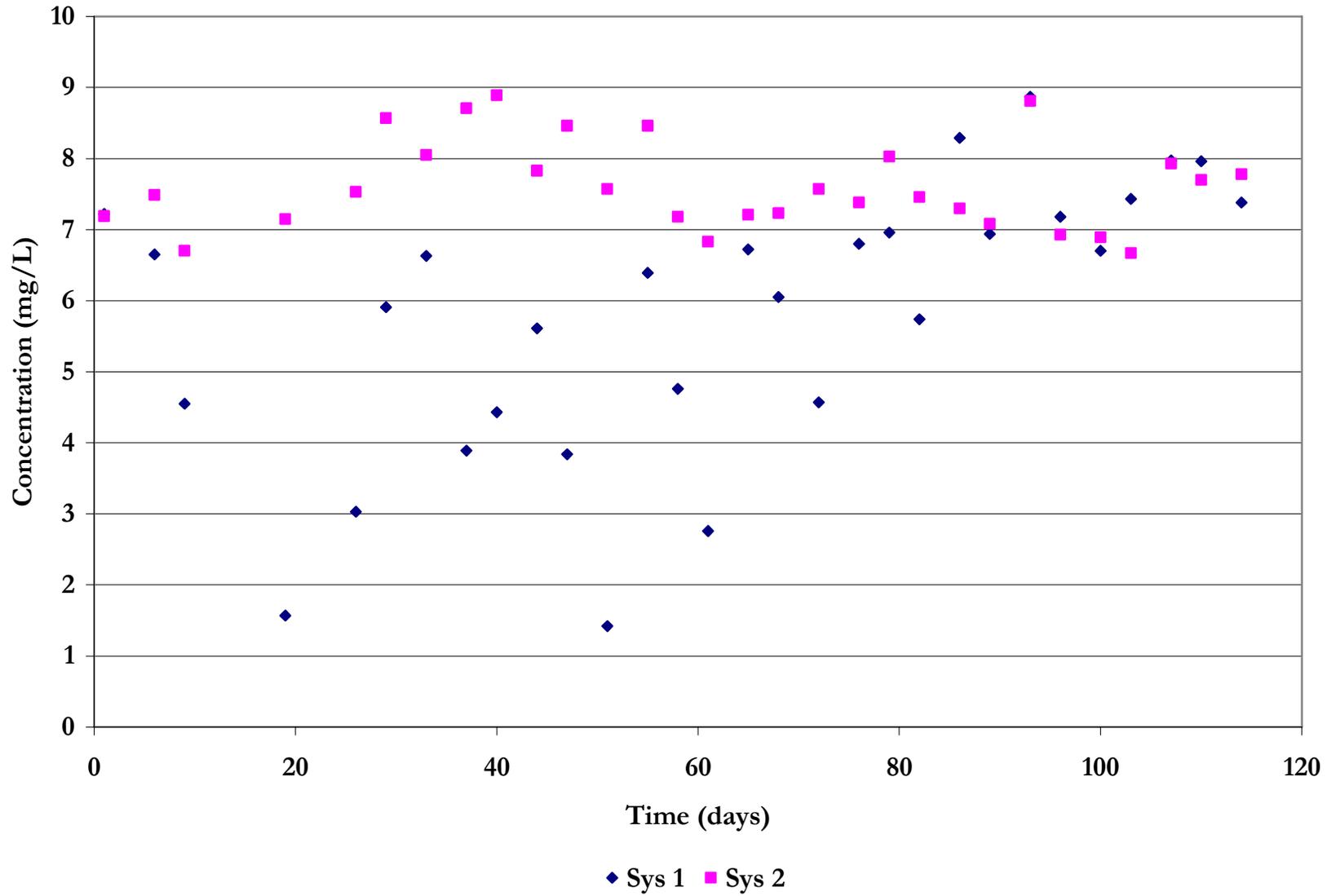


Figure 67 – D.O. trends in the PBR feed reservoirs during continuous feed mode operation

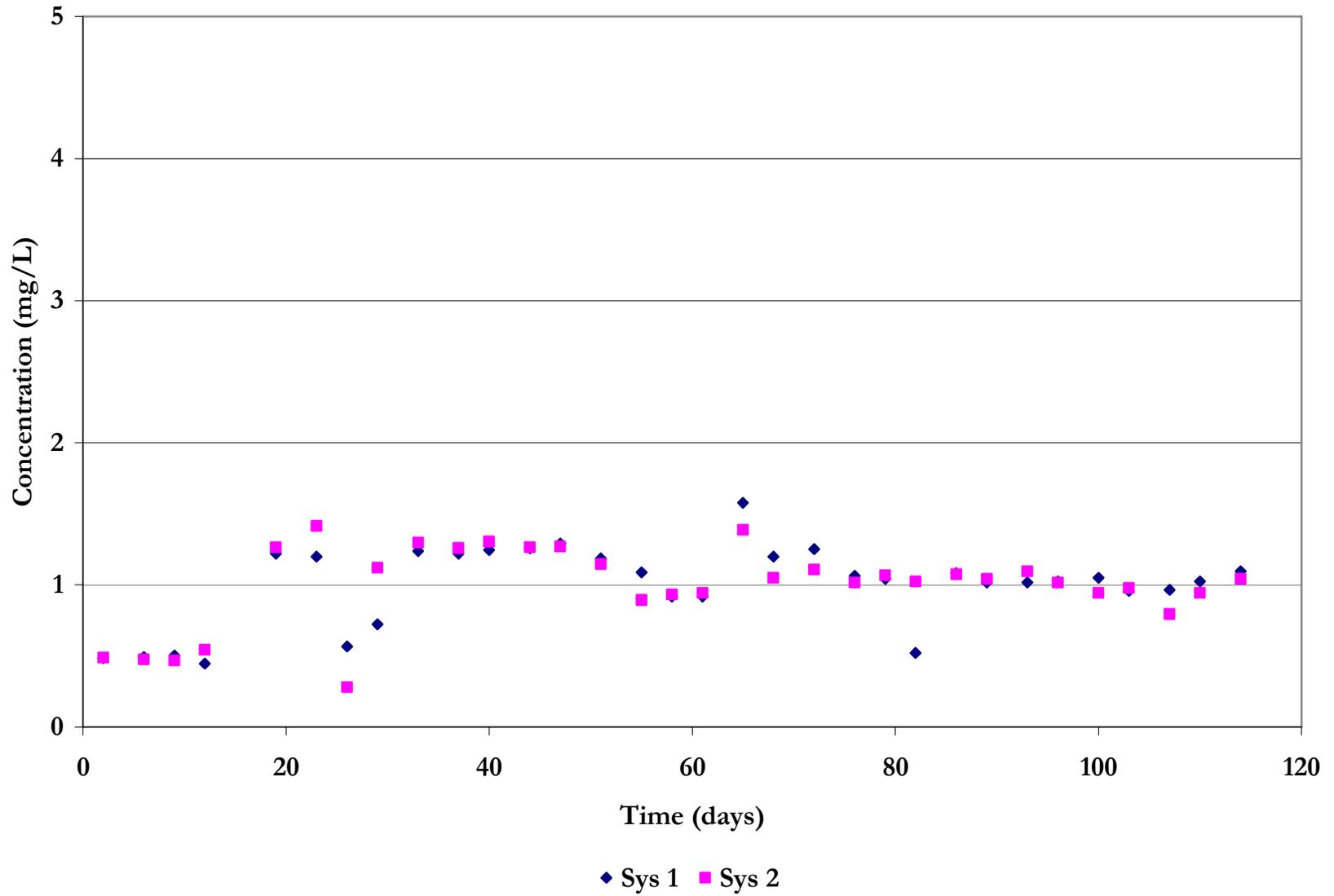


Figure 68 – Phosphate-P concentrations in the PBR feed reservoirs during continuous feed mode operation

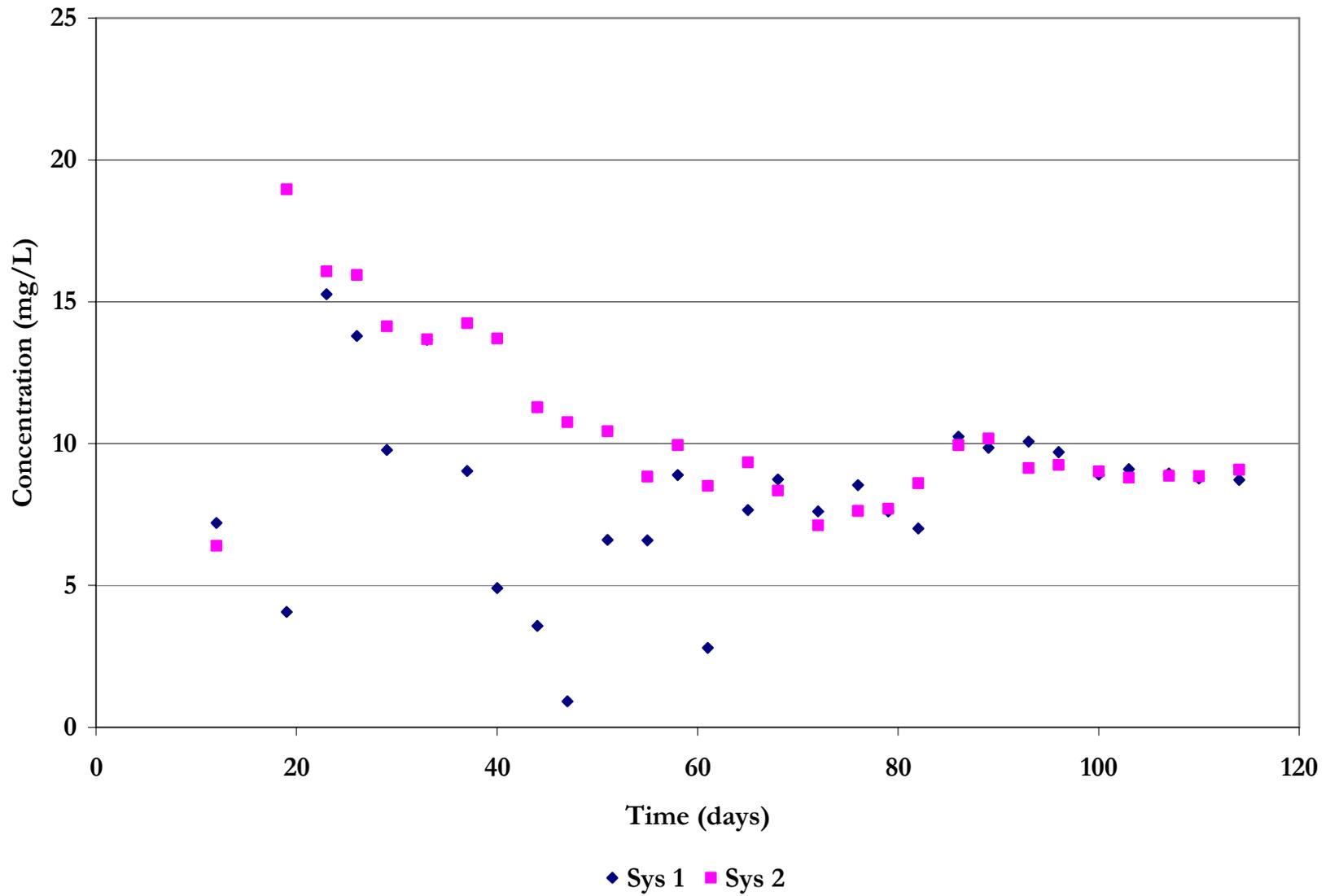


Figure 69 – Ammonium-N concentrations in the PBR feed reservoirs during continuous feed mode operation

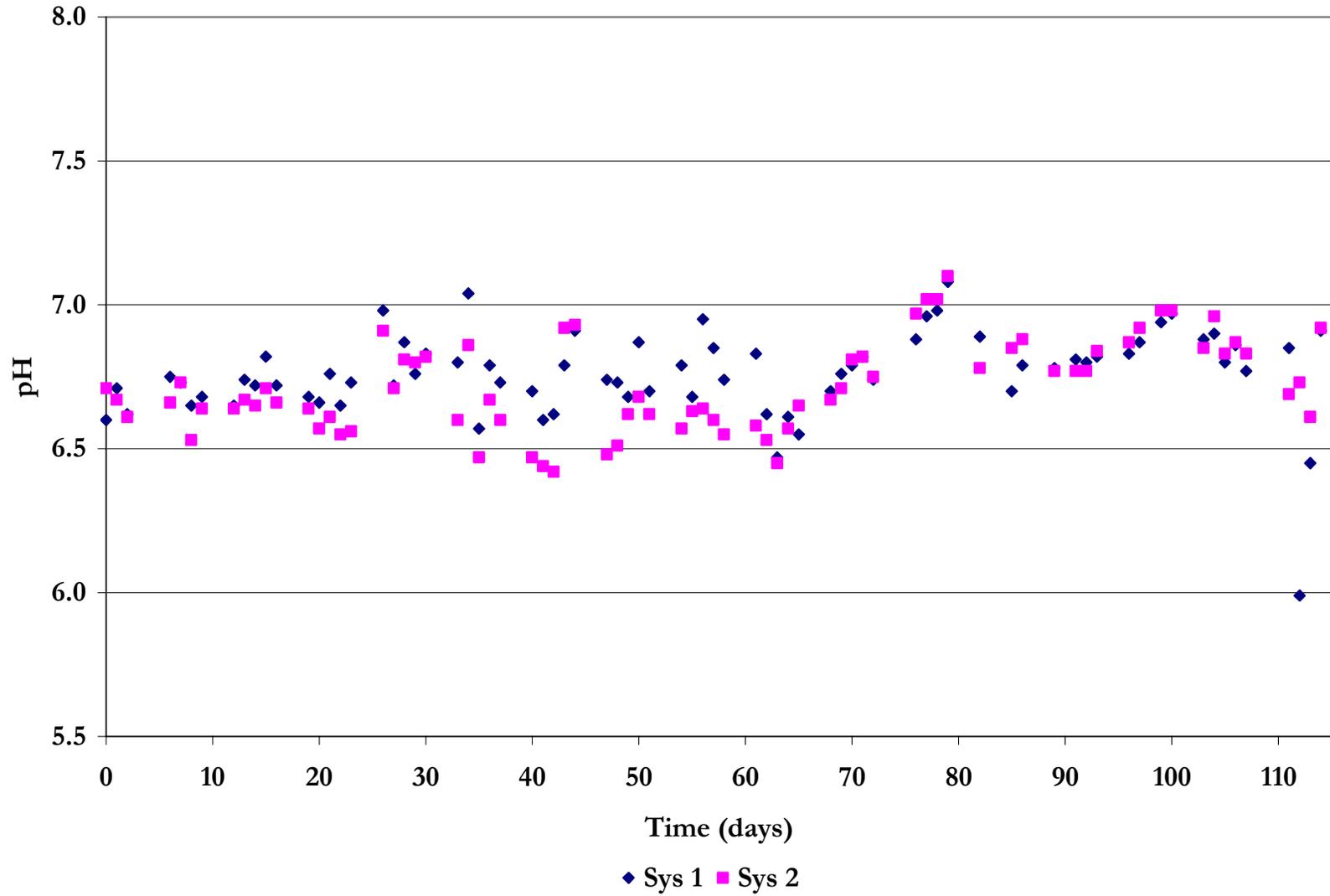


Figure 70 – pH trends in the PBR recycle reservoirs during continuous feed mode operation

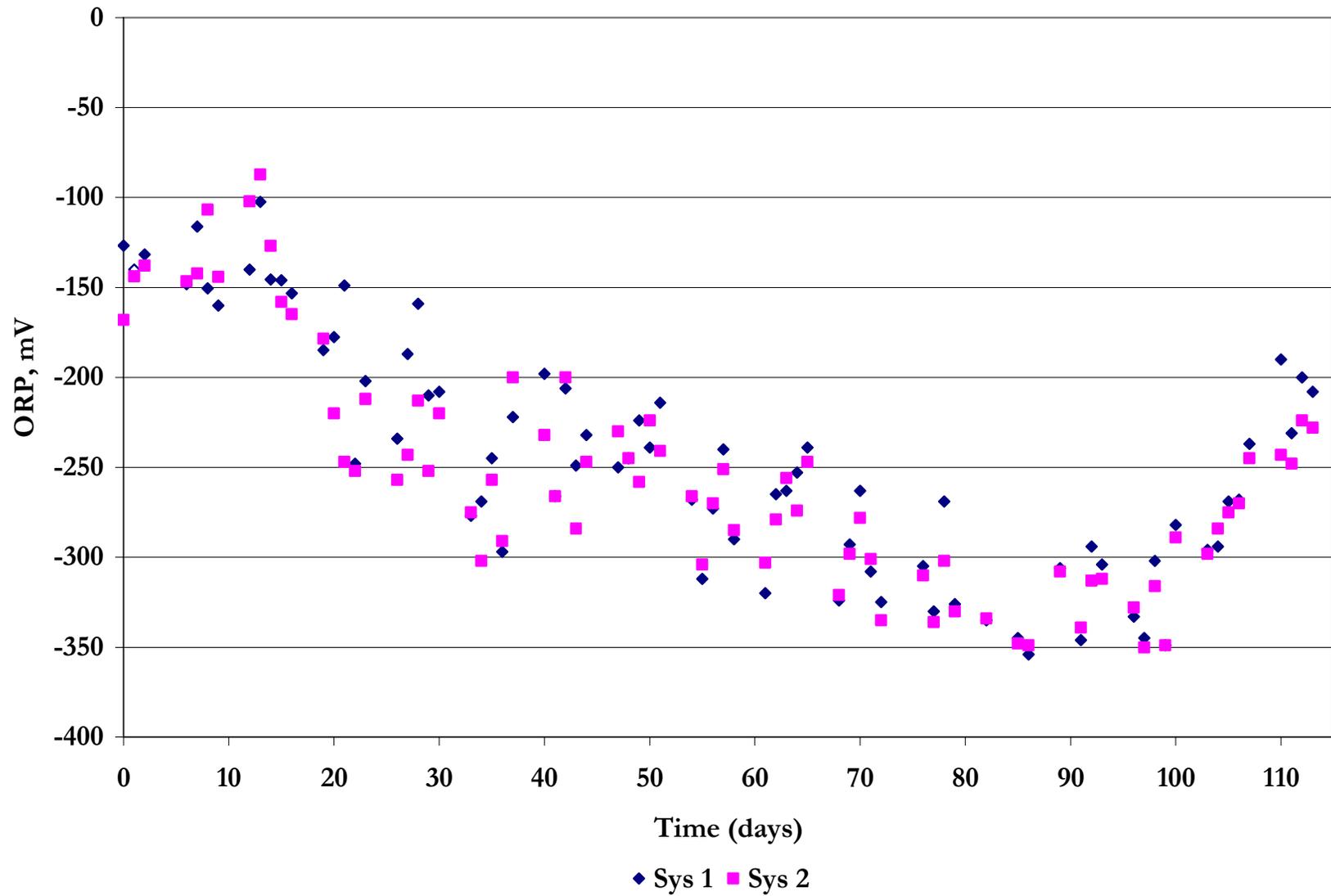


Figure 71 – ORP trends in the PBR recycle reservoirs during continuous feed mode operation

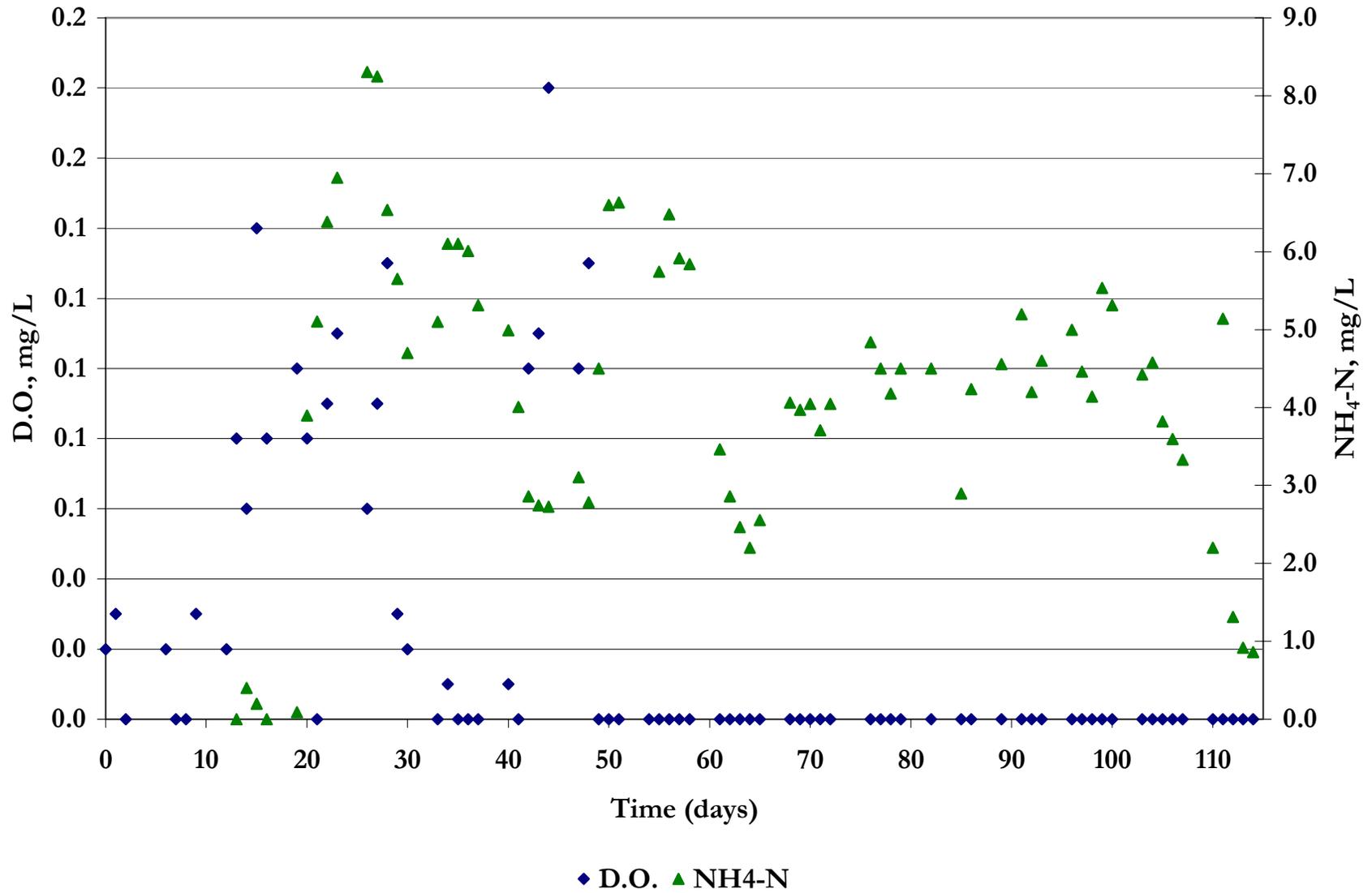


Figure 72 – Influence of PBR System 1 on dissolved oxygen and ammonium concentrations during continuous feed mode operation

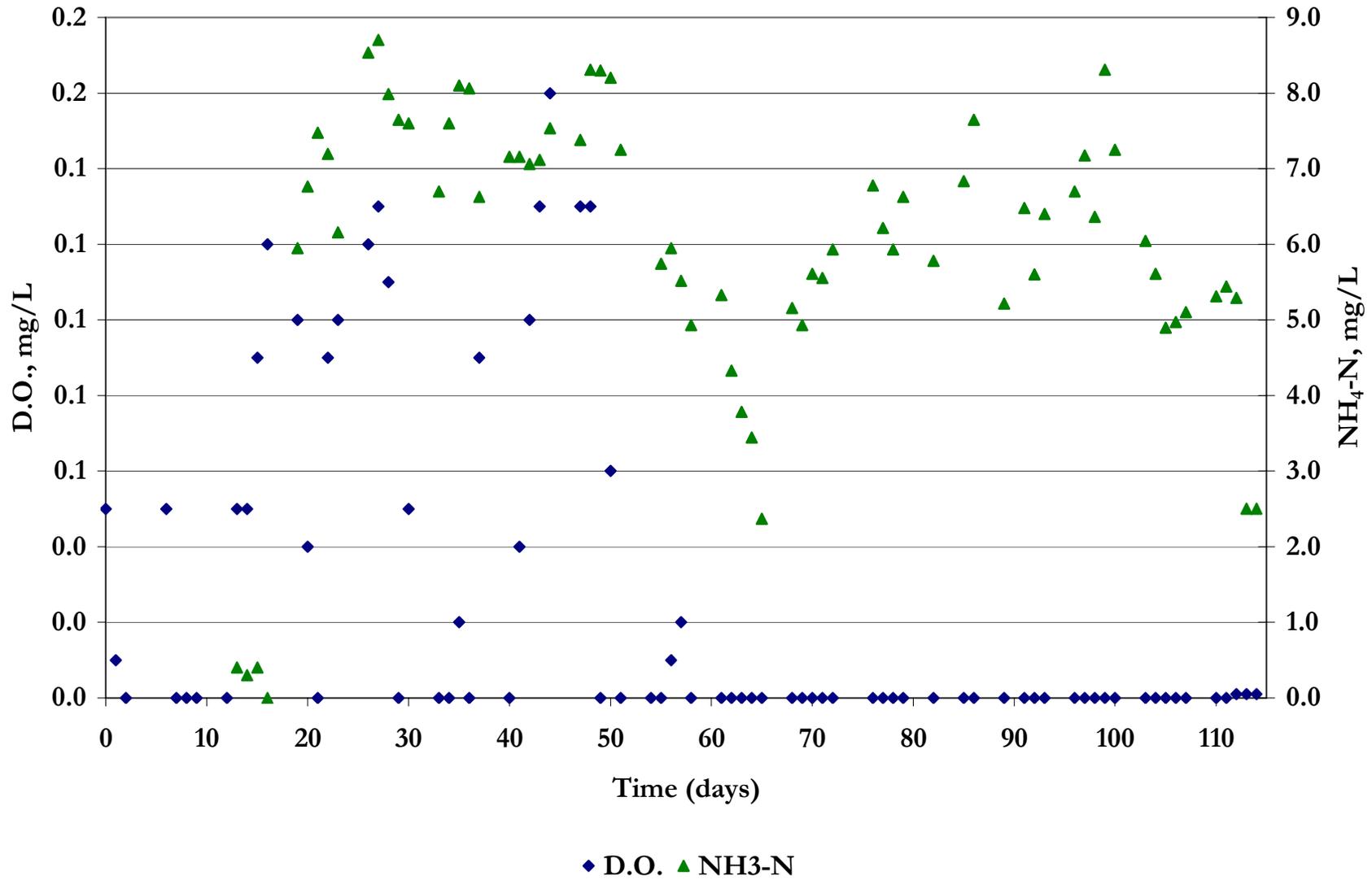


Figure 73 – Influence of PBR System 2 on dissolved oxygen and ammonium concentrations during continuous feed mode operation

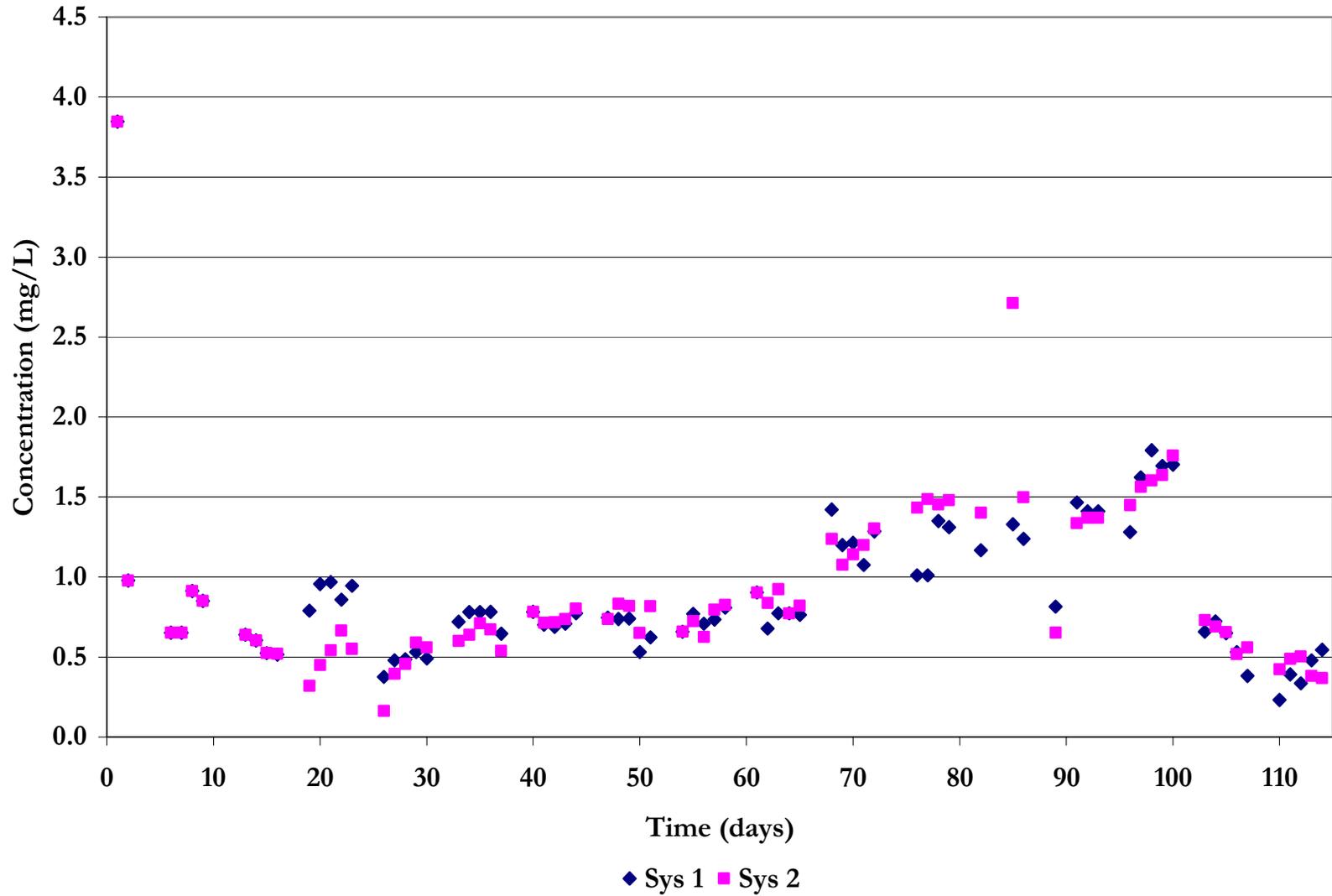


Figure 74 – Influence of PBR Systems 1 & 2 on phosphate-P concentrations during continuous feed mode operation

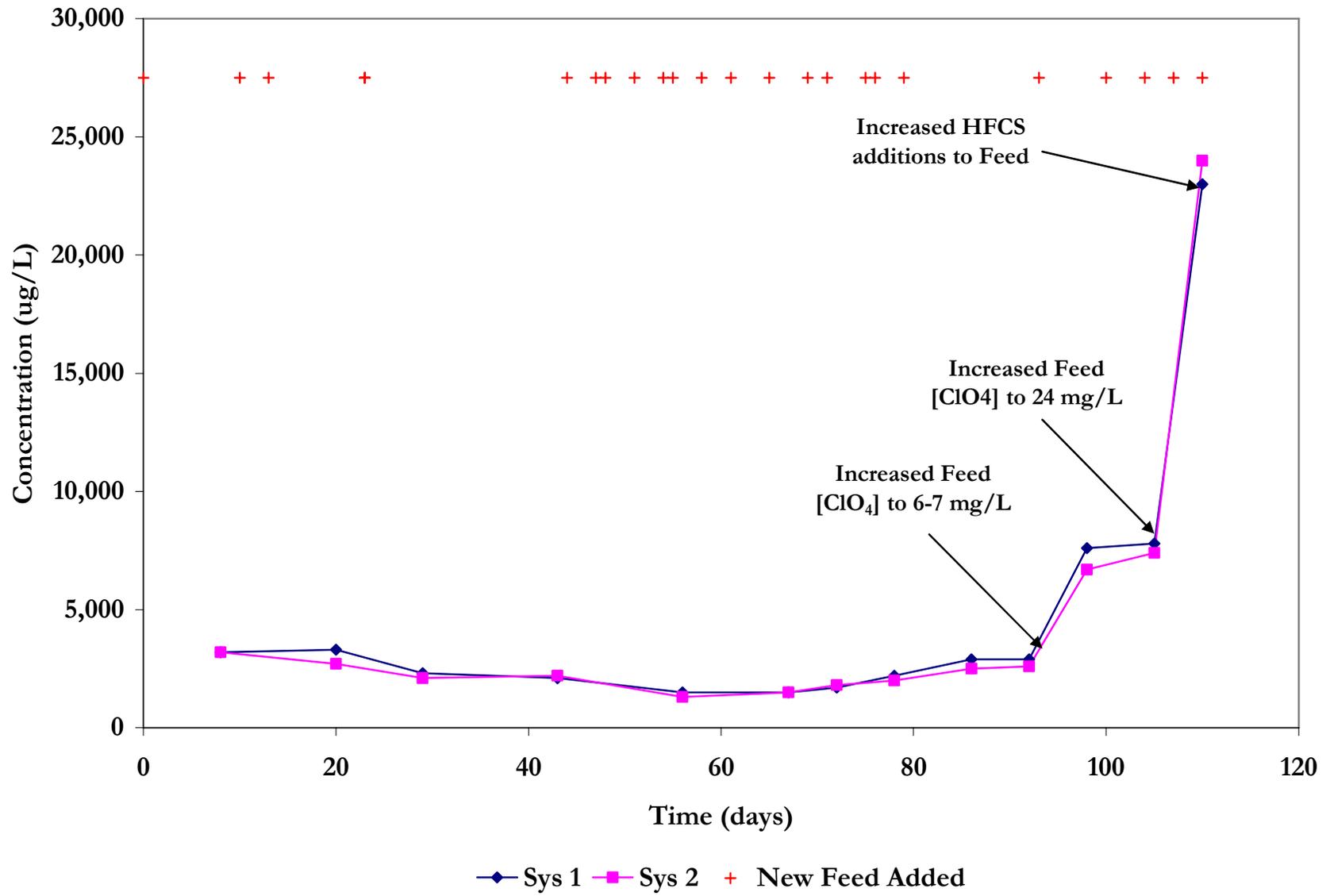


Figure 75 – PBR System 1 and 2 feed perchlorate concentrations

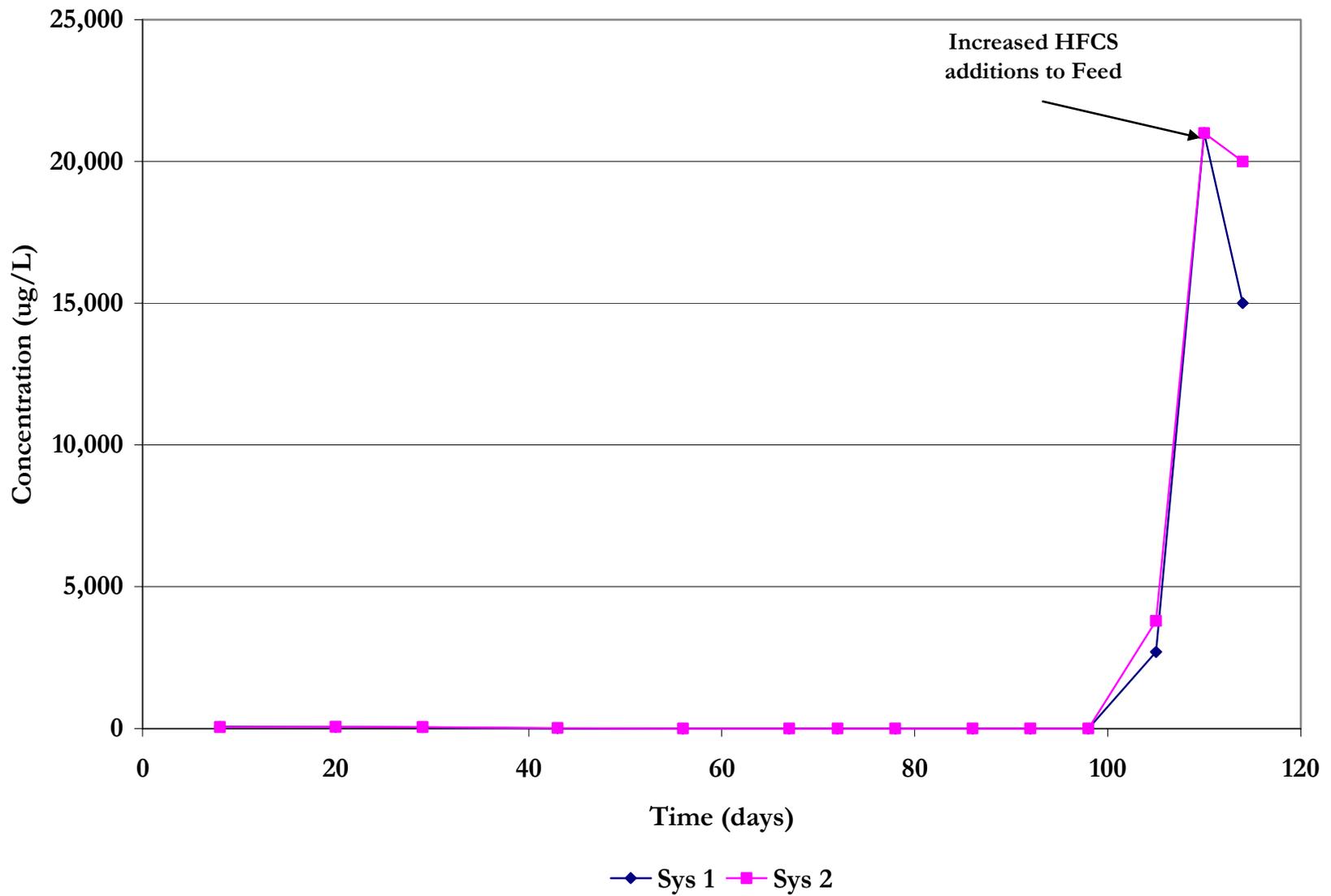


Figure 76 – Influence of PBR Systems 1 and 2 on perchlorate concentrations during continuous feed mode operation

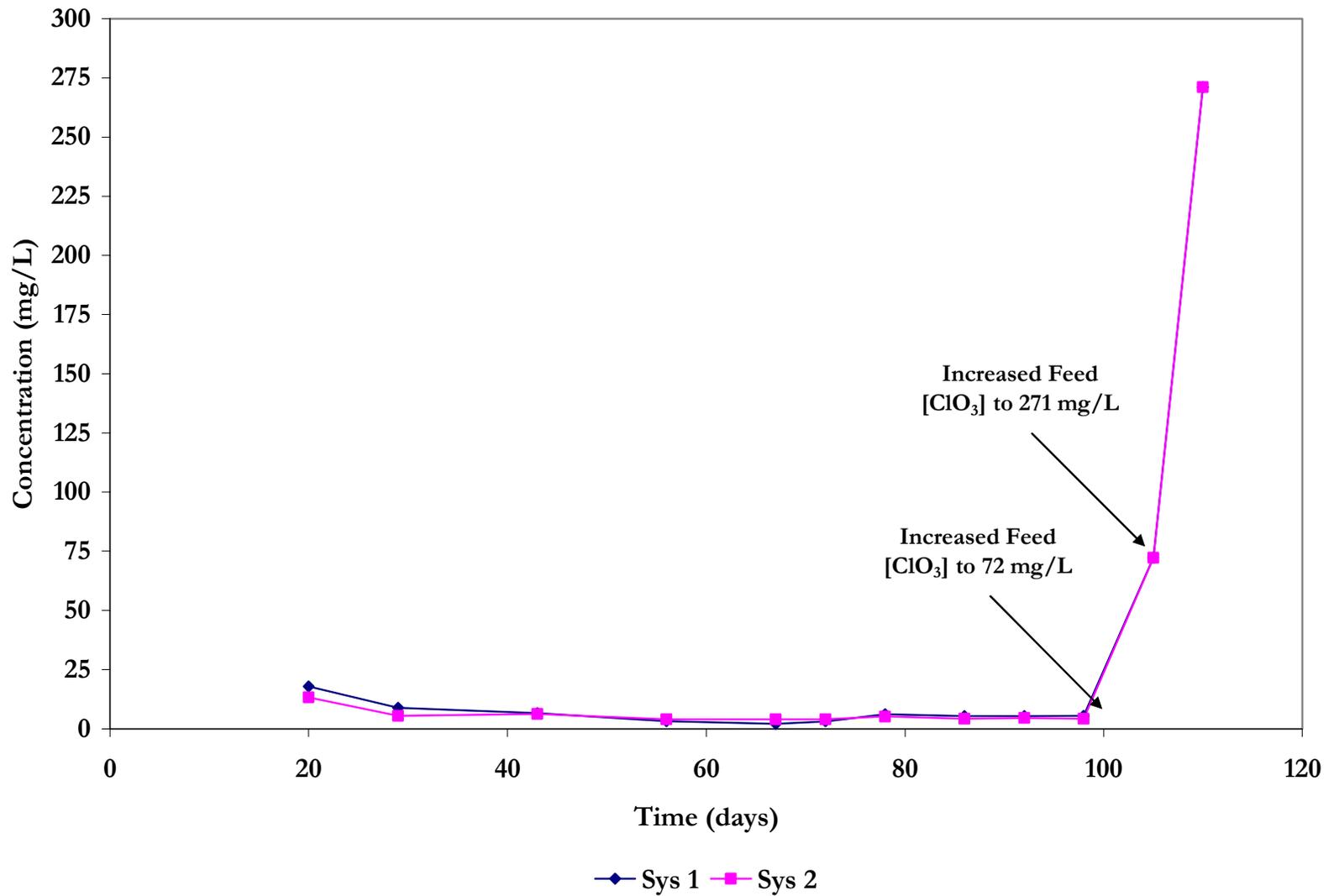


Figure 77 – PBR System 1 and 2 feed chlorate concentrations

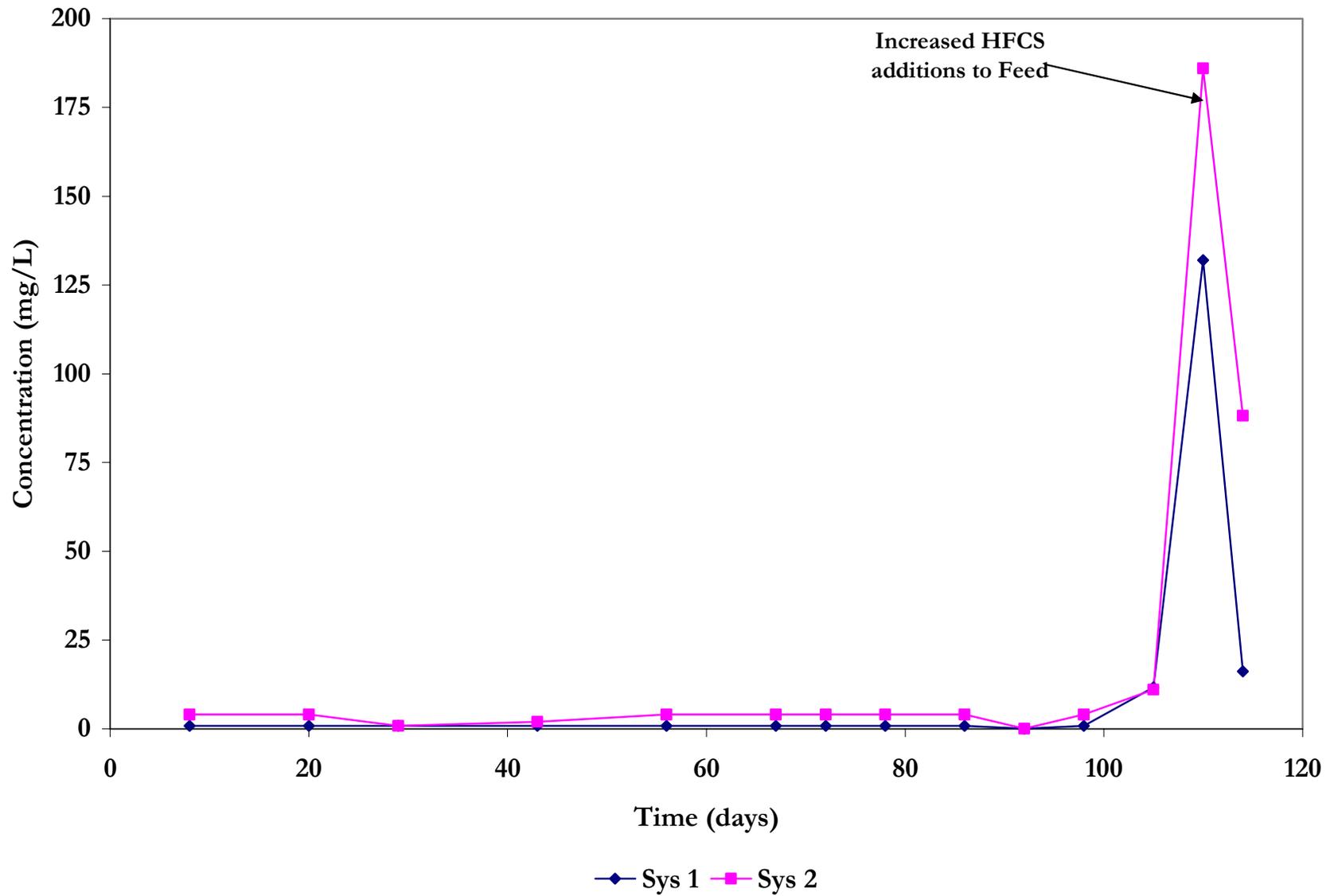


Figure 78 – Influence of PBR Systems 1 and 2 on chlorate concentrations during continuous feed mode operation

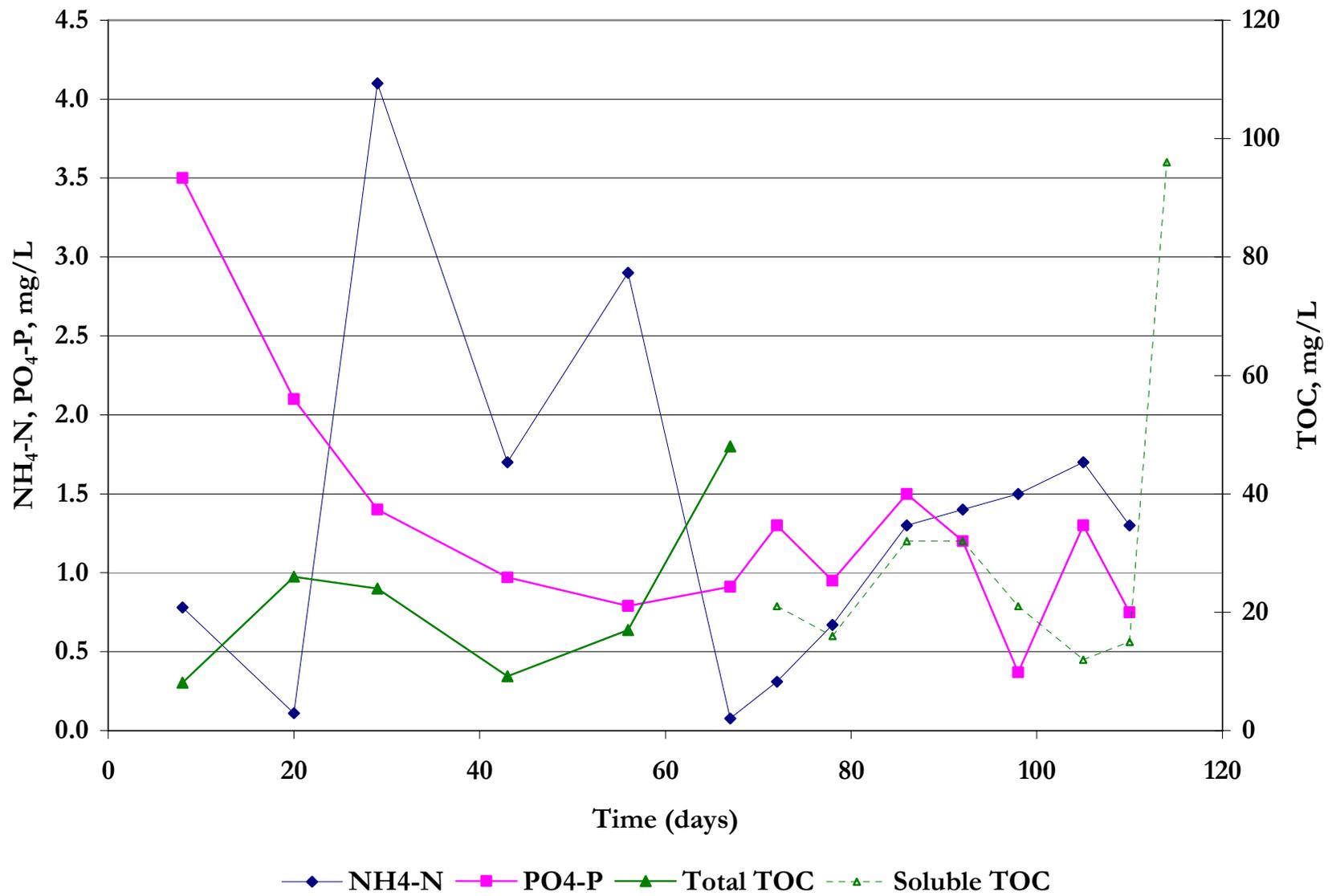


Figure 79 – Influence of PBR System 1 on ammonium, phosphate, and TOC concentrations during continuous feed mode operation

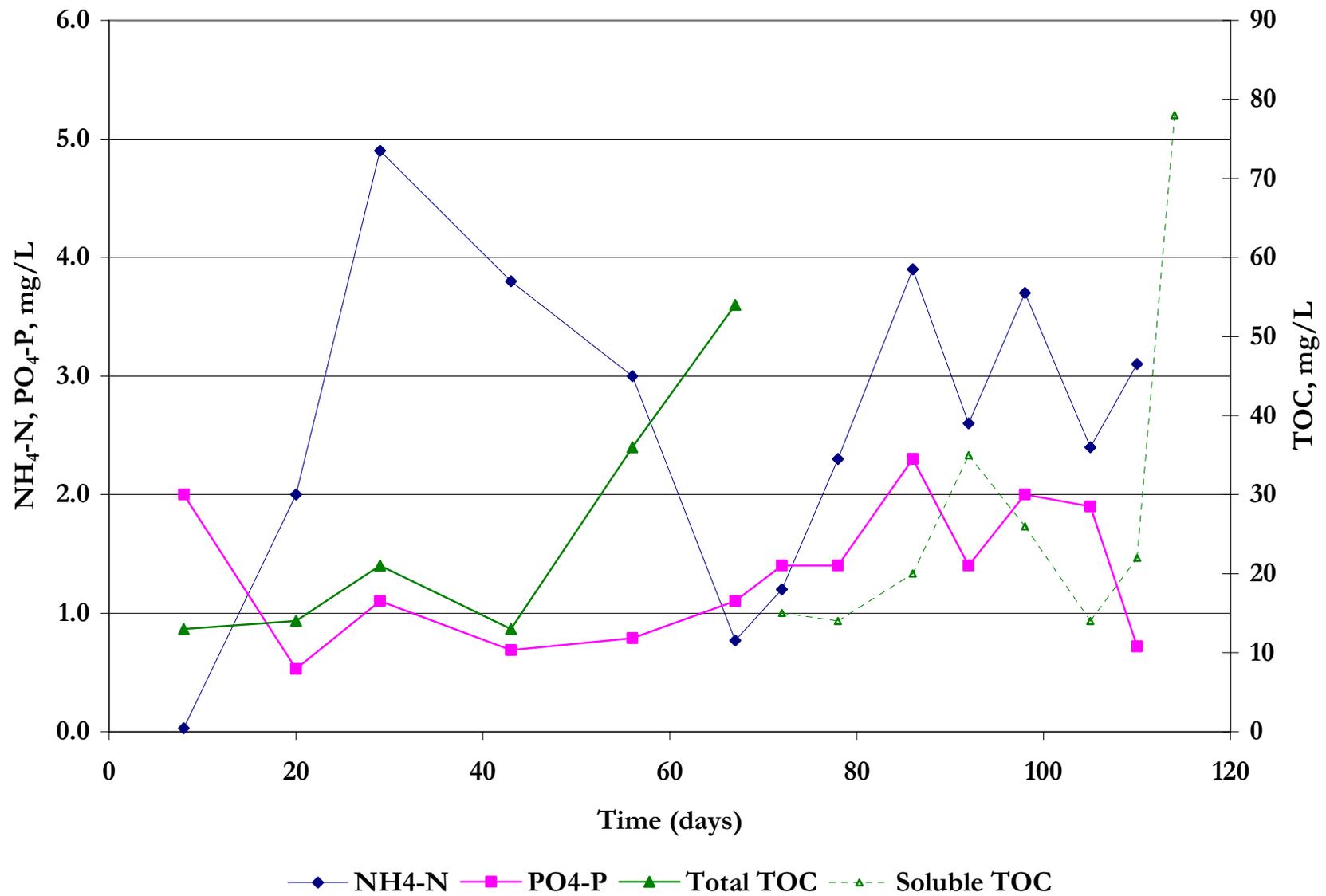


Figure 80 – Influence of PBR System 2 on ammonium, phosphate, and TOC concentrations during continuous feed mode operation

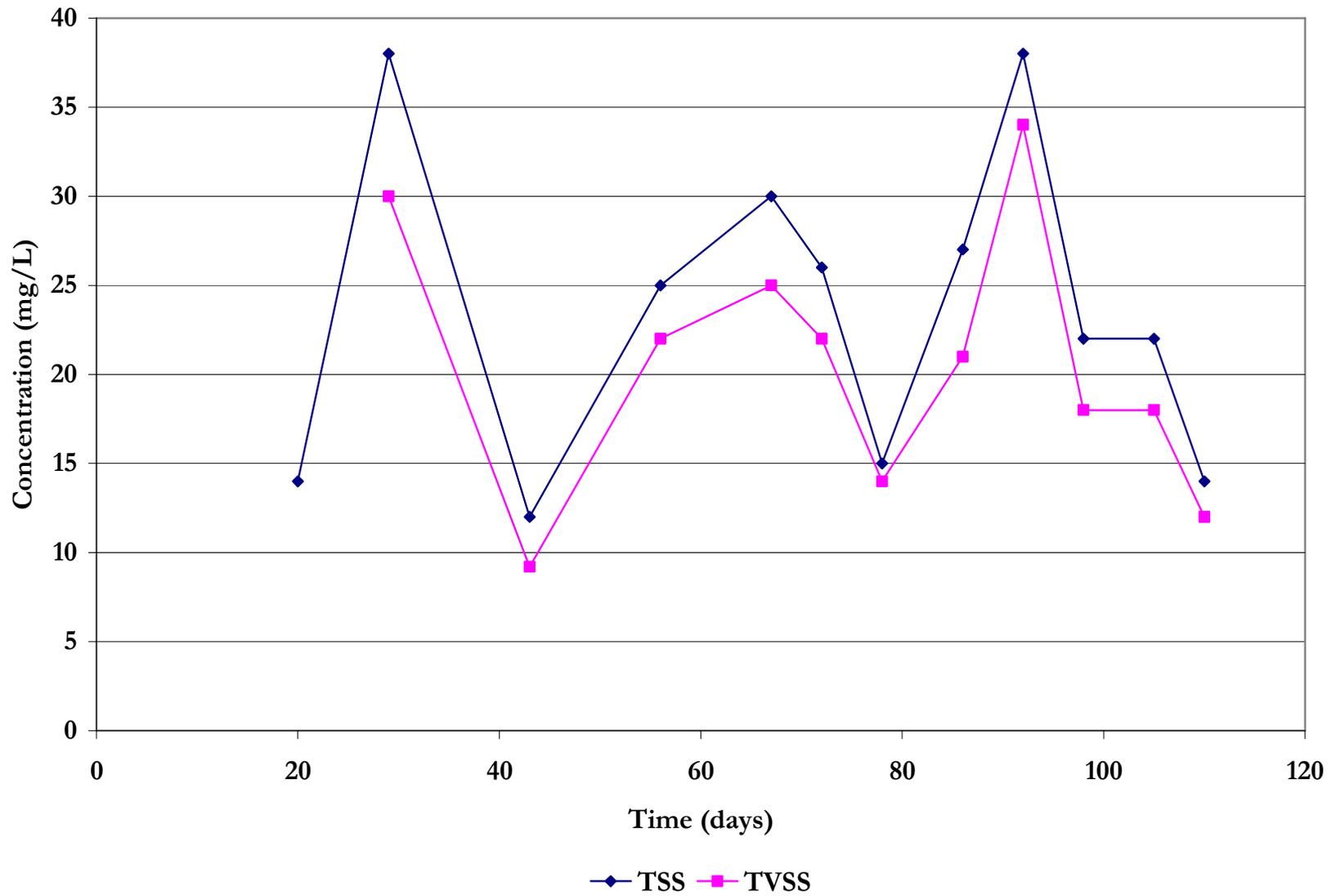


Figure 81 - Influence of PBR System 1 on TSS and TVSS concentrations during continuous feed mode operation

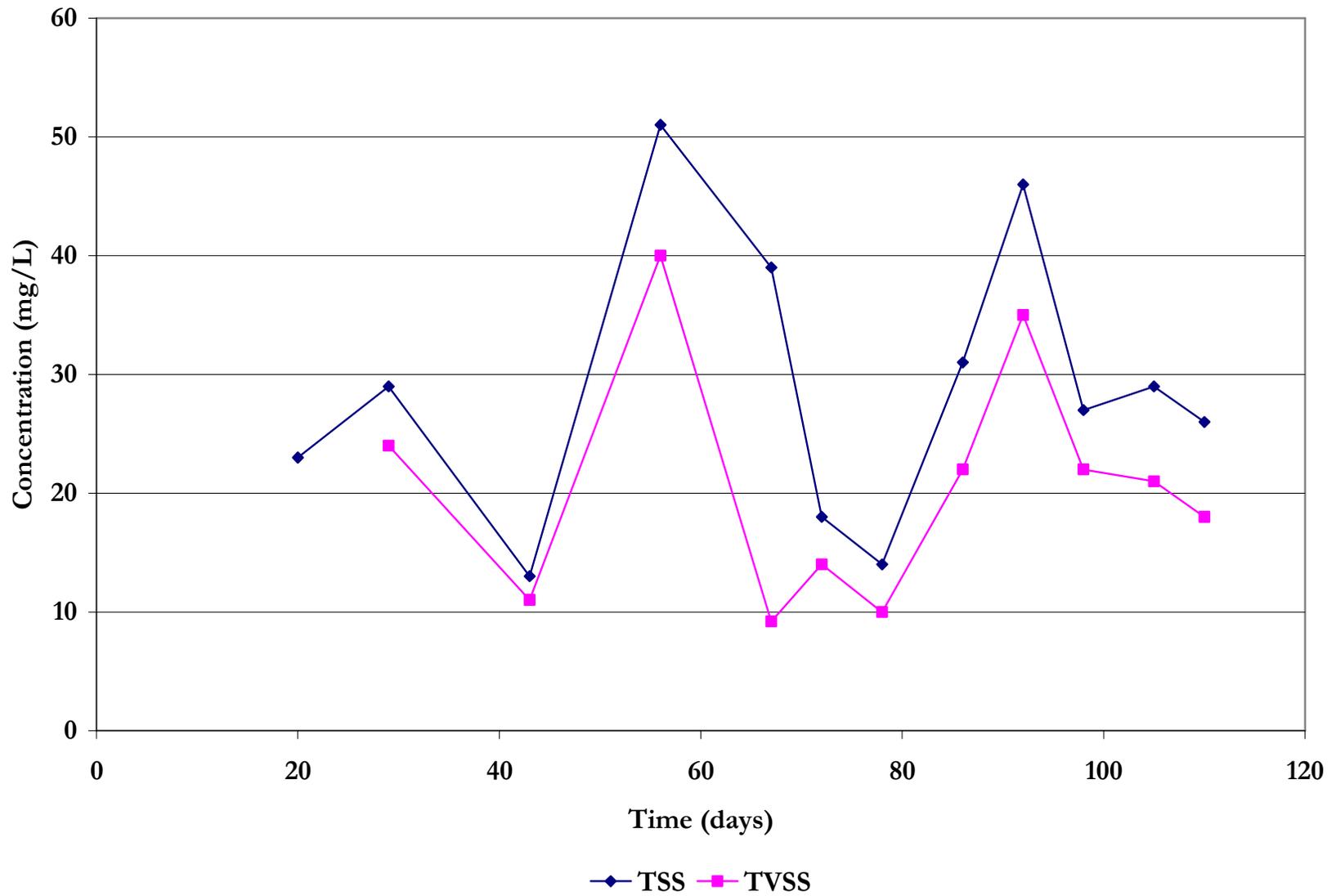


Figure 82 – Influence of PBR System 2 on TSS and TVSS concentrations during continuous feed mode operation

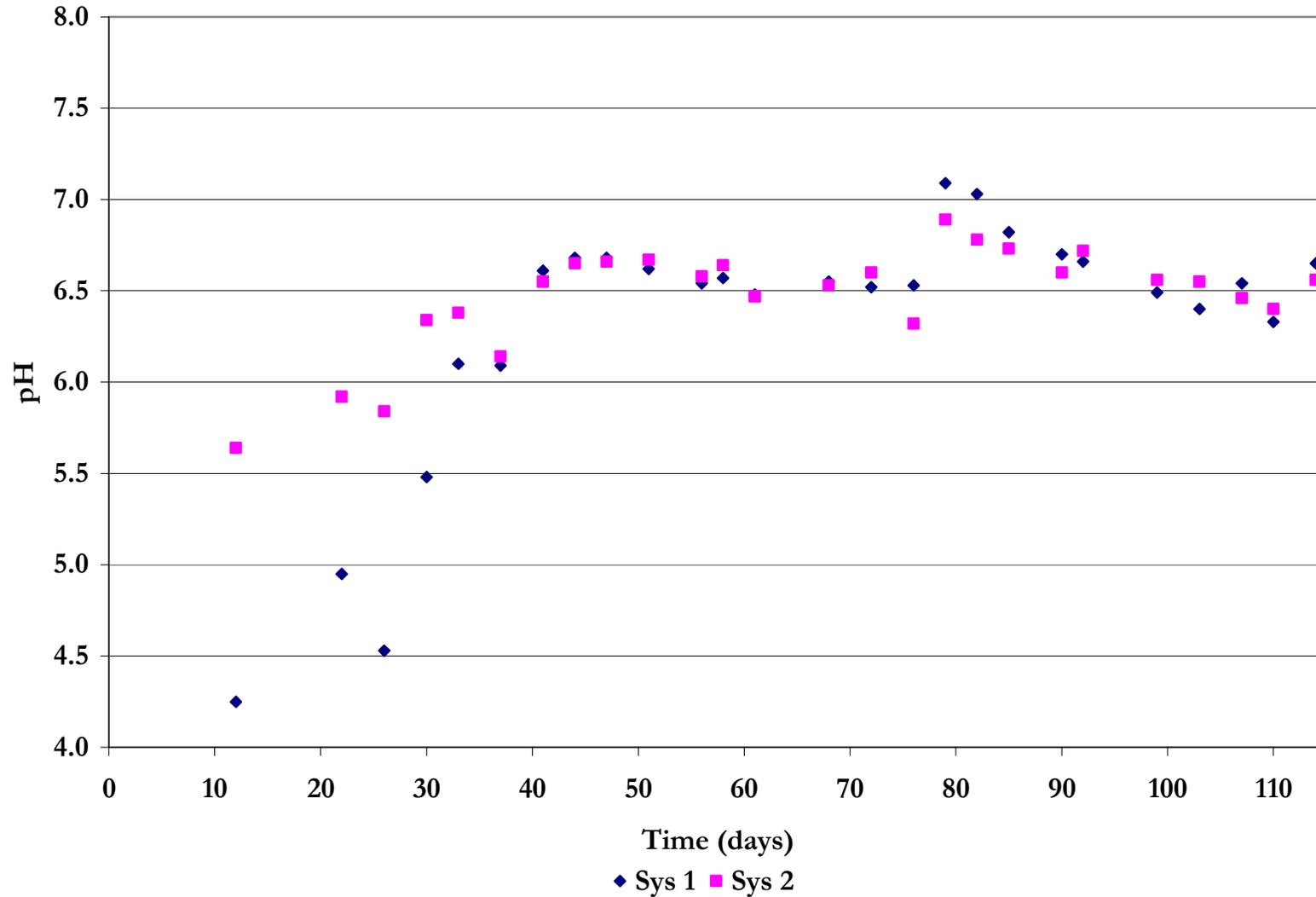


Figure 83 – pH trends in the Alternate Treatment System feeds

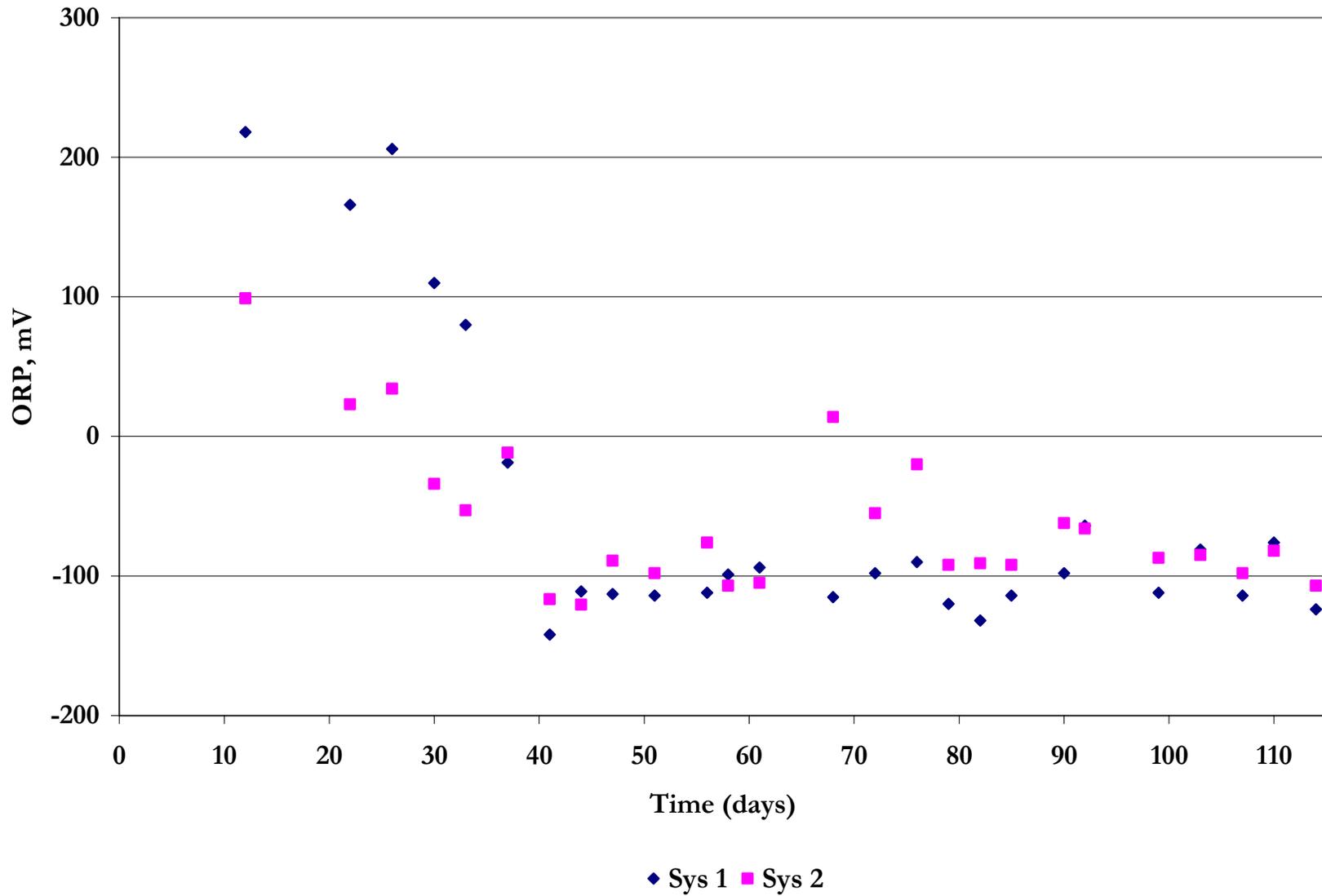


Figure 84 – ORP trends in the Alternate Treatment System feeds

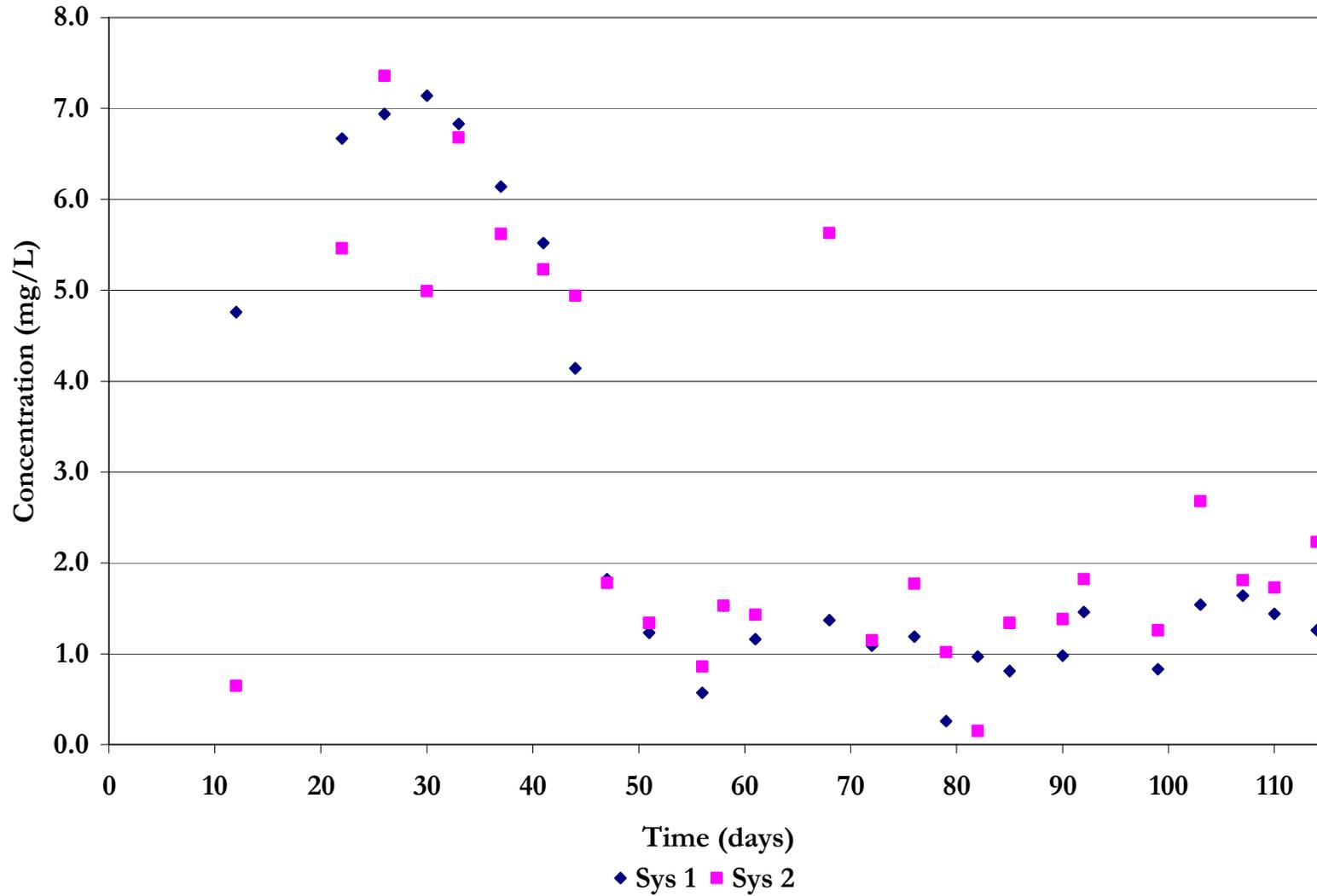


Figure 85 – Dissolved oxygen concentrations in the Alternate Treatment System feeds

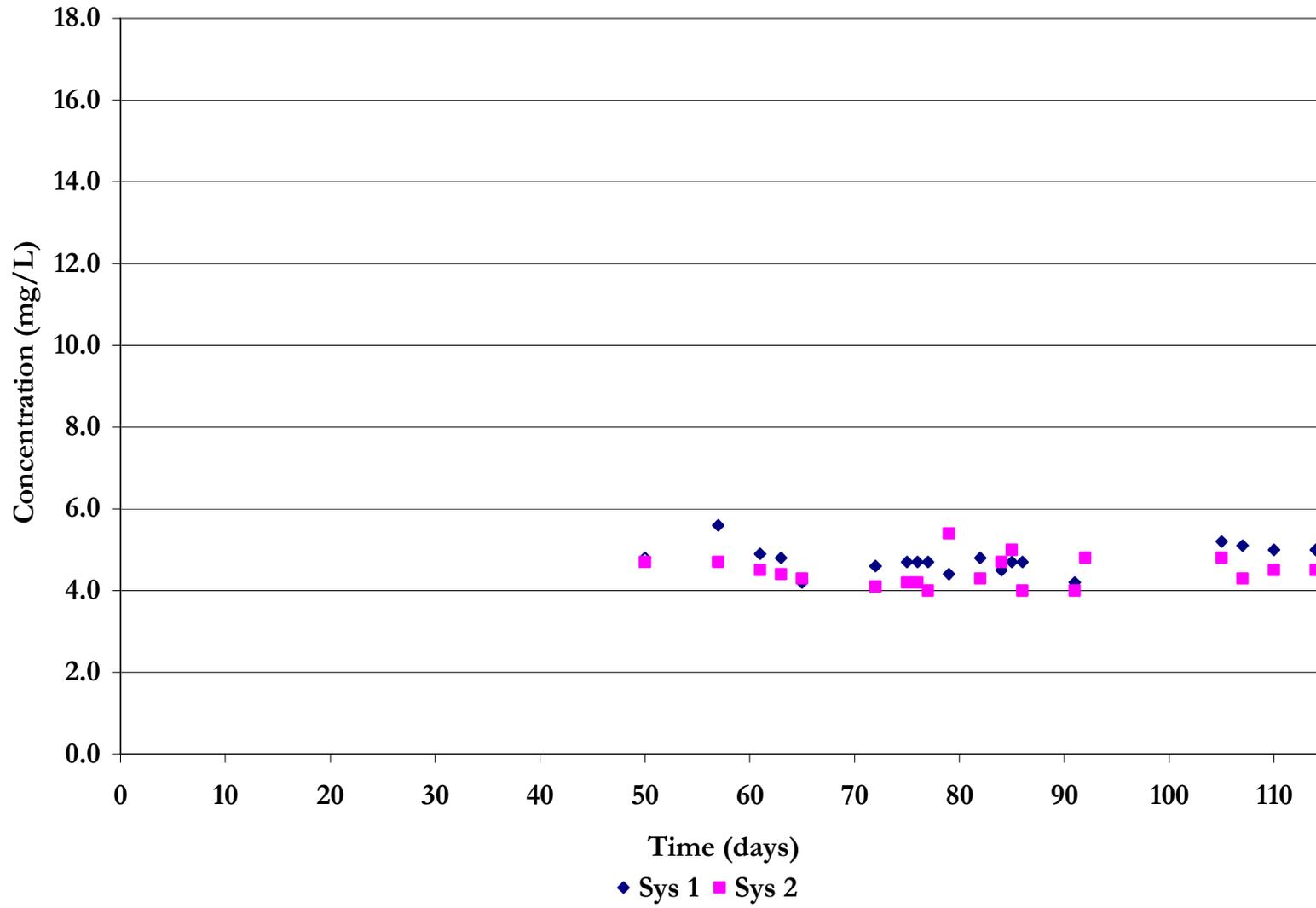


Figure 86 – Ammonium concentrations in the Alternate Treatment System feeds

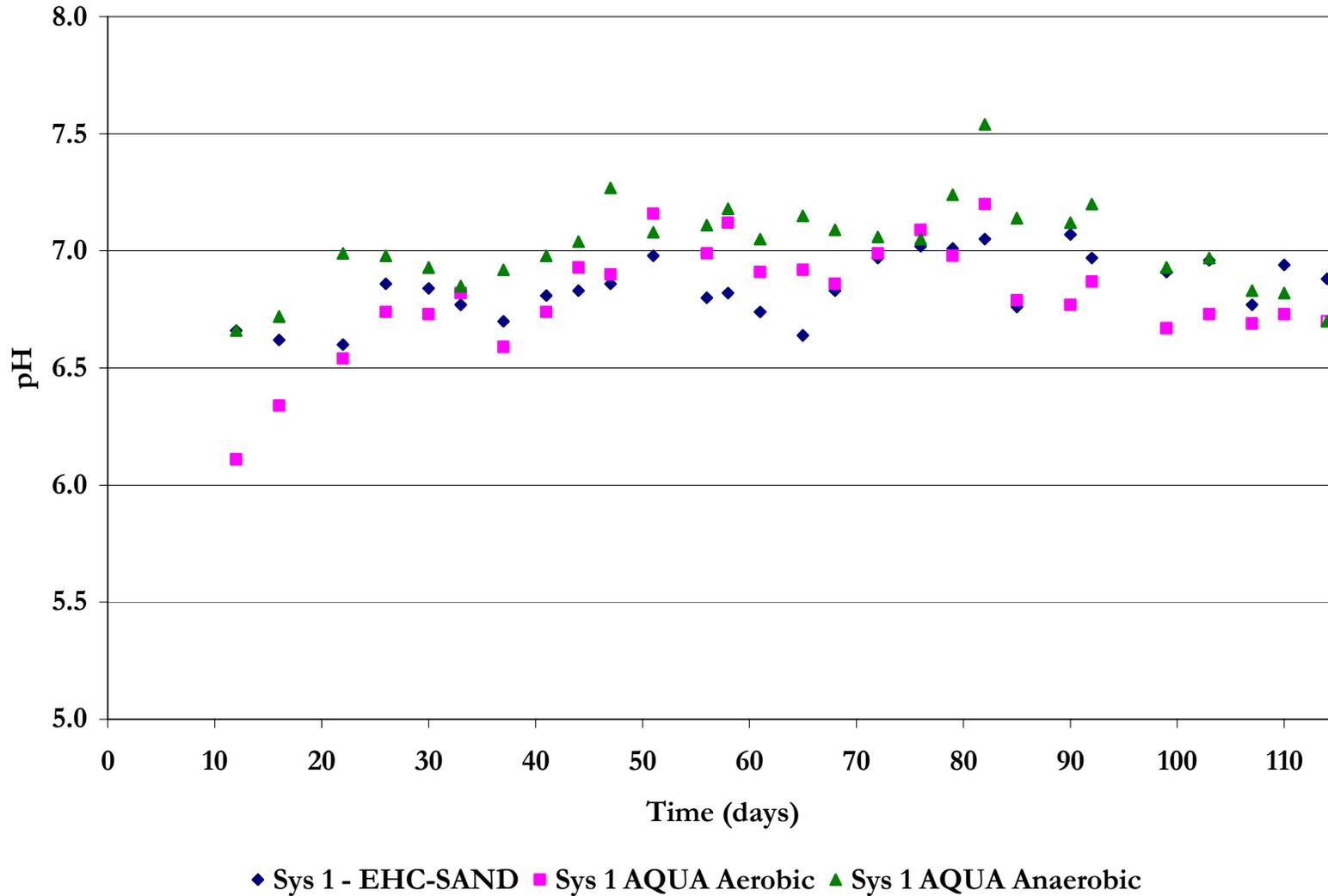


Figure 87 – pH trends in the Alternate Treatment System 1 effluents

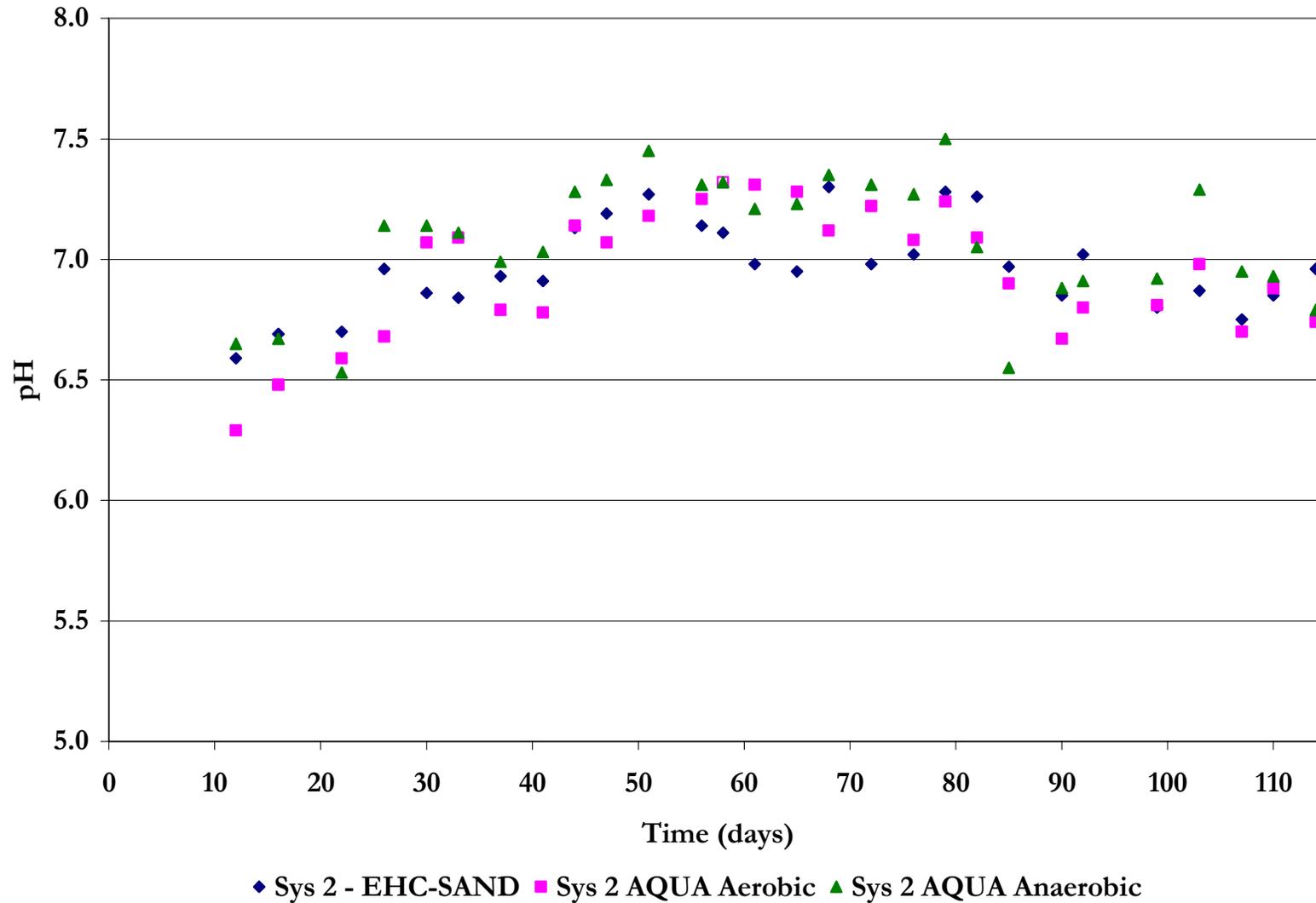


Figure 88 – pH trends in the Alternate Treatment System 2 effluents

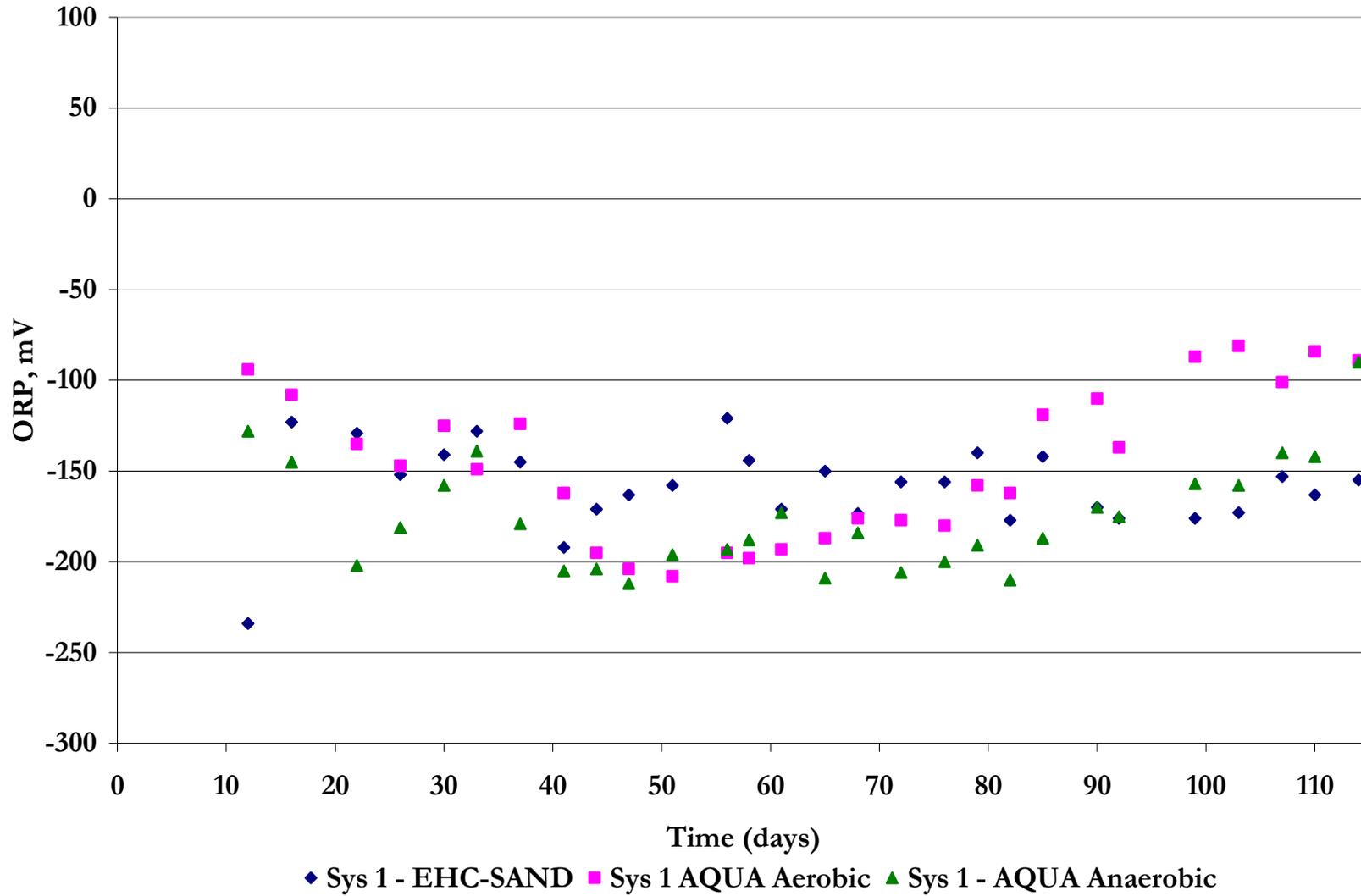


Figure 89 – ORP trends in the Alternate Treatment System 1 effluents

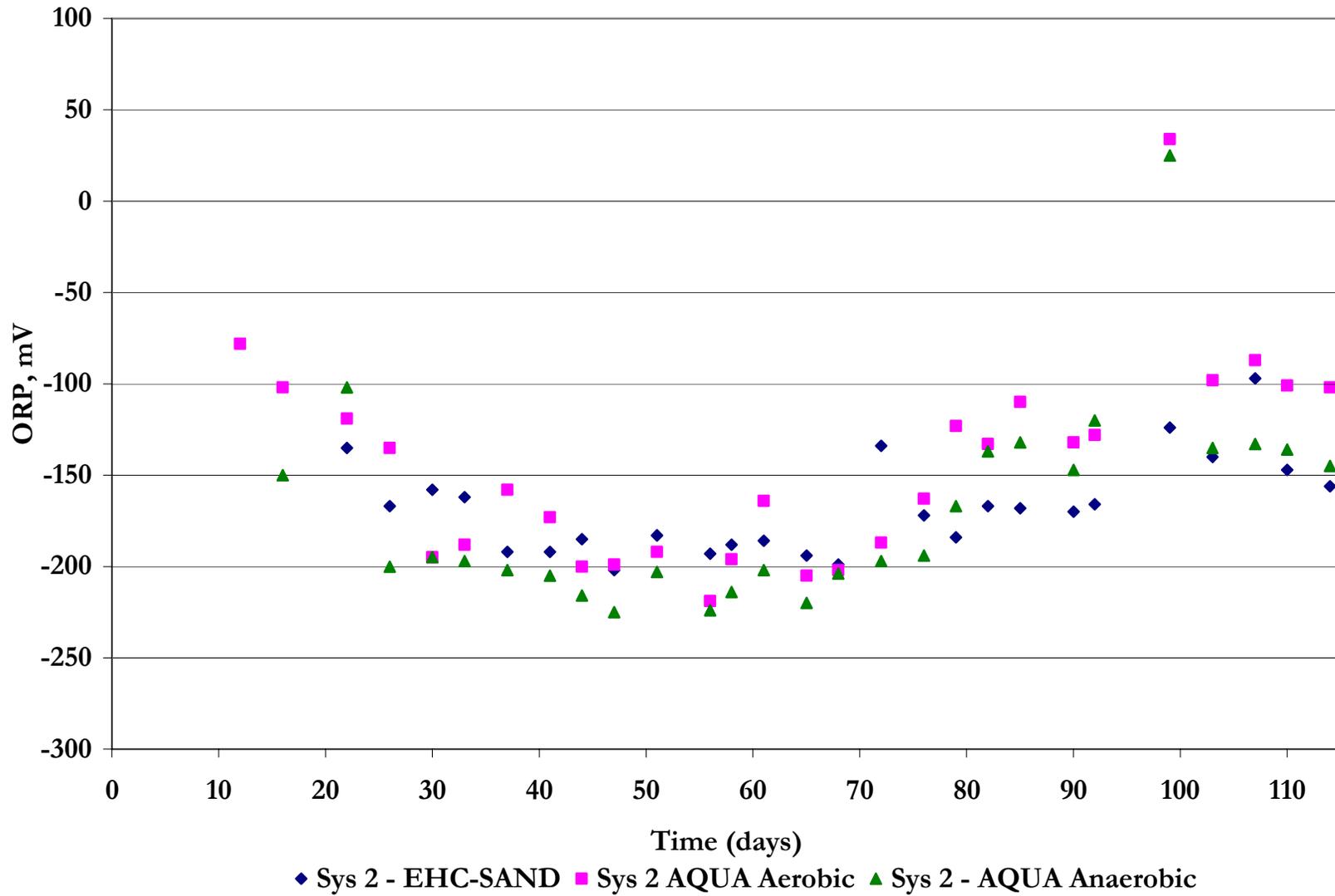


Figure 90 – ORP trends in the Alternate Treatment System 2 effluents

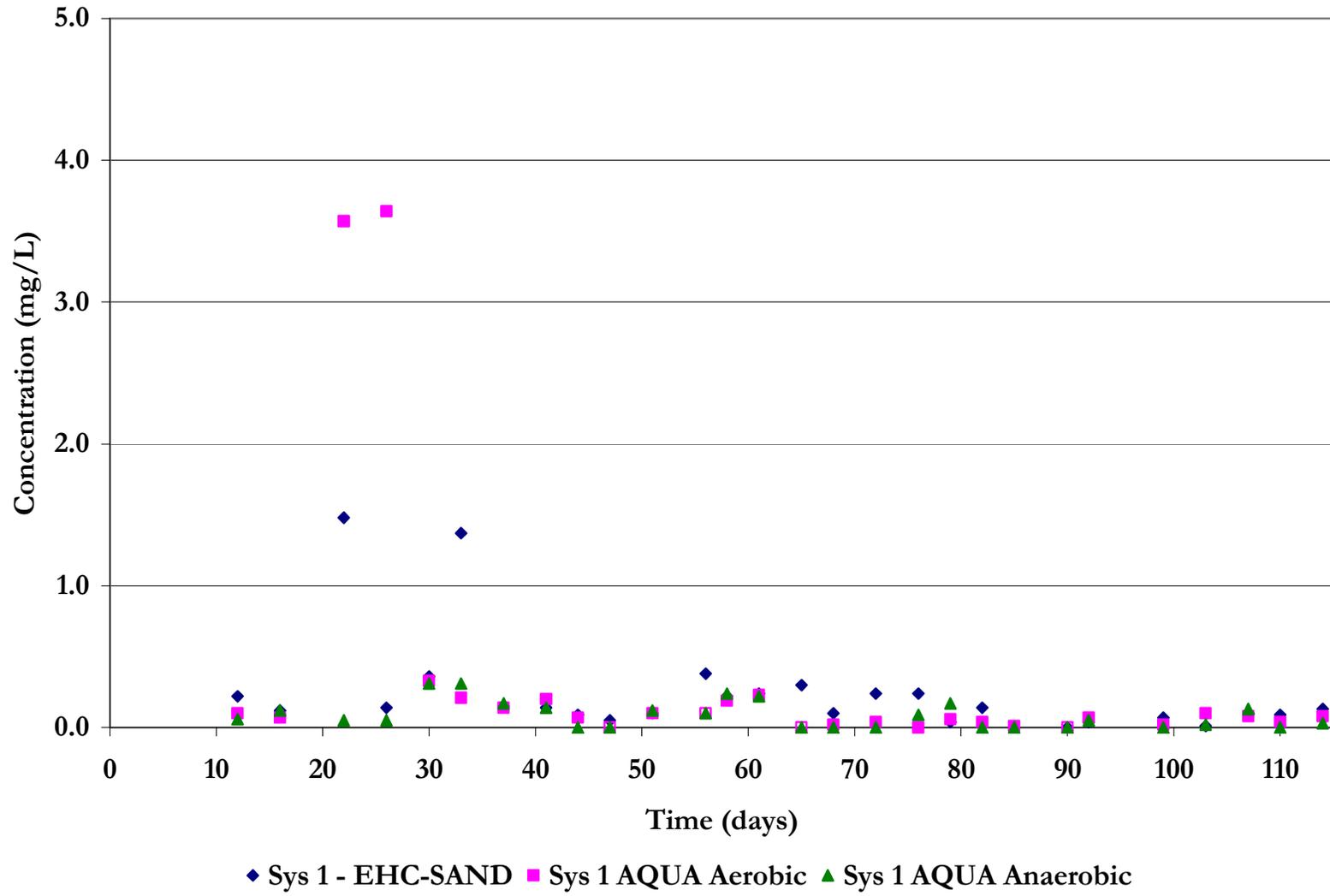


Figure 91 – D.O. trends in the Alternate Treatment System 1 effluents

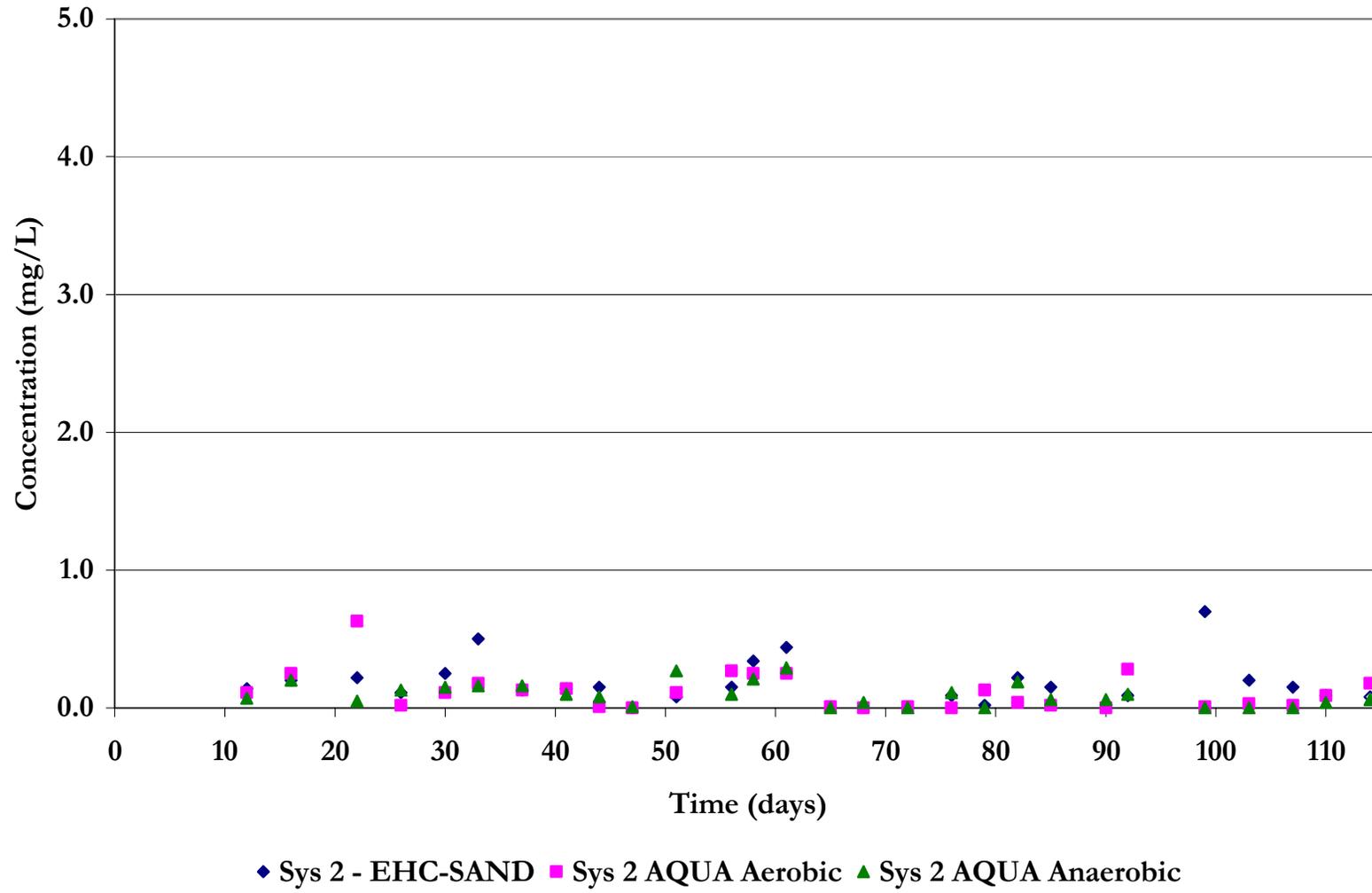


Figure 92 – D.O. trends in the Alternate Treatment System 2 effluents

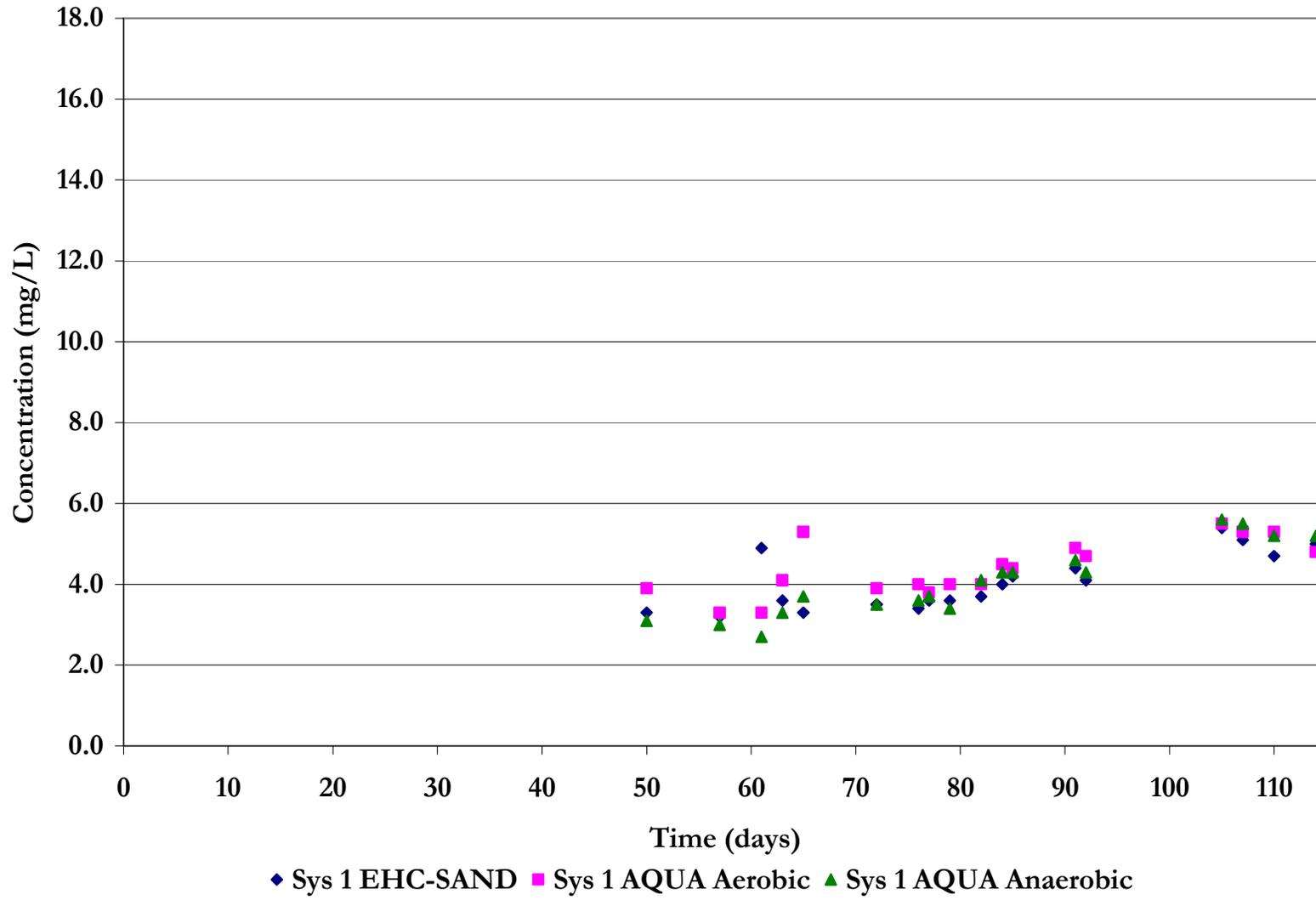


Figure 93 – Influence of Alternate Treatment System 1 on ammonium concentrations

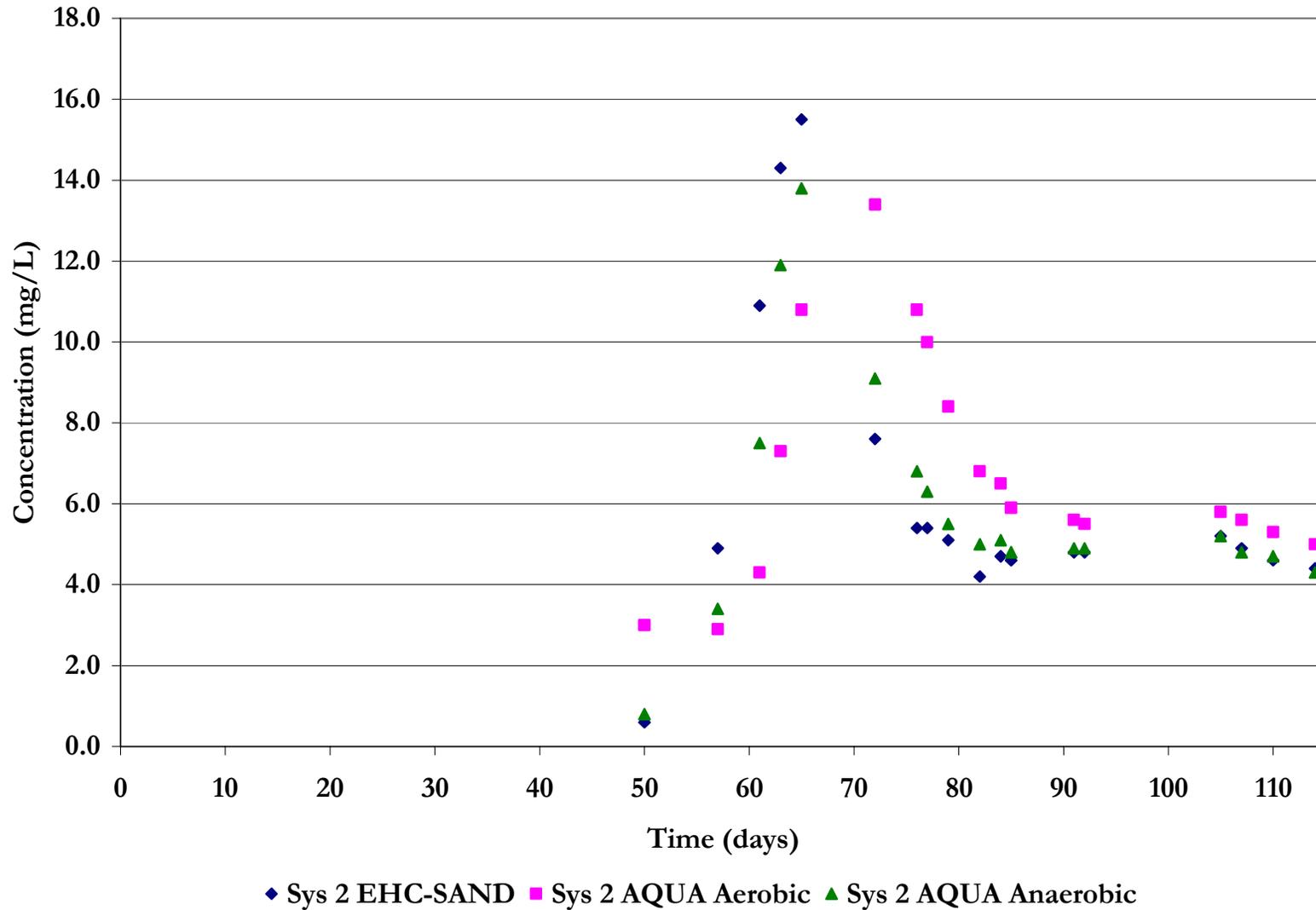


Figure 94 – Influence of Alternate Treatment System 2 on ammonium concentrations

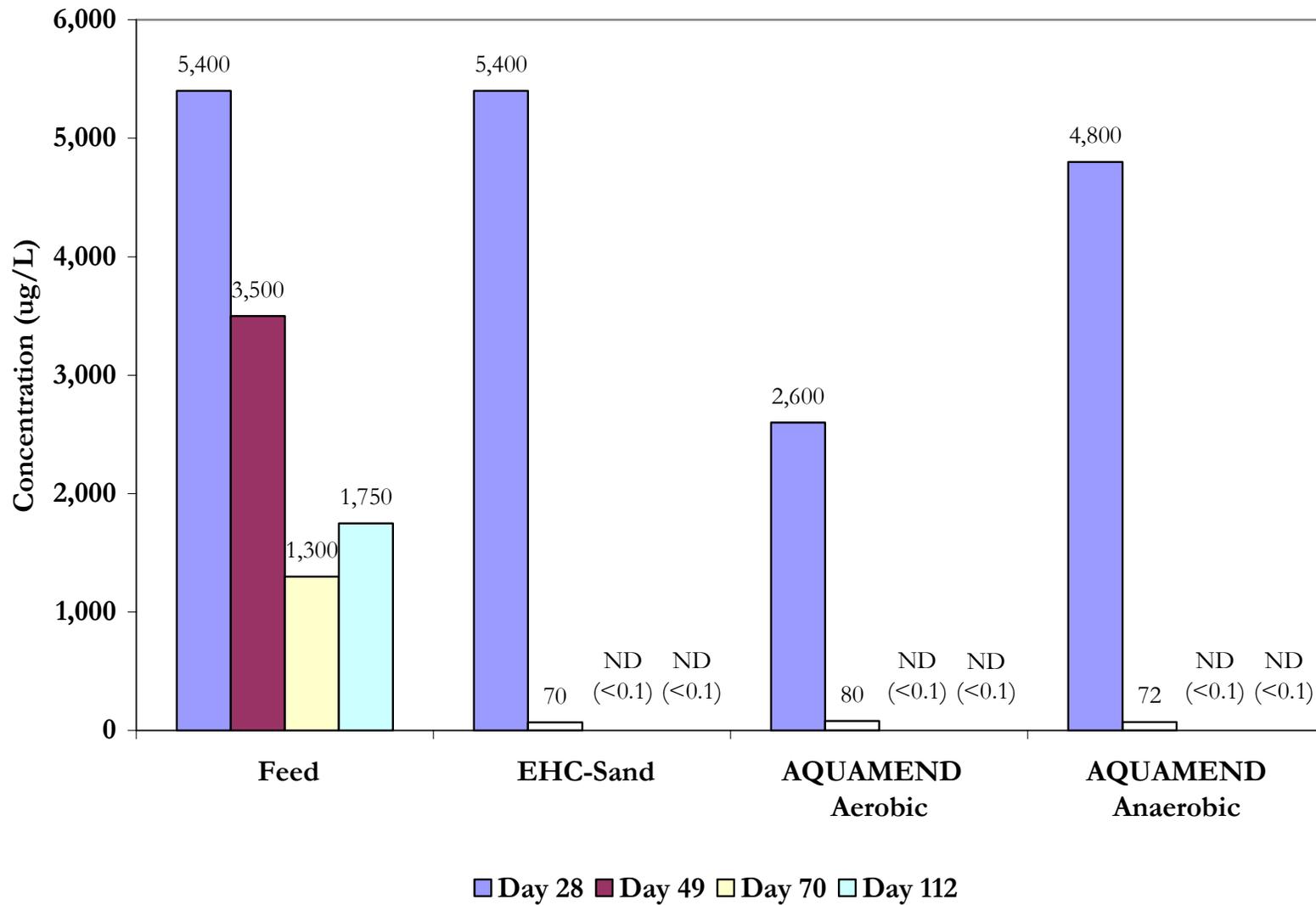


Figure 95 – Influence of Alternate Treatment System 1 on perchlorate concentrations

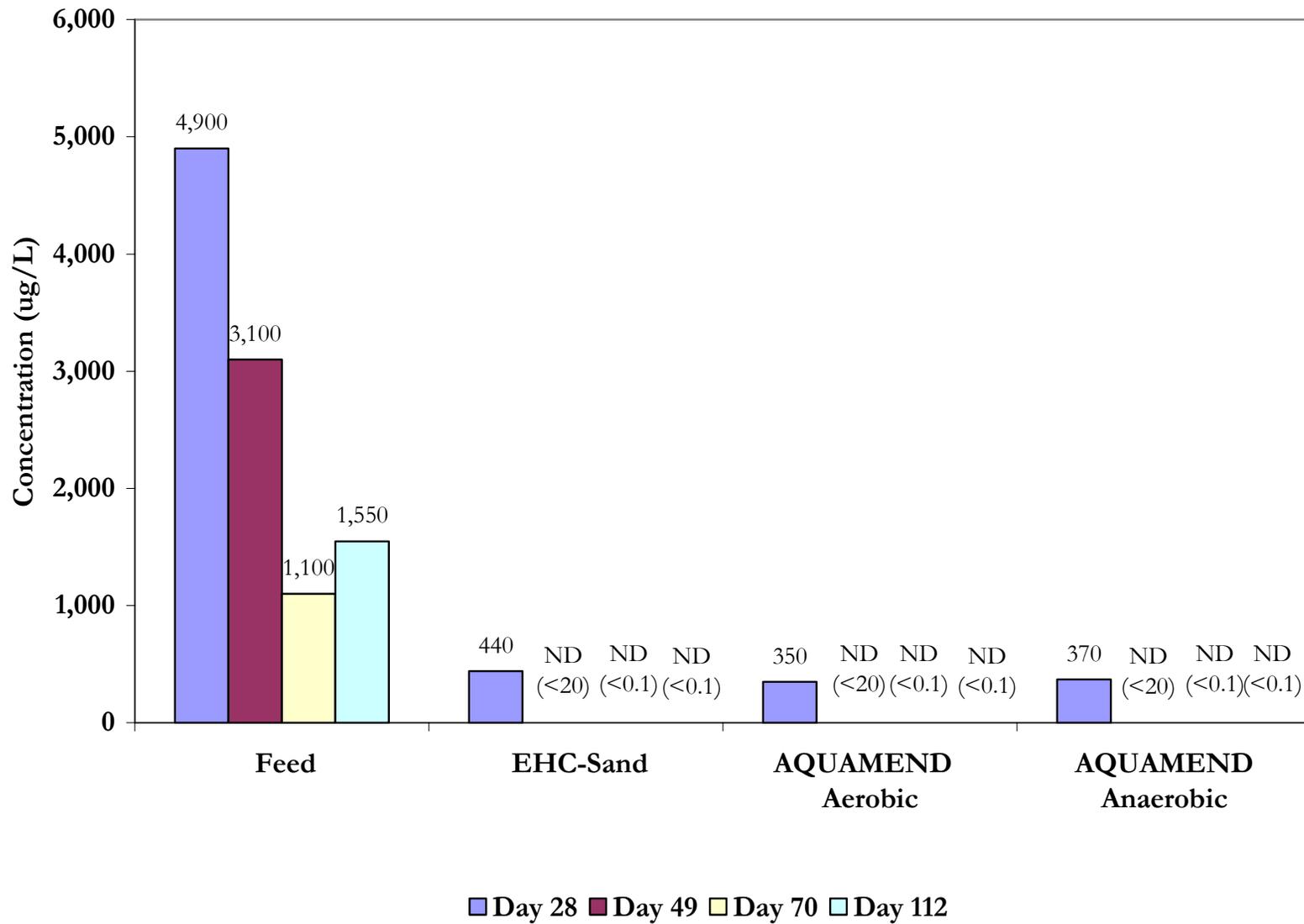


Figure 96 – Influence of Alternate Treatment System 2 on perchlorate concentrations

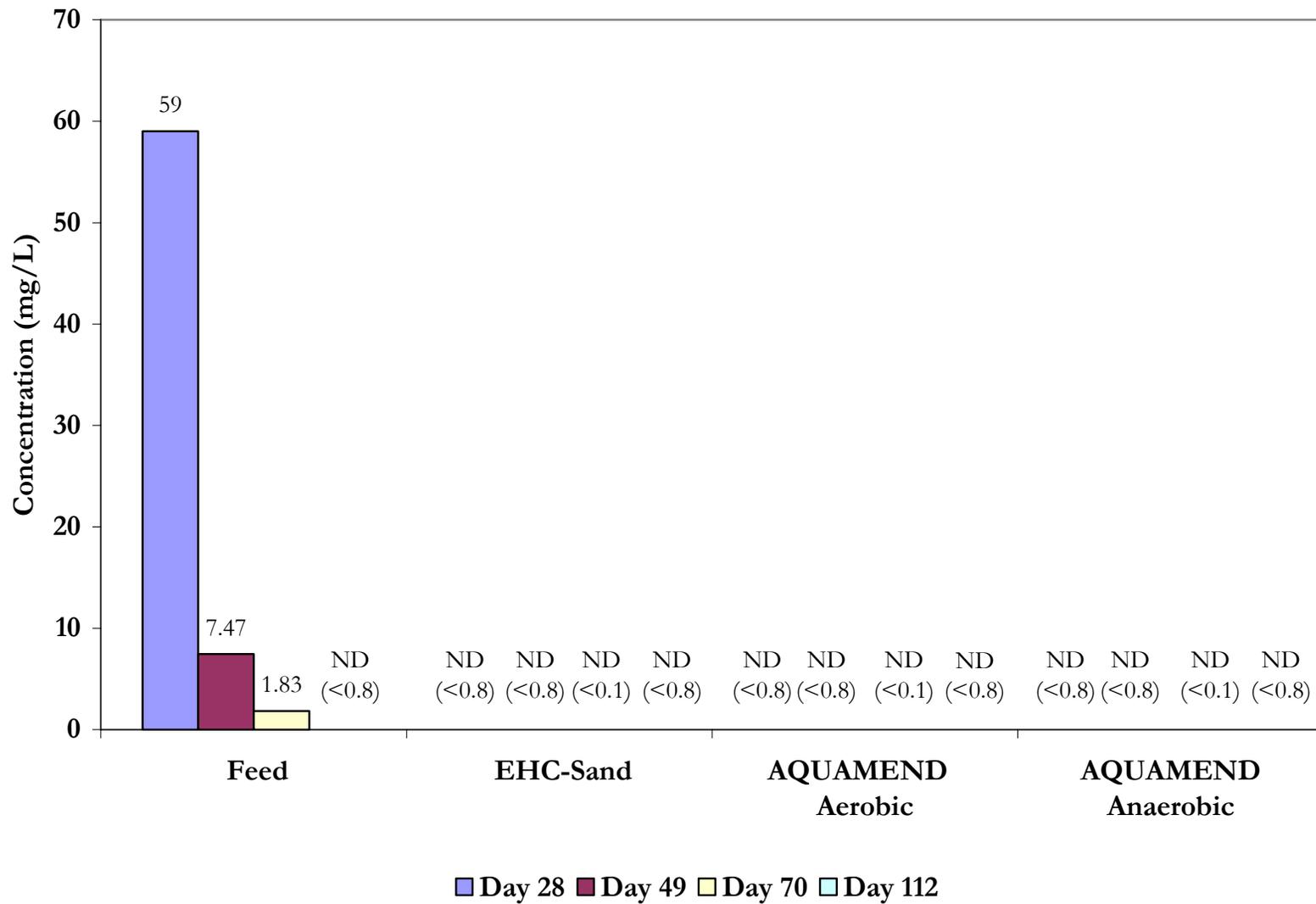


Figure 97 – Influence of Alternate Treatment System 1 on chlorate concentrations

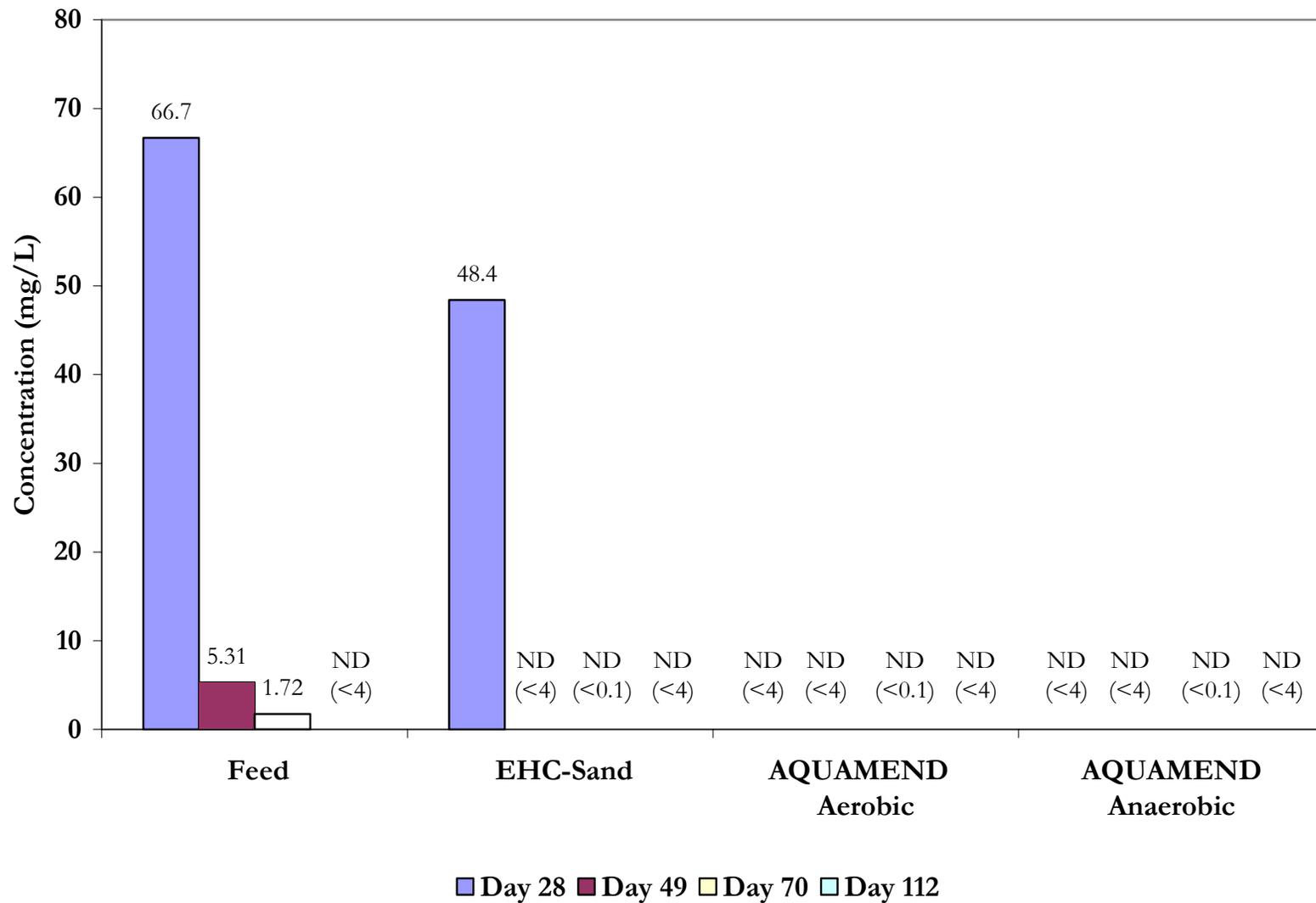


Figure 98 – Influence of Alternate Treatment System 2 on chlorate concentrations

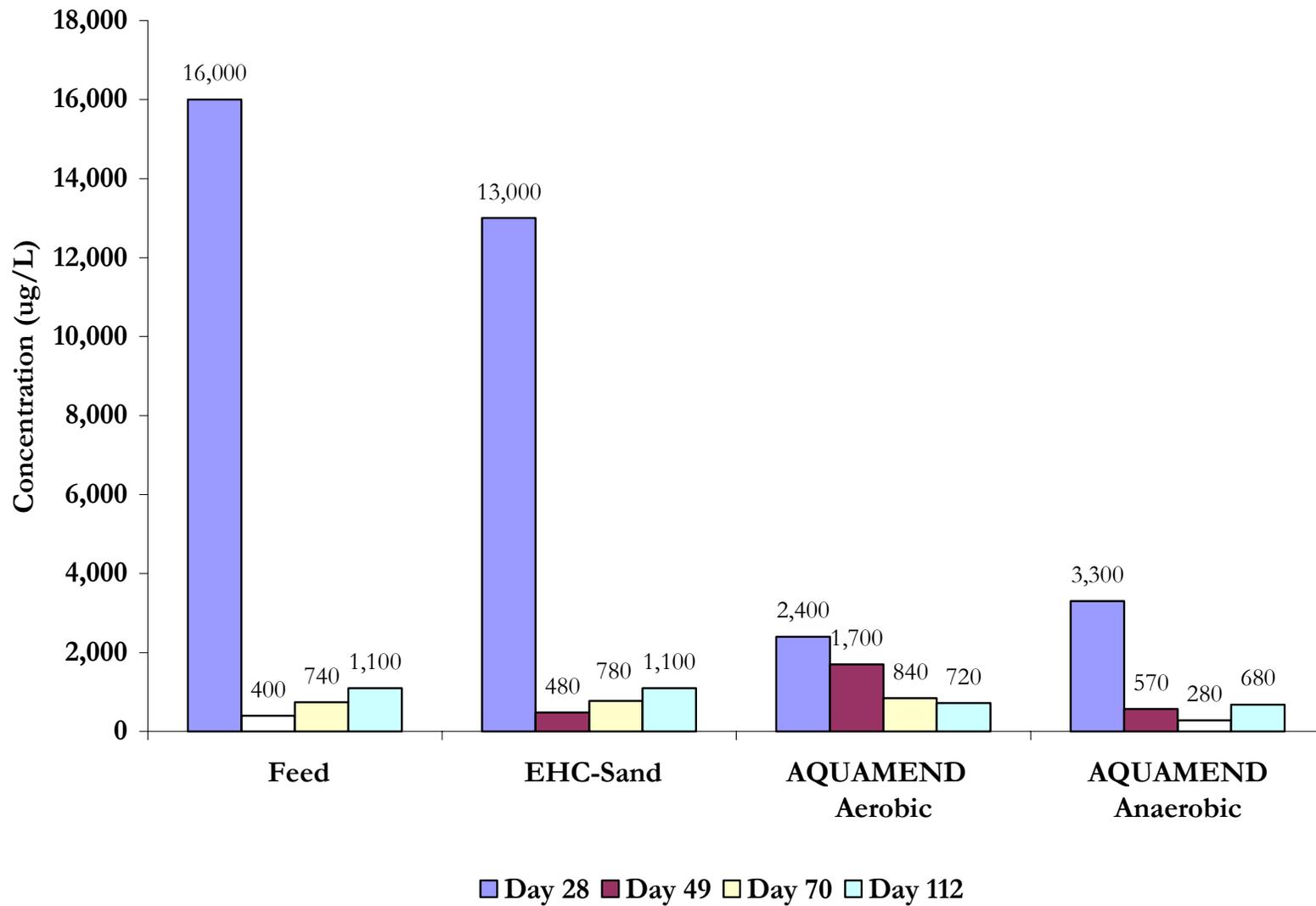


Figure 99 – Influence of Alternate Treatment System 1 on chlorobenzene concentrations

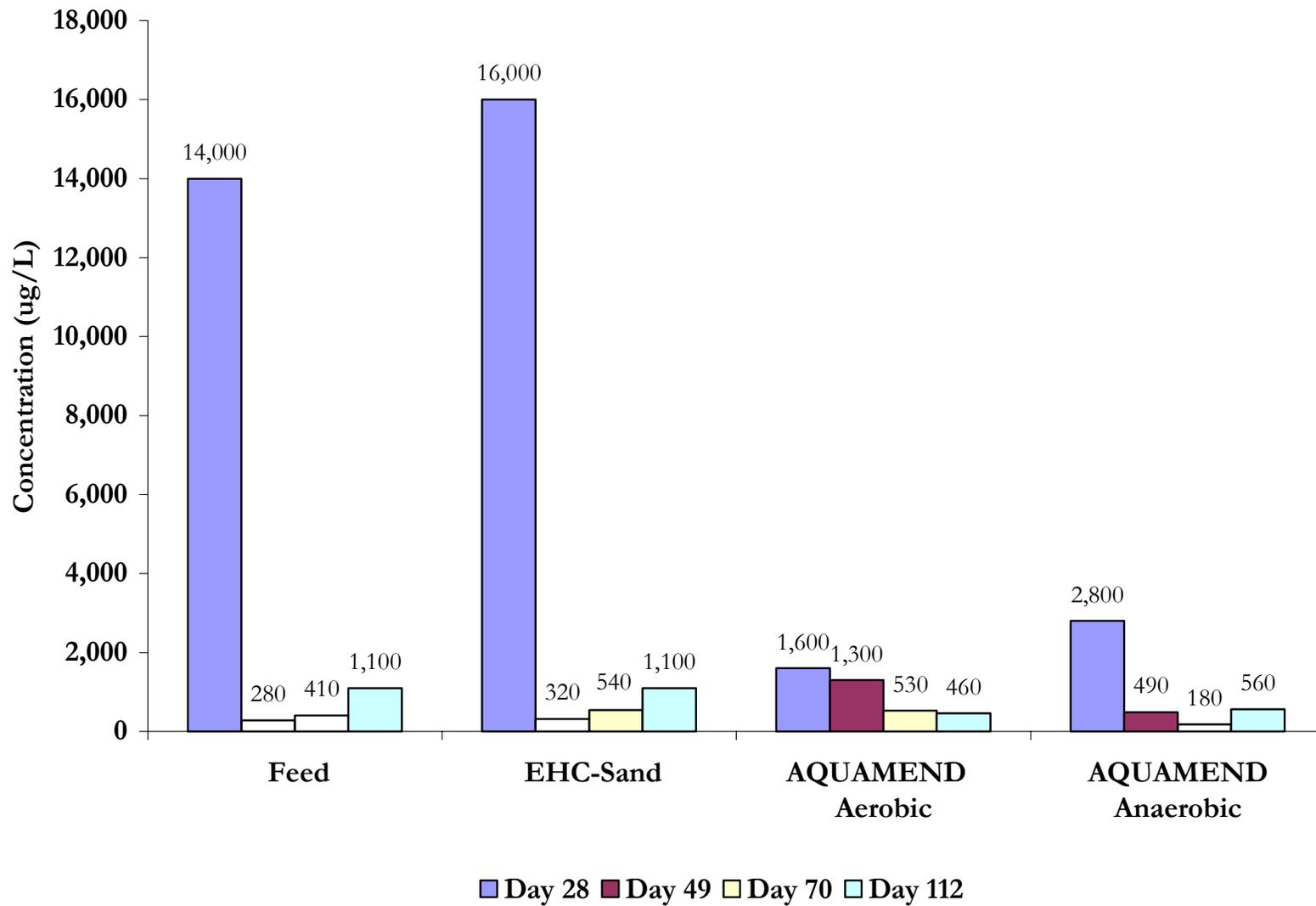


Figure 100 – Influence of Alternate Treatment System 2 on chlorobenzene concentrations

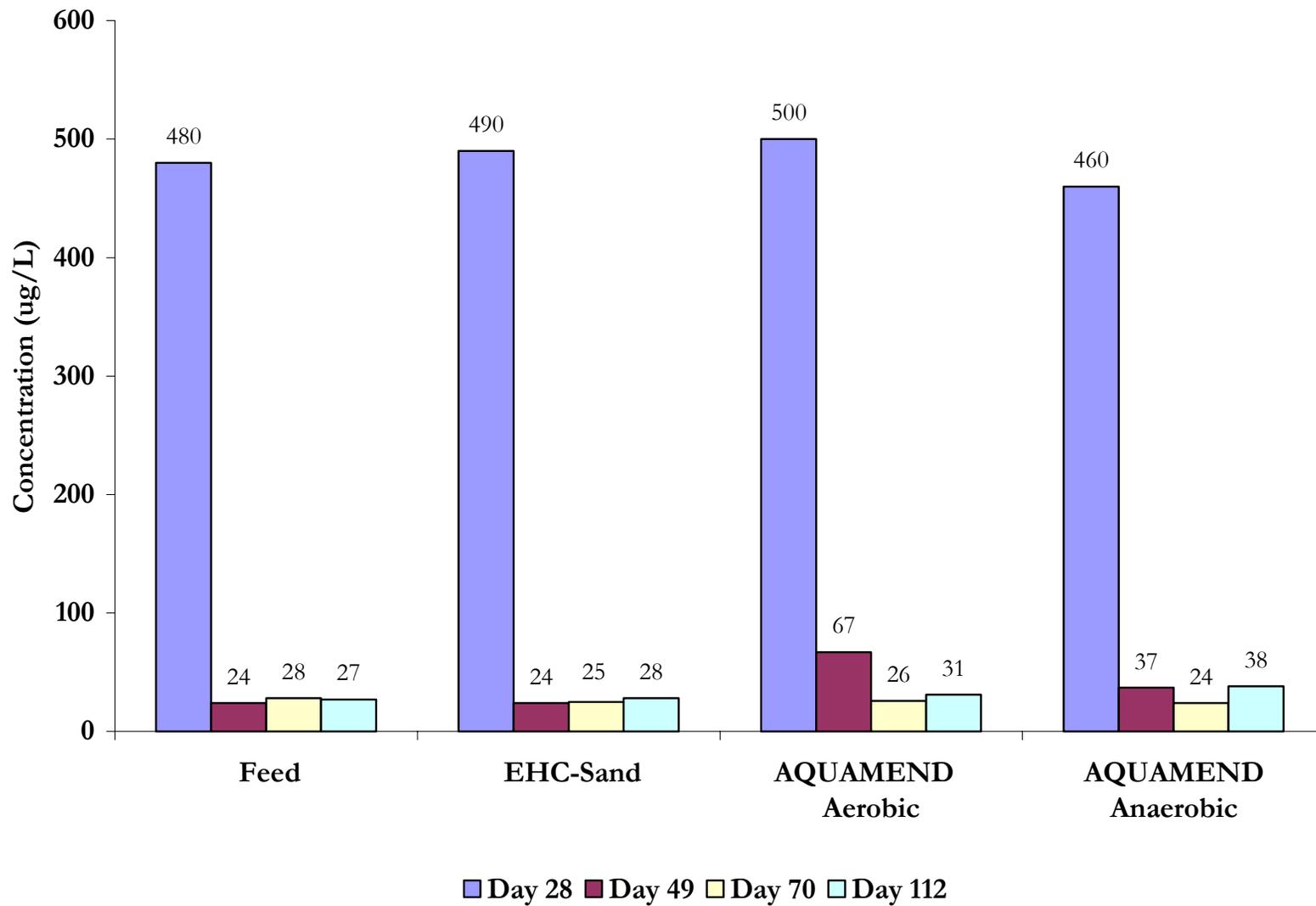


Figure 101 – Influence of Alternate Treatment System 1 on chlorophenol concentrations

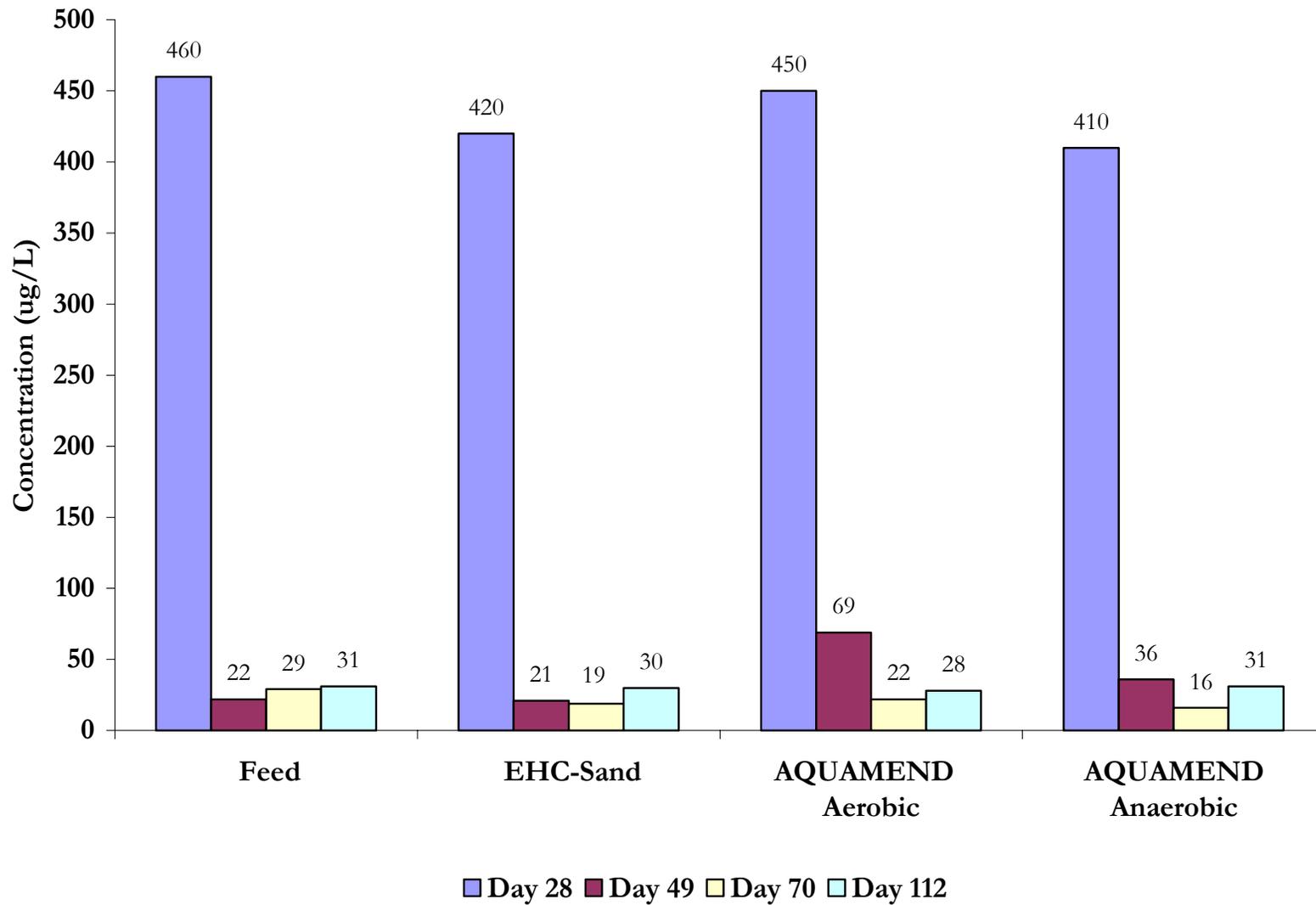


Figure 102 – Influence of Alternate Treatment System 2 on chlorophenol concentrations

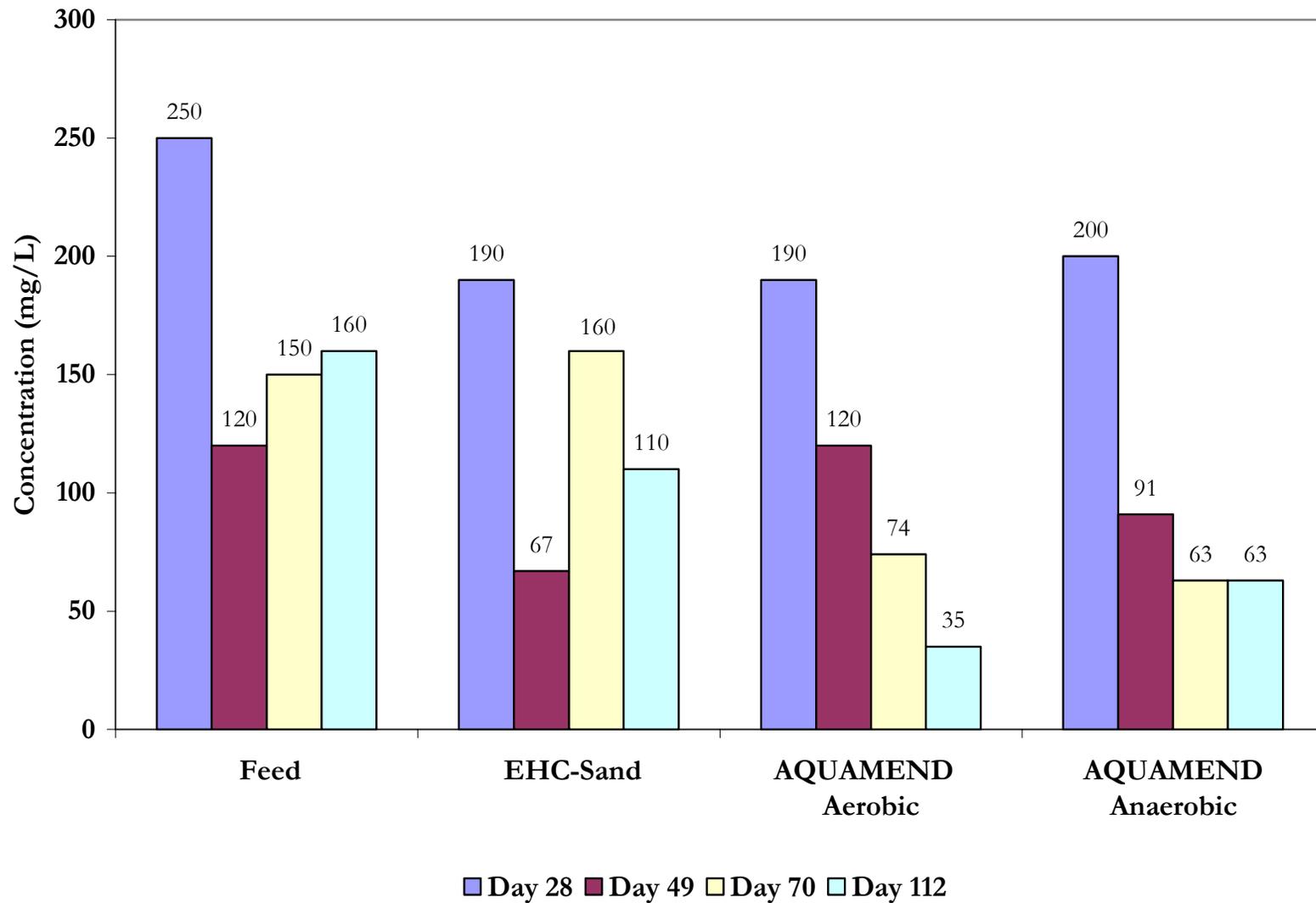


Figure 103 – Influence of Alternate Treatment System 1 on iron concentrations

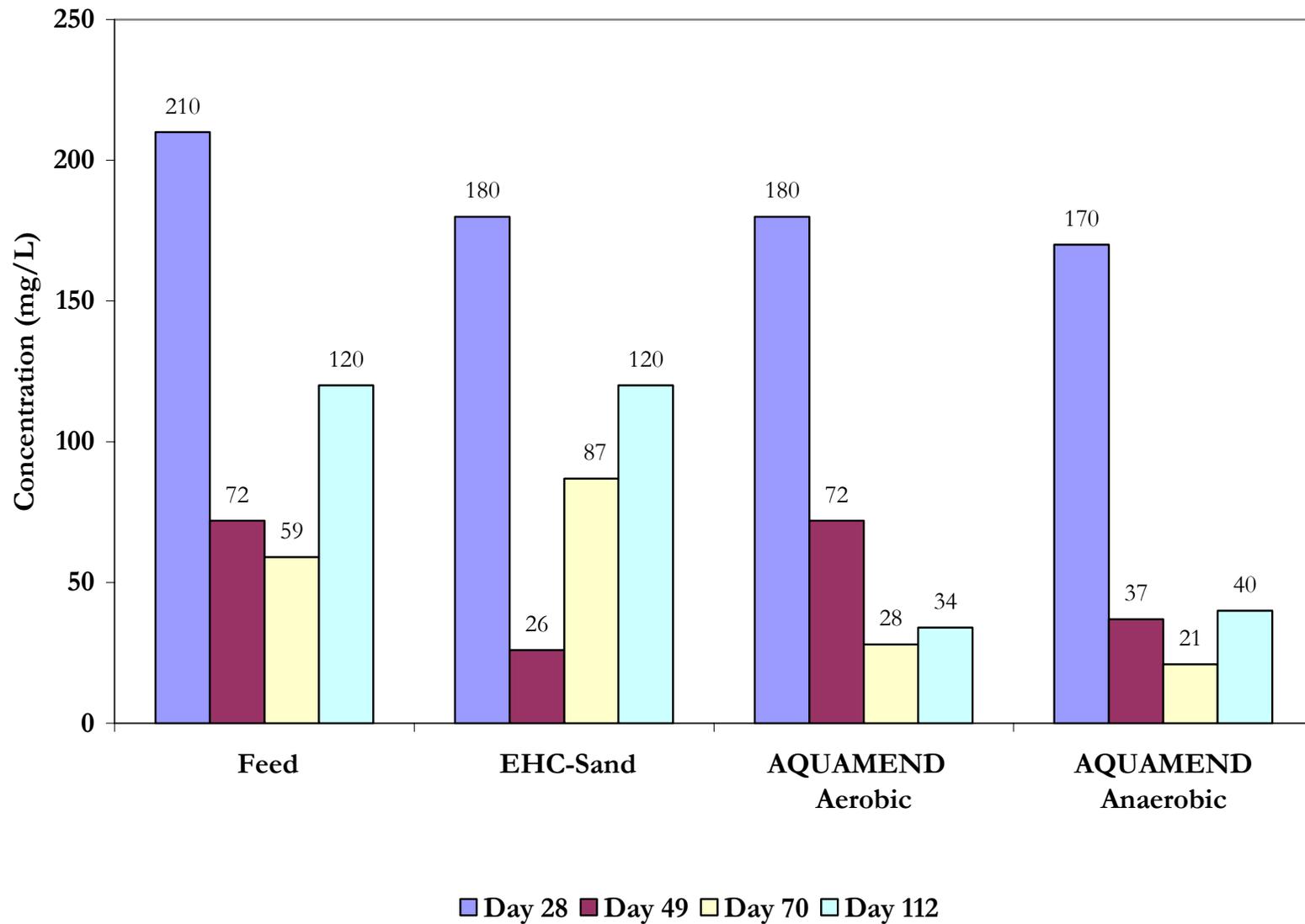


Figure 104 – Influence of Alternate Treatment System 2 on iron concentrations

**TREATMENT OF GROUNDWATER FROM THE ARKEMA FACILITY IN
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APPENDIX A – SUMMARY OF ANALYTICAL DATA

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APPENDIX B – SCHEMATIC DIAGRAMS OF BIOLOGICAL TREATMENT SYSTEMS

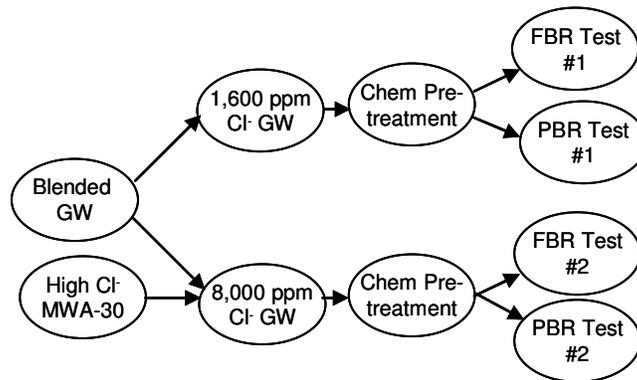


Figure B-1 – Schematic of groundwater used for FBR and PBR testing

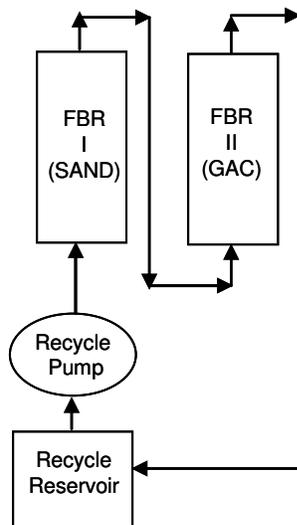


Figure B-2 – Schematic of FBR System during batch mode operation

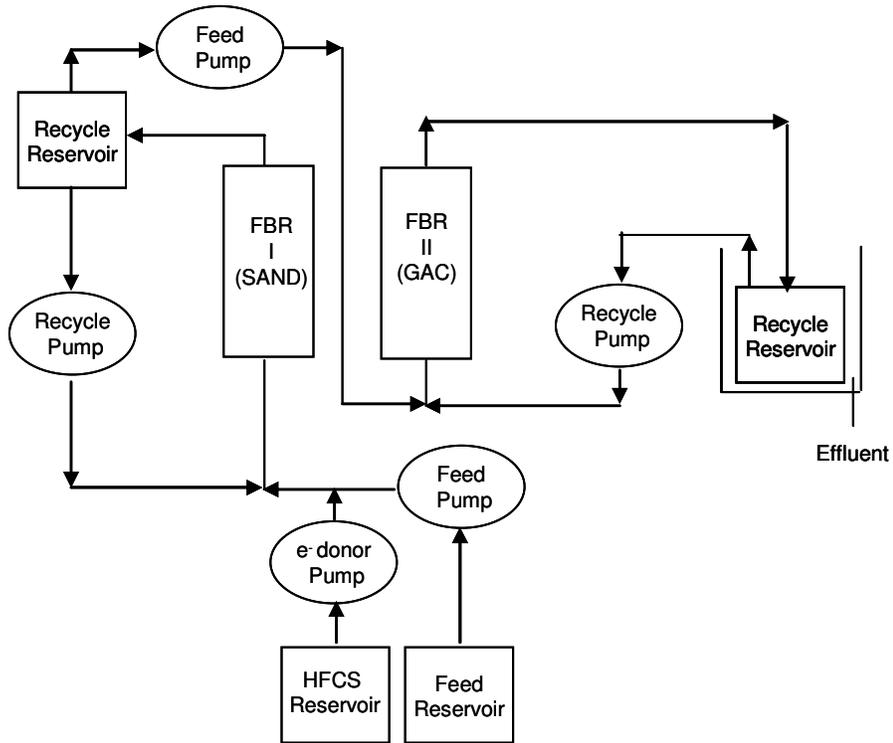


Figure B-3 – Schematic of FBR System during continuous feed mode operation

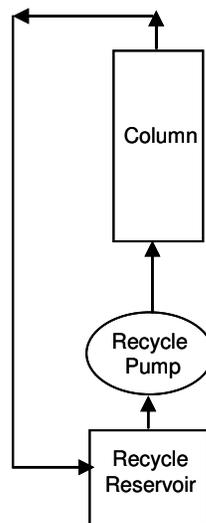


Figure B-4 – Schematic of PBR System during batch mode operation

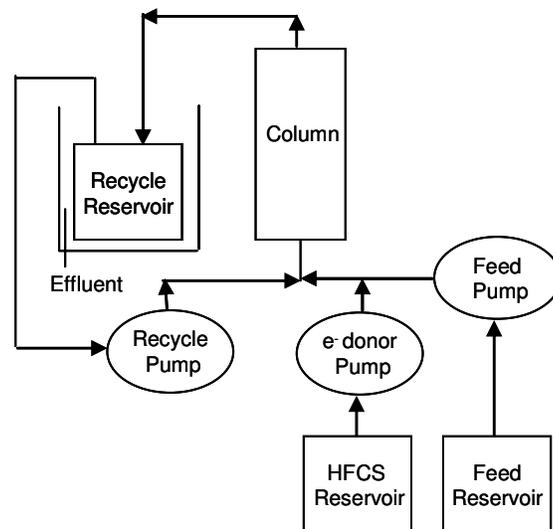


Figure B-5 – Schematic of PBR System during continuous feed mode operation

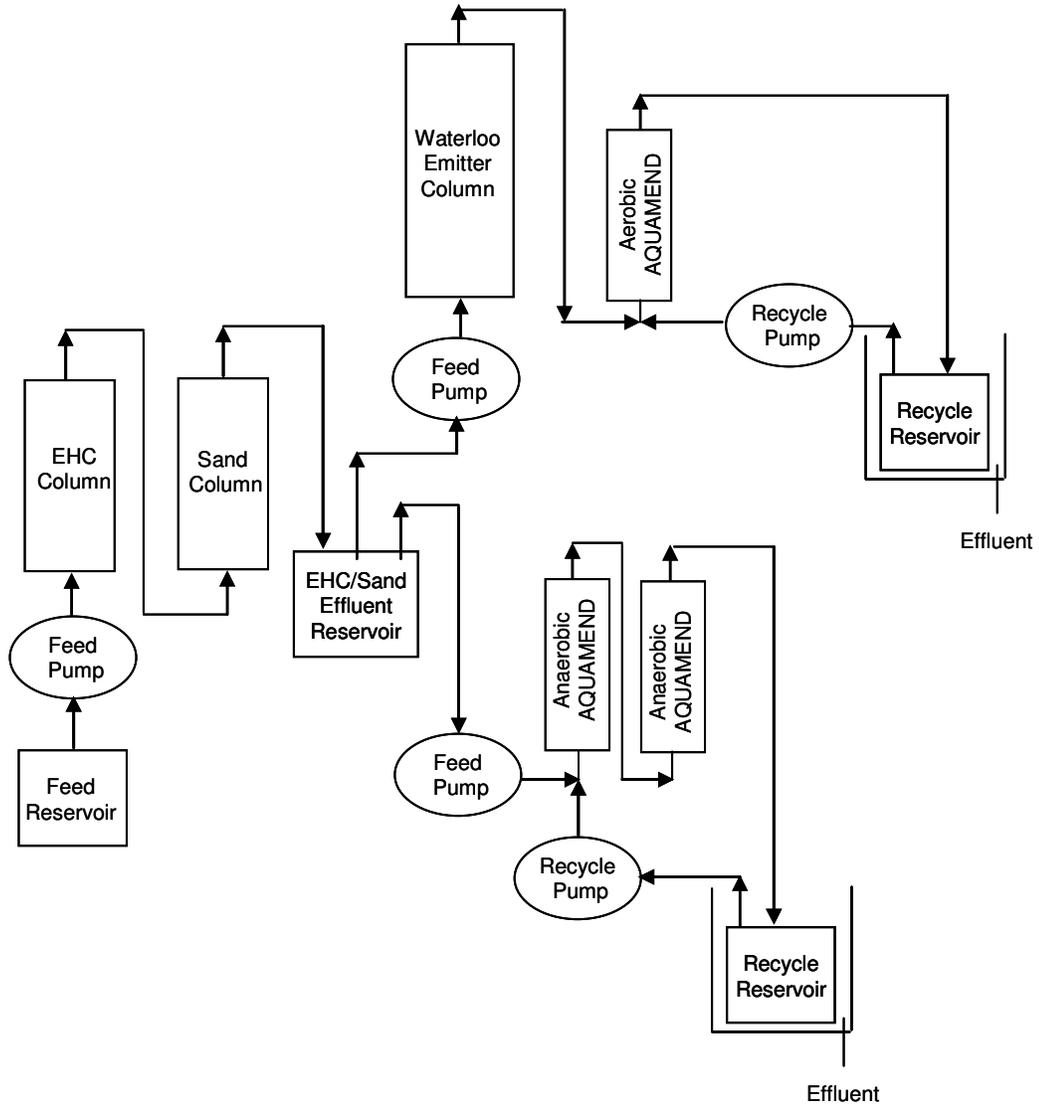


Figure B-6 – Schematic of alternate treatment system