IRON AND MANGANESE REMOVAL FROM GROUNDWATER: ENHANCED AERATION PROCESSES

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March 1992

Citation for this report should read as:

GASReP - Groundwater and Soil Remediation Program. Unpublished Report, No. 89-91-07. (1992). "Iron and Manganese Removal from Groundwater: Enhanced Aeration Processes", 53p.

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ACKNOWLEDGEMENTS

GASReP sponsored the work resulting in this report entitled "Iron and Manganese Removal from Groundwater: Enhanced Aeration Processes".

Agencies that participate in GASReP are listed below alphabetically.

Alberta Environment
American Petroleum Institute (API)
British Columbia Ministry of the Environment
Canadian Petroleum Association (CPA)
Canadian Petroleum Products Institute (CPPI)
Department of Energy, Mines and Resources Canada (EMR)
Environment Canada, Emergencies Engineering Division (EED)
Environment Canada, Industrial Programs Branch (IPB)
Environment Canada, National Hydrology Research Institute (NHRI)
Environment Canada, National Water Research Institute (NWRI)
New Brunswick Department of the Environment
Newfoundland Department of Environment and Lands
Ontario Ministry of the Environment
Prince Edward Island Ministry of the Environment
United States Environmental Protection Agency (USEPA)

Environment Canada's Burlington Environmental Technology Office manages GASReP on behalf of the participants.

Financial support for this project was provided by the Canadian federal government's interdepartmental Panel for Energy Research and Development (PERD).

March 1992

IRON AND MANGANESE REMOVAL FROM GROUNDWATER: ENHANCED AERATION PROCESSES - Waterloo, Ontario

submitted to
The Groundwater and Soil Remediation Program (GASReP)
and
The Regional Municipality of Waterloo

by

The Wastewater Technology Centre (WTC)

March, 1992
WTC Project Number 68861

ACKNOWLEDGEMENTS

This report is part of the ongoing research, technology development and field demonstration activities undertaken by the Wastewater Technology Centre (WTC), on behalf of the Groundwater and Soil Remediation Program (GASReP) and the Regional Municipality of Waterloo.

The author, Marc Halevy, gratefully acknowledges the assistance of Alex Lye, Rob Booth, Abbas Zaidi, Dave Averill, Derek Vachon, Jim Fraser and Gord Speirs (Wastewater Technology Centre); Youssef Hanna, Stuart Wilson and Dave Andrews (Waterloo Region); and F. James Dart (Ontario Ministry of the Environment).

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EXECUTIVE SUMMARY

Introduction

Roughly forty percent of the public water supplies in Canada have iron and manganese above their respective recommended maximum concentrations of 0.30 mg/L and 0.05 mg/L[1].

The problems associated with the presence of these two metals extend beyond factors of aesthetics and potability. In addition to physical fouling problems, iron and manganese may stimulate growth of microorganisms in groundwater treatment plants, in distribution systems and in reservoirs.

The contamination of groundwater by undesirable organic compounds has resulted in the development of process trains aimed at the removal of the organics of concern. However, when iron and/or manganese are present in the groundwater, treatment efforts have to focus initially on the removal of these inorganics prone to precipitation. This will minimize fouling (physical and biological) of the downstream unit processes responsible for the removal of the organics of concern from the groundwater.

The purpose of the present investigation was to improve the performance of a diffused aeration - direct contact sand filtration process train, by using the catalytic effect of recycled solids, e.g. iron(III), manganese(IV), to promote iron(II) and manganese(II) oxidation in a diffused aeration vessel.

Two options were considered: 1) the recycle of a fraction of the aeration vessel effluent to its influent line (Enhanced Aeration Process I: Continuous Recycle Loop), and 2) the addition of sludge collected from the sand filter backwash water to the diffused aeration vessel influent line (Enhanced Aeration Process II: Sludge Recycle). The performance of each Enhanced Aeration Process (I and II) was then compared to that of a conventional aeration process, where no solids were recycled to the aeration vessel.

Specific objectives were to develop and conduct performance evaluations of the following process trains:

1. Conventional Diffused Aeration Process:
   Diffused Aeration - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration
2. Enhanced Aeration Process I:
   Diffused Aeration - Continuous Recycle Loop - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration

3. Enhanced Aeration Process II:
Diffused Aeration - Sludge Recycle - Chemical Oxidant Addition (if required)-Direct Contact Sand Filtration

Pilot Scale Treatability Studies: Conventional Aeration Process - No Solids Recycle

Factorial design studies were conducted to maximize the oxidation of iron(II) and of manganese(II) in the diffused aeration vessel.

Iron(II) was effectively oxidized at a pH of 7.6. At a pH of 7.6, a hydraulic retention time of approximately 28 minutes was necessary to completely oxidize about 2.07 mg/L iron(II) to iron(III).

Diffused aeration was not found effective for the oxidation of manganese(II) to manganese(IV) for pH equal to or below 7.8. Hence, the addition of a chemical oxidant was required, following diffused aeration, to oxidize manganese(II).

The following chemical oxidants were evaluated: hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), chlorine dioxide (ClO_2) and potassium permanganate ($KMnO_4$).

Among the chemical oxidants studied, chlorine dioxide was the oxidant of choice. At 6.5 x stoichiometric dosage virtually complete manganese(II) oxidation rapidly took place. Manganese(II) concentrations were reduced from 0.15 mg/L to $\leq$ 0.01 mg/L in the treated water.

The optimum conventional aeration process train was then operated continuously for five days under the following operating requirements:

Diffused Aeration Vessel:	pH = 7.6 Hydraulic retention time = 28 minutes
On-line Chemical Oxidant Addition:	Oxidant type = ClO_2 Oxidant dosage = 6.5 to 7.0 x stoichiometric Reaction time = 2 minutes
Direct Contact Sand Filtration:	Sand bed depth = 1.1 m Sand effective diameter = 0.52 mm Filtration rate = 4.25×10^{-3} m/s

During this continuous operation, the process train removed an average of 98% iron and 93% manganese. Groundwater entered the train with 2.07 mg/L iron and 0.15 mg/L manganese, and left with 0.05 mg/L iron and 0.01 mg/L manganese.

Pilot Scale Treatability Studies: Enhanced Aeration Process I - Continuous Recycle Loop

Factorial design studies were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when 10% or 20% of the effluent from the vessel was recirculated to its influent point.

Iron(II) was effectively oxidized at a pH of 7.6. The oxidation of 95% of the iron still required a hydraulic retention time of 28 minutes, even when 20% of the effluent was recirculated.

Manganese(II) was not oxidized in the diffused aeration vessel under any of the experimental conditions. Hence, the addition of a chemical oxidant was required, following enhanced aeration, to oxidize manganese(II).

Due to the similarity between this enhanced aeration process and the conventional aeration process, only one run was completed to demonstrate the effectiveness of chlorine dioxide (ClO_2) for manganese(II) oxidation. The diffused aeration vessel was operated at a pH of 7.6, a hydraulic retention time of 28 minutes and a recycle ratio of 20%. ClO_2, at 6 x stoichiometric, was added to the filter influent (reaction time = 2 minutes). The filtration rate was 4.25×10^{-3} m/s.

Ninety-five percent of the iron was oxidized in the aeration vessel. About 98% of the iron was removed in the sand filter. Residual iron(II) was eventually completely oxidized in the sand filter bed.

About 95% of the manganese(II) was rapidly oxidized following ClO_2 addition, at 6 x stoichiometric. About 94% of the manganese was removed in the sand filter; the concentration of total manganese in the treated water was 0.01 mg/L.

The results of this study showed that recirculating 20% of the effluent from the diffused aeration vessel did not improve iron or manganese oxidation.

Pilot Scale Treatability Studies: Enhanced Aeration Process II - Sludge Addition

Factorial design studies were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when sludge was added to maintain a high concentration of iron(III) in that vessel. Specifically, this work assessed if the rates of oxidation of iron and manganese were accelerated by increasing total iron by up to 500%, i.e. sludge addition factor (SAF) = 5, in the diffused aeration vessel.

Iron(III) oxide sludge was generated by operating the diffused aeration - direct contact sand filtration process train.

About 92% of iron(II) was oxidized at a pH of 7.6, a SAF ~ 5, and a hydraulic retention time greater than 22 minutes. For comparison, the conventional diffused aeration process achieved similar iron oxidation results at the identical pH and comparable retention time.

Manganese(II) was not oxidized in the diffused aeration vessel.

In a few experimental runs, outside the original mandate of this study, a substantially large quantity of iron(III) was recirculated back to the diffused aeration vessel. Sludge addition factors of 0 to 59 were experimented with, at a pH of 7.6 and a hydraulic retention time of four minutes. At a SAF = 59, almost complete iron oxidation was recorded. Hence, sludge addition, when SAF = 59, decreased the hydraulic retention time required for virtually complete iron oxidation, from approximately 28 minutes to four minutes. In contrast, manganese(II) was not oxidized in the diffused aeration vessel, for any SAF.

Three main conclusions were drawn from these studies on the performance evaluation of the diffused aeration - sludge addition process. These were:

1. For sludge addition factors less than 7, the design/operation requirements for iron(II) oxidation were similar to those determined during the conventional diffused aeration process. Similarly, the oxidation of manganese(II) was not promoted even at a SAF of 7.
2. For a sludge addition factor of 59, a hydraulic retention time of four minutes was required for virtually complete iron(II) oxidation. Recirculation of the sludge did not, even at this high level, promote manganese(II) oxidation.
3. The addition of a chemical oxidant was required, following aeration, to oxidize manganese(II).

The performance of the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was then evaluated in a continuous mode of operation. Sludge , which was continuously generated nightly, differed from that used earlier because it had not only a high content of iron(III) but also manganese(IV) oxides.

After the sludge was added (SAF = 7.4) to the raw groundwater, the mean concentrations increased from 2.07 mg/L to 15.37 mg/L for iron and 0.17 mg/L to 1.19 mg/L for manganese.

Rapid reduction of manganese(IV) to manganese(II) was observed immediately following sludge addition in the diffused aeration vessel influent. Correspondingly, rapid oxidation of iron(II) to iron(III) was observed, prior to aeration. Sludge addition resulted in the oxidation of 1.52 mg/L of dissolved iron prior to aeration, and in the chemical reduction of 0.59 mg/L of manganese.

This increase in dissolved manganese(II) concentration increased the chemical oxidant demand for ClO_2 to complete manganese oxidation and removal. However, the chemical oxidant dosage of 7 times the stoichiometric requirement of manganese(II) in the raw groundwater was left unchanged to demonstrate the effect of recirculating sludge to the diffused aeration vessel.

Remaining dissolved iron(II) was effectively oxidized in the diffused aeration vessel. Dissolved manganese(II) was incompletely oxidized by ClO_2. The mean concentration of dissolved manganese(II) in the filter influent was 0.22 mg/L, which exceeded the mean dissolved manganese(II) concentration in the raw groundwater of 0.17 mg/L. Furthermore, breakthrough of iron and especially manganese was readily observed.

In conclusion, the performance of the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was poor. This was attributed to two factors. These were:

1. The reduction of manganese oxides(IV) and the corresponding oxidation of iron(II) in the raw groundwater by these oxides in the recirculated sludge prior to aeration defeats the purpose of using air to oxidize iron(II). Furthermore, the additional manganese(II) produced, exerts a substantially higher demand for the costly chemical oxidant, ClO_2, in order to ensure that the manganese level in the filter effluent does not exceed the recommended maximum concentration.
2. An unexpectedly high frequency of filter backwashes is required when sludge is recirculated to the diffused aeration vessel.

Since the present process did not demonstrate any performance advantage over the conventional diffused aeration process, the requirements for frequent backwashes and for the installation of a sludge recirculation process cannot be substantiated.

Pilot Scale Performance Evaluation of Recommended Process Train: Conventional Diffused Aeration Process

The diffused aeration - chemical oxidation (ClO_2) - direct contact sand filtration (A - O (ClO_2) - F) process train was selected for its good performance and simplicity over the enhanced aeration processes in which solids were recirculated to the diffused aeration vessel.

This recommended process train was operated continuously for seven days with the following operating parameters:

Diffused Aeration Vessel:	pH = 7.6
	hydraulic retention time = 23 minutes

On-line Chemical Oxidant Addition:
oxidant type = ClO_2
oxidant dosage ($ClO_2 \rightarrow Cl^-$) = 7 x stoichiometric
reaction time = 2 minutes

Direct Contact Sand Filtration:
sand bed depth = 1.1 m
sand effective diameter = 0.52 mm
filtration rate = 5.3×10^{-3} m/s

The mean concentrations of total iron and manganese in the raw groundwater were 2.02 mg/L and 0.17 mg/L, respectively.

Iron and manganese were effectively removed in the sand filter throughout the duration of the performance evaluation. The mean iron and manganese concentrations in the effluent of the process train were 0.05 mg/L and 0.02 mg/L, respectively.

1.0 INTRODUCTION

Roughly forty percent of the public water supplies in Ontario, Canada have iron and manganese above their respective recommended maximum concentrations of 0.30 mg/L and 0.05 mg/L(1). Although the presence of iron and manganese is generally associated with groundwater, these metals are also found in surface water.

The problems associated with the presence of these two metals in any waters extend beyond factors of aesthetics and potability. In addition to physical fouling problems, iron and manganese may stimulate growth of microorganisms, e.g. *Pseudomonas*, Iron Bacteria, in groundwater treatment plants, in distribution systems and in reservoirs.

The contamination of groundwater by undesirable organic compounds has resulted in the development of process trains aimed at the removal of the organics of concern. However, when iron and/or manganese are present in the groundwater, treatment efforts have to focus initially on the removal of these inorganics which are prone to precipitation. This will minimize fouling (physical and biological) of the downstream unit processes responsible for the removal of the organics of concern from the groundwater.

During 1988-89, a site remediation project was conducted in Ville Mercier, Québec, by The SNC Group, under the auspices of the Wastewater Technology Centre (WTC). One of the objectives of this research, technical development and field demonstration project was to develop an effective iron removal process train, as a pretreatment prior to the removal of the organic contaminants from the groundwater.(2) For the Ville Mercier project, seven iron removal process trains were evaluated at pilot scale. These are presented in Table 1.

Subsequent performance evaluation of the recommended process train was undertaken in a continuous mode of operation (May to August 1989). This process train, comprising fine pore diffused aeration followed by direct contact sand filtration, was demonstrated effective in the oxidation, precipitation and removal of iron from the groundwater, to levels consistently below the recommended maximum concentration of 0.30 mg/L. Design and operating parameters for the diffused aeration - direct contact sand filtration train were optimized to 1) maximize performance, 2) eliminate the need for coagulant(s), flocculant(s) or other aqueous conditioner(s), and 3) minimize sludge production. Moreover, the train requires just two unit operations for the removal of iron from the groundwater.

Throughout the performance evaluation of the recommended process train, iron(II) was effectively oxidized in the diffused aeration vessel: 80 - 90% of the iron(II) was converted to iron(III).

One of the study's findings was that oxidation of the remaining iron(II) consistently took place in the sand filter bed. This complete oxidation in the sand bed, as illustrated in Figure 1, suggested an adsorption and an ensuing contact/catalytic oxidation of iron(II) onto previously deposited iron(III) flocs. Sarikaya(3) reported similar occurrences of improved iron oxidation efficiency in many groundwater treatment plants after a coating of iron(III) had built up on multiple-tray aerators and on sand filter media.

TABLE 1 **IRON REMOVAL PROCESS TRAINS TESTED AT VILLE MERCIER, QUÉBEC (1988-89)[2]**
1. Chemical Oxidation - Coagulation - Flocculation - Sedimentation - Sand Filtration
2. Chemical Oxidation - Direct Contact Sand Filtration
3. Diffused Aeration - Coagulation - Flocculation - Sedimentation - Sand Filtration
4. Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration
5. Diffused Aeration - On-Line Coagulant Addition - Direct Contact Sand Filtration
6. Diffused Aeration - On-Line Flocculant Addition - Direct Sand Filtration
7. Diffused Aeration - Direct Contact Sand Filtration

The purpose of this investigation was to achieve acceptable treatment objectives for both metals in the groundwater. The Groundwater and Soil Remediation Program (GASReP) suggested complete removal of iron and manganese to minimize, if not eliminate, physical fouling caused by iron and manganese deposits. This fouling can significantly affect the operation and lower the efficiency of unit operations responsible for the removal of the organics of concern from groundwater. This goal was to be achieved by improving the performance of the diffused aeration - direct contact sand filtration process train, using the catalytic effect of recycled solids to promote iron(II) and manganese(II) oxidation in a diffused aeration vessel.

The study was conducted in the Regional Municipality of Waterloo, at well W-5, by the Wastewater Technology Centre. The experimental field study was initiated in April 1991, and was concluded in August 1991.

The study was funded by the Groundwater and Soil Remediation Program (GASReP), the Wastewater Technology Centre (WTC) and the Regional Municipality of Waterloo.

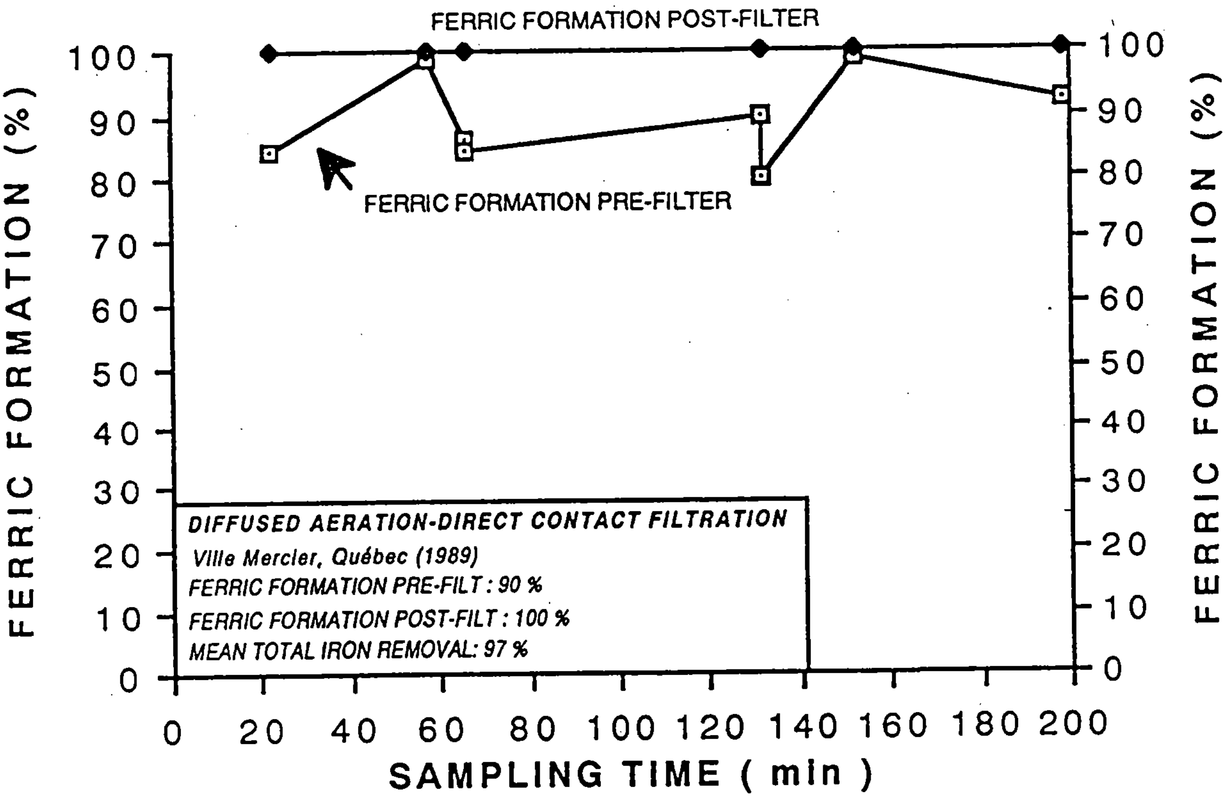

FIGURE 1 CATALYTIC OXIDATION IN SAND FILTER

2.0 STUDY OBJECTIVES

The overall objective of the present study was to investigate if iron and manganese oxides could increase the rates of oxidation of iron(II) and manganese(II) in a diffused aeration vessel. A solids-bearing stream, recycled to the influent line to the aeration vessel, was used to achieve the objective. Two options were considered: 1) the recycle of a fraction of the aeration vessel effluent to its influent line (Enhanced Aeration Process I: Continuous Recycle Loop), and 2) the addition of sludge collected from the sand filter backwash water to the diffused aeration vessel influent line (Enhanced Aeration Process II: Sludge Recycle).

The aim of the study was to develop a simple and effective diffused aeration - direct contact sand filtration process train, effective in removing iron and manganese from the groundwater, to levels below their respective maximum recommended concentrations of 0.30 mg/L and 0.05 mg/L.

Specific objectives were to develop and conduct performance evaluations of the following process trains:

1. Conventional Diffused Aeration Process:
   Diffused Aeration - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration
2. Enhanced Aeration Process I:
   Diffused Aeration - Continuous Recycle Loop - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration
3. Enhanced Aeration Process II:
   Diffused Aeration - Sludge Recycle - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration

3.0 STUDY STRATEGY

The study was subdivided into six phases in order to effectively fulfil the study's objectives and present the findings.

Phase 1	Preliminary Technologies and Methods Selection
Task 1:	Identify the inorganic and organic (if present) contaminants of concern in the groundwater. Assess on a case by case basis, the contaminants that exceed the recommended drinking water guidelines.
Task 2:	Select a list of specific inorganic and organic (if relevant) parameters on which to focus research, development and demonstration efforts.
Task 3:	Design, construct and install a pilot scale treatment plant in the vicinity of the groundwater well station (Regional Municipality of Waterloo, W-5 groundwater station).
Task 4:	Select and modify analytical procedures for field analyses. Elaborate a Quality Assurance/Quality Control programme.
Task 5:	Set up a groundwater field laboratory trailer to carry out all required analytical determinations on-site in a timely and cost-effective manner.

Phase 2	Pilot Scale Process Development Studies: Conventional Aeration Process
Task 1:	Evaluate the performance of diffused aeration to oxidize iron and manganese. Optimize design/operating parameters of the conventional diffused aeration process to maximize oxidation. Assess optimum oxidation kinetic profile for iron and manganese.
Task 2:	Evaluate the performance of selected chemical oxidants as a supplement to diffused aeration to complete manganese oxidation, if required. Assess the performance of the following chemical oxidants: hydrogen peroxide, sodium hypochlorite, chlorine dioxide and potassium permanganate.
Task 3:	Evaluate the performance of the recommended process train, diffused aeration - chemical oxidant addition - direct contact sand filtration. Modify design/ operating parameters to maximize performance, if required.

Phase 3 Pilot Scale Process Development Studies: Enhanced Aeration Process I

Task 1: Evaluate the impact of the continuous recycle loop, for recycle ratio values of 10% and 20%, on the oxidation of iron and manganese in the diffused aeration vessel. Optimize design/operating parameters of the Enhanced Aeration Process I to maximize oxidation. Assess optimum oxidation kinetic profile for iron and manganese.

Task 2: Evaluate the performance of selected chemical oxidants, as a supplement to the continuous recycle loop diffused aeration process, to complete manganese oxidation, if required. Assess the performance of the following chemical oxidants: sodium hypochlorite, chlorine dioxide and potassium permanganate.

Task 3: Evaluate the performance of the recommended process train, diffused aeration - continuous recycle loop - chemical oxidant addition - direct contact sand filtration. Modify design/operating parameters to maximize performance, if required.

Phase 4 Pilot Scale Process Development Studies: Enhanced Aeration Process II

Task 1: Evaluate the impact of sludge addition, for selected sludge addition factor values, on the oxidation of iron and manganese in the diffused aeration vessel. Sludge addition factor values of 1 to 5, i.e. sludge addition to increase by 100% to 500% the total iron concentration in the diffused aeration vessel, were evaluated. Optimize design/operating parameters of the Enhanced Aeration Process II to maximize oxidation. Assess oxidation kinetic profile for iron and manganese.

Task 2: Evaluate the performance of selected chemical oxidants, as a supplement to the sludge addition diffused aeration process, to complete manganese oxidation, if required. Assess the performance of the following chemical oxidants: sodium hypochlorite and chlorine dioxide.

Task 3: Evaluate the performance of the recommended process train, diffused aeration - sludge addition - chemical oxidant addition - direct contact sand filtration. Modify design/operating parameters to maximize performance, if required.

Phase 5	Pilot Scale Process Train Evaluation: Continuous Operation
Task 1:	Select the optimum process train, based on performance data gathered during Phases 2, 3 and 4.
Task 2:	Run the optimum process train for a period of one week in a continuous mode of operation.
Phase 6	Final Report Preparation
Task 1:	Preparation and presentation of the research, technical development and field demonstration study's activities and findings.

4.0 EXPERIMENTAL MATERIALS AND METHOD

Prior to the start of the project, a mobile, continuous flow, pilot plant was designed and built by the Wastewater Technology Centre in January and February 1991. The plant was made of conventional materials, such as PVC and steel, which one would find in a conventional full scale groundwater treatment facility.

A laboratory trailer was fully equipped with the instrumentation required to conduct all necessary analytical determinations. In late March 1991, both trailers were transported from Burlington, Ontario to the Waterloo W-5 site.

Table 2 presents the various physical chemical unit processes incorporated in the pilot plant. The description of the pilot plant unit operations and set-up is addressed in Section 4.1.

TABLE 2 PILOT SCALE TREATMENT PLANT: PROCESS ELEMENTS LISTING

PROCESS ELEMENT	PURPOSE
Diffused Aeration Vessel	Iron(II) and Manganese(II) Oxidation
Chemical Oxidation/Detention Vessel	Manganese(II) Oxidation/ Iron(II) and Manganese(II) Oxidation
Chemical Oxidant Metering Pumps - on line addition	On-Line Manganese(II) Oxidation
Granular Media Filters (2)	Iron(III), Manganese(IV) and other suspended solids removal
Clarifier	Collect and concentrate sludge from sand filter backwash water for solids recycled to the diffused aeration vessel

Table 3 presents the main analytical tools and instruments incorporated in the field groundwater laboratory trailer.

TABLE 3 GROUNDWATER ANALYTICAL LABORATORY: EQUIPMENT LISTING

EQUIPMENT	MANUFACTURER	MODEL NUMBER
Analytical Balance	AND	EW-300A
Analytical Balance	AND	FX-40
Dissolved Oxygen Probe	Orion	97-08
Eppendorf Pipette	Eppendorf	4710
Oven	Blue M	SW 17TA
pH Meter	Orion	301
pH Meter	Orion	701A
Spectrophotometer	LKB Biochrom	4049
Turbidity Meter	Hach	

4.1 Pilot Plant Set-up

Figure 2 is a schematic of the pilot plant. Each unit process is described in detail below.

4.1.1 Flow Rate

The pilot plant was designed to handle groundwater flow rates as high as 60 L/min*. This rate was opted for, as it was felt that the data generated could be used for proper scale-up.

4.1.2 Diffused Aeration Vessel

The diffused aeration vessel had an internal diameter of 37 cm, an effective height of 2.1 m and a liquid capacity of 225 L. For flows of raw groundwater greater than 40 L/min to the aeration vessel, the pump located in the W-5 well station was operated. Below 40 L/min, the piezometric surface was equal to or greater than the height of the effluent line from the aeration vessel, thus eliminating the need for pumping water into the aeration column.

There were four groundwater sample ports, located around the vessel: two located on the influent line, before (A) and after the solids recycle line (S), one on the effluent line (B), and one placed at the bottom of the vessel. The bottom port was also used to drain the column.

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*The units used to express volume, flow rates, dimensions and time will include L, L/min, cm and min, respectively. Due to the magnitude of the values involved, the use of their strict equivalent SI units (m^3, m^3/s, m and s, respectively) is not judged appropriate, in this case.

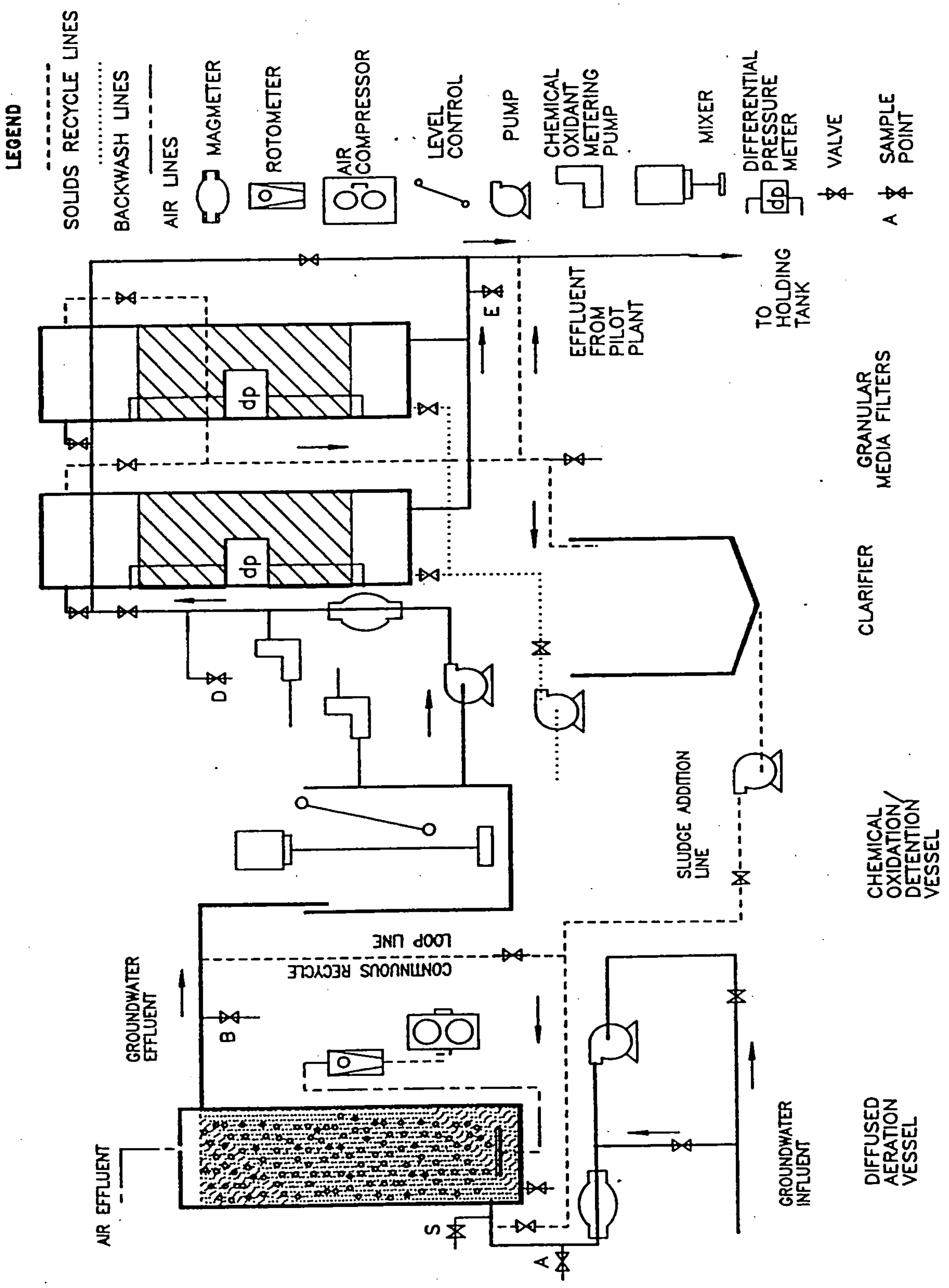


FIGURE 2 PILOT PLANT SCHEMATIC FLOW DIAGRAM

Air was supplied by a blower stationed outside under the trailer. The main switch and a rough flow rate control valve were located on the blower. A rotameter was used to monitor influent air flow rate to the diffused aeration vessel. Fine tuning of influent air flow was achieved through the installation of two additional valves located prior to the rotameter. The air entered at the bottom of the diffused aeration vessel, through a 31 cm OD Elastox-D fine pore elastomer/rubber-based membrane diffuser, manufactured by EIMCO Process Equipment Co.

Selecting the Elastox-D diffuser to aerate the W-5 groundwater was based on the performance offered by this type of diffuser during the 1988-89 site remediation study at Ville Mercier (Québec). During that study, a pilot scale diffused aeration vessel was fitted with an Elastox-D diffuser to aerate groundwater with a high content of iron (mean concentration = 8.3 mg/L). This rubberized diffuser resists biological fouling and allows simple cleaning by inflating and deflating it to remove precipitates. This cleaning method, termed "air bumping", was carried out weekly and consisted of:

1. shutting off the air to the diffuser, in order to allow it to collapse onto its frame; and
2. re-introducing air at a flow twice the normal operating value for < 1 min, prior to returning it to the desired operating condition.

This cleaning method, proven effective throughout the duration of the Ville Mercier study, provided the rationale behind the pursuit of diffused aeration-related research, development and demonstration efforts with this type of diffuser.

The diffuser membrane could accommodate air loadings of up to 325 L/min. The minimum air flow rate, measurable by the rotameter and necessary to expand the Elastox-D diffuser, was approximately 54 L/min. Hence, the operable air loading range was 54 L/min to 325 L/min.

The air exhausted at the top of the vessel. The aerated groundwater exited from the top of the vessel into a chemical oxidation/detention vessel. A bleed-off valve, located on the effluent line, allowed the recirculation of the aerated groundwater to the influent line of the aeration vessel (Enhanced Aeration Process I: Continuous Recycle Loop). This addition point, located on the influent line of the aeration vessel, could also accommodate the recirculation of the effluent, namely thickened sludge (Enhanced Aeration Process II: Sludge Addition), from the clarifier.

4.1.3 Chemical Oxidation/Detention Vessel

The effluent from the diffused aeration vessel was collected in a 500 L cylindrical chemical oxidation/detention vessel. The vessel could be used to either:

1. increase the reaction time required to complete the oxidation reactions (detention); or
2. act as a chemical oxidation vessel, in which a selected chemical oxidant would be added to effect manganese(II) oxidation.

The liquid capacity in this vessel could be adjusted to meet the retention time requirement for either detention or oxidation (chemical oxidant addition). The vessel was equipped with a 0.25 HP mixer and a metering pump. The latter was used to deliver a specific chemical oxidant to the groundwater. The metering pump was designed to handle aqueous solutions of hydrogen peroxide (H_2O_2), sodium hypochlorite ($NaOCl$), chlorine dioxide (ClO_2), and potassium permanganate ($KMnO_4$). The chemical oxidant dosage could be varied over an extremely wide range by metering reagent addition from 1 to 500 mL/min and by selecting the chemical oxidant solution strength.

4.1.4 Chemical Oxidant Metering Pump - On-Line Addition

Two chemical oxidant addition points were installed on the influent line to the sand filters. Each point could be used to add a chemical oxidant to promote on-line oxidation of Mn(II), if required, in the filter influent.

4.1.5 Granular Media Filters

The effluent from the chemical oxidation/detention vessel was pumped upwards for entry at the top of one or both vertical granular media filter column(s). Flow rate was monitored by a magnetic flow meter. A graded single media bed of sand/gravel was used throughout the study.

The support bed of gravel was 30 cm deep and consisted of 2.0 cm coarse and 1.3 cm medium-sized granules.

The nature of the sand bed was changed shortly after the experimental work began. Originally, the sand bed depth, effective sand diameter and uniformity coefficient were 80 cm, 0.52 mm and 1.27, respectively. Only a few experimental runs were conducted when the sand bed depth was 80 cm. The bed depth was increased, in the subsequent stages of the study, to 110 cm to maximize performance and increase the mass storage capacity of each filter.

The bottom of each filter column contained a stainless steel support plate, a backwash distribution plate and a circumferential network of openings for air scouring. The sand filters were each 20 cm ID and 2.2 m high, thereby allowing the sand bed to expand by more than 25% during backwashes. Backwashing consisted of air scouring (~ 1.5 x 10^{-2} m/s), as a first step, followed by a medium velocity (~ 5.5 x 10^{-2} m/s) water wash.

Prefilter and postfilter sampling points, D and E respectively, are shown on Figure 2.

4.1.6 Clarifier

During the evaluation of the Enhanced Aeration Process II: Sludge Addition Process, the backwash water from the sand filter(s) was collected in a 550 L clarifier. Once the solids settled in the clarifier, the thickened sludge was then pumped, at the desired flow rate, to the influent of the diffused aeration vessel.

4.2 Experimental Program

The experimental program is presented in Table 4.

TABLE 4 EXPERIMENTAL PROGRAM

ACTIVITY	PARAMETER	RANGE
1. Diffused Conventional Aeration Process	Q_{GW} (HRT)* Q_A/Q_{GW} (pH)**	5 to 60 L/min 2.5 to 15.0
2. Enhanced Aeration Process I: Continuous Recycle Loop	Recycle Ratio	10% to 20%
3. Enhanced Aeration Process II: Sludge Addition	Sludge Addition Factor (total iron increase in aeration vessel)	100% to 500%
4. Chemical Oxidant Addition (to supplement Mn oxidation, if required)	Type Dosage Reaction Time	H_2O_2, ClO_2, Cl_2, $KMnO_4$ 0.25 to 2.00 x stoichiometric 15 s to 30 min
5. Performance Evaluation of the Optimum Process Train in a Continuous Mode of Operation	Time Q_{GW} Q_A/Q_{GW} Solids Recycle	≥ seven days optimum optimum optimum

* The hydraulic retention time (HRT) of the groundwater in the diffused aeration vessel is primarily a function of the groundwater flow rate (Q_{GW}).

** The aeration pH is primarily a function of the air flow rate (Q_A) to the diffused aeration vessel.

4.2.1 Analytical Procedures

The analytical procedures used generally followed those of "Standard Methods for the Examination of Water and Wastewater"(4).

A brief overview of the analytical methods used, and modifications implemented to reduce the impact of interfering agents, is presented in Appendix A. The groundwater parameters monitored included: total iron, dissolved iron(II), total manganese, dissolved manganese(II), suspended solids, pH, dissolved oxygen, temperature, total alkalinity and hardness. Analysis for these parameters were routinely conducted in the field.

Organic and inorganic scans were carried out by the Wastewater Technology Centre and by the Regional Municipality of Waterloo laboratories.

4.2.2 Quality Assurance/Quality Control Programme

A quality assurance/quality control programme was established with the Regional Municipality of Waterloo and the Wastewater Technology Centre laboratories. Approximately ten percent of all samples were routinely sent in duplicate to both laboratories for the analytical determinations of total iron, dissolved iron(II), total manganese and dissolved manganese(II). A variation in results within ± 10% were deemed acceptable. A good agreement was consistently observed. The QA/QC data are presented in Appendix B.

4.2.3 Process Variables

A list of the twenty most relevant variables specific to a diffused aeration process is presented in Table 5.

From these, the hydraulic retention time (HRT) of the groundwater in the diffused aeration vessel and the aeration pH of the groundwater were selected as the primary independent variables. Additionally, during the development of the enhanced aeration processes (Continuous Recycle Loop (CRL) and Sludge Addition (SA) Processes), variables specific to the solids recycle processes were added to the list of primary independent variables. These were: recycle ratio (RR) for the CRL process and sludge addition factor (SAF) for the SA process. All other independent variables were either 1) kept constant, 2) assumed to remain constant, or 3) presumed to vary minimally and impact negligibly on the process.

Three dependent variables are listed. From these, the Ferric (and Manganic) Formation in the diffused aeration vessel was selected as the primary dependant variables during the evaluation of the rates of oxidation of iron(II) and manganese(II). Furthermore, the impact of the independent variables (pH, HRT, RR, SAF) selected for the optimum operation of the aeration vessel, on the oxidation and removal performance of the downstream process elements, was monitored. Hence, a second optimization conducted on the entire process train would be undertaken if there was a need to increase the performance of the chemical oxidation and removal process elements.

TABLE 5 LIST OF DIFFUSED AERATION PROCESS VARIABLES

I. INDEPENDENT VARIABLES

A. GROUNDWATER
   1. Iron (and manganese) valence and concentration
   2. Organic ligand(s) characteristics and concentration
   3. Inorganic ligand(s) characteristics and concentration
   4. Metal(s) catalyst/inhibitor type and concentration
   5. pH
   6. Temperature
   7. Alkalinity
   8. Dissolved Oxygen
   9. Suspended Solids
   10. Background organic type and concentration (chemical oxidant demand)

B. AIR
   1. Partial pressures of oxygen/carbon dioxide
   2. Temperature

C. AERATION VESSEL
   1. Aeration vessel configuration
   2. Diffuser membrane characteristics
   3. Aeration vessel flow dynamics

D. PROCESS CONDITIONS
   1. Groundwater flow rate (hydraulic retention time)
   2. Air flow rate (aeration pH)
   3. Solids recycle characteristics (recycle ratio; sludge addition factor)
   4. Gas transfer efficiencies (oxygen, carbon dioxide)
   5. Others (solids deposit on diffuser membrane, presence of microbiologically active organisms)

II. DEPENDENT VARIABLES

1. Ferric (and Manganic) Formation in diffused aeration vessel
2. Manganic (and Ferric) Formation in downstream process elements
3. Total Iron (and Manganese) Removal in downstream process elements

5.0 PILOT SCALE TREATABILITY STUDIES: CONVENTIONAL DIFFUSED AERATION PROCESS

This section presents the studies conducted to develop a process train, based on a conventional diffused aeration process.

5.1 Diffused Aeration Process

Factorial design studies were conducted to maximize the two output functions of interest, namely the oxidation of iron(II) and of manganese(II) in the diffused aeration vessel.

Preliminary experimental pilot runs were conducted on the aeration vessel to determine the minimal operating requirements of the diffuser to achieve oxygen saturation in the groundwater. These runs are presented in Table 6. The tabulated data also include pH and temperature measurements taken prior to and following diffused aeration.

TABLE 6 EFFECT OF AERATION ON GROUNDWATER pH AND DISSOLVED OXYGEN

Air Flow Rate-Q_A (L/min)	Groundwater Flow Rate-Q_{GW} (L/min)	Pre-Aeration Dissolved Oxygen (mg/L)	Pre-Aeration pH	Pre-Aeration Temp (°C)	Post-Aeration Dissolved Oxygen (mg/L)	Post-Aeration pH	Post-Aeration Temp (°C)
54	40	< 1	7.1	11	saturated	7.4	12
54	60	< 1	7.1	11	saturated	7.4	11
108	40	< 1	7.1	11	saturated	7.5	11
216	40	< 1	7.1	11	saturated	7.6	11
324	40	< 1	7.1	11	saturated	7.7	12

These runs determined that oxygen saturation of the groundwater in the diffused aeration vessel was readily achieved under all experimental conditions, for air flow rates ranging from the minimum (54 L/min) to the maximum (324 L/min) design values and, for groundwater flow rates as high as 60 L/min. Nevertheless, the dissolved oxygen content of the groundwater was monitored throughout the study.

The experimental program aimed at optimizing the hydraulic retention time (HRT) of the groundwater in the diffused aeration vessel and the aeration pH. HRT ranged from 3.8 minutes to 45 minutes, by varying the groundwater flow rate. The aeration pH ranged from 7.4

to 7.8, mainly by varying the air flow rate.

Twenty-three runs were completed to evaluate the optimum experimental conditions in the diffused aeration vessel for iron and manganese oxidation and to determine the associated oxidation profile. The experimental results are presented below. Duplicates of runs were undertaken on several occasions to ensure performance reproducibility.

5.1.1 Results and Discussion

The scans for inorganics and organics are presented in Appendix C. Aside from iron and manganese, the inorganic scans did not detect other metals at concentrations above drinking water guidelines. The concentrations of iron and manganese in the raw groundwater, sent to the Wastewater Technology Centre laboratory, were 2.3 mg/L and 0.21 mg/L, respectively. No organic contaminants of concern were detected in the groundwater.

Raw data for the conventional diffused aeration process are presented in Appendix D. Summary figures and table are presented below. Figures 3 to 6 display data for runs conducted at pHs of 7.4, 7.6, 7.7 and 7.8. Each figure shows the percent ferric formation at various hydraulic retention times. Table 7 contains the data for these plots.

The concentration of total iron in the raw groundwater varied between 1.91 mg/L and 2.31 mg/L. Iron was determined to be completely in a solution state (II). Minor discrepancies (< 10%) between total iron and iron in solution (II) concentrations were attributed to the margin of error associated with the field analytical procedure.

The concentration of total manganese in the raw groundwater varied between 0.08 mg/L and 0.14 mg/L. Manganese was determined to be completely in a solution state (II). Minor discrepancies between total manganese and manganese in solution (II) concentrations were attributed to the margin of error associated with the field analytical procedure.

The dissolved oxygen content of the groundwater following aeration increased from less than 1 mg/L to saturation. Aeration pH depended on the degree of CO_2 stripped from the groundwater. Alkalinity and hardness remained constant.

As seen in Figure 4, iron(II) was completely oxidized at a pH of 7.6. A pH of 7.7 produced similar iron oxidation performance (Figure 5), although requiring a significantly higher air flow to strip more carbon dioxide (CO_2) from the groundwater. Low pH (7.4) and high pH (7.8) values (Figures 3 and 6 respectively) were not favourable for iron(II) oxidation. Throughout the performance evaluation of the diffused aeration process, ferric formation was at a minimum for pH values of 7.4 and 7.8, and at a maximum for a pH of 7.6 and 7.7. As

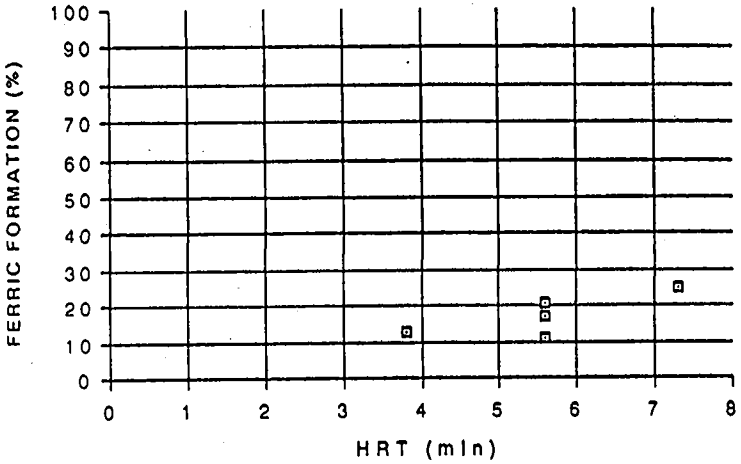


FIGURE 3 IRON(II) OXIDATION AT pH = 7.4

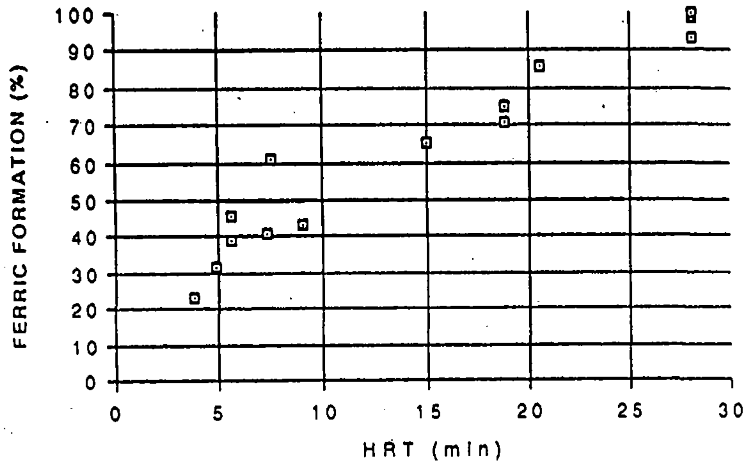


FIGURE 4 IRON(II) OXIDATION AT pH = 7.6

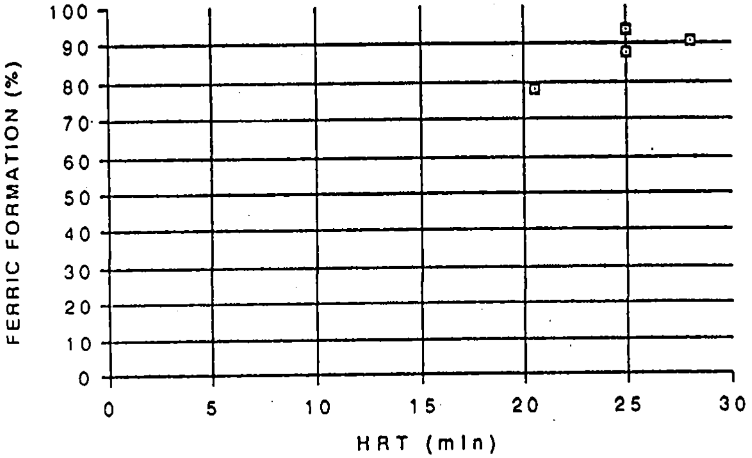


FIGURE 5 IRON(II) OXIDATION AT pH = 7.7

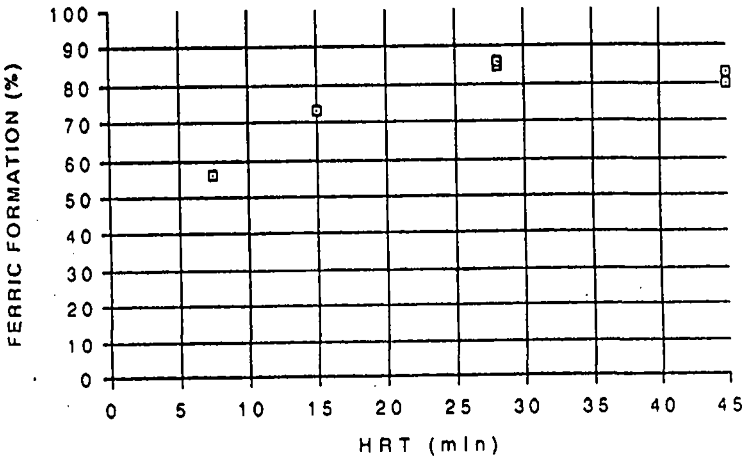


FIGURE 6 IRON(II) OXIDATION AT pH = 7.8

Figure 4 shows, a pH of 7.6 and a hydraulic retention time of approximately 28 minutes were necessary to oxidize all iron(II) to iron(III).

Manganese(II) was not significantly oxidized within experimental error, in the diffused aeration vessel under any of the experimental conditions (see Table 7).

TABLE 7 SUMMARY DATA FOR 23 RUNS

pH	HRT (min)	FERRIC FORMATION (%)	MANGANIC FORMATION (%)	RUN NUMBER
7.4	3.8	13	n.d.	19
7.4	5.6	11	n.d.	1
7.4	5.6	17	n.d.	1
7.4	5.6	21	n.d.	4
7.4	7.3	25	n.d.	3
7.6	3.8	23	3	20
7.6	4.8	32	5	21
7.6	5.6	46	8	2
7.6	5.6	39	4	8
7.6	7.3	41	n.d.	5
7.6	7.5	61	8	7
7.6	9.0	43	n.d.	9
7.6	15.0	65	4	10
7.6	18.8	71	n.d.	12
7.6	18.8	75	3	12
7.6	20.5	86	n.d.	16
7.6	28.1	93	n.a.	23
7.6	28.1	100	17	14
7.6	28.1	100	n.a.	14
7.7	20.5	78	n.d.	17
7.7	25.0	88	n.a.	18
7.7	25.0	94	3	18
7.7	28.1	91	n.a.	22
7.8	7.5	56	15	6
7.8	15.0	73	n.d.	11
7.8	15.0	73	3	11
7.8	28.1	85	n.d.	15
7.8	28.1	86	n.a.	15
7.8	45.0	80	n.a.	13
7.8	45.0	83	n.d.	13

n.a.: not available n.d.: non-detectable

Two main conclusions were derived from the performance evaluation of the diffused aeration process. These were:

1. Diffused aeration of the groundwater is technically feasible and was found effective in the oxidation of iron(II) to iron(III) at an aeration pH of 7.6 and a hydraulic retention time of 28 minutes (Figure 4).
2. Diffused aeration was not found effective for the oxidation of manganese(II) to manganese(IV) for solution pH equal to or below 7.8. Hence, the addition of chemical oxidant(s) will be required, following diffused aeration, to oxidize manganese(II).

5.2 Diffused Aeration - Chemical Oxidation Process

Twenty-two batch pilot scale runs were completed to evaluate the optimum chemical oxidant, dose and reaction time necessary to oxidize manganese(II). The diffused aeration vessel was operated under the previously determined optimum conditions, namely at an aeration pH of 7.6 and a hydraulic retention time of 28 minutes. The effluent of the diffused aeration vessel, collected in the chemical oxidation/detention vessel, was used for this study of chemical oxidants.

Approximately 120 L of aerated groundwater was collected in this vessel to carry out the performance evaluation in a batch mode. A mixer dispersed the chemical oxidant solution in the aerated groundwater. The chemical oxidant solution was added to the aerated groundwater, at time zero, and samples were collected as a function of time.

The following chemical oxidants were evaluated: hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), chlorine dioxide (ClO_2) and potassium permanganate ($KMnO_4$). Various dosages, expressed as multiples of the stoichiometric requirement (x stoic) for Mn(II) oxidation, were appropriately chosen to provide a complete evaluation of each oxidant's performance.

The theoretical REDOX reactions and associated stoichiometric values, expressed in moles and in mg, for these oxidants are tabulated in Table 8. The theoretical REDOX reaction and stoichiometric value for oxygen is also presented for comparative purposes.

Twenty-three runs were completed, including one control run during which no chemical oxidant was added to the aerated groundwater. The experimental results are presented below.

TABLE 8 THEORETICAL REDOX REACTIONS AND STOICHIOMETRIC REQUIREMENT FOR Mn(II) OXIDATION

OXIDANT	REDOX REACTION	STOICHIOMETRIC REQUIREMENT
H_2O_2	$Mn^{+2} + H_2O_2 + 2H^+ \rightarrow Mn^{+4} + 2H_2O$	1 mole H_2O_2/mole Mn or 0.62 mg H_2O_2/mg Mn
NaOCl	$Mn^{+2} + NaOCl + 2H^+ \rightarrow Mn^{+4} + NaCl + H_2O$	1 mole NaOCl/mole Mn or 1.35 mg NaOCl/mg Mn
ClO_2	$5Mn^{+2} + 2ClO_2 + 8H^+ \rightarrow 5Mn^{+4} + 4H_2O + 2Cl^-$	0.4 mole ClO_2/mole Mn or 0.49 mg ClO_2/mg Mn
$KMnO_4$	$3Mn^{+2} + 2KMnO_4 + 8H^+ \rightarrow 3Mn^{+4} + 2MnO_2 + 4H_2O + 2K^+$	0.7 mole $KMnO_4$/mole Mn or 1.92 mg $KMnO_4$/mg Mn
O_2	$Mn^{+2} + 0.5O_2 + 2H^+ \rightarrow Mn^{+4} + H_2O$	*0.5 mole* O_2*/mole Mn or* *0.29 mg* O_2*/mg Mn*

Raw data are presented in Appendix E.

The concentration of total manganese in the raw groundwater varied between 0.12 mg/L and 0.26 mg/L. Manganese was determined to be completely in a solution state(II). Diffused aeration did not result in oxidation of manganese(II), within the ± 0.02 mg/L margin of error of the analytical procedure. All other measured groundwater parameters showed behaviour similar to that described in the previous section.

A control experimental run (Run D), during which no chemical oxidant was used, was carried out to assess the impact of the presence of iron(III) flocs, of mixing and of detention time on the oxidation of manganese(II) in the vessel. Samples of groundwater were taken two and 12 minutes following chemical oxidant addition. Iron was fully oxidized. No evidence of manganese oxidation was obtained. Hence, this run demonstrated that Mn(II) remains stable in the absence of a chemical oxidant. Therefore, manganese(II) oxidation, observed in runs with such oxidants, must be caused by the oxidant itself. The results of the chemical oxidant performance evaluations, are presented below.

Hydrogen Peroxide

Table 9 summarizes the findings, for various reaction times and dosages.

TABLE 9 Mn(II) OXIDATION BY H_2O_2

DOSAGE (x stoichiometric requirement)	MANGANIC FORMATION (%)			
	at 1 minute	at 5 minutes	at 10 minutes	at 20 minutes
1.3	n.a.	7	20	20
6	12	15	1	n.a.
14	n.a.	n.d.	n.d.	7
60	n.d.	n.d.	n.d.	n.a.

n.a.: not available n.d.: non-detectable

The performance of hydrogen peroxide for manganese(II) oxidation and precipitation was poor. Minimal evidence of oxidation and precipitation, was observed during stoichiometric studies ranging from 1.3 to 60 x stoichiometric, reaction times from one minute to 20 minutes, and at a pH of 7.6. Therefore, further experimentation with hydrogen peroxide was not pursued.

Potassium Permanganate

Table 10 summarizes the findings, for various reaction times and dosages.

TABLE 10 Mn(II) OXIDATION BY $KMnO_4$

DOSAGE (x stoichiometric requirement)	MANGANIC FORMATION (%)	
	at 2 minutes	at 12 minutes
0.7	28	31
1.3	91	96
3.2	18	33

The performance of potassium permanganate for manganese(II) oxidation was good. At 0.7 x stoichiometric dosage, oxidation of manganese(II) was incomplete, either at two minutes (28%) or at 12 minutes (31%). At 1.3 x stoichiometric dosage, almost complete oxidation of manganese(II) occurred at two minutes (91%) and at 12 minutes (96%), resulting in a soluble manganese(II) concentration of 0.01 mg/L. At 3.2 x stoichiometric dosage, a substantially high concentration of manganese remained in solution. This result was attributed to the presence of excess unreacted potassium permanganate.

Although potassium permanganate was very effective for manganese(II) oxidation at 1.3 x stoichiometric dosage, further experimentation with potassium permanganate was not pursued. Any unreacted permanganate remaining in the treated water would require an oxidizing contact filter to remove this residual.

Sodium Hypochlorite

Table 11 summarizes the findings, for various reaction times and dosages.

The performance of sodium hypochlorite for manganese(II) oxidation was poor. Dosages well above the stoichiometric requirement were required to oxidize manganese(II) noticeably. The oxidation rates were also much slower than those observed with either $KMnO_4$ or ClO_2. A strong time dependency was observed during most runs. Little oxidation (< 30%) was seen for dosages ranging from 1.7 x to 8 x stoichiometric, and reaction times up to 20 minutes. Adequate oxidation, resulting in a soluble manganese(II) concentration equal to or below 0.05 mg/L, was observed only when the sodium hypochlorite dosage was 50 x stoichiometric. For example, under these conditions, 67% of the manganese(II) was oxidized after two minutes, resulting in a soluble manganese(II) concentration of 0.03 mg/L. At such high dosage, the groundwater had lost some of its aesthetic appeal because of a high chlorine odour.

TABLE 11 Mn(II) OXIDATION BY NaOCl

DOSAGE (x stoichiometric requirement)	MANGANIC FORMATION (%)					
	at 1 min	at 2 min	at 5 min	at 10 min	at 12 min	at 20 min
1.7	n.a.	n.a.	n.d.	n.d.	n.a.	8
3	9	n.a.	9	18	n.a.	n.a.
8	n.a.	16	n.a.	n.a.	29	n.a.
13	n.a.	14	n.a.	n.a.	29	n.a.
17	n.a.	n.a.	27	27	n.a.	27
29	37	n.a.	26	31	n.a.	n.a.
35	n.a.	48	n.a.	55	n.a.	64
50	n.a.	67	n.a.	78	n.a.	78

n.a.: not available n.d.: non-detectable

Despite its poor oxidation performance, sodium hypochlorite was not entirely rejected because it offered adequate oxidative potential at dosages 50 x stoichiometric requirement.

Chlorine Dioxide

Table 12 summarizes the findings, for various reaction times and dosages.

The performance of chlorine dioxide for manganese(II) oxidation was good. At 1.4 x stoichiometric dosage, manganese(II) oxidation was minimal. At 6.5 x stoichiometric dosages, virtually complete manganese(II) oxidation took place. Manganese(II) concentrations of ≤ 0.01 mg/L remained in the treated water. Reaction rates were rapid and comparable to those observed when using potassium permanganate. For example, complete oxidation of Mn(II) was observed at two minutes.

TABLE 12 Mn(II) OXIDATION BY ClO_2

DOSAGE (x stoichiometric requirement)	**MANGANIC FORMATION (%)**				
	at 2 min	**at 5 min**	**at 10 min**	**at 12 min**	**at 20 min**
1.4	n.a.	7	n.d.	n.a.	n.d.
5	28	n.a.	n.a.	30	n.a.
6.5	100	n.a.	n.a.	100	n.a.
8	93	n.a.	n.a.	93	n.a.
10	93	n.a.	n.a.	89	n.a.
10	99	n.a.	n.a.	97	n.a.

n.a.: not available n.d.: non-detectable

The only difference between the performance observed for these two oxidants was the stoichiometric dosage required: ClO_2 required 6.5 x stoichiometric, whereas $KMnO_4$ required slightly more than a stoichiometric amount to oxidize manganese(II) completely.

Nevertheless, dosages, expressed in mg/L, remain unchanged and were found to be comparable, i.e. 2.5 mg $KMnO_4$/mg Mn(II) versus 3.2 mg ClO_2/mg Mn(II).

In summary, the performance of chlorine dioxide was similar to that of potassium permanganate for manganese(II) oxidation.

Three main decisions were derived from the batch performance evaluations of chemical oxidant addition to complement the diffused aeration process. These were:

1. Hydrogen peroxide and potassium permanganate were not to be evaluated at pilot scale in a continuous operating mode.
2. Among the chemical oxidants studied, chlorine dioxide was the oxidant of choice due to:
   - its ability to completely oxidize manganese(II) at 6.5 x stoichiometric dosage and hence promote a complete removal of manganese(IV) during sand filtration,
   - its high rate of oxidation, requiring minimal reaction time, and hence making it feasible to add it on-line, instead of requiring a mixed reactor and detention time,
   - its dual oxidant-disinfecting action, which surpasses that of the other chemical oxidants studied(6), and
   - its lower reactivity with organics in typical water treatment applications(5), and in contaminated groundwater remediation applications(2).
3. Although the effectiveness of sodium hypochlorite was not found comparable to that of chlorine dioxide, evaluation of sodium hypochlorite at pilot scale would be conducted, due to its potentially lower operating costs, and to other logistic factors specific to water treatment operations in the Municipality of Waterloo.

5.3 Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration

The diffused aeration - chemical oxidation - direct contact sand filtration process train was first operated for several hours, to assess under a continuous operating mode, the performance of the chemical oxidation component of the train and the ability of the sand filter to remove the oxides (and other suspended solids) formed (Section 5.3.1). The optimum train was then operated continuously for a longer period of time (several days) to gather long-term data such as overall performance of the process train, mass storage capacity of the sand filter and backwash water characterization (Section 5.3.2).

5.3.1 Preliminary Performance Evaluation: Short Duration Runs

Five runs were completed to evaluate iron and manganese removal by the diffused aeration - chemical oxidation - direct contact sand filtration (A - O - F) process train.

The A - O - F train was operated for several hours at a time to allow for multiple sampling along the sequence of process elements. During this evaluation, the diffused aeration vessel was operated at predetermined optimum conditions, namely at an oxidation pH of 7.6 and a hydraulic retention time of 28 minutes. The independent variables in this phase of experimentation included 1) chemical oxidant type (ClO_2, NaOCl); 2) chemical oxidant dosage (1, 7, 10 x stoichiometric for ClO_2, 50 x stoichiometric for NaOCl); and 3) chemical oxidation reaction time (2, 3, 12 minutes for ClO_2, two minutes for NaOCl). The experimental results are presented below.

Raw data are presented in Appendix F.

A control run (Run 1a), without post-aeration oxidant addition, evaluated manganese(II) removal in the sand filter by purely adsorptive processes. About 90% iron(II) was oxidized in the diffused aeration vessel; the residual iron(II) in solution in the aerated groundwater was 0.19 mg/L. About 98% of the iron was removed in the sand filter; the total iron concentration in the treated water was 0.03 mg/L. Oxidation of remaining iron(II) took place in the sand filter bed (ferric formation in sand filter = 99%). Similar observations were presented earlier in Section 1.0 (Figure 1). The oxidation and removal profiles for iron, described for the control run (1a), followed closely the profiles observed during all subsequent diffused aeration - chemical oxidation - direct contact sand filtration runs (1 → 5).

Manganese, however, was neither oxidized in the diffused aeration vessel, nor removed in the sand filter bed. Hence, the removal of manganese observed in later runs can be attributed to either direct oxidation by a chemical oxidant or to catalytic oxidation in the sand bed promoted by the added oxidant.

Chlorine Dioxide

Four runs evaluated the performance of chlorine dioxide to oxidize and promote the removal of manganese in the filter bed.

Chlorine dioxide was tested successfully at 7 x (Run 4) and 10 x (Runs 1 and 3) stoichiometric dosages. Results for Run 1 showed complete manganese oxidation within 12 minutes in the detention vessel.

On-line addition of chemical oxidant (Runs 3 and 4), in the filter influent, was found just as effective as oxidation in the detention vessel. Results for Runs 3 and 4 showed complete manganese oxidation within the two - three minutes reaction time. During Run 2, a malfunction of the chemical oxidant addition dosing pump resulted in a low dosage of only 1 x stoichiometric requirement. As expected, low manganese oxidation and removal (~ 10%) was observed.

It was, therefore, concluded that the diffused aeration - chemical oxidation (ClO_2) - direct contact sand filtration process train was effective in removing iron and manganese from the W-5 groundwater. The operating requirements for the A - O(ClO_2) - F process train were:

Diffused Aeration Vessel:	Aeration pH = 7.6 Hydraulic retention time = 28 minutes
On-Line Chemical Oxidant Addition:	Oxidant type = ClO_2 Oxidant dosage = 7 x stoichiometric Reaction time = 2 minutes
Direct Contact Sand Filtration:	Sand bed depth = 1.1 m Sand effective diameter = 0.52 mm Filtration rate = 4.25×10^{-3} m/s

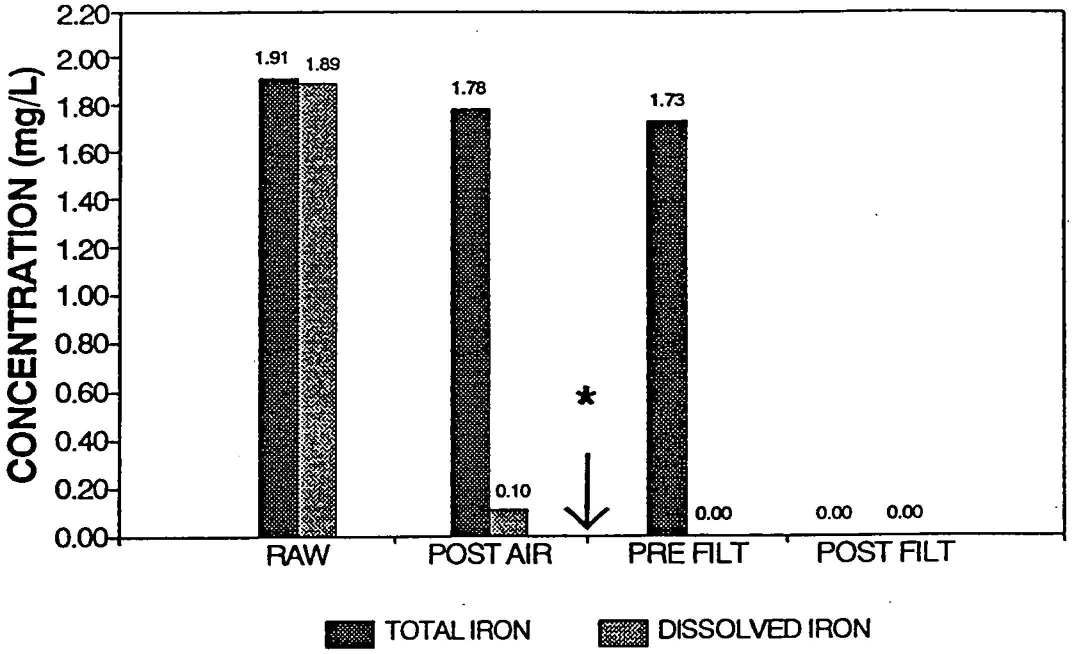
Figures 7 and 8 illustrate the performance profile of this train (Run 4) for iron and manganese removal. As shown in Figure 7, iron removal performance resembles that of the conventional process. By comparison, as seen in Figure 8, minimal oxidation of manganese occurs in the absence of ClO_2. Immediately following the addition of this oxidant, dissolved manganese fell from 0.11 to 0.01 mg/L. These manganese solids were removed by the filter, for an effluent concentration of 0.01 mg/L total manganese.

Sodium Hypochlorite

Run 5 confirmed the previously observed performance of sodium hypochlorite during the pilot scale batch evaluation (Section 5.2). Figures 9 and 10 illustrate the performance profile of this train (Run 5) for iron and manganese removal.

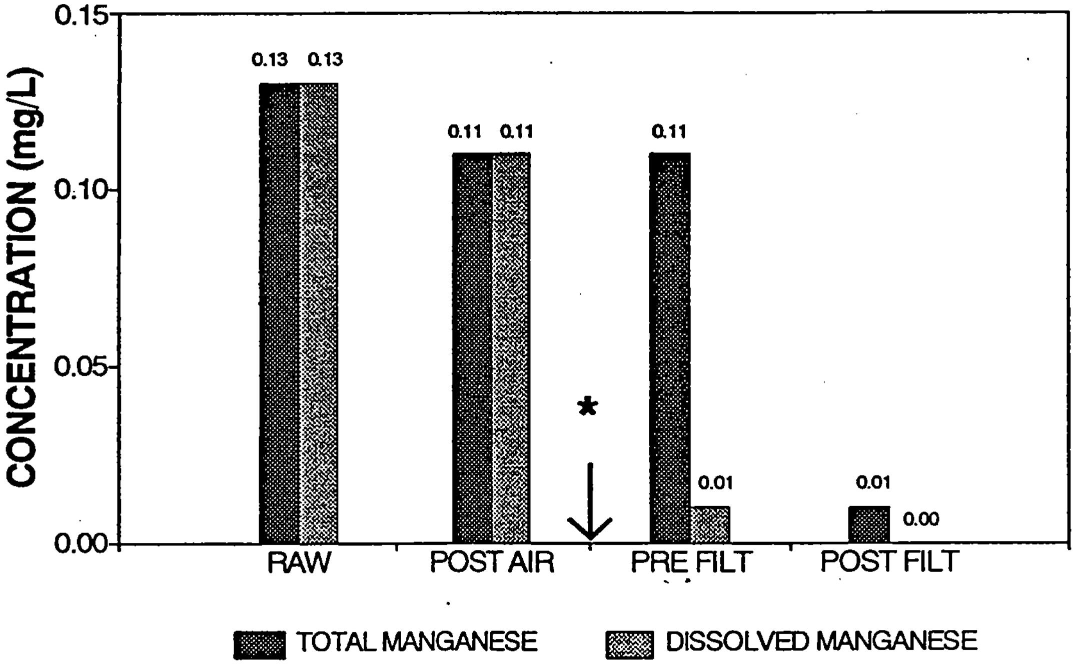
When sodium hypochlorite, at 50 x stoichiometric, reacted with aerated water in the filter influent (two minutes reaction time), 65% of the manganese was oxidized. As a result, manganese(II) fell from 0.13 mg/L to 0.05 mg/L. Some indication that a partial catalytic oxidation of the residual manganese(II) occurred in the sand bed, was recorded. The sand bed reduced the level of manganese(II) from 0.05 mg/L to 0.02 mg/L. Overall, 88% of the manganese was removed by the train. The total manganese concentration in the effluent of the process train was 0.02 mg/L.

Hence, it was concluded that the performance of the A - O - F process train, for iron and manganese removal, was comparable, when either NaOCl (50 x stoichiometric) or ClO_2 (7 x stoichiometric) are used.



*Oxidant added at this point

FIGURE 7 A - O (ClO_2)- F PROCESS TRAIN: IRON RESULTS



*Oxidant added at this point

FIGURE 8 A - O (ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

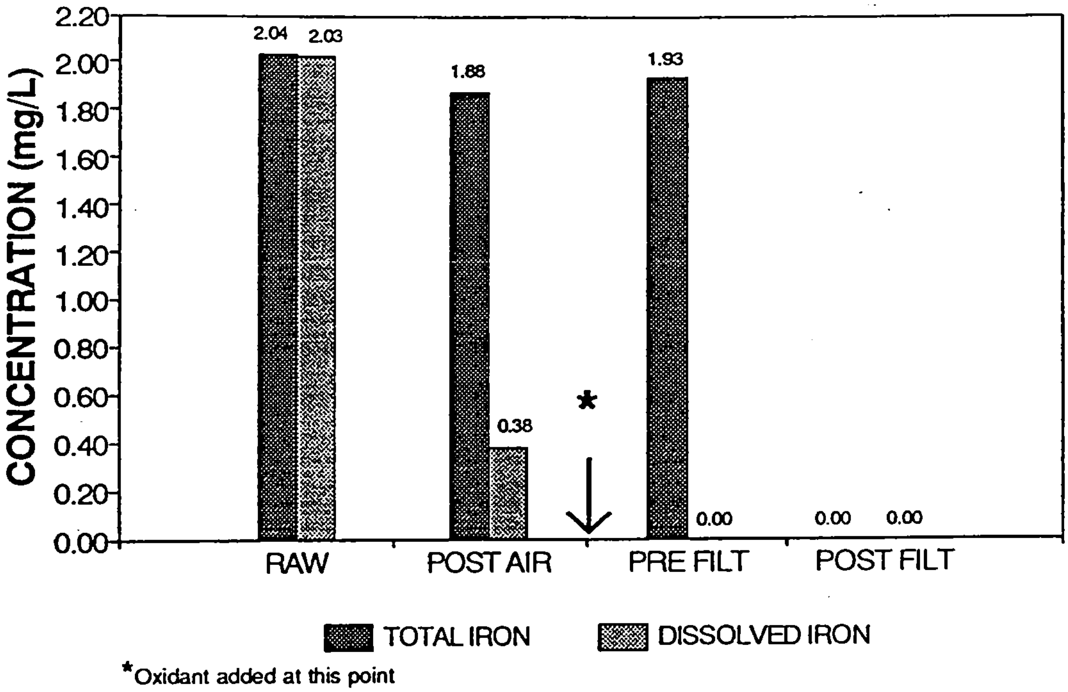


FIGURE 9 A - O (NaOCl) - F PROCESS TRAIN: IRON RESULTS

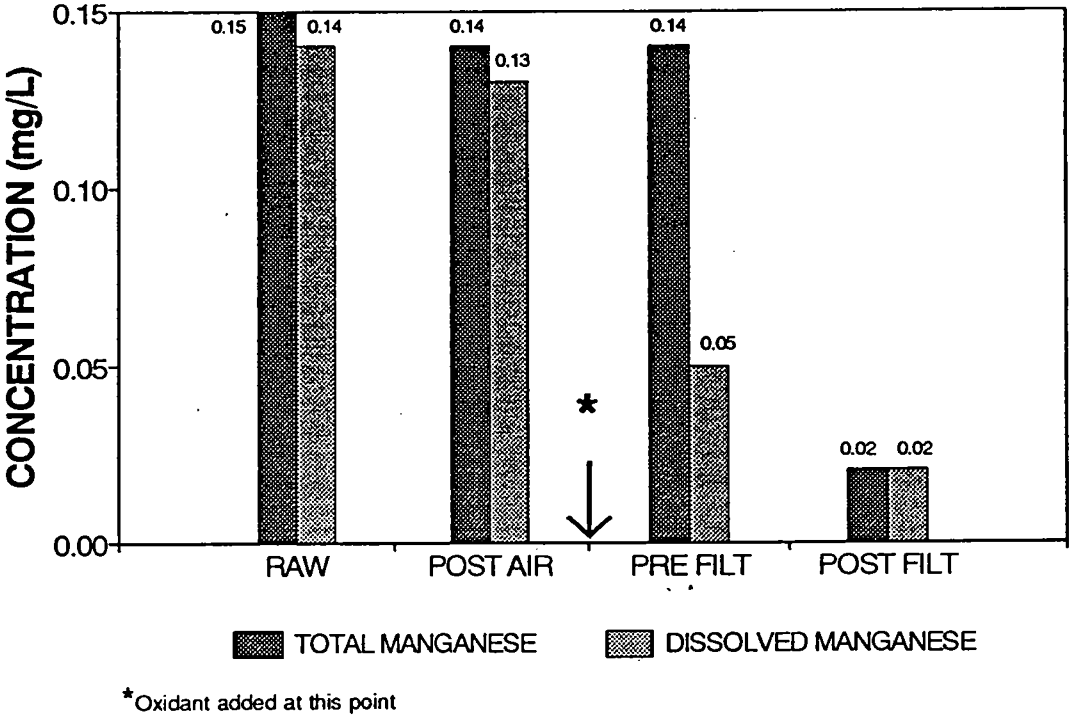


FIGURE 10 A - O (NaOCl) - F PROCESS TRAIN: MANGANESE RESULTS

5.3.2 Performance Evaluation: Continuous Operation

The A - O(ClO_2) - F process train was operated continuously for five days.

The following points were sampled fourteen times during this period:

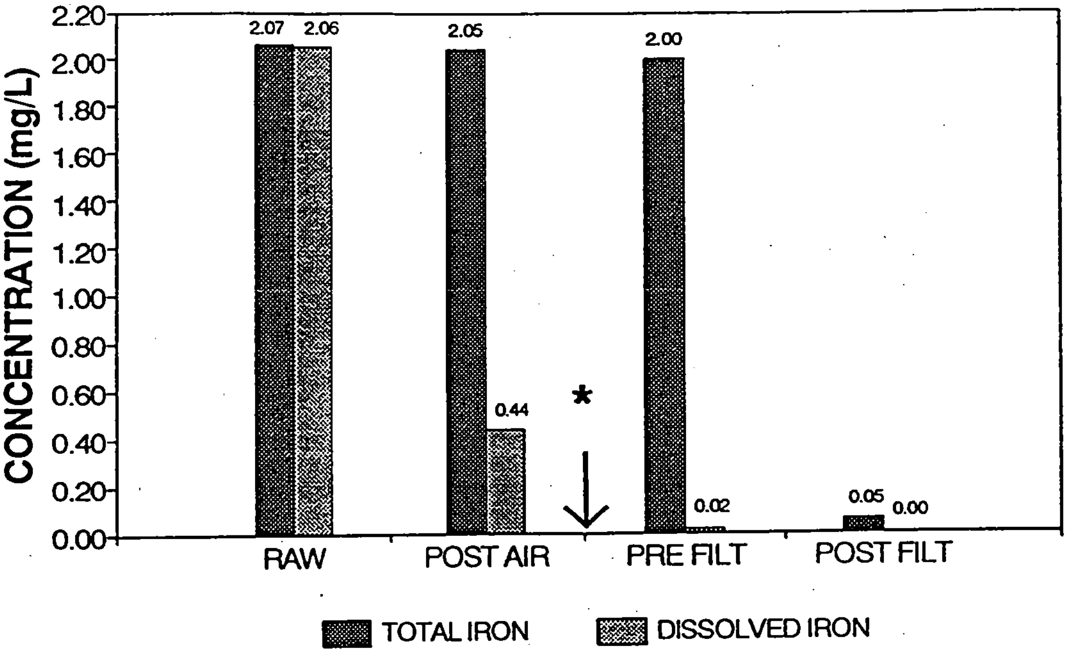
- Raw groundwater (before aeration vessel)
- Post-Aeration (before on-line addition of ClO_2)
- Pre-Filtration (after on-line addition of ClO_2)

The effluent from the process train (Post-Filt) was sampled forty-one times during this period. Raw data are presented in Appendix G. Figures 11 and 12 illustrate the performance profile of the train for iron and manganese removal during this five-day period.

During continuous operation, the process train removed an average of 98% iron and 93% manganese. Groundwater entered the train with 2.07 mg/L iron and 0.15 mg/L manganese and left with only 0.05 mg/L iron and 0.01 mg/L manganese.

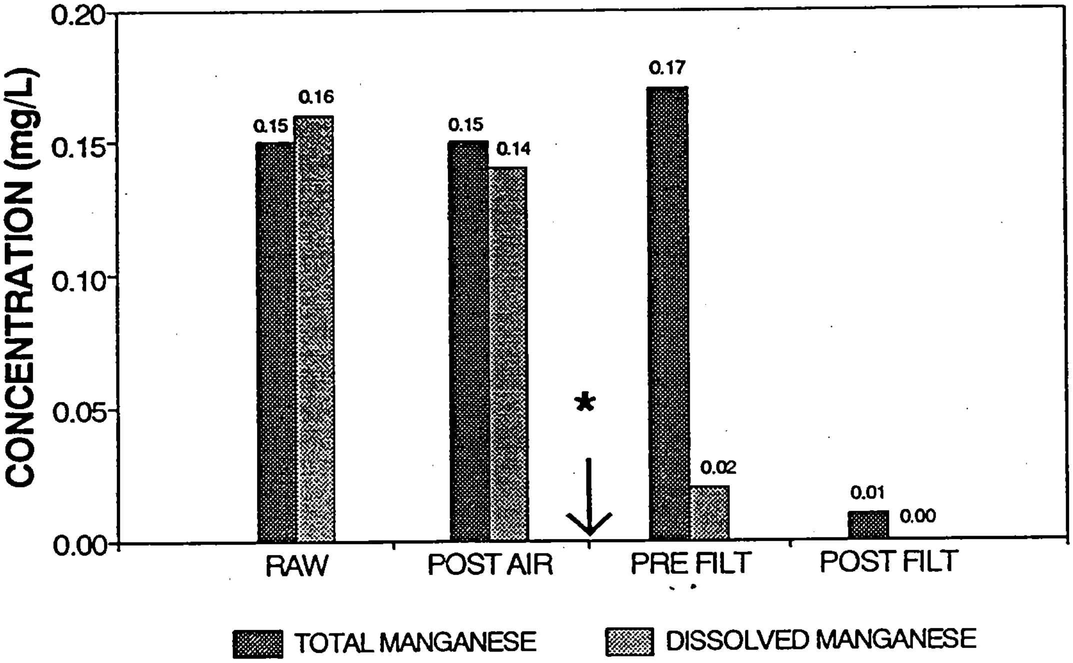
Breakthrough of iron (> 0.30 mg/L) and of manganese (> 0.05 mg/L) did not occur during the five days of continuous operation, so data for calculating the bed's maximum storage capacity were not obtained. The mass storage capacity of the bed was not accurately determined, but a conservative estimate is provided. The mass storage capacity of the sand filter was greater than 1.0 kg suspended solids/m^3 sand, of which 0.4 kg was Fe and 0.03 kg was Mn.

Backwash of the sand bed consisted of first air scouring then backwashing with water, as described in Section 4.1.5. Table 13 shows the content of suspended solids in samples of backwash water collected over 50 minutes. The backwash water requirement was low. Less than one percent of the total volume of treated groundwater was required to properly clean the sand bed.



*Oxidant added at this point

FIGURE 11 CONTINUOUS OPERATION OF A - O (ClO_2) - F PROCESS TRAIN: IRON RESULTS



*Oxidant added at this point

FIGURE 12 CONTINUOUS OPERATION OF A - O (NaOCl) - F PROCESS TRAIN: MANGANESE RESULTS

TABLE 13 TEMPORAL CHANGES IN CONCENTRATIONS OF SUSPENDED SOLIDS IN THE SAND FILTER BACKWASH WATER

TIME (min)	SUSPENDED SOLIDS CONTENT (mg/L)
< 1	> 53 000
2	> 53 000
4	878
6	314
8	131
10	15
12	13
14	11
16	6
18	7
20	5
22	5
24	3
26	1
28	3
30	1
40	1
50	1

6.0 PILOT SCALE TREATABILITY STUDIES: ENHANCED AERATION PROCESS I - CONTINUOUS RECYCLE LOOP

This section presents studies conducted to develop a modified diffused aeration - direct contact filtration process train. In this train, a fraction of the effluent from the diffused aeration vessel was recycled continuously to the vessel's influent line.

6.1 Continuous Recycle Loop - Diffused Aeration Process

Seventeen runs were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when 10% or 20% of the effluent from the vessel was recycled to its influent point. To assess if solids in the recycled stream influenced the rates of oxidation, the first tests involved recycling 20% of the effluent stream. If the process increased reaction rates, additional runs would be conducted with recycling 10% of the effluent stream.

Furthermore, only a few experimental runs were conducted with design/operational requirements (HRT, pH) more demanding than those determined during the optimization of the conventional diffused aeration process. This is due to the added cost(s) directly related to the implementation of a recycle treatment system. Hence, to warrant the installation and operation of such a system, an improvement in the oxidative/removal performance of the train is required.

Raw data are presented in Appendix H.

A summary table and figure are presented below. Table 14 summarizes the iron and manganese oxidation results from all seventeen runs. Figure 13 shows the percent ferric formation at various hydraulic retention times, and at a pH of 7.6.

The concentration of total iron in the raw groundwater varied between 1.89 mg/L and 2.09 mg/L. The concentration of total manganese in the raw groundwater varied between 0.11 mg/L and 0.20 mg/L. Iron(II) was effectively oxidized at a pH of 7.6. The oxidation of about 95% of the iron, at a pH of 7.6, still required a hydraulic retention time of 28 minutes (Figure 13), even when 20% of the effluent was recycled. Complete iron oxidation was observed at a pH of 7.8, but still required approximately 23 minutes.

TABLE 14 ENHANCED AERATION RUNS: CONTINUOUS RECYCLE LOOP PROCESS

pH	HRT (min)	RECYCLE RATIO (%)	FERRIC FORMATION (%)	MANGANIC FORMATION (%)	RUN NUMBER
7.4	5.6	20	35	16	4
7.4	7.5	20	40	7	6
7.6	5.6	20	43	11	5
7.6	7.5	20	72	7	7
7.6	11.3	20	65	1	8
7.6	13.2	20	74	n.d.	14
7.6	15.0	20	84	4	13
7.6	17.3	20	87	7	12
7.6	22.5	10	87	12	1
7.6	22.5	10	86	12	1d
7.6	22.5	20	89	9	2
7.6	22.5	20	89	14	2d
7.6	22.5	20	93	19	10
7.6	25.0	20	87	14	17
7.6	25.0	20	87	18	17d
7.6	28.1	20	92	14	11
7.6	28.1	20	98	17	16
7.6	28.1	20	93	n.d.	16d
7.6	28.1	20	98	n.d.	16t
7.6	32.1	20	93	1	15
7.6	32.1	20	97	14	15d
7.6	32.1	20	98	9	15t
7.8	11.3	20	68	9	9
7.8	22.5	20	100	8	3
7.8	22.5	20	100	8	3d

n.a.: not available   n.d.: non-detectable

Manganese(II) was not oxidized appreciably in the diffused aeration vessel under any of the experimental conditions subjected.

Two main conclusions were drawn from the performance evaluation of the diffused aeration - continuous recycle loop process. These were:

1. At these ratios, the design/operating requirements for iron(II) oxidation were similar to those of the conventional diffused aeration process. Also, the oxidation of manganese(II) was not promoted. The conventional diffused aeration process was equivalent to the diffused aeration continuous recycle loop process, for recycle ratios of 20% or less.

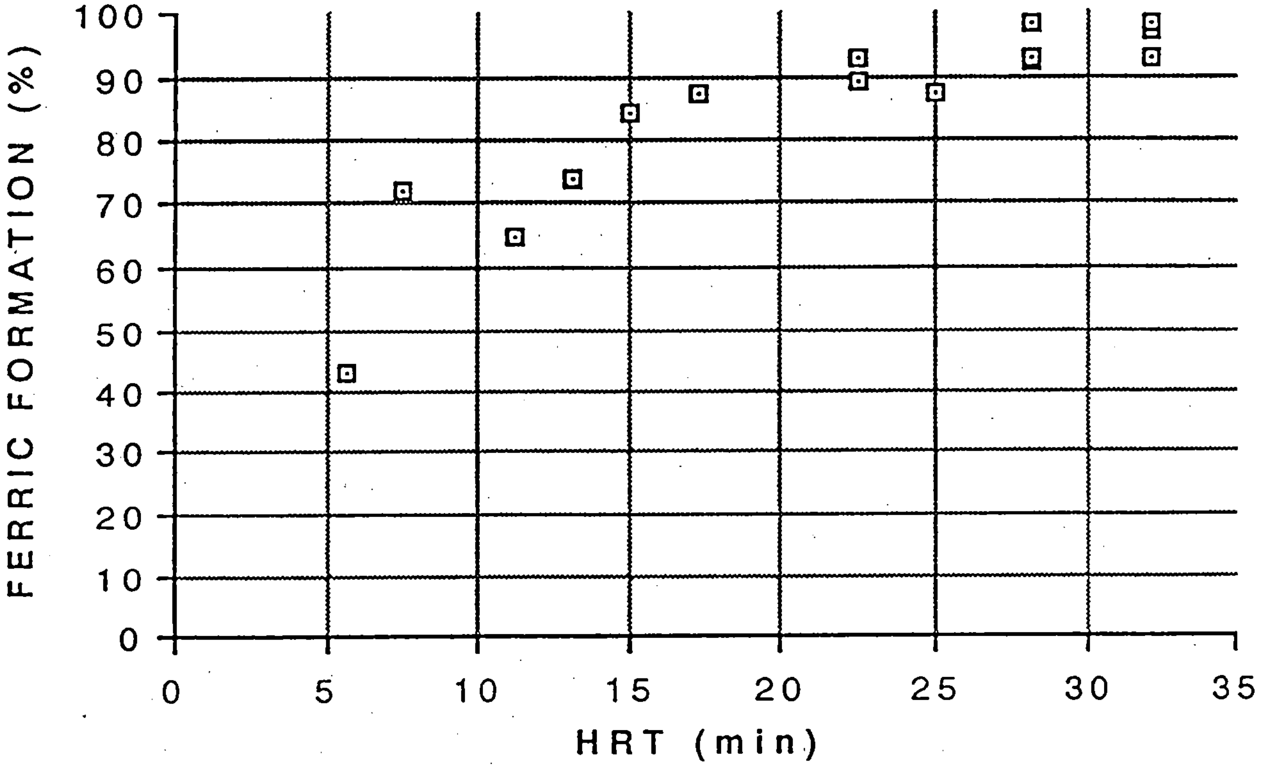


FIGURE 13 IRON(II) OXIDATION AT pH = 7.6 / 20% RECYCLE RATIO

2. The addition of a chemical oxidant will be required, following aeration, to oxidize manganese(II).

6.2 Diffused Aeration - Continuous Recycle Loop - Chemical Oxidation - Direct Contact Sand Filtration Process

Due to the similarity between this process and the conventional process, only one run was completed to demonstrate the effectiveness of chlorine dioxide (ClO_2) for manganese(II) oxidation. The process train was operated for several hours to allow for four samplings along the sequence of process elements. The diffused aeration vessel was operated at a pH of 7.6, a hydraulic retention time of 28 minutes and a recycle ratio of 20%. ClO_2, at 6 x stoichiometric, was added to the filter influent (reaction time = 2 minutes). The filtration rate was 4.25×10^{-3} m/s.

Raw data are presented in Appendix I. Figures 14 and 15 illustrate the performance profile of this train for iron and manganese removal.

About 96% of the iron was oxidized in the aeration vessel; the concentration of iron(II) in the aerated groundwater was 0.09 mg/L. About 98% of the iron was removed in the sand filter. Residual iron(II) was eventually completely oxidized in the sand filter bed.

About 95% of the manganese(II) was oxidized following ClO_2 addition, at 6 x stoichiometric. About 94% of the manganese was removed in the sand filter; the concentration of total manganese in the treated water was 0.01 mg/L.

The results of this study showed that recirculating 20% of the effluent from the diffused aeration vessel did not improve iron or manganese oxidation.

In light of this finding, there was no need to operate this modified train continuously to gather long-term performance data.

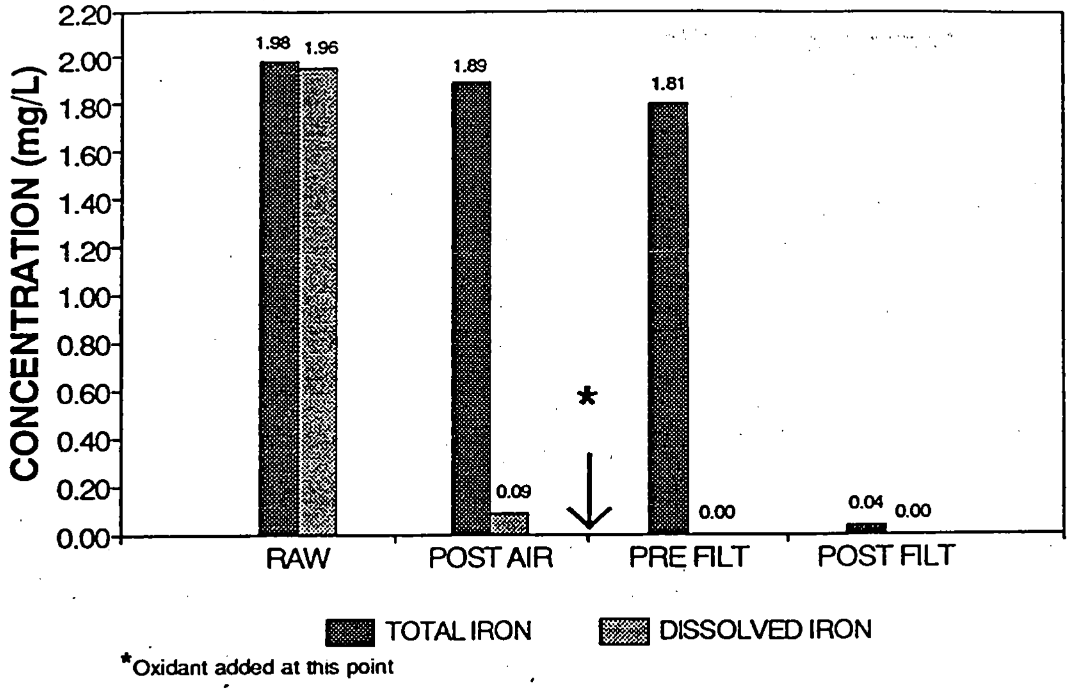


FIGURE 14 A (RECYCLE) - O (ClO_2) - F PROCESS TRAIN: IRON RESULTS

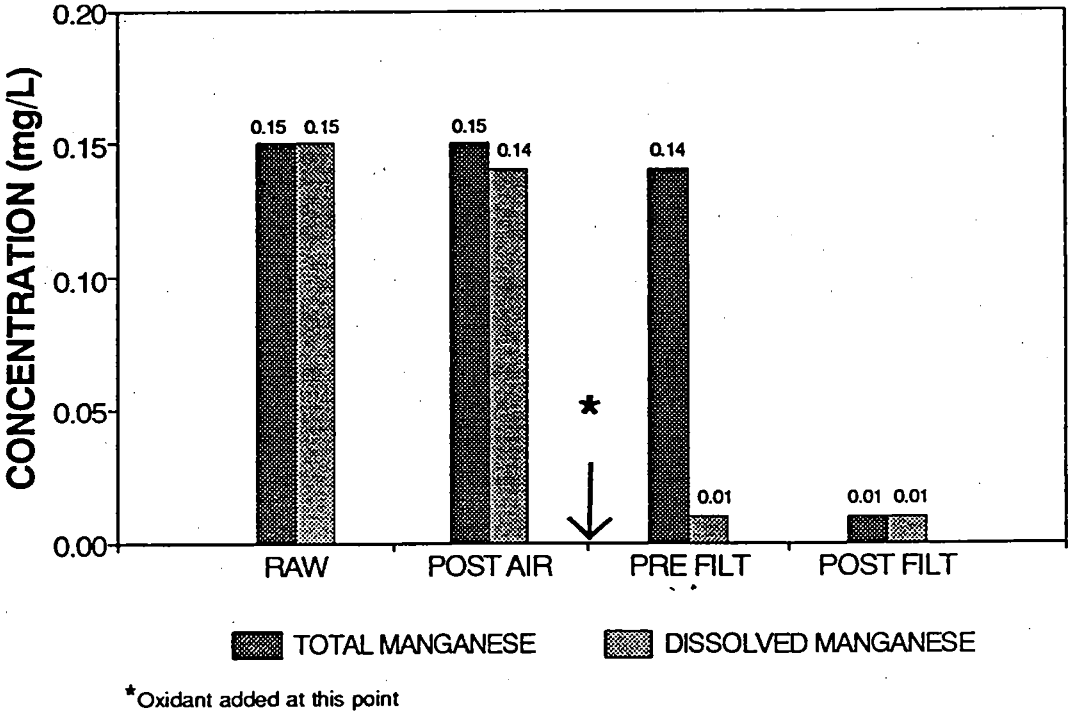


FIGURE 15 A (RECYCLE) - O (ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

7.0 PILOT SCALE TREATABILITY STUDIES: ENHANCED AERATION PROCESS II - SLUDGE ADDITION

This section presents the data and conclusions of the experimental studies which were conducted to develop another modified diffused aeration - direct contact filtration process train. In this train, sludge collected from the sand filter backwash water was recirculated to the influent line of the diffused aeration vessel.

7.1 Sludge Addition - Diffused Aeration Process

Fourteen runs were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when added sludge maintains a high concentration of iron(III) in the vessel. This work assessed if the rates of oxidation of iron and manganese were accelerated by increasing total iron by up to 500% in the diffused aeration vessel. The first step was to assess if these rates were augmented by increasing the total iron concentration in the aeration vessel by a maximum of 500% (sludge addition factor* = 5). If reaction rates were increased, additional runs would be conducted at lower sludge addition factors to assess the impact of lower SAF on the rates of iron and manganese oxidation.

Sludge was generated by operating, at night, the diffused aeration - direct contact sand filtration process train. It consisted, therefore, mainly of iron(III).

Raw data are presented in Appendix J. A summary table and figure are presented below. Table 15 summarizes iron and manganese oxidation results from all fourteen runs. The data collected at a pH of 7.6 and SAF of 4 - 7 has been plotted and presented in Figure 16. For better illustrative purposes, the data collected previously during the conventional diffused aeration process (SAF = 0) has also been plotted (overlay plot) and shows the similarity in oxidation kinetic profile.

The concentration of total iron in the raw groundwater varied between 1.99 mg/L and 2.12 mg/L. The concentration of total manganese in the raw groundwater varied between 0.12 mg/L and 0.17 mg/L.

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*Sludge addition factor (SAF) = mg Fe added to the diffused aeration vessel/mg Fe in raw groundwater

TABLE 15 ENHANCED AERATION RUNS: SLUDGE ADDITION PROCESS

pH	HRT (min)	SLUDGE ADDITION FACTOR (%)	FERRIC FORMATION (%)	MANGANIC FORMATION (%)	RUN NUMBER
7.4	4.0	31.4	67	6	3
7.4	4.1	0.0	14	n.d.	7
7.4	4.1	2.1	16	n.d.	10
7.6	4.0	58.6	90	3	1
7.6	4.0	58.6	89	12	1d
7.6	4.0	30.1	n.a.	4	2
7.6	4.0	30.1	81	12	2d
7.6	4.1	17.8	74	13	4
7.6	4.1	3.7	39	n.d.	5
7.6	4.1	0.0	22	n.d.	6
7.6	4.1	5.3	53	n.d.	8
7.6	4.1	1.9	20	3	9
7.6	4.1	12.0	47	2	11
7.6	11.1	6.9	67	n.d.	13
7.6	14.8	6.1	82	n.d.	12
7.6	22.3	5.1	92	n.d.	14

n.a.: not available n.d.: non-detectable

About 92% of iron was oxidized at a pH of 7.6, a SAF ~ 5, and a hydraulic retention time greater than 22 minutes. For comparison, the conventional diffused aeration process achieved similar iron oxidation results at the identical pH and comparable retention time.

Manganese(II) was not oxidized, within experimental error, in the diffused aeration vessel under any of the experimental conditions subjected.

In a few experimental runs, outside the original mandate of this study, a large quantity of iron(III) was recirculated to the diffused aeration vessel. Sludge addition factors of 0 to 59 were experimented with, for an oxidation pH of 7.6 and for a hydraulic retention time of four minutes. Figure 17 presents ferric formation as a function of SAF, when the oxidation pH is 7.6 and the hydraulic retention time of the groundwater in the diffused aeration vessel is approximately four minutes.

At a SAF = 59, 90% of iron(II) was oxidized in the aeration vessel. In contrast, manganese(II) was not oxidized, within experimental error, in the diffused aeration vessel, at any SAF. Hence, sludge addition, when SAF = 59, decreased the hydraulic retention time

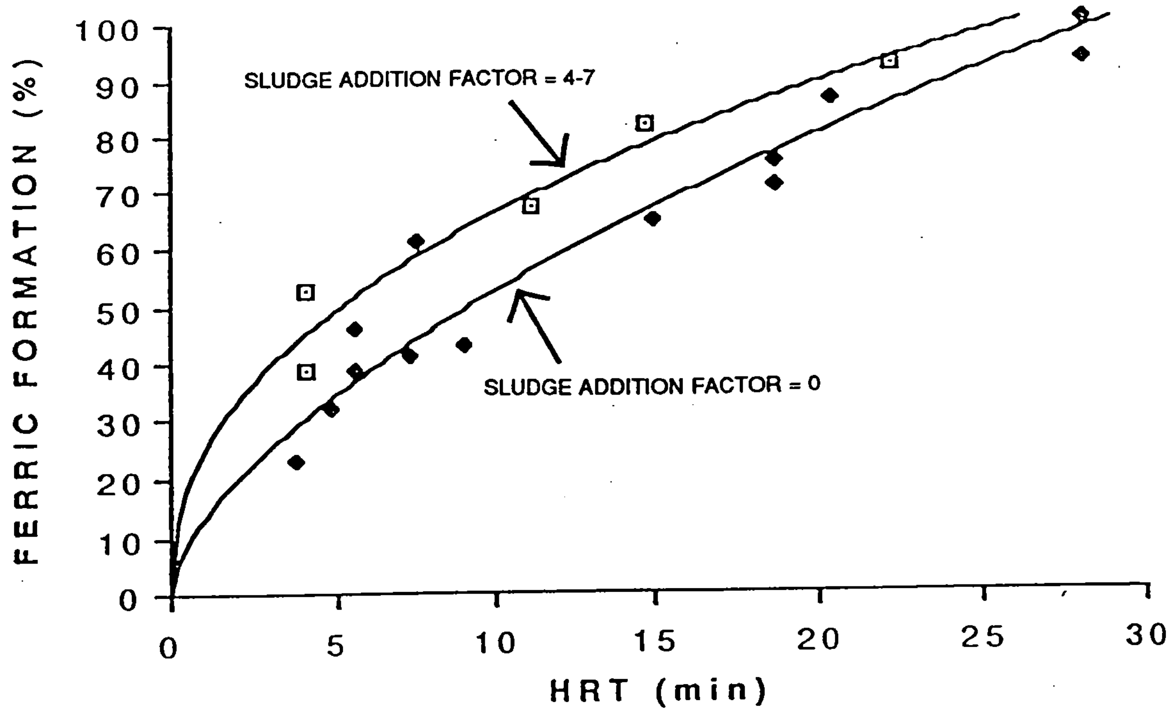


FIGURE 16 IRON (II) OXIDATION FOR SAFs = 0; 4 - 7, pH 7.6

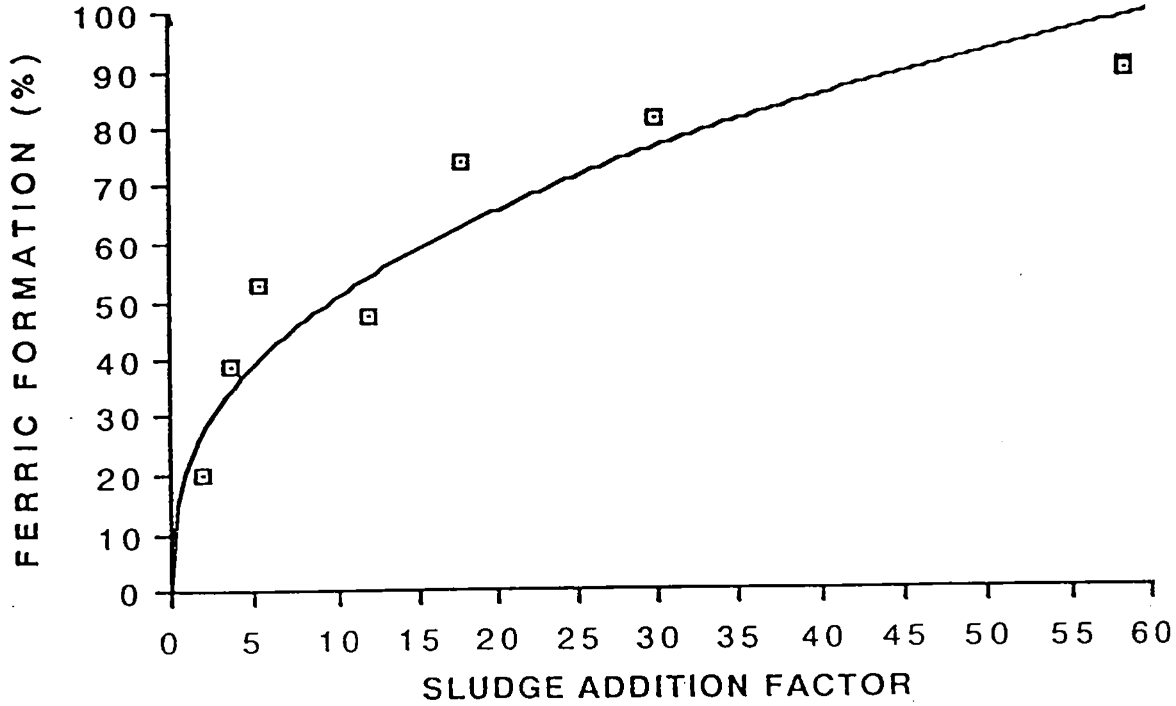


FIGURE 17 IRON(II) OXIDATION FOR SAFs = 0 - 59, pH 7.6

required for virtually complete ferric formation, from approximately 28 minutes to four minutes.

Three main conclusions were drawn from the performance evaluation of the diffused aeration - sludge addition process. These were:

1. For sludge addition factors less than 7, the design/operation requirements for iron(II) oxidation were similar to those determined during the conventional diffused aeration process. Similarly, the oxidation of manganese(II) was not promoted even at a SAF of 7.
2. For a sludge addition factor of 59, the rate of oxidation for iron(II) was substantially promoted. A hydraulic retention time of four minutes was required to oxidize 90% of iron(II). Recirculation of the sludge did not, however, promote manganese(II) oxidation.
3. The addition of a chemical oxidant is required, following aeration, to oxidize manganese(II).

7.2 Diffused Aeration - Sludge Addition - Chemical Oxidation Process

Five batch pilot scale runs were completed to evaluate the performance of ClO_2 and NaOCl to oxidize manganese(II), when solids were recirculated to the diffused aeration vessel.

The diffused aeration vessel was operated at a pH of 7.6 and a hydraulic retention time of 22 minutes and for sludge addition factors of 5 - 6.

The experimental procedure for this batch chemical oxidation study resembles that described earlier in Section 5.2. Lower dosages of ClO_2 and NaOCl were also incorporated in the experimental program to assess the minimum requirement for manganese(II) oxidation. These were 1.3 x stoichiometric, 4.5 x stoichiometric and 7.0 x stoichiometric for ClO_2; and 35 x stoichiometric and 58 x stoichiometric for NaOCl.

Raw data are presented in Appendix K.

About 96% of iron(II) was oxidized in the diffused aeration vessel. The concentration of total manganese in the raw groundwater was stable at 0.14 mg/L. Dissolved manganese(II) concentrations in the raw groundwater remained the same following aeration, indicating that no oxidation of manganese(II) occurred in the diffused aeration vessel.

The performance of sodium hypochlorite for manganese(II) oxidation was poor. Dosages well above stoichiometric requirement were still required to oxidize manganese. The residual soluble manganese(II) concentration was 0.05 mg/L, for a NaOCl dosage of 58 x stoichiometric. This oxidant demand was similar to that required when no solids were recirculated to the diffused aeration vessel (Conventional Diffused Aeration Process).

Similarly, the performance of chlorine dioxide for manganese(II) oxidation was equivalent to that observed when no solids were recirculated to the diffused aeration vessel. At 7 x stoichiometric, ClO_2 effected a virtually complete manganese(II) oxidation, resulting in soluble manganese(II) concentration of less than or equal to 0.02 mg/L.

In conclusion, the performances of ClO_2 and NaOCl observed during these batch experimental runs were not enhanced by the presence of additional solids (SAF = 5-6).

7.3 Diffused Aeration - Sludge Addition - Chemical Oxidation - Direct Contact Sand Filtration Process

The diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was first operated continuously for short periods to evaluate the performance of the chemical oxidation component of the train and the ability of the sand filter to remove the oxides formed. After these data were reviewed, the optimum train was then run continuously for a longer period of time to assess the overall performance of the process train and mass storage capacity of the sand filter.

7.3.1 Preliminary Performance Evaluation: Short Duration Run

Two runs were completed to evaluate iron and manganese removal by the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration (A - S - O - F) process train. The A - S - O - F train was operated for a couple of hours at a time for both runs. The diffused aeration vessel was operated at a pH of 7.6, a hydraulic retention time of 23 minutes and a sludge addition factor of approximately 6. For Run 1, ClO_2 was added on-line (reaction time = 2 minutes) to the filter influent at 6.5 x stoichiometric. For Run 2, NaOCl was added on-line (reaction time = 2 minutes) in the filter influent at 50 x stoichiometric. The filtration rate was 5.3×10^{-3} m/s. The experimental results are presented below. Raw data are presented in Appendix L. The performance profile of this train for iron and manganese removal is illustrated in Figure 18 (ClO_2) and in Figures 19 and 20 (NaOCl).

As shown in Figures 18 and 19, about 87% of iron(II) was oxidized in the diffused aeration vessel. Iron was effectively removed in the sand filter; this treated water contained no iron (Mean Total Iron Removal = 100%). About 94% of manganese(II) was oxidized following ClO_2 addition. Overall, 95% of the manganese was removed in the sand bed; this treated water contained 0.01 mg/L of manganese.

NaOCl oxidized only 37% of manganese (II). Because of this poor performance, 0.09 mg/L of manganese(II) remained in the treated water (Figure 20). However, data suggest

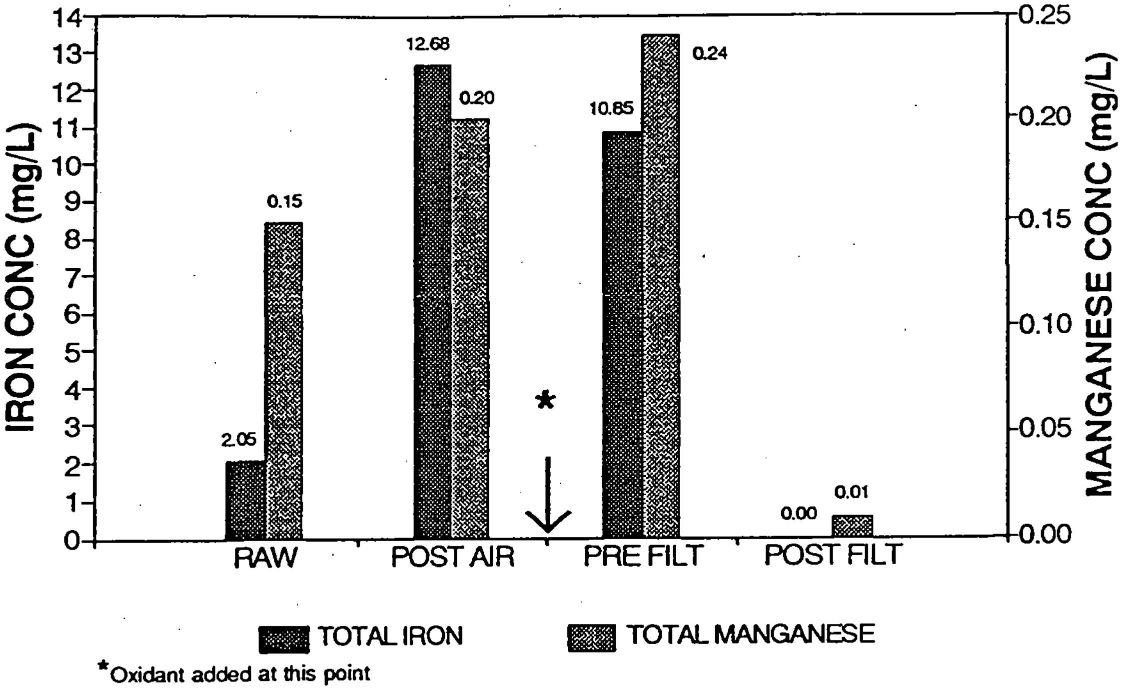


FIGURE 18 A (SLUDGE) - O (ClO_2) - F PROCESS TRAIN: IRON AND MANGANESE RESULTS

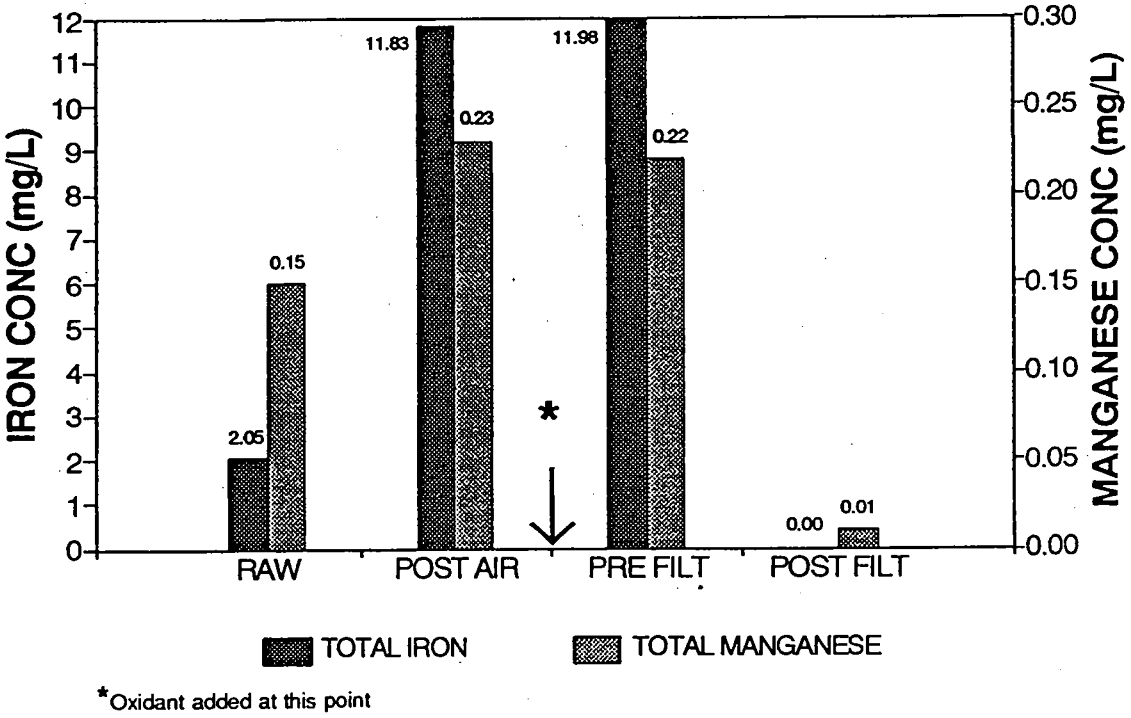
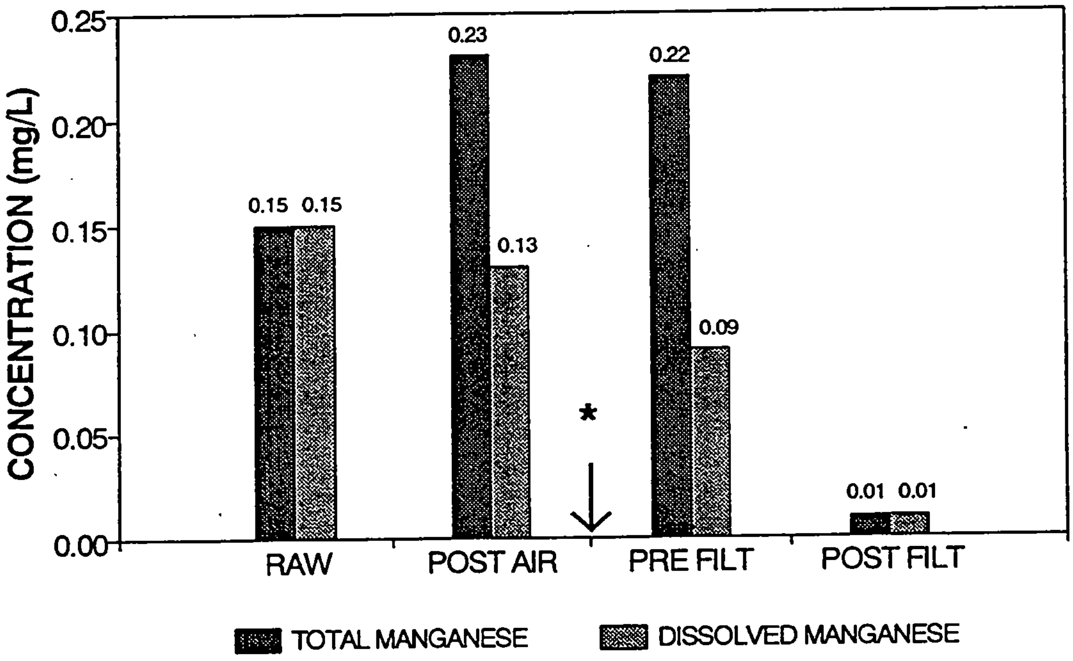


FIGURE 19 A (SLUDGE) - O (NaOCl) - F PROCESS TRAIN: IRON AND MANGANESE RESULTS



*Oxidant added at this point

FIGURE 20 A (SLUDGE) - O (NaOCl) - F PROCESS TRAIN: MANGANESE RESULTS that this residual soluble manganese(II) was oxidized in the sand bed: 89% of the residual manganese(II) was catalytically oxidized there (heterogeneous oxidation). Overall 97% of the manganese was oxidized by the process train, so that treated water contained 0.01 mg/L manganese. It should be noted that heterogeneous oxidation of manganese(II), noted to take place in the sand bed, was also previously observed, to a lesser extent, during the performance evaluation of the diffused aeration - chemical oxidation - direct contact sand filtration process train (Figure 10).

Hence, it was concluded that the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was effective in removing iron and manganese from the W-5 groundwater, when sodium hypochlorite (50 x stoichiometric) or chlorine dioxide (7 x stoichiometric) were used as oxidants.

Although this process train, at a SAF less than 7, did not demonstrate any advantages over the conventional diffused aeration process, a longer performance evaluation was undertaken in order to determine the overall performance of this process train until breakthrough of the sand bed.

7.3.2 Performance Evaluation: Long-Term Continuous Operation

The diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration was operated continuously for fifteen hours.

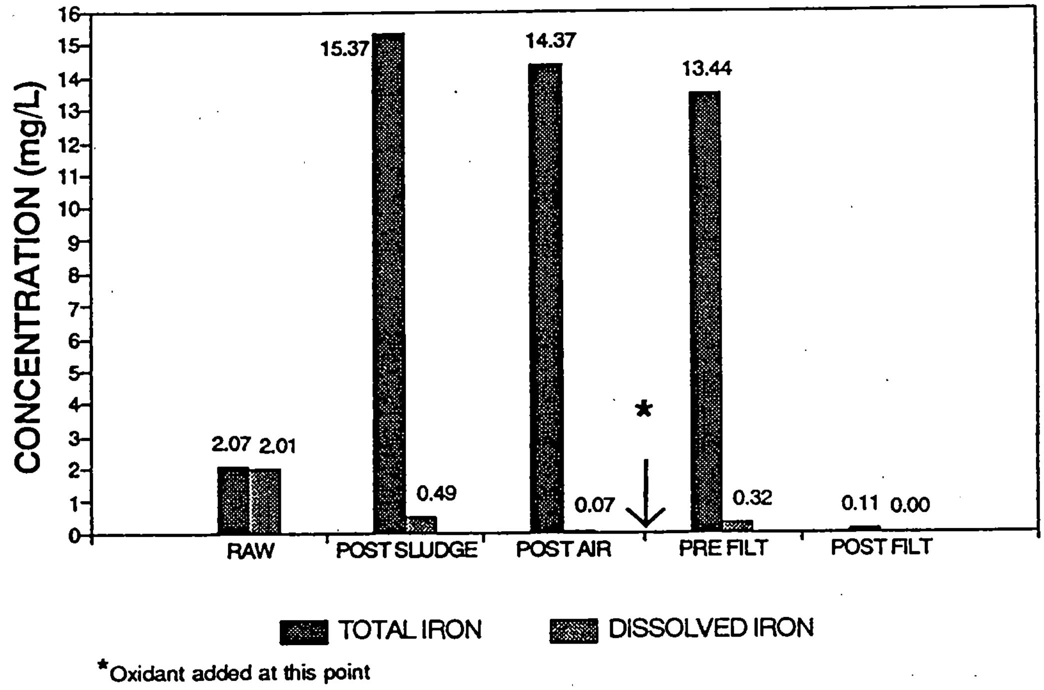
The following points were sampled three times during that period:

- Raw groundwater (before sludge addition)
- Post-Sludge (before aeration vessel)
- Post-Air (before on-line ClO_2 addition)

The effluent from the process train (Post-Filt) was sampled 11 times over the 15-hour period at approximately one-hour intervals. Raw data are presented in Appendix M. The performance profile of this train for iron and manganese is illustrated in Figures 21 and 22, respectively.

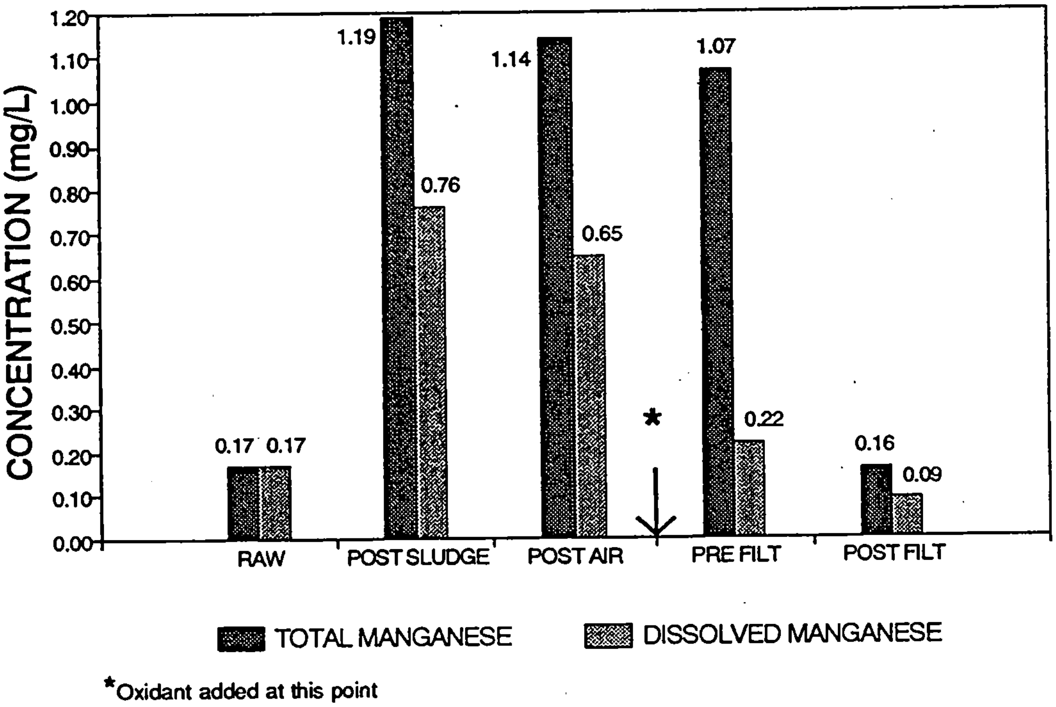
The mean concentrations of total iron and manganese in the raw groundwater were 2.07 mg/L and 0.17 mg/L, respectively. After the sludge was added (SAF = 7.4) to the raw groundwater, the mean concentrations increased from 2.07 mg/L to 15.37 mg/L for iron and 0.17 mg/L to 1.19 mg/L for manganese.

Sludge, being continuously generated nightly during the operation of the diffused aeration - chemical oxidation - direct contact sand filtration process train, had a high content in iron(III) and manganese(IV) oxides.



*Oxidant added at this point

FIGURE 21 A (SLUDGE) - O (ClO_2) - F PROCESS TRAIN: IRON RESULTS



*Oxidant added at this point

FIGURE 22 A - (SLUDGE) - O (ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

Rapid reduction of manganese(IV) to manganese(II) was observed immediately following sludge addition in the diffused aeration vessel influent (Figure 22). Correspondingly, rapid oxidation of iron(II) to iron(III) was observed (Figure 21), prior to aeration. Sludge addition resulted in the oxidation of (2.01 mg/L - 0.49 mg/L) 1.52 mg/L of dissolved iron (mean ferric formation = 76%) prior to aeration, and in the reduction of (0.76 mg/L - 0.17 mg/L) 0.59 mg/L of manganese. Because levels of dissolved manganese(II) rose, more ClO_2 had to be added in the filter influent to complete manganese oxidation and removal. However, the chemical oxidant dosage of seven times the stoichiometric requirement of manganese(II) in the raw groundwater was left unchanged to demonstrate the effect of recirculating sludge to the diffused aeration vessel.

Remaining dissolved iron(II) was effectively oxidized in the diffused aeration vessel (mean ferric formation = 97%). Dissolved manganese(II) was, as expected, incompletely oxidized by ClO_2 (mean manganic formation = 66%). The mean concentration of dissolved manganese(II) in the filter influent was 0.22 mg/L and was found to exceed the mean dissolved manganese(II) concentration in the raw groundwater of 0.17 mg/L (Figure 22).

Breakthrough of manganese was readily observed only two hours into the run; the postfilter total manganese concentration was 0.16 mg/L. Breakthrough of iron was observed eleven hours into the run. The mass storage capacity of the sand filter was equal to or less than 6.2 kg suspended solids/m^3 sand, of which $\leq$ 2.5 kg was Fe and $\leq$ 0.04 kg was Mn.

In conclusion, the performance of the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was poor. This was attributed to two factors. These were:

1. The reduction of manganese oxides(IV) and the corresponding oxidation of iron(II) in the raw groundwater prior to aeration: the use of this costly oxidant (manganese oxides) defeats the purpose of using air to oxidize iron(II). Furthermore, the reduced manganese, hence produced, demands a substantially higher dosage of the costly chemical oxidant, ClO_2, in order to enable the treated water to meet its manganese objectives.
2. Early breakthrough of manganese oxides (and dissolved manganese) was observed. Hence, an unexpectedly high frequency of backwashes is required when sludge is recirculated to the diffused aeration vessel.

Since the present process did not demonstrate any performance advantage over the conventional diffused aeration process, the requirements for frequent backwashes and for the installation of a sludge recirculation process cannot be substantiated.

8.0 PILOT SCALE PERFORMANCE EVALUATION OF RECOMMENDED PROCESS TRAIN: CONVENTIONAL DIFFUSED AERATION PROCESS

The diffused aeration - chemical oxidation (ClO_2) - direct contact sand filtration process train was selected for its good performance and simplicity over the enhanced aeration processes in which solids were recirculated to the diffused aeration vessel.

This recommended process train was operated continuously for seven days. The operating requirements for the A - O(ClO_2) - F process train were:

Diffused Aeration Vessel:	aeration pH = 7.6
	hydraulic retention time = 23 minutes
On-Line Chemical Oxidant Addition:	oxidant type = ClO_2
	oxidant dosage ($ClO_2 \rightarrow Cl^-$) = 7 x stoichiometric
	reaction time = 2 minutes
Direct Contact Sand Filtration:	sand bed depth = 1.1 m
	sand effective diameter = 0.52 mm
	filtration rate = 5.3×10^{-3} m/s

The following points were sampled eighteen times during that period:

- Raw Groundwater (before aeration vessel)
- Post-Air (before on-line ClO_2 addition)
- Pre-Filt (after on-line ClO_2 addition)

The effluent from the process train (Post-Filt) was sampled seventy-eight times during that period.

Raw data are presented in Appendix N. The performance profile of the recommended process train is illustrated in Figures 23 and 24.

The mean concentrations of total iron and manganese in the raw groundwater were 2.02 mg/L and 0.17 mg/L, respectively. About 81% of iron(II) was oxidized in the diffused aeration vessel at a hydraulic retention time of 22 minutes and a pH of 7.6. Manganese(II) was not oxidized, within experimental error, in the diffused aeration vessel.

ClO_2 addition, at 7 x stoichiometric, oxidized 82% of manganese(II) and left a residual of 0.03 mg/L, in the filter influent.

Iron and manganese solids were effectively removed in the sand filter throughout the duration of the experimental run. The mean total iron and manganese concentrations in the effluent of the process train were 0.05 mg/L and 0.02 mg/L, respectively.

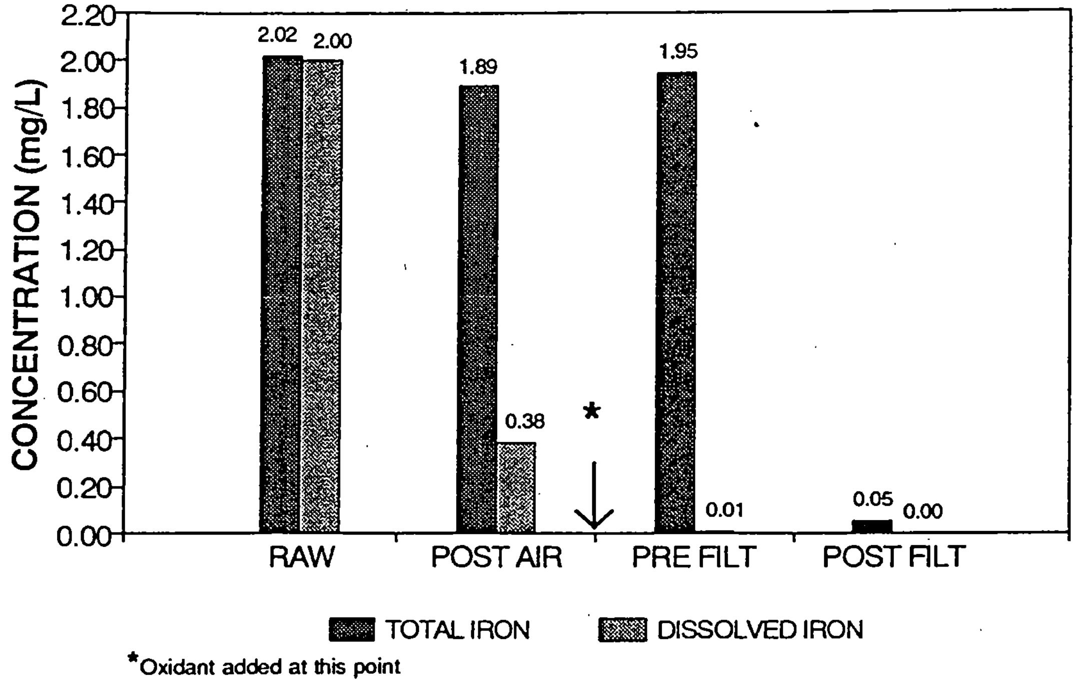


FIGURE 23 PERFORMANCE EVALUATION OF A - O (ClO_2) - F PROCESS TRAIN: IRON RESULTS

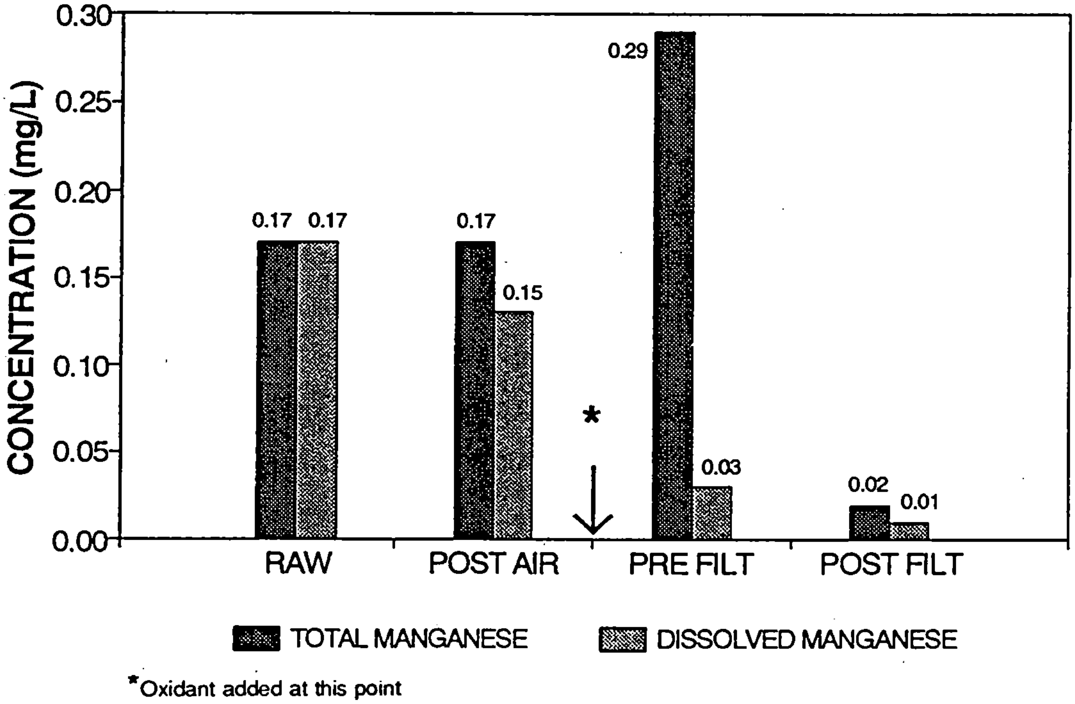


FIGURE 24 PERFORMANCE EVALUATION OF A - O (ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

9.0 CONCLUSIONS

The primary objective of the investigation was to maximize iron and manganese oxidation and removal processes. The development work focused on increasing the rates of oxidation of iron and manganese in a diffused aeration vessel, through the introduction of iron and manganese solids to the diffused aeration vessel.

Two enhanced processes were investigated, and compared to a conventional co-current diffused aeration - direct contact sand filtration process train. These were: 1) a continuous recycle loop process, where a fraction of the aeration vessel effluent was recycled to the vessel's influent line; and 2) a sludge recirculation process, where sludge, collected from the sand filter backwash water, was recirculated to the diffused aeration vessel influent line.

Based on the performance evaluations of the three process trains, the following conclusions were formulated:

1. Diffused aeration of the groundwater is technically feasible, and was found effective in the oxidation of iron(II) to iron(III), at a pH of 7.6 and a hydraulic retention time of 23 minutes.
2. Diffused aeration was not found effective for the oxidation of manganese(II) for pH values equal to or below 7.8. Hence, the addition of a chemical oxidant is required, following aeration.
3. Chlorine dioxide was found effective for the rapid on-line oxidation of manganese(II) to manganese(IV).
4. The diffused aeration - on-line chlorine dioxide addition - direct contact sand filtration process train was found highly effective in removing iron and manganese, resulting in levels of these metals below drinking water objectives.
5. The continuous recycle of 20% of the aeration vessel effluent to its influent point did not promote iron or manganese oxidation in the diffused aeration vessel. The design/operating requirements of the continuous recycle loop process were equivalent to those of the conventional diffused aeration process, for recycle ratios of 20% or less.
6. The recirculation of iron(III) sludge to the aeration vessel influent, for total iron concentration increases of up to 700% in the groundwater undergoing aeration, did not increase the rates of oxidation of iron or manganese. The design/operating requirements of the sludge addition process were equivalent to those of the conventional diffused aeration process, for sludge addition factors of seven or less.

7. The recirculation of iron(III) and manganese(IV) sludge to the aeration vessel influent was found detrimental to the operation of an iron and manganese removal process train. Chemical reduction of manganese oxides coupled with oxidation of iron(II) in the raw groundwater, immediately prior to aeration, was observed, defeating the purpose of using air to oxidize iron(II). Furthermore, the resulting reduced manganese exerted a substantially higher chemical oxidant demand in order to enable the treated water to meet drinking water objectives for iron and manganese. Early breakthrough of manganese oxides from the sand filter bed was observed, resulting in a substantial decrease in the maximum mass storage capacity of the bed.
8. A few additional runs, outside the original mandate of the study, were conducted with large quantities of iron(III) sludge recirculated to the diffused aeration vessel. SAF greater than 50 substantially increased the rate of oxidation of iron in the diffused aeration vessel. The hydraulic retention time required for complete iron oxidation decreased from 28 minutes to four minutes.
9. The selected process train was the diffused aeration - chemical oxidation - direct contact sand filtration process train. It was demonstrated most effective in removing iron and manganese from the groundwater without requiring the addition of coagulant, flocculant or aqueous pH conditioner. The process train minimizes the number of unit processes required for iron and manganese removal and minimizes sludge production. The optimum design/operating parameters, based on the pilot scale process train treatability studies, are presented in Table 16.

TABLE 16 RECOMMENDED PROCESS TRAIN: DIFFUSED AERATION - CHEMICAL OXIDATION - DIRECT CONTACT SAND FILTRATION

PROCESS ELEMENT	DESIGN/OPERATING PARAMETERS
1. Diffused Aeration Vessel	pH: 7.6 Hydraulic Retention Time: 22 minutes
2. Chemical Oxidation	On-Line Addition (Reaction Time $\leq$ 2 minutes) Oxidant Type: ClO_2 Oxidant Dosage ($ClO_2 \rightarrow Cl^-$): 7 x stoichiometric
3. Direct Contact Sand Filtration	Sand Bed Depth: 1.1 m Sand Effective Diameter: 0.52 mm Filtration Rate: 5.3×10^{-3} m/s

10.0 RECOMMENDATIONS

Recommendations for future experimental work to improve the performance of the diffused aeration - on-line ClO_2 addition - direct contact sand filtration process train, include the development and evaluation of an enhanced sand filtration operation, during which manganese(II) oxidation (and removal) would be conducted.

The proposed study would require a properly engineered oxide-coated sand media bed which would act as an effective adsorber of soluble manganese, an oxidizing contact medium and a filter medium. The intent of the work will be to achieve a high oxidative capacity of the modified sand bed, and the substitution of a strong regenerating chemical oxidant, such as potassium permanganate, by a weaker one.

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APPENDICES

APPENDIX A

Analytical Procedures

Iron

Total iron content was determined by the phenanthroline method. Iron is brought into solution through a digestion step, reduced to the ferrous(II) state by boiling for approximately one (1) hour with hydrochloric acid and hydroxylamine hydrochloride. The total iron content of the sample was then determined through the addition of 1,10-phenanthroline at a pH of 3.0-3.5, and a photometric measurement at 510 nm.

The observed absorbance value was then translated into an iron concentration value by means of a calibration curve. The method was slightly modified to take into account the presence of interfering agents, strong residual chemical oxidants and high concentrations of iron. Interferences associated with the presence of inorganic/organic agents were resolved by the addition of larger amounts of the reducing agent hydroxylamine (5 x more than the amount recommended in standard methods) and of the complexing agent phenanthroline (2 x more). With these modifications implemented, the analytical determination of iron, using the phenanthroline method, matched the values obtained using an atomic absorption (AA) unit. Figure A1 illustrates a typical iron calibration curve. Figure A2 depicts a calibration curve that attempted to relate absorbance values to the high iron concentrations which were encountered during the conduct of the Enhanced Aeration Process II: Sludge Addition. The data points clearly indicate the presence of a linear relation between absorbance and iron concentration for the range between 0 and 10 mg/L, and of a non-linear relation for iron concentrations exceeding 10 mg/L. Hence, groundwater samples with total iron concentration above 10 mg/L were diluted to reduce their iron concentration below the 10 mg/L threshold value.

The phenanthroline method measures the total iron concentration in a groundwater sample. In order to determine the valence of the iron, vacuum filtration, using a 0.45 μm cellulose acetate filter membrane, was carried out immediately following sample collection. This procedure allowed an efficient capture of the iron oxides(III) on the filter membrane. Hence, the filtrate obtained contained only dissolved iron(II). The filtrate was then analyzed by the phenanthroline method to give the iron(II) concentration.

The content of iron(III) was thereafter calculated by subtracting the iron(II) concentration from the total iron concentration.

FERRIC FORMATION, measuring the extent of the oxygenation/oxidation reactions, was calculated by subtracting the iron(II) content in the effluent of the process element studied, from the iron(II) content in the raw groundwater, divided by the iron(II) content in the raw groundwater.

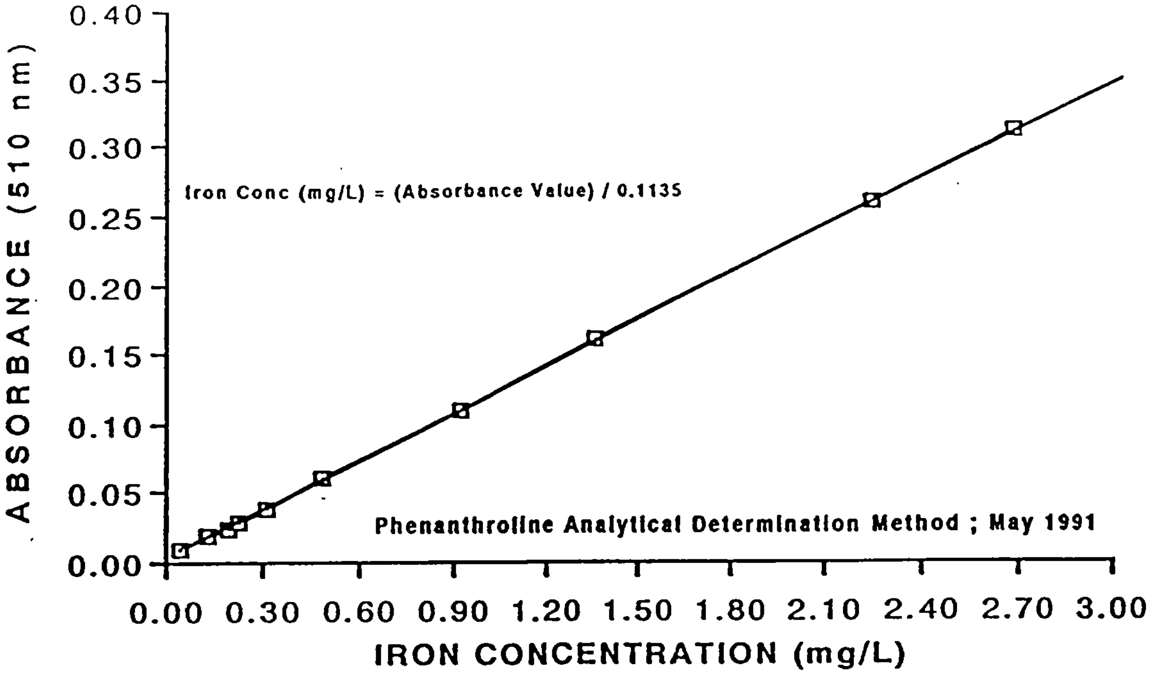

FIGURE A1 IRON CALIBRATION CURVE

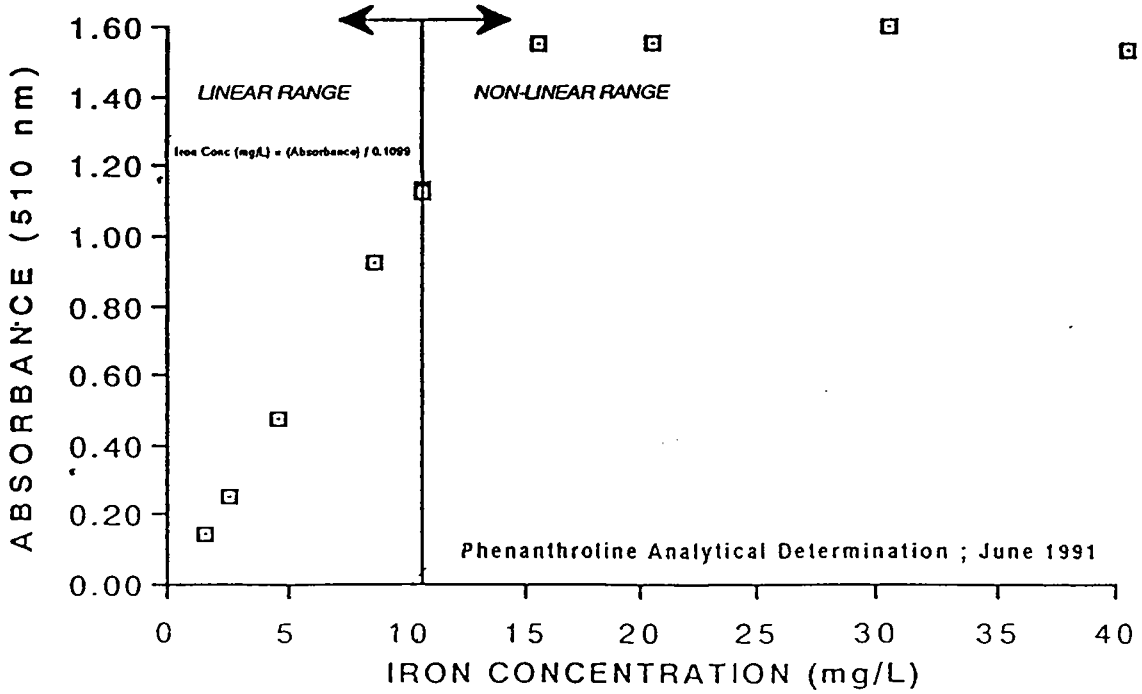

FIGURE A2 ABSORBANCE VALUES - HIGH IRON CONCENTRATIONS

TOTAL IRON REMOVAL, measuring the removal performance of a unit operation, was calculated by subtracting the total iron content in the effluent of the unit operation studied from the total iron content in the raw groundwater, divided by the total iron content in the raw groundwater.

Both Ferric Formation and Total Iron Removal represent cumulative values for consecutive process elements, except when specifically stated otherwise.

Manganese

Total manganese content was determined by the 1-(2-Pyridylazo)-2-Naphthol/Triton X-100 spectrophotometric method.

The method is based on the measurement of absorbance of the manganese-PAN chelated complex, solubilized by a non-ionic surface active agent, Triton X-100. The observed absorbance value was then translated into a manganese concentration value by means of a calibration curve. Figure A3 illustrates a typical manganese calibration curve.

The discussion engaged above for the analytical determination of total iron, dissolved iron(II) and iron oxides(III) applies here as well for the analytical determination of total manganese, dissolved manganese(II) and manganese oxides(IV). The reader is asked to refer back to it.

MANGANIC FORMATION, measuring the extent of the oxygenation/oxidation reactions, was calculated by subtracting the manganese(II) content in the effluent of the process element studies, from the manganese(II) content in the raw groundwater, divided by the manganese(II) content in the raw groundwater.

TOTAL MANGANESE REMOVAL, measuring the removal performance of a unit operation, was calculated by subtracting the total manganese content in the effluent of the unit operation studied, from the total manganese content in the raw groundwater, divided by the total manganese content in the raw groundwater.

Both Manganic Formation and Total Manganese Removal represent cumulative values for consecutive process elements, except when specifically stated otherwise.

Suspended Solids

Suspended solids were determined by vacuum filtration using 1.2 µm glass microfibre filter paper. The filter paper was first rinsed with distilled water and then dried at 105-110°C, cooled and weighed. The procedure was repeated until a constant weight was obtained. The

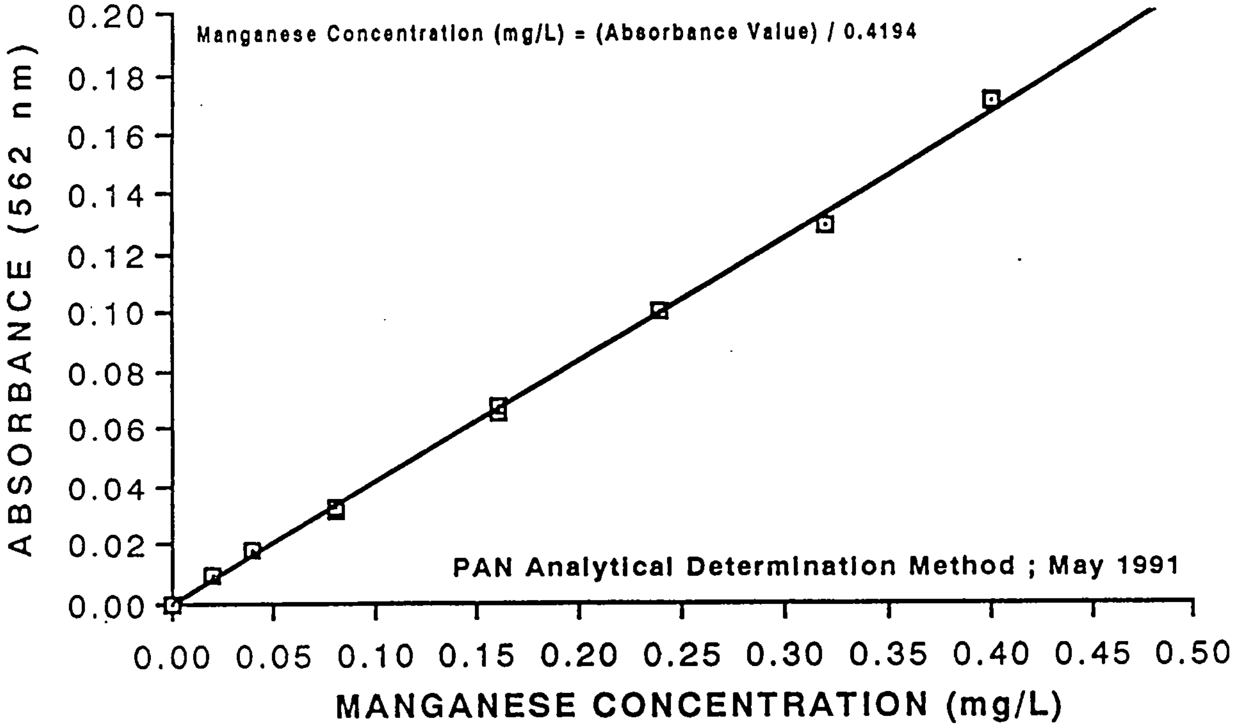

FIGURE A3 MANGANESE CALIBRATION CURVE difference between the weight of the dry filter paper before and after filtration gave the total suspended solids content in the groundwater.

pH

A pH electrode was used to measure the pH of the groundwater sample.

Dissolved Oxygen

An oxygen-selective electrode was used to measure the dissolved oxygen concentration in the groundwater.

Temperature

A thermometer was used to measure the temperature of the groundwater.

Total Alkalinity

Titration with 0.02 N H_2SO_4 to a pH end point of 4.5 gave total alkalinity (expressed in mg $CaCO_3$/L) of the groundwater.

Hardness

Hardness was measured by EDTA titration. This titration method depends on the ability of EDTA to form stable unionized complexes with Ca or Mg.

A reaction-sensitive dye, Eriochrome Black T, was added to the groundwater. A pink complex was formed. When the groundwater was then titrated with EDTA, which removed Ca or Mg from the dye complex, the dye reverted back to its original blue colour. This marked the end of the titration. Total hardness in the groundwater (expressed in mg $CaCO_3$/L) was then related to the amount of EDTA required.

APPENDIX B

Quality Assurance/Quality Control Programme

QUALITY ASSURANCE/QUALITY CONTROL PROGRAMME

May 2, 1991:

Iron conc (mg/L)

No.	*WTC*	*on-site GW Lab*
1	2.18	2.05
2	2.22	2.05
3	2.27	2.03
4	1.43	1.21
5	0.20	0.14
6	0.16	0.14

Manganese conc (mg/L)

No.	*WTC*	*on-site GW Lab*
1	0.14	0.19
2	0.15	0.19
3	0.16	0.19
4	0.17	0.19
5	0.16	0.20
6	0.16	0.20

May 6, 1991:

Iron conc (mg/L)

No.	*WTC*	*on-site GW Lab*
9	1.97	1.84
10	0.04	0.00
11(9d)	1.99	1.85
12(10d)	0.03	0.00
13	1.84	1.98
14	0.01	0.00
15(13d)	1.86	1.98
16(14d)	0.01	0.00

QUALITY ASSURANCE/QUALITY CONTROL PROGRAMME

	Manganese conc (mg/L)	
No.	*WTC*	*on-site GW Lab*
1	<0.01	0.00
2	0.02	0.02
3	0.04	0.04
4	0.05	0.06
5	0.09	0.08
6	0.11	0.10
7	0.16	0.14
8	0.19	0.16
9	0.14	0.19
10	0.14	0.17
11(9d)	0.14	0.17
12(10d)	0.14	0.17
13	0.10	0.23
14	0.10	0.23
15(13d)	0.11	0.23
16(14d)	0.09	0.23

May 9, 1991:

		Iron conc (mg/L)	
No.	*WTC*	*on-site GW Lab*	*Region**
1	2.14	n.a.	2.16 (2.04)
2	2.39	n.a.	2.08 (2.09)
3	1.33	n.a.	1.22 (1.26)
4	<0.01	0.00	0.02 (0.03)
5	1.90	1.96	n.a.

		Manganese conc (mg/L)	
No.	*WTC*	*on-site GW Lab*	*Region*
1	0.86	*0.75* (extrapolated from our 0.00 to 0.40 ppm calibration curve)	0.94 (0.87)
2	0.22	0.20	0.22 (0.20)
3	0.13	0.13	0.12 (0.15)
4	<0.01	0.01	<0.01 (<0.01)
5	0.08	n.a.	0.13 (0.13)

* Laboratory of the Regional Municipality of Waterloo

QUALITY ASSURANCE/QUALITY CONTROL PROGRAMME

May 15, 1991:

No.	*WTC*	**Iron conc (mg/L)** *on-site GW Lab*	*Region*
1	1.980	1.97	2.039
2	2.000	1.97	2.005
3	0.258	0.27	0.254
4	1.891	1.84	1.840
5	<0.05	0.00	<0.005
6	1.853	1.81	1.848
7	<0.05	0.00	<0.002
8	<0.05	0.00	<0.002

No.	*WTC*	**Manganese conc (mg/L)** *on-site GW Lab*	*Region*
1	0.131	0.10	0.126
2	0.131	0.10	0.129
3	0.129	0.11	0.129
4	0.129	0.10	0.125
5	<0.01	0.00	<0.002
6	0.121	0.10	0.126
7	<0.01	0.00	<0.002
8	<0.01	0.00	<0.002

June 10, 1991:

No.	*WTC*	**Iron conc (mg/L)** *on-site GW Lab*	*Region*
1	2.07	2.01	1.91
2	2.12	1.97	1.86
3	0.27	0.26	0.26
4	1.97	1.84	1.74
5	2.08	1.98	1.84
6	2.11	1.98	1.90
7	0.32	0.28	0.29
8	1.93	1.83	1.76
9	2.07	1.96	1.79
10	2.11	1.97	1.87
11	0.24	0.21	0.22
12	1.96	1.84	1.64
13	2.11	1.98	1.76
14	2.12	2.00	1.80
15	0.26	0.22	0.23
16	1.98	1.82	1.77

QUALITY ASSURANCE/QUALITY CONTROL PROGRAMME

No.	*WTC*	**Manganese conc (mg/L)** *on-site GW Lab*	*Region*
1	0.12	0.14	0.13
2	0.11	0.14	0.13
3	0.13	0.15	0.12
4	0.12	0.12	0.13
5	0.13	0.14	0.12
6	0.12	0.14	0.13
7	0.12	0.12	0.13
8	0.12	0.14	0.13
9	0.12	0.13	0.12
10	0.12	0.14	0.13
11	0.12	0.12	0.13
12	0.13	0.13	0.12
13	0.12	0.14	0.12
14	0.13	0.14	0.11
15	0.13	0.13	0.13
16	0.12	0.12	0.14

June 25, 1991:

No.	*WTC*	**Iron conc (mg/L)** *on-site GW Lab*	*Region*
1	1.98	2.11	1.93
2	1.90	2.12	1.73
3	116	124	116
4	107	n.a.	122
5	120	124	124
6	1.91	2.04	1.78
7	1.88	2.03	1.79
8	75	62	67
9	0.52	0.38	0.53
10	63	60	68
11	0.30	0.31	0.30
12	56	62	73
13	1.48	1.58	1.44

QUALITY ASSURANCE/QUALITY CONTROL PROGRAMME

Manganese conc (mg/L)

No.	*WTC*	*on-site GW Lab*	*Region*
1	0.13	0.14	0.13
2	0.13	0.14	0.12
3	0.20	0.37	0.17
4	0.19	0.19	0.19
5	0.20	0.46	0.18
6	0.12	0.14	0.12
7	0.12	0.14	0.12
8	0.17	0.30	0.16
9	0.12	0.13	0.13
10	0.16	0.27	0.17
11	0.11	0.12	0.12
12	0.18	0.33	0.16
13	0.11	0.14	0.13

APPENDIX C

Groundwater Scans for Organics and Inorganics

SUBMISSION SHEET FOR INORGANIC ANALYSIS.

REGION OF WATERLOO / LABORATORY SERVICES.
100 Maplegrove Road, Cambridge, Ontario.
N3H 4R6. Phone (519) 885-9500.

SECTION 1.	SECTION 2.
PROJECT NAME : WTC Iron/Manganese	REPORT TO BE SENT TO :
DEPARTMENT : Water Operations	NAME : D. Stendahl
INVOICE TO : Water Operations	ADDRESS :
ACCOUNT No. :	
SAMPLE SUBMITTED BY : D. Stendahl	
RECEIVED AT LAB BY :	PHONE :
DATE : Nov. 5/90	FAX :

SECTION 3.		FOR LAB USE ONLY.
SAMPLE NAME / I.D	ANALYSIS REQUIRED	LABORATORY I.D. No.
WELL W5 RAW WATER BEFORE FILTER	METALS (ICAP SCAN) AND GENERAL CHEMISTRY	11-49
WELL W5 RAW WATER AFTER FILTER	METALS (ICAP SCAN) AND GENERAL CHEMISTRY	11-49

ADDITIONAL COMMENTS :

FOR LAB USE ONLY.

SECTION 4.	
DATE OF FINAL REPORT :	INVOICE No. :
DATE FAX SENT (WHEN REQUIRED) :	PREPARED BY :

The
REGIONAL
MUNICIPALITY
of WATERLOO

REPORT OF INORGANIC ANALYSIS

PROJECT: WTC Iron/Manganese Study	DATE: NOV. 5/90	LAB #: 11–49

TEST PARAMETERS	SAMPLE LOCATION DATE AND LAB NUMBER					
	11–49	11–49				
	UNFILTERED	FILTERED	UNFILTERED	FILTERED	UNFILTERED	FILTERED
D.S.	930	1190				
pH	7.3	7.4				
Cond.	1360	1400				
Hardness	203.0	197.0				
SO_4	330	695				
Cl	13.2	37.1				
Colour	90	45				
Cu	0.04	<0.01				
Cr	<0.01	<0.01				
Ni	<0.01	<0.01				
Zn	0.18	0.09				
Cd	<0.01	<0.01				
Fe	1.85	0.32				
Mn	0.13	0.14				
Ca	204.1	202.8				
Mg	46.2	43.6				

Date

Authorized By

SUBMISSION SHEET FOR INORGANIC ANALYSIS.

REGION OF WATERLOO / LABORATORY SERVICES.
100 Maplegrove Road, Cambridge, Ontario.
N3H 4R6. Phone (519) 885-9500.

SECTION 1.

PROJECT NAME : WTC Iron/Manganese
DEPARTMENT : Water Operations
INVOICE TO : Water Operations
ACCOUNT No. : ______
SAMPLE SUBMITTED BY : D. Stendahl
RECEIVED AT LAB BY : ______
DATE : Nov. 6/90

SECTION 2.

REPORT TO BE SENT TO :
NAME : D. Stendahl
ADDRESS : ______
PHONE : ______
FAX : ______

SECTION 3.		FOR LAB USE ONLY.
SAMPLE NAME / I.D	ANALYSIS REQUIRED	LABORATORY I.D. No.
WELL W5 RAW WATER BEFORE FILTER	202	11-78
WELL W5 RAW WATER AFTER FILTER	202	11-78

ADDITIONAL COMMENTS :

FOR LAB USE ONLY.

SECTION 4.

DATE OF FINAL REPORT : ______
DATE FAX SENT (WHEN REQUIRED) : ______
INVOICE No. : ______
PREPARED BY : ______

The
REGIONAL
MUNICIPALITY
of WATERLOO

REPORT OF INORGANIC ANALYSIS

PROJECT: WTC Iron/Manganese Study	DATE: NOV. 6/90	LAB #: 11-78

TEST PARAMETERS	SAMPLE LOCATION DATE AND LAB NUMBER					
	11-78	11-78				
	UNFILTERED	FILTERED	UNFILTERED	FILTERED	UNFILTERED	FILTERED
D.S.	1388	1270				
pH	7.3	7.7				
SO_4	660	680				
Cl	5.3	4.0				
Turbidity (JTU)	20	10				
Colour	100	35				
Ni	<0.01	<0.01				
Cu	0.23	0.23				
Cr	<0.01	<0.01				
Zn	0.51	0.21				
Cd	<0.01	<0.01				
Fe	1.75	0.40				
Pb	<1.0	<1.0				
Mn	0.13	0.13				
Nitrates (NO_3) N	0.55	0.61				
Ammonia (NH_4) N	0.25	0.21				
Hardness	780	780				

Date

Authorized By

SUBMISSION SHEET FOR INORGANIC ANALYSIS.

REGION OF WATERLOO / LABORATORY SERVICES.
100 Maplegrove Road, Cambridge, Ontario.
N3H 4R6. Phone (519) 885-9500.

SECTION 1.

PROJECT NAME : WTC Iron/Manganese
DEPARTMENT : Water Operations
INVOICE TO : Water Operations
ACCOUNT No. :
SAMPLE SUBMITTED BY : D. Stendahl
RECEIVED AT LAB BY :
DATE : Nov. 5/90

SECTION 2.

REPORT TO BE SENT TO :

NAME : D. Stendahl
ADDRESS :
PHONE :
FAX :

SECTION 3.		FOR LAB USE ONLY.
SAMPLE NAME / I.D	ANALYSIS REQUIRED	LABORATORY I.D. No.
WELL W5 RAW WATER BEFORE FILTER	METAL SCAN	11-48
WELL W5 RAW WATER AFTER FILTER	METAL SCAN	11-48
WELL W5 RAW WATER	GENERAL CHEMISTRY	

ADDITIONAL COMMENTS :

FOR LAB USE ONLY.

SECTION 4.

DATE OF FINAL REPORT :
DATE FAX SENT (WHEN REQUIRED) :
INVOICE No. :
PREPARED BY :

The
REGIONAL
MUNICIPALITY
of WATERLOO

REPORT OF INORGANIC ANALYSIS

PROJECT: WTC Iron/Manganese Study

DATE: NOV. 5/90

LAB #: 11–48

TEST PARAMETERS	SAMPLE LOCATION DATE AND LAB NUMBER					
	11–48	11–48	11–48			
		UNFILTERED	FILTERED		UNFILTERED	FILTERED
pH	7.3					
Cond.	1360					
D.S.	920					
Cl	10.6					
SO_4	300					
Hardness	200					
Colour (JTU)	90					
Cu		0.02	0.04			
Cr		<0.01	<0.01			
Ni		<0.01	<0.01			
Zn		0.03	0.03			
Cd		<0.01	<0.01			
Fe		1.90	1.87			
Mn		0.13	0.12			
Ca		213.8	0.06			
Mg		50.1	<0.01			

Date

Authorized By

SUBMISSION SHEET FOR INORGANIC ANALYSIS.

REGION OF WATERLOO / LABORATORY SERVICES.
100 Maplegrove Road, Cambridge, Ontario.
N3H 4R6. Phone (519) 885-9500.

SECTION 1.	SECTION 2.
PROJECT NAME : WTC Iron/Manganese	REPORT TO BE SENT TO :
DEPARTMENT : Water Operations	NAME : D. Stendahl
INVOICE TO : Water Operations	ADDRESS :
ACCOUNT No. :	
SAMPLE SUBMITTED BY : D. Stendahl	
RECEIVED AT LAB BY :	PHONE :
DATE : Nov. 5/90	FAX :

SECTION 3.		FOR LAB USE ONLY.
SAMPLE NAME / I.D	ANALYSIS REQUIRED	LABORATORY I.D. No.
WELL W5	METALS (UNFILTERED)	11-46

ADDITIONAL COMMENTS :

FOR LAB USE ONLY.

SECTION 4.	
DATE OF FINAL REPORT :	INVOICE No. :
DATE FAX SENT (WHEN REQUIRED) :	PREPARED BY :

The
REGIONAL
MUNICIPALITY
of WATERLOO

GENERAL ANALYSIS

COMPANY NAME AND LOCATION **WTC IRON AND MANGANESE REMOVAL**	**LABORATORY NUMBER:** 11-46 **TYPING DATE:**

LABORATORY COMMENTS

PARAMETER	RESULT	PARAMETER	RESULT	PARAMETER	RESULT
B.O.D.		CU	0.04	TOTAL COLIFORM per 100ml	
S.S.		CR	<0.01	FECAL COLIFORM per 100ml	
D.S.		NI	<0.01	BACKGROUND COUNT per 100ml	
T.S.		ZN	0.02		
C.O.D.		CD	<0.01		
pH at LAB		FE	1.85		
FREON SOLUBLES		AL			
HARDNESS as $CaCO_3$		CN			
ALKALINITY as $CaCO_3$		CONDUCTIVITY µMHOS			
SULPHIDES as H_2S		PHENOLS µg/l			
		Mn	0.13		

COMMENTS: All results expressed in mg/L except pH unless otherwise noted, By-Law 1-90 as amended.

SUBMISSION SHEET FOR ORGANIC ANALYSIS.

REGION OF WATERLOO / LABORATORY SERVICES.
100 Maplegrove Road, Cambridge, Ontario.
N3H 4R6. Phone (519) 885-9500.

SECTION 1.

PROJECT NAME : WTC Iron/Manganese
DEPARTMENT : Water Operations
INVOICE TO : Water Operations
ACCOUNT No. :
SAMPLE SUBMITTED BY : D. Stendahl
RECEIVED AT LAB BY : F. Haniff
DATE : Nov. 6/90

SECTION 2.

REPORT TO BE SENT TO :

NAME : D. Stendahl
ADDRESS :
PHONE :
FAX :

SECTION 3.		FOR LAB USE ONLY.
SAMPLE NAME / I.D	ANALYSIS REQUIRED	LABORATORY I.D. No.
#4 Waterloo	Open-VOC	366-0419-001
#5 Waterloo	Open-VOC	367-0419-002
#6 Waterloo	Open-VOC	368-0419-003

ADDITIONAL COMMENTS :

FOR LAB USE ONLY.

SECTION 4.

DATE OF FINAL REPORT :
DATE FAX SENT (WHEN REQUIRED) :
INVOICE No. :
PREPARED BY : F. Haniff

OPEN CHARACTERIZATION–VOLATILES

REPORT OF ANALYSIS

PROJECT: WTC Iron and Manganese Removal

SAMPLE NAME	LAB #	% RECOVERY SURROGATE (1)	% RECOVERY SURROGATE (2)	RESULT
#4 Waterloo	366–0419–001	103	105	ND
#5 Waterloo	367–0419–002	103	99	ND
#6 Waterloo	368–0419–003	96	98	ND
Blank	MAY01–01	99	97	ND
SURROGATE (1) : D10–ETHYL BENZENE.				
SURROGATE (2) : D4–1,2–DICHLOROBENZENE.				
RESULT: ND – NO COMPOUND GREATER THAN 5–ppb DETECTED.				

ANALYST

NOTE:
(1) The limit of quantification in OPEN VOC is 5–ppb (ug/L) relative to an internal standard of 1,3–Dichlorobutane.
(2) Fit quality uses a Probality–Based Matching algorithm (PBM) using a WILEY–NBS DATA BASE of 130,544 MASS SPECTRAS.
(3) Mass 39 to 300 amu scanned on the MSD.

WASTEWATER TECHNOLOGY CENTRE
REPORT OF ANALYSIS

PROJECT 361
JOB NO. 910418-3

SAMPLE ID *PARAMETER*	*#7*
Al	*0.20*
Ca	*180*
Cd	*<.05*
Cr	*0.10*
Cu	*<.05*
Fe	*2.3*
Mn	*0.21*
Ni	*<.05*
Pb	*0.07*
Zn	*<.05*
As (ug/l)	*6.8*

SAMPLE ID *PARAMETER*	*#7*
Se (ug/l)	*<2.0*
Mg	*46*
Na	*28*
K	*5.0*
B	*<.05*
Si	*5.2*
Co	*<.05*
Mo	*<.05*
Sr	*16*
Be	*<.03*

NOTE:Results are in ppm,unless specified otherwise.

RESULTS RELEASED:
June 10/91

AUTHORIZED BY:

WASTEWATER TECHNOLOGY CENTRE
REPORT OF ANALYSIS **PROJ. 361 -** *Purge & Trap GC-MS*
Job: 910419 *SAMPLE #8 - 4 reps. run*

PARAMETER	*Rep. #1 ng/ml*	*Rep. #2 ng/ml*	*Rep. #3 ng/ml*	*Rep. #4 ng/ml*
t-1,2-dichloroethylene	*ND*	*ND*	*ND*	*ND*
1,1-dichloroethane	*ND*	*ND*	*ND*	*ND*
chloroform	*ND*	*ND*	*ND*	*ND*
1,1,1-trichloroethane	*ND*	*ND*	*ND*	*ND*
carbontetrachloride	*ND*	*ND*	*ND*	*ND*
1,2-dichloroethane	*ND*	*ND*	*ND*	*ND*
benzene	*ND*	*ND*	*ND*	*ND*
trichloroethylene	*ND*	*ND*	*ND*	*ND*
1,2-dichloropropane	*ND*	*ND*	*ND*	*ND*
bromodichloromethane	*ND*	*ND*	*ND*	*ND*
dibromomethane	*ND*	*ND*	*ND*	*ND*
toluene	*ND*	*ND*	*0.4*	*0.4*
1,1,2-trichloroethane	*ND*	*ND*	*ND*	*ND*
tetrachloroethylene	*ND*	*ND*	*ND*	*ND*
chlorobibromomethane	*ND*	*ND*	*ND*	*ND*
1,2-dibromoethane	*ND*	*ND*	*ND*	*ND*
ethylbenzene	*ND*	*ND*	*ND*	*ND*
m-xylene	*ND*	*ND*	*ND*	*0.2*
o-xylene	*ND*	*ND*	*ND*	*0.1*
bromoform	*ND*	*ND*	*ND*	*ND*
cumene	*ND*	*ND*	*ND*	*ND*
1,1,2,2tetraclethane	*ND*	*ND*	*ND*	*ND*
propylbenzene	*ND*	*ND*	*ND*	*ND*
3-ethyltoluene	*ND*	*ND*	*ND*	*ND*
4-ethyltoluene	*ND*	*ND*	*ND*	*ND*
1,3-diethylbenzene	*ND*	*ND*	*ND*	*ND*
1,4-diethylbenzene	*ND*	*ND*	*ND*	*ND*
1,2-diethylbenzene	*ND*	*ND*	*ND*	*ND*
1,3-dichlorobenzene	*ND*	*ND*	*ND*	*ND*
1,4-dichlorobenzene	*ND*	*ND*	*ND*	*ND*
1,2-dichlorobenzene	*ND*	*ND*	*ND*	*ND*
trichlorofluoromethane	*0.2*	*0.2*	*0.1*	*0.2*
1,1-dichloroethylene	*ND*	*ND*	*ND*	*ND*
dichloromethane	*0.4*	*0.2*	*ND*	*0.4*
t-1,3dichloropropylene	*ND*	*ND*	*ND*	*ND*
c-1,3dichloropropylene	*ND*	*ND*	*ND*	*ND*
chlorobenzene	*ND*	*ND*	*ND*	*ND*
p-xylene	*ND*	*ND*	*0.1*	*0.4*
styrene	*ND*	*ND*	*ND*	*ND*
1,2,4-trimethylbenzene	*ND*	*ND*	*ND*	*0.1*
1,2,3-trimethylbenzene	*ND*	*ND*	*ND*	*ND*
naphthalene	*ND*	*0.3*	*ND*	*ND*
2-methylnaphthalene	*ND*	*ND*	*ND*	*ND*
1-methylnaphthalene	*ND*	*ND*	*ND*	*ND*
c-1,2-dichloroethylene	*ND*	*ND*	*ND*	*ND*

ND - NOT DETECTED

Surrogate Recovery (percent)	*Rep. #1 %*	*Rep. #2 %*	*Rep. #3 %*	*Rep. #4 %*
fluorobenzene	*91.3*	*85.5*	*107.8*	*101.5*
d8-toluene	*86.1*	*81.8*	*110.8*	*103.4*
1,3-dichlorobutane	*91.0*	*91.9*	*113.0*	*104.6*
1-bromo4-fluorobenzene	*83.3*	*73.6*	*104.4*	*94.0*

RESULTS RELEASED:

Jly 15/91

AUTHORIZED BY:

APPENDIX D

Conventional Diffused Aeration Process:

Diffused Aeration Data

Pilot-Scale Run
Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	1	
DATE:	5-04-91	
Air Flow Rate:	0.054	m3/min
Groundwater Flow Rate:	0.040	m3/min
Sampling time(1):	6.0	x HRT
HRT:	5.6	min
Sampling time (2):	10.0	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.31	2.31	2.32	2.43			0.79	0.75
	filtered	mg/L	2.34	2.34	2.08	1.94			0.66	0.78
Manganese	non-filtered	mg/L	0.12	0.12	0.15	0.15			0.15	0.13
	filtered	mg/L	0.12	0.12	0.15	0.15			0.14	0.13
Alkalinity		mg CaCO3/L	179		177				174	
Hardness		mg CaCO3/L	805		792				774	
Temperature		C	12	12	13	12			13	12
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated			saturated	saturated
pH		-	7.1	7.1	7.4	7.4			7.4	7.4
Suspended Solids		mg/L								

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	11%	17%			72%	67%
Total Iron Removal		-	-	0%	-5%			66%	68%
MANGANESE									
Manganic Formation		-	-	-20%	-19%			-10%	-8%
Total Manganese Removal		-	-	-24%	-19%			-20%	-6%

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	2	
DATE:	5-04-91	
Air Flow Rate:	0.216	m3/min
Groundwater Flow Rate:	0.040	m3/min
Sampling time(1):	10.0	x HRT
HRT:	5.6	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.00		1.96				0.14	
	filtered	mg/L	1.93		1.04				0.13	
Manganese	non-filtered	mg/L	0.12		0.13				0.12	
	filtered	mg/L	0.13		0.12				0.12	
Alkalinity		mg CaCO3/L	178		173				173	
Hardness		mg CaCO3/L	772		796				794	
Temperature		C	12		12				12	
Dissolved Oxygen		mg/L	<1		saturated				saturated	
pH		-	7.1		7.6				7.6	
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	46%				93%	
Total Iron Removal	-	-	2%				93%	
MANGANESE								
Manganic Formation	-	-	8%				8%	
Total Manganese Removal	-	-	-8%				0%	

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	8	
DATE:	5-04-91	
Air Flow Rate:	0.042	m3/min
Groundwater Flow Rate:	0.031	m3/min
Sampling time(1):	10.0	x HRT
HRT:	7.3	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.08		1.96				0.24	
	filtered	mg/L	1.98		1.49				0.18	
Manganese	non-filtered	mg/L	0.11		0.11				0.11	
	filtered	mg/L	0.12		0.12				0.12	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12				12	
Dissolved Oxygen		mg/L	<1		saturated				saturated	
pH		-	7.1		7.4				7.4	
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	25%				91%	
Total Iron Removal	-	-	6%				89%	
MANGANESE								
Manganic Formation	-	-	0%				0%	
Total Manganese Removal	-	-	0%				0%	

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	4	
DATE:	6-04-91	
Air Flow Rate:	0.054	m3/min
Groundwater Flow Rate:	0.040	m3/min
Sampling time(1):	10.0	x HRT
HRT:	5.6	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05		1.97					
	filtered	mg/L	2.05		1.62					
Manganese	non-filtered	mg/L	0.14		0.15					
	filtered	mg/L	0.14		0.15					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.4					
Suspended Solids		mg/L								

Calculations

			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	21%					
Total Iron Removal			-	-	4%					
MANGANESE										
Manganic Formation			-	-	-7%					
Total Manganese Removal			-	-	-7%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	5	
DATE:	6-04-91	
Air Flow Rate:	0.167	m3/min
Groundwater Flow Rate:	0.031	m3/min
Sampling time(1):	10.0	x HRT
HRT:	7.3	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.05		2.03				0.14	
	filtered	mg/L	2.05		1.21				0.14	
Manganese	non-filtered	mg/L	0.11		0.11				0.12	
	filtered	mg/L	0.11		0.11				0.11	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13				13	
Dissolved Oxygen		mg/L	<1		saturated				saturated	
pH		-	7.1		7.6				7.6	
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	41%				93%	
Total Iron Removal	-	-	1%				93%	
MANGANESE								
Manganic Formation	-	-	0%				0%	
Total Manganese Removal	-	-	0%				-9%	

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	6	
DATE:	7-04-91	
Air Flow Rate:	0.324	m3/min
Groundwater Flow Rate:	0.030	m3/min
Sampling time(1):	10.0	x HRT
HRT:	7.5	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.11		2.19					
	filtered	mg/L	2.11		0.94					
Manganese	non-filtered	mg/L	0.11		0.10					
	filtered	mg/L	0.11		0.09					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		13					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.8					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	56%					
Total Iron Removal	-	-	-4%					
MANGANESE								
Manganic Formation	-	-	15%					
Total Manganese Removal	-	-	12%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	7	
DATE:	7-04-91	
Air Flow Rate:	0.162	m3/min
Groundwater Flow Rate:	0.030	m3/min
Sampling time(1):	10.0	x HRT
HRT:	7.5	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.06		2.03					
	filtered	mg/L	2.06		0.81					
Manganese	non-filtered	mg/L	0.12		0.11					
	filtered	mg/L	0.12		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		13					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	61%					
Total Iron Removal	-	-	1%					
MANGANESE								
Manganic Formation	-	-	8%					
Total Manganese Removal	-	-	8%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	8	
DATE:	7-04-91	
Air Flow Rate:	0.216	m3/min
Groundwater Flow Rate:	0.040	m3/min
Sampling time(1):	10.0	x HRT
HRT:	5.6	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point* A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.03		1.98					
	filtered	mg/L	2.03		1.24					
Manganese	non-filtered	mg/L	0.09		0.09					
	filtered	mg/L	0.10		0.09					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		13					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	39%					
Total Iron Removal	-	-	2%					
MANGANESE								
Manganic Formation	-	-	4%					
Total Manganese Removal	-	-	-2%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	9	
DATE:	10-04-91	
Air Flow Rate:	0.135	m3/min
Groundwater Flow Rate:	0.025	m3/min
Sampling time(1):	15.0	x HRT
HRT:	9.0	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.98		1.94				0.68	
	filtered	mg/L	2.03		1.15				0.15	
Manganese	non-filtered	mg/L	0.12		0.11				0.11	
	filtered	mg/L	0.11		0.11				0.11	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11				11	
Dissolved Oxygen		mg/L	<1		saturated				saturated	
pH		-	7.1		7.6				7.6	
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	43%				93%	
Total Iron Removal	-	-	2%				66%	
MANGANESE								
Manganic Formation	-	-	-2%				3%	
Total Manganese Removal	-	-	6%				11%	

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	10	
DATE:	11-04-91	
Air Flow Rate:	0.081	m3/min
Groundwater Flow Rate:	0.015	m3/min
Sampling time(1):	10.0	x HRT
HRT:	15.0	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.09		2.03					
	filtered	mg/L	2.07		0.73					
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.11		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	65%					
Total Iron Removal		-	-	3%					
MANGANESE									
Manganic Formation		-	-	4%					
Total Manganese Removal		-	-	0%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	11	
DATE:	11-04-91	
Air Flow Rate:	0.160	m3/min
Groundwater Flow Rate:	0.015	m3/min
Sampling time(1):	10.0	x HRT
HRT:	15.0	min
Sampling time (2):	15.0	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.16	2.09	2.02	1.99				
	filtered	mg/L	2.12	2.11	0.57	0.57				
Manganese	non-filtered	mg/L	0.12	0.12	0.13	0.13				
	filtered	mg/L	0.11	0.12	0.12	0.11				
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11	11	11	11				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.8	7.8				
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	73%	73%				
Total Iron Removal	-	-	7%	5%				
MANGANESE								
Manganic Formation	-	-	-5%	3%				
Total Manganese Removal	-	-	-10%	-7%				

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER: 12
DATE: 11-04-91

Air Flow Rate: 0.054 m3/min
Groundwater Flow Rate: 0.012 m3/min
Sampling time(1): 10.0 x HRT
HRT: 18.8 min
Sampling time (2): 15.0 x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.09	2.10	n.a.	2.05				
	filtered	mg/L	2.08	2.11	0.60	0.53				
Manganese	non-filtered	mg/L	0.09	0.09	0.09	0.09				
	filtered	mg/L	0.08	0.09	0.09	0.09				
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11	11	11	11				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.6	7.8				
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	71%	75%				
Total Iron Removal	-	-	n.a.	2%				
MANGANESE								
Manganic Formation	-	-	-4%	3%				
Total Manganese Removal	-	-	0%	-1%				

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER: 18
DATE: 12-04-91

Air Flow Rate: 0.054 m3/min
Groundwater Flow Rate: 0.005 m3/min
Sampling time(1): 5.0 x HRT
HRT: 45.0 min
Sampling time (2): 10.0 x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.09	2.04	2.00	2.00				
	filtered	mg/L	2.11	2.03	0.35	0.41				
Manganese	non-filtered	mg/L	0.09		0.09					
	filtered	mg/L	0.08		0.09					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	11	12	12				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.8	7.8				
Suspended Solids		mg/L								

Calculations

			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	83%	80%				
Total Iron Removal			-	-	4%	2%				
MANGANESE										
Manganic Formation			-	-	-3%					
Total Manganese Removal			-	-	0%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	14	
DATE:	12-04-91	
Air Flow Rate:	0.048	m3/min
Groundwater Flow Rate:	0.008	m3/min
Sampling time(1):	5.0	x HRT
HRT:	28.1	min
Sampling time (2):	10.0	x HRT

Data

Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.13	2.04	1.98	1.92				
	filtered	mg/L	2.05	2.06	0.00	0.00				
Manganese	non-filtered	mg/L	0.13		0.13					
	filtered	mg/L	0.13		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	10	11	10	11				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.6	7,6				
Suspended Solids		mg/L								

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	100%	100%				
Total Iron Removal		-	-	7%	6%				
MANGANESE									
Manganic Formation		-	-	17%					
Total Manganese Removal		-	-	2%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	15	
DATE:	14-04-91	
Air Flow Rate:	0.086	m3/min
Groundwater Flow Rate:	0.008	m3/min
Sampling time(1):	5.0	x HRT
HRT:	28.1	min
Sampling time (2):	10.0	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.97	1.98	1.92	1.93				
	filtered	mg/L	1.99	2.00	0.30	0.27				
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.12		0.12					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	9	10	11	10				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.8	7.8				
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	85%	86%				
Total Iron Removal	-	-	3%	3%				
MANGANESE								
Manganic Formation	-	-	-4%					
Total Manganese Removal	-	-	-3%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	16	
DATE:	15-04-91	
Air Flow Rate:	0.059	m3/min
Groundwater Flow Rate:	0.011	m3/min
Sampling time(1):	10.0	x HRT
HRT:	20.5	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.04		1.96					
	filtered	mg/L	2.04		0.29					
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.12		0.13					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		12					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	86%					
Total Iron Removal			-	-	4%					
MANGANESE										
Manganic Formation			-	-	-5%					
Total Manganese Removal			-	-	-3%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	17	
DATE:	15-04-91	
Air Flow Rate:	0.118	m3/min
Groundwater Flow Rate:	0.011	m3/min
Sampling time(1):	10.0	x HRT
HRT:	20.5	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.06		1.90					
	filtered	mg/L	2.04		0.45					
Manganese	non-filtered	mg/L	0.08		0.08					
	filtered	mg/L	0.08		0.08					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.7					
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	78%					
Total Iron Removal	-	-	8%					
MANGANESE								
Manganic Formation	-	-	-3%					
Total Manganese Removal	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	18	
DATE:	15-04-91	
Air Flow Rate:	0.049	m3/min
Groundwater Flow Rate:	0.009	m3/min
Sampling time(1):	10.0	x HRT
HRT:	25.0	min
Sampling time (2):	15.0	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.91	1.92	n.a.	1.95				
	filtered	mg/L	1.85	1.90	0.12	0.22				
Manganese	non-filtered	mg/L	0.09		0.09					
	filtered	mg/L	0.09		0.09					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	12	12	12				
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated				
pH		-	7.1	7.1	7.7	7.7				
Suspended Solids		mg/L								

Calculations

			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	94%	88%				
Total Iron Removal			-	-	n.a.	-1%				
MANGANESE										
Manganic Formation			-	-	3%					
Total Manganese Removal			-	-	0%					

Pilot-Scale Run
Diffused Aeration-Contact Sand Filtration

RUN NUMBER: 19
DATE: 17-04-91

Air Flow Rate: 0.081 m3/min
Groundwater Flow Rate: 0.060 m3/min
Sampling time(1): 10.0 x HRT
HRT: 3.8 min
Sampling time (2): - x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.99		2.01					
	filtered	mg/L	1.98		1.73					
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.11		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.2		7.4					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	13%					
Total Iron Removal	-	-	-1%					
MANGANESE								
Manganic Formation	-	-	-3%					
Total Manganese Removal	-	-	4%					

Pilot-Scale Run
Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	20	
DATE:	17-04-91	
Air Flow Rate:	0.324	m3/min
Groundwater Flow Rate:	0.060	m3/min
Sampling time(1):	10.0	x HRT
HRT:	3.8	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.01		1.97					
	filtered	mg/L	2.03		1.56					
Manganese	non-filtered	mg/L	0.11		0.12					
	filtered	mg/L	0.11		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	23%					
Total Iron Removal	-	-	2%					
MANGANESE								
Manganic Formation	-	-	3%					
Total Manganese Removal	-	-	-9%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	21	
DATE:	17-04-91	
Air Flow Rate:	0.254	m3/min
Groundwater Flow Rate:	0.047	m3/min
Sampling time(1):	10.0	x HRT
HRT:	4.8	min
Sampling time (2):	-	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.00		2.00					
	filtered	mg/L	2.00		1.37					
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.11		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	32%					
Total Iron Removal	-	-	0%					
MANGANESE								
Manganic Formation	-	-	5%					
Total Manganese Removal	-	-	1%					

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER: 22
DATE: 22-04-91

Air Flow Rate: 0.054 m3/min
Groundwater Flow Rate: 0.008 m3/min
Sampling time(1): 3.0 x HRT
HRT: 28.1 min
Sampling time (2): - x HRT

Data

Parameter		*Unit*	A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.98		1.94					
	filtered	mg/L	1.98		0.18					
Manganese	non-filtered	mg/L								
	filtered	mg/L								
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11					
Dissolved Oxygen		mg/L	<1		saturated					
pH		-	7.1		7.7					
Suspended Solids		mg/L								

Sampling point

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	91%					
Total Iron Removal	-	-	2%					
MANGANESE								
Manganic Formation	-	-						
Total Manganese Removal	-	-						

Pilot-Scale Run

Diffused Aeration-Contact Sand Filtration

RUN NUMBER:	23	
DATE:	2-05-91	
Air Flow Rate:	0.081	m3/min
Groundwater Flow Rate:	0.008	m3/min
Sampling time(1):	10.0	x HRT
HRT:	28.1	min
Sampling time (2):	15.0	x HRT

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.93		1.82				0.00	0.00
	filtered	mg/L	1.93		0.14				0.00	0.00
Manganese	non-filtered	mg/L								
	filtered	mg/L								
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11				12	12
Dissolved Oxygen		mg/L	<1		saturated				saturated	saturated
pH		-	7.1		7.6				7.6	7.6
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	93%				100%	
Total Iron Removal	-	-	6%				100%	
MANGANESE								
Manganic Formation	-	-						
Total Manganese Removal	-	-						

APPENDIX E

Conventional Diffused Aeration Process:

Diffused Aeration - Chemical Oxidation Data

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	A		
DATE:	24-04-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* H2O2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 6x stoic
Sampling time(1):	2.0	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	1 min	5 min	10 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.00		1.96				
	filtered	mg/L	2.02		0.31		0.04	0.01	0.04
Manganese	non-filtered	mg/L	0.26		0.25				
	filtered	mg/L	0.25		0.26		0.23	0.22	0.26
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	11		11		11	11	11
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	1 min	5 min	10 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	85%		98%	100%	98%
Total Iron Removal	-	-	2%				
MANGANESE							
Manganic Formation	-	-	-4%				
Total Manganese Removal	-	-	5%		12%	15%	1%

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	A	
DATE:	24-04-91	
Air Flow Rate:	0.081	m3/min
Groundwater Flow Rate:	0.008	m3/min
Sampling time(1):	2.0	x HRT
HRT (aeration):	28.1	min
Sampling time (2):	-	x HRT

CHEMICAL OXIDANT TYPE:	H2O2	
CHEMICAL OXIDANT DOSAGE:	60x	stoic

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	1 min	5 min	10 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.00		1.96				
	filtered	mg/L	2.02		0.31		0.04	0.01	0.02
Manganese	non-filtered	mg/L	0.26		0.25				
	filtered	mg/L	0.25		0.26		0.26	0.26	0.24
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	11		11		11	11	11
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	1 min	5 min	10 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	85%		98%	100%	99%
Total Iron Removal	-	-	2%				
MANGANESE							
Manganic Formation	-	-	-4%		-5%	-3%	2%
Total Manganese Removal	-	-	5%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

				RUN NUMBER:	A					
				DATE:	24-04-91					
				Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*		NaOCl	
				Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*		3x	stoic
				Sampling time:	2.0	x HRT				
				HRT (BUBBLER):	28.1	min				
				Sampling time (duplicate):	-	x HRT				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	1 min	5 min	10 min	
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX	
Iron	non-filtered	mg/L	2.00		1.96					
	filtered	mg/L	2.02		0.31		0.01	0.02	0.01	
Manganese	non-filtered	mg/L	0.26		0.25					
	filtered	mg/L	0.25		0.26		0.22	0.22	0.20	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		11		11	11	11	
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated	
pH		-	7.1		7.6		7.6	7.6	7.6	
Suspended Solids		mg/L								
					Calculations					
			A1	A2	B1	B2	1 min	5 min	10 min	
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX	
IRON										
Ferric Formation			-	-	85%		100%	99%	100%	
Total Iron Removal			-	-	2%					
MANGANESE										
Manganic Formation			-	-	-4%		9%	9%	18%	
Total Manganese Removal			-	-	5%					

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	A		
DATE:	24-04-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* NaOCl
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 29x stoic
Sampling time(1):	2.0	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point* A1	 A2	 B1	 B2	 1 min	 5 min	 10 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.00		1.96				
	filtered	mg/L	2.02		0.31		0.04	0.00	0.00
Manganese	non-filtered	mg/L	0.26		0.25				
	filtered	mg/L	0.25		0.26		0.15	0.18	0.17
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	11		11		11	11	11
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	1 min	5 min	10 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	85%		98%	100%	100%
Total Iron Removal	-	-	2%				
MANGANESE							
Manganic Formation	-	-	-4%		37%	26%	31%
Total Manganese Removal	-	-	5%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	B			
DATE:	6-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.4x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*						
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	5 min POST-OX	10 min POST-OX	20 min POST-OX
Iron	non-filtered	mg/L	1.97		1.80				
	filtered	mg/L	1.85		0.32		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.14		0.14				
	filtered	mg/L	0.14		0.12		0.13	0.14	0.14
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	10		10		10	10	10
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	5 min POST-OX	10 min POST-OX	20 min POST-OX
IRON							
Ferric Formation	-	-	83%		100%	100%	100%
Total Iron Removal	-	-	9%				
MANGANESE							
Manganic Formation	-	-	14%		7%	0%	0%
Total Manganese Removal	-	-	0%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	B				
DATE:	6-05-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2	
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	14x	stoic
Sampling time(1):	>2	x HRT			
HRT (aeration):	28.1	min			
Sampling time (2):	-	x HRT			

Data

Parameter		*Unit*	*Sampling point* A1 RAW	 A2 RAW	 B1 POST-AIR	 B2 POST-AIR	 5 min POST-OX	 10 min POST-OX	 20 min POST-OX
Iron	non-filtered	mg/L	1.85		1.76				
	filtered	mg/L	1.74		0.32		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.14		0.14				
	filtered	mg/L	0.14		0.12		0.03	0.03	0.03
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	10		10		10	10	10
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

		A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	5 min POST-OX	10 min POST-OX	20 min POST-OX
IRON								
Ferric Formation		-	-	82%		100%	100%	100%
Total Iron Removal		-	-	5%				
MANGANESE								
Manganic Formation		-	-	14%		79%	79%	79%
Total Manganese Removal		-	-	0%				

Pilot-Scale Run
Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER: B
DATE: 3-05-91

Air Flow Rate: 0.081 m3/min
Groundwater Flow Rate: 0.008 m3/min
Sampling time(1): >2 x HRT
HRT (aeration): 28.1 min
Sampling time (2): - x HRT

CHEMICAL OXIDANT TYPE: NaOCl
CHEMICAL OXIDANT DOSAGE: 1.7x stoic

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	5 min	10 min	20 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.02		1.96				
	filtered	mg/L	2.02		0.41		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.12		0.12				
	filtered	mg/L	0.12		0.11		0.12	0.12	0.11
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	11		11		12	12	12
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.7		7.7	7.7	7.7
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	5 min	10 min	20 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	80%		100%	100%	100%
Total Iron Removal	-	-	3%				
MANGANESE							
Manganic Formation	-	-	8%		0%	0%	8%
Total Manganese Removal	-	-	0%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	B			
DATE:	3-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	NaOCl
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	17x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	5 min	10 min	20 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.03		1.89				
	filtered	mg/L	2.03		0.37		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.12		0.12				
	filtered	mg/L	0.12		0.12		0.08	0.08	0.08
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	11		11		12	12	12
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.7		7.7	7.7	7.7
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	5 min	10 min	20 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	82%		100%	100%	100%
Total Iron Removal	-	-	7%				
MANGANESE							
Manganic Formation	-	-	0%		27%	27%	27%
Total Manganese Removal	-	-	0%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	B			
DATE:	6-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	H2O2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.3x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	5 min	10 min	20 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.94		1.76				
	filtered	mg/L	1.94		0.27		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.15		0.15				
	filtered	mg/L	0.15		0.13		0.14	0.12	0.12
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	10		11		11	11	11
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.7	7.7	7.7
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	5 min	10 min	20 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	86%		100%	100%	100%
Total Iron Removal	-	-	9%				
MANGANESE							
Manganic Formation	-	-	13%		7%	20%	20%
Total Manganese Removal	-	-	0%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER: B
DATE: 6-05-91

Air Flow Rate: 0.081 m3/min
Groundwater Flow Rate: 0.008 m3/min
Sampling time(1): >2 x HRT
HRT (aeration): 28.1 min
Sampling time (2): - x HRT

CHEMICAL OXIDANT TYPE: H2O2
CHEMICAL OXIDANT DOSAGE: 14x stoic

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	5 min	10 min	20 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.85		1.85				
	filtered	mg/L	1.85		0.28		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.14		0.14				
	filtered	mg/L	0.14		0.14		0.14	0.14	0.13
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	10		11		11	11	11
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.1		7.6		7.7	7.7	7.7
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	5 min	10 min	20 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	85%		100%	100%	100%
Total Iron Removal	-	-	0%				
MANGANESE							
Manganic Formation	-	-	0%		0%	0%	7%
Total Manganese Removal	-	-	0%				

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	C			
DATE:	10-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	5x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*					
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
Iron	non-filtered	mg/L	1.89	1.89	1.78	1.80	1.78	1.76
	filtered	mg/L	1.89	1.85	0.25	0.24	0.00	0.01
Manganese	non-filtered	mg/L	0.12		0.13		0.12	0.12
	filtered	mg/L	0.12		0.12		0.09	0.08
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	15		15	15	15	15
Dissolved Oxygen		mg/L	<1		saturated	saturated	saturated	saturated
pH		-	7.1		7.6	7.6	7.5	7.5
Suspended Solids		mg/L						

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
IRON						
Ferric Formation	-	-	87%	87%	100%	100%
Total Iron Removal	-	-	6%	5%	6%	7%
MANGANESE						
Manganic Formation	-	-	-4%		28%	30%
Total Manganese Removal	-	-	-8%		0%	2%

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	C			
DATE:	10-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	10x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.90	1.93	1.79	1.84	1.76	1.81
	filtered	mg/L	1.90	1.89	0.25	0.31	0.00	0.00
Manganese	non-filtered	mg/L	0.12		0.11		0.11	0.10
	filtered	mg/L	0.11		0.10		0.01	0.01
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	13	13	13	13	13	13
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated	saturated	saturated
pH		-	7.1	7.1	7.6	7.6	7.7	7.7
Suspended Solids		mg/L						

Calculations

		A1	A2	B1	B2	2 min	12 min
		RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON							
Ferric Formation		-	-	87%	84%	100%	100%
Total Iron Removal		-	-	6%	5%	7%	5%
MANGANESE							
Manganic Formation		-	-	7%		92%	89%
Total Manganese Removal		-	-	4%		6%	19%

					Pilot-Scale Run					
					Diffused Aeration-Chemical Oxidant Addition					
				RUN NUMBER:	C					
				DATE:	14-05-91					
				Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*		KMnO4	
				Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*		3.2x	stoic
				Sampling time(1):	>2	x HRT				
				HRT (aeration):	28.1	min				
				Sampling time (2):	-	x HRT				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	2 min	12 min		
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX		
Iron	non-filtered	mg/L	1.96		1.83		1.84	1.83		
	filtered	mg/L	1.92		0.30		0.09	0.01		
Manganese	non-filtered	mg/L	0.13		n.a.		0.33	0.33		
	filtered	mg/L	0.13		0.13		0.10	0.09		
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12		13	14		
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated		
pH		-	7.1		7.6		7.7	7.7		
Suspended Solids		mg/L								
					Calculations					
			A1	A2	B1	B2	5 min	10 min		
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX		
IRON										
Ferric Formation			-	-	84%		95%	100%		
Total Iron Removal			-	-	7%		6%	7%		
MANGANESE										
Manganic Formation			-	-	0%		18%	33%		
Total Manganese Removal			-	-	n.a.		-163%	-160%		

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	C			
DATE:	14-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	KMnO4
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.3x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.97		1.86		1.83	1.83
	filtered	mg/L	1.96		0.19		0.00	0.00
Manganese	non-filtered	mg/L	0.16		n.a.		0.21	0.21
	filtered	mg/L	0.16		0.13		0.01	0.01
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	13		13		13	14
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.6		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1	A2	B1	B2	2 min	12 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON						
Ferric Formation	-	-	91%		100%	100%
Total Iron Removal	-	-	6%		7%	7%
MANGANESE						
Manganic Formation	-	-	17%		91%	96%
Total Manganese Removal	-	-	n.a.		-32%	-37%

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	C				
DATE:	14-05-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	KMnO4	
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	0.7x	stoic
Sampling time(1):	>2	x HRT			
HRT (aeration):	28.1	min			
Sampling time (2):	-	x HRT			

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.00		1.79		1.84	1.81
	filtered	mg/L	1.94		0.18		0.00	0.00
Manganese	non-filtered	mg/L	0.15		n.a.		0.18	0.17
	filtered	mg/L	0.15		0.12		0.11	0.10
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		13		13	13
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.6		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1	A2	B1	B2	2 min	12 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON						
Ferric Formation	-	-	91%		100%	100%
Total Iron Removal	-	-	11%		8%	10%
MANGANESE						
Manganic Formation	-	-	14%		28%	31%
Total Manganese Removal	-	-	n.a.		-21%	-15%

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D			
DATE:	16-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.85		1.76			
	filtered	mg/L	1.70		0.38		0.00	0.00
Manganese	non-filtered	mg/L	0.15		0.15			
	filtered	mg/L	0.14		0.12		0.12	0.12
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		12		14	14
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.7		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1	A2	B1	B2	2 min	12 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON						
Ferric Formation	-	-	78%			
Total Iron Removal	-	-	5%			
MANGANESE						
Manganic Formation	-	-	14%		14%	14%
Total Manganese Removal	-	-	0%			

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D		
DATE:	15-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 6.5x stoic
Sampling time(1):	>2	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point*					
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
Iron	non-filtered	mg/L	1.85		1.76			1.81
	filtered	mg/L	1.70		0.37		0.00	0.00
Manganese	non-filtered	mg/L	0.15		0.15			
	filtered	mg/L	0.14		0.12		0.00	0.00
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		12		13	14
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.7		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
IRON						
Ferric Formation	-	-	78%		100%	100%
Total Iron Removal	-	-	5%			2%
MANGANESE						
Manganic Formation	-	-	14%		100%	100%
Total Manganese Removal	-	-	0%			

Pilot-Scale Run
Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D		
DATE:	15-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 8x stoic
Sampling time(1):	>2	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.91		1.77			1.81
	filtered	mg/L	1.87		0.17		0.04	0.04
Manganese	non-filtered	mg/L	0.14		0.14			
	filtered	mg/L	0.14		0.14		0.01	0.01
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		13		13	14
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.7		7.6	7.7
Suspended Solids		mg/L						

Calculations

	A1	A2	B1	B2	2 min	12 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON						
Ferric Formation	-	-	91%		98%	98%
Total Iron Removal	-	-	7%			5%
MANGANESE						
Manganic Formation	-	-	0%		93%	93%
Total Manganese Removal	-	-	0%			

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D				
DATE:	15-05-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2	
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	10x	stoic
Sampling time(1):	>2	x HRT			
HRT (aeration):	28.1	min			
Sampling time (2):	-	x HRT			

Data

Parameter		*Unit*	*Sampling point*					
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
Iron	non-filtered	mg/L	1.89		1.74			1.81
	filtered	mg/L	1.86		0.34		0.01	0.01
Manganese	non-filtered	mg/L	0.16		0.15			
	filtered	mg/L	0.16		0.13		0.00	0.00
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		12		13	13
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.6		7.7	7.6
Suspended Solids		mg/L						

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
IRON						
Ferric Formation	-	-	82%		99%	99%
Total Iron Removal	-	-	8%			4%
MANGANESE						
Manganic Formation	-	-	19%		99%	97%
Total Manganese Removal	-	-	6%			

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D		
DATE:	16-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* NaOCl
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 8x stoic
Sampling time(1):	>2	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point*					
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
Iron	non-filtered	mg/L	1.98		1.89		1.88	1.86
	filtered	mg/L	1.98		0.20		0.00	0.01
Manganese	non-filtered	mg/L	0.15		0.13			
	filtered	mg/L	0.15		0.12		0.13	0.12
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		13		14	14
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.6		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
IRON						
Ferric Formation	-	-	90%		100%	100%
Total Iron Removal	-	-	5%		5%	6%
MANGANESE						
Manganic Formation	-	-	20%		16%	17%
Total Manganese Removal	-	-	13%			

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	D		
DATE:	16-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* NaOCl
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 13x stoic
Sampling time(1):	>2	x HRT	
HRT (aeration):	28.1	min	
Sampling time (2):	-	x HRT	

Data

Parameter		*Unit*	*Sampling point*					
			A1	A2	B1	B2	2 min	12 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	1.99		1.87		1.85	1.85
	filtered	mg/L	1.98		0.32		0.02	0.00
Manganese	non-filtered	mg/L	0.15		0.14			
	filtered	mg/L	0.14		0.12		0.12	0.10
Alkalinity		mg CaCO3/L						
Hardness		mg CaCO3/L						
Temperature		C	12		12		13	13
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated
pH		-	7.1		7.6		7.7	7.7
Suspended Solids		mg/L						

Calculations

	A1	A2	B1	B2	2 min	12 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON						
Ferric Formation	-	-	84%		99%	100%
Total Iron Removal	-	-	6%		7%	7%
MANGANESE						
Manganic Formation	-	-	14%		14%	29%
Total Manganese Removal	-	-	7%			

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER:	E			
DATE:	22-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	NaOCl
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	35x stoic
Sampling time(1):	>2	x HRT		
HRT (aeration):	28.1	min		
Sampling time (2):	-	x HRT		

Data

Parameter		*Unit*	*Sampling point* A1 RAW	 A2 RAW	 B1 POST-AIR	 B2 POST-AIR	 2 min POST-OX	 10 min POST-OX	 20 min POST-OX
Iron	non-filtered	mg/L	2.02		1.89		2.07	1.99	1.95
	filtered	mg/L	1.99		0.31		0.09	0.00	0.00
Manganese	non-filtered	mg/L	0.16		0.16		0.16	0.16	0.16
	filtered	mg/L	0.16		0.14		0.08	0.07	0.06
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	12		12		12	12	12
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.0		7.6		7.6	7.6	7.7
Suspended Solids		mg/L							

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	10 min POST-OX	20 min POST-OX
IRON							
Ferric Formation	-	-	84%		95%	100%	100%
Total Iron Removal	-	-	6%		-2%	1%	4%
MANGANESE							
Manganic Formation	-	-	14%		48%	55%	64%
Total Manganese Removal	-	-	4%		4%	4%	3%

Pilot-Scale Run

Diffused Aeration-Chemical Oxidant Addition

RUN NUMBER: E
DATE: 22-06-91

Air Flow Rate: 0.081 m3/min
Groundwater Flow Rate: 0.008 m3/min
Sampling time(1): >2 x HRT
HRT (aeration): 28.1 min
Sampling time (2): - x HRT

CHEMICAL OXIDANT TYPE: NaOCl
CHEMICAL OXIDANT DOSAGE: 50x stoic

Data

Parameter		*Unit*	*Sampling point*						
			A1	A2	B1	B2	2 min	10 min	20 min
			RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.02		1.90		1.94	1.95	1.94
	filtered	mg/L	2.02		0.31		0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.16		0.16		0.16	0.16	0.16
	filtered	mg/L	0.15		0.14		0.05	0.03	0.03
Alkalinity		mg CaCO3/L							
Hardness		mg CaCO3/L							
Temperature		C	12		12		12	12	12
Dissolved Oxygen		mg/L	<1		saturated		saturated	saturated	saturated
pH		-	7.0		7.6		7.6	7.6	7.6
Suspended Solids		mg/L							

Calculations

	A1	A2	B1	B2	2 min	10 min	20 min
	RAW	RAW	POST-AIR	POST-AIR	POST-OX	POST-OX	POST-OX
IRON							
Ferric Formation	-	-	85%		100%	100%	100%
Total Iron Removal	-	-	6%		4%	3%	4%
MANGANESE							
Manganic Formation	-	-	7%		67%	78%	78%
Total Manganese Removal	-	-	1%		-3%	1%	0%

APPENDIX F

Conventional Diffused Aeration Process:

Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration Data

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1a		
DATE:	9-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
HRT(aeration):	28.1	min	
HRT(chem ox):	12.0	min	
Sampling time(1):	2.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.89		1.74		1.75		0.03	
	filtered	mg/L	1.84		0.19		0.14		0.01	
Manganese	non-filtered	mg/L	0.18		0.18		0.18		0.19	
	filtered	mg/L	0.17		0.17		0.18		0.17	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12		12		12	
Dissolved Oxygen		mg/L	<1		saturated		saturated		saturated	
pH		-	7.1		7.6		7.6		7.6	
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	90%		92%		99%	
Total Iron Removal	-	-	8%		7%		98%	
MANGANESE								
Manganic Formation	-	-	5%		-1%		1%	
Total Manganese Removal	-	-	2%		2%		-4%	

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1b			
DATE:	9-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	10.0x stoic
HRT(aeration):	28.1	min		
HRT(chem ox):	12.0	min		
Sampling time(1):	6.0	x HRT(aeration)		
Sampling time (2):	9.0	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	1.91	2.00	1.79	1.88	1.77	1.82	0.01	0.00
	filtered	mg/L	1.91	1.91	0.26	0.26	0.01	0.00	0.01	0.00
Manganese	non-filtered	mg/L	0.17	0.19	0.16	0.16	0.14	0.19	0.02	0.02
	filtered	mg/L	0.16	0.17	0.16	0.16	0.01	0.02	0.01	0.02
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12	12	13	13	13	13
Dissolved Oxygen		mg/L	<1		saturated	saturated	saturated	saturated	saturated	saturated
pH		-	7.1		7.6	7.6	7.6	7.6	7.6	7.6
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	86%	87%	99%	100%	99%	100%
Total Iron Removal	-	-	6%	6%	7%	9%	99%	100%
MANGANESE								
Manganic Formation	-	-	-3%	8%	92%	90%	92%	90%
Total Manganese Removal	-	-	10%	13%	18%	-1%	90%	91%

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1c				
DATE:	9-05-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2	
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	10.0x	stoic
HRT(aeration):	28.1	min			
HRT(chem ox):	12.0	min			
Sampling time(1):	11.0	x HRT(aeration)			
Sampling time (2):	-	x HRT(aeration)			

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.97		1.84		1.81		0.00	
	filtered	mg/L	1.97		0.27		0.00		0.00	
Manganese	non-filtered	mg/L	0.10		0.11		0.10		0.00	
	filtered	mg/L	0.10		0.10		0.00		0.00	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		15		15		15	
Dissolved Oxygen		mg/L	<1		saturated		saturated		saturated	
pH		-	7.1		7.6		7.6		7.6	
Suspended Solids		mg/L								

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	86%		100%		100%	
Total Iron Removal		-	-	7%		8%		100%	
MANGANESE									
Manganic Formation		-	-	0%		95%		100%	
Total Manganese Removal		-	-	-16%		-5%		100%	

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	2a			
DATE:	21-05-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.0x stoic
HRT(aeration):	28.1	min		
HRT(chem ox):	12.0	min		
Sampling time(1):	2.0	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.04		1.88		1.93		0.01	
	filtered	mg/L	1.98		0.26		0.00		0.01	
Manganese	non-filtered	mg/L	0.15		0.13		0.12		0.12	
	filtered	mg/L	0.15		0.12		0.12		0.11	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12		13		13	
Dissolved Oxygen		mg/L	<1		saturated		saturated		saturated	
pH		-	7.1		7.6		7.6		7.6	
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	87%		100%		100%	
Total Iron Removal	-	-	8%		6%		100%	
MANGANESE								
Manganic Formation	-	-	21%		20%		28%	
Total Manganese Removal	-	-	18%		22%		22%	

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	2b		
DATE:	21-05-91		
Air Flow Rate:	0.081 m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008 m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.0x stoic
HRT(aeration):	28.1 min		
HRT(chem ox):	12.0 min		
Sampling time(1):	3.0 x HRT(aeration)		
Sampling time (2):	- x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point* A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	1.96		1.83		1.94		0.02	
	filtered	mg/L	1.96		0.34		0.03		0.02	
Manganese	non-filtered	mg/L	0.14		0.15		0.13		0.13	
	filtered	mg/L	0.13		0.13		0.11		0.13	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12		13		14	
Dissolved Oxygen		mg/L	<1		saturated		saturated		saturated	
pH		-	7.1		7.7		7.7		7.7	
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	83%		99%		99%	
Total Iron Removal	-	-	7%		1%		99%	
MANGANESE								
Manganic Formation	-	-	0%		12%		0%	
Total Manganese Removal	-	-	-7%		7%		7%	

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	2c		
DATE:	21-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 1.0x stoic
HRT(aeration):	28.1	min	
HRT(chem ox):	12.0	min	
Sampling time(1):	5.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point* A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.03		1.85		1.86		0.01	
	filtered	mg/L	2.03		0.07		0.04		0.01	
Manganese	non-filtered	mg/L	0.14		0.14		0.12		0.11	
	filtered	mg/L	0.13		0.12		0.12		0.11	
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12		13		14	
Dissolved Oxygen		mg/L	<1		saturated		saturated		saturated	
pH		-	7.1		7.7		7.7		7.7	
Suspended Solids		mg/L								

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	97%		98%		100%	
Total Iron Removal	-	-	9%		8%		100%	
MANGANESE								
Manganic Formation	-	-	8%		8%		12%	
Total Manganese Removal	-	-	0%		14%		19%	

Pilot-Scale Run
Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	8		
DATE:	23/ 5/91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 10.0x stoic
HRT(aeration):	28.1	min	
HRT(chem ox):	3.0	min	
Sampling time(1):	3.0	x HRT(aeration)	
Sampling time (2):	4.0	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.92	1.92	n.a.	n.a.	n.a.	n.a.	0.30	0.24
	filtered	mg/L	1.92	1.92	0.00	0.02	0.01	0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.14	0.14	0.13	0.13	n.a.	n.a.	0.03	0.02
	filtered	mg/L	0.14	0.14	0.13	0.13	0.01	0.01	0.01	0.01
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	13	14	13	14	13	22	22
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated	saturated	saturated	saturated	saturated
pH		-	7.1	7.1	7.7	7.7	7.6	7.6	7.6	7.6
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	100%	99%	99%	100%	100%	100%
Total Iron Removal	-	-	n.a.	n.a.	n.a.	n.a.	84%	88%
MANGANESE								
Manganic Formation	-	-	10%	10%	95%	95%	93%	90%
Total Manganese Removal	-	-	7%	4%	n.a.	n.a.	78%	84%

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER:	4	
DATE:	5-06-91	
Air Flow Rate:	0.081	m3/min
Groundwater Flow Rate:	0.008	m3/min
HRT(aeration):	28.1	min
HRT(chem ox):	2.0	min
Sampling time(1):	4.0	x HRT(aeration)
Sampling time (2):	7.0	x HRT(aeration)

CHEMICAL OXIDANT TYPE:	ClO2	
CHEMICAL OXIDANT DOSAGE:	7.0 x	stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.87	1.94	1.84	1.71	1.74	1.71	0.00	0.00
	filtered	mg/L	1.83	1.94	0.19	0.01	0.00	0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.13	0.13	0.11	0.11	0.11	0.11	0.01	0.01
	filtered	mg/L	0.12	0.13	0.11	0.11	0.00	0.01	0.00	0.00
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11	11	13	12	13	12	13	13
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated	saturated	saturated	saturated	saturated
pH		-	7.1	7.1	7.5	7.6	7.8	7.7	7.8	7.7
Suspended Solids		mg/L								

Calculations

			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	90%	100%	100%	100%	100%	100%
Total Iron Removal			-	-	2%	12%	7%	12%	100%	100%
MANGANESE										
Manganic Formation			-	-	4%	15%	98%	95%	98%	100%
Total Manganese Removal			-	-	17%	15%	15%	15%	94%	95%

Pilot-Scale Run

Diffused Aeration-Chem Ox-Contact Sand Filtration

RUN NUMBER: 5
DATE: 3-07-91

Air Flow Rate: 0.068 m3/min
Groundwater Flow Rate: 0.010 m3/min
HRT(aeration): 22.5 min
HRT(chem ox): 2.0 min
Sampling time(1): 4.0 x HRT(aeration)
Sampling time (2): 6.0 x HRT(aeration)

CHEMICAL OXIDANT TYPE: NaOCl
CHEMICAL OXIDANT DOSAGE: 50 x stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.04	2.04	1.86	1.89	2.03	1.82	0.00	0.00
	filtered	mg/L	2.02	2.03	0.36	0.39	0.00	0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.15	0.16	0.14	0.14	0.15	0.13	0.02	0.01
	filtered	mg/L	0.14	0.14	0.13	0.13	0.05	0.06	0.02	0.01
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11	11	12	12	12	13	13	13
Dissolved Oxygen		mg/L	<1	<1	saturated	saturated	saturated	saturated	saturated	saturated
pH		-	7.1	7.1	7.6	7.7	7.8	7.8	7.7	7.7
Suspended Solids		mg/L	0.00	0.00	3.49	2.81	2.60	2.45	0.00	0.00

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	82%	81%	100%	100%	100%	100%
Total Iron Removal	-	-	9%	7%	0%	11%	100%	100%
MANGANESE								
Manganic Formation	-	-	8%	5%	66%	60%	85%	91%
Total Manganese Removal	-	-	6%	11%	-2%	14%	86%	92%

APPENDIX G

Diffused Aeration - Chemical Oxidation (ClO_2) - Direct Contact Sand Filtration:

Performance Evaluation Continuous Operation

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

5th JULY - 10th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT A (RAW GROUNDWATER)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
2.0	1.99	2.01	0.10	0.10	11	7.10	< 1		0.00
6.0	2.08	2.06	0.14	0.14	13	7.10	< 1	0.5	0.00
14.0	2.10	2.06	0.15	0.14	13	7.20	< 1	0.4	0.00
22.0	2.06	2.06	0.18	0.19	13	7.20	< 1		0.00
34.0	1.98	1.97	0.15	0.14	14	7.05	< 1		0.00
48.0	2.07	2.07	0.15	0.16	13	7.10	< 1	0.1	0.00
54.0	2.00	2.00	0.14	0.14	13	7.20	< 1	0.0	0.00
61.5	2.00	2.00	0.15	0.15	14	7.05	< 1		0.00
67.0	2.07	2.02	0.16	0.15	12	7.10	< 1		0.00
86.0	2.32	2.45	0.14	0.14	12	7.20	< 1		0.00
93.0	2.09	2.09	0.21	0.23	11	7.20	< 1		0.00
98.0	2.09	2.05	0.20	0.22	11	7.20	< 1		0.00
102.0	2.02	2.04	0.14	0.13	12	7.20	< 1	0.7	0.00
118.5	2.04	1.93	0.15	0.16	11	7.20	< 1		0.00
MEAN	2.07	2.06	0.15	0.16	12	7.15	< 1	0.3	0.00

SAMPLE POINT B (POST-AIR)

2.0	1.97	0.32	0.14	0.12	12	7.60	sat		4.33
6.0	2.00	0.47	0.14	0.14	13	7.60	sat	9.8	3.77
14.0	1.99	0.51	0.14	0.14	14	7.70	sat	10.0	3.20
22.0	1.97	0.28	0.19	0.18	15	7.70	sat	9.0	3.86
34.0	1.94	0.46	0.14	0.12	14	7.60	sat		3.86
48.0	1.97	0.42	0.11	0.15	13	7.60	sat	9.5	3.68
54.0	1.89	0.41	0.15	0.13	14	7.60	sat	9.8	2.74
61.5	1.88	0.45	0.14	0.14	14	7.60	sat		2.45
67.0	1.92	0.46	0.14	0.14	13	7.60	sat		3.49
86.0	2.63	0.59	0.14	0.14	12	7.70	sat	9.5	3.77
93.0	1.94	0.51	0.22	0.16	12	7.70	sat		3.68
98.0	2.83	0.43	0.19	0.16	12	7.70	sat		3.86
102.0	1.94	0.45	0.15	0.15	13	7.70	sat	9.3	3.49
118.5	1.88	0.38	0.14	0.13	12	7.70	sat		4.34
MEAN	2.05	0.44	0.15	0.14	13	7.65	sat	9.6	3.61

SAMPLE POINT D (PRE-FILT)

2.0	1.95	0.00	0.10	0.01	13	7.60	sat		4.98
6.0	1.98	0.00	0.14	0.00	13	7.75	sat	10.6	5.07
14.0	2.02	0.01	0.14	0.00	14	7.70	sat	11.8	4.88
22.0	1.96	0.05	0.19	0.00	15	7.80	sat	10.2	4.60
34.0	2.03	0.00	0.27	0.00	14	7.70	sat		5.35
48.0	1.94	0.00	0.17	0.00	15	7.70	sat	10.3	4.41
54.0	2.15	0.00	0.16	0.01	15	7.70	sat	11.8	5.92
61.5	1.86	0.00	0.14	0.03	14	7.65	sat		4.79
67.0	1.89	0.04	0.15	0.01	13	7.70	sat		5.07
86.0	2.42	0.14	0.22	0.01	12	7.60	sat	12.5	4.60
93.0	1.96	0.02	0.24	0.14	12	7.70	sat		5.07
98.0	1.91	0.06	0.18	0.02	12	7.70	sat		4.69
102.0	1.88	0.00	0.14	0.01	14	7.80	sat	10.1	4.41
118.5	2.08	0.00	0.16	0.01	12	7.70	sat		4.97
MEAN	2.00	0.02	0.17	0.02	13	7.70	sat	11.0	4.92

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

5th JULY - 10th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT E (POST-FILT)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
2.0	0.00	0.00	0.00	0.00	13	7.60	sat		0.00
4.0	0.01		0.00						
6.0	0.05	0.00	0.01	0.00	13	7.60	sat	0.3	0.00
8.0	0.06		0.01					0.4	
10.0	0.05		0.01					0.2	
12.0	0.08					7.60		0.2	
14.0	0.10	0.01	0.01	0.00	14	7.60	sat	0.4	0.00
20.0	0.05		0.00						
22.0	0.06	0.04	0.00	0.01	16	7.70	sat	0.4	0.00
24.0	0.06		0.00						
26.0	0.06		0.01						
34.0	0.06	0.00	0.00	0.00	14	7.60	sat	0.5	0.00
36.0	0.05		0.00					0.5	
38.0	0.05		0.00					0.5	
45.0	0.05		0.00						
46.0	0.06		0.00						
48.0	0.04	0.00	0.00	0.00	15	7.70	sat	0.3	0.00
54.0	0.04	0.00	0.00	0.00	16	7.70	sat	0.3	0.00
57.0	0.03		0.02			7.60			
59.0	0.03		0.01			7.70		0.4	
61.5		0.00	0.03	0.00	14	7.60	sat		0.00
65.0	0.02		0.01					0.1	
67.0	0.02	0.00	0.01	0.00	13	7.60	sat		0.00
71.0	0.02		0.01						
79.0	0.04		0.01			7.65		0.3	
81.0	0.05		0.01			7.65		0.3	
83.5	0.07		0.02			7.65		0.4	
86.0	0.07	0.00	0.01	0.00	13	7.65	sat	0.2	0.00
91.0	0.07		0.02						
93.0	0.03	0.00	0.02	0.02	13	7.60	sat	0.4	0.00
96.0	0.02		0.01						
98.0	0.08	0.01	0.02	0.01	12	7.60	sat		0.00
100.0	0.05		0.02						
102.0	0.04	0.00	0.01	0.01	14	7.70	sat	0.4	0.00
106.0	0.05		0.01					0.2	
109.0	0.05		0.02					0.3	
111.0	0.05		0.01					0.3	
116.0	0.04		0.02					0.4	
117.0	0.12		0.01					0.3	
118.0	0.08		0.02						
118.5	0.22	0.00	0.02	0.01	13	7.60	sat	0.3	0.00
MEAN	0.05	0.00	0.01	0.00	14	7.64	sat	0.3	0.00

APPENDIX H

Enhanced Aeration Process I:

Diffused Aeration - Continuous Recycle Loop Data

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1		
DATE:	24-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0010	m3/min	
Recycle Ratio:	10	%	
HRT(aeration):	22.5	min	
HRT(chem ox):	-	min	
Sampling time:	3.0	x HRT(aeration)	
Sampling time (duplicate):	4.0	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.97	1.98	1.84	1.83				
	filtered	mg/L	2.01	1.98	0.26	0.28				
Manganese	non-filtered	mg/L	0.14	0.14	0.15	0.14				
	filtered	mg/L	0.14	0.14	0.12	0.12				
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	12	14	14				
Dissolved Oxygen		mg/L	1.5	1.6	11.6	11.5				
pH		-	7.1	7.1	7.6	7.6				
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	87%	86%				
Total Iron Removal	-	-	7%	8%				
MANGANESE								
Manganic Formation	-	-	12%	12%				
Total Manganese Removal	-	-	-3%	0%				

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	2		
DATE:	24-05-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0020	m3/min	
Recycle Ratio:	20	%	
HRT(aeration):	22.5	min	
HRT(chem ox):	-	min	
Sampling time:	3.0	x HRT(aeration)	
Sampling time (duplicate):	4.0	x HRT(aeration)	

Data

Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.97	2.00	1.84	1.82				
	filtered	mg/L	1.96	1.98	0.21	0.22				
Manganese	non-filtered	mg/L	0.14	0.14	0.13	0.13				
	filtered	mg/L	0.13	0.14	0.12	0.12				
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11	11	12	12				
Dissolved Oxygen		mg/L	1.3	1.7	11.6	11.7				
pH		-	7.1	7.1	7.6	7.6				
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	89%	89%				
Total Iron Removal	-	-	7%	9%				
MANGANESE								
Manganic Formation	-	-	9%	14%				
Total Manganese Removal	-	-	5%	8%				

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	3		
DATE:	28-05-91		
Air Flow Rate:	0.216	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0020	m3/min	
Recycle Ratio:	20	%	
HRT(aeration):	22.5	min	
HRT(chem ox):	-	min	
Sampling time:	5.0	x HRT(aeration)	
Sampling time (duplicate):	6.0	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.93	1.90	1.83	1.82				
	filtered	mg/L	1.91	1.91	0.00	0.00				
Manganese	non-filtered	mg/L	0.14	0.14	0.13	0.13				
	filtered	mg/L	0.13	0.13	0.12	0.12				
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	12	14	13				
Dissolved Oxygen		mg/L	2.1	3.0	11.3	11.2				
pH		-	7.1	7.1	7.8	7.8				
Suspended Solids		mg/L	0.57	0.47	4.91	4.34				

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	100%	100%				
Total Iron Removal	-	-	5%	4%				
MANGANESE								
Manganic Formation	-	-	8%	8%				
Total Manganese Removal	-	-	7%	7%				

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	4		
DATE:	29-05-91		
Air Flow Rate:	0.054	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.040	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0074	m3/min	
Recycle Ratio:	19	%	
HRT(aeration):	5.6	min	
HRT(chem ox):	-	min	
Sampling time:	> 10	x HRT(aeration)	
Sampling time (duplicate):		x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point* A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.01		1.97					
	filtered	mg/L	2.00		1.30					
Manganese	non-filtered	mg/L	0.20		0.19					
	filtered	mg/L	0.19		0.16					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		14					
Dissolved Oxygen		mg/L	1.7		10.6					
pH		-	7.1		7.4					
Suspended Solids		mg/L	0.00		2.45					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	35%					
Total Iron Removal	-	-	2%					
MANGANESE								
Manganic Formation	-	-	16%					
Total Manganese Removal	-	-	5%					

					Pilot-Scale Run					
					Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration					
				RUN NUMBER:	5					
				DATE:	29-05-91					
				Air Flow Rate:	0.162	m3/min	*CHEMICAL OXIDANT TYPE:*		-	
				Groundwater Flow Rate:	0.040	m3/min	*CHEMICAL OXIDANT DOSAGE:*		-	stoic
				Recycle Flow Rate:	0.0080	m3/min				
				Recycle Ratio:	20	%				
				HRT(aeration):	5.6	min				
				HRT(chem ox):	-	min				
				Sampling time:	>10	x HRT(aeration)				
				Sampling time (duplicate):		x HRT(aeration)				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.04		1.97					
	filtered	mg/L	2.03		1.16					
Manganese	non-filtered	mg/L	0.20		0.19					
	filtered	mg/L	0.19		0.17					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	1.6		10.5					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		1.32					
					Calculations					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	43%					
Total Iron Removal			-	-	3%					
MANGANESE										
Manganic Formation			-	-	11%					
Total Manganese Removal			-	-	5%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	6			
DATE:	29-05-91			
Air Flow Rate:	0.027	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.030	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0060	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	7.5	min		
HRT(chem ox):	-	min		
Sampling time:	>10	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.09		1.89					
	filtered	mg/L	1.91		1.14					
Manganese	non-filtered	mg/L	0.15		0.14					
	filtered	mg/L	0.15		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		14					
Dissolved Oxygen		mg/L	2.2		10.3					
pH		-	7.1		7.4					
Suspended Solids		mg/L	0.00		1.04					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	40%					
Total Iron Removal	-	-	10%					
MANGANESE								
Manganic Formation	-	-	7%					
Total Manganese Removal	-	-	7%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

				RUN NUMBER:	7					
				DATE:	29-05-91					
				Air Flow Rate:	0.162	m3/min	*CHEMICAL OXIDANT TYPE:*		-	
				Groundwater Flow Rate:	0.030	m3/min	*CHEMICAL OXIDANT DOSAGE:*		-	stoic
				Recycle Flow Rate:	0.0060	m3/min				
				Recycle Ratio:	20	%				
				HRT(aeration):	7.5	min				
				HRT(chem ox):	-	min				
				Sampling time:	>10	x HRT(aeration)				
				Sampling time (duplicate):		x HRT(aeration)				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.08		2.11					
	filtered	mg/L	1.88		0.52					
Manganese	non-filtered	mg/L	0.16		0.16					
	filtered	mg/L	0.15		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13		18					
Dissolved Oxygen		mg/L	1.8		10.6					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		1.23					
					Calculations					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	72%					
Total Iron Removal			-	-	-1%					
MANGANESE										
Manganic Formation			-	-	7%					
Total Manganese Removal			-	-	0%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER: 8
DATE: 30-05-91

Air Flow Rate: 0.108 m3/min
Groundwater Flow Rate: 0.020 m3/min
Recycle Flow Rate: 0.0040 m3/min
Recycle Ratio: 20 %
HRT(aeration): 11.3 min
HRT(chem ox): - min
Sampling time: >10 x HRT(aeration)
Sampling time (duplicate): x HRT(aeration)

CHEMICAL OXIDANT TYPE: -
CHEMICAL OXIDANT DOSAGE: - stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.01		1.82					
	filtered	mg/L	2.01		0.70					
Manganese	non-filtered	mg/L	0.15		0.15					
	filtered	mg/L	0.14		0.13					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	1.2		11.0					
pH		-	7.2		7.6					
Suspended Solids		mg/L	0.01		1.88					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	65%					
Total Iron Removal	-	-	9%					
MANGANESE								
Manganic Formation	-	-	1%					
Total Manganese Removal	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	9	
DATE:	30-05-91	
Air Flow Rate:		m3/min
Groundwater Flow Rate:	0.020	m3/min
Recycle Flow Rate:	0.0040	m3/min
Recycle Ratio:	20	%
HRT(aeration):	11.3	min
HRT(chem ox):	-	min
Sampling time:	>10	x HRT(aeration)
Sampling time (duplicate):		x HRT(aeration)

CHEMICAL OXIDANT TYPE:	-
CHEMICAL OXIDANT DOSAGE:	- stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	1.97		1.84					
	filtered	mg/L	1.92		0.62					
Manganese	non-filtered	mg/L	0.15		0.15					
	filtered	mg/L	0.15		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	1.7		12.0					
pH		-	7.2		7.8					
Suspended Solids		mg/L	0.09		3.40					

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	68%					
Total Iron Removal	-	-	7%					
MANGANESE								
Manganic Formation	-	-	9%					
Total Manganese Removal	-	-	-2%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	10			
DATE:	4-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0020	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	22.5	min		
HRT(chem ox):	-	min		
Sampling time:	>10	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.00		1.83					
	filtered	mg/L	1.94		0.14					
Manganese	non-filtered	mg/L	0.16		0.17					
	filtered	mg/L	0.16		0.13					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	10		12					
Dissolved Oxygen		mg/L	2.3		11.8					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.46		3.39					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	93%					
Total Iron Removal	-	-	9%					
MANGANESE								
Manganic Formation	-	-	19%					
Total Manganese Removal	-	-	-2%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	11			
DATE:	4-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0016	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	28.0	min		
HRT(chem ox):	-	min		
Sampling time:	>10	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point* A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	1.99		1.85					
	filtered	mg/L	1.98		0.16					
Manganese	non-filtered	mg/L	0.17		0.16					
	filtered	mg/L	0.16		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	2.5		11.7					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.28		3.31					

Calculations

	A1 RAW	A2 RAW	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON								
Ferric Formation	-	-	92%					
Total Iron Removal	-	-	7%					
MANGANESE								
Manganic Formation	-	-	14%					
Total Manganese Removal	-	-	2%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	12			
DATE:	10-06-91			
Air Flow Rate:	0.054	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.013	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0026	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	17.3	min		
HRT(chem ox):	-	min		
Sampling time:	>10	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.96		1.81					
	filtered	mg/L	1.95		0.25					
Manganese	non-filtered	mg/L	0.15		0.15					
	filtered	mg/L	0.15		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	2.5		11.7					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	87%					
Total Iron Removal	-	-	8%					
MANGANESE								
Manganic Formation	-	-	7%					
Total Manganese Removal	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

				RUN NUMBER:	18					
				DATE:	11-06-91					
				Air Flow Rate:	0.108	m3/min	*CHEMICAL OXIDANT TYPE:*		-	
				Groundwater Flow Rate:	0.015	m3/min	*CHEMICAL OXIDANT DOSAGE:*		-	stoic
				Recycle Flow Rate:	0.0030	m3/min				
				Recycle Ratio:	20	%				
				HRT(aeration):	15.0	min				
				HRT(chem ox):	-	min				
				Sampling time:	>10	x HRT(aeration)				
				Sampling time (duplicate):		x HRT(aeration)				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.00		1.80					
	filtered	mg/L	1.88		0.30					
Manganese	non-filtered	mg/L	0.14		0.15					
	filtered	mg/L	0.14		0.14					
Alkalinity		mg CaCO3/L	182		178					
Hardness		mg CaCO3/L	978		966					
Temperature		C	10		12					
Dissolved Oxygen		mg/L	2.6		11.4					
pH		-	7.1		7.6					
Suspended Solids		mg/L								
					Calculations					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	84%					
Total Iron Removal			-	-	10%					
MANGANESE										
Manganic Formation			-	-	4%					
Total Manganese Removal			-	-	-3%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	14		
DATE:	11-06-91		
Air Flow Rate:	0.108	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.017	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0034	m3/min	
Recycle Ratio:	20	%	
HRT(aeration):	13.2	min	
HRT(chem ox):	-	min	
Sampling time:	>10	x HRT(aeration)	
Sampling time (duplicate):		x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.99		1.81					
	filtered	mg/L	1.95		0.60					
Manganese	non-filtered	mg/L	0.14		0.14					
	filtered	mg/L	0.14		0.14					
Alkalinity		mg CaCO3/L	183		179					
Hardness		mg CaCO3/L	984		968					
Temperature		C	10		12					
Dissolved Oxygen		mg/L	2.3		10.2					
pH		-	7.1		7.6					
Suspended Solids		mg/L								

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	74%					
Total Iron Removal	-	-	9%					
MANGANESE								
Manganic Formation	-	-	0%					
Total Manganese Removal	-	-	0%					

				Pilot-Scale Run						
		Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration								
				RUN NUMBER:	15					
				DATE:	12-06-91					
				Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*		-	
				Groundwater Flow Rate:	0.007	m3/min	*CHEMICAL OXIDANT DOSAGE:*		-	stoic
				Recycle Flow Rate:	0.0014	m3/min				
				Recycle Ratio:	20	%				
				HRT(aeration):	32.1	min				
				HRT(chem ox):	-	min				
				Sampling time:	3.0	x HRT(aeration)				
				Sampling time (duplicate):		x HRT(aeration)				
					Data					
Parameter		*Unit*			*Sampling point*					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.92		1.78					
	filtered	mg/L	1.80		0.12					
Manganese	non-filtered	mg/L	0.13		0.13					
	filtered	mg/L	0.14		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		12					
Dissolved Oxygen		mg/L	4.6		11.2					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		5.70					
Turbidity		NTU	0.10		9.20					
					Calculations					
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation			-	-	93%					
Total Iron Removal			-	-	7%					
MANGANESE										
Manganic Formation			-	-	1%					
Total Manganese Removal			-	-	-2%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	15			
DATE:	12-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.007	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0014	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	32.1	min		
HRT(chem ox):	-	min		
Sampling time:	5.0	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.92		1.81					
	filtered	mg/L	1.89		0.06					
Manganese	non-filtered	mg/L	0.14		0.14					
	filtered	mg/L	0.14		0.12					
Alkalinity		mg CaCO3/L	187		185					
Hardness		mg CaCO3/L	943		897					
Temperature		C	11		13					
Dissolved Oxygen		mg/L	3.9		11.7					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		4.10					
Turbidity		NTU	0.08		9.30					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	97%					
Total Iron Removal	-	-	6%					
MANGANESE								
Manganic Formation	-	-	14%					
Total Manganese Removal	-	-	4%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	15		
DATE:	12-06-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.007	m3/min	*CHEMICAL OXIDANT DOSAGE:* - stoic
Recycle Flow Rate:	0.0014	m3/min	
Recycle Ratio:	20	%	
HRT(aeration):	32.1	min	
HRT(chem ox):	-	min	
Sampling time:	6.0	x HRT(aeration)	
Sampling time (duplicate):		x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.93		1.80					
	filtered	mg/L	1.92		0.04					
Manganese	non-filtered	mg/L	0.13		0.11					
	filtered	mg/L	0.13		0.12					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		13					
Dissolved Oxygen		mg/L	2.8		12.1					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		4.20					
Turbidity		NTU	0.05		9.30					

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	98%					
Total Iron Removal		-	-	7%					
MANGANESE									
Manganic Formation		-	-	9%					
Total Manganese Removal		-	-	13%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	16			
DATE:	12-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0016	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	28.1	min		
HRT(chem ox):	-	min		
Sampling time:	3.0	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.89		1.78					
	filtered	mg/L	1.89		0.04					
Manganese	non-filtered	mg/L	0.13		0.12					
	filtered	mg/L	0.12		0.10					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12					
Dissolved Oxygen		mg/L	3.7		11.8					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		3.20					
Turbidity		NTU	0.08		9.00					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	98%					
Total Iron Removal	-	-	6%					
MANGANESE								
Manganic Formation	-	-	17%					
Total Manganese Removal	-	-	8%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	16				
DATE:	12-06-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-	
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	-	stoic
Recycle Flow Rate:	0.0016	m3/min			
Recycle Ratio:	20	%			
HRT(aeration):	28.1	min			
HRT(chem ox):	-	min			
Sampling time:	5.0	x HRT(aeration)			
Sampling time (duplicate):		x HRT(aeration)			

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.92		1.77					
	filtered	mg/L	1.79		0.12					
Manganese	non-filtered	mg/L	0.12		0.12					
	filtered	mg/L	0.11		0.12					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12		12					
Dissolved Oxygen		mg/L	3.4		11.0					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.00		3.20					
Turbidity		NTU	0.06		9.10					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	93%					
Total Iron Removal	-	-	8%					
MANGANESE								
Manganic Formation	-	-	-9%					
Total Manganese Removal	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	16			
DATE:	12-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0016	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	28.1	min		
HRT(chem ox):	-	min		
Sampling time:	6.0	x HRT(aeration)		
Sampling time (duplicate):		x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.90		1.76					
	filtered	mg/L	1.90		0.04					
Manganese	non-filtered	mg/L	0.11		0.11					
	filtered	mg/L	0.11		0.11					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	11		12					
Dissolved Oxygen		mg/L	3.4		12.0					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.10		4.20					
Turbidity		NTU	0.56		8.80					

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	98%					
Total Iron Removal	-	-	7%					
MANGANESE								
Manganic Formation	-	-	0%					
Total Manganese Removal	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	17				
DATE:	12-06-91				
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-	
Groundwater Flow Rate:	0.009	m3/min	*CHEMICAL OXIDANT DOSAGE:*	-	stoic
Recycle Flow Rate:	0.0018	m3/min			
Recycle Ratio:	20	%			
HRT(aeration):	25.0	min			
HRT(chem ox):	-	min			
Sampling time:	3.0	x HRT(aeration)			
Sampling time (duplicate):	-	x HRT(aeration)			

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.96		1.80					
	filtered	mg/L	1.89		0.25					
Manganese	non-filtered	mg/L	0.18		n.a.					
	filtered	mg/L	0.17		0.16					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	10		11					
Dissolved Oxygen		mg/L	1.9		12.1					
pH		-	7.1		7.6					
Suspended Solids		mg/L	0.10		n.a.					
Turbidity		NTU	0.08		8.30					

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	87%					
Total Iron Removal		-	-	8%					
MANGANESE									
Manganic Formation		-	-	14%					
Total Manganese Removal		-	-	n.a.					

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	17			
DATE:	12-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.009	m3/min	*CHEMICAL OXIDANT DOSAGE:*	- stoic
Recycle Flow Rate:	0.0018	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	25.0	min		
HRT(chem ox):	-	min		
Sampling time:	6.0	x HRT(aeration)		
Sampling time (duplicate):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.95		1.77					
	filtered	mg/L	1.90		0.24					
Manganese	non-filtered	mg/L	0.17		n.a.					
	filtered	mg/L	0.17		0.14					
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	10		11					
Dissolved Oxygen		mg/L	1.7		11.8					
pH		-	7.1		7.6					
Suspended Solids		mg/L								
Turbidity		NTU	0.09		8.30					

Calculations

		A1	A2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON									
Ferric Formation		-	-	87%					
Total Iron Removal		-	-	9%					
MANGANESE									
Manganic Formation		-	-	18%					
Total Manganese Removal		-	-	n.a.					

APPENDIX I

Enhanced Aeration Process I:
Diffused Aeration - Continuous Recycle Loop - Chemical Oxidation - Direct Contact Sand Filtration Data

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1		
DATE:	13-06-91		
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:* ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:* 6x stoic
Recycle Flow Rate:	0.0016	m3/min	
Recycle Ratio:	20	%	
HRT(aeration):	28.1	min	
HRT(chem ox):	2.0	min	
Sampling time:	2.0	x HRT(aeration)	
Sampling time (duplicate):	3.0	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.94	1.97	1.78	1.81	1.71	1.74	0.00	0.00
	filtered	mg/L	1.93	1.97	0.09	0.10	0.00	0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.15	0.15	0.15	0.15	0.14	0.13	0.01	0.01
	filtered	mg/L	0.15	0.15	0.13	0.14	0.02	0.00	0.01	0.01
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	13	13	13	13	14	14	14	14
Dissolved Oxygen		mg/L	2.5	1.5	11.5	11.5	11.7	11.2	11.5	11.3
pH		-	7.1	7.1	7.6	7.6	7.6	7.6	7.6	7.7
Suspended Solids		mg/L	0.20	0.00	3.20	3.70	4.20	4.80	0.10	0.20
Turbidity		NTU	0.03	0.09	9.10	9.10	10.00	10.00	0.09	0.10

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	95%	95%	100%	100%	100%	100%
Total Iron Removal	-	-	8%	8%	12%	12%	100%	100%
MANGANESE								
Manganic Formation	-	-	13%	7%	87%	100%	93%	93%
Total Manganese Removal	-	-	0%	0%	7%	13%	93%	93%

Pilot-Scale Run

Diffused Aeration-Continuous Recycle Loop-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1			
DATE:	13-06-91			
Air Flow Rate:	0.081	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.008	m3/min	*CHEMICAL OXIDANT DOSAGE:*	6x stoic
Recycle Flow Rate:	0.0016	m3/min		
Recycle Ratio:	20	%		
HRT(aeration):	28.1	min		
HRT(chem ox):	2.0	min		
Sampling time:	10.0	x HRT(aeration)		
Sampling time (duplicate):	12.0	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.99	2.01	2.01	1.91	1.78	1.98	0.14	0.00
	filtered	mg/L	1.95	2.00	0.08	0.09	0.00	0.00	0.00	0.00
Manganese	non-filtered	mg/L	0.14	0.15	0.14	0.14	0.14	0.14	0.01	0.01
	filtered	mg/L	0.14	0.15	0.14	0.13	0.01	0.01	0.01	0.01
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12	14	12	14	12	14	13	15
Dissolved Oxygen		mg/L	3.4	2.0	11.7	11.5	11.6	11.2	11.5	11.5
pH		-	7.0	7.0	7.6	7.6	7.6	7.6	7.7	7.6
Suspended Solids		mg/L		0.20				3.70		0.30
Turbidity		NTU	0.03	0.04	9.10	9.30	10.00	9.90	0.09	0.05

Calculations

	A1	A2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON								
Ferric Formation	-	-	96%	96%	100%	100%	100%	100%
Total Iron Removal	-	-	-1%	5%	11%	1%	93%	100%
MANGANESE								
Manganic Formation	-	-	5%	10%	93%	95%	95%	95%
Total Manganese Removal	-	-	-1%	1%	4%	3%	94%	95%

APPENDIX J

Enhanced Aeration Process II:
Diffused Aeration - Sludge Addition Data

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1	
DATE:	24-06-91	
Air Flow Rate:	0.324	m3/min
Groundwater Flow Rate:	0.055	m3/min
Sludge Flow Rate:	0.001	m3/min
Sludge Addition Factor:	58.6	(mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration):	4.0	min
HRT(chem ox):	-	min
Sampling time(1):	4.0	x HRT(aeration)
Sampling time (2):	5.0	x HRT(aeration)

CHEMICAL OXIDANT TYPE: -

CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.11		124		124	128				
	filtered	mg/L	2.12		1.54		0.21	0.24				
Manganese	non-filtered	mg/L	0.14		0.46		0.42	0.37				
	filtered	mg/L	0.14		0.14		0.13	0.12				
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	13		13		14	14				
Dissolved Oxygen		mg/L	<1		<2		saturated	saturated				
pH		-	7.0		7.1		7.6	7.6				
Suspended Solids		mg/L	0		335		335	338				

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	27%		90%	89%				
Total Iron Removal	-	-	-	-	0%	-3%				
MANGANESE										
Manganic Formation	-	-	-2%		3%	12%				
Total Manganese Removal	-	-	-	-	10%	19%				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: 2
DATE: 24-06-91

Air Flow Rate: 0.324 m3/min
Groundwater Flow Rate: 0.055 m3/min
Sludge Flow Rate: 0.001 m3/min
Sludge Addition Factor: 30.1 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 4.0 min
HRT(chem ox): - min
Sampling time(1): 4.0 x HRT(aeration)
Sampling time (2): 5.0 x HRT(aeration)

CHEMICAL OXIDANT TYPE: -
CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.04		62		62	60				
	filtered	mg/L	2.03		1.58		n.a.	0.38				
Manganese	non-filtered	mg/L	0.14		0.33		0.30	0.27				
	filtered	mg/L	0.14		0.14		0.13	0.12				
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	14		14		14	14				
Dissolved Oxygen		mg/L	<1		<2		saturated	saturated				
pH		-	7.0		7.0		7.6	7.6				
Suspended Solids		mg/L	0		137		137	149				

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	22%		n.a.	81%				
Total Iron Removal	-	-	-	-	0%	3%				
MANGANESE										
Manganic Formation	-	-	0%		4%	12%				
Total Manganese Removal	-	-	-	-	10%	19%				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: 8
DATE: 25-06-91

Air Flow Rate: 0.270 m3/min
Groundwater Flow Rate: 0.055 m3/min
Sludge Flow Rate: 0.000 m3/min
Sludge Addition Factor: 31.4 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 4.1 min
HRT(chem ox): - min
Sampling time(1): 6.0 x HRT(aeration)
Sampling time (2): - x HRT(aeration)

CHEMICAL OXIDANT TYPE: -
CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.10		65		67					
	filtered	mg/L	2.10		1.65		0.70					
Manganese	non-filtered	mg/L	0.17		0.29		0.27					
	filtered	mg/L	0.16		0.14		0.15					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.1		7.1		7.4					
Suspended Solids		mg/L	0		86		92					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	21%		67%					
Total Iron Removal	-	-	-	-	-3%					
MANGANESE										
Manganic Formation	-	-	13%		6%					
Total Manganese Removal	-	-	-	-	7%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	4		
DATE:	25-06-91		
Air Flow Rate:	0.324	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:* -
Sludge Flow Rate:	0.000	m3/min	
Sludge Addition Factor:	17.8	(mg Fe added to aerator/mg Fe in raw groundwater) per min	
HRT(aeration):	4.1	min	
HRT(chem ox):	-	min	
Sampling time(1):	6.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05		36		37					
	filtered	mg/L	1.93		1.77		0.51					
Manganese	non-filtered	mg/L	0.17		0.23		0.23					
	filtered	mg/L	0.16		0.15		0.14					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		11					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.0		7.1		7.6					
Suspended Solids		mg/L	0		66		66					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	8%		74%					
Total Iron Removal	-	-	-	-	-3%					
MANGANESE										
Manganic Formation	-	-	6%		13%					
Total Manganese Removal	-	-	-	-	0%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	5		
DATE:	26-06-91		
Air Flow Rate:	0.324	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:* -
Sludge Flow Rate:	0.000	m3/min	
Sludge Addition Factor:	3.7	(mg Fe added to aerator/mg Fe in raw groundwater) per min	
HRT(aeration):	4.1	min	
HRT(chem ox):	-	min	
Sampling time(1):	6.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.00		7.50		7.32					
	filtered	mg/L	2.03		1.93		1.24					
Manganese	non-filtered	mg/L	0.12		0.17		0.16					
	filtered	mg/L	0.12		0.12		0.12					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		12		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.1		7.1		7.6					
Suspended Solids		mg/L	0		27		26					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	5%		39%					
Total Iron Removal	-	-	-	-	2%					
MANGANESE										
Manganic Formation	-	-	0%		0%					
Total Manganese Removal	-	-	-	-	6%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: 6
DATE: 25-06-91

Air Flow Rate: 0.324 m3/min
Groundwater Flow Rate: 0.055 m3/min
Sludge Flow Rate: 0 m3/min
Sludge Addition Factor: 0 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 4.1 min
HRT(chem ox): - min
Sampling time(1): 6.0 x HRT(aeration)
Sampling time (2): - x HRT(aeration)

CHEMICAL OXIDANT TYPE: -
CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05		2.06		1.96					
	filtered	mg/L	2.01		2.03		1.57					
Manganese	non-filtered	mg/L	0.17		0.17		0.16					
	filtered	mg/L	0.16		0.14		0.16					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.1		7.2		7.6					
Suspended Solids		mg/L										

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	-1%		22%					
Total Iron Removal	-	-	-	-	5%					
MANGANESE										
Manganic Formation	-	-	13%		0%					
Total Manganese Removal	-	-	-	-	6%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: 7
DATE: 26-06-91

Air Flow Rate: 0.270 m3/min
Groundwater Flow Rate: 0.055 m3/min
Sludge Flow Rate: 0 m3/min
Sludge Addition Factor: 0 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 4.1 min
HRT(chem ox): - min
Sampling time(1): 6.0 x HRT(aeration)
Sampling time (2): - x HRT(aeration)

CHEMICAL OXIDANT TYPE: -
CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
Iron	non-filtered	mg/L	2.02		1.99		1.93					
	filtered	mg/L	2.02		1.96		1.74					
Manganese	non-filtered	mg/L	0.12		0.13		0.12					
	filtered	mg/L	0.12		0.13		0.12					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.1		7.1		7.4					
Suspended Solids		mg/L	0		0		1					

Calculations

	A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON										
Ferric Formation	-	-	3%		14%					
Total Iron Removal	-	-	-	-	3%					
MANGANESE										
Manganic Formation	-	-	-8%		0%					
Total Manganese Removal	-	-	-	-	8%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	8				
DATE:	26-06-91				
Air Flow Rate:	0.324	m3/min	*CHEMICAL OXIDANT TYPE:*		-
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:*		-
Sludge Flow Rate:	0.000	m3/min			
Sludge Addition Factor:	5.3	(mg Fe added to aerator/mg Fe in raw groundwater) per min			
HRT(aeration):	4.1	min			
HRT(chem ox):	-	min			
Sampling time(1):	6.0	x HRT(aeration)			
Sampling time (2):	-	x HRT(aeration)			

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	1.99		10.41		10.82					
	filtered	mg/L	1.99		1.75		0.93					
Manganese	non-filtered	mg/L	0.12		0.18		0.16					
	filtered	mg/L	0.12		0.12		0.12					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.1		7.1		7.6					
Suspended Solids		mg/L	0		36		41					

Calculations

		A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
		RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON											
Ferric Formation		-	-	12%		53%					
Total Iron Removal		-	-	-	-	-4%					
MANGANESE											
Manganic Formation		-	-	0%		0%					
Total Manganese Removal		-	-	-	-	11%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	9		
DATE:	28-06-91		
Air Flow Rate:	0.324	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:* -
Sludge Flow Rate:	0.000	m3/min	
Sludge Addition Factor:	1.9	(mg Fe added to aerator/mg Fe in raw groundwater) per min	
HRT(aeration):	4.1	min	
HRT(chem ox):	-	min	
Sampling time(1):	6.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05		3.71		3.91					
	filtered	mg/L	2.04		2.06		1.63					
Manganese	non-filtered	mg/L	0.16		0.20		0.17					
	filtered	mg/L	0.16		0.16		0.16					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		12		11					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.6					
Suspended Solids		mg/L	0		5		5					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	-1%		20%					
Total Iron Removal	-	-	-	-	-5%					
MANGANESE										
Manganic Formation	-	-	1%		3%					
Total Manganese Removal	-	-	-	-	13%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	10			
DATE:	28-06-91			
Air Flow Rate:	0.054	m3/min	*CHEMICAL OXIDANT TYPE:*	-
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:*	-
Sludge Flow Rate:	0.000	m3/min		
Sludge Addition Factor:	2.1	(mg Fe added to aerator/mg Fe in raw groundwater) per min		
HRT(aeration):	4.1	min		
HRT(chem ox):	-	min		
Sampling time(1):	6.0	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05		4.19		1.25					
	filtered	mg/L	2.03		1.82		1.71					
Manganese	non-filtered	mg/L	0.14		0.19		0.20					
	filtered	mg/L	0.14		0.16		0.16					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		12		13					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.4					
Suspended Solids		mg/L	0		6		5					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	10%		16%					
Total Iron Removal	-	-	-	-	70%					
MANGANESE										
Manganic Formation	-	-	-11%		-10%					
Total Manganese Removal	-	-	-	-	-5%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	11		
DATE:	28-06-91		
Air Flow Rate:	0.311	m3/min	*CHEMICAL OXIDANT TYPE:* -
Groundwater Flow Rate:	0.055	m3/min	*CHEMICAL OXIDANT DOSAGE:* -
Sludge Flow Rate:	0.000	m3/min	
Sludge Addition Factor:	12.0	(mg Fe added to aerator/mg Fe in raw groundwater) per min	
HRT(aeration):	4.1	min	
HRT(chem ox):	-	min	
Sampling time(1):	6.0	x HRT(aeration)	
Sampling time (2):	-	x HRT(aeration)	

Data

Parameter		*Unit*	A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
							Sampling point					
Iron	non-filtered	mg/L	2.04		24.09		24.09					
	filtered	mg/L	2.04		2.05		1.08					
Manganese	non-filtered	mg/L	0.16		0.26		0.22					
	filtered	mg/L	0.15		0.16		0.14					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		11		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.6					
Suspended Solids		mg/L										

Calculations

	A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	D1 PRE-FILT	D2 PRE-FILT	E1 POST-FILT	E2 POST-FILT
IRON										
Ferric Formation	-	-	0%		47%					
Total Iron Removal	-	-	-	-	0%					
MANGANESE										
Manganic Formation	-	-	-6%		2%					
Total Manganese Removal	-	-	-	-	17%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	12	
DATE:	30-06-91	
Air Flow Rate:	0.068	m3/min
Groundwater Flow Rate:	0.015	m3/min
Sludge Flow Rate:	0.000	m3/min
Sludge Addition Factor:	6.1	(mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration):	14.8	min
HRT(chem ox):	-	min
Sampling time(1):	6.0	x HRT(aeration)
Sampling time (2):		x HRT(aeration)

CHEMICAL OXIDANT TYPE: -

CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.01		12.55		11.95					
	filtered	mg/L	1.96		1.95		0.36					
Manganese	non-filtered	mg/L	0.13		0.18		0.19					
	filtered	mg/L	0.13		0.13		0.14					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	12		12		13					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.6					
Suspended Solids		mg/L	0		33		30					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	1%		82%					
Total Iron Removal	-	-	-	-	5%					
MANGANESE										
Manganic Formation	-	-	6%		-3%					
Total Manganese Removal	-	-	-	-	-8%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	13	
DATE:	30-06-91	
Air Flow Rate:	0.095	m3/min
Groundwater Flow Rate:	0.020	m3/min
Sludge Flow Rate:	0.000	m3/min
Sludge Addition Factor:	6.9	(mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration):	11.1	min
HRT(chem ox):	-	min
Sampling time(1):	6.0	x HRT(aeration)
Sampling time (2):		x HRT(aeration)

CHEMICAL OXIDANT TYPE: -

CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.12		15.36		14.05					
	filtered	mg/L	2.09		1.50		0.70					
Manganese	non-filtered	mg/L	0.14		0.15		0.19					
	filtered	mg/L	0.13		0.13		0.13					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11		12		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.6					
Suspended Solids		mg/L	0		31		25					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	28%		67%					
Total Iron Removal	-	-	-	-	9%					
MANGANESE										
Manganic Formation	-	-	0%		-4%					
Total Manganese Removal	-	-	-	-	-23%					

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	14	
DATE:	1-07-91	
Air Flow Rate:	0.054	m3/min
Groundwater Flow Rate:	0.010	m3/min
Sludge Flow Rate:	0.000	m3/min
Sludge Addition Factor:	5.1	(mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration):	22.3	min
HRT(chem ox):	-	min
Sampling time(1):	6.0	x HRT(aeration)
Sampling time (2):		x HRT(aeration)

CHEMICAL OXIDANT TYPE: -

CHEMICAL OXIDANT DOSAGE: -

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.11		10.14		11.41					
	filtered	mg/L	2.10		2.03		0.17					
Manganese	non-filtered	mg/L	0.14		0.18		0.17					
	filtered	mg/L	0.13		0.14		0.14					
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	12		12		12					
Dissolved Oxygen		mg/L	<1		<2		saturated					
pH		-	7.2		7.2		7.6					
Suspended Solids		mg/L	0		24		22					

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-	3%		92%					
Total Iron Removal	-	-	-	-	-13%					
MANGANESE										
Manganic Formation	-	-	-11%		-5%					
Total Manganese Removal	-	-	-	-	1%					

APPENDIX K

Enhanced Aeration Process II:

Diffused Aeration - Sludge Addition - Chemical Oxidation Data

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: A
DATE: 1-07-91

Air Flow Rate: 0.054 m3/min
Groundwater Flow Rate: 0.010 m3/min
Sludge Flow Rate: 0.000 m3/min
Sludge Addition Factor: 6.4 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 22.3 min
HRT(chem ox): - min
Sampling time(1): >6 x HRT(aeration)
Sampling time (2): - x HRT(aeration)

CHEMICAL OXIDANT TYPE: NaOCl
CHEMICAL OXIDANT DOSAGE: 35 x stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	S1	S2	B1	B2	2 min	12 min
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.11				13.41			
	filtered	mg/L	2.10				0.20		0.08	0.07
Manganese	non-filtered	mg/L	0.14				0.19			
	filtered	mg/L	0.13				0.14		0.09	0.07
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12				14		14	14
Dissolved Oxygen		mg/L	<1				saturated		saturated	saturated
pH		-	7.2				7.6		7.6	7.6
Suspended Solids		mg/L	0				31		34	34

Calculations

	A1	A2	S1	S2	B1	B2	2 min	12 min
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON								
Ferric Formation	-	-			90%		96%	97%
Total Iron Removal	-	-	-	-				
MANGANESE								
Manganic Formation	-	-			-5%		28%	43%
Total Manganese Removal	-	-	-	-				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	B			
DATE:	1-07-91			
Air Flow Rate:	0.054	m3/min	*CHEMICAL OXIDANT TYPE:*	NaOCl
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:*	58 x stoic
Sludge Flow Rate:	0.000	m3/min		
Sludge Addition Factor:	5.7	(mg Fe added to aerator/mg Fe in raw groundwater) per min		
HRT(aeration):	22.3	min		
HRT(chem ox):	-	min		
Sampling time(1):	>6	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	S1	S2	B1	B2	2 min	12 min
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.11				12.05			
	filtered	mg/L	2.10				0.07		0.04	0.04
Manganese	non-filtered	mg/L	0.14				0.13			
	filtered	mg/L	0.13				0.13		0.06	0.05
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12				13		14	14
Dissolved Oxygen		mg/L	<1				saturated		saturated	saturated
pH		-	7.2				7.6		7.6	7.6
Suspended Solids		mg/L	0				31		30	32

Calculations

	A1	A2	S1	S2	B1	B2	2 min	12 min
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON								
Ferric Formation	-	-			97%		98%	98%
Total Iron Removal	-	-	-	-				
MANGANESE								
Manganic Formation	-	-			-1%		52%	63%
Total Manganese Removal	-	-	-	-				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	C			
DATE:	1-07-91			
Air Flow Rate:	0.054	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:*	1.3 x stoic
Sludge Flow Rate:	0.000	m3/min		
Sludge Addition Factor:	4.7	(mg Fe added to aerator/mg Fe in raw groundwater) per min		
HRT(aeration):	22.3	min		
HRT(chem ox):	-	min		
Sampling time(1):	>6	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	S1	S2	B1	B2	2 min	12 min
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.11				10.00			
	filtered	mg/L	2.10				0.03		0.00	0.00
Manganese	non-filtered	mg/L	0.14				0.18			
	filtered	mg/L	0.13				0.14		0.14	0.13
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12				13		13	13
Dissolved Oxygen		mg/L	<1				saturated		saturated	saturated
pH		-	7.2				7.6		7.7	7.7
Suspended Solids		mg/L	0				31		28	30

Calculations

	A1	A2	S1	S2	B1	B2	2 min	12 min
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON								
Ferric Formation	-	-			99%		100%	100%
Total Iron Removal	-	-	-	-				
MANGANESE								
Manganic Formation	-	-			-5%		-6%	-3%
Total Manganese Removal	-	-	-	-				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	D	
DATE:	1-07-91	
Air Flow Rate:	0.054	m3/min
Groundwater Flow Rate:	0.010	m3/min
Sludge Flow Rate:	0.000	m3/min
Sludge Addition Factor:	5.7	(mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration):	22.3	min
HRT(chem ox):	-	min
Sampling time(1):	>6	x HRT(aeration)
Sampling time (2):	-	x HRT(aeration)

CHEMICAL OXIDANT TYPE:	ClO2
CHEMICAL OXIDANT DOSAGE:	4.5 x stoic

Data

Parameter		*Unit*	*Sampling point*							
			A1	A2	S1	S2	B1	B2	2 min	12 min
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
Iron	non-filtered	mg/L	2.11				12.09			
	filtered	mg/L	2.10				0.04		0.00	0.00
Manganese	non-filtered	mg/L	0.14				0.20			
	filtered	mg/L	0.13				0.13		0.08	0.07
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12				14		14	14
Dissolved Oxygen		mg/L	<1				saturated		saturated	saturated
pH		-	7.2				7.7		7.7	7.7
Suspended Solids		mg/L	0				30		30	31

Calculations

	A1	A2	S1	S2	B1	B2	2 min	12 min
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	POST-OX	POST-OX
IRON								
Ferric Formation	-	-			98%		100%	100%
Total Iron Removal	-	-	-	-				
MANGANESE								
Manganic Formation	-	-			1%		38%	46%
Total Manganese Removal	-	-	-	-				

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER: E
DATE: 1-07-91

Air Flow Rate: 0.054 m3/min
Groundwater Flow Rate: 0.010 m3/min
Sludge Flow Rate: 0.000 m3/min
Sludge Addition Factor: 4.7 (mg Fe added to aerator/mg Fe in raw groundwater) per min
HRT(aeration): 22.3 min
HRT(chem ox): - min
Sampling time(1): >6 x HRT(aeration)
Sampling time (2): - x HRT(aeration)

CHEMICAL OXIDANT TYPE: ClO2
CHEMICAL OXIDANT DOSAGE: 7.0 x stoic

Data

Parameter		*Unit*	*Sampling point* A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
Iron	non-filtered	mg/L	2.11				9.95			
	filtered	mg/L	2.10				0.04		0.00	0.00
Manganese	non-filtered	mg/L	0.14				0.14			
	filtered	mg/L	0.13				0.14		0.02	0.01
Alkalinity		mg CaCO3/L								
Hardness		mg CaCO3/L								
Temperature		C	12				14		14	14
Dissolved Oxygen		mg/L	<1				saturated		saturated	saturated
pH		-	7.2				7.6		7.6	7.6
Suspended Solids		mg/L	0				23		28	28

Calculations

	A1 RAW	A2 RAW	S1 POST-SLDG	S2 POST-SLDG	B1 POST-AIR	B2 POST-AIR	2 min POST-OX	12 min POST-OX
IRON								
Ferric Formation	-	-			98%		100%	100%
Total Iron Removal	-	-	-	-				
MANGANESE								
Manganic Formation	-	-			-8%		87%	93%
Total Manganese Removal	-	-	-	-				

APPENDIX L

Enhanced Aeration Process II:

Diffused Aeration - Sludge Addition - Chemical Oxidation -

Direct Contact Sand Filtration Data

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	1			
DATE:	3-07-91			
Air Flow Rate:	0.068	m3/min	*CHEMICAL OXIDANT TYPE:*	ClO2
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:*	6.5 x stoic
Sludge Flow Rate:	0.000	m3/min		
Sludge Addition Factor:	6.2	(mg Fe added to aerator/mg Fe in raw groundwater) per min		
HRT(aeration):	22.5	min		
HRT(chem ox):	2.0	min		
Sampling time(1):	4.0	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05				12.68		10.85		0.00	
	filtered	mg/L	2.07				0.30		0.00		0.00	
Manganese	non-filtered	mg/L	0.15				0.20		0.24		0.01	
	filtered	mg/L	0.15				0.13		0.01		0.01	
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11				13		13		13	
Dissolved Oxygen		mg/L	<1				saturated		saturated		saturated	
pH		-	7.1				7.6		7.6		7.6	
Suspended Solids		mg/L	0.00				24.64		25.67		0.00	

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-			86%		100%		100%	
Total Iron Removal	-	-	-	-					100%	
MANGANESE										
Manganic Formation	-	-			14%		94%		95%	
Total Manganese Removal	-	-	-	-					95%	

Pilot-Scale Run

Diffused Aeration-Sludge Addition-Chem Ox-Contact Sand Filtration

RUN NUMBER:	2			
DATE:	3-07-91			
Air Flow Rate:	0.068	m3/min	*CHEMICAL OXIDANT TYPE:*	NaOCl
Groundwater Flow Rate:	0.010	m3/min	*CHEMICAL OXIDANT DOSAGE:*	50 x stoic
Sludge Flow Rate:	0.000	m3/min		
Sludge Addition Factor:	5.8	(mg Fe added to aerator/mg Fe in raw groundwater) per min		
HRT(aeration):	22.5	min		
HRT(chem ox):	2.0	min		
Sampling time(1):	6.0	x HRT(aeration)		
Sampling time (2):	-	x HRT(aeration)		

Data

Parameter		*Unit*	*Sampling point*									
			A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
			RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
Iron	non-filtered	mg/L	2.05				11.83		11.98		0.00	
	filtered	mg/L	1.97				0.26		0.00		0.00	
Manganese	non-filtered	mg/L	0.15				0.23		0.22		0.01	
	filtered	mg/L	0.15				0.13		0.09		0.01	
Alkalinity		mg CaCO3/L										
Hardness		mg CaCO3/L										
Temperature		C	11				12		12		13	
Dissolved Oxygen		mg/L	<1				saturated		saturated		saturated	
pH		-	7.2				7.6		7.7		7.7	
Suspended Solids		mg/L	0.00				27.89		21.93		0.00	

Calculations

	A1	A2	S1	S2	B1	B2	D1	D2	E1	E2
	RAW	RAW	POST-SLDG	POST-SLDG	POST-AIR	POST-AIR	PRE-FILT	PRE-FILT	POST-FILT	POST-FILT
IRON										
Ferric Formation	-	-			87%		100%		100%	
Total Iron Removal	-	-	-	-					100%	
MANGANESE										
Manganic Formation	-	-			13%		37%		97%	
Total Manganese Removal	-	-	-	-					95%	

APPENDIX M

Enhanced Aeration Process II:

Diffused Aeration - Sludge Addition - Chemical Oxidation (ClO_2) -

Direct Contact Sand Filtration:

Performance Evaluation Continuous Operation Data

DIFFUSED AERATION - SLUDGE ADDITION - CHEMICAL OXIDATION - DIRECT CONTACT SAND FILTRATION

11th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic
Sludge Addition Factor = 7.4

SAMPLE POINT A (RAW GROUNDWATER)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
1.0	1.99	1.98	0.17	0.17	12	7.25	<1	0.3	0.00
5.0	2.10	2.00	0.19	0.19	11	7.25	<1		0.00
9.5	2.11	2.06	0.16	0.16	11	7.20	<1		
MEAN	2.07	2.01	0.17	0.17	11	7.23	<1	0.3	0.00
SAMPLE POINT S (POST-SLUDGE)									
1.0	13.77	0.56	1.13	0.69	12	7.25	<2	59	27.40
5.0	15.05	0.52	1.09	0.71	11	7.25	<2		31.60
9.5	17.30	0.38	1.36	0.87	11	7.20	<2		
MEAN	15.37	0.49	1.19	0.76	11	7.23	<2	59	29.50
SAMPLE POINT B (POST-AIR)									
1.0	12.50	0.03	1.01	0.60	12	7.70	sat	53	34.10
5.0	14.55	0.01	1.13	0.63	11	7.70	sat		35.00
9.5	16.05	0.16	1.27	0.72	12	7.70	sat		
MEAN	14.37	0.07	1.14	0.65	12	7.70	sat	53	34.55
SAMPLE POINT D (PRE-FILT)									
1.0	10.86	0.00	0.94	0.12	12	7.60	sat	46	31.00
5.0	13.95	0.70	1.09	0.26	11	7.70	sat		35.10
9.5	15.50	0.26	1.18	0.29	12	7.70	sat		
MEAN	13.44	0.32	1.07	0.22	12	7.67	sat	46	33.05
SAMPLE POINT E (POST-FILT)									
1.0	0.00	0.00	0.00	0.00	12	7.60	sat	0.2	0.50
2.0	0.00		0.20					0.2	
3.0	0.03		0.27						
5.0	0.01	0.00	0.26	0.00	11	7.70	sat	0.1	0.00
7.0	0.01		0.26						
8.0	0.02		0.27						
9.5	0.02	0.00	0.27	0.26	12	7.60	sat	0.2	
11.0	0.31		0.07					0.7	
12.0	0.35		0.08					0.7	
13.0	0.12		0.03					0.7	
15.0	0.32		0.10	0.10				0.8	
MEAN	0.11	0.00	0.16	0.09	12	7.63	sat	0.4	0.25

APPENDIX N

Performance Evaluation of Recommended Process Train:
Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

13th JULY - 20th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT A (RAW GROUNDWATER)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
7.0	2.05	2.04	0.15	0.14	13	7.20	< 1	0.3	0.00
18.0	2.02	2.00	0.18	0.17	11	7.10	< 1		0.00
24.0	2.03	2.00	0.15	0.15	13	7.20	< 1	0.1	0.00
36.0	2.04	2.01	0.15	0.15	11	7.15	< 1		0.00
42.0	1.94	1.94	0.19	0.17	11	7.15	< 1		0.00
48.0	1.95	2.00	0.17	0.17	12	7.10	< 1		0.00
64.0	2.02	1.98	0.19	0.19		7.10	< 1	0.1	0.00
68.0	1.93	1.93	0.17	0.19	14	7.10	< 1	0.1	0.00
79.0	2.04	2.04	0.13	0.13	13	7.20	< 1	0.4	0.00
90.0	2.05	2.06	0.18	0.19	13	7.10	< 1	0.6	0.00
95.5	1.99	1.99	0.19	0.21	12	7.10	< 1	0.1	0.00
103.5	2.04	2.00	0.18	0.19		7.15	< 1		0.00
106.5	2.04	2.00	0.19	0.18	14	7.10	< 1		0.00
114.0	2.02	1.99	0.19	0.19	13	7.20	< 1	0.2	0.00
119.5	2.06	1.99	0.18	0.18	12	7.15	< 1	0.2	0.00
126.5	2.05	2.04	0.18	0.18		7.20	< 1		0.00
138.0	2.02	2.02	0.18	0.18	11	7.15	< 1		0.00
BACKWASH 163.0	2.01	1.96	0.17	0.17	13	7.10	< 1	7.1	0.00
MEAN	2.02	2.00	0.17	0.17	12	7.14	< 1	0.9	0.00

SAMPLE POINT B (POST-AIR)

7.0	1.97	0.51	0.14	0.14	13	7.60	sat	10.0	3.49
18.0	1.97	0.32	0.12	0.12	13	7.60	sat		4.62
24.0	1.95	0.36	0.13	0.13	13	7.70	sat	8.9	3.94
36.0	1.98	0.41	0.13	0.13	11	7.60	sat		3.11
42.0	1.78	0.36	0.22	0.17	12	7.65	sat		4.15
48.0	1.81	0.24	0.17	0.15	13	7.60	sat		3.96
64.0	1.94	0.28	0.20	0.19		7.60	sat	9.5	4.30
68.0	1.78	0.19	0.17	0.15	14	7.70	sat	8.8	5.85
79.0	1.94	0.49	0.14	0.12	13	7.60	sat	10.3	3.30
90.0	1.91	0.32	0.18	0.15	13	7.60	sat	10.1	4.44
95.5	1.86	0.36	0.19	0.15	13	7.70	sat	9.8	4.42
103.5	1.90	0.54	0.20	0.15		7.60	sat	10.2	3.58
106.5	1.86	0.47	0.19	0.15	14	7.60	sat	9.6	3.58
114.0	1.86	0.29	0.16	0.13	13	7.70	sat	9.3	4.15
119.5	1.85	0.31	0.17	0.14	13	7.70	sat	9.4	3.40
126.5	1.93	0.57	0.17	0.15		7.65	sat	9.8	3.85
MEAN	1.89	0.38	0.17	0.15	13	7.64	sat	9.6	4.01

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

13th JULY - 20th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT D (PRE-FILT)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
7.0	2.02	0.00	0.15	0.02	13	7.70	sat	11.8	4.98
18.0	1.91	0.00	0.18	0.02	12	7.60	sat	11.3	5.26
24.0	1.95	0.00	0.15	0.01	14	7.70	sat	11.7	4.98
36.0	1.97	0.00	0.15	0.02	11	7.70	sat		5.73
42.0	1.85	0.00	0.31	0.03	13	7.60	sat		5.63
48.0	1.88	0.00	0.33	0.04	14	7.60	sat		5.26
64.0	2.00	0.00	0.30	0.00		7.70	sat	11.2	5.20
68.0	1.79	0.00	0.18	0.02	15	7.70	sat	10.9	4.13
79.0	2.03	0.00	0.26	0.00	13	7.60	sat		5.63
90.0	1.94	0.01	0.20	0.02	15	7.70	sat	10.8	5.54
95.5	2.00	0.00	0.41	0.02	13	7.70	sat	11.9	5.07
103.5	1.91	0.00	0.31	0.04		7.60	sat	14.7	5.72
106.5	1.86	0.00	0.20	0.03	14	7.60	sat	11.6	4.32
114.0	2.06	0.00	0.48	0.02	13	7.65	sat	11.7	4.88
119.5	1.94	0.13	0.32	0.03	13	7.65	sat	11.3	5.07
126.5	1.87	0.00	0.41	0.04		7.60	sat	15.2	3.66
138.0	2.20	0.00	0.72	0.14	13	7.65	sat		4.97
BACKWASH									
163.0	1.98	0.04	0.24	0.02	13	7.70	sat		
MEAN	1.95	0.01	0.29	0.03	13	7.65	sat	12.0	5.06

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

13th JULY - 20th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT E (POST-FILT)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
2.0	0.00		0.01					0.1	
4.0	0.00		0.01					0.1	
7.0	0.03	0.00	0.01	0.01	13	7.60	sat	0.2	0.00
10.0	0.04		0.01					0.2	
12.0	0.03		0.01					0.2	
18.0	0.01	0.00	0.01	0.01	13	7.60	sat	0.2	0.00
22.0	0.00		0.00						
23.0	0.02		0.01						
24.0	0.00	0.00	0.02	0.00	14	7.60	sat	0.3	0.00
26.0	0.00		0.00						
28.0	0.02		0.01					0.3	
30.5	0.01		0.01					0.3	
33.0	0.06		0.01					0.4	
36.0	0.05	0.00	0.01	0.01	11	7.60	sat		0.00
40.0	0.00		0.01						
42.0	0.00	0.00	0.04	0.04	13	7.60	sat		0.00
44.0	0.00		0.01						
46.0	0.00		0.06						
48.0	0.00	0.00	0.01	0.01	14	7.60	sat		0.00
50.0	0.06		0.02					0.5	
53.0	0.08		0.03					0.5	
54.0	0.09		0.02					0.5	
55.0	0.06		0.01					0.5	
57.0	0.07		0.01					0.6	
59.0	0.09		0.01					0.5	
61.0	0.09		0.01					0.5	
64.0	0.14		0.01	0.02		7.60	sat	0.5	0.00
66.0	0.00		0.01						
68.0	0.00	0.00	0.01	0.01	14	7.60		0.3	0.00
70.0	0.09		0.00						
72.0	0.07		0.00						
75.0	0.06		0.00					0.4	
77.0	0.06		0.00					0.4	
79.0	0.08	0.00	0.00	0.00	13	7.60	sat	0.4	0.50
82.0	0.07		0.00					0.5	
85.0	0.07		0.00					0.5	
88.0	0.05		0.02						
90.0	0.05	0.00	0.03	0.02	15	7.70	sat	0.3	0.94
92.5	0.04		0.01						
95.5	0.04	0.04	0.01	0.01	14	7.65	sat	0.4	0.00
100.0	0.08		0.04					0.4	
102.0	0.13		0.04					0.5	
103.5	0.08	0.01	0.02	0.03		7.55	sat	0.7	0.56
105.0	0.06		0.02						
106.5	0.08	0.00	0.03	0.01	14	7.60	sat	0.4	0.00
109.0	0.07		0.02					0.7	
110.0	0.07		0.02					0.5	
111.0	0.07		0.02					0.4	
112.0	0.04		0.01					0.4	
114.0	0.04	0.00	0.01	0.01	14	7.65	sat	0.3	0.50
116.0	0.05		0.01						
118.0	0.04		0.02						
119.5	0.04	0.00	0.01	0.01	14	7.60	sat	0.4	0.50
122.0	0.02		0.02					0.4	
124.5	0.05		0.03					0.4	
126.5	0.06	0.00	0.03	0.01		7.60	sat	0.4	0.50
128.5	0.05		0.03					0.4	
129.5	0.07		0.03					0.6	
130.5	0.07		0.02					0.5	
132.0	0.10		0.03					0.5	
133.0	0.32		0.05					1.0	
134.0	0.14		0.04					1.2	

DIFFUSED AERATION-CHEMICAL OXIDATION-DIRECT CONTACT SAND FILTRATION

13th JULY - 21th JULY 1991

Groundwater Flow Rate = 10 L/min
Air Flow Rate = 55 L/min
Chemical Oxidant Type = ClO2
Chemical Oxidant Dose = 7 X stoic

SAMPLE POINT E (POST-FILT)

Run Time (h)	Total Iron (mg/L)	Dissolved Iron (II) (mg/L)	Total Mang (mg/L)	Dissolved Mang (II) (mg/L)	Temp (oC)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)
135.0	0.15		0.02						
136.0	0.15		0.03						
137.0	0.06		0.02						
138.0	0.06	0.04	0.02	0.01	13	7.65	sat		0.30
139.0	0.09		0.02						
140.0	0.09		0.02						
145.0	0.04	0.00	0.00	0.00	16	7.60	sat	0.4	
146.0	0.02	0.00	0.01	0.01	15	7.60	sat	0.3	
BACKWASH									
160.0	0.01		0.01						
161.0	0.00		0.01						
162.0	0.00		0.01						
163.0	0.00		0.01						
164.0	0.00	0.00	0.01	0.01	13	7.65	sat		
166.0	0.00		0.05						
167.0	0.00		0.06						
169.0	0.00		0.06						
MEAN	0.05	0.00	0.02	0.01	12	7.25	sat	0.4	0.19