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REMOVAL OF ORGANICS FROM COLOURED WATER PHASE TWO REPORT

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SUMMARY

I OBJECTIVE

To investigate the production of disinfection by-products during the treatment of coloured water and to define suitable, cost effective, methods for their removal or control with due regard to other water quality determinands, such as colour, iron, manganese and aluminium.

II REASONS

The presence of disinfection by-products in drinking water derived from coloured sources may pose a health risk to the consumer and exceed regulated water quality criteria. Dissolved air flotation and 2 stage filtration has been identified as the most likely process to be used for treatment of upland coloured water; this process requires investigation and optimisation with respect to the control of the trace organics of concern.

III CONCLUSIONS

(i) Pre-chlorination increases disinfection by-products.

(ii) Interfiltration chlorination increases disinfection by-products; for manganese removal it may be possible to discontinue chlorination when the filter is "conditioned".

(iii) Low pre-ozonation doses do not adversely affect disinfection by-products, and can result in small savings in coagulant.

(iv) High pre-ozonation doses disrupt the coagulation/flocculation process, resulting in poor quality final water.

(v) When ozonating waters containing manganese, the manganese may be oxidised to a form that is difficult to remove by conventional filtration.

(vi) Interfiltration or post-treatment ozonation reduces disinfection by-products.

IV RECOMMENDATIONS

Pre-oxidation should not be used unless considered necessary (e.g. for algal removal), and where possible ozone should be considered in preference to chlorine.

The interfiltration chlorine dose for manganese removal should be kept as low as possible; to minimise by-product levels the secondary filters should not be used to provide residence time for disinfection.

Where there are high levels of disinfection by-products, these can be reduced by using ozone instead of chlorine after the first stage of rapid gravity filtration. In this event, site specific studies should be carried out to determine how ozonation can be achieved without adversely affecting manganese removal.

V RESUME

A series of tests, examining the application of ozone or chlorine at various points within a three stage treatment stream, has been carried out as the second phase of a 3 phase experimental programme. The details and results of each test are provided and conclusions have been drawn.

CONTENTS

SECTION 1 - INTRODUCTION

This report details the results obtained from running a three stage dissolved air flotation (DAF) water treatment pilot plant for the removal of organics from upland water. It contains all the results obtained from the second phase of a three phase experimental programme. A full description of the pilot plant, its operation, and the three phases of the experimental programme are given in the First Interim Progress Report (1). The results obtained from the first part of the experimental programme are detailed in the Phase One Report (2).

Because of the nature of the programme and large number of results involved, operational details and tables of results have not generally been included within the main body of this report; details of each experiment together with all results are supplied as appendices.

SECTION 2 - EXPERIMENTAL DETAILS

2.1 ADDITIONS AND ALTERATIONS TO THE PILOT PLANT

For phase II of the experimental programme, a number of additions and alterations were made to the pilot plant. These included the addition of ozone equipment, streaming current detectors, two extra secondary rapid gravity filters (2° RGFs) and some pipework modifications.

2.1.1 Ozone Generator

The ozone generator was an Ozobloc O.C.2. generator supplied by Ozotech Ltd. The generator contained two ozonation tubes, and could generate a maximum of 38 g/hr of ozone. The generator was supplied with compressed air from a Hydrovane "5 puts" rotary vane compressor.

Ozone from the generator could be supplied to any of three ozone contactors (described below), or to the thermal ozone destructor. The destructor allowed the dosing of very low quantities of ozone, whilst maintaining a reliable ozone output from the generator; surplus ozone being fed to the destructor. A flowsheet for the ozone equipment is shown in figure 1.

2.1.2 Ozone Contactors

Three ozone contactors were installed for phase II; they were designed by WRc and constructed by Portobello Fabrications Ltd. Each contactor consisted of a base section, including viewing window, beneath a stainless steel column (figure 2). Three nominal sizes of column were used one for each contactor: 4", 6", and 8". A more detailed description of the contactors is given in Appendix A.

It was possible to use any single contactor, or two in series, to ozonate either the raw water, or the primary (1°) RGF filtrate. If required, the raw water and 1° RGF filtrate could be ozonated simultaneously using two separate contactors.

2.1.3 Additional Secondary RGFs and Modified Pipework

Two extra 2° RGFs, identical to those used in phase I, were installed at the beginning of phase II. There were also a number of alterations made to the pipework, which are shown in figure 3. These alterations made it possible to;

(i) Run two 2° RGFs from the same 1° RGF.

(ii) Run both 1° RGFs from the same DAF.

(iii) Ozonate the feed to stream B 2° RGFs.

(iv) Ozonate the combined filtrates from RGFs A2, B2 and B3

The description of the experimental programme (section 2.2 below) details how these options were used.

2.1.4 Streaming Current Detectors

During phase II, two streaming current detectors (SCDs) were installed; one on each stream. At first, these were used to monitor and record. But later on they were used to control the coagulant dose.

2.2 EXPERIMENTAL PROGRAMME

The objective of phase II was to investigate the use of ozone and chlorine as pre- and inter-filtration oxidants. The flow scheme is shown in figure 3. The experimental programme was divided up into a number of trials, described below. The filter nomenclature used in figure 3 has been kept throughout the description of each trial.

Trial 1a. Prechlorination

During this trial both DAFs were run, with hypochlorite dosed to stream B before the flocculators to give a free residual after the DAF. The ferric dose ranged from 3.7 to 4.2 mg/l, being approximately equal for each stream. The prechlorine dose ranged from 1.30 to 1.76 mg/l, which was sufficient to give a free residual after the DAF ranging from 0.19 to 0.35 mg/l. Water from DAF A fed RGF A1, and then RGF A2; water from DAF B fed RGF B1, and then RGF A3. Both 2° RGFs continued to use the sand that had been used in phase I.

Trial 1b. Inter Filtration Chlorination

During this trial only one DAF and one 1° RGF were run; the ferric dose was kept in the range 4.1 to 4.5 mg/l. Water from DAF A fed RGF A1, and then split to feed RGFs A2 and A3. The chlorine dose to RGF A2 was kept constant to provide a residual of 0.1-0.2mg/l after the filter. The dose to RGF A3 was varied to give a range of free chlorine residuals after the filter; the chlorine dosed ranged from no chlorine, to enough to provide a free residual of 0.5 mg/l after allowing the filtrate to stand for 30 minutes. The sand in both 2° RGFs was the same as had been used throughout phase I.

Trial 2a. Raw Water Ozonation

During this trial, raw water was passed through one of the ozone contactors, and then sampled without further treatment. The applied ozone dose was varied from 0.5 to 9 mg/l, and the contact time between 1.5 and 10 minutes. Variations in ozone dose were achieved by altering the concentration of ozone in the ozonated air stream (by adjusting the power applied to and the gas flowrate through the ozone generator), and by the division of ozone flow to the contactor and destructor. Variations in contact time were achieved by adjusting the raw water flow and the size of the ozone contactor.

Trial 2b. Preozonation

During this trial, stream A was the control stream and the raw water feed for stream B was passed through one of the ozone contactors before addition of coagulant. The ozone dose was varied, between 0.5 and 6 mg/l; a contact time suited to a particular ozone dose was chosen. During this trial, the ferric doses were varied from 2.9 to 5.5 mg/l.

However, for most of the trial, the ferric doses in both streams were equal. For the last run, the ferric dose to the ozonated stream was intentionally set lower than that to the control stream. The flowsheet for the pilot plant was exactly the same as in trial 1a, except the trial stream was pre ozonated, instead of pre chlorinated. The sand in both 2° RGFs was the same as had been used throughout.

Trial 3a. Inter Filtration Ozonation - Fixed pH

At the beginning of this trial, the two new 2° RGFs (B2 and B3) were commissioned. The old sand from RGF A2 was transferred to RGF B3, and new sand was placed in RGFs A2 and B2. Only one DAF (A) was run during this trial. The caustic for pH correction before the 1° RGFs was dosed into the DAF outlet after which the stream was split to feed RGFs A1 and B1. These in turn fed RGFs A2 (new sand) and A3 (old sand) or RGFs B2 (new sand) and B3 (old sand) respectively.

For the first five runs of this trial, filtrate from RGF A1 was dosed with caustic and chlorine before being split to feed RGFs A2 and A3. For the last three runs only caustic was dosed prior to the split. RGF A3 was fed with chlorinated water and RGF A2 was fed with non oxidised water; both operated at pH 9. This was done in order to test how long manganese removal could be maintained without the use of an oxidant. The sand in RGF A2 had been new at the beginning of this trial, and had been conditioned with chlorinated water for six weeks before stopping its chlorine dose.

For the first half of this trial, all the filtrate from RGF B1 was passed through the small ozone contactor before feeding RGFs B2 and B3 thus providing a comparison of new and old sand. However, during the second half of this trial, the filtrate from RGF B1 was split, half going to the ozone contactor to feed RGF B3, the other half feeding RGF B2 directly. Ozone was then applied to the base of RGF B2, as shown in figure 4. This arrangement was intended to give counter current contact of ozone with water within the bed of sand to encourage deposition of MnO_2. However, the pressure drop across the sand was too great, and the result was that both ozone and filtrate left in the filtrate outlet. The effect of this was to give a very short inefficient contact between ozone and non oxidised 2° RGF filtrate.

The above arrangement gave an ozone contact time prior to the 2° filtration of 8 minutes during the first half of the trial and 15 minutes during the second. During the second half of the trial, the un-oxidised filtrate from RGF B2 was contacted with ozone for a very short period estimated to be 15 seconds.

During each half of the trial, the ozone dose was varied between 0.3 and 5.0 mg/l, and the ferric dose was controlled between 2.1 and 4.1 mg/l. During the second half of the trial, the ferric dose was controlled by an SCD at between 2.1 and 2.6 mg/l.

Trial 3b. Inter Filtration Ozonation - Fixed Dose and Contact Time, Variable pH

During this trial, the pilot plant was run as in the second half of trial 3a (i.e. RGF B2 was ozonated directly), except that the caustic dose before RGF A3 and prior to ozonation was varied to vary the filtrate pH. The pH of RGF A2 filtrate was maintained at pH 9, with no chlorine dosed to this filter or B2 and B3. The ferric dose during this trial was controlled within the range 1.5 to 2.0 mg/l by an SCD.

Trial 3c. Ozone Disinfection (Post ozonation)

During this trial, the pilot plant was run as in trial 3b, except that RGFs B2 and B3 were fed with unozonated water. Thus RGFs A2, B2 and B3 were all fed with unoxidised water at pH 9. The filtrates from these three filters were combined, and fed to the ozone contactor at a contact time of 8 minutes. RGF A3 was fed with chlorinated water at pH 9, as a control. The ferric dose was controlled to 1.7 and 1.9 mg/l by an SCD.

Trial 4. Dual Point Ozonation

During this trial both DAFs were operated; DAF A was the control and DAF B the trial. Ozone was applied to the trial stream raw water at a contact time of 3 minutes before coagulation; DAF A fed RGFs A1, A2 and A3, and DAF B fed RGFs B1, B2 and B3. The trial stream 2° RGFs were fed with ozonated 1° filtrate; the contactor had a contact time of 8 minutes. The trial stream ferric dose was controlled by an SCD between 1.5 and 2.1 mg/l. However, the control stream SCD malfunctioned at the beginning of this trial, so the control stream ferric dose was manually controlled between 1.6 and 2.5 mg/l.

2.3 SAMPLING AND ANALYSIS

With the exception of chlorine residual measurement, the sampling and analysis during phase II were identical to those during phase I. Details of these analyses are given in the first interim progress report (1).

During phase II, it became apparent that oxidised forms of manganese were giving serious errors in the measurement of free chlorine using DPD powder, especially when analysing ozonated waters. This can be corrected by using 'steady fac' tablets, available from Pallintest Ltd. These work by quenching chlorine in the water, to give the reading attributable to oxidised manganese. This can then be subtracted from the overall reading, to give the reading for free chlorine. These tablets were used from the beginning of trial 3b to the end of the experimental programme.

2.4 PILOT PLANT CONTROL AND OPERATION

In addition to the operational problems and observations encountered during phase I (2), the following occurred during phase II.

(i) Flotation in Flocculators After Pre Ozonation

Because the ozone contactors have a liquid depth of almost 5m, water is effectively contacted with ozonated air at 50kPa pressure. Thus, when water from the contactors flows into the flocculators at atmospheric pressure, it may be supersaturated with air. When this air comes out of solution, it causes floc to rise to the top of the water in the flocculators and form a float. At high ozone doses, ozone residual would also degas resulting in high concentrations of ozone in the air above the flocculator. In an attempt to lessen this effect, two contactors were always run in series when pre ozonation was practised. Ozone was fed to the first contactor, and the second was used to allow some degassing and decay. Unfortunately, a column is not the optimum shape for degassing, and there were still some problems caused by float in the first flocculator. In order to investigate if this affected the treatment process, one run during trial 2b was carried out where air was contacted with the raw water before coagulation. The results indicated that although flotation took place in the flocculators it did not affect the quality of the final water (Appendix B, trial 2b, ozone dose = 0.0mg/l).

(ii) Very Long pH Stabilisation Periods

On a number of occasions, control of filtration pH failed for a short period, (e.g. if dosing pumps failed over the weekend). After these periods, it took a number of hours for 1° RGFs to reach the correct pH, and the old-sand 2° RGFs could take two days. This is in contrast to the residence times which are about 10 minutes and 5 minutes respectively. The reason for this is not clear but it may be that the surface of the conditioned sand was acting as a buffer by some unidentified ion exchange phenomena.

SECTION 3 - RESULTS

Unless indicated otherwise, the curves drawn in all figures are the interpretation of the operator.

3.1 RAW WATER QUALITY

Figures 5 to 10 show plots of raw water quality against time. Results from both phase I and phase II are included, so a comparison can be made between the raw water quality for each phase.

Figure 5 shows very clearly the annual cycle for uv absorbance and colour, with maximum uv absorbance and colour in the Autumn (November/December), and minimum uv absorbance and colour in the Spring (May/June).

The plot for turbidity, in figure 6, is far more erratic than the plots seen in figure 5. This shows that turbidity is more influenced by short term weather conditions (increasing after heavy rain or violent winds), than by the annual variations in raw water quality.

The plot for pH in figure 6 seems to follow an annual cycle. From Autumn through to Summer (November through to September), the pH gradually increases, but during October, there was a drop in pH.

Figure 7 shows that changes in the raw water iron concentration follows the same trend as the raw water colour. However, changes in the aluminium concentrations seem to coincide with changes in pH, with low pH coinciding with high aluminium. It would therefore seem likely that a large proportion of the iron is closely bound with humic substances, but that aluminium is not and can therefore be leached from the soil more effectively by water at low pH. The plot for raw water manganese shows much less variation with time. There seem to be two plateaus, with the concentration remaining constant for most of the year, but changing during the summer.

Figures 8 and 9 show that both TOC and chlorine demand follow a similar pattern to colour and uv absorbance, but the peak chlorine demand is earlier.

The plots for THMs and AOX formed during hand chlorination of raw water, figure 10, do not show clear seasonal trends. THM potential appears to decrease through the final period whereas AOX potential appears to increase.

3.2 CORRELATIONS BETWEEN DETERMINANDS

3.2.1 uv vs. TOC

Figure 11 shows a plot of uv absorbance against TOC. It can be seen that there are two correlations for the raw water with slope depending on whether or not it had been ozonated. This is because ozone is effective at reducing uv absorbance, but has very little effect on TOC. This stresses the point that, although uv absorbance can be a very good surrogate for TOC, there are times (i.e. when ozone is involved) when it is not. The correlation for both data sets is good ($r = 0.96$) for ozonated and ($r = 0.87$) for unozonated.

The results for filtered samples did not show the same degree of difference between ozonated and unozonated samples. This is because the results for uv absorbance for ozonated filtrates were increased by the presence of colloidal manganese in the samples.

3.2.2 AOX vs. THMs

Figure 12 shows that there is a positive correlation ($r = 0.68$) between AOX and THMs, but it is not a useful correlation due to the high scatter.

3.2.3 AOX vs. Mutagenic Activity

Figure 13 shows that there is a positive correlation ($r = 0.74$) between AOX (below 40µg/l) and TA 100 mutagenic activity, and weaker correlation (r = 0.61) between AOX and TA 98 activity. There is, however, little correlation between high AOX levels (<70 µg/l) and mutagenic activity.

3.2.4 THMs vs. Chlorine Demand

Figure 14 shows a positive correlation (r = 0.62) between chlorine demand and THMs, but the scatter makes it impossible to use the correlation in a predictive way.

3.3 EFFECT OF TREATMENT ON INORGANIC DETERMINANDS

3.3.1 Effect of Prechlorination

Prechlorination at a dose of 1.3-1.8 mg/l had no effect on inorganic determinands.

3.3.2 Effect of Interfiltration Chlorination

Variations in interfiltration chlorine dose up to 1.3 mg/l did not produce discernible variations in metals or turbidity. This was considered to be due to the effectiveness of the 1° RGFs in removing iron, aluminium and turbidity.

During the last three months of the experimental programme it was possible to compare the performance of a 2° RGF fed with chlorinated water, with one fed with unchlorinated water. Two runs during this period produced relatively high aluminium and iron concentrations (0.1-0.2 mg/l) in the 1° filtrate due to poor pH control. The chlorinated 2° RGF was then capable of removing about 50% of this iron, but none of the aluminium. The unchlorinated 2° RGF could not remove any iron.

The unchlorinated 2° RGF was capable of removing manganese from about 0.2 mg/l in the 1° filtrate down to about 0.01 mg/l over a three month period (for the second half of this three month period, the filter was not backwashed, thus ensuring no chlorinated water was fed to the filter). However, during one run, the 2° filtrate pH dropped to about 7.2; at this pH, chlorine was required for effective manganese removal.

3.3.3 Effect of Preozonation and Ozonation of Raw Water

The effect of preozonation was dependent on ozone dose. At low doses (up to 2 mg/l), preozonation had little effect on metals or turbidity. At higher doses, the concentration of iron, aluminium and turbidity in the final water increased. However, ozonation resulted in some manganese removal by the DAF and the 1° RGF but the concentration of manganese in the final water was slightly higher in the preozonated stream, (it was still 20 µg/l or less). The effect of ozone dose on 1° RGF manganese removal is shown in figure 15.

Figure 16 shows colour generated by adding DPD (No. 1) to raw water, after passage through the ozone contactor, plotted against ozone dose. DPD was used to measure ozone residual concentration in the water but the DPD was probably affected more by manganese than by ozone, it is therefore considered to be more a measure of oxidised forms of manganese. It can be seen in figure 16 that low ozone doses result in virtually no oxidised manganese or ozone residual, but that at higher ozone doses where there would be an expected ozone residual, (greater than 2.5 mg/l) manganese becomes oxidised. Once oxidised, some of this manganese can be removed by coagulation, dissolved air flotation and rapid gravity filtration at pH 6.5, as shown previously by figure 15.

Figure 16 suggests that at low doses, ozone is rapidly depleted by reacting with organic matter and there is little or no ozone residual and the coagulation process is unaffected. At higher doses, where there will be free ozone, inorganic matter also becomes oxidised and the coagulation/flocculation chemistry is disturbed. High preozone doses thus result in poorer final water quality particularly in respect of iron, aluminium and turbidity.

3.3.4 Effect of Interfiltration Ozonation

As with interfiltration chlorination, if the iron residual in the 1° filtrate was high, then ozonation before 2° filtration enabled the removal of some (~50%) of that iron by the 2° filters.

Interfiltration ozonation appeared to oxidise manganese present in the 1° filtrate but the 2° filters were not capable of removing more than about 50% of this manganese; the remaining manganese was present in a form which significantly contributed to the colour and turbidity of the water. This increased the turbidity of the final water by up to 0.8 NTU, and the colour by up to 14 Hazen. Only some of this manganese (~50%), and associated colour, could be removed by filtration through a 0.45 µm membrane.

When the water containing manganese was ozonated, the manganese appeared to be oxidised to manganese dioxide very quickly and as a result formed a colloidal suspension which was not readily removed by rapid gravity filtration. This contrasts with the process which occurs with chlorination, where the oxidation process is much slower and is catalysed by the manganese coated sand surface; oxidation occurs at the surface of the sand, and results in the deposition of the manganese dioxide on the filter as it forms.

When one of the 2° filters was run with application of ozone to the base of the filter (see figure 4), manganese was successfully removed, not by ozonation, but by the combination of high pH and manganese coated sand. The non-chlorinated, non-ozonated, 2° RGF showed that high pH and sand alone were effective for manganese removal.

The chemistry of manganese removal is very complex, and is dependant on a number of factors, including redox potential, hardness/alkalinity, and pH. It is therefore not necessarily true that observation at Clough Bottom would be repeated at other sites.

3.3.5 Effect of Dual Point Ozonation

The overall effect of dual point ozonation (pretreatment and interfiltration) on inorganic determinands is exactly the same as the combined effects of ozonation at each point.

3.4 BACTERIOLOGICAL QUALITY OF TREATED WATER

The bacteriological quality of the water after hand chlorination was not affected by the use of ozone at any point in the treatment process. The water disinfected by ozone alone was also of the same, acceptable, bacteriological quality that resulted from chlorination.

3.5 EFFECT OF TREATMENT ON ORGANIC DETERMINANDS

3.5.1 Effect of Pre and Interfiltration Chlorination

Both pre and interfiltration chlorination resulted in a slight reduction (no more than 10%) in final water colour and uv absorbance. Neither pre nor interfiltration chlorination had any effect on TOC.

3.5.2 Effect of Raw Water Ozonation

Figures 17 to 19 show plots of true colour, true uv absorbance and TOC respectively, plotted against ozone dose. The results were obtained at a number of different contact times.

Figure 17 shows that ozone doses up to about 2.3 mg/l resulted in a reduction in true colour proportional to ozone dose. True colour was reduced by approximately 4 Hazen for every mg/l of ozone dosed. Above doses of 2.5 mg/l, no further reduction in colour was achieved, giving a minimum colour of about 14 Hazen. This colour reduction is very much less than reported from previous trials (3), where reductions of 10 Hazen for every mg/l ozone dosed, and minimum colours of 5 Hazen are reported. It is probable that the manganese is being oxidised (figure 16) into a colloidal form which is not removed by the 0.45 µm membranes used when measuring true colour; thus the organic colour may have continued to be reduced by ozone doses above 2.5 mg/l but this was counteracted by an increase in inorganic colour due to manganese oxidation.

Figure 17 shows that colour removal was independant of contact time.

Figure 18 shows that ozone reduced uv absorbance and that the rate of reduction decreased with increasing dose. As with colour, uv reduction was independant of contact time.

Figure 19 shows that ozone dose had no effect on TOC concentration.

3.5.3 Effect of Preozonation

Figures 20, 21 and 22 show the effect of preozone dose on final water colour, uv absorbance and TOC respectively. During these runs, the coagulant dose of the preozonated stream was equal to the coagulant dose of the control stream. Ozone doses up to about 2 mg/l resulted in a reduction in final water colour and uv absorbance (fig. 20, 21); however, ozone doses greater than about 4 mg/l resulted in a deterioration in final water colour and uv absorbance. This is considered to be due to ozone interfering with the flocculation/coagulation chemistry. The results in figure 22 indicate that preozonation had little or no effect on the concentration of TOC in the final water.

At the end of this trial, one run was carried out where 1 mg/l of ozone was dosed to the raw water of the trial stream. The trial stream ferric dose was then reduced until the final water colour of the trial stream equalled that of the control stream. This enabled a reduction in ferric dose of 20%, from 4.0 to 3.2 mg Fe/l.

3.5.4 Effect of Interfiltration Ozonation

Interfiltration ozonation resulted in an increase in final water colour, this was considered to be due to the production of colloidal manganese. However, when ozone was applied to water from which manganese had already been removed (i.e. direct application of ozone to the base of a 2° RGF, or during the disinfection trial), the final water colour was reduced from 2 or 3 Hazen down to 1 Hazen.

Figure 23 shows final water uv absorbance plotted against interfiltration ozone dose. It can be seen that increasing ozone doses resulted in a reduction in uv absorbance. All the points lie close to the curve, including those derived from direct ozonation to the base of the filter thus showing that only a short contact time was required. The curve is similar to the curve observed for raw water ozonation (figure 18), and it would seem that little benefit is obtained for uv absorbance reduction at ozone doses higher than 2 mg/l. However when ozone was applied to final water during the disinfection trial, lower final water uv absorbances (about 1.0 m-1) were obtained. This may have been because there was no colloidal manganese present which could have interfered with the measurements in figure 23.

Figure 24 shows a plot of the difference between the trial stream final TOC and the control stream final TOC. From this figure it can be seen that interfiltration ozone appeared to increase TOC removal by up to 0.5 mg/l at ozone doses over 2 mg/l. There is also an indication that removal increased with increasing contact time.

The trials investigating ozonation pH indicated that pH had no consistent effect on colour, uv absorbance or TOC oxidation by ozone.

3.5.5 Effect of Dual Point Ozonation

The effect of dual point ozonation was found to be the same as combining the separate effects of pre and interfiltration ozonation.

3.6 EFFECT OF TREATMENT ON DISINFECTION BY-PRODUCTS

3.6.1 Effect of Prechlorination

Although prechlorination reduced the chlorine demand of the treated water it produced significant increases in total chlorine consumption and disinfection by-products. These are summarised in table 1, which shows percentage increase in each determinand in the prechlorinated stream compared to the control stream. Chlorine consumption is the total chlorine dosed to the raw water, before the 2° filter and in the lab, minus the free residual after 30 minutes of hand chlorination. The results for chlorine consumption and total THMs are an average from two runs, those for AOX and mutagenic activity are from a single run.

Table 1 - Percentage Increase in Disinfection By-Products

Determinand	% Increase
Cl Consumption	180
Total THMs	125
AOX	40
TA 98 Mutagenic Activity	40
TA 100 Mutagenic Activity	70

The increase in chlorine consumption appears to have increased THM production to a greater extent than AOX or mutagenic activity.

3.6.2 Effect of Interfiltration Chlorination

Generally, the sum of the chlorine consumed during 2° filtration and the chlorine consumed during the laboratory chlorination of the 2° filtrate was greater than the chlorine consumed during the laboratory chlorination of the 1° filtrate. In both cases chlorination conditions were similar; the final residual was 0.5 mg/l, the pH was 9.0, and the contact time was c 30 minutes (c5 minutes contact in the filter plus 30 minutes in the laboratory, or 30 minutes in the laboratory).

When no chlorine was dosed prior to the 2° filter, the chlorine consumption of the 1° filtrate and the 2° filtrate was comparable, indicating that, on this occasion, the chlorine demand of the water was not greatly affected by passage through the 2° filter. However, when the interfiltration dose was increased, to give a higher free residual after the 2° filter the total consumption of chlorine also increased, despite a reduction in the chlorine dose required to give a residual of 0.5 mg/l after 30 minutes in the laboratory. The greater the proportion of the total chlorine dose that was applied before the 2° filters, the greater was the increase in total consumption of chlorine and this increase was reflected in increased THM production.

Figures 25 and 26 show the increased chlorine consumption and total THMs respectively, plotted against 2° filtrate free chlorine residual; the higher residuals reflect a greater proportion of the chlorine dose applied before the 2° filters. The increases shown are far greater than would be expected by the relatively small increase in contact time due to passage through the 2° filter (~5 minutes).

These observations are supported by results obtained during the last three months of the experimental programme, when 14 runs were carried out where a chlorinated 2° filter was compared with an unchlorinated 2° filter. A summary of the results for total consumption of chlorine and total THMs is given in table 2.

Table 2 - Comparison of chlorinated and un chlorinated 2° filters

	Chlorinated 2° filter	Un chlorinated 2° filter
Chlorine Consumption[1] % greater than 1° RGF Std. Dev.	 98.2 44.9	 12.6 13.4
Total THMs[2] % greater than 1° RGF Std. Dev.	 61.4 59.9	 11.0 19.8
2° Filtrate Free Cl Average (mg/l) Std. Dev. (mg/l)	 0.07 0.014	 0 0

[1] inclusive of hand chlorination
[2] after hand chlorination

Table 2 shows that there were large differences in both total chlorine consumption and THM production between the chlorinated 2° filtrate and the 1° filtrate, despite low chlorine doses applied to the 2° filter (as shown by the free residual). The results for the chlorinated 2° filter in table 2, and those in figures 25 and 26 indicate that chlorine consumption and the production of by products is increased during passage through the 2° filter, it may be that the sand surface is catalysing the reaction taking place, resulting in the increases.

In slight contrast to a previous observation, table 2 shows that there were increases in chlorine consumption and THMs when chlorine was applied only after the 2° filter. Although these increases were small, the differences were statistically significant (at the 99% confidence level in the case of chlorine consumption, and at the 90% confidence level in the case of THMs). The reason for these increases is not clear.

Table 3 - Comparison of Chlorinated and Unchlorinated 2° Filter AOX

	Mean (µg/l)	Std. Dev. (µg/l)	No. of Points
Non Hand Chlorinated			
Chlorinated 2° Filter	28.1	7.7	5
Hand Chlorinated			
1° Filter	26.8	3.6	7
Un Chlorinated 2° Filter	30.0	3.7	6
Chlorinated 2° Filter	31.2	5.9	7

Table 3 shows a summary of AOX results obtained over the same period. There was no significant difference between the results in table 3 (at the 95% confidence level). It therefore seems that THM production was more sensitive than AOX to chlorine consumption. This was also true of the prechlorination trial.

Table 4 - Comparison of Chlorinated and Unchlorinated 2° Filter Mutagenic activity after hand chlorination

MUTAGENIC ACTIVITY MEASURED IN HAND CHLORINATED FILTRATE	Mean (Slope)		Std. Dev.(Slope)		No. of Points
	TA 98	TA 100	TA 98	TA 100	
Un Chlorinated 2° Filter	7.06	33.06	1.2	0.7	3
Chlorinated 2° Filter	7.53	35.67	0.5	2.9	3

Table 4 shows a summary of mutagenic activity results obtained over the same period. The table shows that, as for AOX, there was no significant difference in mutagenic activity between the hand chlorinated filtrates from the chlorinated 2° filter and the unchlorinated 2° filter.

3.6.3 Effect of Preozonation and Ozonation of Raw Water

Raw water ozonation had no measurable effect on chlorine demand or total THMs, as shown by figures 27 and 28.

Figures 29, 30 and 31 show chlorine consumption, total THMs, and AOX, respectively, plotted against preozonation ozone dose. The corresponding values for the control stream are shown to indicate how the raw water quality changed during the trial.

From figures 29 and 30, it can be seen that there was no reduction in chlorine consumption or total THMs as a result of preozonation, and that if anything, there was a slight increase. However, figure 31 shows that there was a reduction in AOX with preozonation, although there is too much scatter in the figure to be able to tell how dependant this reduction was on ozone dose.

Table 5 shows the percentage reduction in mutagenic activity in the final chlorinated water resulting from a preozonation dose of 4 mg/l. The table shows that preozonation reduced mutagenic activity, as well as AOX.

Table 5 - Percentage Reduction in Mutagenic Activity with Pre Ozonation

Activity	% Reduction
TA 98	54
TA 100	24

3.6.4 Effect of Interfiltration Ozonation

There were a number of problems with measuring chlorine consumption of waters ozonated before 2° filtration, due to oxidised forms of manganese interfering with chlorine residual measurement. However, from the disinfection and direct ozonation runs, where manganese was removed before ozonation, it was apparent that interfiltration or post ozonation had little effect on chlorine consumption.

THM production was measured in samples collected after the 1° filters (before ozonation) and after the 2° filters (after ozonation) (similarly samples were collected before and after postozonation), so it was possible to examine the effect of ozonation directly without the need to compare the trial stream with the control stream.

Figure 32 shows a plot of percentage decrease in total THMs between 2° and 1° filtrates plotted against ozone dose (i.e. a high value on the graph corresponds to a low value for THMs). There are five data sets included, corresponding to 8 minutes ozone contact time followed by rapid gravity filtration with new or old sand; 15 minutes ozone contact time followed by rapid gravity filtration; direct application of ozone to a filter; and ozone disinfection of 2° filtrate.

From figure 32, it can be seen that there was a reduction in total THMs with ozonation, but that this reduction was not a function of ozone dose. It can also be seen that there was no difference in filtrates from the new or old sand. Although care must be taken in interpreting this data, the postozonation disinfection runs resulted in the greatest reduction in

THM production, and the direct ozonation runs resulted in the smallest reduction. There was, however, no significant difference in THM production between the 8 and 15 minutes contact times.

Since there is no clear effect of ozone dose in figure 32, it may be that only a small ozone dose was required for THM reduction, higher doses could have had a counteractive effect.

Figure 33 shows a similar plot of percentage decrease as used in figure 32, but for AOX against ozone dose. The five data sets in the figure are the same as for figure 32. As with THMs, there was a definite reduction in AOX resulting from ozonation and again there was no marked effect of ozone dose.

Table 6 gives a summary of the results for mutagenic activity. The results are expressed as the percentage difference (reduction) between the trial stream and the control stream hand chlorinated final waters.

Table 6 - % Reduction in Mutagenic Activity (compared to control stream)

OZONE DOSE (mg/l)	CONTACT TIME (mins)	TA 98	TA 100
0.4	8	51	54
5.0	8	96	72
5.0	15	82	73
5.0	DIRECT	76	46

Table 6 shows that interfiltration ozonation resulted in large reductions in the generation of mutagenic activity during subsequent hand chlorination. It also indicates that increasing the ozone dose above 0.4 mg/l was more beneficial. The result for TA 100 activity after direct ozonation is significantly lower (i.e. greater activity) than the other results at the same ozone dose. This sample also produced an extremely high AOX result (50% greater than the raw water). It would therefore seem that a greater contact time, and therefore better utilisation of the ozone, is required than is provided by direct ozonation.

3.6.5 Effect of Interfiltration Ozonation pH

Figures 34, 35 and 36 show total THMs respectively plotted against ozonation pH. Figure 34 shows results obtained by taking 1° filtrate, ozonating at various pHs and then adjusting the pH to 9 in the lab, before hand chlorination. Figure 35 shows results obtained by taking the same ozonated 1° filtrates, and then hand chlorinating the water without modifying the pH. Figure 36 shows the results from taking unozonated 1° filtrate, adjusting its pH in the lab to various pHs, and then hand chlorinating.

From figure 34, it can be seen that there was no effect of ozonation pH when the pH of the ozonated water was adjusted to 9, in the lab, before hand chlorination.

From figures 35 and 36, it can be seen that it was the hand chlorination pH (i.e. disinfection, or final water pH), that was important for THM production. Above a pH of about 7, THM formation was constant, but below a pH of about 7, THM formation dropped rapidly. This effect was true for both the unozonated, and the ozonated samples and is consistent with the fact that the THM formation reaction is favoured by alkaline conditions.

Figure 37 shows the results for AOX; although ozonation reduced AOX production, there was no consistent effect of pH.

3.3.6 Effect of Dual Point Ozonation

The effect of dual point ozonation on disinfection by-products is the same as combining the effects of ozonation at each point.

SECTION 4 - CONCLUSIONS AND RECOMMENDATIONS

(i) When ozonating waters containing manganese, oxidised, colloidal manganese may be formed which cannot be removed by subsequent filtration. Site specific investigations into this effect are therefore necessary if ozone is to be used.

(ii) Prechlorination increases disinfection by-products.

(iii) Preozonation does not affect THM formation, but can reduce AOX and mutagenic activity.

(iv) Small preozonation doses (up to 2 mg/l) may allow a small reduction in coagulant dose but large preozonation doses (greater than 4 mg/l) appear to disrupt the coagulation/flocculation process, resulting in poor quality final water.

(v) If preoxidation is considered necessary (i.e. when there are algal problems) then ozone at low doses should be considered instead of chlorine to maintain low levels of disinfection by-products.

(vi) Increasing interfiltration chlorine dose allows a reduction in the final disinfection chlorine dose but results in increased overall chlorine consumption and THMs.

(vii) Continuous interfiltration chlorination may not be necessary for manganese removal if pH control is good. However, chlorination will compensate for the effects of poor pH control.

(viii) Interfiltration or postozonation reduces disinfection by-products (but not chlorine consumption) and, for the quality of water encountered in this study, only a short ozone contact time is required.

(ix) For AOX and THM reduction, only a small ozone dose is required (about 0.3 mg/l) but for uv absorbance and mutagenic activity reduction, the optimum ozone dose is greater (about 2 mg/l).

SECTION 5 - REFERENCES

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2. ATTENBOROUGH A and WALKER I. Removal of Organics from Coloured Water; Phase 1 Report. WRc Report No. UC 638. December 1989.

3. CONNOR K. Oxidative Techniques Involving the Use of Ozone for Colour Removal During Water Treatment. WRc Report No. UM 1002. April 1989.

SECTION 6 - ACKNOWLEDGEMENT

The authors would like to thank the supply staff of North West Water, Eastern Division for their willingness to help whenever asked.

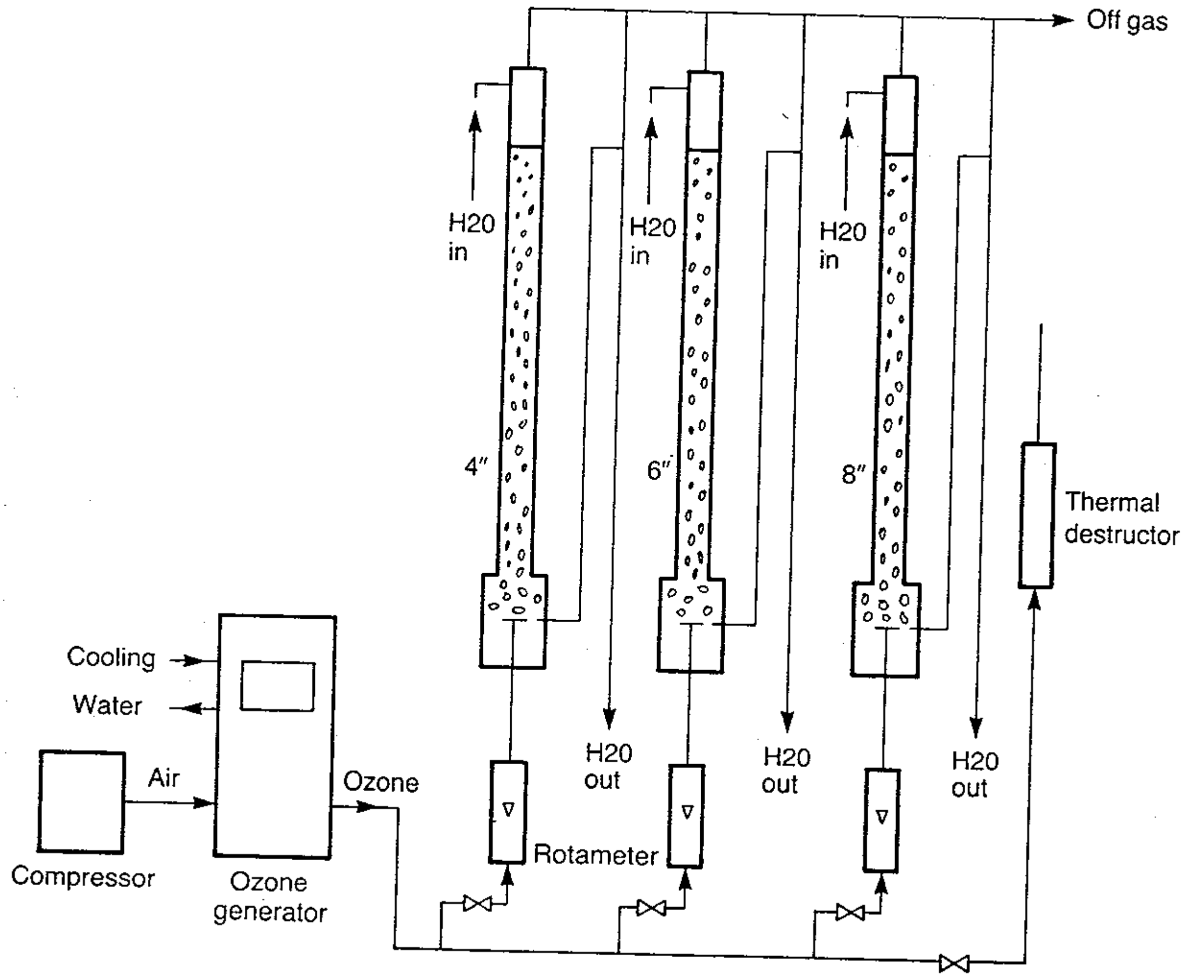


Figure 1 Ozone Flowsheet

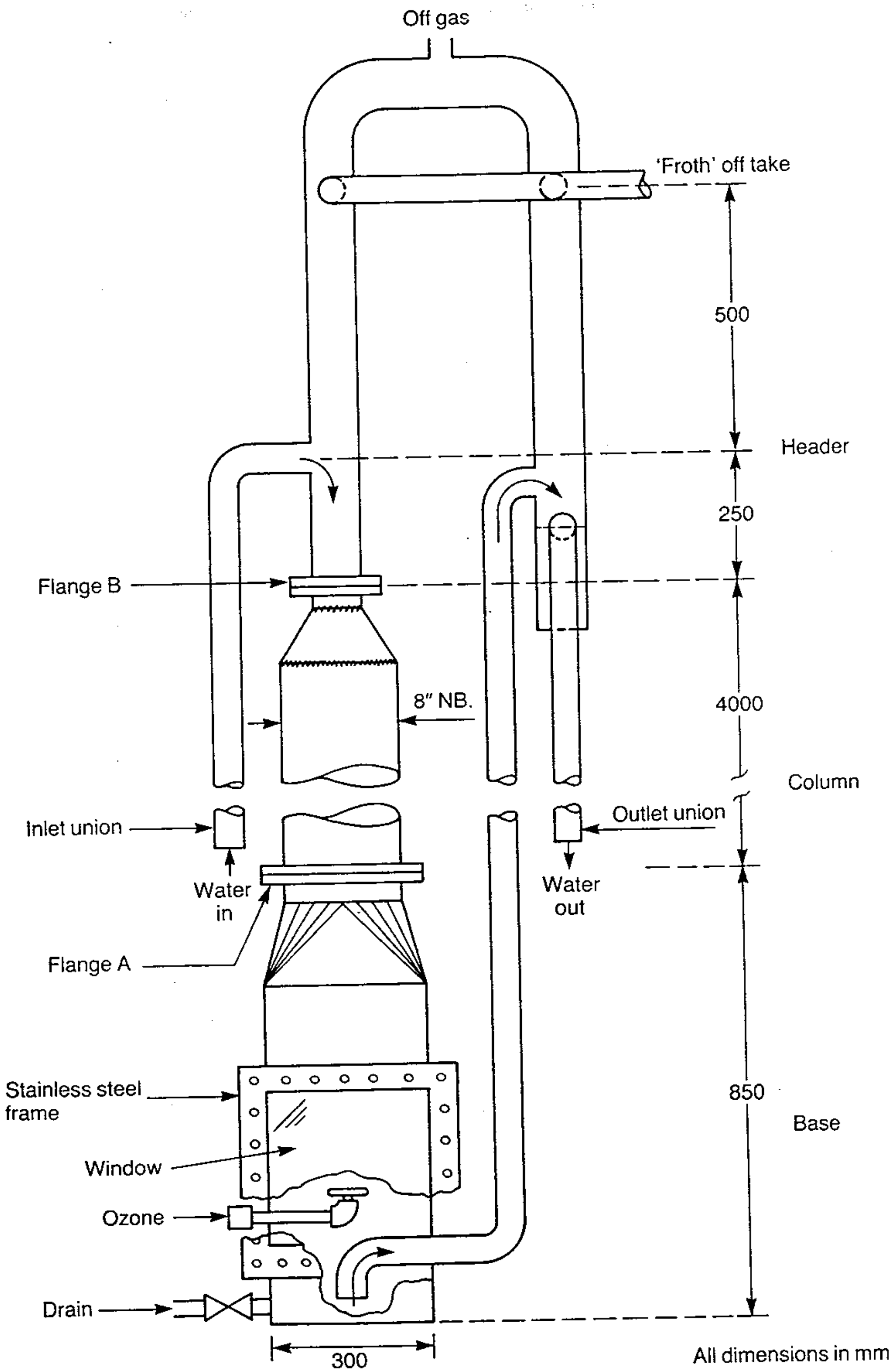


Figure 2 8" NB. Ozone Contactor

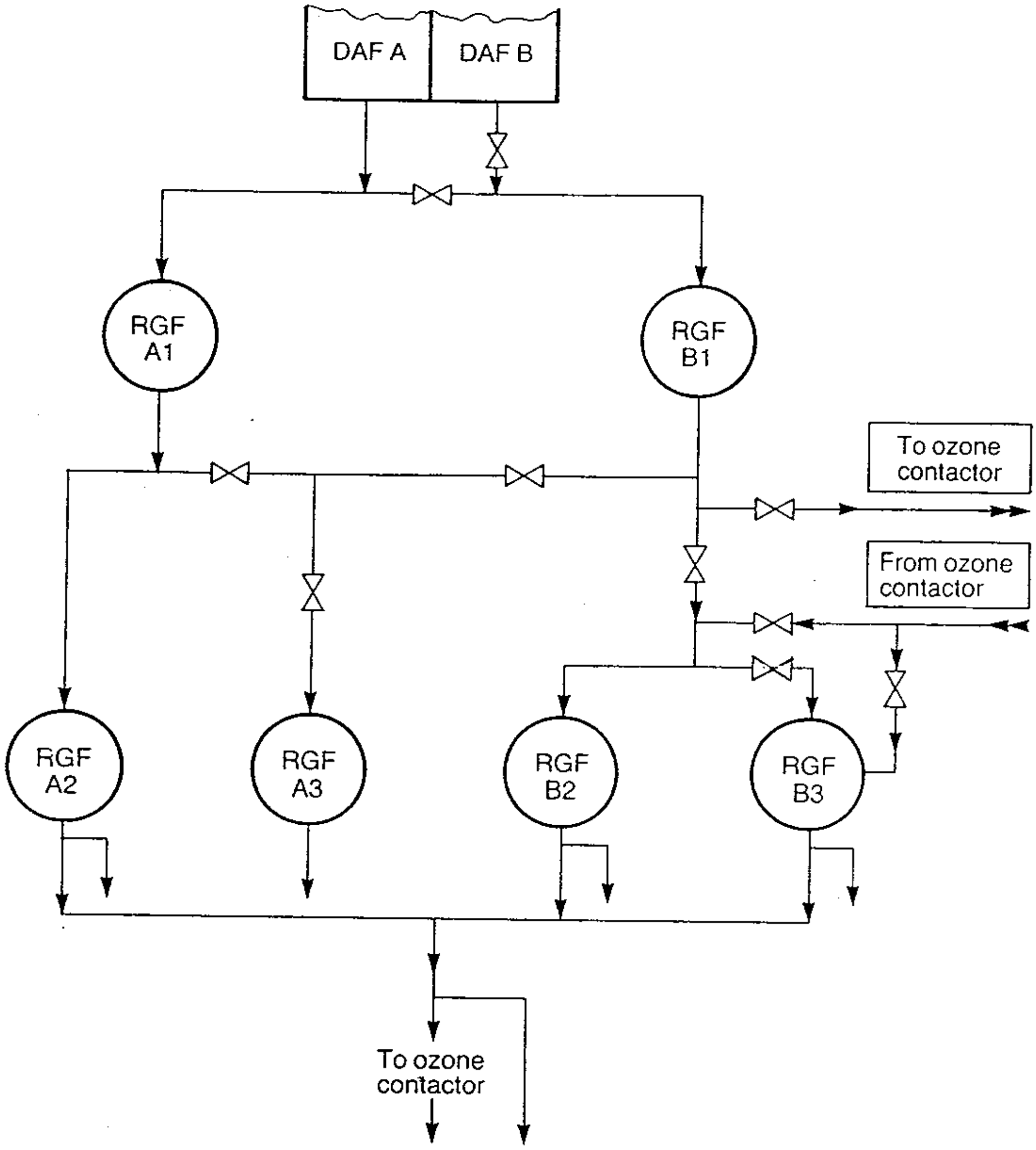


Figure 3 Flowsheet Showing Modified Pipework for Phase 2

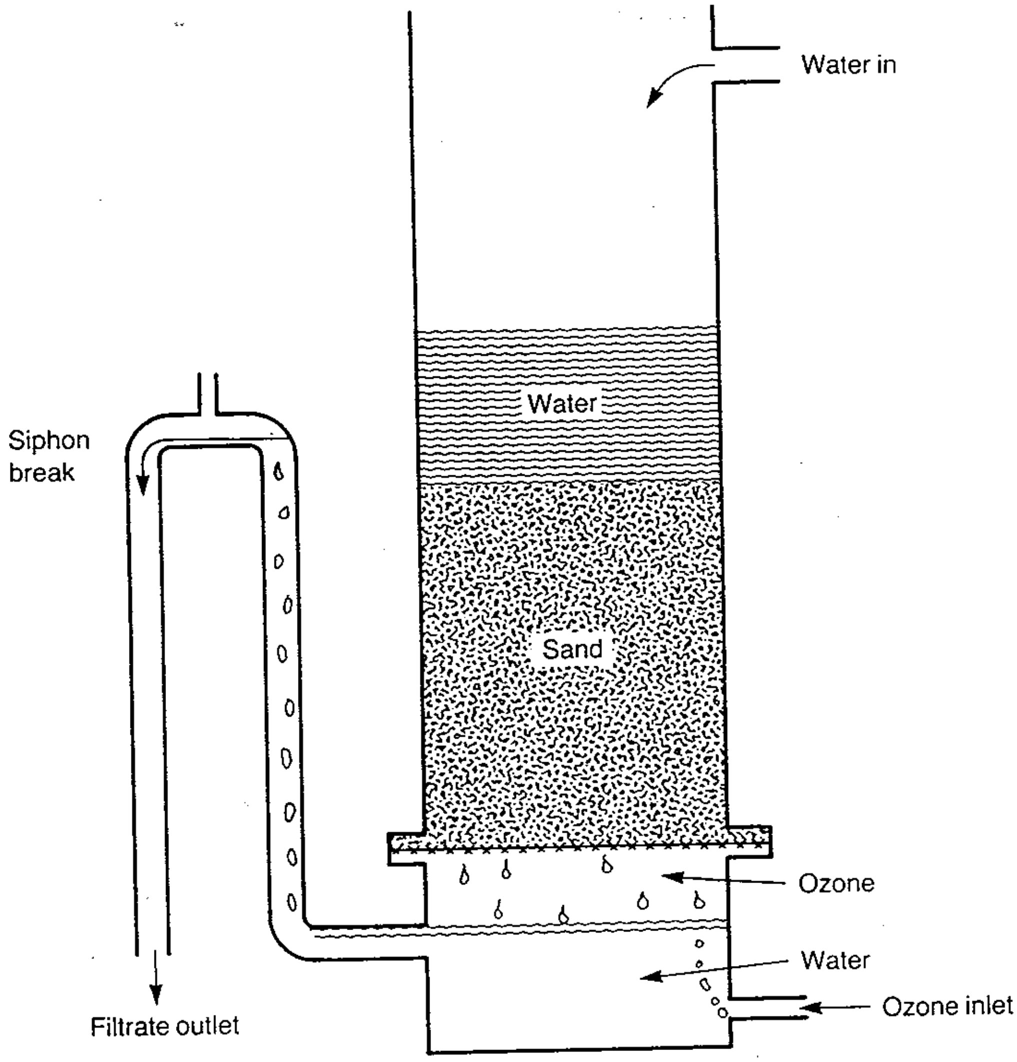


Figure 4 Application of Ozone During "Direct Ozonation" of an RGF

Figure 5. Raw Water Colour & uv Absorbance

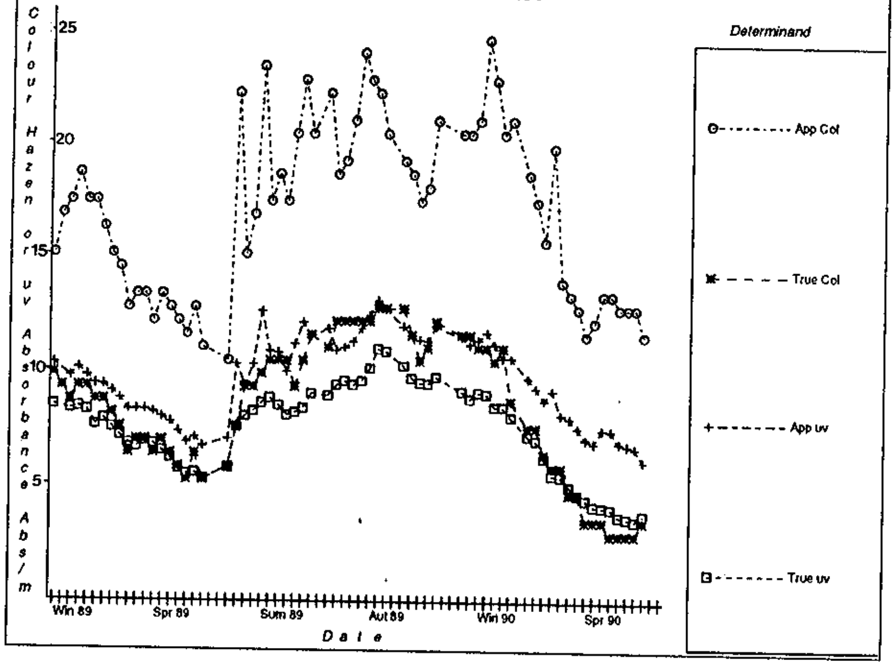


Figure 6. Raw Water pH & Turbidity

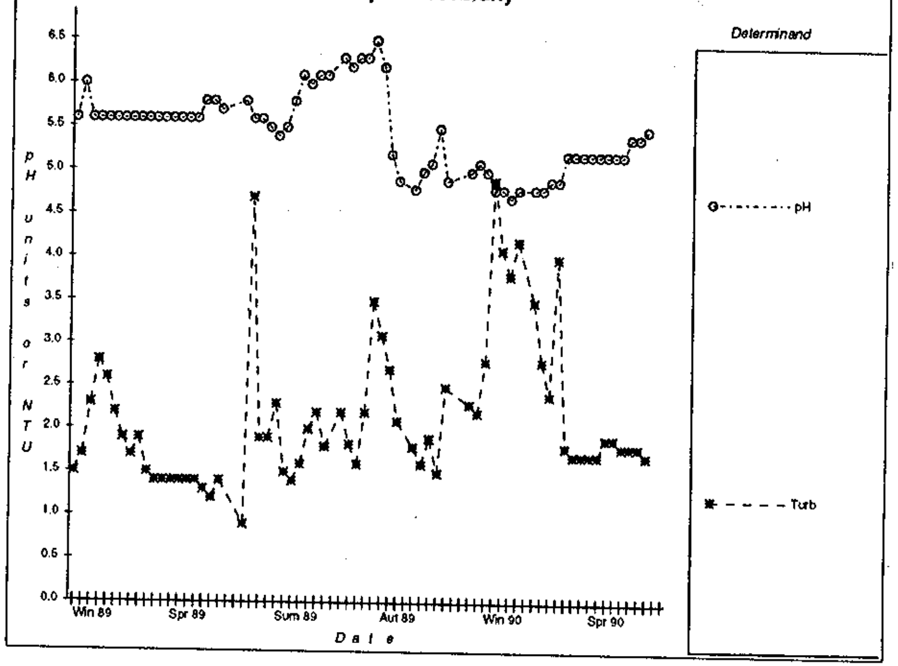


Figure 7. Raw Water Metals

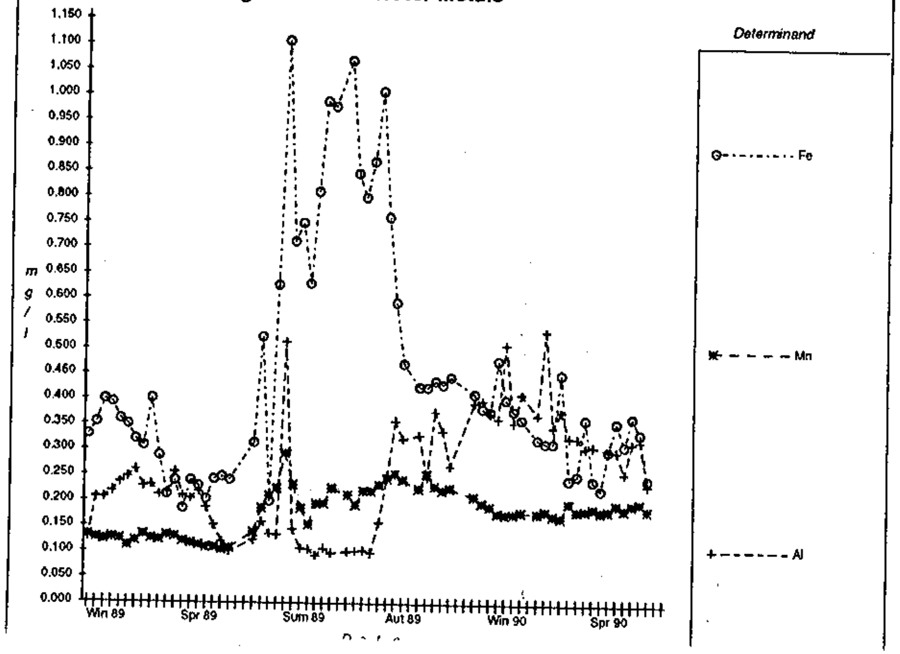
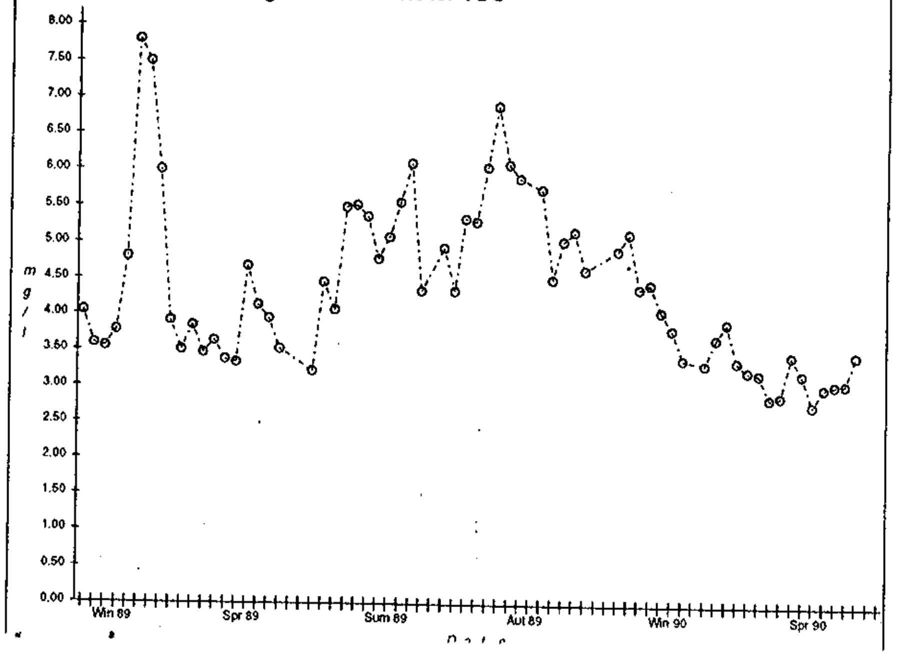
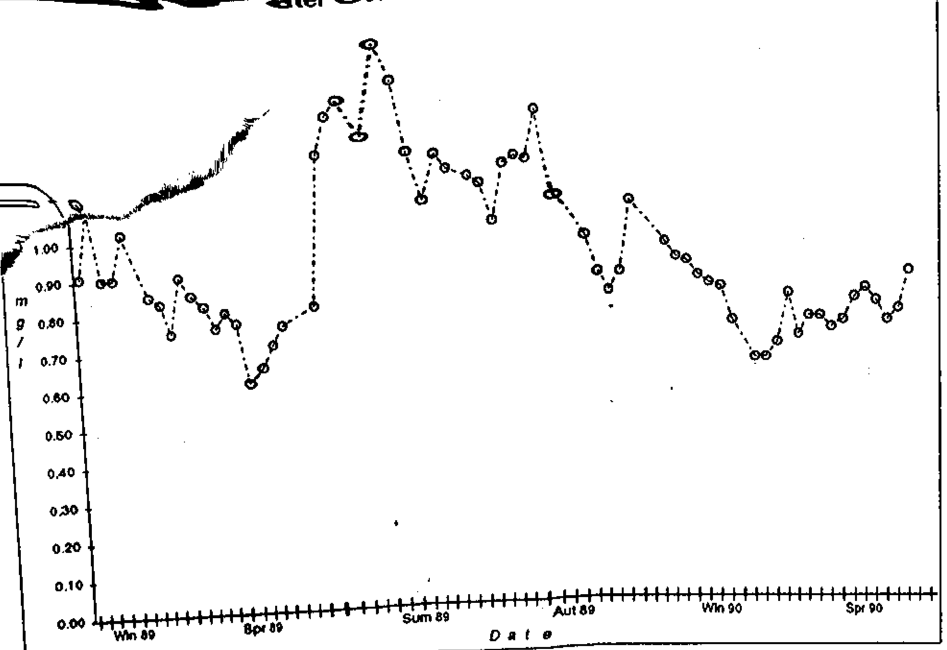


Figure 8. Raw Water TOC





...ater Chlorine Demand

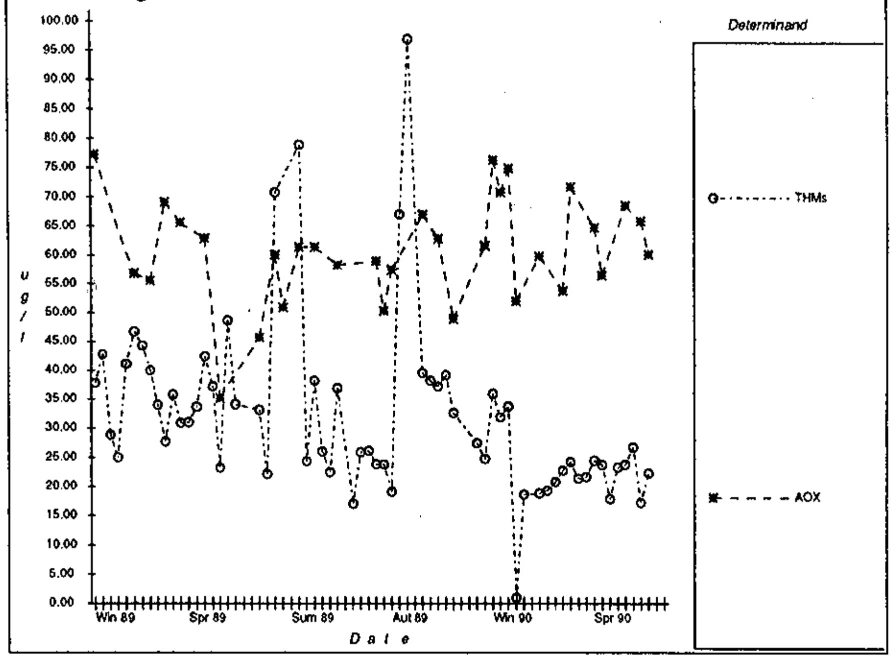


Figure 10. Raw Water Total THMs & AOX

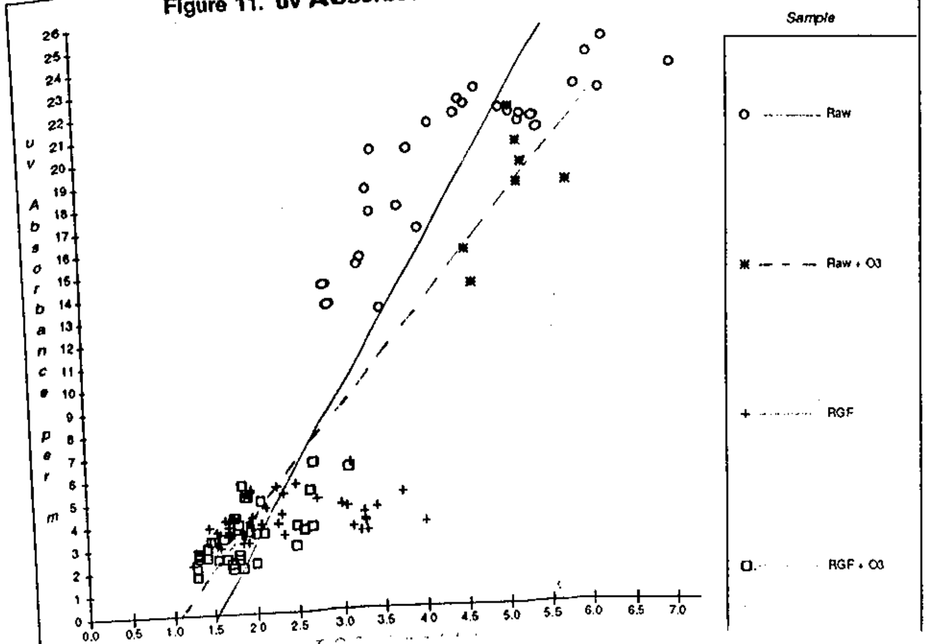


Figure 11. uv Absorbance vs. TOC

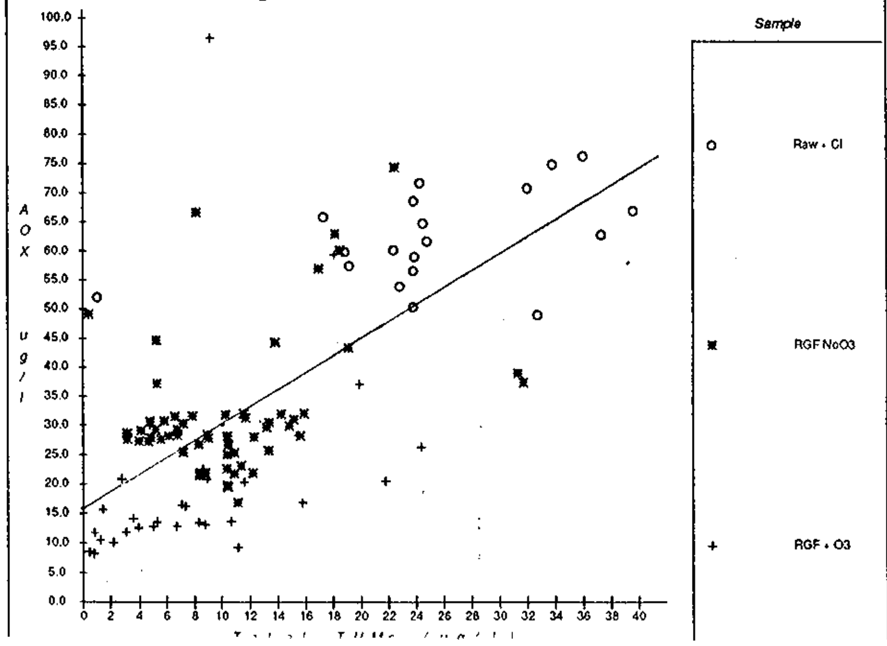


Figure 12. AOX vs. THMs

Figure 13. AOX vs. Mutagenic Activity

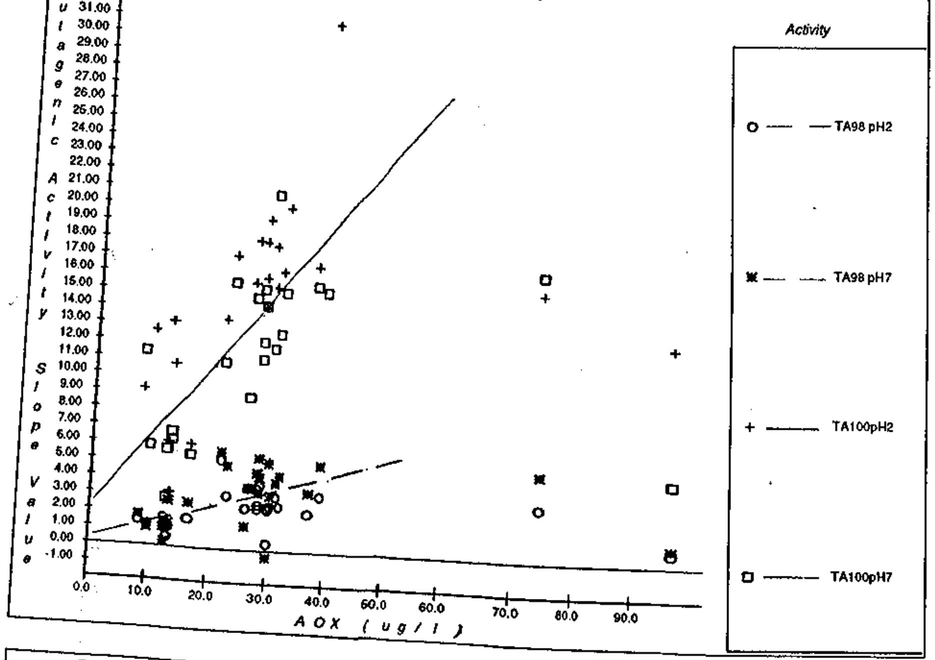


Figure 14. Total THMs vs. Chlorine Demand

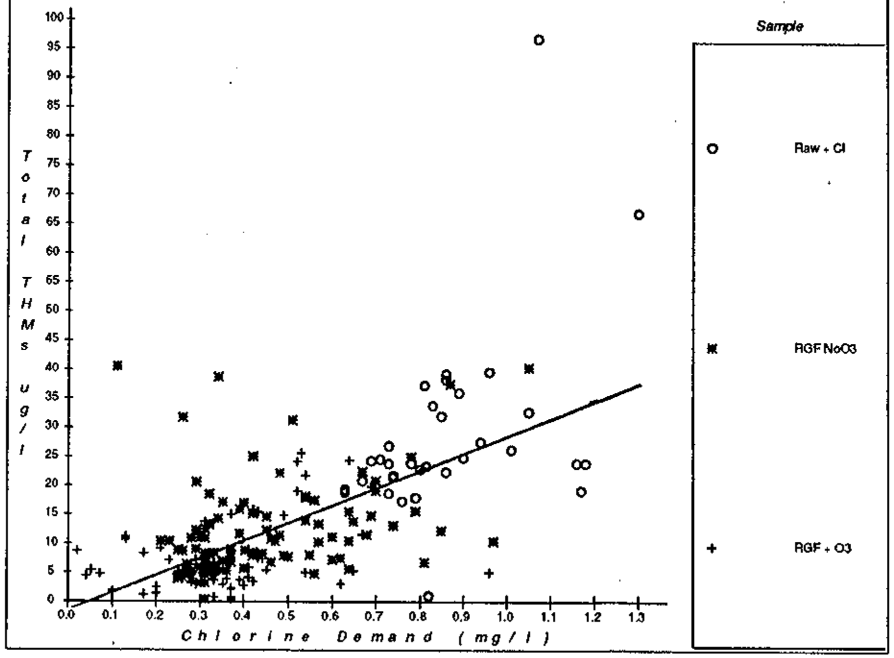


Figure 15. 1' RGF Manganese vs. Pre Ozone

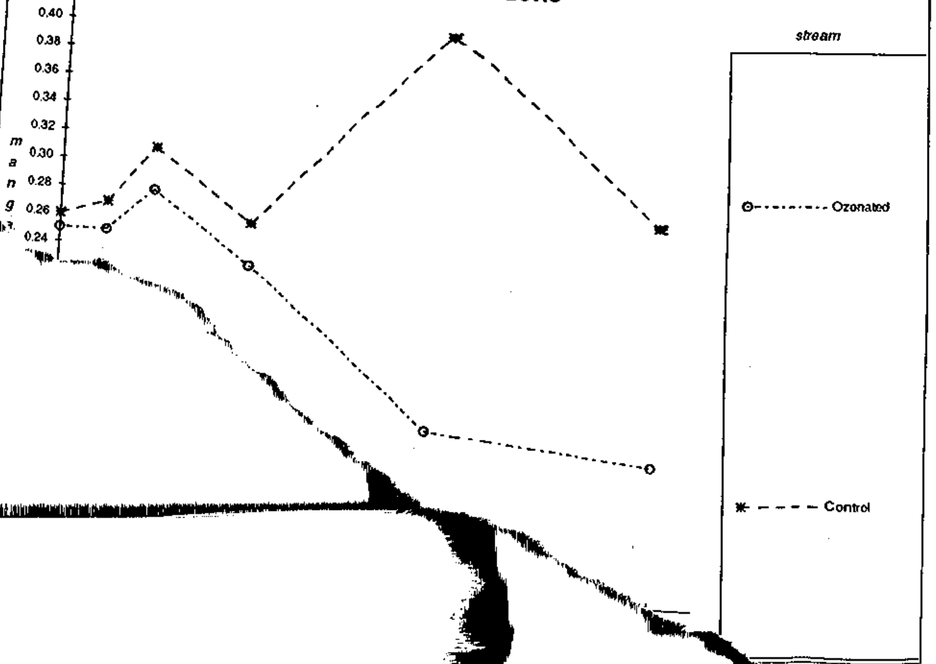


Figure 16. DPD Absorbance vs. Raw Water O3

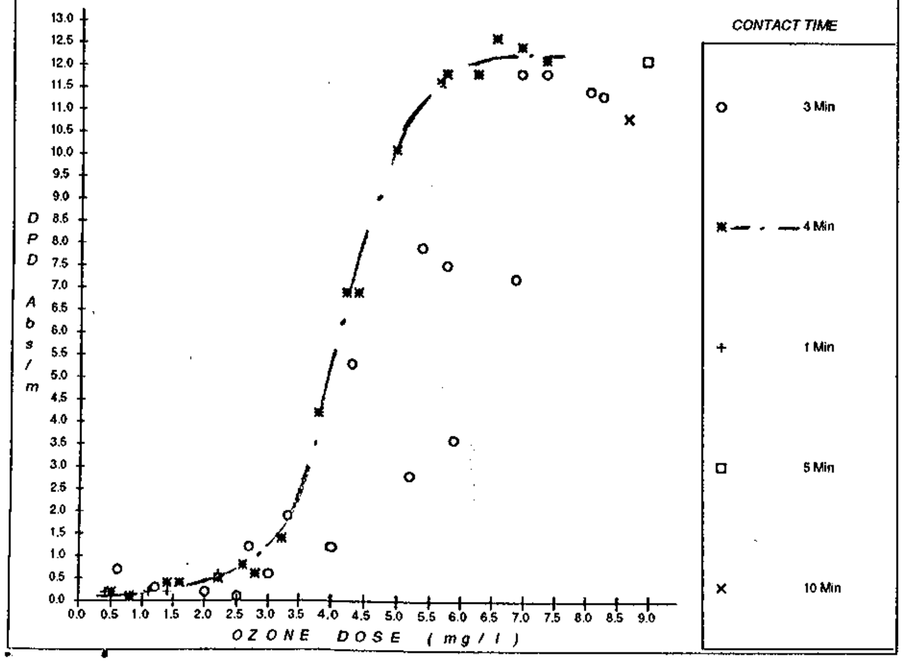


Figure 17. True Colour vs. Raw Water O3

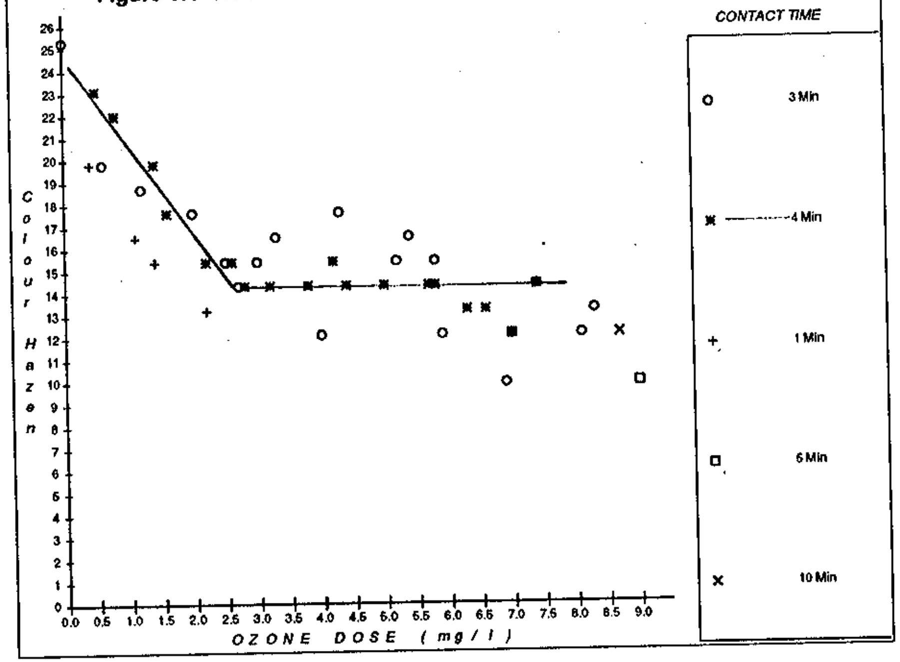


Figure 18. True uv. vs. Raw Water O3

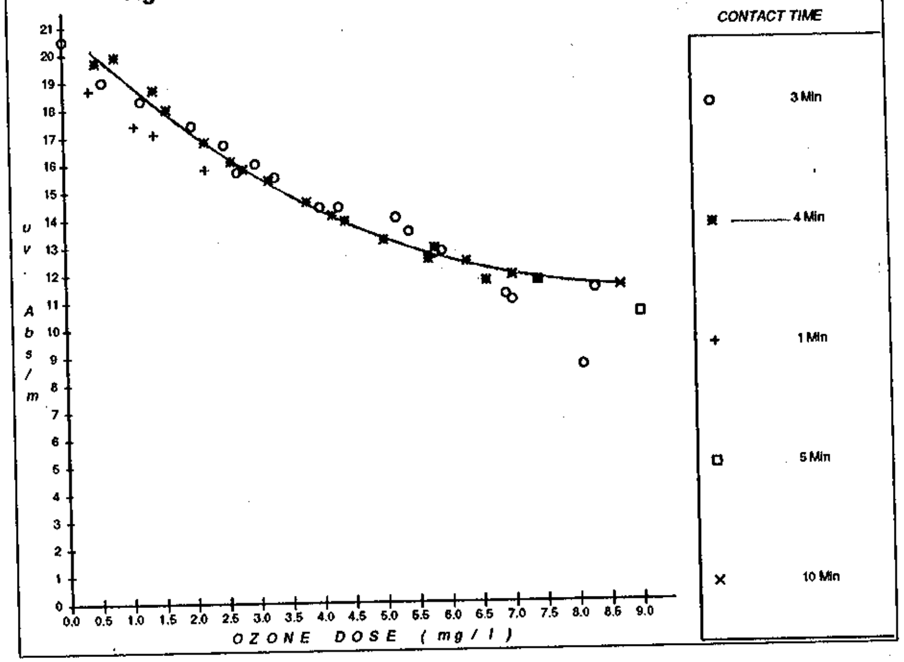


Figure 19. TOC vs. Raw Water O3

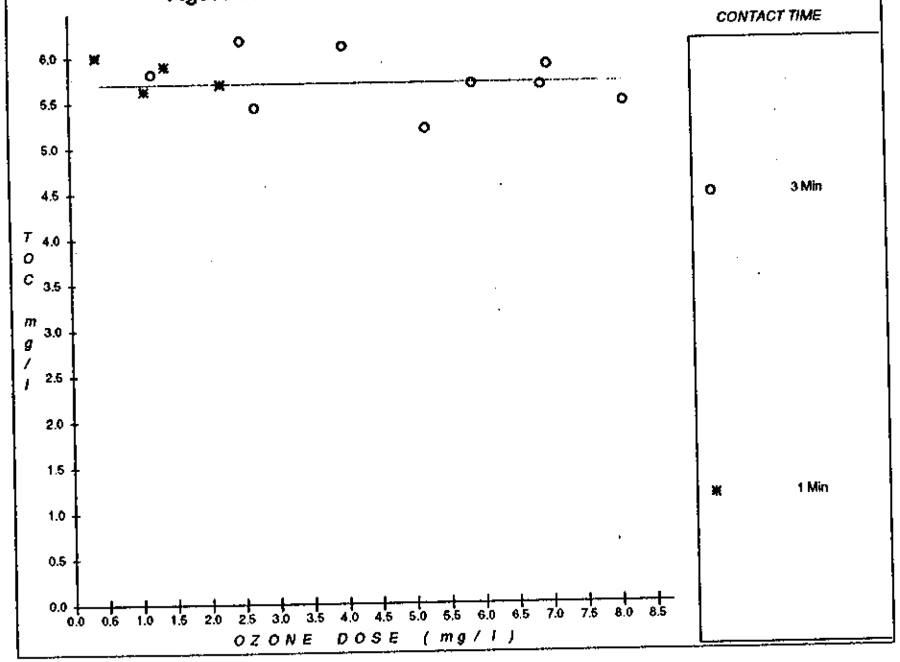


Figure 20. Final Water Colour vs. Pre O3

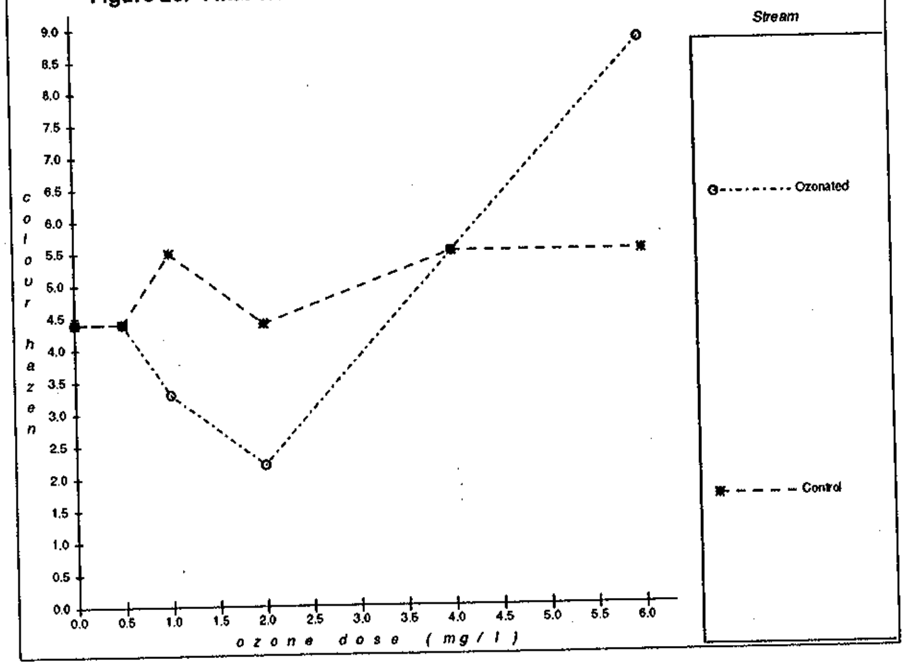


Figure 21. Final Water uv vs. Pre O3

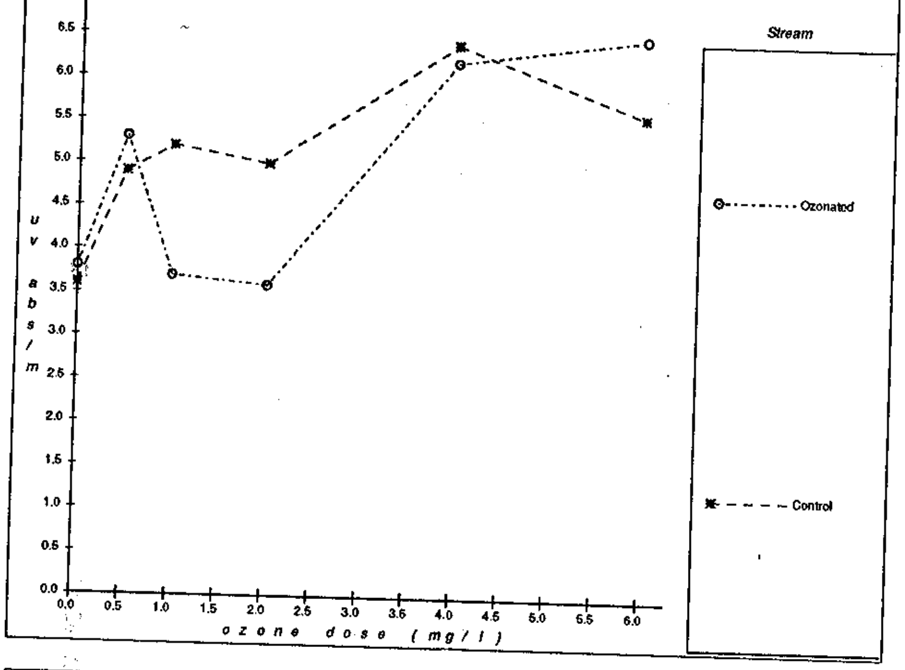


Figure 22. Final Water TOC vs. Pre O3

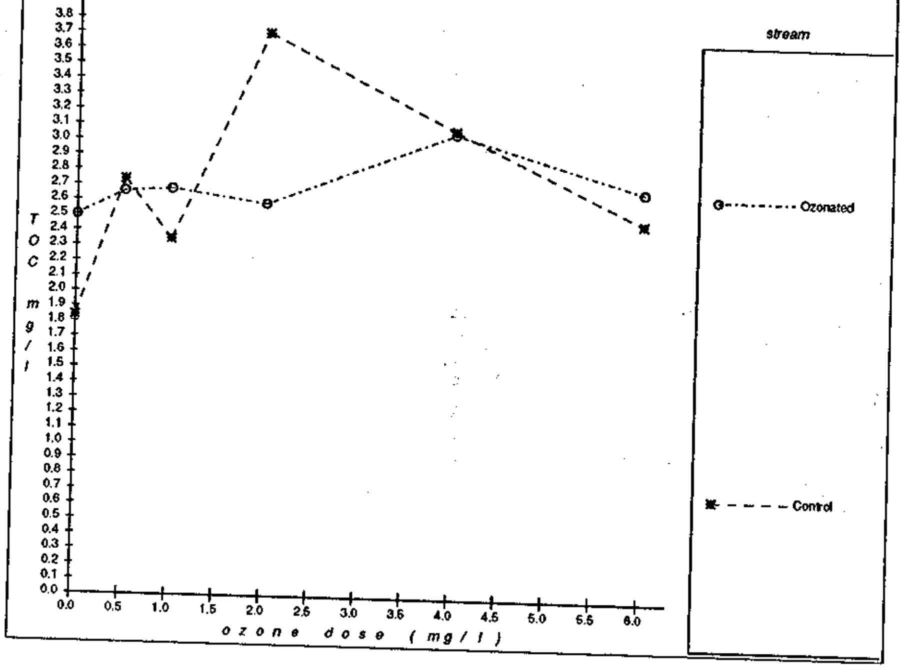


Figure 23. Final uv vs. Inter O3

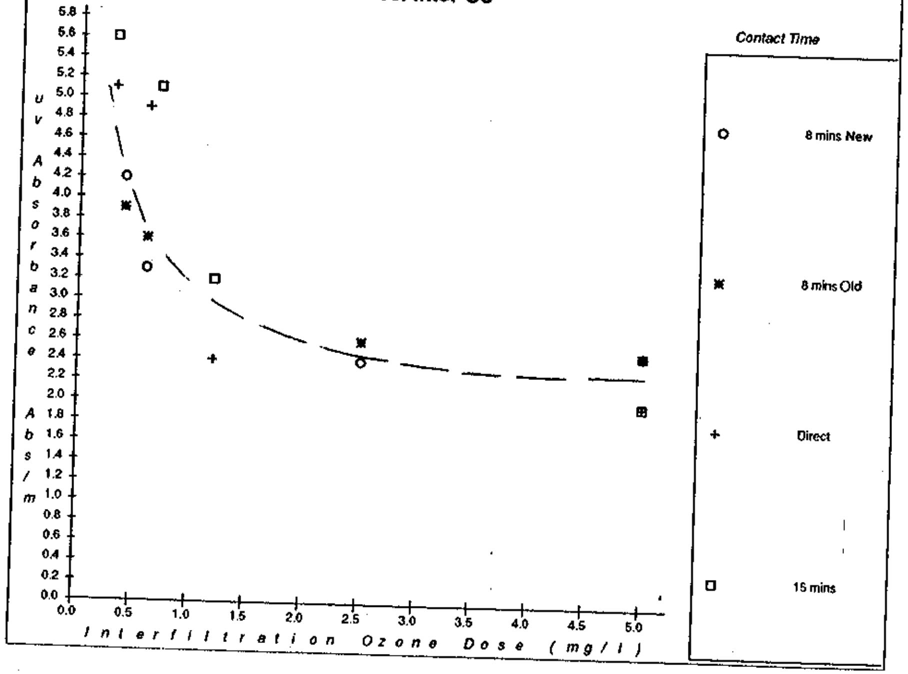


Figure 24. Final TOC vs. Inter O3

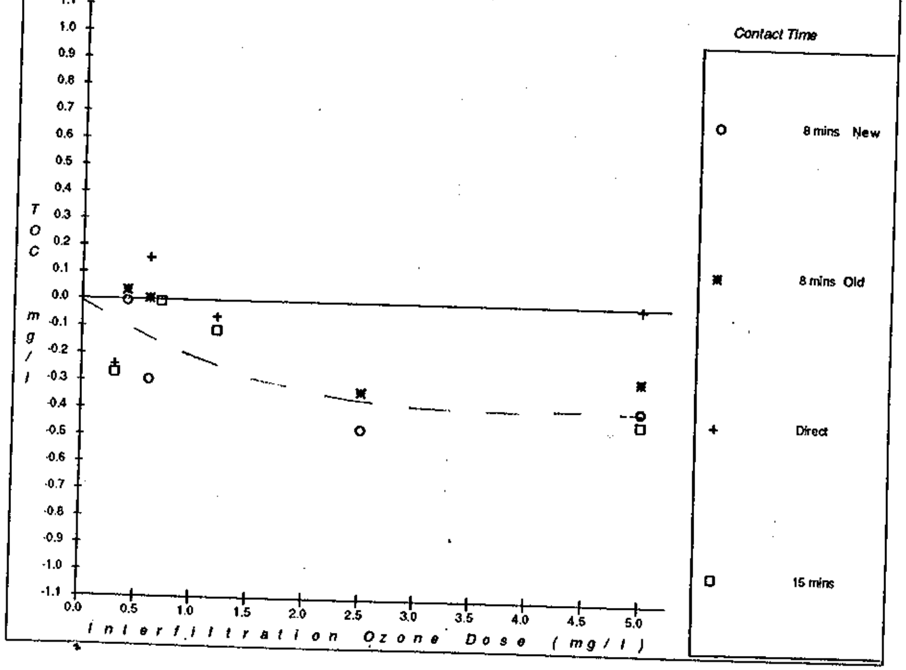


Figure 25. Increase in Total Cl Consumed
vs. Free Residual After 2' RGF

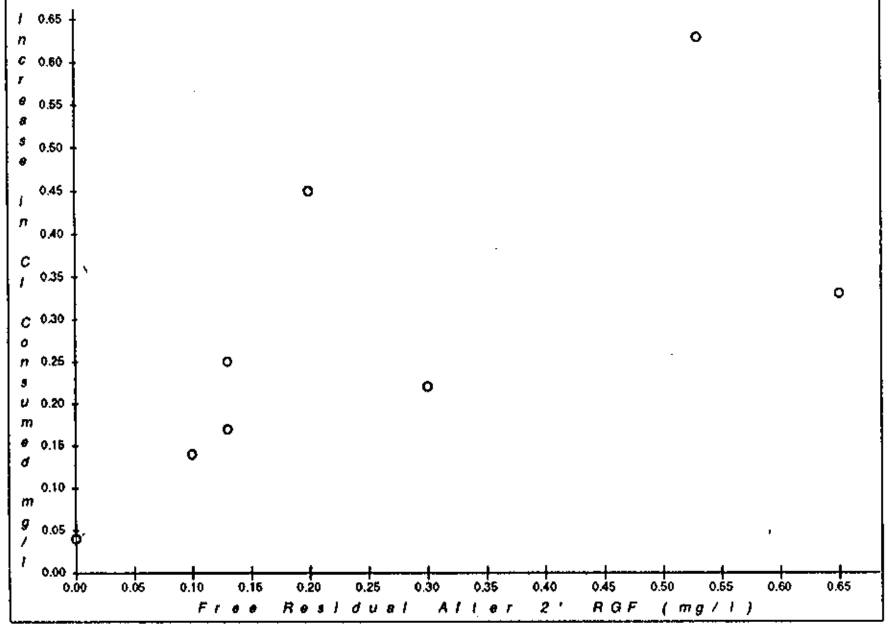


Figure 26. % Increase in Total THMs
vs. Free Residual After 2' RGF

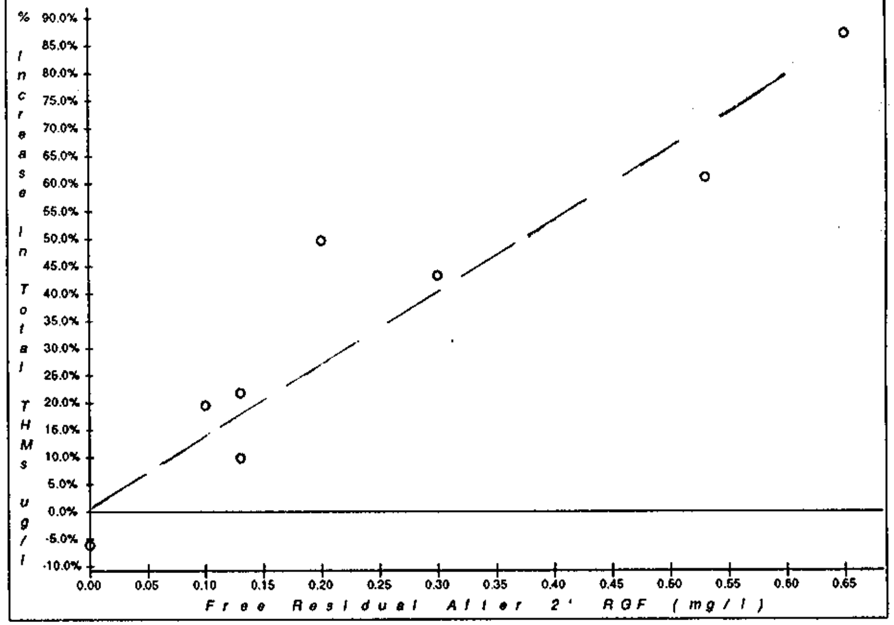


Figure 27. Cl Demand vs. Raw O3

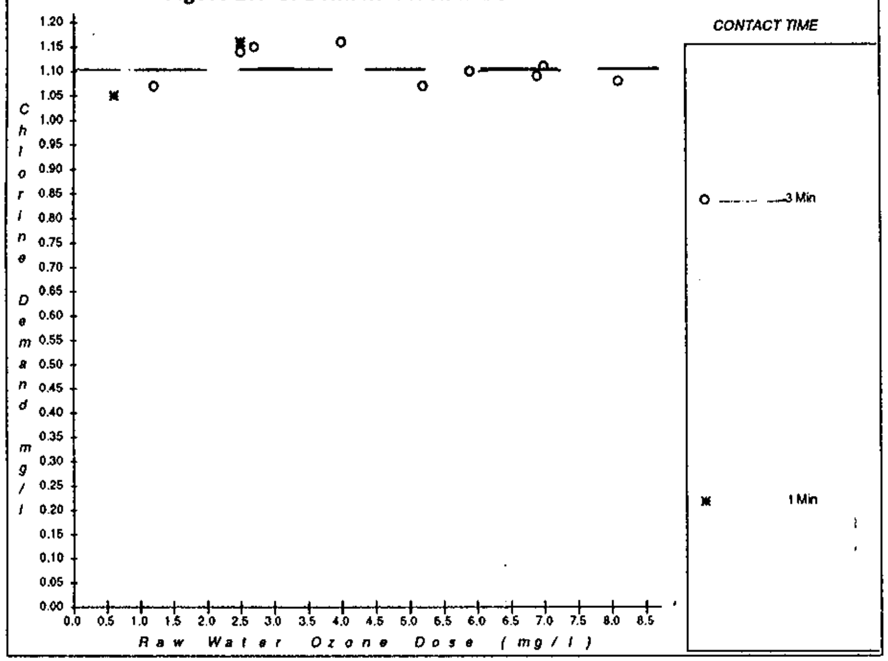


Figure 28. Total THMs vs. Raw O3

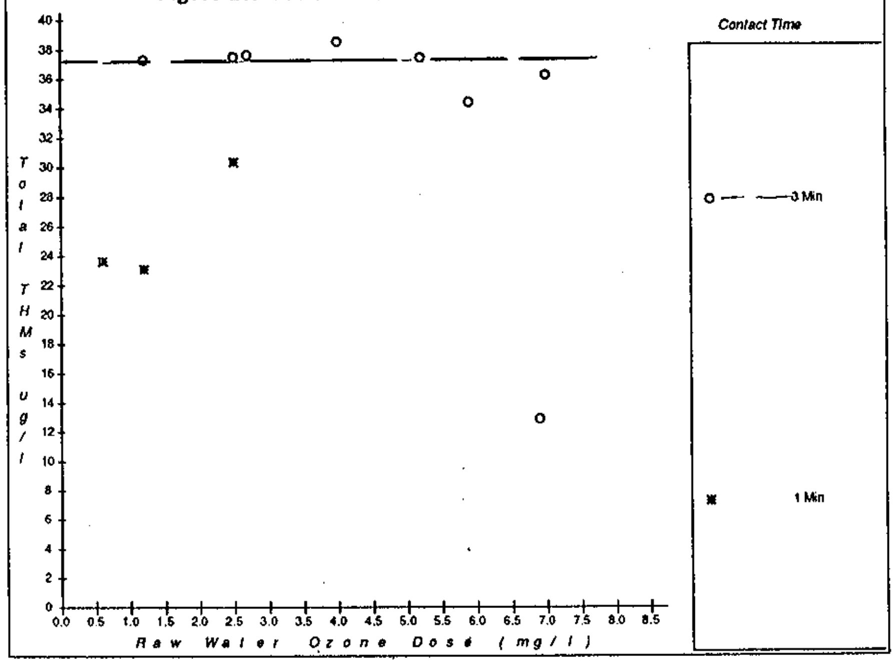


Figure 29. Final Cl Demand vs. Pre O3

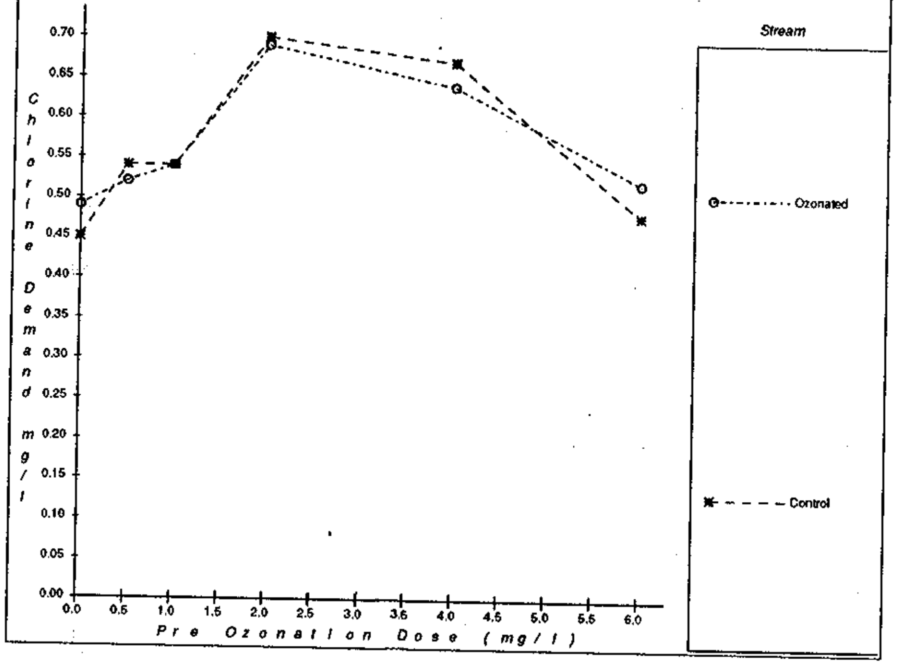


Figure 30. Final THMs vs. Pre O3

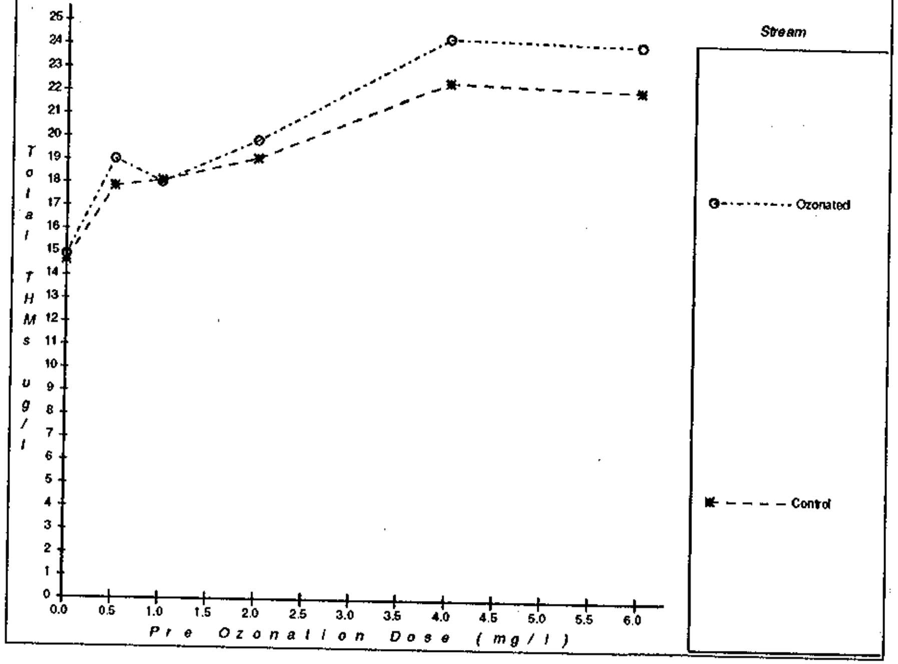


Figure 31. 1' RGF AOX vs. Pre O3

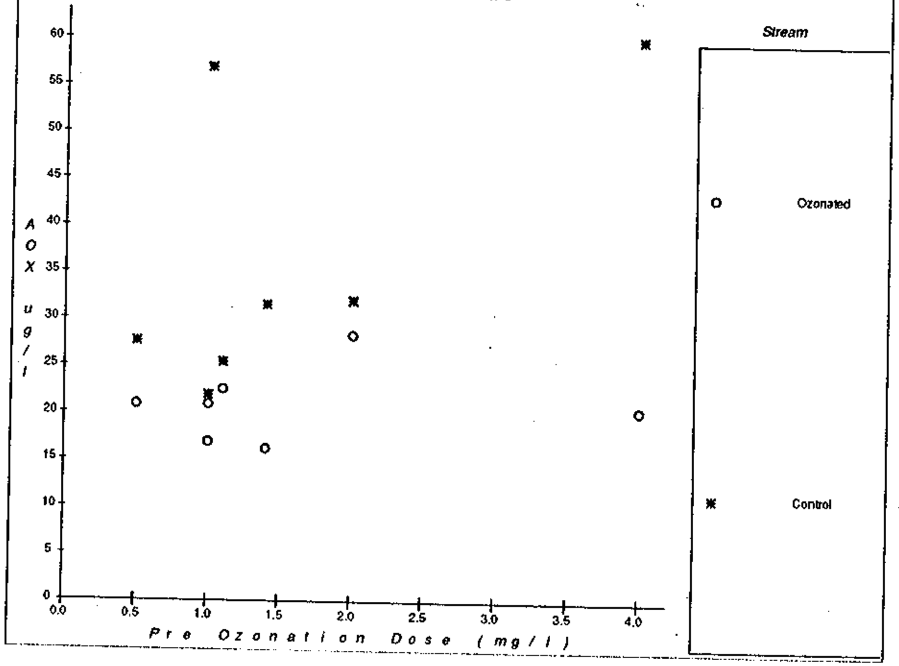


Figure 32. Percentage Decrease in THMs
vs. Interfiltration Ozone Dose

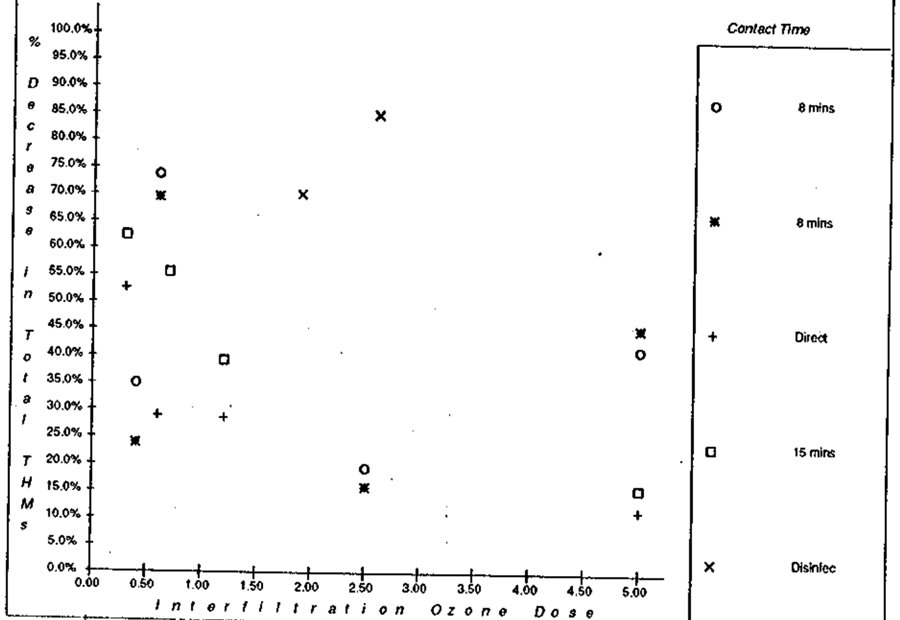


Figure 33. Percentage Decrease in AOX
vs. Interfiltration Ozone Dose

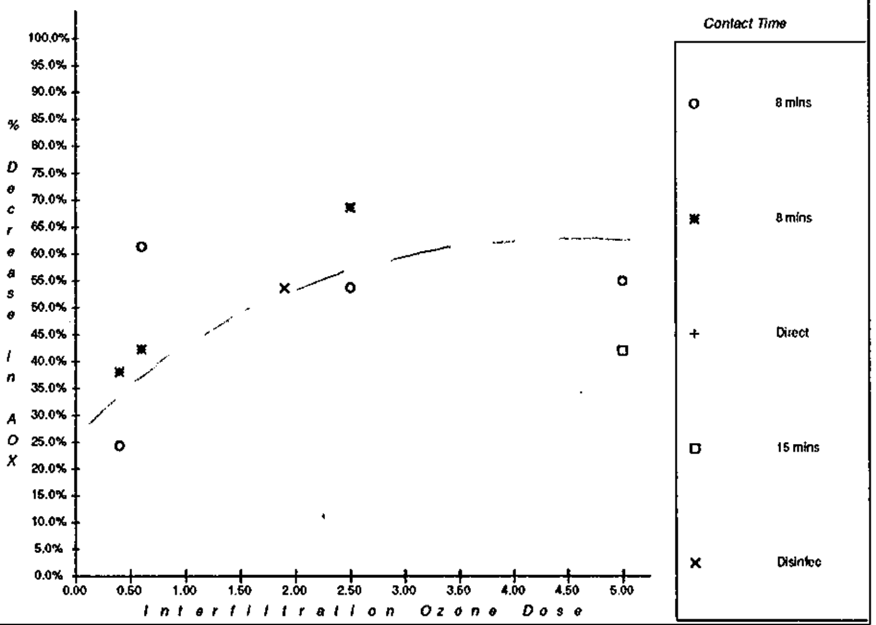


Figure 34. THMs vs. Interfiltration pH
Ozonated Samples, Hand Chlorinated at pH 9

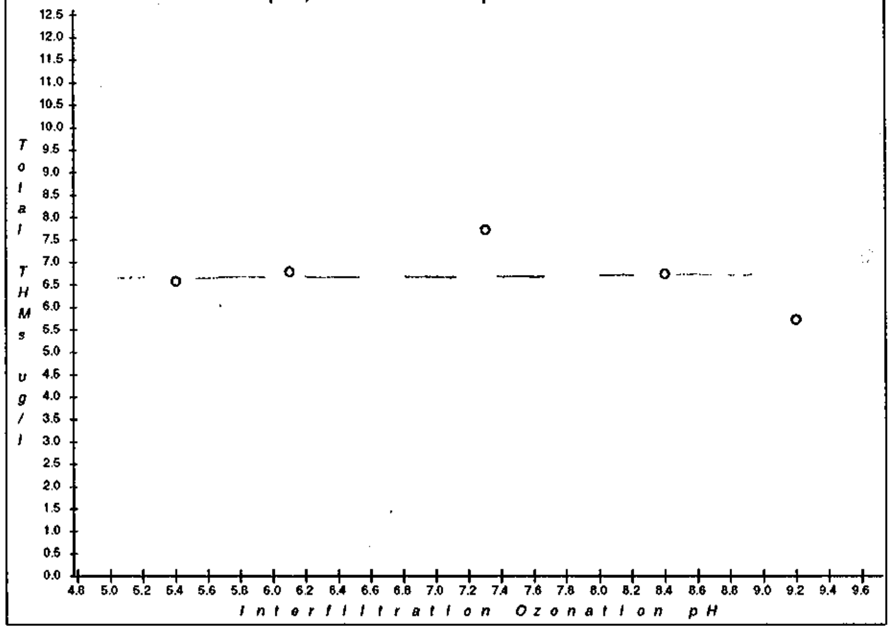


Figure 35. THMs vs. Interfiltration pH
Ozonated Samples, Hand Chlorinated at variable pH

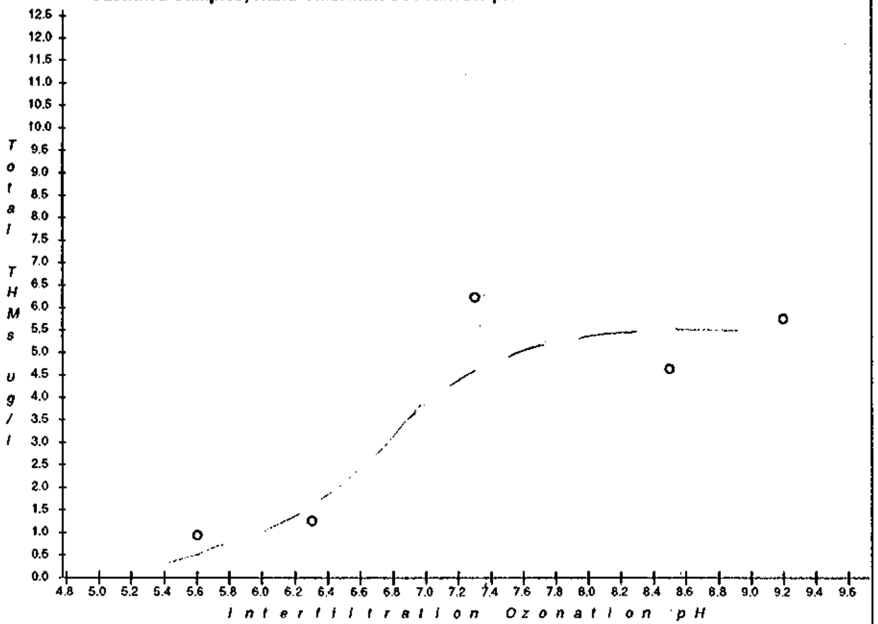


Figure 36. THMs vs. Interfiltration pH
Non Ozonated Samples, Hand Chlorinated at Variable pH

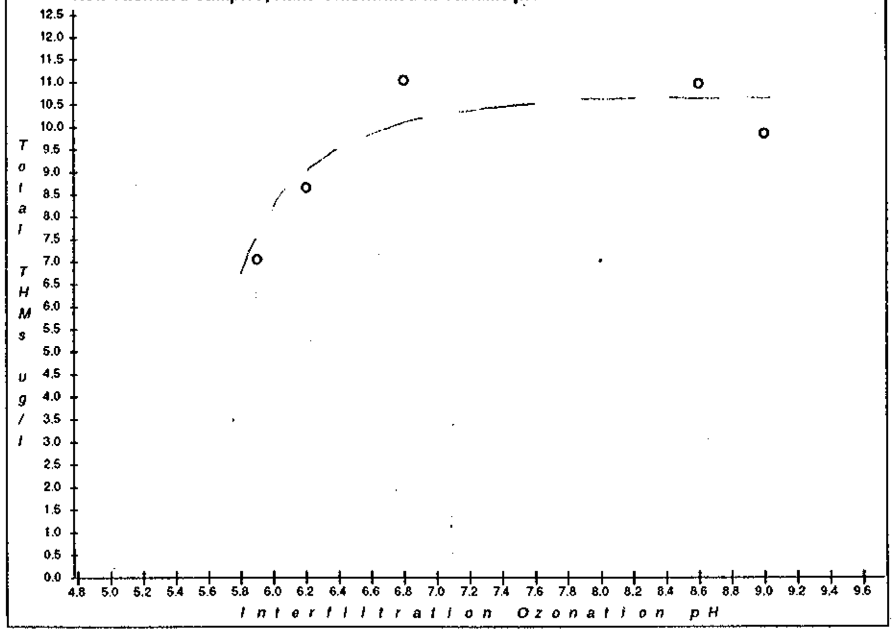
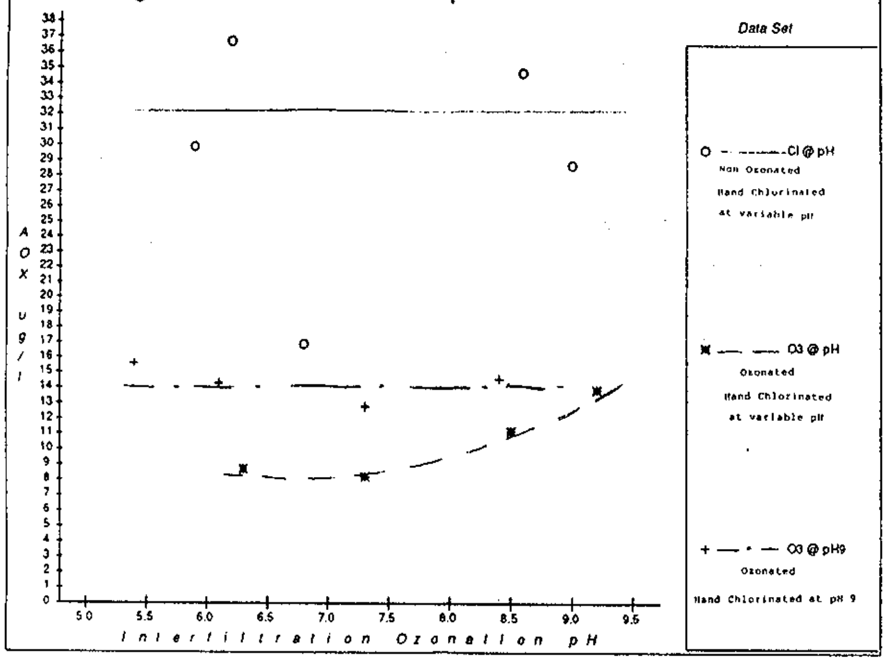


Figure 37. AOX vs. Interfiltration pH



APPENDIX A - OZONE CONTACTORS DETAILED DESCRIPTION

Figure 2 shows a drawing of the 8" contactor. The contactor can be divided into three sections; the base section below flange A, the top section above flange B, and the middle section between the two flanges. Each of the three contactors is constructed from identical base and top sections, with a different bore middle section.

The base section is 300mm square in cross section, and 850mm from the bottom to flange A, which is 8" nominal bore. One side of the square section contains a clear 'Lexan' viewing window, held in place by a stainless steel frame. The ozone inlet is made from ½" N.B. stainless steel, and ends in a diffuser made from sintered steel. The water outlet is made from 1½" N.B. stainless steel, and is taken from the bottom of the contactor up to the top of the column, and then down to a 1½" union. This arrangement prevents the column from draining if the feed flow stops.

The middle section of the contactor consists of a 4m section of 8" N.B. stainless steel pipe, ending in flange A at one end and flange B at the other. For the other contactors, the middle section consists of a 4m section of 6" N.B. or 4" N.B. stainless steel pipe, ending in the same size flanges.

The top section of the column starts at flange B, which is 3" N.B. The feed enters 250mm above flange B (in 1½" N.B. stainless steel ending in a union), and there is an overflow take off 750mm above flange B. Above the overflow take off, the top section forms a U-bend, with the off gas outlet at the top of the bend. The other side of the U-bend (also connected to the overflow take off) collects water from the water outlet, and feeds this to the outlet union. This arrangement prevents syphoning of the contents of the contactor.

Table A1 shows the volumes of the three contactors. For each contactor, two values are given. The first is the volume of water above the diffuser, assuming that this is equal to a column 4.85m tall at the relevant diameter; the second is the volume of the base section (60 l) plus the volume of the 4m tall column, at the relevant diameter, above the box. The "nominal contact" time is based on the second volume.

Table A1 - Ozone Contactor Volumes (all values rounded to nearest 5l)

Contactor	Volume of 4.85m Section of Column	Total Volume Including Base Section
Small	40	90
Medium	85	130
Large	150	185

APPENDIX B - TABLES OF RESULTS

All of the analytical results are provided in this appendix in the following tables:

Trial 1	Pre and interfiltration chlorination	B1.1 to B1.17
Trial 2a	Raw water ozonation	B2a.1 to B2a.5
Trial 2b	Effect of preozonation	B2b.1 to B2b.17
Trial 3a	Effect of interfiltration ozonation:dose	B3a.1 to B3a.19
Trial 3b	Effect of interfiltration ozonation:pH	B3b.1 to B3b.19
Trial 3bR	Effect of interfiltration ozonation:pH and hand chlorination pH	B3bR.1 to B3bR.4
Trial 3c	Effect of ozone disinfection (postozonation)	B3c.1 to B3c.7
Trial 4	Effect of dual point ozonation	B4.1 to B4.18

Unless indicated otherwise, values in brackets in the tables refer to the control stream.

PHASE II. TRIAL 1. EFFECT OF PRE AND INTER FILTRATION CHLORINATION

This trial consisted of six runs, of which two investigated pre-chlorination, and the remaining four investigated inter-filtration chlorination. In the tables below, all the results are presented together. The first two rows in each table are the results for prechlorination, and the last four rows in each table are the results for inter-filtration chlorination.

PILOT PLANT CONTROL

For three of the runs during this trial, the final pHs were high (up to 9.4) on the morning of sampling. When this occurred, the final caustic dose was reduced, and the final water sampled later in the day. If the pH was still too high, it was reduced in the lab for hand chlorination.

Table B1.1 - Coagulant Doses and Sample pHs

DATE	DOSE (mg Fe/l)	pH			
		RAW WATER	DAF TREATED	1° RGF	2° RGF
3 Oct 89	4.0 (4.2)	6.3	4.6 (4.6)	6.6 (6.5)	9.1 (9.2)
10 Oct 89	3.7 (3.9)	6.3	4.6 (4.6)	6.4 (6.5)	8.7 (8.7)
17 Oct 89	4.3	6.5	4.6	6.6	9.1 (8.9)
24 Oct 89	4.5	6.2	4.7	6.7	9.4 (9.2)
31 Oct 89	4.4	5.2	4.6	6.5	9.1 (9.1)
7 Nov 89	4.1	4.9	4.7	6.4	9.0 (9.1)

Table B1.1a - Trial Stream Prechlorination Dose

	DOSE	DAF OVERFLOW		1° RGF	
DATE	(mg/l)	FREE	TOTAL	FREE	TOTAL
3 Oct 89	1.76	0.35	0.36	0.01	0.11
10 Oct 89	1.30	0.19	0.22	0.02	0.11

Table B1.2 - Colour: °Hazen (= Abs/m @400nm * 11)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER		DAF FLOATED		1° RGF	2° RGF
		APP	TRUE	APPARENT	TRUE		
1.76 (0)	0.18 (0.10)	36	23	13 (15)	2 (2)	2 (2)	3 (3)
1.30 (0)	0.08 (0.06)	40	23	15 (18)	2 (2)	2 (2)	2 (2)
0 (0)	0.00 (0.13)	45	23	20	3	4	6 (4)
0 (0)	0.30 (0.10)	42	24	18	4	3	3 (4)
0 (0)	0.53 (0.20)	39	24	15	3	3	3 (3)
0 (0)	0.65 (0.13)	43	23	17	3	3	2 (3)

Table B1.3 - u.v. Absorbance (Abs/m @ 254nm)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER		DAF FLOATED		1° RGF	2° RGF
		APP	TRUE	APPARENT	TRUE		
1.76 (0)	0.18 (0.10)	20.9	18.1	7.9 (8.8)	3.2 (3.3)	3.5 (3.6)	3.4 (3.7)
1.30 (0)	0.08 (0.06)	21.4	17.8	8.8 (9.5)	3.2 (3.4)	3.4 (3.5)	3.4 (3.6)
0 (0)	0.00 (0.13)	22.5	18.1	10.3	3.6	3.8	3.9 (3.8)
0 (0)	0.30 (0.10)	24.8	20.8	12.2	5.1	4.4	4.3 (4.6)
0 (0)	0.53 (0.20)	24.1	20.6	10.9	5.1	4.6	4.5 (4.6)
0 (0)	0.65 (0.13)	23.6	19.2	10.6	4.5	4.5	4.2 (4.4)

Table B1.4 - Turbidity (NTU)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
1.76 (0)	0.18 (0.10)	1.6	0.7 (0.8)	0.0 (0.0)	0.1 (0.1)
1.30 (0)	0.08 (0.06)	2.2	1.0 (1.0)	0.0 (0.0)	0.0 (0.0)
0 (0)	0.00 (0.13)	3.5	1.3	0.0	0.0 (0.0)
0 (0)	0.30 (0.10)	2.7	1.0	0.1	0.0 (0.1)
0 (0)	0.53 (0.20)	2.1	0.8	0.1	0.1 (0.1)
0 (0)	0.65 (0.13)	3.1	1.0	0.0	0.1 (0.1)

Table B1.5 - Total Organic Carbon (mg/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	FINAL WATER
1.76 (0)	0.18 (0.10)	5.35	3.21 (3.98)
1.30 (0)	0.08 (0.06)	5.31	3.29 (3.11)
0 (0)	0.00 (0.13)	6.06	3.26 (3.27)
0 (0)	0.30 (0.10)	6.10	2.33 (2.14)
0 (0)	0.53 (0.20)	5.91	3.04 (2.99)
0 (0)	0.65 (0.13)	6.91	3.25 (3.41)

Table B1.6 - Iron (mg/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
1.76 (0)	0.18 (0.10)	0.80	0.71 (0.96)	0.04 (0.02)	0.02 (0.03)
1.30 (0)	0.08 (0.06)	0.87	0.82 (0.99)	0.03 (0.02)	0.02 (0.03)
0 (0)	0.00 (0.13)	1.01	1.10	0.03	0.02 (0.02)
0 (0)	0.30 (0.10)	0.59	1.00	0.04	0.04 (0.04)
0 (0)	0.53 (0.20)	0.47	0.79	0.03	0.02 (0.02)
0 (0)	0.65 (0.13)	0.76	0.98	0.03	0.01 (0.00)

Table B1.7 - Manganese (mg/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
1.76 (0)	0.18 (0.10)	0.22	0.20 (0.20)	0.21 (0.21)	0.00 (0.00)
1.30 (0)	0.08 (0.06)	0.22	0.21 (0.22)	0.21 (0.22)	0.00 (0.00)
0 (0)	0.00 (0.13)	0.23	0.23	0.23	0.00 (0.00)
0 (0)	0.30 (0.10)	0.25	0.25	0.26	0.00 (0.00)
0 (0)	0.53 (0.20)	0.24	0.26	0.26	0.00 (0.01)
0 (0)	0.65 (0.13)	0.25	0.24	0.30	0.01 (0.02)

Table B1.8 - Aluminium (mg/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
1.76 (0)	0.18 (0.10)	0.10	0.04 (0.04)	0.03 (0.03)	0.03 (0.03)
1.30 (0)	0.08 (0.06)	0.10	0.02 (0.03)	0.01 (0.00)	0.00 (0.00)
0 (0)	0.00 (0.13)	0.16	0.05	0.01	0.00 (0.00)
0 (0)	0.30 (0.10)	0.36	0.21	0.03	0.02 (0.02)
0 (0)	0.53 (0.20)	0.32	0.24	0.02	0.02 (0.02)
0 (0)	0.65 (0.13)	0.25	0.12	0.01	0.01 (0.01)

Table B1.9 - Hand chlorinated final water - bacteriological quality

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	COLIFORMS *		CFU	
		E-Coli	Total	37°C 1-Day	22°C 3-Day
1.76 (0)	0.18 (0.10)	0 (0)	0 (0)	0 (0)	0 (0)
1.30 (0)	0.08 (0.06)	0 (0)	0 (0)	0 (0)	0 (0)
0 (0)	0.00 (0.13)	0 (0)	0 (0)	0 (0)	6 (0)
0 (0)	0.30 (0.10)	0 (0)	0 (0)	1 (1)	0 (11)
0 (0)	0.53 (0.20)	0 (0)	0 (0)	0 (0)	0 (0)
0 (0)	0.65 (0.13)	0 (0)	0 (0)	0 (0)	1 (0)

* per 100 ml
CFU : colony forming unit per ml

Table B1.10 - Chloroform (ug/l)

	PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
				RAW	1° RGF	2° RGF
	1.76 (0)	0.18 (0.10)	27.62 (8.36)	24.38	33.26 (12.41)	31.49 (13.68)
	1.30 (0)	0.08 (0.06)	20.80 (7.72)	21.74	25.29 (11.48)	24.97 (13.39)
	0 (0)	0.00 (0.13)	2.95 (5.63)	21.50	9.19	8.47 (10.12)
	0 (0)	0.30 (0.10)	10.05 (5.60)	64.88	16.62	24.08 (20.14)
	0 (0)	0.53 (0.20)	20.20 (15.22)	94.35	22.95	37.35 (35.07)
#	0 (0)	0.65 (0.13)	5.9 (3.1)	18.8	5.3	9.7 (6.5)

Table B1.11 - Bromodichloromethane (ug/l)

	PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
				RAW	1° RGF	2° RGF
	1.76 (0)	0.18 (0.10)	5.52 (1.26)	1.73	6.38 (1.47)	6.33 (1.65)
	1.30 (0)	0.08 (0.06)	5.01 (1.39)	1.97	5.55 (1.72)	5.47 (2.02)
	0 (0)	0.00 (0.13)	<0.01 (1.70)	2.21	1.85	1.89 (2.01)
	0 (0)	0.30 (0.10)	0.46 (0.21)	1.38	0.71	0.80 (0.59)
	0 (0)	0.53 (0.20)	1.76 (1.51)	2.28	1.80	2.76 (2.16)
#	0 (0)	0.65 (0.13)	0.3 (<0.1)	0.3	0.2	0.6 (0.2)

Table B1.12 - Dibromochloromethane (ug/l)

	PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED RAW	HAND CHLORINATED 1° RGF	HAND CHLORINATED 2° RGF
	1.76 (0)	0.18 (0.10)	0.85 (<0.05)	<0.05	0.81 (<0.05)	0.81 (0.15)
	1.30 (0)	0.08 (0.06)	0.81 (0.12)	0.14	0.83 (0.12)	0.82 (0.16)
	0 (0)	0.00 (0.13)	<0.05 (<0.05)	<0.05	<0.05	<0.05 (<0.05)
	0 (0)	0.30 (0.10)	<0.05 (0.06)	0.66	<0.05	<0.05 (<0.05)
	0 (0)	0.53 (0.20)	0.13 (0.14)	0.13	0.12	0.17 (0.17)
#	0 (0)	0.65 (0.13)	<0.1 (<0.1)	<0.1	<0.1	<0.1 (<0.1)

Table B1.13 - Bromoform (ug/l)

	PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED RAW	HAND CHLORINATED 1° RGF	HAND CHLORINATED 2° RGF
	1.76 (0)	0.18 (0.10)	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
	1.30 (0)	0.08 (0.06)	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
	0 (0)	0.00 (0.13)	<0.03 (<0.03)	<0.03	<0.03	<0.03 (<0.03)
	0 (0)	0.30 (0.10)	<0.03 (<0.03)	<0.03	<0.03	<0.03 (<0.03)
	0 (0)	0.53 (0.20)	<0.03 (<0.03)	<0.03	0.14	<0.03 (<0.03)
#	0 (0)	0.65 (0.13)	<0.2 (<0.2)	<0.2	<0.2	<0.2 (<0.2)

Table B1.14 - Total trihalomethanes (ug/l)

	PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED RAW	HAND CHLORINATED 1° RGF	HAND CHLORINATED 2° RGF
	1.76 (0)	0.18 (0.10)	34.02 (9.70)	26.19	40.48 (13.96)	38.66 (15.51)
	1.30 (0)	0.08 (0.06)	26.65 (9.26)	23.88	31.70 (13.35)	31.29 (15.60)
	0 (0)	0.00 (0.13)	3.04 (7.41)	23.79	11.12	10.44 (12.21)
	0 (0)	0.30 (0.10)	10.59 (5.90)	66.95	17.41	24.96 (20.81)
	0 (0)	0.53 (0.20)	22.12 (16.90)	96.79	25.01	40.31 (37.43)
#	0 (0)	0.65 (0.13)	6.2 (3.1)	19.1	5.5	10.3 (6.7)

These samples were analysed by WRc Medmenham.

Table B1.15 - Chlorine demand (mg/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW	1° RGF	2° RGF		
				FILTER	LAB	TOTAL
1.76 (0)	0.18 (0.10)	1.01	0.11 (0.54)	0.25 (0.54)	0.09 (0.10)	0.34 (0.64)
1.30 (0)	0.08 (0.06)	1.16	0.26 (0.57)	0.39 (0.65)	0.12 (0.14)	0.51 (0.79)
0 (0)	0.00 (0.13)	1.18	0.60	0.00 (0.74)	0.64 (0.11)	0.64 (0.85)
0 (0)	0.30 (0.10)	1.30	0.56	0.66 (0.55)	0.12 (0.15)	0.78 (0.70)
0 (0)	0.53 (0.20)	1.07	0.42	0.88 (0.78)	0.17 (0.09)	1.05 (0.87)
0 (0)	0.65 (0.13)	1.17	0.64	0.84 (0.70)	0.13 (0.11)	0.97 (0.81)

Table B.116 - Adsorbable organic halide (AOX) (ug/l)

PRE Cl DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
			RAW	1° RGF	2° RGF
1.30 (0)	0.08 (0.06)	29.6 (16.0)	58.9	37.3 (25.7)	38.9 (28.2)
0 (0)	0.00 (0.13)	<8 (12.3)	50.3	16.9	19.5 (21.9)
0 (0)	0.65 (0.13)	24.3 (20.8)	57.4	27.6	25.0 (29.3)

Table B1.17 - Mutagenic activity (slope value)

PRE Cl DOSE (mg/l)	NON CHLORINATED				HAND CHLORINATED FINAL WATER							
	TRIAL 1° RGF				TRIAL STREAM				CONTROL STREAM			
	TA 98		TA 100		TA 98		TA 100		TA 98		TA 100	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
1.30 (0)	1.53	4.37	12.02	10.56	3.32	5.15	31.01	15.32	2.66	3.38	16.01	11.21

PHASE II. EXPERIMENT 2a). EFFECT OF RAW WATER OZONATION

Five trials were carried out, each at a different contact time, to investigate the effect of raw water ozonation. A summary of the conditions used for each trial is given in table B2a.1.

RESULTS

The raw water quality for each day of the trials is shown in table B2a.2.

Table B2a.3 shows the conditions recorded from the ozone generator and contactor during each run. The final column gives the ozone dose calculated from the previous columns. For each trial, the rows are in order of target ozone dose, which increased from 0.5 to 9.0 in 0.5 mg/l increments for trials A and B, and from 0.5 to 2.0 in increments of 0.5mg/l for trial C. The same order of rows is used in table B2a.4, which gives the onsite analyses for each run. Table B2a.5 gives the offsite TOC and THM analyses, as well as chlorine demand. A simplified hand chlorination procedure was used, where a constant chlorine dose (of 1.5 mg/l) was applied to each sample. Samples for offsite analyses covered ozone doses of 1 to 9 in increments of 1 mg/l.

Table B2a.1 - Summary of Trial Conditions

TRIAL	OZONE		RAW WATER FLOW (l/hr)	CONATACT TIME (mins)
	CONCENTRATION	FLOWRATE		
A	FIXED	VARIED	3600	3
B	VARIED	FIXED	2800	4
C	FIXED	VARIED	3600	1.5
D	SINGLE RUN		2200	5
E	SINGLE RUN		1100	10

Table B2a.2 - Raw Water Quality During Trials

DATE	pH	TURBIDITY (NTU)	COLOUR		UV	
			APPARENT (Abs/m)	TRUE (Abs/m)	APPARENT (Abs/m)	TRUE (Abs/m)
8 Nov 89	4.9	2.1	3.6	2.4	23.9	20.6
9 Nov 89	4.8	2.1	3.7	2.2	24.0	20.5
10 Nov 89	4.7	2.0	3.5	2.2	23.9	20.4
13 Nov 89	4.9	2.0	3.4	2.1	23.7	20.2
15 Nov 89	4.7	1.9	3.4	2.1	23.7	20.1
16 Nov 89	4.8	1.8	3.3	2.0	23.2	19.8

Table B2a.3 - Ozone generator and contactor conditions

TRIAL	DATE	TIME	GENERATOR			CONTACTOR		OZONE	
			FLOW	POWER	PRESSURE	GAS FLOW	WATER FLOW	CONC	DOSE
			l/hr	(W)	(kPa)	(l/hr)	(l/hr)	g/m3	mg/l
A	10/11	09.20	1650	140	690	350	3600	6.6	0.6
	09/11	09.15	1700	140	700	680	3600	6.6	1.2
	10/11	10.25	1700	140	740	1080	3600	6.6	2.0
	09/11	09.55	1700	140	710	1370	3600	6.6	2.5
	10/11	09.45	1600	140	700	1630	3600	6.6	3.0
	09/11	14.25	1700	400	730	530	3600	18.0	2.7
	08/11	13.20	1700	400	720	650	3600	18.0	3.3
	09/11	12.20	1750	400	710	790	3600	18.0	4.0
	08/11	11.30	1750	420	690	860	3600	18.0	4.3
	09/11	13.40	2000	400	760	1040	3600	18.0	5.2
	08/11	15.25	1750	410	730	1080	3600	18.0	5.4
	09/11	11.55	1750	400	720	1180	3600	18.0	5.9
	08/11	14.45	1700	400	730	1150	3600	18.0	5.8
	09/11	10.40	1600	420	690	1370	3600	18.0	6.9
	08/11	12.20	1900	400	750	1480	3600	18.0	7.4
	09/11	13.00	1500	390	740	1400	3600	18.0	7.0
	08/11	16.00	1800	400	720	1650	3600	18.0	8.3
	09/11	15.05	1600	400	720	1620	3600	18.0	8.1
B	15/11	12.00	800	30	600	530	2800	2.7	0.5
	15/11	13.55	800	30	610	820	2800	2.7	0.8
	15/11	14.40	800	55	610	820	2800	4.9	1.4
	15/11	13.40	850	70	610	820	2800	5.6	1.6
	15/11	14.10	850	095	610	820	2800	7.4	2.2
	15/11	14.55	850	115	610	820	2800	8.8	2.6
	15/11	13.10	800	130	610	820	2800	9.6	2.8
	15/11	10.45	800	150	610	820	2800	10.9	3.2
	15/11	12.45	800	185	610	820	2800	12.9	3.8
	15/11	11.00	800	210	610	820	2800	14.3	4.2
	15/11	10.20	850	225	610	820	2800	15.0	4.4
	15/11	14.25	850	265	610	820	2800	17.0	5.0
	15/11	09.10	850	290	610	890	2800	18.1	5.8
	15/11	11.45	800	325	610	820	2800	19.6	5.7
	15/11	13.25	800	370	610	820	2800	21.4	6.3
	15/11	11.15	800	410	610	820	2800	22.6	6.6
	15/11	10.05	850	470	610	820	2800	23.9	7.0
	15/11	11.30	800	515	610	820	2800	25.2	7.4
C	13/11	11.45	400	200	670	41	3600	28	0.4
	13/11	13.35	400	190	650	138	3600	28	1.1
	13/11	12.50	400	200	620	186	3600	28	1.4
	13/11	10.20	400	190	640	284	3600	28	2.2
D	16/11		1200	310	670	1100	2200	18	9.0
E	16/11		600	150	500	530	1100	18	8.7

Table B2a.4 - Onsite analyses for each run

CONTACT TIME (mins)	OZONE DOSE (mg/l)	TURBIDITY (NTU)	pH	DPD (Abs/m)	COLOUR		UV ABSORBANCE	
					APPARENT (Abs/m)	TRUE Abs/m	APPARENT (Abs/m)	TRUE Abs/m
3	0.6	1.9	4.7	0.7	3.2	1.8	22.5	19.0
	1.2	1.9	4.7	0.3	3.0	1.7	21.6	18.3
	2.0	1.9	4.7	0.2	2.8	1.6	20.7	17.4
	2.5	2.0	4.7	0.1	2.6	1.4	19.8	16.7
	3.0	1.8	4.7	0.6	2.6	1.4	19.1	16.0
	2.7	1.9	4.7	1.2	2.4	1.3	18.8	15.7
	3.3	1.8	4.7	1.9	2.5	1.5	18.5	15.5
	4.0	1.7	4.6	1.2	2.1	1.1	17.3	14.4
	4.3	1.7	4.5	5.3	2.6	1.6	17.0	14.4
	5.2	1.7	4.7	2.8	2.4	1.4	16.9	14.0
	5.4	1.8	4.6	7.9	2.5	1.5	16.2	13.5
	5.9	1.7	4.7	3.6	2.0	1.1	15.3	12.8
	5.8	1.9	4.6	7.5	2.5	1.4	15.3	12.7
	6.9	2.0	4.6	7.2	1.9	0.9	13.6	11.2
	7.4	2.6	4.6	11.8	2.7	1.3	14.4	11.7
	7.0	2.6	4.5	11.8	2.5	1.1	13.7	11.0
	8.3	2.6	4.5	11.3	2.6	1.2	14.0	11.4
	8.1	3.9	4.2	11.4	2.8	1.1	14.0	8.6
4	0.5	1.9	NA	0.2	3.4	2.1	23.3	19.7
	0.8	1.8	NA	0.1	3.3	2.0	23.3	19.9
	1.4	1.8	NA	0.4	3.1	1.8	22.2	18.7
	1.6	1.8	NA	0.4	2.8	1.6	21.3	18.0
	2.2	1.8	NA	0.5	2.6	1.4	19.9	16.8
	2.6	1.8	NA	0.8	2.5	1.4	19.2	16.1
	2.8	1.7	NA	0.6	2.4	1.3	18.8	15.8
	3.2	1.7	NA	1.4	2.4	1.3	18.3	15.4
	3.8	1.7	NA	4.2	2.3	1.3	17.4	14.6
	4.2	1.7	NA	6.9	2.4	1.4	16.9	14.1
	4.4	1.7	NA	6.9	2.3	1.3	16.7	13.9
	5.0	1.6	NA	10.1	2.3	1.3	15.7	13.2
	5.8	1.6	NA	11.8	2.2	1.3	15.5	12.9
	5.7	1.7	NA	11.6	2.3	1.3	15.0	12.5
	6.3	1.7	NA	11.8	2.1	1.2	14.7	12.4
	6.6	1.7	NA	12.6	2.1	1.2	13.8	11.7
	7.0	1.7	NA	12.4	2.1	1.1	14.1	11.9
	7.4	1.7	NA	12.1	2.0	1.3	13.8	11.7
1.5	0.4	2.0	4.8	0.2	3.0	1.8	22.2	18.7
	1.1	1.9	4.8	0.2	2.8	1.5	20.8	17.4
	1.4	1.9	4.8	0.2	2.5	1.4	20.3	17.1
	2.2	1.8	4.7	0.6	2.2	1.2	18.5	15.8
5	9.0	1.9	4.5	12.1	1.9	0.9	12.9	10.5
10	8.7	2.4	4.4	10.8	2.5	1.1	14.1	11.5

Table B2a.5 - Offsite analyses for each run

CONTACT TIME (mins)	OZONE DOSE (mg/l)	TOC (mg/l)	HAND CHLORINATION			T H M s				
				DEMAND (mg/l)	RESIDUAL (mg/l)	C13 ug/l	C12Br ug/l	ClBr2 ug/l	Br3 ug/l	Total ug/l
3	1.2	5.81	8.8	1.07	0.43	35.33	1.72	0.18	0.09	37.32
	2.5	6.17	9.0	1.14	0.36	35.55	1.77	0.17	<.03	37.52
	2.7	5.43	8.9	1.15	0.35	35.61	1.83	0.19	<.03	37.66
	4.0	6.10	8.8	1.16	0.34	36.43	1.94	0.17	<.03	38.57
	5.2	5.19	8.9	1.07	0.43	35.40	1.89	0.17	<.03	37.49
	5.9	5.68	9.0	1.10	0.40	32.28	1.96	0.16	<.03	34.43
	6.9	5.66	8.7	1.09	0.41	11.27	1.39	0.17	0.04	12.87
	7.0	5.88	8.9	1.11	0.39	33.97	2.12	0.17	<.03	36.29
	8.1	5.47	9.0	1.08	0.42					
1.5	0.4	6.00	9.3	1.05	0.45	23.29	0.28	<.05	<.03	23.65
	1.1	5.62	8.8			22.63	0.40	<.05	<.03	23.11
	1.4	5.89	9.1	1.31	0.62	38.47	0.54	<.05	<.03	39.09
	2.2	5.69	8.9	1.16	0.34	29.93	0.38	<.05	<.03	30.39

PHASE II. TRIAL 2b. EFFECT OF PREOZONATION

This trial included 7 runs where the ozone dose applied to the raw water was varied, prior to coagulation.

The ozone doses selected were 0.5, 1, 2, 4 and 6 mg/l. The two higher doses were used at a nominal 5 minute contact time, with the three lower doses at a nominal 1 minute contact time. After the completion of these five runs, two additional runs were made. The first additional run was a control run to investigate the effects of aeration prior to coagulation. A trial stream pre-ozonation dose of 0.0 mg/l was used for this run. The water was however contacted with air at the same air/water flowrates as the 6mg/l ozone dose run. For the final run, the possibility of reducing coagulant dose with pre-ozonation was investigated. For this run, a pre-ozonation dose of 1mg/l was applied to the trial stream, and the trial stream ferric dose was reduced to give the same final water quality as the control stream.

PILOT PLANT CONTROL

Pilot plant control was generally good during this trial. There was one run with a low final pH (8.6) which was increased in the lab for hand chlorination. There was also one run with a low trial stream DAF pH (4.3).

Table B2b.1 - Doses and pHs

DATE	FERRIC DOSE (mg/l)	OZONE		pH			
		DOSE mg/l	TIME mins	RAW	DAF FLOATED	1° RGF	2° RGF
21 Nov 89	3.1 (3.2)	2	1	4.8	4.6 (4.6)	6.6 (6.6)	8.9 (8.9)
28 Nov 89	3.6 (3.4)	0.5	1	5.0	4.7 (4.6)	6.5 (6.5)	8.6 (9.0)
5 Dec 89	2.9 (3.3)	4	5	5.1	4.7 (4.6)	6.5 (6.5)	8.8 (9.1)
12 Dec 89	3.5 (3.3)	6	5	5.5	4.6 (4.6)	6.5 (6.5)	8.9 (9.0)
19 Dec 89	5.4 (5.5)	1	1	4.9	4.3 (4.6)	6.3 (6.6)	8.8 (9.0)
9 Jan 90	5.3 (5.5)	0.0	5	5.0	4.7 (4.6)	6.6 (6.6)	9.1 (9.0)
16 Jan 90	3.2 (4.0)	1	1	5.1	4.6 (4.6)	6.4 (6.5)	8.9 (8.9)

Table B2b.2 - Colour: °Hazen (= Abs/m @400mm * 11)

OZONE DOSE (mg/l)	RAW WATER		OZONE RAW		DAF FLOATED		1° RGF	2° RGF
	APP	TRUE	APP	TRUE	APPARENT	TRUE		
0.0	38	22	38	21	14 (20)	3 (3)	3 (3)	4 (4)
0.5	35	22	31	18	17 (20)	4 (4)	4 (4)	4 (4)
1	40	23	32	17	18 (17)	3 (3)	2 (4)	3 (6)
2	36	24	26	14	18 (21)	3 (4)	2 (3)	2 (4)
4	33	20	19	11	15 (15)	2 (3)	6 (4)	6 (6)
6	34	21	30	12	23 (20)	4 (4)	9 (6)	9 (6)
Low Fe	39	22	33	17	17 (18)	4 (4)	3 (4)	4 (4)

Table B2b.3 - U.V. (Abs/m @ 254nm)

OZONE DOSE (mg/l)	RAW WATER		OZONE RAW		DAF FLOATED		1° RGF	2° RGF
	APP	TRUE	APP	TRUE	APPARENT	TRUE		
0.0	21.8	17.3	21.8	17.4	9.0 (10.4)	3.6 (3.7)	3.7 (3.5)	3.8 (3.6)
0.5	22.0	18.4	20.3	16.9	11.0 (12.0)	4.6 (5.0)	5.0 (4.9)	5.3 (4.9)
1	22.7	18.5	19.4	15.4	10.2 (9.8)	4.0 (3.8)	3.3 (5.1)	3.7 (5.2)
2	22.7	19.4	18.5	15.5	11.3 (12.8)	4.5 (5.3)	3.7 (5.1)	3.6 (5.0)
4	21.6	18.0	15.6	12.6	10.6 (10.8)	4.4 (4.5)	5.7 (5.2)	6.2 (6.4)
6	21.5	17.9	14.1	11.0	12.6 (11.3)	4.8 (4.8)	6.6 (5.9)	6.5 (5.6)
Low Fe	21.2	16.7	18.5	14.5	9.4 (9.5)	3.8 (3.3)	2.8 (3.4)	2.9 (3.4)

Table B2b.4 - Turbidity (NTU)

OZONE DOSE (mg/l)	RAW WATER APP	RAW WATER OZONE	DAF FLOATED	1° RGF	2° RGF
0.0	2.3	2.3	0.7 (0.8)	0.0 (0.1)	0.1 (0.1)
0.5	1.6	1.6	1.0 (1.0)	0.1 (0.1)	0.1 (0.0)
1	2.5	2.3	0.9 (0.7)	0.1 (0.1)	0.1 (0.1)
2	1.8	N/A	0.9 (1.0)	0.1 (0.1)	0.0 (0.0)
4	1.9	1.3	1.0 (0.9)	0.3 (0.1)	0.2 (0.1)
6	1.5	2.1	1.5 (1.0)	0.5 (0.1)	0.4 (0.1)
Low Fe	2.2	2.3	1.0 (1.1)	0.0 (0.1)	0.0 (0.1)

Table B2b.5 - TOC (mg/l)

OZONE DOSE (mg/l)	RAW WATER NO O3	RAW WATER OZONE	FINAL WATER
0.0	4.93	5.05	2.50 (1.84)
0.5	4.52	5.13	2.66 (2.74)
1	4.65	5.18	2.68 (2.35)
2	5.76	5.13	2.59 (3.71)
4	5.05	4.49	3.07 (3.09)
6	5.18	4.57	2.71 (2.50)
Low Fe	5.16	5.66	2.49 (2.35)

Table B2b.6 - Iron (mg/l)

OZONE DOSE (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
0.0	0.41	1.29 (1.19)	0.03 (0.03)	0.01 (0.01)
0.5	0.43	1.06 (0.96)	0.05 (0.02)	0.07 (0.03)
1	0.45	1.37 (0.99)	0.08 (0.09)	0.04 (0.07)
2	0.43	1.21 (0.90)	0.03 (0.03)	0.02 (0.02)
4	0.44	1.23 (0.93)	0.28 (0.07)	0.30 (0.09)
6	0.43	1.78 (1.04)	0.52 (0.11)	0.44 (0.07)
Low Fe	0.38	0.93 (1.58)	0.05 (0.03)	0.02 (0.01)

Table B2b.7 - Manganese (mg/l)

OZONE DOSE (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
0.0	0.21	0.23 (0.24)	0.25 (0.26)	0.00 (0.00)
0.5	0.25	0.25 (0.27)	0.25 (0.27)	0.00 (0.00)
1	0.23	0.26 (0.27)	0.28 (0.31)	0.02 (0.00)
2	0.23	0.22 (0.25)	0.23 (0.26)	0.01 (0.00)
4	0.23	0.15 (0.26)	0.12 (0.40)	0.01 (0.01)
6	0.22	0.14 (0.25)	0.10 (0.27)	0.02 (0.00)
Low Fe	0.20	0.22 (0.23)	0.21 (0.22)	0.01 (0.00)

Table B2b.8 - Aluminium (mg/l)

OZONE DOSE (mg/l)	RAW WATER	DAF FLOATED	1° RGF	2° RGF
0.0	0.40	0.29 (0.25)	0.02 (0.02)	0.03 (0.04)
0.5	0.25	0.21 (0.21)	0.02 (0.02)	0.03 (0.03)
1	0.27	0.22 (0.20)	0.04 (0.05)	0.04 (0.07)
2	0.33	0.23 (0.23)	0.01 (0.02)	0.03 (0.06)
4	0.38	0.29 (0.24)	0.06 (0.07)	0.10 (0.17)
6	0.34	0.26 (0.19)	0.07 (0.04)	0.10 (0.05)
Low Fe	0.40	0.30 (0.32)	0.02 (0.03)	0.02 (0.02)

Table B2b.9 - Hand chlorinated final water bacteriological quality

OZONE DOSE (mg/l)	COLIFORMS *		CFU	
	E-Coli	Total	1-Day	3-Day
0.0	0 (0)	0 (0)	0 (0)	0 (0)
0.5	0 (0)	0 (0)	0 (0)	0 (2)
1	0 (0)	0 (0)	0 (0)	0 (0)
2	0 (0)	0 (0)	1 (3)	0 (0)
4	0 (0)	0 (0)	1 (0)	0 (0)
6	0 (0)	0 (0)	0 (0)	0 (0)
Low Fe	0 (0)	0 (0)	0 (0)	6 (3)

* per 100 ml
CFU : colony forming unit per ml

Table B2b.9b - Ozonated raw water bacteriological quality

OZONE DOSE (mg/l)	COLIFORMS *		CFU	
	E-Coli	Total	37°C 1-Day	22°C 3-Day
0.0	3	6	10	488
0.5	1	0	100	0
1	0	8	1	68
2	0	0	4	62
4	0	0	24	0
6	0	0	0	2
Low Fe	0	0	2	712

* per 100 ml
CFU : colony forming units per ml

Table B2b.10 - Chloroform (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
		RAW	1° RGF	2° RGF
0.0	10.20 (8.47)	25.72	11.79 (10.92)	13.28 (13.00)
0.5	8.77 (7.70)	36.85	13.89 (15.88)	17.83 (16.57)
1	10.76 (10.84)	31.00	14.20 (15.36)	16.25 (16.46)
2	8.91 (N/A)	37.94	14.28 (14.68)	18.50 (18.04)
4	12.51 (12.62)	34.95	19.22 (16.36)	21.38 (19.91)
6	14.22 (12.56)	36.57	19.79 (18.42)	21.63 (19.81)
Low Fe	4.60 (4.22)	23.60	7.91 (7.53)	10.70 (9.42)

Table B2b.11 - Bromodichloromethane (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
		RAW	1° RGF	2° RGF
0.0	1.55 (1.34)	1.69	1.53 (1.50)	1.53 (1.55)
0.5	0.80 (0.82)	1.31	1.06 (1.13)	1.12 (1.22)
1	1.31 (1.30)	1.64	1.48 (1.49)	1.64 (1.53)
2	0.81 (N/A)	1.51	1.05 (1.05)	1.24 (0.95)
4	1.87 (1.85)	2.23	2.15 (2.02)	2.53 (2.14)
6	1.88 (1.90)	2.44	5.45 (1.98)	2.29 (2.14)
Low Fe	0.52 (0.53)	0.78	0.71 (0.65)	0.72 (0.70)

Table B2b.12 - Dibromochloromethane (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
		RAW	1° RGF	2° RGF
0.0	0.17 (<0.05)	<0.05	0.40 (<0.05)	<0.05 (<0.05)
0.5	<0.05 (<0.05)	<0.05	<0.05 (<0.05)	<0.05 (<0.05)
1	<0.05 (<0.05)	<0.05	<0.05 (<0.05)	0.13 (0.11)
2	<0.05 (N/A)	0.11	0.09 (0.12)	0.11 (0.09)
4	<0.05 (<0.05)	<0.05	0.37 (<0.05)	0.41 (0.36)
6	0.19 (0.22)	0.16	0.29 (0.16)	0.16 (0.18)
Low Fe	<0.05 (<0.05)	0.06	<0.05 (<0.05)	<0.05 (<0.05)

Table B2b.13 - Bromoform (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
		RAW	1° RGF	2° RGF
0.0	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
0.5	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
1	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
2	<0.03 (N/A)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
4	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
6	<0.03 (<0.03)	<0.03	<0.03 (<0.03)	<0.03 (<0.03)
Low Fe	<0.03 (<0.03)	0.34	0.23 (0.15)	0.13 (0.10)

Table B2b.14 - Total trihalomethanes (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	HAND CHLORINATED		
		RAW	1° RGF	2° RGF
0.0	11.95 (9.89)	27.49	13.75 (12.50)	14.89 (14.63)
0.5	9.65 (8.60)	38.24	15.03 (17.09)	19.03 (17.87)
1	12.15 (12.22)	32.72	15.76 (16.93)	18.05 (18.13)
2	9.80 (N/A)	39.59	15.45 (15.88)	19.88 (19.11)
4	14.46 (14.55)	37.26	21.77 (18.46)	24.35 (22.44)
6	16.32 (14.71)	39.20	25.56 (20.59)	24.11 (22.16)
Low Fe	5.20 (4.83)	24.78	8.90 (8.38)	11.60 (10.27)

Table B2b.15 - Chlorine demand (mg/l)

OZONE DOSE (mg/l)	POST Cl RESIDUAL (mg/l)	RAW WATER	1° RGF	2° RGF		
				FILTER	LAB	TOTAL
0.0	0.14 (0.13)	0.94	0.31 (0.31)	0.42 (0.39)	0.07 (0.06)	0.49 (0.45)
0.5	0.10 (0.07)	0.86	0.37 (0.35)	0.41 (0.42)	0.11 (0.12)	0.52 (0.54)
1	0.09 (0.07)	1.05	0.42 (0.40)	0.41 (0.39)	0.13 (0.15)	0.54 (0.54)
2	0.16 (0.14)	0.96	0.43 (0.39)	0.58 (0.60)	0.11 (0.10)	0.69 (0.70)
4	0.10 (0.13)	0.81	0.54 (0.32)	0.47 (0.53)	0.17 (0.14)	0.64 (0.67)
6	0.13 (0.09)	0.86	0.53 (0.29)	0.41 (0.38)	0.11 (0.10)	0.52 (0.48)
Low Fe	0.12 (0.13)	0.90	0.41 (0.33)	0.60 (0.50)	0.07 (0.07)	0.67 (0.57)

Table B2b.16 - Adsorbable organic halide (AOX) (ug/l)

OZONE DOSE (mg/l)	NON HAND CHLORINATED 2° RGF	H A N D C H L O R I N A T E D		
		RAW	1° RGF	2° RGF
1	13.9 (36.1)	48.9	16.9 (56.9)	59.3 (62.9)
2	20.8 (37.4)	66.9	28.3 (32.0)	37.0 (43.3)
4	18.4 (36.6)	62.8	20.5 (60.1)	26.3 (74.3)
Low Fe	18.4 (22.1)	61.6	20.9 (21.9)	20.3 (31.8)

Table B2b.17 - Mutagenic activity (slope value)

OZONE DOSE (mg/l)	NON CHLORINATED				HAND CHLORINATED FINAL WATER							
	TRIAL 1° RGF				TRIAL STREAM				CONTROL STRAM			
	TA 98		TA 100		TA 98		TA 100		TA 98		TA 100	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
4	0.37	0.77	0.01	0.24	2.43	1.41	15.70	8.97	3.19	5.15	15.75	16.84

PHASE II. TRIAL 3a. EFFECT OF INTERFILTRATION OZONATION (FIXED pH)

During this trial, pH control was generally good. However, there were a couple of runs where the accuracy of the 1° filtrate pH measurement was suspect. It is thought that the pH of the 1° filtrate during the second half of the trial, at ozone doses of 0.3 and 0.6 mg/l, were much higher than quoted in table B3a.2 (the actual values were probably between 7 and 8). There were also a number of occasions when the 2° filtrate pHs dropped (on one occasion as low as 7.2), and on these occasions, the sample pH was adjusted to 9.0, in the lab, before hand chlorination.

The additional 2° filters were commissioned for this trial, one in each stream contained "new" sand and the other contained the "old", conditioned sand; in the results tables the two filters are therefore headed "OLD" or "NEW".

Table B3a.1 - Chemical doses

DATE	FERRIC DOSE (mg/l)	OZONATED STREAM						CHLORINATED STREAM			
		DOSE (mg/l)		CONTACT TIME		DPD RESIDUAL		DOSE (mg/l)		RESIDUAL (mg/l)	
		NEW	OLD	NEW	OLD	NEW	OLD	NEW	OLD	NEW	OLD
25 Jan 90	3.8	0.6	0.6	8	8	-	-	0.44	0.44	0.09	0.08
30 Jan 90	3.7	0.4	0.4	8	8	-	-	0.39	0.39	0.16	0.06
6 Feb 90	4.1	2.5	2.5	8	8	-	-	0.41	0.41	0.13	0.05
13 Feb 90	2.7	5.0	5.0	8	8	4.9	5.1	0.42	0.42	0.14	0.04
20 Feb 90	2.6	1.2	1.2	RGF	15	0.9	5.0	0.47	0.47	0.08	0.04
6 Mar 90	2.5	5.0	5.0	RGF	15	0.4	3.8	0.00	0.48	0.00	0.08
13 Mar 90	2.1	0.6	0.7	RGF	15	0.0	1.6	0.00	0.43	0.00	0.06
20 Mar 90	2.1	0.3	0.3	RGF	15	0.2	1.6	0.00	0.46	0.00	0.09

Table B3a.2 - pHs

OZONATION		RAW WATER	DAF	1° RGF		2° RGF			
DOSE (mg/l)	TIME (mins)			O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	4.8	4.5	6.5	6.6	9.0	8.9	8.9	8.9
0.6	8, 8	5.0	4.7	6.6	6.6	8.9	8.9	9.0	8.9
2.5	8, 8	4.8	4.6	6.7	6.7	8.3	9.0	9.1	9.1
5.0	8, 8	4.7	4.6	6.7	6.8	9.0	9.0	9.0	7.1
0.3	RGF,15	4.9	4.6	6.8	6.9	9.0	9.0	9.1	9.1
0.6	RGF,15	4.8	4.7	6.7	6.6	8.9	8.9	9.1	9.1
1.2	RGF,15	4.8	4.6	6.7	6.6	9.0	7.2	8.7	8.8
5.0	RGF,15	4.8	4.6	6.5	6.5	8.9	8.6	8.8	8.9

Table B3a.3 - Colour: °Hazen (= Abs/m @400nm * 11)

OZONATION		RAW WATER		DAF		1°RGF		2°RGF			
DOSE (mg/l)	TIME (mins)	APP	TRUE	APP	TRUE	O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	46	21	25	3	2	2	15	15	3	3
0.6	8, 8	40	21	21	4	2	3	11	16	3	3
2.5	8, 8	43	20	19	3	3	3	8	8	4	4
5.0	8, 8	38	21	23	4	3	2	8	9	3	2
0.3	RGF,15	30	12	16	2	5	5	4	8	5	5
0.6	RGF,15	33	14	21	4	4	4	5	11	5	5
1.2	RGF,15	40	16	20	3	2	2	2	12	3	3
5.0	RGF,15	35	14	21	4	3	3	3	9	3	4

Table B3a.4 - uv Absorbance (Abs/m @ 254nm)

OZONATION		RAW WATER		DAF		1°RGF		2° RGF			
DOSE (mg/l)	TIME (mins)	APP	TRUE	APP	TRUE	O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	22.2	17.1	11.8	4.0	3.4	3.5	4.2	3.9	3.6	3.5
0.6	8, 8	21.6	17.2	11.4	4.1	3.5	3.7	3.3	3.6	3.9	4.0
2.5	8, 8	21.2	16.0	10.0	3.6	3.8	3.8	2.4	2.6	3.9	4.2
5.0	8, 8	21.0	16.0	11.3	4.2	4.3	4.2	2.5	2.5	4.1	4.2
0.3	RGF,15	16.6	11.8	9.2	3.6	6.1	6.1	5.1	5.6	5.5	5.4
0.6	RGF,15	17.6	13.3	10.3	4.0	5.5	5.6	4.9	5.1	5.3	5.2
1.2	RGF,15	20.1	15.2	11.1	4.1	3.7	3.8	2.4	3.2	3.6	3.8
5.0	RGF,15	18.4	13.6	10.7	4.2	3.5	3.4	2.0	2.0	3.5	3.4

Table B3a.4b - Ozonated 2° RGF samples before and after membrane filtration

OZONATION		BEFORE MEMBRANE FILTRATION						AFTER MEMBRANE FILTRATION					
		NEW SAND			OLD SAND			NEW SAND			OLD SAND		
DOSE (mg/l)	TIME (mins)	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l
0.4	8, 8	15	4.2	0.13	15	3.9	0.12	8	3.5	0.06	6	2.8	0.03
0.6	8, 8	11	3.3	0.09	16	3.6	0.10	-	-	-	-	-	-
2.5	8, 8	8	2.4	0.09	8	2.6	0.09	7	2.3	0.03	7	2.3	0.06
5.0	8, 8	8	2.5	0.14	9	2.5	0.14	6	1.8	0.10	7	2.0	0.11
0.3	RGF,15	4	5.1	0.01	8	5.6	0.07	-	-	-	4	4.8	0.05
0.6	RGF,15	5	4.9	0.01	11	5.1	0.08	-	-	-	7	4.5	0.05
1.2	RGF,15	2	2.4	0.02	12	3.2	0.17	-	-	-	4	2.1	0.07
5.0	RGF,15	3	2.0	0.01	9	2.0	0.12	-	-	-	7	1.5	0.08

Table B3a.5 - Turbidity (NTU)

OZONATION		RAW WATER	DAF	1° RGF		2° RGF			
DOSE (mg/l)	TIME (mins)			O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	4.9	1.7	0.1	0.1	0.9	1.1	0.1	0.1
0.6	8, 8	2.8	1.2	0.1	0.1	0.7	1.0	0.1	0.1
2.5	8, 8	4.1	1.2	0.1	0.1	0.2	0.2	0.1	0.2
5.0	8, 8	3.8	1.6	0.2	0.2	0.2	0.2	0.1	0.1
0.3	RGF,15	2.4	1.1	0.3	0.3	0.2	0.2	0.2	0.2
0.6	RGF,15	2.8	1.3	0.2	0.2	0.2	0.2	0.2	0.2
1.2	RGF,15	4.2	1.5	0.1	0.1	0.1	0.2	0.1	0.1
5.0	RGF,15	3.5	1.8	0.1	0.1	0.1	0.3	0.1	0.1

Table B3a.6 - Iron (mg/l)

OZONATION		RAW WATER	DAF	1° RGF		2° RGF			
DOSE (mg/l)	TIME (mins)			O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	0.48	1.28	0.03	0.02	0.02	0.02	0.02	0.02
0.6	8, 8	0.38	0.96	0.02	0.02	0.02	0.02	0.02	0.04
2.5	8, 8	0.40	0.90	0.03	0.03	0.03	0.03	0.01	0.01
5.0	8, 8	0.38	1.00	0.03	0.04	0.02	0.02	0.01	0.04
0.3	RGF,15	0.32	0.78	0.12	0.13	0.08	0.08	0.07	0.08
0.6	RGF,15	0.32	0.90	0.08	0.08	0.06	0.04	0.05	0.06
1.2	RGF,15	0.36	1.01	0.02	0.03	0.03	0.01	0.03	0.01
5.0	RGF,15	0.32	0.99	0.02	0.01	0.01	0.01	0.01	0.01

Table B3a.7 - Manganese (mg/l)

OZONATION		RAW WATER	DAF	1° RGF		2° RGF			
DOSE (mg/l)	TIME (mins)			O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	0.18	0.20	0.20	0.22	0.13	0.12	0.01	0.00
0.6	8, 8	0.19	0.22	0.23	0.24	0.09	0.10	0.01	0.02
2.5	8, 8	0.18	0.19	0.26	0.27	0.09	0.09	0.00	0.00
5.0	8, 8	0.18	0.19	0.28	0.26	0.14	0.14	0.00	0.01
0.3	RGF,15	0.17	0.19	0.19	0.17	0.01	0.07	0.00	0.00
0.6	RGF,15	0.18	0.19	0.18	0.18	0.01	0.08	0.00	0.00
1.2	RGF,15	0.18	0.21	0.25	0.25	0.02	0.17	0.01	0.01
5.0	RGF,15	0.18	0.20	0.25	0.24	0.01	0.12	0.00	0.00

Table B3a.8 - Aluminium (mg/l)

OZONATION		RAW WATER	DAF	1° RGF		2° RGF			
DOSE (mg/l)	TIME (mins)			O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	0.36	0.27	0.01	0.03	0.03	0.03	0.03	0.04
0.6	8, 8	0.38	0.32	0.01	0.03	0.03	0.03	0.03	0.07
2.5	8, 8	0.51	0.33	0.05	0.06	0.05	0.05	0.05	0.07
5.0	8, 8	0.36	0.30	0.08	0.07	0.10	0.10	0.10	0.12
0.3	RGF,15	0.35	0.25	0.19	0.21	0.19	0.19	0.19	0.18
0.6	RGF,15	0.54	0.28	0.14	0.12	0.12	0.13	0.12	0.11
1.2	RGF,15	0.41	0.39	0.01	0.03	0.08	0.05	0.02	0.12
5.0	RGF,15	0.37	0.30	0.04	0.02	0.04	0.06	0.04	0.04

Table B3a.9 - Total Organic Carbon (mg/l)

OZONATION		RAW WATER	2° RGF			
DOSE (mg/l)	TIME (mins)		NewO3	OldO3	NewCl	OldCl
0.4	8, 8	4.46	1.75	1.79	1.69	1.82
0.6	8, 8	4.40	1.63	1.93	1.93	1.92
2.5	8, 8	4.08	1.65	1.79	2.28	1.96
5.0	8, 8	3.83	1.31	1.42	1.65	1.74
0.3	RGF, 15	3.93	1.87	1.84	2.27	1.95
0.6	RGF, 15	3.71	2.07	1.91	1.94	1.89
1.2	RGF, 15	3.42	1.56	1.51	1.55	1.69
5.0	RGF, 15	3.35	1.72	1.29	1.59	1.86

Table B3a.10 - Hand Chlorinated Final Water Bacteriological Quality (Total Coliforms, E-Coli per 100 ml); 37°C 1-Day Colonies, 22°C 3-Day Colonies (per ml

OZONATION		OZONATED		CHLORINATED	
DOSE (mg/l)	TIME (mins)	NEW SAND	OLD SAND	NEW SAND	OLD SAND
0.4	8, 8	0, 0, 0, 0	0, 0, 0, 0	0, 0, 0, 0	0, 0, 0, 0
0.6	8, 8	0, 0, 0, 0	0, 0, 0, 0	0, 0, 1, 4	0, 0, 1, 0
2.5	8, 8	0, 0, 0, 0	0, 0, 1, 2	0, 0, 0, 0	0, 0, 1, 1
5.0	8, 8	0, 0, 1, 2	0, 0, 0, 1	0, 0, 4, 5	0, 0, 2, 1
0.3	RGF,15	0, 0, 0, 0	0, 0, 0, 6	0, 0, 1, 7	0, 0, 1, 1
0.6	RGF,15	0, 0, 0, 5	L O S T	0, 0, 0,183	0, 0, 0,34
1.2	RGF,15	0, 0, 0, 0	0, 0, 0, 0	0, 0, 0, 1	0, 0, 1, 2
5.0	RGF,15	0, 0, 0, 0	0, 0, 1, 0	0, 0, 0, 4	0, 0, 0, 0

Table B3a.11 - Chloroform (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
DOSE	TIME					RAW	1° RGF		2° RGF				
mg/l	mins	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
0.4	8,8	2.00	1.60	3.00	5.00	31.40	9.50	9.60	6.90	7.20	10.70	11.20	
0.6	8,8	<0.13	<0.13	<0.13	<0.13	35.00	4.50	5.00	1.00	1.20	7.50	8.01	*
2.5	8,8	4.62	4.51	7.33	8.04	32.53	12.22	12.35	9.54	10.06	13.28	14.04	
5.0	8,8	0.97	6.75	3.23	4.40	0.92	7.23	7.40	3.88	3.55	7.82	9.34	
0.3	RGF15	<0.13	<0.13	<0.13	0.98	20.73	6.68	6.05	3.12	2.46	5.74	7.58	
0.6	RGF15	<0.13	<0.13	<0.13	<0.13	19.27	4.05	4.82	2.85	1.75	4.76	8.04	#
1.2	RGF15	2.85	2.77	6.63	5.40	17.47	7.90	7.72	5.38	4.44	10.38	9.67	
5.0	RGF15	5.78	5.73	5.79	7.00	17.35	8.97	8.99	7.76	7.26	9.02	9.92	

* Analysed 4 days after sampling
# Analysed 3 days after sampling

Table B3a.12 - Bromodichloromethane (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
DOSE	TIME					RAW	1° RGF		2° RGF				
mg/l	mins	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
0.4	8,8	<0.01	<0.01	<0.01	<0.01	0.50	1.30	1.20	0.10	1.00	1.50	0.40	
0.6	8,8	<0.01	<0.01	<0.01	<0.01	0.90	0.10	0.10	0.10	0.10	0.20	0.20	*
2.5	8,8	0.58	0.60	0.60	0.57	1.11	0.87	0.89	0.90	0.94	0.85	0.94	
5.0	8,8	<0.01	<0.01	0.70	0.75	<0.01	0.83	0.85	0.80	0.81	0.88	0.95	
0.3	RGF15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
0.6	RGF15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	#
1.2	RGF15	<0.01	<0.01	1.31	0.76	1.12	0.90	0.88	0.88	0.87	1.79	0.99	
5.0	RGF15	1.20	<0.01	1.19	1.21	1.40	1.31	1.31	1.31	1.39	1.36	1.38	

* Analysed 4 days after sampling
# Analysed 3 days after sampling

Table B3a.13 - Dibromochloromethane (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
DOSE	TIME					RAW	1° RGF		2° RGF				
mg/l	mins	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
0.4	8,8	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
0.6	8,8	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	0.10	0.10	0.12	<0.05	*
2.5	8,8	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	0.08	0.12	0.06	<0.05	0.08	
5.0	8,8	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
0.3	RGF15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
0.6	RGF15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	#
1.2	RGF15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
5.0	RGF15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

* Analysed 4 days after sampling
# Analysed 3 days after sampling

Table B3a.14 - Bromoform (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
DOSE	TIME					RAW	1° RGF		2° RGF				
mg/l	mins	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
0.4	8,8	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
0.6	8,8	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	*
2.5	8,8	<0.03	<0.03	<0.03	<0.03	0.08	0.08	0.07	0.11	0.06	0.05	0.07	
5.0	8,8	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
0.3	RGF15	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
0.6	RGF15	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	#
1.2	RGF15	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
5.0	RGF15	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	

* Analysed 4 days after sampling
# Analysed 3 days after sampling

Table B3a.15 - Total Trihalomethanes (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
DOSE	TIME					RAW	1° RGF		2° RGF				
mg/l	mins	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
0.4	8,8	2.09	1.69	3.09	5.09	31.98	10.88	10.88	7.08	8.28	12.28	11.68	
0.6	8,8	<0.22	<0.22	<0.22	<0.22	35.98	4.68	5.25	1.23	1.43	7.85	8.29	*
2.5	8,8	5.28	5.19	8.01	8.69	33.78	13.22	13.39	10.67	11.12	14.23	15.13	
5.0	8,8	1.06	6.84	4.01	5.23	1.01	8.14	8.33	4.76	4.44	8.78	10.37	
0.3	RGF15	<0.22	<0.22	<0.22	1.07	20.82	6.77	6.14	3.21	2.55	5.83	7.67	
0.6	RGF15	<0.22	<0.22	<0.22	<0.22	19.36	4.14	4.91	2.94	1.84	4.85	8.13	#
1.2	RGF15	2.94	2.86	8.02	6.24	18.67	8.88	8.68	6.34	5.39	12.25	10.74	
5.0	RGF15	7.06	5.82	7.06	8.29	18.83	10.36	10.38	9.15	8.73	10.46	11.38	

* Analysed 4 days after sampling
# Analysed 3 days after sampling

Table B3a.16 - Chlorine demand (mg/l)

OZONATION		CHLORINE DEMAND (mg/l)										
DOSE	TIME	RAW WATER	1° RGF		CHLORINATED 2° RGF						OZONATED 2° RGF	
					NEW SAND			OLD SAND				
mg/l	(mins)		O3	Cl	RGF	Lab	Total	RGF	Lab	Total	New Sand	Old Sand
0.4	8, 8	0.85	0.31	0.28	0.23	0.06	0.29	0.33	0.06	0.39	0.23	0.17
0.6	8, 8	0.89	0.31	0.31	0.35	0.07	0.42	0.36	0.08	0.44	0.17	0.20
2.5	8, 8	0.83	0.32	0.32	0.28	0.06	0.34	0.36	0.06	0.42	0.13	0.13
5.0	8, 8	0.82	0.32	0.31	0.28	0.12	0.40	0.38	0.09	0.47	0.07	0.04
0.3	RGF,15	0.67	0.37	0.33	0.00	0.31	0.31	0.37	0.13	0.50	0.28	0.20
0.6	RGF,15	0.63	0.26	0.27	0.00	0.26	0.26	0.37	0.06	0.43	0.29	0.10
1.2	RGF,15	0.73	0.25	0.26	0.39	0.06	0.45	0.43	0.03	0.46	0.29	0.05
5.0	RGF,15	0.63	0.23	0.21	0.00	0.23	0.23	0.40	0.08	0.48	0.21	0.02

Table B3a.17 - Adsorbable organic halide (AOX) (ug/l)

OZONATION		NON HAND CHLORINATED 2° RGF				HAND CHLORINATED						
DOSE	TIME					RAW	1° RGF		2° RGF			
mg/l	(mins)	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl
0.4	8, 8	15.7	9.7	17.8	20.5	70.7	21.8	25.3	16.5	13.5	28.0	31.3
0.6	8, 8	8.3	<8	18.1	20.8	76.2	27.2	44.6	10.5	15.7	31.6	26.8
2.5	8, 8	14.5	29.6	20.9	24.8	74.8	29.6	30.5	13.7	9.3	31.9	31.0
5.0	8, 8	13.0	<8	14.3	26.8	52.0	66.6	21.4	30.0	<8	21.9	28.2
5.0	RGF,15	<8	<8	9.1	20.1	59.8	22.6	19.8	96.5	13.1	26.7	23.1

Table B3a.18 - TA 98 Mutagenic activity (slope value)

OZOATION		OZONATED 2° RGF				CHLORINATED 2° RGF			
DOSE	TIME	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
mg/l	(mins)	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
0.4	8, 8	1.67	2.63	0.56	2.67	3.61	4.55	3.18	4.01
5.0	8, 8	0.42	-0.39	-0.15	0.91	5.22	5.70	2.44	5.42
5.0	RGF,15	0.77	1.04	1.08	0.28	3.62	3.65	3.14	4.90

Table B3a.19 - TA 100 Mutagenic activity (slope value)

OZOATION		OZONATED 2° RGF				CHLORINATED 2° RGF			
DOSE	TIME	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
mg/l	(mins)	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
0.4	8, 8	6.08	5.46	10.72	6.76	18.11	15.34	16.40	12.76
5.0	8, 8	5.21	2.50	5.07	1.73	13.46	10.94	14.28	12.24
5.0	RGF,15	12.79	4.84	6.15	2.84	18.16	14.81	17.23	15.68

PHASE II. TRIAL 3b. EFFECT OF INTERFILTRATION OZONATION pH

PILOT PLANT CONTROL

The DAF and 1° filtrate pH control were reasonable during this trial. Because ozonation reduced the pH of the water the 2° filtrate pHs did not cover the target range very evenly: most of the values were grouped at the lower end of the range. The pH of each sample was adjusted to 9.0 in the lab before hand chlorination.

Table B3b.1 - Chemical Doses

DATE	FERRIC DOSE (mg/l)	OZONATED STREAM						CHLORINATED STREAM			
		DOSE (mg/l)		CONTACT TIME		DPD RESIDUAL		DOSE (mg/l)		RESIDUAL (mg/l)	
		NEW	OLD	NEW	OLD	NEW	OLD	NEW	OLD	NEW	OLD
20 Feb 90	2.6	1.2	1.2	RGF	15	0.9	5.0	0.47	0.47	0.08	0.04
27 Mar 90	2.0	1.9	1.2	RGF	15	1.1	0.0	0.00	0.57	0.00	0.09
3 Apr 90	1.8	2.1	2.4	RGF	15	5.0	0.0	0.00	0.53	0.00	0.04
10 Apr 90	1.5	1.7	2.2	RGF	15	3.5	4.5	0.00	0.59	0.00	0.07

Table B3b.2 - pH

DATE	RAW WATER	DAF	1° RGF		2° RGF			
			O3	Cl	NewO3	OldO3	NewCl	OldCl
20 Feb 90	4.8	4.6	6.7	6.6	9.0	7.2	8.7	8.8
27 Mar 90	4.9	4.7	6.1	6.2	5.9	5.7	9.3	6.1
3 Apr 90	5.2	4.8	6.5	6.4	6.6	6.6	8.8	6.9
10 Apr 90	5.2	4.8	6.3	6.3	7.2	7.0	8.8	6.8

Table B3b.3 - Colour: °Hazen (= Abs/m @400nm * 11)

NEW OZONE pH	RAW WATER		DAF		1°RGF		2°RGF			
	APP	TRUE	APP	TRUE	O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	37	11	17	3	2	2	19	11	2	1
6.6	26	11	18	3	3	2	2	11	4	3
7.2	25	9	16	3	3	3	2	12	4	3
9.0	40	16	20	3	2	2	2	12	3	3

Table B3b.4a - uv Absorbance (Abs/m @ 254nm)

NEW OZONE pH	RAW WATER		DAF		1°RGF		2° RGF			
	APP	TRUE	APP	TRUE	O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	17.4	10.4	9.4	3.4	2.7	2.7	2.7	1.7	2.9	2.2
6.6	15.4	10.3	9.2	3.7	3.8	3.6	2.4	2.6	4.0	3.9
7.2	15.1	9.5	9.7	3.8	3.6	3.7	2.2	2.9	3.8	3.5
9.0	20.1	15.2	11.1	4.1	3.7	3.8	2.4	3.2	3.6	3.8

Table B3b.4b - Ozonated 2° RGF samples before and after membrane filtration

NEW OZONE pH	BEFORE MEMBRANE FILTRATION						AFTER MEMBRANE FILTRATION					
	NEW SAND			OLD SAND			NEW SAND			OLD SAND		
	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l	COL DegH	UV Ab/m	Mn mg/l
5.9	19	2.7	0.18	11	1.7	0.10	8	2.0	0.11	1	1.0	0.03
6.6	2	2.4	0.08	11	2.6	0.07	2	2.5	0.03	6	1.8	0.01
7.2	2	2.2	0.02	12	2.9	0.18	2	1.9	0.02	10	2.5	0.14
9.0	2	2.4	0.02	12	3.2	0.17	-	-	-	4	2.1	0.07

Table B3b.5 - Turbidity (NTU)

NEW OZONE pH	RAW WATER	DAF	1° RGF		2° RGF			
			O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	4.0	1.2	0.1	0.1	0.5	0.4	0.1	0.1
6.6	1.8	1.0	0.1	0.1	0.1	0.1	0.1	0.1
7.2	1.7	1.0	0.1	0.1	0.1	0.2	0.1	0.1
9.0	4.2	1.5	0.1	0.1	0.1	0.2	0.1	0.1

Table B3b.6 - Iron (mg/l)

NEW OZONE pH	RAW WATER	DAF	1° RGF		2° RGF			
			O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	0.45	0.78	0.02	0.03	0.01	0.01	0.03	0.01
6.6	0.25	0.70	0.01	0.01	0.01	0.01	0.01	0.01
7.2	0.25	0.72	0.01	0.02	0.01	0.01	0.01	0.01
9.0	0.36	1.01	0.02	0.03	0.03	0.01	0.03	0.01

Table B3b.7 - Manganese (mg/l)

NEW OZONE pH	RAW WATER	DAF	1° RGF		2° RGF			
			O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	0.17	0.19	0.19	0.19	0.18	0.10	0.00	0.03
6.6	0.20	0.20	0.19	0.20	0.08	0.07	0.00	0.02
7.2	0.18	0.19	0.19	0.19	0.02	0.18	0.01	0.00
9.0	0.18	0.21	0.25	0.25	0.02	0.17	0.01	0.01

Table B3b.8 - Aluminium (mg/l)

NEW OZONE pH	RAW WATER	DAF	1° RGF		2° RGF			
			O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	0.38	0.29	0.03	0.01	0.01	0.02	0.03	0.01
6.6	0.33	0.26	0.01	0.01	0.16	0.00	0.06	0.02
7.2	0.33	0.24	0.03	0.03	0.03	0.02	0.03	0.02
9.0	0.41	0.39	0.01	0.03	0.08	0.05	0.02	0.12

Table B3b.9 - Total Organic Carbon (mg/l)

NEW OZONE DOSE (mg/l)	RAW WATER	2° RGF			
		NewO3	OldO3	NewCl	OldCl
5.9	3.39	1.30	1.29	1.59	1.23
6.6	3.26	1.79	1.30	1.69	2.08
7.2	3.22	1.71	1.42	1.45	1.73
9.0	3.42	1.56	1.51	1.55	1.69

Table B3b.10 - Hand Chlorinated Final Water Bacteriological Quality (Total Coliforms, E-Coli (per 100 ml); 37°C 1-Day Colonies, 22°C 3-Day Colonies (per ml)

NEW OZONE pH	OZONATED		CHLORINATED	
	NEW SAND	OLD SAND	NEW SAND	OLD SAND
5.9	0, 0, 2, 1	0, 0, 1, 0	0, 0, 0,52	0, 0, 0, 2
6.6	0, 0, 2, 1	0, 0, 1, 5	0, 0, 4, 0	0, 0, 5,17
7.2	0, 0, 0,24	0, 0, 0, 2	0, 0, 2, 3	0, 0, 0, 0
9.0	0, 0, 0, 0	0, 0, 0, 0	0, 0, 0, 1	0, 0, 1, 2

Table B3b.11 - Chloroform (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED						
					RAW	1° RGF		2° RGF			
	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	<0.1	<0.1	<0.1	<0.1	22.5	<0.1	8.7	<0.1	5.0	5.0	10.3 *
6.6	<0.13	<0.13	<0.13	2.20	23.72	4.03	3.90	2.67	4.11	5.63	12.46
7.2	<0.13	<0.13	<0.13	<0.13	20.74	6.50	9.87	3.77	4.36	7.57	11.04
9.0	2.85	2.77	6.63	5.40	17.47	7.90	7.72	5.38	4.44	10.38	9.67

* Analysed at Broughton

Table B3b.12 - Bromodichloromethane (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
					RAW	1° RGF		2° RGF				
	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
5.9	<0.1	<0.1	<0.1	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4.3	*
6.6	<0.01	<0.01	<0.01	<0.01	0.46	<0.01	<0.01	0.32	0.72	0.11	1.21	
7.2	<0.01	<0.01	<0.01	<0.01	0.58	0.28	0.97	0.32	0.56	0.48	1.75	
9.0	<0.01	<0.01	1.31	0.76	1.12	0.90	0.88	0.88	0.87	1.79	0.99	

*Analysed at Broughton

Table B3b.13 - Dibromochloromethane (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED							
					RAW	1° RGF		2° RGF				
	NewO3	OldO3	NewCl	OldCl	WATER	O3	Cl	NewO3	OldO3	NewCl	OldCl	
5.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	*
6.6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.18	<0.05	0.11	
7.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	<0.05	0.11	<0.05	0.26	
9.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

*Analysed at Broughton

Table B3b.14 - Bromoform (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED						
					RAW WATER	1° RGF		2° RGF			
	NewO3	OldO3	NewCl	OldCl		O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1 *
6.6	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
7.2	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
9.0	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

*Analysed at Broughton

Table B3b.15 - Total trihalomethanes (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED						
					RAW WATER	1° RGF		2° RGF			
	NewO3	OldO3	NewCl	OldCl		O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	<0.4	<0.4	<0.4	1.1	22.8	<0.4	9.0	<0.4	5.3	5.3	14.8 *
6.6	<0.22	<0.22	<0.22	2.29	24.26	4.12	3.99	3.07	5.04	5.82	13.81
7.2	<0.22	<0.22	<0.22	<0.22	21.40	6.86	10.99	4.17	5.06	8.13	13.08
9.0	2.94	2.86	8.02	6.24	18.67	8.88	8.68	6.34	5.39	12.25	10.74

*Analysed at Broughton

Table B3b.16 - Chlorine demand (mg/l)

NEW OZONE pH	CHLORINE DEMAND (mg/l)										
	RAW WATER	1° RGF		CHLORINATED 2° RGF						OZONATED 2° RGF	
				NEW SAND			OLD SAND			New Sand	Old Sand
		O3	Cl	RGF	Lab	Total	RGF	Lab	Total		
5.9	0.80	0.31	0.29	0.00	0.35	0.35	0.48	0.21	0.69	0.37	0.65
6.6	0.69	0.25	0.25	0.00	0.27	0.27	0.49	0.16	0.65	0.62	0.96
7.2	0.74	0.35	0.30	0.00	0.37	0.37	0.52	0.22	0.74	0.41	0.54
9.0	0.73	0.25	0.26	0.39	0.06	0.45	0.43	0.03	0.46	0.29	0.05

Table B3b.17 - Adsorbable organic halide (AOX) (ug/l)

NEW OZONE pH	NON HAND CHLORINATED 2° RGF				HAND CHLORINATED						
					RAW WATER	1° RGF		2° RGF			
	NewO3	OldO3	NewCl	OldCl		O3	Cl	NewO3	OldO3	NewCl	OldCl
5.9	8.9	9.5	<8	39.0	53.8	49.1	27.8	8.5	13.6	37.1	29.9
6.6	<8	<8	<8	35.6	71.6	29.1	27.3	11.9	12.8	30.7	44.2

Table B3b.18 - TA 98 Mutagenic activity (slope value)

NEW OZONE pH	OZONATED 2° RGF				CHLORINATED 2° RGF			
	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
5.9	1.46	1.76	1.13	1.38	2.27	3.50	2.39	5.14

Table B3b.19 - TA 100 Mutagenic activity (slope value)

NEW OZONE pH	OZONATED 2° RGF				CHLORINATED 2° RGF			
	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
5.9	9.18	11.40	3.20	6.30	16.79	15.65	17.85	20.89

TRIAL B3bR (REPEAT) - EFFECT OF OZONATION AND CHLORINATION pH

Because of the poor results from the runs investigating effect of ozonation pH, it was decided to carry out a single run to investigate ozonation pH and chlorination pH. For this run, one DAF was run without pH adjustment before the 1° RGF. The 1° RGF filtrate was then dosed with caustic before being pumped to the ozone contactors. The ozonated water was not passed through a 2° RGF prior to sampling.

Five nominal ozonation/chlorination pHs were chosen, 5, 6, 7, 8 and 9. These were the target pHs from the ozone contactor, and ozonated waters were then hand chlorinated both without further pH adjustment, and with pH adjustment to 9 in the lab. samples of 1° RGF filtrate were also pH adjusted in the lab, to enable hand chlorination (of un-ozonated water), at the target pHs.

RESULTS

Table B3bR.1a - Non hand chlorinated samples

Sample	Fe mg/l	Mn mg/l	Al mg/l	TOC mg/l	COLOUR		UV		pH	TURB NTU
					App Hazen	True Hazen	App Abs/m	True Abs/m		
RAW	0.25	0.19	0.24	-	22	7	11.6	7.2	5.5	1.7
DAF	0.77	0.20	0.09		13	2	7.2	2.9	5.4	0.8
1'RGF	0.03	0.36	0.02		2	-	2.5	-	6.4	0.1

Table B3bR.1b - Hand chlorinated raw water

ClDem mg/l	Trihalomethanes (ug/l)					AOX ug/l
	Cl3	Cl2Br	ClBr2	Br3	Total	
0.86	21.19	1.08	<0.05	<0.03	22.35	60.1

Table B3bR.2 - 1° Filtrate chlorinated at variable pH

pH		Turb	Colou	uv	ClDem	Trihalomethanes (ug/l)					AOX
Before	After	NTU	Hazen	Abs/m	mg/l	Cl3	Cl2Br	ClBr2	Br3	Total	ug/l
5.6	5.9	0.1	1	2.2	0.71	4.28	1.91	0.84	<0.03	7.06	29.9
6.0	6.2	0.2	1	2.0	0.60	5.49	2.27	0.87	<0.03	8.66	36.7
5.6	6.8	0.2	1	2.1	0.62	6.83	3.00	1.19	<0.03	11.05	16.9
6.2	8.6	0.2	2	2.3	0.55	8.36	2.07	0.52	<0.03	10.98	34.7
6.4	9.0	0.2	1	2.5	0.63	8.13	1.39	0.32	<0.03	9.87	28.7

Table B3bR.3 - Ozonated 1° filtrate chlorinated at variable pH

pH	O3 Resid	Turb	Colou	uv	ClDem	Trihalomethanes (ug/l)					AOX
	mg Cl	NTU	Hazen	Abs/m	mg/l	Cl3	Cl2Br	ClBr2	Br3	Total	ug/l
5.6	0.30	1.3	26	3.4	0.53	<0.13	0.51	0.27	<0.03	0.94	-
6.3	0.32	1.1	38	4.1	0.47	<0.13	0.66	0.44	<0.03	1.26	8.7
7.3	0.03	0.6	24	3.5	0.65	2.66	1.73	1.51	0.32	6.22	8.2
8.5	0.04	1.0	37	4.4	0.51	1.43	1.77	1.23	0.20	4.63	11.2
9.2	0.00	1.0	30	4.7	0.53	4.47	1.19	0.41	<0.03	5.74	13.9

Table B3bR.4 - Ozonated 1° filtrate chlorinated at pH 9

pH	O3 Resid mg Cl	Turb NTU	Colou Hazen	uv Abs/m	ClDem mg/l	Trihalomethanes (ug/l) Cl3	Cl2 r	ClBr2	Br3	Total	AOX ug/l
5.4	0.30	1.3	26	3.7	0.50	4.81	1.31	0.43	<0.03	6.58	15.6
6.1	0.32	1.0	34	4.2	0.29	5.03	1.32	0.42	<0.03	6.80	14.3
7.3	0.03	0.6	19	3.4	0.51	6.18	1.15	0.38	<0.03	7.74	12.8
8.4	0.04	1.0	32	4.3	0.26	5.01	1.30	0.42	<0.03	6.76	14.6
9.2	0.00	1.0	30	4.7	0.53	4.47	1.19	0.41	<0.03	5.74	13.9

PHASE II. TRIAL B3c. EFFECT OF OZONE DISINFECTION (POST OZONATION)

INTRODUCTION

As a result of the trials varying ozone dose and contact time for interfiltration ozonation, it was considered that the best way of applying ozone was to first remove manganese from the water, before applying ozone. Since one filter had been run with no interfiltration oxidant for nearly two months, and this filter had successfully removed manganese during this period, three out of the four 2° RGFs were run with no interfiltration oxidant. The remaining 2° RGF was run as a control, with chlorine applied as the interfiltration oxidant. The three un-oxidised 2° filtrates were then combined and pumped to the ozone contactor, where they were contacted with ozone for about 8 minutes, with an ozone dose of approximately 2 mg/l. The dose was chosen from the results of uv absorbance vs. ozone dose obtained in trial 3a.

RESULTS

Table B3c.1 - Doses and residuals

DATE	18 Apr 90 24 Apr 90				
FERRIC DOSE (mg Fe/l)	1.7 1.9				
	New O3	Old O3	New Cl	Old Cl	Dis
CHLORINE DOSE (mg Cl/l)	- -	- -	- -	0.57 0.49	- -
OZONE DOSE (mg O3/l)	- -	- -	- -	- -	2.6 1.9
Cl/O3 RESIDUAL (mg Cl/l equivalent)	0.00 0.00	0.00 0.00	0.00 0.00	0.13 0.09	0.40 0.15
Mn Interference (mg Cl/l equivalent)	- -	- -	- -	- -	0.07 0.03

Dis: Post ozonation contactor

Table B3c.2 - Colour, uv and turbidity

DETERMINAND	RAW WATER	DAF	1° RGF		2° R G F				
			O3	Cl	New O3	Old O3	New Cl	Old Cl	Dis
pH	5.2 5.2	4.7 4.6	6.2 6.5	6.2 6.5	9.0 8.8	8.8 8.8	8.9 8.9	9.0 8.9	7.2 7.2
APPARENT COLOUR (Degrees Hazen)	24 22	16 15	3 1	2 1	3 2	3 2	3 2	3 2	1 0
TRUE COLOUR (Degrees Hazen)	9 7	2 1	- -	- -	- -	- -	- -	- -	- -
APPARENT uv (Abs/m)	14.3 13.4	9.0 9.3	3.4 3.3	3.4 3.2	3.2 3.5	3.2 3.5	3.4 3.4	3.0 3.1	1.0 1.1
TRUE uv (Abs/m)	8.8 8.4	3.5 3.4	- -	- -	- -	- -	- -	- -	- -
TURBIDITY	1.7 1.7	1.0 1.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1

Dis: Post ozonation contactor

Table B3c.3 - Metals

DETERMINAND	RAW WATER	DAF	1° RGF		2° R G F			
			O3	Cl	New O3	Old O3	New Cl	Old Cl
IRON (mg/l)	0.36 0.24	0.93 0.97	0.01 0.01	0.02 0.01	0.05 0.05	0.02 0.01	0.05 0.01	0.01 0.01
MANGANESE (mg/l)	0.18 0.19	0.19 0.20	0.19 0.22	0.19 0.21	0.04 0.03	0.01 0.01	0.01 0.01	0.00 0.00
ALUMINIUM (mg/l)	0.31 0.31	0.22 0.25	0.02 0.03	0.03 0.02	0.03 0.03	0.03 0.03	0.03 0.02	0.03 0.03

Table B3c.4 - TOC and bacteriological quality

DETERMINAND	RAW WATER	Hand Chlorinated 2° RGF				Dis
		New O3	Old O3	New Cl	Old Cl	
TOC (mg/l)	2.88 2.91	1.47 2.11	1.51 2.00	1.68 1.70	1.55 1.84	1.32 1.70
COLIFORMS TOTAL (per 100ml)	- -	0 0	0 0	0 0	0 0	0 0
E-COLI (per 100ml)	- -	0 0	0 0	0 0	0 0	0 0
COLONIES 37°C 1-DAY (per ml)	- -	0 1	1 4	3 1	1 1	0 1
COLONIES 22°C 3-DAY (per ml)	- -	6 10	5 4	4 18	1 0	10 1

Dis: Post ozonation contactor

Table B3c.5 - Non-hand chlorinated samples: disinfection by-products

DETERMINAND	2° RGF				Dis	Dis
	New O3	Old O3	New Cl	Old Cl	Feed	Outlet
Cl3 (ug/l)	<0.13 <0.13	<0.13 <0.13	<0.13 <0.13	<0.13 <0.13	- -	<0.13 <0.13
Cl2 Br (ug/l)	<0.01 <0.01	<0.01 <0.01	<0.01 <0.01	<0.01 <0.01	- -	<0.01 <0.01
Cl Br2 (ug/l)	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	<0.05 <0.05
Br3 (ug/l)	<0.03 <0.03	<0.03 <0.03	<0.03 <0.03	<0.03 <0.03	- -	<0.03 <0.03
Total THMs (ug/l)	<0.22 <0.22	<0.22 <0.22	<0.22 <0.22	<0.22 <0.22	- -	<0.22 <0.22
AOX	-	-	-	21.6	9.6	<8

Dis: Post ozonation contactor

Table B3c.6 - Hand chlorinated samples: disinfection by-products

DETERMINAND	RAW	1° RGF		2° RGF				Dis	Dis
	WATER	O3	Cl	New O3	Old O3	New Cl	Old Cl	Feed	Outlet
Cl3 (ug/l)	21.43 24.06	3.91 5.03	3.81 4.72	- 6.09	5.43 6.68	4.97 6.07	7.06 6.63	- -	0.51 1.31
Cl2 Br (ug/l)	0.20 0.35	<0.01 0.08	<0.01 0.06	- 0.31	0.27 0.39	0.24 0.29	0.33 0.49	- -	<0.01 0.16
Cl Br2 (ug/l)	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	<0.05 <0.05
Br3 (ug/l)	<0.03 <0.03	<0.03 <0.03	<0.03 <0.03	- <0.03	<0.03 <0.03	<0.03 <0.03	<0.03 <0.03	- -	<0.03 <0.03
Total THMs (ug/l)	21.71 24.49	4.00 5.19	3.90 4.86	- 6.48	5.78 7.15	5.29 6.44	7.47 7.20	- -	0.60 1.55
AOX	64.7	29.3	27.9	-	-	-	30.3	29.4	13.6
Cl Demand (mg/l)	0.74 0.71	0.28 0.28	0.25 0.26	0.27 0.36	0.34 0.29	0.36 0.27	0.62 0.60	- 0.27	0.36 0.28

Dis: Post ozonation contactor

Table B3c.7 - Mutagenic activity (dose-response slope value)

ACTIVITY	Inter Filter Cl and Hand Chlorination	No Inter Filtration Oxidant		
			Post + Ozonation	Post + Ozonation + Hand Cl
TA 98 pH 2	2.60	0.86	0.46	0.40
TA 98 pH 7	3.22	1.63	0.03	0.54
TA 100 pH 2	15.46	0.82	0.01	9.15
TA 100 pH 7	11.88	0.94	-0.07	3.80

Negative value indicates a negative slope, i.e. notional anti-mutagenic action.

PHASE II. TRIAL 4. EFFECT OF DUAL POINT OZONATION

PILOT PLANT CONTROL

There were some problems with pH control of the 2° filters. Where this resulted in low pH, caustic was dosed in the lab, before hand chlorination, to increase the pH to 9.0.

Table B4.1 - Doses and residuals

DATE	FERRIC DOSE		OZONE DOSE		INT Cl DOSE		O3 RESIDUAL		Cl RESIDUAL	
	Trial mg/l	Cont mg/l	Pre mg/l	Inter mg/l	New mg/l	Old mg/l	New Cl eq	Old Cl eq	New mg/l	Old mg/l
1 May 90	1.7	2.1	1.1	0.9	0.00	0.48	0.00	0.00	0.00	0.00
9 May 90	1.5	2.0	0.8	0.8	0.00	0.38	0.00	0.00	0.00	0.10
15 May 90	1.9	1.9	1.8	0.5	0.00	0.44	0.00	0.00	0.00	0.08
22 May 90	1.9	1.9	1.4	0.5	0.00	0.42	0.00	0.00	0.00	0.09
30 May 90	1.9	2.5	0.4	1.7	0.00	0.39	0.00	0.01	0.00	0.07
6 Jun 90	2.1	1.6	0.5	1.7	0.00	0.41	0.00	0.00	0.00	0.06

Cl eq:DPD colour (corrected for manganese) equivalent to a chlorine residual, i.e. a check on the presence of ozone

Table B4.2 - pH

OZONE DOSE Pre/ Inter	RAW WATER	D A F		1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	Trial	Cont	New	Old	New	Old
50/50	5.2	4.6	4.7	6.4	6.4	8.6	8.2	7.4	7.2
50/50	5.2	4.7	4.6	6.8	6.6	9.2	9.1	8.8	9.1
80/20	5.2	4.6	4.4	6.4	6.4	8.6	8.4	9.0	8.9
80/20	5.2	4.7	4.8	7.0	6.8	9.2	9.2	9.2	9.3
20/80	5.4	4.6	4.7	6.6	6.6	8.8	8.8	9.0	9.0
20/80	5.4	4.8	4.6	6.6	6.5	8.9	8.9	8.9	9.0

Table B4.3 - Colour: °Hazen (= Abs/m @400nm * 11)

OZONE DOSE Pre/ Inter	RAW WATER		TRIAL DAF		CONTROL DAF		1° RGF		O3 2° RGF		Cl 2° RGF	
	App	True	App	True	App	True	Trial	Cont	New	Old	New	Old
50/50	23	7	13	2	14	2	3	2	3	4	2	2
50/50	25	7	15	2	15	2	3	2	3	4	3	2
80/20	25	5	15	1	16	2	2	2	3	4	2	2
80/20	24	5	13	1	14	1	4	2	3	3	3	2
20/80	24	5	12	1	12	1	1	1	3	5	2	1
20/80	24	5	10	1	15	2	2	3	2	3	3	3

Table B4.4 - uv absorbance (Abs/m)

OZONE DOSE Pre/ Inter	RAW WATER		TRIAL DAF		CONTROL DAF		1° RGF		03 2° RGF		Cl 2° RGF	
	App	True	App	True	App	True	Trial	Cont	New	Old	New	Old
50/50	13.1	7.9	8.1	3.2	8.3	3.8	3.4	3.4	2.0	2.2	3.5	3.1
50/50	14.2	7.8	8.4	3.1	8.4	3.2	3.4	2.6	2.3	2.5	3.0	2.7
80/20	14.1	7.7	8.6	2.8	8.9	4.0	3.5	3.5	2.7	2.7	3.5	3.4
80/20	13.1	7.1	7.2	2.2	8.3	3.3	3.9	3.7	2.4	2.5	3.7	3.2
20/80	12.9	6.9	7.2	2.6	7.3	2.6	2.8	2.9	1.7	2.3	3.0	2.9
20/80	12.7	6.7	6.7	2.4	8.8	3.0	2.9	3.7	1.4	1.6	3.7	3.5

Table B4.5 - Turbidity (NTU)

OZONE DOSE Pre/ Inter	RAW WATER	D A F		1° RGF		03 2° RGF		Cl 2° RGF	
		Trial	Cont	Trial	Cont	New	Old	New	Old
50/50	1.7	0.9	0.8	0.1	0.1	0.1	0.1	0.1	0.1
50/50	1.9	1.0	1.0	0.2	0.1	0.1	0.1	0.1	0.1
80/20	1.9	1.2	1.2	0.2	0.1	0.1	0.1	0.1	0.1
80/20	1.8	0.9	0.9	0.3	0.2	0.1	0.1	0.2	0.1
20/80	1.8	0.8	0.7	0.1	0.1	0.1	0.2	0.1	0.1
20/80	1.8	0.6	1.0	0.1	0.2	0.1	0.2	0.2	0.2

Table B4.6 - TOC (mg/l)

OZONE DOSE Pre/ Inter	RAW WATER	03 2° RGF		Cl 2° RGF	
		New	Old	New	Old
50/50	3.48	1.83	2.00	1.82	1.91
50/50	3.22	1.73	1.81	2.23	1.66
80/20	2.79	1.67	1.70	1.87	2.13
80/20	3.03	1.61	1.73	1.70	1.48
20/80	3.08	1.56	1.64	1.68	1.45
20/80	3.09	1.75	1.79	1.69	1.74

Table B4.7 - Iron (mg/l)

OZONE DOSE Pre/ Inter	RAW WATER	D A F		1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	Trial	Cont	New	Old	New	Old
50/50	0.23	0.83	0.62	0.05	0.02	0.01	0.01	0.01	0.01
50/50	0.30	0.80	0.86	0.06	0.01	0.01	0.01	0.01	0.01
80/20	0.36	0.91	0.68	0.10	0.03	0.04	0.05	0.02	0.03
80/20	0.31	0.91	0.62	0.22	0.05	0.08	0.07	0.05	0.02
20/80	0.37	0.72	0.62	0.06	0.03	0.00	0.02	0.02	0.02
20/80	0.34	0.58	0.69	0.10	0.12	0.02	0.02	0.09	0.08

Table B4.8 - Manganese (mg/l)

OZONE DOSE Pre/ Inter	RAW WATER	D A F		1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	Trial	Cont	New	Old	New	Old
50/50	0.18	0.18	0.19	0.18	0.19	0.05	0.06	0.05	0.00
50/50	0.18	0.18	0.20	0.26	0.28	0.04	0.05	0.01	0.00
80/20	0.20	0.15	0.20	0.11	0.21	0.07	0.08	0.01	0.00
80/20	0.19	0.11	0.20	0.09	0.22	0.03	0.04	0.00	0.00
20/80	0.20	0.20	0.21	0.20	0.20	0.05	0.07	0.01	0.00
20/80	0.20	0.20	0.21	0.21	0.22	0.02	0.04	0.00	0.00

Table B4.9 - Aluminium (mg/l)

OZONE DOSE Pre/ Inter	RAW WATER	D A F		1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	Trial	Cont	New	Old	New	Old
50/50	L	O	S	T	-	L	O	S	T
50/50	0.30	0.25	0.21	0.04	0.02	0.06	0.10	0.02	0.04
80/20	0.30	0.29	0.21	0.03	0.02	0.03	0.03	0.03	0.03
80/20	0.26	0.18	0.17	0.05	0.01	0.04	0.04	0.02	0.02
20/80	0.32	0.17	0.16	0.02	0.02	0.03	0.02	0.03	0.02
20/80	0.32	0.15	0.33	0.02	0.02	0.03	0.03	0.03	0.04

Table B4.10 - Hand Chlorinated Final Water Bacteriological Quality (Total Coliforms, E-Coli (per 100 ml); 37°C 1-Day Colonies, 22°C 3-Day Colonies (per ml)

OZONE DOSE Pre/ Inter	TRIAL STREAM		CONTROL STREAM	
	NEW SAND	OLD SAND	NEW SAND	OLD SAND
50/50	0, 0, 3, 5	0, 0, 0, 0	0, 0, 1, 9	0, 0, 0, 9
50/50	0, 0, 1,13	0, 0, 0,13	0, 0, 1,13	0, 0, 0, 5
80/20	0, 0, 4, 6	0, 0, 0, 0	0, 0, 0,10	0, 0, 3, 3
80/20	0, 0, 0, 6	0, 0, 0, 1	0, 0, 3, 8	0, 0, 1, 3
20/80	0, 0, 1,10	0, 0, 0, 1	0, 0, 0,19	0, 0, 0, 6
20/80	0, 0, 3, 5	0, 0, 0, 1	0, 0, 0, 6	0, 0, 3,36

Table B4.11 - Hand chlorinated chloroform (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF		
		Trial	Cont	New	Old	New	Old	
50/50	23.07	7.89	6.85	1.00	5.52	8.29	10.62	
50/50	17.49	5.29	4.02	3.07	3.30	6.42	7.78	
80/20	22.55	5.10	5.25	1.53	1.90	5.45	7.47	
80/20	23.08	6.25	6.31	3.20	3.06	5.96	6.58	
20/80	25.2	5.9	5.3	3.7	3.9	6.6	7.1	*
20/80	16.52	1.26	2.72	<0.13	<0.13	2.72	4.27	

* Analysed at Samlesbury

Table B4.12 - Hand chlorinated bromodichloromethane (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF		
		Trial	Cont	New	Old	New	Old	
50/50	0.63	0.64	0.27	0.96	0.98	0.55	0.82	
50/50	0.36	0.46	0.23	0.29	0.30	0.53	0.56	
80/20	0.71	0.23	0.12	0.57	0.72	0.17	0.43	
80/20	0.66	1.01	0.21	0.60	0.40	0.14	0.13	
20/80	1.4	1.3	0.4	1.0	1.0	0.8	0.6	*
20/80	0.69	0.82	0.37	0.43	0.41	0.35	0.45	

* Analysed at Samlesbury

Table B4.13 - Hand chlorinated dibromochloromethane (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	New	Old	New	Old
50/50	<0.05	<0.05	<0.05	0.20	0.22	<0.05	0.06
50/50	<0.05	<0.05	<0.05	0.07	0.06	<0.05	0.08
80/20	<0.05	<0.05	<0.05	0.21	0.31	<0.05	<0.05
80/20	<0.05	0.07	<0.05	0.09	0.07	<0.05	<0.05
20/80	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1 *
20/80	<0.05	0.68	<0.05	0.22	0.20	<0.05	<0.05

* Analysed at Samlesbury

Table B4.14 - Hand chlorinated bromoform (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	New	Old	New	Old
50/50	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
50/50	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
80/20	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
80/20	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
20/80	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1 *
20/80	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

* Analysed at Samlesbury

Table B4.15 - Hand chlorinated total THMs (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	New	Old	New	Old
50/50	23.78	8.61	7.20	2.19	6.75	8.92	11.53
50/50	17.93	5.83	4.33	3.46	3.69	7.03	8.45
80/20	23.34	5.41	5.45	2.34	2.96	5.70	7.98
80/20	23.82	7.36	6.60	3.92	3.56	6.18	6.79
20/80	26.8	7.4	5.9	4.9	5.1	7.6	7.9 *
20/80	17.29	2.79	3.17	0.81	0.77	3.15	4.80

* Analysed at Samlesbury

Table B4.16 - Chlorine demand (mg/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF.		Cl 2° RGF			
		Trial	Cont	New	Old	New	Old Sand RGF	LAB	TOTAL
50/50	0.73	0.37	0.31	0.37	0.33	0.37	0.48	0.20	0.68
50/50	0.79	0.41	0.33	0.42	0.39	0.35	0.28	0.14	0.42
80/20	0.81	0.45	0.33	0.37	0.35	0.40	0.36	0.19	0.55
80/20	0.78	0.44	0.31	0.36	0.33	0.32	0.33	0.13	0.46
20/80	0.73	0.43	0.30	0.30	0.25	0.37	0.32	0.17	0.49
20/80	0.76	0.40	0.30	0.33	0.37	0.31	0.35	0.21	0.56

Table B4.17 - Hand chlorinated AOX (ug/l)

OZONE DOSE Pre/ Inter	RAW WATER	1° RGF		O3 2° RGF		Cl 2° RGF	
		Trial	Cont	New	Old	New	Old
50/50	56.5	22.5	25.4	10.1	12.9	28.4	32.0
80/20	68.5	16.2	31.5	12.6	14.2	28.2	28.3
20/80	65.8	20.9	27.6	11.8	8.2	28.7	30.6

Table B4.18a- TA 98 Mutagenic activity (slope value)

OZONE DOSE Pre/ Int	OZONATED 2° RGF				CHLORINATED 2° RGF			
	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
50/50	1.23	1.05	1.67	1.11	3.83	4.31	2.62	4.41

Table B4.18b - TA 100 Mutagenic activity (slope value)

OZONE DOSE Pre/ Int	OZONATED 2° RGF				CHLORINATED 2° RGF			
	NEW SAND		OLD SAND		NEW SAND		OLD SAND	
	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7	pH 2	pH 7
50/50	12.66	5.90	13.21	5.67	19.41	14.35	20.16	15.20