8 Recommendations for further work

Details of further experimentation that could be carried out on the pool with minor or no modifications are detailed below.

8.1 Improvement of pool aeration
As the model pool employs no method of agitation to mimic bathers, it is likely that volatilisation in the model pool is lower than that found in real pools. Agitation to mimic the action of bathers could be attempted using a wave machine, which would increase surface movement of the pool water if waves were allowed to break against the side of the pool. This could easily be attached to the balance tank in the deep end of the pool. Aeration could also be achieved with the employment of a bubble mat, such as those used in home spas/baths. By positioning the bubble mat in the base of the pool, and pumping air which has been recycled from the pool hall, then a degree of controlled aeration could be achieved. This method of aeration could also be achieved by pumping air through the sampling taps which lie 1cm below the surface of the pool. This would perhaps be more representative to the splashing of bathers at the pool surface.

8.2 Testing of other technologies
There are various other technologies that are regularly used in municipal pools which could be tested using the model pool. These include using ozone and UV in conjunction (which could be achieved with no alterations to the pool) and ozone in conjunction with hydrogen peroxide ($\text{H}_2\text{O}_2$). Other halogen-based chemical disinfectant such as chloroisocyanurates and BCDMH could also be tested with very few modifications to the pool. Experiments by Black (1997), for example, have shown that using bromine-based disinfectants greatly alters the speciation and concentration of DBPs that form when compared to chlorine based disinfectants.
8.3 Experiments involving varied pH/chlorine conditions

The two experimental conditions used in experiments detailed in Section 5.14 were chosen as they are often used in municipal pools in the UK when using chlorine alone (high free chlorine) or when in combination with other technologies (low free chlorine). Since the speciation of HOCl/OCl⁻ changes greatly between the two pH values employed, then a more rigorous testing regime at various pH values would be useful in identifying an optimum pH. This is because a change in pH may decrease certain types of DBPs but increase others, depending on chlorine dose and bather load. As certain DBPs are more toxic than others, then identifying ways of reducing their formation would be of great use to pool operators. Varying one parameter at once would also give a better understanding of the effects of pH and chlorine individually on DBP formation. This is possibly the most useful and also the simplest extension to the study.

8.4 Evaluation of GAC

To ascertain whether denitrification is definitely occurring in the GAC filter, then two tests could be carried out:

1) microbiological sampling of the backwash water from the GAC filter or sampling of the media from the GAC to test for denitrifying bacteria.

2) Sampling of the DO content of the water leaving the base of the GAC filter. If denitrifying bacteria were living in the filter, then anoxic conditions would be required in parts of the GAC, resulting a drop in the DO concentration of the water at the base of the filter.

A longer test run involving GAC alone (as at the end of Run 12) would also be useful to see if GAC affects the equilibrium levels of carbon and chloramines when employed for extended periods. It would also be useful to see whether the effect of ozone/GAC and GAC alone on nitrate formation (as seen in Run 12) could be replicated, and whether using the GAC filter for an extended period has any effect on microbiological growth.
8.5 Unaccounted for TN

To see if the % of unaccounted for N is affected by slower reacting species in the BFA an experiment could be undertaken where only quick reacting species (as identified from lab based experiments) or ammonia alone are employed. Various authors have already reported the effects of chlorinating ammonia, however these have not been conducted in an open recirculating system. This data may clarify whether the TN measurement is possibly a reflection of ‘other’ nitrogenous DBPs in the pool. Another simple experiment that would clarify the source if the TN measurement, would involve ceasing BFA dosing, whilst continuing all other dosing parameters at the end of a run. If non of this unaccounted TN measurement is actually ‘other’ DBPs, then there would be a slow decrease in the unaccounted for TN measurement as it would eventually be breakpointed. It may be the case, however, that ‘other’ DBPs would also be eventually breakpointed. In this case more rigorous analysis of the pool water would have to be undertaken.

8.6 Extensive measurement of other DBPs

The DBPs that were measured throughout all runs detailed in Section 6.2 are those which are regularly measured in pool water, and those which are known to readily form under the conditions used. There are many ‘other’ DBPs, however, that are known to form under similar conditions, and that have also been measured in municipal pools (Section 3.5.2). Measurement of a wider range of DBPs in the model pool would be beneficial in two ways:

1) identifying ‘other’ routes of C, N and Cl loss from the pool and therefore adding to mass balance calculations

2) identifying the formation of potentially toxic DBPs under certain dosing conditions. This data could greatly effect the ‘optimum’ dose/conditions chosen for a particular treatment technology.

DBPs that are known to form in pools in appreciable amounts (mg/l) are MCAA and DCAA as noted by Stottmeister and Naglitsch (1996). The presence of such DBPs at this concentration (especially if they accumulate like nitrate) would have an effect on the mass balance, and decrease the unaccounted for N, Cl and possibly C in the pool. The formation of bromate and chlorate in the pool would also be of interest as they are both known carcinogens.
8.7 Improvements to air sampling method

Improving the efficiency of the air sampling method would be of great benefit for two reasons:

1) quantifying loss to the air (in terms of mass balance)
2) accurately measuring certain DBPs that are harmful to bathers and pool staff, such as THMs and nitrogen trichloride.

As Henry's Law is unlikely to be obeyed within the pool system, it is unlikely that there is a major loss of DBPs to the atmosphere, in terms of mass balance calculations, however the presence of NCl3 at low levels is known to be lachrymating (Hery et al, 1995).

The use of more complicated air sampling techniques has been detailed by authors such as Hery (1995) and Aggazzotti et al, (1995) and both of these authors have reported good air sampling efficiency rates.

8.8 Affect of other factors

Bather loading rate, pollution type, pH and chlorine concentration have all been shown to greatly affect DBP formation within the model pool. It is therefore likely that other factors such as pool air and water temperature (and in particular the difference between the two), and fresh air ventilation rate that may also affect DBP formation or loss to the pool air. As there was no air recycling within the model pool (as in normal municipal pools) it is likely that there is a greater loss of DBPs from the model pool.

Even though the ‘zero ventilation’ run showed that running the pool with no ventilation did not increase THMs in the pool atmosphere substantially, to assess whether this is true over long periods of time, then a longer experiment would have to be carried out. Even if a suitable air sampling method could not be identified to assess loss of DBPs to the pool air, it is likely that changes in loss to the atmosphere (due to varied ventilation rates) would be reflected in some way in the equilibrium levels seen in the pool water.
Intermittent dosing has also been shown by Black (1997) to affect DBP formation, and as municipal pools are only open for set hours of the day, in which there would also be peak bather loading times, then this would be an important variable to assess. The simplest test that could be undertaken is to limit the dosing time to 12 hours a day and to double the rate at which the BFA and HA is dosed, whilst allowing chlorine to pump on demand as normal. This would give a better picture of the equilibrium that is reached in a real pool, although would not account for the ‘shock’ dosing that occurs in real pools at peak times.

8.9 Loss of C to HCO$_3^-$

If 100% of the carbon not accounted for in the pool is being mineralised to CO$_2$ during standard chlorine disinfection, then build up of carbonaceous material in pool water would not be considered a problem to pool operators (unlike nitrate). If, however, formation of large amounts of HCO$_3^-$ (which is being deposited as scale) is occurring within the pool, then this could be a major problem to pool operators. Although no HCO$_3^-$ was measured in backwash water and not was visible around the edge of the pool, it may still be occurring in pipework and in dead spots. This could be costly for pool operators to remove and therefore an optimum dosing regime concerning HCO$_3^-$ formation could be identified for pools where it may be a problem.

8.10 UV extended run

Due to time restraints, it was necessary to conduct Run 14 following straight on from Run 13. This meant that materials such as unreacted N, inorganic carbon (as alkalinity) and DBPs such as nitrate had accumulated in the pool already. This may have had an effect on the subsequent formation of DBPs within the pool, and not allow a fair comparison between Run 13 and Run 14. As seen in Run 12 (when employing the use of ozone/GAC), DBP formation at the beginning and end of the run under identical dosing conditions, were very different. It is also postulated that carbon equilibrium had not been reached before UV was employed. This would also not allow a fair comparison between the two runs.
8.11 General extended run

Due to time constraints, some experiments were halted when changes were still seen to be occurring in the pool. In most of the chlorine based experiments, once a carbon and chloramine equilibrium was reached, no major changes were seen in DBP formation (except nitrate) until the end of the run. This is not the case in experiments employing ozone/GAC where some effects of using this technology occur after delays of several 100 hours, and vary with time (e.g. the effect of ozone/GAC on nitrate formation, THM speciation and IC equilibrium). The effect of GAC alone has also not been fully explored, as has the use of UV at a higher pH.