10. OVERALL CONCLUSIONS AND RECOMMENDATIONS

10.1 Research Conclusions

This research work has achieved the aim and objectives presented in Chapter 1 (section 1.4). The following section summarises the main conclusions of the study undertaken.

Algal biomass has a strong influence on the behaviour of Rhodamine WT as a tracer. Hydraulic characteristics in a WSP calculated from tracer concentration-time series may be affected by the adsorption of tracer onto in-pond suspended organic matter. The typical content of suspended organic matter in surface waters with low algal activity, during successful tracer experiments undertaken in water bodies, cannot be compared with those expected in a WSP system when primary productivity has reached its maximum rate (e.g., summer conditions); it is suggested that tracer experiments with Rhodamine WT in maturation ponds should be carried out under conditions of low suspended algal biomass, in order to minimise tracer adsorption and thus avoid unrepresentative hydraulic characteristic results.

The performance of maturation ponds is strongly dependent on weather conditions. The final effluent of two maturation ponds in series, fed with facultative pond effluent and operated under UK climate conditions, may meet the EU Urban Waste Water Treatment Directive for WSP systems (mean values of ≤25 mg filtered BOD/l and ≤150 mg SS/l). However, conventional maturation ponds in the UK would mainly contribute to improve the quality of facultative pond effluents in terms of faecal bacterial removal as they are not able to maintain throughout the year the same low ammonia concentrations found in summer. In the view of the UK environmental regulators, maturation ponds may not be able to meet either a “10/15/5” standard (BOD/SS/NH_4^+) or a “40/60” standard (BOD/SS), both as 95-percentiles.

Ammonia volatilisation had generally been reported as (or assumed to be) the main nitrogen removal mechanism in WSP. However, models developed to predict ammonium removal in WSP have been based on ammonia volatilisation rates obtained from synthetic alkaline waters with no biological activity. Ammonia volatilisation could only be considered the main mechanism for ammonium removal in waters with low algal activity and pH values higher than 8.5; very low ammonia volatilisation rates should be expected in alkaline waters with high algal activity, which is the rule in WSP systems.

Ammonia removal by volatilisation makes little or no contribution to nitrogen removal by WSP either in summer or winter. High pH and water temperature values should not necessarily favour ammonia volatilisation over alternative mechanisms like algal uptake. An increasing pond water temperature increases phytoplanktonic activity and consequently, in-pond algal biomass would take up and remove ammonium to a faster rate than expected via ammonia stripping. The increment of pH in WSP is a consequence of algal activity and it makes a little contribution to ammonia volatilisation as ammonia concentration drops due to algal uptake.

Algal nitrogen uptake was clearly identified as the major mechanism for ammonium removal under favourable environmental and operational conditions for phytoplanktonic activity in WSP. In summer, algal nitrogen uptake was found responsible for the majority of the ammonium removed and along with sedimentation of dead algal biomass, it constitutes the dominant nitrogen removal mechanism in maturation ponds. However, it is important to highlight that once dead algal biomass reaches the bottom of the pond, anaerobic digestion of pond sediments partially recycles ammonium nitrogen to the water column and hence it is to be expected that total nitrogen removal rates would be low as most of the ammonium nitrogen removed by algal uptake would be washed out as suspended solids in the pond effluent.

Nitrification can definitely be considered as an intermediate step in nitrogen transformation and removal in WSP. However, nitrification may be masked by simultaneous biochemical reactions such as biological nitrate uptake and/or denitrification. This would explain why nitrite and nitrate concentrations are commonly low in maturation pond effluents.

Nitrification-denitrification could be counted as the dominant mechanism for permanent nitrogen removal under unfavourable conditions for algal growth. In this study, the presence of denitrifiers in maturation ponds was revealed by molecular microbiology analyses. They were found not only in samples collected from the pond sidewall and sludge layer as expected, but also in water column samples. Denitrification supported either by AOB or methanotrophs in WSP may be counted as a feasible mechanism for permanent nitrogen removal both in summer and winter, but its relative supremacy over other nitrogen removal mechanisms (e.g., biological uptake) would depend upon algal activity.

Maturation ponds are clearly a suitable technology for ammonium and total nitrogen removal in warm and hot climates countries; however, the design of maturation ponds should be updated in order to achieve removal targets by improving in-pond phytoplanktonic activity. Considering that algal nitrogen uptake would be the dominant nitrogen removal mechanism under warmer weather conditions, enhanced maturation ponds should be designed, equipped and operated to facilitate algal growth and the removal of suspended solids from the final effluent. Solids removal units should be incorporated to WSP systems especially when taking into account the potential to harvest wastewater-grown algae for further economic exploitation (e.g., the production of biofuel, green fertilizer, animal food, etc.).

This study has developed a reliable procedure for studying nitrogen removal in WSP and indeed other types of wastewater treatment processes based on tracer experiments with ^{15}N stable isotopes. The results obtained have made a major contribution to our understanding of how nitrogen species are transformed and removed in WSP, and this is a necessary prerequisite for the development of an improved criterion or improved criteria for WSP system design for nitrogen removal.

10.2 Further Research

Further research is needed to improve our understanding of algal activity in WSP, which would give the ability to predict algal biomass concentrations and algal nitrogen uptake rates under specific environmental and operational conditions. Also, there is still much to understand about the nitrification-denitrification process in WSP; a sufficiently detailed understanding of the process kinetics and the identification of specialised bacterial groups would help to identify the real potential of that nitrogen removal mechanism and consequently, re-engineer current approaches used to design maturation pond. Because of increasing interest in reducing greenhouse gases (e.g., CH_4 and CO_2) and the exploitation of renewable energy sources, maturation ponds could be considered as an attractive technology not only for nitrogen control, but also for fixing carbon dioxide, reducing NOx emissions and production of biofuels; therefore, further investigation to develop high-performance and low-cost solids removal units would be highly beneficial considering the potential to harvest wastewater-grown algae for total nitrogen removal and the production of third generation biofuels (e.g., ‘algoil’).