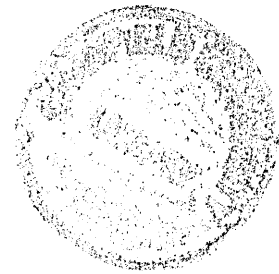


Cranfield University

Yasmin Jaffer



**Assessing the Potential of Full-scale Phosphorus
Recovery by Struvite Precipitation**

School of Water Sciences

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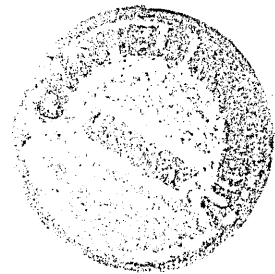
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MRes Thesis

Academic Year 1999-2000

Yasmin Jaffer



**Assessing the Potential of Full-scale Phosphorus Recovery
by Struvite Precipitation**

Supervisor: Dr S.A. Parsons
September 2000

**This thesis is submitted in partial fulfillment of the requirements for the
Degree of Master of Research**

Abstract

Formation of struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) at sewage treatment works can cause major operational problems and decrease efficiency. Struvite has a commercial value and the controlled formation of it, in a specified location, would be beneficial.

A mass balance was conducted at full-scale across a whole sewage treatment plant, to identify a stream to conduct bench-scale struvite crystallisation studies on. The most suitable stream was identified as the centrifuge liquors. The average flow of the liquor stream was $393 \text{ m}^3 \text{ d}^{-1}$ and the composition was as follows: 167 mg L^{-1} phosphorus, 44 mg L^{-1} magnesium, 615 mg L^{-1} ammonium, 56 mg L^{-1} calcium and 2580 mg L^{-1} of alkalinity. The pH averaged at 7.6 and the stream had a predicted struvite precipitation potential of 140 mg L^{-1} .

Struvite crystallisation occurred quickly during the trials, by raising the pH of the centrifuge liquors to 9.0 and dosing with magnesium. Up to 97% phosphorus removal, as struvite was achieved. Struvite formation occurred when the molar ratio of magnesium : phosphorus was at least 1.05 : 1. Below this ratio phosphorus removals of 72% were observed, but not exclusively as struvite. Annual yields of struvite were calculated to be 42-100 tonnes a year, depending on the dose regime. Revenue from the sale of produced struvite could be £8,400-20,000 a year.

Executive Summary

Introduction

The need for nutrient removal as part of the wastewater treatment process in the United Kingdom has arisen from the Urban Wastewater Treatment Directive (UWWTD) (Council of European Communities, 1991). The Directive has been formed due to increasing concerns over the condition of inland and coastal waters. The Directive sets discharge limits on certain determinants of water quality e.g. biological oxygen demand (BOD), suspended solids and the nutrients nitrogen and phosphorus. Table A shows the nutrient limits set by the UWWTD.

Table A. Nitrogen and phosphorus limits as set by the UWWTD for plants which discharge to sensitive areas (as identified in Annex II.A (a))

<i>Nutrient</i>	<i>Population Equivalents</i>	<i>Concentration</i>	<i>Minimum Percentage Reduction)</i>
<i>Total Nitrogen</i>	10,000-100,000	15 mg L ⁻¹	70%-80%
	>100,000	10 mg L ⁻¹	70-80%
<i>Total Phosphorus</i>	10,000-100,000	2 mg L ⁻¹	80%
	>100,000	1 mg L ⁻¹	80%

One option for meeting phosphorus discharges is to incorporate biological nutrient removal (BNR) into the treatment plant. BNR is becoming increasingly popular, for instance within the Thames region biological phosphorus removal is predicted to increase over 100 times within the next five years.

Effluent from BNR treatment plants are of a high quality and usually meet discharge consents. However the sludge from BNR plants are high in phosphates, which are released if the sludge is stabilised anaerobically. The released phosphates can become refixed as a number of species, one of which is struvite (MgNH₄PO₄). The formation of struvite in post-digestion equipment is an expensive and time-consuming result of BNR; it can block pipework and equipment, leading to increasing pumping costs and lost man-hours.

Slough sewage treatment works

In 1994 Thames Water agreed with the Environmental Agency to treat a larger volume of wastewater at Slough sewage treatment works (STW), before discharging to stormflow. The flow to treatment was doubled and a new plant commissioned to deal with the extra volume. It was decided to build the extension to Slough STW as a BNR plant. A three stage Barenpho plant was designed and treats approximately 75% of the flow to works. The remaining 25% is treated by the old plant.

Since the commissioning of the new plant at Slough, problems with the formation of struvite have been detected. Eight months after the new plant was operational, the pipe between the digesters and the digested sludge holding tank became blocked with an accumulation of small struvite crystals in a matrix of digested sludge solids. One year after operating, the pipeline between digested sludge holding tank and the centrifuge had become restricted to such an extent that it was no longer possible to transfer sludge to the centrifuge. The 100mm diameter pipe fittings close to the pump had been reduced to 50mm. Temporary pipework had to be installed while the problem was investigated. The pipe was 800m in length and most of it was located underground, so the full extent of the deposition was not determined. The extent of the deposition can be seen clearly in Figure A.



Figure A. Struvite deposition within a centrate pipe at Slough STW

What is struvite?

Struvite is a white crystalline substance consisting of magnesium, ammonium and phosphorus (Figure 2.2) in equal molar concentrations ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$). Struvite precipitation can be separated into two stages, nucleation and growth. Nucleation occurs when constituent ions combine to form crystal embryos. Growth is the process of incorporating constituent ions into the crystal lattice of the embryos, to form detectable crystals. Crystal growth continues until equilibrium is reached (Ohlinger *et al.*, 1999). In systems continuously replenished with struvite constituents e.g. wastewater treatment plants, crystal growth continues indefinitely. Struvite can therefore be a major problem at wastewater treatment works.

This project aims to investigate the problem at Slough STW and find possible solutions to alleviate the operational disruptions that are caused due to the formation of struvite.

Aims

The aim of this project is to create a comprehensive mass balance of phosphorus, ammonia and magnesium loads at full scale. Slough STW is to be used for this purpose as it is configured for BNR. Alongside this works, a laboratory scale process for struvite formation will be operated to assess struvite production and optimum operation.

Objectives

- To assess the movement of phosphorus, magnesium and ammonia through Slough STW.
- To assess the struvite precipitation potential (SPP) across Slough STW.
- Identify which stream is the most suitable for sidestream treatment.
- Undertake bench-scale studies to confirm the SPP of chosen stream.
- To determine optimum conditions for the bench-scale formation of struvite.

Experimental

Mass balance

Samples were taken from various sites around Slough STW. Some of the samples obtained were composite samples, as the samples were expected to be highly variable. All other samples were grab samples. Table B lists the locations of all samples taken. All samples were sent to Thames Water Quality Centre Laboratories, which has NAMAS (National Measurement Accreditation Service) accreditation. Samples were analysed for various determinants, which included phosphorus, magnesium and ammonium, the three components of struvite.

Table B **Details of sampling sites**

<i>Sample</i>	<i>Comments</i>
<i>Crude Sewage (C)</i>	Inlet after detritors. Automated sampling.
<i>Settled Sewage (S)</i>	Clarified fluid outfall. Automated sampling
<i>Effluent A (EA)</i>	Automated sampling
<i>Effluent C (EC)</i>	Automated sampling
<i>Humus Sludge (HS)</i>	From de-sludge pump for tank N°3. Pump located in a well and had to be opened manually.
<i>BNR Lanes 1-4 (B1-B4)</i>	From walkway above aeration lanes. Samples filtered on site using coffee filters
<i>RAS</i>	From RAS bell-mouth
<i>BSAS</i>	From SAS buffer tank.
<i>Thickened SAS (TSAS)</i>	From pipe valve in belt thickener room
<i>Belt thickener liquor (BTL)</i>	From sump below belts
<i>PFT Feed (PFT F)</i>	From sump by high level pump station
<i>PFT Liquors (PFT L)</i>	From overflow at the top of PFT N°1
<i>PFT Sludge (PFT S)</i>	From valve at the base of PFT N°1
<i>Imports (IMP)</i>	From pump valve in imported sludge pump house
<i>Anaerobic Digester Feed (ADF)</i>	From the feed well, at the top of digester N°3.
<i>Digested Sludge (DS)</i>	From pipe valve
<i>Centrifuge liquors (CL)</i>	From pipe feeding the centrate well, at rear of polymer storage building
<i>Centrifuge cake (CK)</i>	From cake compound area, beneath cake hopper

To calculate the daily loads of each of the determinants, the flow rates of the corresponding stream had to be determined. Initially the SCADA system from Slough STW was used to ascertain flow rates, but on closer inspection the flows did not seem accurate. Flow rates were therefore determined from other sources.

The struvite precipitation potential (SPP) for each sampling point was then calculated using a computer model called Struvite (Version 3.1). R.E Loewenthal and I.R Morrison, from the Department of Civil Engineering, University of Cape Town, developed the model. The model was developed for the Water Research Commission, South Africa and is based on work done by Lowenthal *et al.*, (1994).

Bench-Scale crystallisation studies

A bench-scale pilot plant was operated to see if struvite could be crystallised from the centrate liquors. A photograph of the pilot plant can be seen in Figure B.



Figure B **Bench-scale pilot plant**

Two peristaltic pumps (Watson and Marlow) were used to feed centrate liquors and magnesium chloride into the reactor. Aeration was supplied by an aquarium aeration unit, which consisted of a pump and two aeration stones. The conditions the pilot plant operated at, can be seen in Table C.

Table C **Reactor conditions**

<i>Parameter</i>	<i>Value</i>	<i>Units</i>
<i>Volume</i>	3.5	Litres
<i>Centrate Feed</i>	7	ml min ⁻¹
<i>Chemical Feed</i>	12	ml min ⁻¹
<i>Total Feed</i>	19	ml min ⁻¹
<i>HRT* of centrate + MgCl₂</i>	3.07	Hours
<i>Aeration</i>	220 (x2)	ml min ⁻¹

The reactor was fed with centrate liquors obtained from Slough STW. The liquors were collected in 25L plastic containers and stored at room temperature. The pH of the liquors were recorded and then adjusted to 9.0, using 20% sodium hydroxide solution. Samples of the liquors prior to pH adjustment and after pH adjustment were taken and sent to the Thames Water Centre Laboratories for analysis. Samples were taken before and after pH adjustment to determine if raising the pH affected the chemical composition of the liquors.

The reactor was also fed with magnesium chloride, which was obtained from NedMag chemicals. Solutions of the required concentration of magnesium were prepared using deionised water and tested with Dr Lange kit LCK 326 to verify the amount of magnesium present. Deionised water was used to prevent the addition of extra magnesium and calcium ions, due to the hardness of the water in the Thames region.

On the spot analysis was carried out on the effluent samples for pH, ammoniacal nitrogen ($\text{NH}_4\text{-N}$), soluble phosphorus (P-PO_4), total phosphorus (P.tot) and total magnesium (Mg.tot). Spot analyses were carried out using Dr Langer test kits.

Results

Mass Balance

The results of the mass balance determinations can be seen in Figure C. From the mass balance it was concluded that the centrifuge liquor stream at Slough STW would be the most suitable stream to conduct bench-scale crystallisation studies on. A previous study had identified the surplus activated sludge liquors as a potential stream for crystallisation, but this work did not confirm this result.

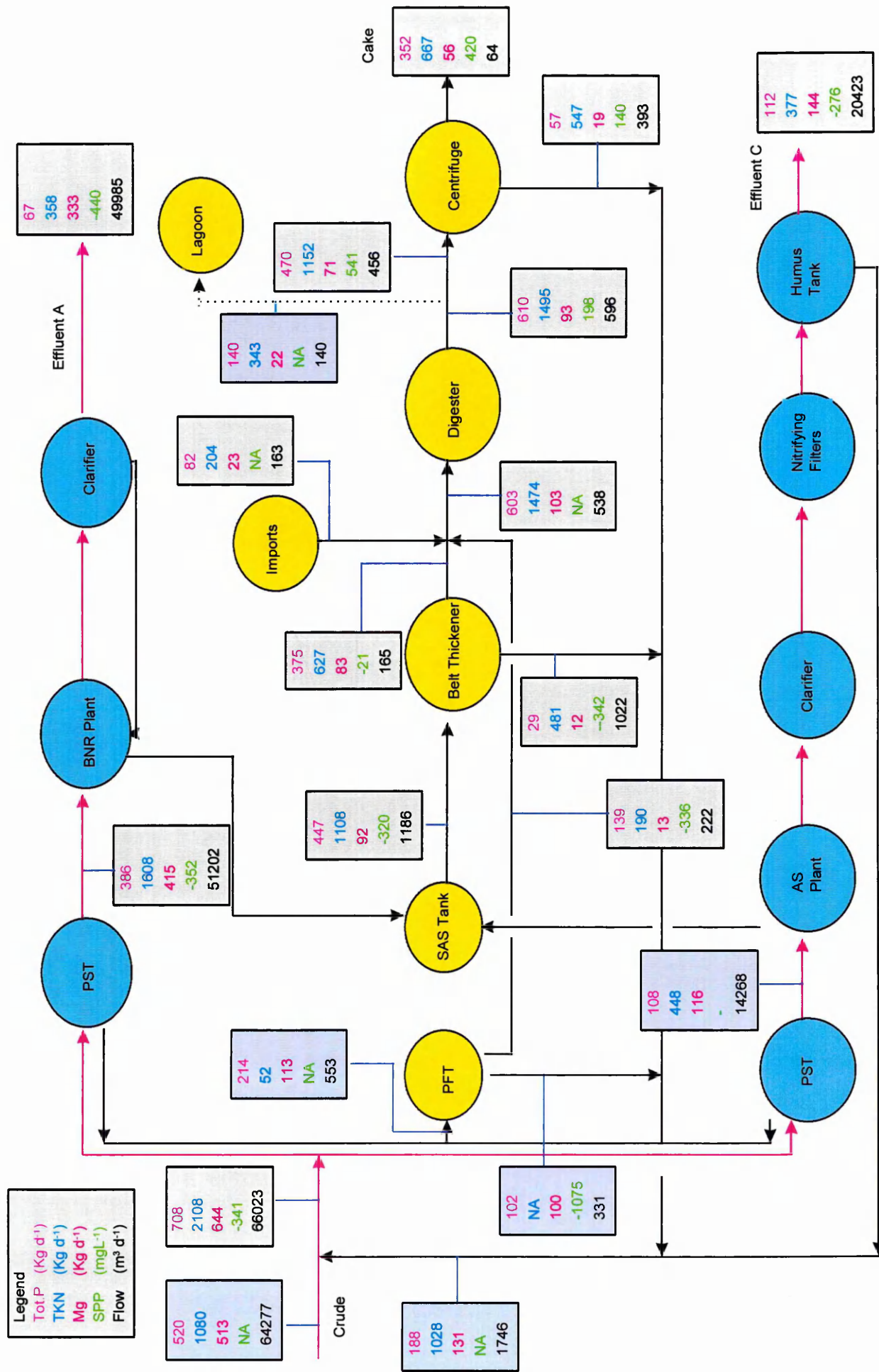


Figure C Mass Balance of phosphorus, ammonia and magnesium at Slough STW

Bench-scale crystallisation studies

The pilot plant was started on the 7th July, using centrifuge liquors and a dose of 252 mg L⁻¹ of MgCl₂. Crystals were seen on the surface of the porous pot, by the 8th of July. Samples of crystals were taken and analysed by x-ray diffraction (XRD) at the laboratories at Cranfield university. The crystals produced were validated to be struvite and were of a high purity.

Once it was established that struvite could be formed from the centrifuge liquors at Slough STW, the magnesium dose to the pilot plant was altered to determine an optimum dosing regime. Figure D shows the influent and effluent concentrations of ammonia, phosphorus and magnesium when the pilot plant was dosed with 252 mg L⁻¹ of MgCl₂.

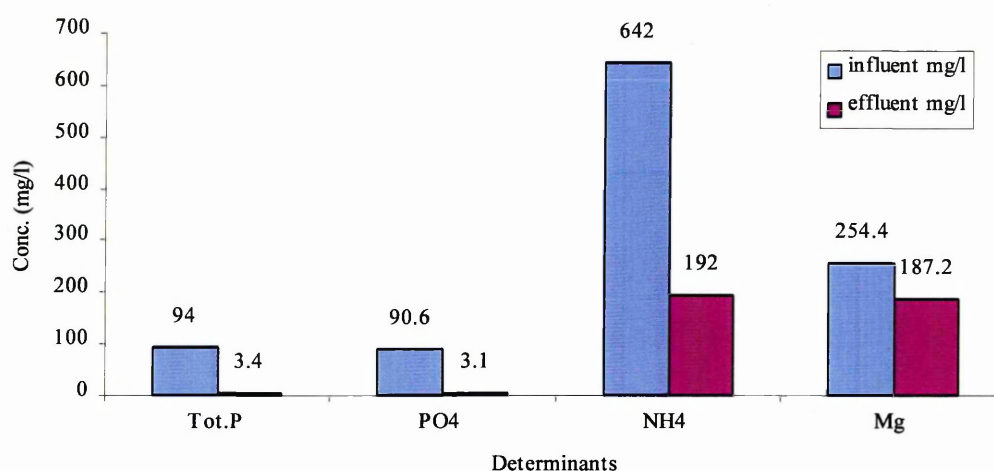


Figure D Influent and effluent concentrations of struvite components with a magnesium addition of 252 mg L⁻¹

The dosing regime equated to a magnesium : phosphorus (Mg : P) ratio of approximately 3.5 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 96%. The soluble phosphorus was reduced by 97% and the ammonium by 70%. The ratio of P_{sol} : NH₄ : Mg removed in the pilot plant was 2.8 : 32 : 2.8 (mM L⁻¹). The 1:1 ratio of P : Mg shows that the phosphorus is probably being removed as struvite. The mass of struvite

formed was 0.69 g L^{-1} (assuming one mole of struvite weighs 245 g i.e. water of crystallisation is taken into account). On a plant the size of Slough STW, which has an average centrifuge liquor flow of 393 m^3 , this would be equivalent to 271 Kg d^{-1} . On a yearly basis approximately 100 tons of struvite could be formed with this dosing regime.

The ammonium removal was greater than the requirement for struvite. The surplus ammonium is probably being removed from the reactor by air stripping. The ammonia is being volatilised and converted into a gaseous form by the high pH in the reactor and the air flow. Ammonium removal by air stripping is a method used in treatment works for the reduction of nitrogen from wastewater.

The magnesium dose was sequentially reduced to find the least magnesium dose that could be used to guarantee phosphorus removal exclusively as struvite. The dosage was found to be approximately 83 mg L^{-1} of magnesium. The results of this experiment are shown in Figure E.

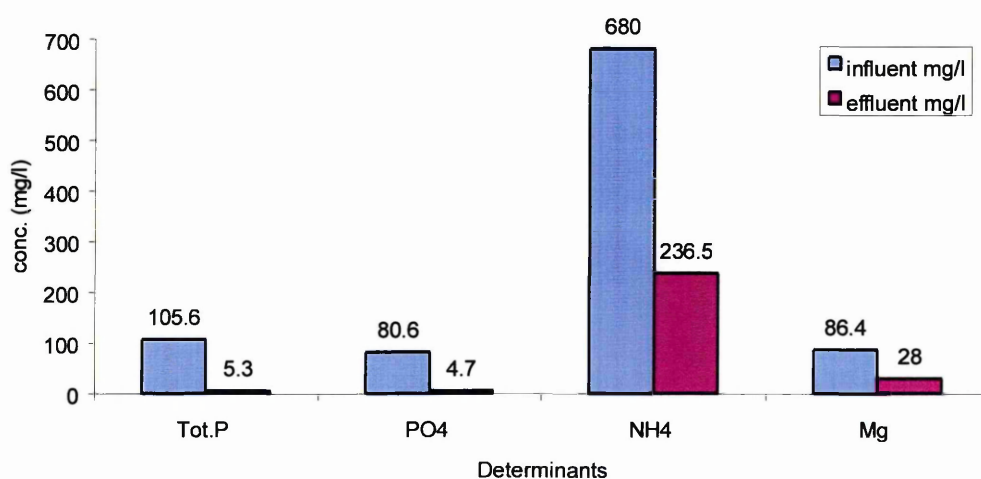


Figure E Influent and effluent concentrations of struvite components with a magnesium addition of 82.7 mg L^{-1}

The dosing regime equated to a Mg:P ratio of approximately 1.05 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 95%. Dosage levels below 1.05 :1 removed phosphorus, but not solely as struvite. At the lowest magnesium dose evaluated, 36.3 mg L⁻¹, 88% phosphorus removal was achieved, but not only as struvite. When no magnesium was added to the reactor only 19% phosphorus removal was accomplished, but none of the magnesium entering the reactor in the centrifuge liquors was removed.

Costs of a full-scale plant

The costs of a pilot plant, with a capacity to treat all of the average centrifuge liquor flow was estimated. The costs were based on the addition of chemicals only and did not take into account the civil engineering of a side-stream phosphorus removal process. The cost to build a full-scale struvite crystallisation plant, based on the Phosnix process would be in the region of £200,000 (personal communication, Thames Water Engineering). The annual chemical cost of phosphorus removal as struvite is shown in Figure F.

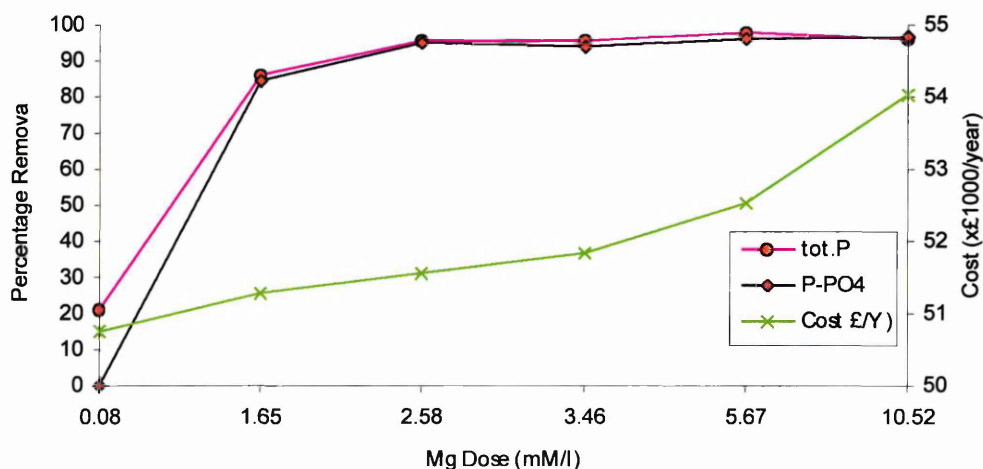


Figure F Estimated annual chemical cost of phosphorus removal by struvite precipitation

As the percentage phosphorus removal increases the cost of chemical addition also increases. Between a magnesium dose of 2.6 to 10.5 mM L⁻¹ (62-253 mgL⁻¹) the percentage phosphorus removal ranges between 96-97% i.e. there is no difference in phosphorus removal. In terms of phosphorus removal there is no benefit to be gained by increasing the magnesium dose above 62 mgL⁻¹. However in terms of struvite production the magnesium dose needs to be around 83 mgL⁻¹ (3.5 mM L⁻¹ Mg). This increase in dose, increases the cost from £51,500 to £52,000. The increase in cost, in terms of increasing magnesium dose is small. The majority of the chemical costs can be attributed to the addition of sodium hydroxide, to raise the pH.

The cost of sodium hydroxide was based on the amount required to raise the pH of the centrifuge liquors from 7.5 to 9.0, during the bench-scale work. The amount of sodium hydroxide required was around 150 ml per 25 litres. Considering the flow of centrifuge liquors at Slough STW a dose of 2.36 m³d⁻¹ of sodium hydroxide would be required to raise the pH to 9.0 at full-scale. Assuming the cost of sodium hydroxide is £59 ton⁻¹, the daily cost of sodium hydroxide addition would be £139, or £50,735 per year. 97% of the total chemical cost can be attributed to the addition of sodium hydroxide.

Table D summaries the amount of struvite that could be produced at full-scale at each of the dosing regimes used during the bench-scale work. The percentage removals of phosphorus are also included in the table. The amount of struvite produced is based on the amount magnesium used in the reactor. By using the magnesium results it is assumed that all the magnesium used in the reactor is due to the formation of struvite. Daily struvite production rates were based on average centrifuge liquor flows.

Table D Possible production of struvite at full-scale

<i>Mg dose</i> <i>mg L⁻¹</i>	<i>Bench-scale production of struvite</i> <i>mM L⁻¹</i>	<i>Full-scale production of struvite</i> <i>Kg d⁻¹</i>	<i>Full-scale production of struvite</i> <i>ton y⁻¹</i>	<i>Possible income from struvite*</i> <i>£ y⁻¹</i>	<i>Tot. Phosphorus removal</i> <i>%</i>
0	0	0	0	0	19
36	1.2	116	42	8,400	88
62	1.8	173	63	12,600	95
83	2.4	231	84	16,800	95
136	2.6	250	91	18,200	97
252	2.8	272	99	19,800	96

* Based on a price of £200 per tonne

Conclusions

- 26% of the phosphorus load to treatment is due to phosphorus feedback.
- The centrifuge liquor is the most suitable stream for sidestream treatment.
- At bench-scale, struvite can be formed rapidly by raising the pH to 9.0 and a magnesium addition of at least 1.05 :1 magnesium : phosphorus. A magnesium addition lower than the 1.05 : 1 ratio will result in a mixture of struvite and hydroxyapatite. At full-scale a magnesium dose of 1.3 : 1 is recommended.
- 97% phosphorus removal as struvite can be achieved.
- Chemical costs of a full-scale struvite crystallisation plant will be at least £50,000 per annum. The addition of sodium hydroxide to raise the pH, accounts for 97% of this cost.
- Revenue of £16,000-20,000 can be generated from selling the struvite produced.

Further Work

- Evaluate the use of magnesium hydroxide as a source of magnesium and base addition. Raising the pH of centrifuge liquors by sodium hydroxide is expensive, so by using a dual function chemical cost savings can be made.
- Investigate the effects of lower pH on the system effectiveness. Some pilot studies have been carried out on digested sludge supernatant, with no pH correction. Again, by eliminating the requirement for sodium hydroxide, cost savings can be achieved.

Preliminary studies have been started in this area, giving 80% phosphorus removal. As yet, the purity of the product is unknown.

- Examine methods to increase the size of the struvite crystals produced. At present, the product resembles a powder. A more granular product would be desirable, as it would be easier to handle.
- Look at possible ways of releasing the phosphorus bound in the centrifuge cake and placing it in the centrifuge liquors. By increasing the phosphorus content of the centrifuge liquors, the yield of struvite could be increased.
- Scale-up the bench work to an on-site pilot plant.

Contents	Page No
Abstract.....	I
Executive Summary.....	II
 Chapter 1 Introduction.....	 1
2.1 Slough Sewage Treatment Works.....	3
 Chapter 2 Literature Review.....	 7
2.1 Urban Wastewater Treatment Directive.....	7
2.2 Sources of Phosphorus.....	8
2.2.1 Chemical Phosphorus Removal.....	8
2.2.2 Biological Nutrient Removal.....	9
2.3 What is Struvite?	13
2.4 Deposition of Struvite within Wastewater Treatment Plants.....	13
2.5 Sources of Struvite Components.....	14
2.5.1 Phosphorus.....	14
2.5.2 Ammonium.....	14
2.5.3 Magnesium.....	15
2.6 Struvite Formation.....	16
2.6.1 Mass Balances.....	20
2.7 Controlling Struvite Formation.....	21
2.8 Beneficial Formation of Struvite.....	23
2.8.1 Additional Nitrogen and Phosphorus Removal.....	24
2.9 Pilot-Scale Production of Struvite using Digested Sludge Supernatant.....	25
2.10 Commercial Struvite Precipitation Technologies.....	26
2.11 Economic Feasibility.....	27
2.12 Summary	29
 Chapter 3 Aims and Objectives.....	 31
 Chapter 4 Experimental.....	 32

4.1	Slough STW.....	32
4.1.1	Works Inlet.....	32
4.1.2	Treatment Stream “C”.....	33
4.1.2.1	Primary Treatment.....	33
4.1.2.2	Secondary Treatment.....	33
4.1.3	Treatment Stream “A”.....	33
4.1.3.1	Primary Treatment.....	33
4.1.3.2	Secondary Treatment.....	33
4.1.4	Sludge Treatment.....	34
4.1.5	Digestion and Gas Management.....	35
4.1.6	Dewatering.....	35
4.2	Mass Balance.....	35
4.2.1	Sampling.....	35
4.2.2	Sample Analysis.....	36
4.2.3	Conversion of Units.....	39
4.2.4	Flow Rates.....	40
4.2.5	Struvite Precipitation Potential.....	41
4.3	Pilot Plant.....	42
4.3.1	Pilot Plant Feed.....	43
4.3.2	Analysis.....	44
Chapter 5	Results.....	46
5.1	Flows.....	46
5.2	Wastewater characteristics.....	47
5.2.1	Influent and Effluent Streams.....	47
5.2.2	BNR Lanes.....	49
5.2.3	Return Activated Sludge.....	50
5.2.4	Other Sludge Streams.....	51
5.3	Magnesium, Ammonium and Phosphorus Through Slough STW.....	56
5.4	Mass Balance Across Slough STW.....	58
5.5	Possible Ways to Reduce the Struvite Precipitation Potential.....	62

5.5.1	Dilute Digested Sludge with Belt Thickener Liquor.....	62
5.5.2	Dilute Centrifuge Liquor with Belt Thickener Liquor.....	63
5.5.3	Lower pH of Digested Sludge.....	63
5.5.4	Side-stream Treatment to Remove Phosphorus.....	63
5.6	Bench-scale Struvite Precipitation using Centrifuge Liquors.....	64
5.6.1	Struvite Crystallisation.....	64
5.6.2	Optimum Magnesium Dose.....	65
5.6.3	Costs.....	73
Chapter 6	Discussion.....	76
6.1	Wastewater Characteristics.....	76
6.1.2	Phosphorus Recycle.....	78
6.1.3	Reducing the Struvite Precipitation Potential.....	78
6.2	Bench-scale Struvite Formation.....	79
6.3	Cost Considerations.....	81
Chapter 7	Conclusions.....	84
Chapter 8	Further Work.....	86
References.....		87
Appendix A	Raw Data	
Appendix B	On-site Sampling Log and Site Map	
Appendix C	Chemical Information	
Appendix D	Contact Details	

List Of Tables	Page N°
Table 1.1	Consents for Slough STW..... 4
Table 2.1	Nitrogen and phosphorus limits, as set by the UWWTD for plants which discharge to sensitive areas..... 7
Table 2.2	Sources of phosphorus in Europe..... 8
Table 2.3	Typical effluent quality achieved by BNR..... 11
Table 2.4	Comparison of BNR sludge and activated sludge..... 11
Table 2.5	Comparison of minimum ionic concentration required for struvite formation and actual concentrations in digesters..... 16
Table 2.6	Comparison of struvite solubility products..... 17
Table 2.7	Comparison of ideal pH values for struvite formation..... 18
Table 4.1	Details of sampling sites..... 37
Table 4.2	List of determinants and how they were measured..... 38
Table 4.3	Details of sample analysis..... 39
Table 4.4	Reactor conditions..... 43
Table 4.5	Laboratory analysis of centrate liquors..... 44
Table 4.6	Tests used for spot analysis..... 45
Table 5.1	Average flows of various streams..... 46
Table 5.2	Characteristics of influent and effluent streams..... 47
Table 5.3	Characteristics of BNR lanes 49
Table 5.4	Characteristics of RAS from AS and BNR plant..... 51
Table 5.5	PFT Streams..... 52
Table 5.6	SAS Streams..... 53
Table 5.7	Imported Sludge..... 54

Table 5.8	Digester influent and effluent.....	54
Table 5.9	Centrifuge streams.....	55
Table 5.10	Sampling location numbers.....	57
Table 5.11	Data used to calculate SPP of various streams.....	61
Table 5.12	Analysis of centrate liquor before and after pH adjustment.....	64
Table 5.13	Other analysis performed by Thames Laboratories on pilot plant effluent.....	70
Table 5.14	Cost of chemical addition.....	75
Table 5.15	Possible production of struvite at full-scale.....	75
Table 6.1	Previous wastewater characteristics at Slough STW.....	76

List of Figures	Page N°
Figure 1.1	Levels of wastewater treatment in four E.U member states in 1994..... 1
Figure 1.2	Predicted levels of wastewater treatment in four EU Member States after the implementation of the UWWTD..... 2
Figure 1.3	Current trends in phosphorus removal techniques in Thames Water..... 2
Figure 1.4	Predicted trends in phosphorus removal techniques in Thames Water..... 3
Figure 1.5	Struvite deposition within a centrate pipe at Slough STW..... 5
Figure 1.6	Diagram of Slough STW..... 6
Figure 2.1	Schematic diagram of a BNR reactor 10
Figure 2.2	Struvite crystals..... 13
Figure 2.3	How pH effects the SPP of a solution..... 17
Figure 2.4	An example of a full wastewater treatment works mass balance..... 21
Figure 2.5	Outline of Phosnix process..... 27
Figure 2.6	Struvite deposits in a digested sludge pump..... 29
Figure 2.7	Struvite deposition on a Klampress belt thickener..... 30
Figure 4.1	Diagram of Pilot Plant..... 42
Figure 4.2	Bench-scale pilot plant..... 42
Figure 5.1	Concentration of magnesium, total phosphorus and ammonia through Slough STW..... 57
Figure 5.2	Concentration of magnesium, soluble phosphorus and ammonia through Slough STW..... 58

Figure 5.3	Mass balance of phosphorus, TKN and magnesium across Slough STW.....	60
Figure 5.4	XRD of crystals produced in pilot plant.....	65
Figure 5.5	Influent and effluent concentrations of struvite components with a magnesium addition of 252 mg L ⁻¹	66
Figure 5.6	Influent and effluent concentrations of struvite components with a magnesium addition of 136 mg L ⁻¹	67
Figure 5.7	Influent and effluent concentrations of struvite components with a magnesium addition of 82.7 mg L ⁻¹	68
Figure 5.8	Influent and effluent concentrations of struvite components with a magnesium addition of 62.1 mg L ⁻¹	69
Figure 5.9	Influent and effluent concentrations of struvite components with a magnesium addition of 36.3 mg L ⁻¹	70
Figure 5.10	Influent and effluent concentrations of struvite components with no magnesium addition.....	71
Figure 5.11	Percentage removal of phosphorus and ammonia with increasing magnesium dose.....	72
Figure 5.12	Molar removal of phosphorus and ammonia and molar usage of magnesium, against molar addition of magnesium.....	72
Figure 5.13	Molar removal of phosphorus and molar usage of magnesium, against molar addition of magnesium.....	73
Figure 5.14	Estimated annual cost of phosphorus removal by struvite precipitation.....	74

1.0 Introduction

Phosphorus pollution in surface waters can lead to problems with eutrophication in the receiving water. A number of legislative initiatives exist to overcome this problem, one of which is the Urban Wastewater Treatment Directive 91/271 (UWWTD). The widespread implementation of the UWWTD has led to an expansion in secondary and tertiary wastewater treatment in Europe to meet new discharge standards (Figures 1.1 and 1.2).

One option for meeting phosphorus discharges is to incorporate biological nutrient removal (BNR) into the treatment plant. BNR is becoming increasingly popular, for instance within the Thames region biological phosphorus removal is predicted to increase over 100 times within the next five years (Figures 1.3 and 1.4). It should be noted that these figures are based on population equivalents (PE) and not on the number of sites.

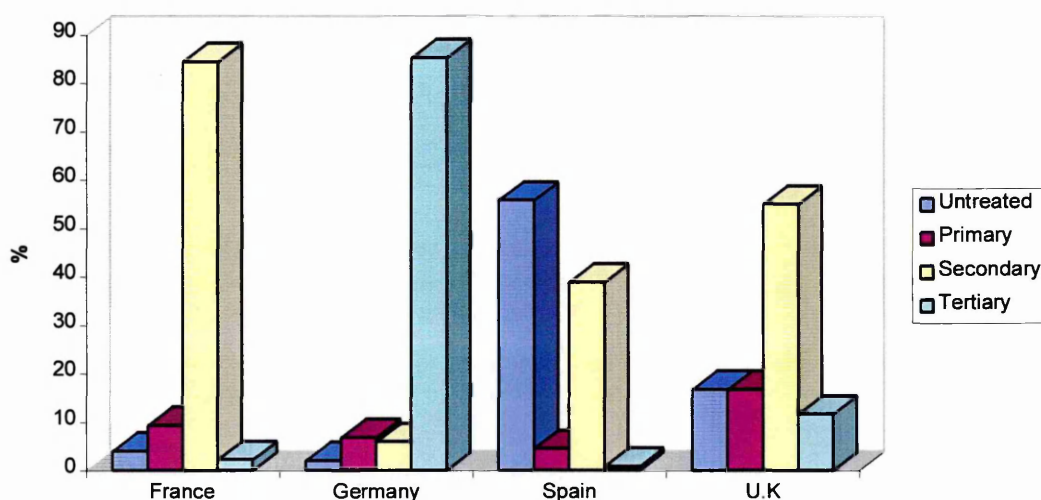


Figure 1.1 Levels of wastewater treatment in four E.U. member states in 1994

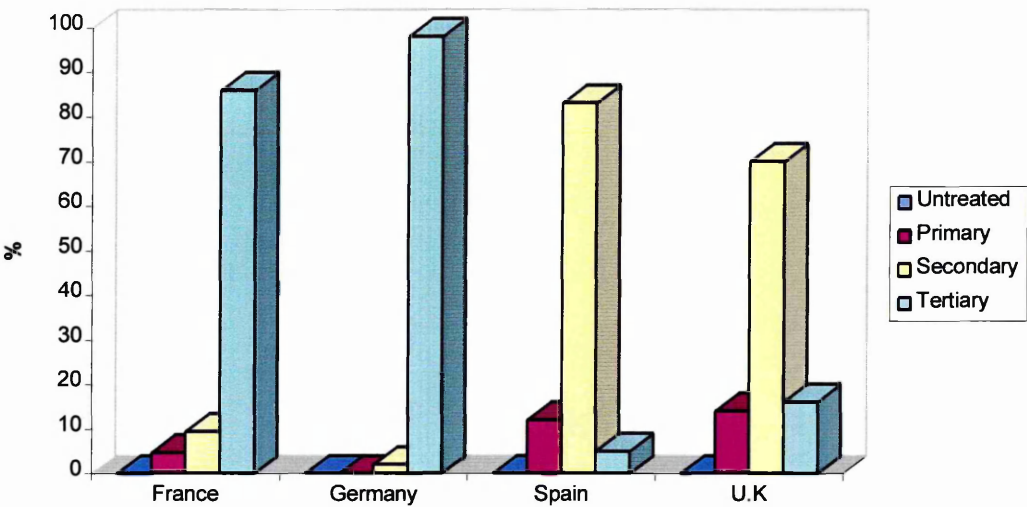


Figure 1.2 Predicted levels of wastewater treatment in four EU member states after the implementation of the UWWTD

Effluent from BNR treatment plants are of a high quality and usually meet discharge consents. However the sludge from BNR plants are high in phosphates, which are released if the sludge is stabilised anaerobically. The released phosphates can become refixed as a number of species, one of which is struvite (MgNH_4PO_4). The formation of struvite in post-digestion equipment is an expensive and time-consuming result of BNR; it can block pipework and equipment, leading to increasing pumping costs and lost man-hours.

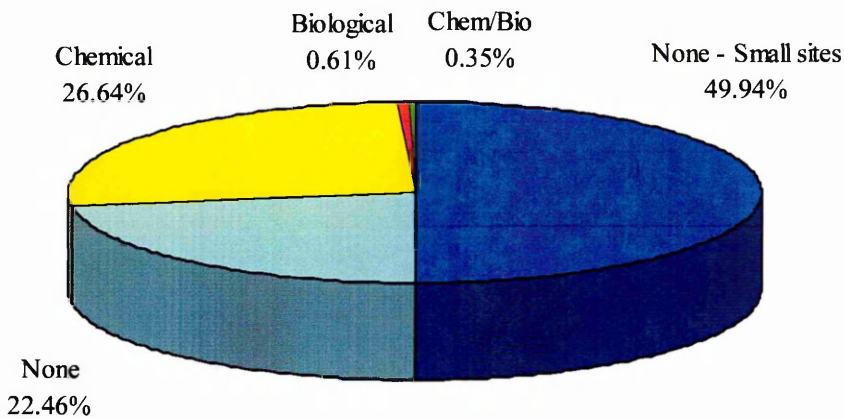


Figure 1.3 Current trends in phosphorus removal techniques in Thames Water (based on PE)

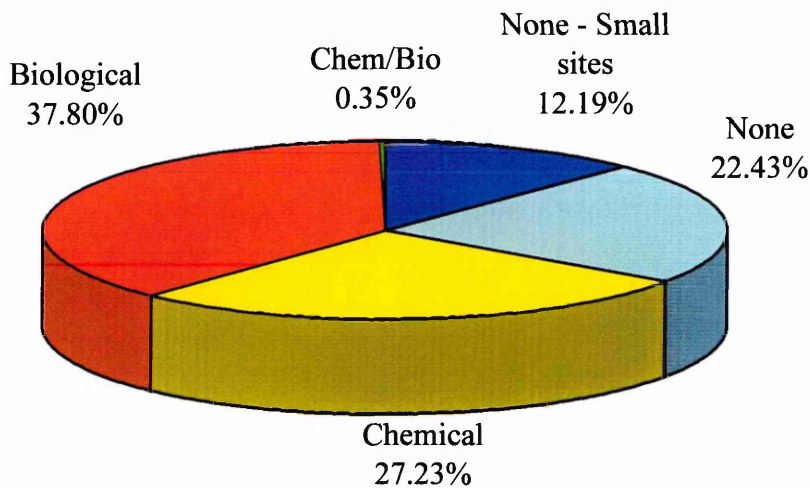


Figure 1.4 Predicted trends in phosphorus removal techniques in Thames Water (based on PE)

1.1 Slough Sewage Treatment Works

Slough is a complicated works as it has two parallel treatment streams. Figure 1.6 shows a simplified diagram representing Slough sewage treatment works (STW). Up until 1996 the wastewater at Slough STW was treated using a two stage biological process, the first stage being an activated sludge plant and the second stage, nitrifying filters.

In 1994 Thames Water agreed with the Environmental Agency to treat a larger volume of wastewater before discharging to stormflow. The flow to treatment was doubled and a new plant commissioned to deal with the extra volume. It was decided to build the extension to Slough STW as a BNR plant. A three stage Barenpho plant was designed and treats approximately 75% of the flow to works. The remaining 25% is treated by the old plant.

At present there is no phosphorus consent for Slough, although with the AMP 3 (asset management plan), a consent of 1 mg L^{-1} will be enforced by the year 2004 (Table 1.1)

Table 1.1 **Consents for Slough STW**

<i>Determinant</i>	<i>Value</i>	<i>Determinant</i>	<i>Value</i>
<i>Suspended Solids</i>	30 mg L^{-1}	<i>Lead</i>	$20\text{ }\mu\text{g L}^{-1}$
<i>BOD</i>	20 mg L^{-1}	<i>Iron</i>	$520\text{ }\mu\text{g L}^{-1}$
<i>Ammonical Nitrogen</i>	9 mg L^{-1}	<i>HCH</i>	$0.5\text{ }\mu\text{g L}^{-1}$
<i>Copper</i>	$60\text{ }\mu\text{g L}^{-1}$	<i>Chloroform</i>	$4\text{ }\mu\text{g L}^{-1}$
<i>Zinc</i>	$310\text{ }\mu\text{g L}^{-1}$	<i>Boron</i>	$2500\text{ }\mu\text{g L}^{-1}$
<i>Chromium</i>	$30\text{ }\mu\text{g L}^{-1}$	<i>Nickel</i>	$80\text{ }\mu\text{g L}^{-1}$

Since the commissioning of the new plant at Slough, problems with the formation of struvite have been detected. Eight months after the new plant was operational, the pipe between the digesters and the digested sludge holding tank became blocked with an accumulation of small struvite crystals in a matrix of digested sludge solids. One year after operating, the pipeline between digested sludge holding tank and the centrifuge had become restricted to such an extent that it was no longer possible to transfer sludge to the centrifuge. The 100mm diameter pipe fittings close to the pump had been reduced to 50mm. Temporary pipework had to be installed while the problem was investigated. The pipe was 800m in length and most of it was located underground, so

the full extent of the deposition was not determined. The extent of the deposition can be seen clearly in Figure 1.5.



Figure 1.5 Struvite deposition within a centrate pipe at Slough STW

As a temporary measure, pipes were cleaned with an acidic solution and flushed through to remove the struvite. The problem of struvite formation at Slough STW still exists and a time consuming maintenance program has been incorporated to try and keep the problem manageable. As yet no long term solution has been found to improve the situation.

This project aims to investigate the problem at Slough STW and find possible solutions to alleviate the operational disruptions that are caused due to the formation of struvite.

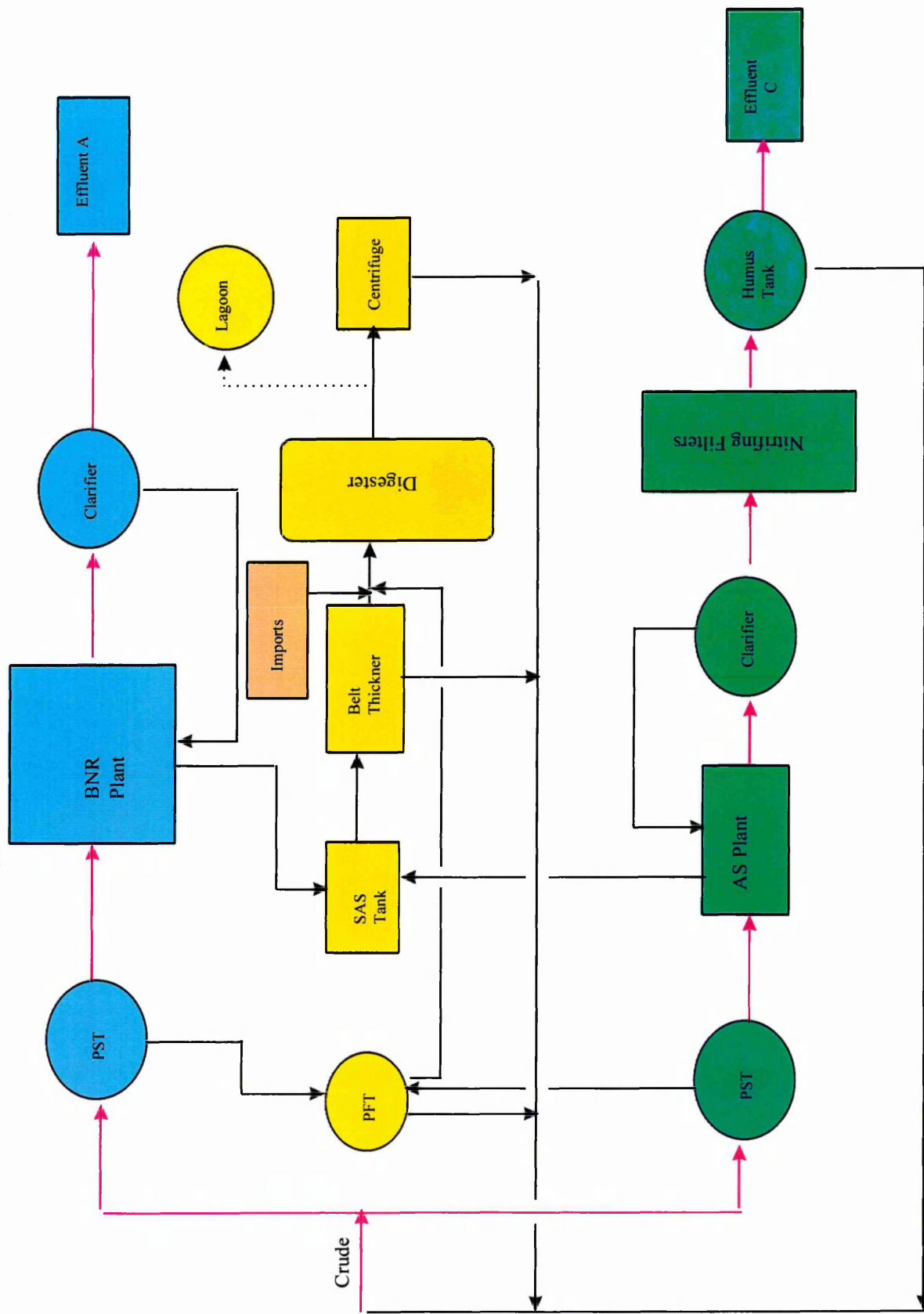


Figure 1.6 Diagram of Slough STW

2.0 Literature Review

2.1 Urban Wastewater Treatment Directive

The need for nutrient removal as part of the wastewater treatment process in the United Kingdom has arisen from the Urban Wastewater Treatment Directive (UWWTD) (Council of European Communities, 1991). The Directive has been formed due to increasing concerns over the condition of inland and coastal waters. The UWWTD deals with the collection, treatment and discharge of urban wastewater and the treatment and discharge of some industrial wastewater. The Directive sets discharge limits on certain determinants of water quality e.g. biological oxygen demand (BOD), suspended solids and the nutrients nitrogen and phosphorus. These standards became effective on or before December 31 1998, for wastewater treatment works which discharge to water courses that are designated as “sensitive”. The limits for nutrients, as stipulated by the UWWTD, are shown in Table 2.1.

Table 2.1 Nitrogen and phosphorus limits as set by the UWWTD for plants which discharge to sensitive areas (as identified in Annex II.A (a))

<i>Nutrient</i>	<i>Population Equivalents</i>	<i>Concentration (see Note 1)</i>	<i>Minimum Percentage Reduction (Notes 1 and 2)</i>
<i>Total Nitrogen (Notes 3 and 4)</i>	10,000-100,000	15 mg L ⁻¹	70%-80%
	>100,000	10 mg L ⁻¹	70-80%
<i>Total Phosphorus</i>	10,000-100,000	2 mg L ⁻¹	80%
	>100,000	1 mg L ⁻¹	80%

Taken from UWWTD

- Notes:
- 1) Standards expressed as annual mean values
 - 2) Reduction in relation to the load of the effluent
 - 3) The sum of total Kjeldahl nitrogen, nitrate and nitrite
 - 4) Alternatively the daily average must not exceed 20mgL⁻¹. This requirement refers to a water temperature of 12°C or more during the operation of the biological reactor of the wastewater treatment plant.

The nutrients nitrogen and phosphorus are normally present in domestic sewage at concentrations of around 40 mg L⁻¹ and 10 mg L⁻¹, respectively (Cooper *et al.*, 1994).

The nutrients nitrogen and phosphorus are of particular importance, as they are generally attributed to the eutrophication of receiving waters. Eutrophication is defined by the UWWTD as “ the enrichment of water by nutrients, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned”.

2.2 Sources of phosphorus

Phosphorus pollution arises from a number of sources and varies throughout Europe (Table 2.2). The principle sources of phosphates in municipal wastewater are human and animal wastes and fertilisers.

Table 2.2 Sources of phosphorus in Europe

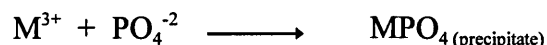
Source (%)	Human	Detergents	Livestock	Fertilisers	Industry	Background
<i>Austria</i>	20	10	36	16	6	12
<i>Belgium</i>	26	11	43	7	8	5
<i>Denmark</i>	12	11	55	11	5	6
<i>Finland</i>	18	9	17	15	3	38
<i>France</i>	18	15	31	19	6	11
<i>Germany</i>	28	3	44	12	6	7
<i>Greece</i>	21	7	18	34	5	15
<i>Ireland</i>	9	7	49	24	2	9
<i>Italy</i>	35	2	26	18	8	11
<i>Netherlands</i>	23	3	57	9	5	3
<i>Portugal</i>	24	14	27	16	7	12
<i>Spain</i>	19	16	18	26	7	14
<i>Sweden</i>	21	10	15	14	7	33
<i>UK</i>	24	19	29	14	8	6
<i>Total</i>	23	11	32	17	7	10

Taken from Morse *et al.*, (1993)

2.2.1 Chemical phosphorus removal

Phosphorus can be removed from wastewater using chemical precipitation or biological processes. A good review of the process options available can be found in Yeoman *et*

al., (1988). Chemical phosphorus removal is well established and is achieved by adding a multivalent metal salt. A generic reaction is shown below.



The addition of metal salts to wastewater will produce insoluble salts of phosphate, which can then be removed via sedimentation. Chemicals typically used are alum, ferric chloride or sulphate and lime. The metal salt is usually added in a molar ratio exceeding 1:1 metal to total phosphorus. This ratio overcomes competing reactions and removes suspended solids and colloids (Cooper *et al.*, 1994). Ferrous chloride and sulphate can be used in activated sludge processes, but not on biological filters (Brett *et al.*, 1997). In activated sludge plants there is a ready supply of dissolved oxygen (DO) to oxidise ferrous salts to ferric salts. Ferric salts (Fe^{3+}) are more efficient than ferrous salts (Fe^{2+}) at phosphorus removal as they are only required in a 1 : 1 ratio of P : Fe, as opposed to a 3 : 2 ratio required by Fe^{2+} (Brett *et al.*, 1997). On biological filters there is less DO for oxidation to occur, however ferrous sulphate has been used on biological aerated filters (Pearce, 1998). There is no advantage to adding ferrous salts directly to a filter, as it is easier to add upstream where better mixing can occur.

The addition of chemicals is an expensive procedure and leads to an increase in the amount of sludge produced at a treatment works. As the cost of sludge disposal is a significant portion of the overall costs incurred at a wastewater treatment plant, increasing the amount of sludge produced is not desirable (Edge, 1999).

2.2.2 Biological nutrient removal

Biological nutrient removal (BNR) has become more popular during the last decade as it can accomplish nitrogen and phosphorus removal in one unit process. However it should be noted that chemical phosphorus removal is a better option at some STW, particularly if the influent BOD is not high enough to sustain a biological process. In some regions sewage treatment works (STWs) requiring phosphorus removal utilise trickling filters for either part or all of the flow. Most of Anglia Water STW sites are trickling filters (Strickland, 1999) and 74% of STW in the Thames region are trickling filter sites (Clark and Pearce, unpublished). BNR can only be applied to activated

sludge plants, so unless radical and expensive works replacement is employed, only metal salt addition can be used for phosphorus removal.

During BNR the settled sewage travels through three distinct reactor zones, anaerobic, anoxic and aerobic (Figure 2.1). Of particular importance to the formation of struvite is the fate of phosphorus. The sequence of aerobic and anaerobic zones selects groups of bacteria that are able to concentrate phosphorus in their cells as poly-phosphate chains (Levin and Shapiro, 1965). These poly-phosphate chains enable the organism to use acetic acid in the anaerobic stage and assimilate it as energy in the form of poly-B-hydroxylbutyrate (PHB), whilst releasing phosphates into the surrounding water. During the aerobic stage of the process, PHB is used to take up all the phosphorus released in the anaerobic stage plus additional phosphorus in the wastewater effluent. When the phosphorus loaded cells are removed with the waste or surplus activated sludge, very low levels of phosphorus in the effluent can be achieved (Table 2.3).

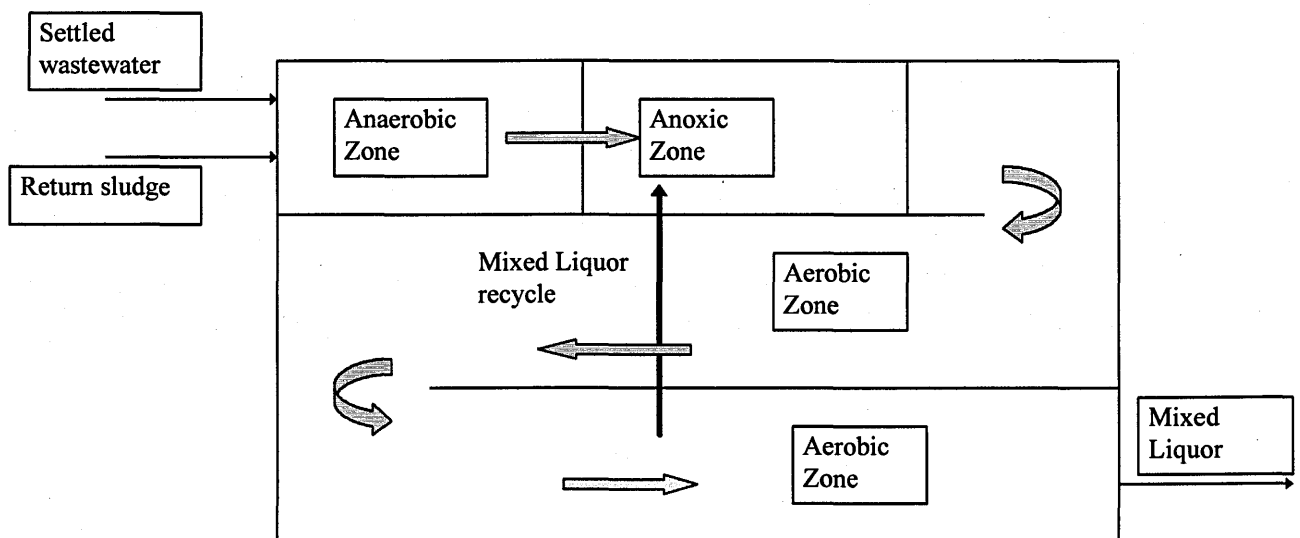


Figure 2.1 Schematic diagram of a BNR reactor

Table 2.3 Typical effluent quality achieved by BNR

<i>Parameter</i>	<i>Settled wastewater mg L⁻¹</i>	<i>Final Effluent mg L⁻¹</i>
<i>Ammoniacal N</i>	34	0.3
<i>Oxidisable N</i>	-	5.6
<i>Soluble phosphorus</i>	7.0	1.0

(Williams, 1999)

The sludge formed during BNR has a higher phosphorus content than sludge from an activated sludge plant. Table 2.4 shows the typical compositions of BNR and activated sludge. The levels of phosphorus, nitrogen and magnesium are highlighted, as these are the constituents of struvite.

Table 2.4 Comparison of BNR sludge and activated sludge

<i>Parameters</i>	<i>Units</i>	<i>BNR Sludge</i>	<i>Activated Sludge</i>
<i>Total-COD</i>	mg L ⁻¹	15320	13640
<i>Volatile Fatty Acids</i>	mg L ⁻¹	152	275
<i>Total Solids</i>	mg L ⁻¹	12620	11080
<i>Total Nitrogen</i>	mg L ⁻¹	486	399
<i>Total Kjeldahl Nitrogen</i>	mg L ⁻¹	482	369
<i>Organic Nitrogen</i>	mg L ⁻¹	429	355
<i>Ammoniacal Nitrogen</i>	mg L ⁻¹	53	41
<i>Total Phosphorus</i>	mg L ⁻¹	335	143
<i>Soluble Phosphorus</i>	mg L ⁻¹	55	34
<i>Total Calcium</i>	mg L ⁻¹	686	247
<i>Soluble Calcium</i>	mg L ⁻¹	153	148
<i>Total Magnesium</i>	mg L ⁻¹	108	39
<i>Soluble Magnesium</i>	mg L ⁻¹	13	6
<i>pH</i>	mg L ⁻¹	7.2	7.4
<i>Alkalinity (as CaCO₃)</i>	mg L ⁻¹	436	358

Adapted from Hwang and Choi (1998)

Sludge formed during wastewater treatment are thickened and typically stabilised via anaerobic digestion, prior to dewatering to form sludge cake for disposal. The amount of magnesium and phosphorus solubilised during anaerobic digestion and available for precipitation is about 68% of the feed total magnesium and total phosphorus (Maimas *et al.*, 1994). Theoretically, the sludge from a BNR plant undergoing anaerobic digestion should release most of the phosphorus stored as poly-phosphate due to cell lysis.

However this is not always the case. In some treatment plants the soluble phosphorus load in the digested sludge is quite low. Wedi and Wilderer (1994) only measured a 4-10% release of phosphorus in an anaerobic reactor at full scale, though during laboratory batch tests a maximum of 20% release was achieved.

Jardin and Popel (1996) during their work on the treatment of sludge from BNR plants, found that the amount of phosphorus released during thickening is related to the temperature. At low temperatures (5 °C), 12% of phosphorus is released increasing to 37% at 20 °C. These release measurements were based on a sludge retention time of one day. Jardin and Popel (1996) derived the following model :

$$\frac{dP}{dt} = -\frac{dX_{pp}}{dt} = k \times X_{pp} \quad \text{where } X_{pp} \text{ is Poly-P content and } k \text{ is a first order reaction rate constant of P-release.}$$

The model can be used to show that 90% of the poly-phosphate stored in cells is released, within 1.5 days. Murakami *et al.*(1987) showed that 60% of phosphorus removed in BNR was released during anaerobic digestion, which is in agreement with Knocke *et al.*, (1988).

The phosphorus released during anaerobic digestion can then be recycled back to the head of the works via the return liquors . The extra phosphorus load at the beginning of the works can then put additional pressure on the BNR plant and effect its performance.

Phosphorus released in the digester can also be refixed with various ions contained in the sludge. Magnesium, calcium and zeolites (from detergents) are the main species involved in the refixation of dissolved phosphorus (Wild *et al*, 1996). Magnesium can fix phosphorus as magnesium ammonia phosphate, struvite. It has been estimated that the amount of phosphate that can be precipitated as struvite is approximately 20% of the total phosphorus in the digester (Jardin and Popel, 1994).

2.3 What is struvite?

Struvite is a white crystalline substance consisting of magnesium, ammonium and phosphorus (Figure 2.2) in equal molar concentrations ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$). It is found naturally in guano deposits, peat beds, organically rich sediments and basalt caves (Abbona and Boistelle, 1979). It is also a component of kidney stones in animals and humans (Griffith, 1978).

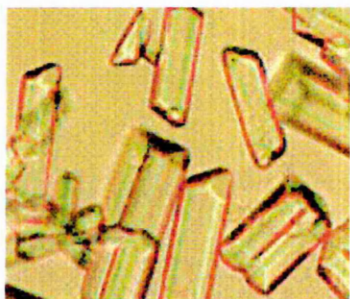


Figure 2.2 Struvite crystals

2.4 Deposition of struvite within wastewater treatment plants.

Struvite precipitation can be separated into two stages, nucleation and growth. Nucleation occurs when constituent ions combine to form crystal embryos. Growth is the process of incorporating constituent ions into the crystal lattice of the embryos, to form detectable crystals. Crystal growth continues until equilibrium is reached (Ohlinger *et al.*, 1999). In systems continuously replenished with struvite constituents e.g. wastewater treatment plants, crystal growth continues indefinitely. Struvite can therefore be a major problem at wastewater treatment works.

Struvite in wastewater treatment plants was identified as early as 1939. Whilst studying digestion, Rawn (1939) found crystalline material, identified as struvite, in the digested sludge supernatant lines. Problems with struvite formation date back to the 1960s when it was noticed at the Hyperion treatment plant, Los Angeles (Borgerding, 1972). Operators at the plant noticed that the underside of post digestion screens had crystalline deposits on them. The digested sludge stream was diluted and it was thought the problem was solved until five years later when the normal gravity flow of digested sludge had decreased to such a stage that pumping was required. The pipeline diameter had diminished from twelve inches to six (Borgerding, 1972). Similar instances of pipe

blockages have been reported elsewhere (Pitman *et al.*, 1991, Mohajit *et al.*, 1989, Webb and Ho, 1992, Mamais *et al.*, 1994).

The blockage of pipes leads to an increase in pumping costs; as the diameter of the pipe is reduced, more energy is required to move the sludge. Also, the time taken for the sludge to be moved from one place to another increases. The pipelines can be cleared by flushing through with 10% sulphuric acid and leaving to soak for at least 24 hours (Williams, 1999). Sometimes the extent of fouling is so bad that there is no option but to replace the pipework. At the Sacramento Regional Wastewater Treatment Plant, California, 5.6 km of pipework had to be replaced due to struvite formation (Ohlinger *et al.*, 1998). Replacing pipework is not only an expensive procedure, it can also be extremely disruptive especially if most of the pipework is located below ground.

It is not only pipes that are affected by struvite deposits; pumps, centrifuges and aerators are also prone to contamination (Mohajit *et al.*, 1989). Most plants which have a struvite problem, incorporate a time consuming maintenance program into the normal operation of the plant. For example at the Ponggol Pigwaste plant, Singapore, floating aerators are regularly cleaned resulting in the loss of 8-10 man hours each time (Mohajit *et al.*, 1989). At Slough STW, UK, struvite deposits are manually chipped from the centrifugal pump casing on a regular basis, resulting in the estimated time loss of 10 man hours. The manual process of removing struvite is laborious and time consuming, but at present seems to be the most effective method (Williams, 1999).

2.5 Sources of struvite components

2.5.1 Phosphorus

The sources of phosphorus in wastewater have been discussed previously

2.5.2 Ammonium

Sources of ammonium in wastewater are difficult to quantify as they are produced *in-situ* during the degradation of nitrogenous material and are present due to urea in the wastewater. Ammonia is typically in excess, relative to magnesium and phosphorus

(Schulze-Rettmer, 1991).

2.5.3 Magnesium

Levels of magnesium in the flow to treatment can come from a number of sources. If the treatment plant is located in a hard water area, there will be an abundance of magnesium ions. Also, if the water treatment works is in a coastal area, seawater entering the works can be a source of magnesium (Fujimoto *et al.*, 1991). For example, intrusion of seawater at the Southeast Water Pollution Control Plant, San Francisco was also a major source of magnesium (Maimas *et al.*, 1994). If the works receives industrial discharge, this may also be a source of magnesium.

Also, in some treatment works it is common practice to add support material to the anaerobic digesters. The material provides a surface area for biomass to become attached, preventing it from being removed with the effluent. The material used as supports, can be a source of magnesium ions. Rodriguez *et al.*, (1991) showed that clay materials used in digesters have a great influence on the precipitation of struvite. The clay minerals can release part of their structural components into the media and provide exchange sites for certain cations and anions. As these clay materials are in the digester for a long period of time, the amount of magnesium they add can be significant. Maqueda *et al.*, (1994) also showed that supports used in digesters can be a source of magnesium, with benonite readily exchanging magnesium for other cations.

Wild *et al.*, (1996) state that in the digestion of BNR sludge, magnesium is mainly supplied by the stabilising counterions of polyphosphate in a molar ratio of 0.3 moles magnesium per mole of phosphate. An almost quantitative precipitation of this magnesium as struvite can be assumed. As Table 2.4 demonstrates, BNR sludge can contain a higher concentration of magnesium than activated sludge. The higher levels of magnesium found in BNR sludge enable more struvite to be formed. In a later piece of work, Wild *et al.*, (1997) found that the amount of magnesium released during polyphosphate hydrolysis was around 0.25g of magnesium per gram of phosphorus. Jardin and Popel, (1996) found that magnesium is taken up with polyphosphate

formation, at a molar ratio of 0.34 moles magnesium per mole of phosphorus. Assuming all the magnesium taken up during polyphosphate formation is also released during hydrolysis, equates to 0.26g magnesium per gram of phosphorus, which is the same amount (0.25g) found by Wild *et al.*, (1997).

2.6 Struvite formation

Struvite precipitation occurs when the concentrations of magnesium ions (Mg^{2+}), ammonium ions (NH_4^+) and phosphate ions (PO_4^{3-}) exceed the solubility product (K_{sp}) for struvite. The K_{sp} is given by the following expression:

$$K_{sp} = [Mg^{2+}] [NH_4^+] [PO_4^{3-}]$$

The minimum concentrations of the three ionic species required to form struvite, if a K_{sp} of 3.9×10^{-10} is used, can be seen in Table 2.5. The table compares these minimum ionic concentrations to actual concentrations typically found in a digester.

Table 2.5 Comparison of minimum ionic concentrations required for struvite formation and actual concentrations in digesters

<i>Ionic concentration (mg L⁻¹)</i>	<i>Mg²⁺</i>	<i>NH₄⁺</i>	<i>PO₄³⁻</i>
<i>Minimum concentration*</i>	17.5	13.1	69.5
<i>Actual concentration</i>	35	905	1,010

*Assuming $K_{sp} = 3.9 \times 10^{-10}$. Taken from Borgerding (1972)

Table 2.6 shows values quoted in the literature for pK_{sp} (-log K_{sp}) values and where possible the conditions in which they were obtained. The value of 12.6 is most often used (Horenstein *et al.*, 1990, Maimas *et al.*, 1994, Siegrist *et al.*, 1992) even though it is not based on conditions normally found in sewage treatment works. The value of 9.4, determined by Borgerding (1972) is probably more useful as it is based on digester conditions.

Table 2.6 Comparison of struvite solubility products

pK_{sp}	Comments	Reference
9.4	Based on conditions in anaerobic digester	Borgerding (1972)
12.76	Based on field samples taken from piggery lagoons. Values adjusted for 25°C	Webb and Ho (1992)
9.94	Calculated at 25 °C	Abbona <i>et al.</i> , (1982)
13.26	Based on mixtures of $MgSO_4 \cdot 7H_2O$ and $NH_4H_2PO_4$ in deionised water at 25°C	Ohlinger <i>et al.</i> , (1998)
12.6	Calculated at 25 °C, no correction made for ionic strength	Snoeyink and Jenkins (1980)

The pH of the system is probably the most important controlling factor of struvite formation. Availability of the three components of struvite is dependent on the pH of the system and the total dissolved concentrations of Mg^{2+} , NH_4^+ and PO_4^{3-} . Speciation of the components is pH dependent, so it follows that the solubility of struvite also varies with pH. Struvite solubility increases as the pH decreases and decreases as the system pH increases above 7.0. Table 2.7 compares ideal pH values for struvite formation. Figure 2.3 shows how the struvite precipitation potential (SPP) of a solution containing 167 mg L⁻¹ phosphorus, 44 mg L⁻¹ magnesium, 615 mg L⁻¹ ammonium and 2580 mg L⁻¹ alkalinity, varies with respect to pH. From Figure 2.3 it can also be seen that the greatest potential to precipitate struvite from a solution lies in the pH range 8.5-9.0.

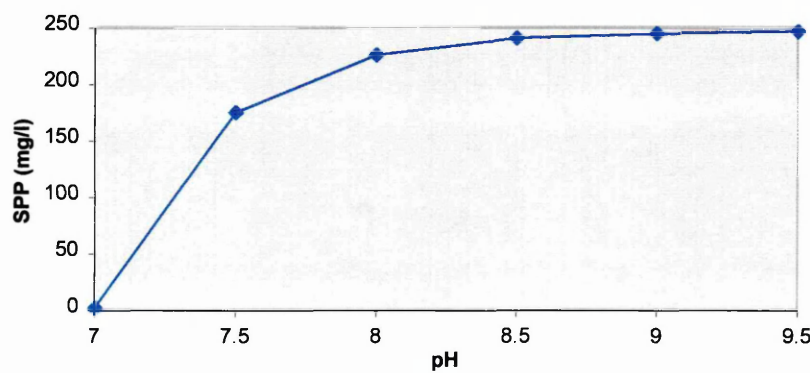


Figure 2.3 How pH effects the SPP of a solution

Table 2.7 Comparison of ideal pH values for struvite formation

<i>Optimum pH</i>	<i>Comments</i>	<i>Reference</i>
9.0-9.4	Minimum ionic concentration of all three species	Booker <i>et al</i> (1999)
8.6-10.6	Laboratory scale crystallisation experiments	Momberg and Oellermann (1992)
>8.0	Bench scale experiments using anaerobic digester supernatants	Fujimoto <i>et al</i> (1991)
9.5	97% recovery of phosphorus as struvite, using digester supernatant	Salutsky <i>et al</i> (1972)
9.0	Digester supernatant and chemical addition	Siegrist <i>et al</i> (1992)
10.3	Minimum struvite solubility, takes into consideration magnesium phosphate complexes.	Ohlinger <i>et al</i> (1998)

Areas of turbulence within the treatment works are more prone to struvite deposition (Borgerding, 1972 and Mohajit *et al.*, 1989). It is thought that areas that have more turbulent flow, such as flanges, pipe elbows and pumps, experience localised release of carbon dioxide. Loewenthal *et al.*, (1994) found that a reduction in the partial pressure of carbon dioxide is the trigger mechanism for struvite formation. The discharge of carbon dioxide from solution causes the alkalinity of the wastewater to decrease, subsequently increasing the pH. An increase in pH gives rise to conditions which are supersaturated with respect to struvite, causing struvite to precipitate (Pitman *et al.*, 1991).

However, raising the pH above 10.0 can actually reduce the amount of struvite formed. This effect can be attributed to a number of things. At higher pH values volatilisation of ammonium can occur, thereby reducing its availability for struvite formation (Booker *et al.*, 1999). Other authors have shown that at pH values above 10, struvite decomposes to form trimagnesium phosphate ($\text{Mg}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$). The formation of trimagnesium phosphate could also be due to the reduced amounts of available ammonium (Salutsky *et al.*, 1972). Mohajit *et al.*, (1989) postulated that elevated pH caused magnesium to precipitate as magnesium hydroxide ($\text{Mg}(\text{OH})_2$) reducing the availability of magnesium to form struvite.

Factors other than pH influence the formation of struvite. The surface roughness of the pipeline or equipment can effect the rate of deposition. If a surface is rough it provides ideal sites for crystal nucleation. Once a nucleation site is established the crystal can then grow rapidly. Surface roughness can also cause localised turbulence and increase local mixing (Ohlinger *et al.*, 1999). It has been shown that smooth PVC pipes do not foul as readily as steel pipes (Borgerding, 1972, Ohlinger *et al.*, 1999). Mohajit *et al.*, (1989) found that acrylic pipes were better than PVC for preventing the deposition of struvite. In a test conducted over a period of 24 days, there was no deposition of struvite in the acrylic pipe, compared to 10.6 mm deposition of struvite in the PVC pipe.

The surface area to volume ratio can also affect the precipitation of struvite. If the surface area is large in comparison to the volume, there are more potential nucleation sites for struvite crystallisation (Ohlinger *et al.*, 1999). Also areas which have high mixing intensities seem to correlate well with struvite accumulation rate. Ohlinger *et al.*, (1999) showed that the struvite crystal growth rate is transport-controlled and mixing energies were primarily responsible for controlling growth rates and crystal habit. Borgerding (1972) also observed that vibrational energies influence the deposition of struvite crystals. Salutsky *et al.*, (1972) reported that a high degree of agitation favoured struvite formation, as agitation exposed a large surface area and enhanced carbon dioxide evolution.

Struvite is not only formed chemically, it can also be formed biochemically by a number of microbial species; *Staphylococcus aureus*, *Psuedomonas sp*, *Flavobacterium*, *Arthrobacter* and *Proteus sp* (Perez-Garcia *et al.*, 1989). Ben Omar *et al.*, (1994) and Perez-Garcia *et al.*, (1989) showed that pH is also an important factor in the microbiological precipitation of struvite. Ben Omar *et al.* (1994) found that the highest rate of precipitation occurred in the pH range 7.8-8.0. Perez-Garcia *et al.*, (1989) also found similar values, pH 7.0-8.0, enabled a larger range of micro-organisms to form struvite. However, pH could not have been the only factor effecting microbial

formation of struvite as different quantities of struvite were formed within a narrow pH band and similar levels were formed at differing pH values.

To understand struvite formation it is important to examine the movement of the three components throughout a water treatment works. The best way to do this is by conducting a mass balance across the works on these components, thereby tracing where they appear in the works and where they increase in concentration.

2.6.1 Mass balances

There has been very little work done on mass balances at full-scale. A few authors have looked at mass balances of heavy metals across full-scale sewage treatment works (STWs) (Goldstone and Lester 1991, Stoveland *et al.*, 1979), but there has not been much work done on phosphorus loads across a whole STW.

A mass balance is a static method of viewing a STW, a “snapshot” of the works. Typically a mass balance is calculated on the basis of an average flow and an average value for the determinant in question (Metcalf and Eddy, 1991). An example of a mass balance can be seen in Figure 2.4

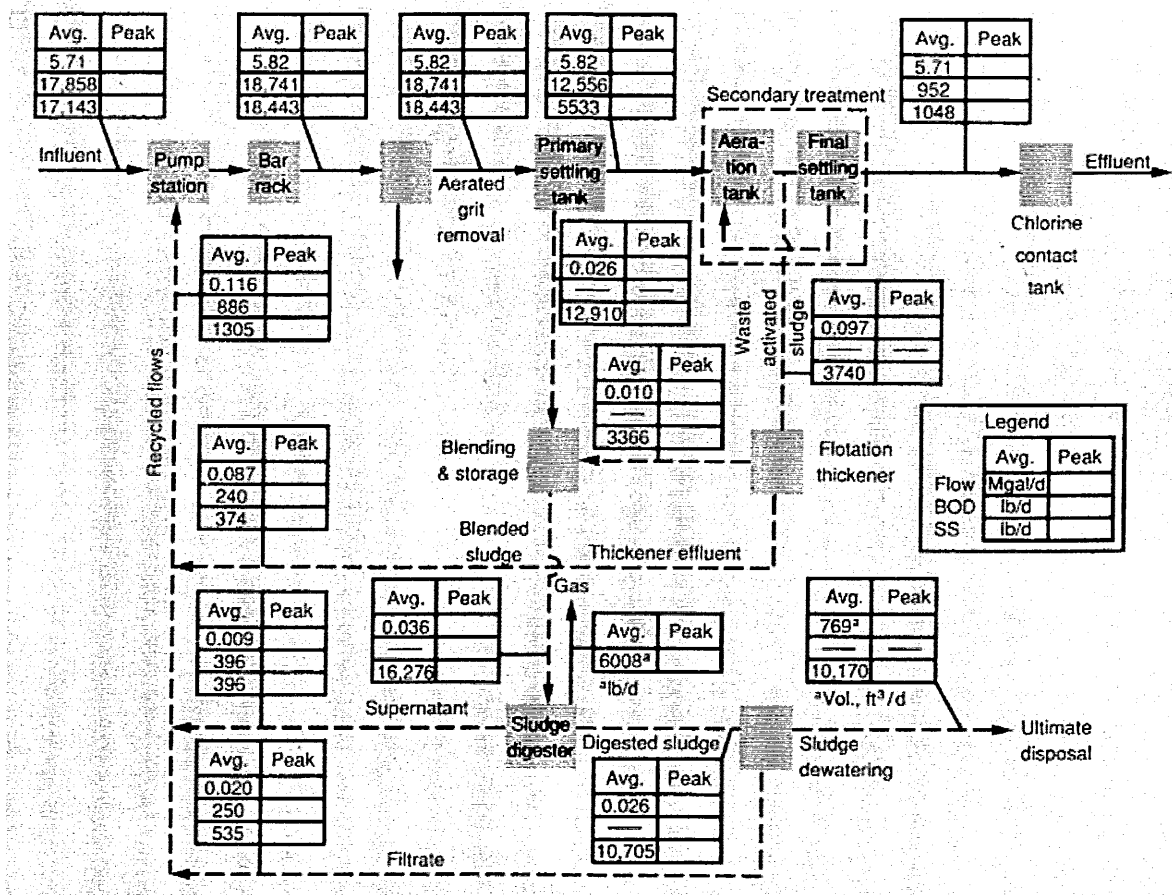


Figure 2.4 An example of a full wastewater treatment works mass balance
(Taken from Metcalf and Eddy 1991)

2.7 Controlling struvite formation

The formation of struvite within wastewater treatment plants is obviously detrimental to the operation of the plant. The most significant factors in the formation of struvite are the molar concentration of the constituent ions and the pH of the system. Theoretically struvite can be controlled by controlling the operating pH of the treatment works, or by removing one of the components.

One way in which the formation of struvite can be controlled is by the fixation of phosphorus in the anaerobic digester. At the Hyperion Treatment Plant, Los Angeles, ferric chloride is dosed into the raw and digested sludge (Horenstein *et al.*, 1990). The ferric chloride binds the phosphorus released in the digester, as vivianite ($\text{Fe}_3(\text{PO}_4)_8\text{H}_2\text{O}$). As the iron dose is increased the soluble phosphorus concentration

should decrease, as vivianite is precipitated, preventing the formation of struvite. However, vivianite is a bright blue precipitate, which may also cause problems within a plant, though problems were not encountered at the Hyperion Treatment Plant. Studies at the South-East Pollution Control Plant, San Francisco, showed that the minimum iron dose required to achieve conditions undersaturated with respect to struvite was 13.5 mM ferric chloride per litre or 100 Kg per ton of total solids (Mamais *et al.*, 1994). For a STW the size of Slough, the typical dry solids content of anaerobic digester feed is 4% and flow rate of feed is about $560 \text{ m}^3 \text{ d}^{-1}$. This equates to a total solids load of around 22.4 tonnes. Assuming a cost of £50 per tonne of ferric chloride, the cost of dosing digesters to prevent struvite formation is £112 per day. This equates to £41,000 per annum. Lime has also been used to achieve the same effect, but lime is more effective when used in conjunction with iron (Fujimoto *et al.*, 1991).

Another method of controlling struvite formation is by replacing the carbon dioxide lost in the digested sludge. By reintroducing carbon dioxide, the pH of the sludge is decreased and struvite formation prevented. The addition of carbon dioxide was successfully evaluated at the South East Pollution Control Plant, San Francisco (Maimas *et al.*, 1994). During pilot scale studies Horenstein *et al.*, (1990) also found that the addition of carbon dioxide into sludge streams, prior to centrifugation, effectively lowered the pH of the centrate, inhibiting struvite formation. Some studies have shown that aerating waste activated sludge prior to digestion prevents struvite formation (Pitman *et al.*, 1991). It is thought that aeration increases the degree of phosphate binding to the solid fraction of the sludge, inhibiting and delaying its release under anaerobic conditions. Co-aeration of primary sludge and BNR sludge caused the virtual complete removal of phosphate from the liquid phase, without the addition of any chemicals. The primary sludge provides a good chemical oxygen demand (COD) source for biological phosphorus uptake. Careful sludge handling can reduce the amount of phosphorus released.

The method by which BNR sludge is handled can affect the amount of phosphorus release and therefore struvite formation. Jardin and Popel (1996) found that short

hydraulic retention times in mechanical sludge thickening equipment reduced the amount of phosphorus released from the sludge. If gravity thickeners were used substantial phosphorus release could be expected. Pitman (1999), recommend keeping waste activated sludge from BNR processes as aerobic as possible, to reduce phosphorus release. In the event of system breakdowns the sludge should be kept in the BNR reactor in preference to storage in thickeners or holding tanks.

Magnetic devices have also been used to try and prevent struvite formation. At the Slough STW, United Kingdom, Scalewatcher devices were attached to susceptible pipes and pumps, with limited results (Williams, 1999). It has been demonstrated that a magneto-hydrodynamic device can change struvite scale from an adherent crystal to a soft mud (Lloyd, 1991). The formation of the softer form of struvite has been attributed to the formation of active nuclei and crystallisation in suspension rather than deposition on surfaces.

There are commercially available products which claim to prevent the formation of struvite. Schaners Wastewater Products Inc, (<http://www.schaners.com>) produce chemicals for use in wastewater streams and belt presses. Ciba Chemicals also produce a product which claims to prevent struvite formation, but relies on the system being cleared of struvite.

2.8 Beneficial formation of struvite

Even though struvite formation within a sewage treatment works is damaging to the operation of the works, there is a case for optimising the amount of struvite formed. If the formation of struvite and the location crystallisation occurs at, can be controlled then struvite precipitation can be a beneficial process.

Potential drivers for implementing phosphorus recovery as struvite are:

- Lower effluent phosphorus and nitrogen levels can be achieved, by reducing the amount recycled to the head of the works
- Recovered struvite can be a valuable commodity.

- Significant reductions in sludge handling costs can be achieved. By recovering phosphorus as struvite, instead of accumulating it, sludge generation can be reduced by up to 49% (Woods *et al.*, 1999).

2.8.1 Additional nitrogen and phosphorus removal

Pitman *et al.*, (1991) estimated that 20% of the phosphorus load at a STW is due to recycled phosphorus. Munch and Barr (unpublished) estimated 20-50% of the total phosphorus load was due to recycled phosphorus, based on the assumption that the sludge stream is 1% of the total flow. In a pilot-scale trial of an enhanced biological phosphorus removal plant, Jardin and Popel, (1994) found a phosphorus feed back of over 40%, though they did state that at a typical German treatment works this figure would be reduced to no more than 20%. Also the solids recapture of a thickening process can affect the amount phosphorus recycled to the BNR plant. If the solids capture of the thickening process is poor, phosphorus rich bio-solids are recycled back to the head of the works. When these solids settle during primary treatment there is a high possibility of phosphorus release due to the presence of organic acids in the primary sludge (Popel and Jardin, 1993)

Momberg and Oellermann (1992), evaluated the removal of phosphorus from three types of effluent by crystallisation methods. A phosphorus removal of 87% was achieved within a one hour retention time. Phosphorus levels were reduced from 10 mg L⁻¹ to 1 mg L⁻¹ within one minute. It should be noted that these results were based on the phosphate precipitating as hydroxyapatite, not struvite.

Schulze and Rettmer (1991) proposed a number of various methods in which the amount of ammonia and phosphorus could be reduced by struvite precipitation. The proposed configurations are summarised as follows:

- Biological pre-treatment, struvite precipitation, biological main treatment. Ammonia and phosphorus removals of 60% are achievable.

- Biological pre-treatment with simultaneous struvite precipitation, biological final treatment and sludge digestion
- Installation of struvite process in the sludge treatment plant.

Siegrist *et al.*, (1992) looked at eliminating nitrogen from digesters to comply with the UWWTD regulations. A pilot plant consisting of three reactors in series was used. Phosphoric acid (H_3PO_4) was added to the first reactor, where carbon dioxide was stripped. Magnesium oxide (MgO) suspension was added to the second reactor after adjusting the pH to 9. Struvite was removed from the third reactor using a lamella settler and dewatered by gravity to 30% solids. An ammonia elimination of 85-90% was achieved. However this method seems an expensive way to remove ammonia, compared to conventional biological treatments.

2.9 Pilot-scale production of struvite using digested sludge supernatant

Battistoni *et al.*, (1997) managed to achieve struvite formation from digested sludge supernatant without the use of any chemicals. The supernatant was aged and gave good struvite formation within 3 days. Phosphorus removals of 80% (as struvite) were attained. The appropriate pH values required for struvite precipitation were reached by air stripping carbon dioxide from the supernatant. The supernatant used was belt press liquor from a 100,000PE plant with nitrification, denitrification and anaerobic digestion. The composition of the liquor was as follows:

PO_4	18 mg L ⁻¹	NH_4	220 mg L ⁻¹
Mg	53 mg L ⁻¹	HCO_3	1430 mg L ⁻¹
Ca	184 mg L ⁻¹	pH	7.3

In a later piece of work Battistoni *et al.*, (1998) repeated the experiments with centrifuge liquor from a 100,000PE A_2O plant i.e. phosphorus and nitrogen removal. The composition of this liquor was as follows:

PO_4	139 mg L ⁻¹	NH_4	914 mg L ⁻¹
Mg	24 mg L ⁻¹	HCO_3	3550 mg L ⁻¹
Ca	153 mg L ⁻¹	pH	7.7

From this supernatant they were unable to exclusively produce struvite, obtaining instead a mixture of struvite and hydroxyapatite. Salutsky *et al.*, (1972) achieved 93% phosphorus removal from centrate, by the addition of sodium hydroxide only to raise the pH to 9.0. The phosphorus was removed as a mixture of calcium and magnesium phosphates.

The problem with trying to produce struvite from digested sludge supernatant is that there are a number of ions present, apart from magnesium, which can react with phosphorus. The most notable ion is calcium, which reacts with phosphorus to give calcium phosphate (hydroxyapatite). However magnesium and bicarbonate ions inhibit the formation of hydroxyapatite (Battistoni, 1997). Hwang and Choi, (1998) found that for effective struvite formation, the calcium (Ca) : magnesium (Mg) molar ratio must be lower than one. If the Ca : Mg is greater than one, calcium phosphate or hydroxyapatite dominates. Mustovo *et al.*, (2000) found the Mg : Ca ratio should be greater than 0.6 for struvite to precipitate and if there is a high concentration of magnesium and phosphorus, trimagnesium phosphate will form ($\text{Mg}_3(\text{PO}_4)_2 \cdot 22\text{H}_2\text{O}$ or $\text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$). Siegrist (1996) and Munch and Barr (unpublished) both recommended a Mg : P ratio of 1.3 : 1 for effective removal as phosphorus as struvite. Salutsky *et al.*, (1972) also stated that the molar ratio of magnesium: phosphorus should be 25% greater than the stoichiometric demand i.e. a ratio of 1.25 : 1. Fujimoto (1991) found a ratio of 1.05 : 1 was sufficient to precipitate phosphorus as struvite.

2.10 Commercial struvite precipitation technologies

There is only one full-scale commercial process which recovers phosphorus as struvite, using sewage. This process is the Phosnix process.

The Phosnix process was developed by Unitika Ltd., Japan (see Appendix D for contact details). The process is a side stream treatment which uses phosphorus enriched wastewater (Stratful *et al.*, 1999) . A diagram of the process is shown in Figure 2.5. Digested sludge supernatant is fed into the base of the tower where it is mixed with

magnesium hydroxide. The pH is maintained in the range 8.5-8.8 with sodium hydroxide addition, as required. A blower forces air into the base of the column, providing the agitation required for complete mixing and suspension of the crystals. The recovered product is granular struvite, with typical diameters of 2-3mm. It is easy to handle and has no storage difficulties.

The product has excellent fertiliser properties. Nutrients appear to be released at a controlled rate, over an extended period of time (Booker *et al.*, 1999). Struvite recovered from wastewater by Unitika Ltd Japan is currently being sold to fertiliser companies in the United States for \$150-200 per tonne (Driver *et al.*, 1999).

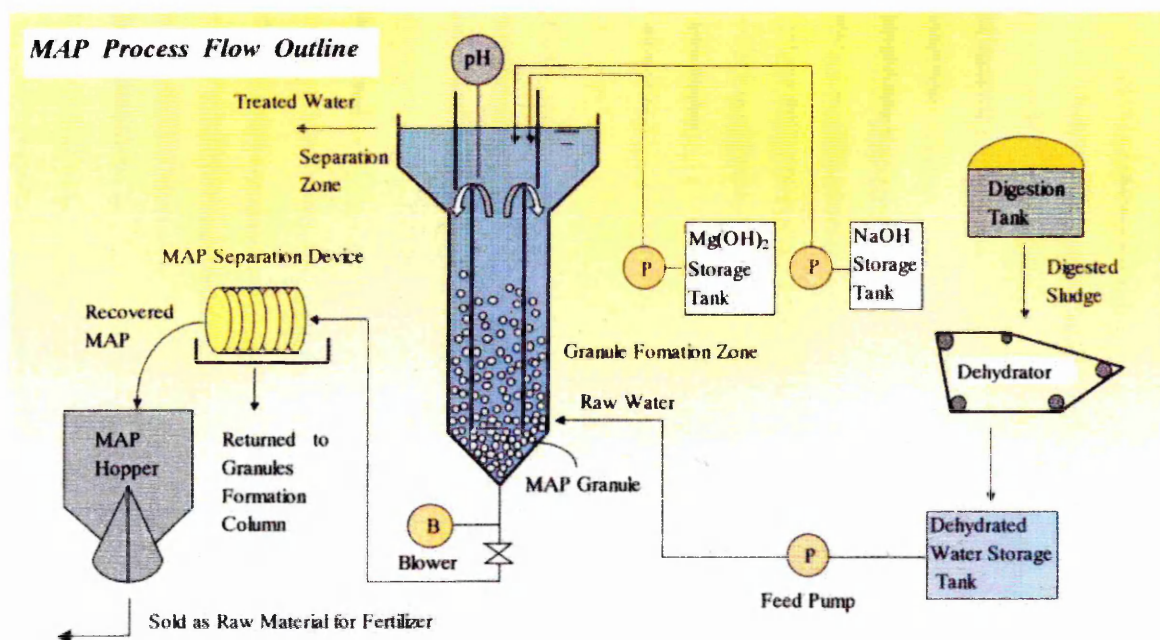


Figure 2.5 Outline of Phosnix process

2.11 Economic feasibility

The implementation of phosphorus recovery technologies on a significant scale at wastewater treatment plants will depend mainly on economic feasibility. Recycling the struvite can reduce costs of phosphorus recovery. Schulze and Rettmer (1991) found struvite crystallisation was not commercially viable due to the cost of chemicals. They

suggested recycling the struvite into the system again by thermal decomposition into MgHPO_4 and NH_4 . The ammonium could then be sold to fossil fuelled power stations to reduce the nitrous oxide content of stack gases. The MgHPO_4 could then be fed back into the system as a source of magnesium. Recycling the struvite by thermal decomposition was also examined to reduce the cost of chemical additions by Seigrest *et al.*, (1992) who also suggested the ammonia produced could be sold for flue gas cleaning to reduce costs.

The source of magnesium to optimise the formation of struvite can have a significant impact on the cost of a recovery system. If magnesium chloride is used, than a system for pH control would be required. If magnesium hydroxide is used as the source of magnesium ions than base addition would not be required to raise the pH of the treatment stream. However by using magnesium hydroxide the pH of the system can not be optimised, as it would be difficult to control. Additional pH control may be required as in the case of the Phosnix process (Taruya *et al.*, 2000). The requirement for base addition would be less with magnesium hydroxide than magnesium chloride. Munch and Barr (unpublished) used magnesium hydroxide in a pilot study, with no base addition. At higher magnesium hydroxide concentrations good phosphorus removal was achieved (94%), declining rapidly at lower concentrations. The decline could be due to the correlation between magnesium hydroxide dosing and pH; the more magnesium hydroxide the higher the pH. Seawater was used as a source of magnesium by Matsumiya *et al.*, (2000) in their pilot plant. The seawater had a concentration of 1250 mg L^{-1} magnesium and was dosed at a ratio of 2-12% of the influent flow. A phosphorus removal of 70% was achieved using centrate liquors with a pH of 7.7. No pH adjustment occurred.

Woods *et al.*, (1999) modelled a feasibility evaluation for STWs. They found that phosphorus recovery appears to be cost effective at STWs with high phosphorus, low BOD wastewater and high sludge disposal costs. The capital payback period may be as low as 3-5 years for an influent concentration of 11 mg L^{-1} of phosphorus and a sludge disposal cost of £300 per tonne.

Even though P recovery is feasible, broad based incentives may be necessary to increase the attractiveness and demand for implementation i.e. public demands for sustainable resources, regulatory demands that impose recovery or reuse requirements.

2.12 Summary

Struvite deposition at STWs can be a major operational nuisance. Figures 2.6 and 2.7 demonstrate how severe deposition can be. Predicting struvite precipitation potential is therefore crucial to designers and operators for anticipating potential problems and remediating existing struvite damage. For the purposes of process control it is important to be able to ;

- predict the conditions under which struvite precipitation fouling problems are likely to arise
- determine the potential mass of struvite which can precipitate
- formulate chemical dosing strategies so precipitation will be negligible in certain areas.

There are various published models which go some way towards trying to predict the potential for struvite to form (Loewenthal *et al.*, 1994, Mustovo *et al.*, 2000). The former model is used later in this work.

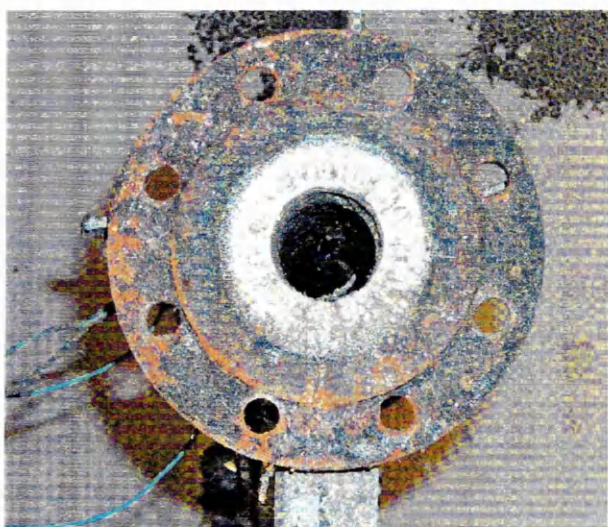


Figure 2.6 Struvite deposits in a digested sludge pump (Scalewatcher device attached)

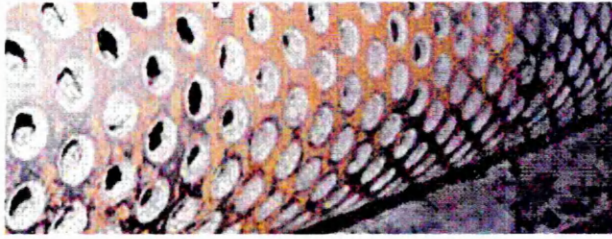


Figure 2.7 Struvite deposition on a Klamppress belt thickener (Taken from Schaner website)

3.0 Aims and Objectives

3.1 Aims

The aim of this project is to create a comprehensive mass balance of phosphorus, ammonia and magnesium loads at full scale. Slough STW is to be used for this purpose as it is configured for BNR. Alongside this works, a laboratory scale process for struvite formation will be operated to assess struvite production and optimum operation.

3.2 Objectives

- To assess the movement of phosphorus, magnesium and ammonia through Slough STW
- To assess the struvite precipitation potential (SPP) across Slough STW.
- Identify which stream is the most suitable for sidestream treatment.
- Undertake bench-scale studies to confirm the SPP of chosen stream.
- To determine optimum conditions for the bench-scale formation of struvite.

4.0 Experimental

4.1 Slough STW

Slough STW is located in a residential area, off junction 6 of the M4. Slough treats a population equivalent (PE) of approximately 250,000, of which 114,000PE is industrial effluent. The industrial effluent to Slough is variable and the major types of effluent discharged are:

- Highly biodegradable wash down water (consisting mainly of sugars)
- Detergents
- Water-based emulsions and gloss paints
- Water-based adhesives
- Waste from metal finishing industries.

The works consists of two treatment streams; “A”, which is the new extension and “C” which is the old works.

4.1.1 Works inlet

The works inlet receives flow from five pumping stations :

- Chavely
- Western Area Pumping Station 1
- Western Area Pumping Station 2, taking in Slough Industrial Estate
- Oakley Green Pumping Station
- The Main Pump House, which serves Bell Farm and Eton College

The sewage is screened using two guard 6 mm screens. The screenings are macerated, dewatered and discharged into a skip. Grit is removed by two detritors and discharged into another skip. The skips are removed by contractors, as required. At the main works penstock, there is a facility for flow balancing; the balancing tanks serve as a buffer to the storm tanks. Sewage from the balancing tanks is returned via the Western Area pumping station and from the storm tanks, via the Main Pump House. Storm discharges to Roundmoor ditch. Typical dry weather flows are in the order of

55,000 m³ d⁻¹. The flow is split between the old works and the new works in a 25 : 75% ratio.

4.1.2 Treatment stream “C”

4.1.2.1 Primary treatment

The flow is split evenly via two weirs, to two 33 m diameter primary settling tanks (PSTs). The PSTs are desludged on auto-timers for approximately 3 hours every day. The sludge is removed by dedicated progressive cavity pumps, plus a common spare. Scum from the PSTs is decanted to a sump and removed as required by a duty progressive cavity pump.

4.1.2.2 Secondary treatment

Settled sewage from the PSTs is fed into a covered surface activated sludge (AS) plant. The control of this plant is manual and not by the use of dissolved oxygen (DO) probes. The sludge is sampled daily to monitor quality. Mixed liquor suspended solids (MLSS) are kept between 3000-35000 mg L⁻¹ and the sludge settleability volume index (SSVI) at 105. There are four 21.5 m diameter final sedimentation tanks (FSTs), and removal of surplus activated sludge (SAS) is timed; typically for 5-6 hours a day. The flow then goes on to four 36.2 m long rectangular biological filters, filled with traditional clinker material. Finally effluent goes into four 21.4 m diameter humus tanks, which are desludged by timers.

4.1.3 Treatment stream “A”

4.1.3.1 Primary treatment

Primary treatment is the same as for stream “C”.

4.1.3.2 Secondary treatment

Settled sewage is fed into the aeration lane distribution chamber where it is mixed with return activated sludge (RAS) before being fed to the four aeration lanes of the

Bardenpho process. The aeration lanes consist of an anaerobic zone with mixers, an anoxic zone with mixers and an aerobic zone with submerged air diffusers. Submerged pumps recirculate liquor from the aerobic zone back to the anoxic zone.

The common outfall from the aeration lanes is then divided equally between the four FSTs by weirs in the FST distribution chamber. The flow of activated sludge from each FST is controlled by a dedicated actuated Bellmouth. All four Bellmouths are situated in a chamber. A single line from the Bellmouth chamber routes the sludge via a flow meter to the RAS pumping station where RAS and SAS pumps are located.

Final effluent leaves the four FSTs and is discharged to Roundmoor Ditch.

4.1.4 Sludge treatment

The sludge on-site comes from three sources:

- Primary sludge generated on-site, thickened in the picket fence thickeners (PFTs).
- SAS generated on site, thickened on Aquabelt thickeners (ABTs).
- Imported sludge.

Sludge from the four PSTs is delivered by 5 positive displacement pumps to the distribution chamber, from which it passes to the PFT. Normally only one PFT will be operating. The PFTs are 10.0 m in diameter and are covered; desludging is controlled by timers. Primary sludge is typically fed continuously, with a sludge of approximately 2% dry solids (DS) and a target product of 5% DS.

SAS is removed from the BNR and AS plants for approximately 12-14 hours a day. SAS from both plants is fed into a common sump and blended (BSAS) and is pumped onto two ABTs. Feed is approximately 0.8% DS, resulting in product which is 5-6% DS.

Imported sludge is generally received from surrounding works, mainly Maidenhead and Windsor. Tankered sludge is discharged through one of two Rotamat screens.

All three sources of sludge are mixed in a blending tank prior to digestion. The tank has a hydraulic retention time (HRT) of 6-8 hours.

4.1.5 Digestion and gas management

There are two banks of digesters on site:

- N°s 1-4, capacity 2250 m³ each, with floating roofs
- N°s 7 and 8, capacity 2250 m³ each, with fixed roofs and gas burper mixing systems.
- N°s 5 and 6 are redundant.

There is a spiral Alfa Laval heat exchanger associated with each digester. Gas is stored in the roofs of digesters 1-4 and is used to fire:

- The 680 kWh Combined Heat and Power (CHP) plant
- A back-up boiler, which will also operate on diesel
- The waste gas burner

4.1.6 Dewatering

Digested sludge is displaced to the sludge holding tank from where it is pumped across the site to either a centrifuge buffer tank or a sludge lagoon. There are five sludge lagoons, each with a nominal capacity of 1800 m³. The lagoons are used as back-up storage in the event of the centrifuge being out of commission, and for emergency storage of sludge from other sites.

Sludge is fed from the holding tank into an Alfa Laval centrifuge, which normally operates 24 hours a day. The cake produced typically has a DS content of 20-22%. Sludge cake is recycled to agricultural land by TERRA Ecosystems.

4.2 Mass Balance

4.2.1 Sampling

Samples were taken from various sites around Slough STW. Details of the sampling sites can be found in Table 4.1 and locations can be seen on the site map in Appendix B. Some of the samples obtained were composite samples, as the samples were

expected to be highly variable. Composite samples were obtained using automatic samplers (American Sigma, model 900). For the composites, hourly samples of 100ml were taken over a period of 24 hours (12am-12am). Samples were stored in the base unit of the sampler and each daily sample consisted of four bottles. The programme for the automated samplers ran for six days and samples were collected weekly. The four collection bottles were thoroughly mixed, before decanting into bottles for analysis. All samplers were placed on a flat surface and tubing placed in areas of high turbulence. Tubing was also weighted to prevent it rising out of the bulk fluid.

All other samples taken were grab samples. It was assumed that the sites grab samples were obtained from were well mixed.

4.2.2 Sample analysis

All samples were sent to Thames Water Quality Centre Laboratories, which has NAMAS (National Measurement Accreditation Service) accreditation. A list of determinants and the methods in which they were obtained are shown in Table 4.2. Samples were analysed for different determinants, as shown in Table 4.3.

The pH of each sample was measured on site, using a WTW pH probe (model SenTix 41-3) and a WTW portable unit (model pH197-S). The probe was calibrated prior to use. Where possible, pH measurements were taken from the bulk flow of liquid. In some instances accessibility was difficult and the pH had to be measured from the sample obtained. How the pH measurement was taken is indicated in Table 4.3. Temperature was also recorded at the same time as pH.

Table 4.1 Details of sampling sites

<i>Sample</i>	<i>Comments</i>
<i>Crude Sewage (C)</i>	Inlet after detritors. Automated sampling.
<i>Settled Sewage (S)</i>	Clarified fluid outfall. Automated sampling
<i>Effluent A (EA)</i>	Automated sampling
<i>Effluent C (EC)</i>	Automated sampling
<i>Humus Sludge (HS)</i>	From de-sludge pump for tank N°3. Pump located in a well and had to be opened manually.
<i>BNR Lanes 1-4 (B1-B4)</i>	From walkway above aeration lanes. Samples filtered on site using coffee filters
<i>RAS</i>	From RAS bell-mouth
<i>BSAS</i>	From SAS buffer tank.
<i>Thickened SAS (TSAS)</i>	From pipe valve in belt thickener room
<i>Belt thickener liquor (BTL)</i>	From sump below belts
<i>PFT Feed (PFT F)</i>	From sump by high level pump station
<i>PFT Liquors (PFT L)</i>	From overflow at the top of PFT N°1
<i>PFT Sludge (PFT S)</i>	From valve at the base of PFT N°1
<i>Imports (IMP)</i>	From pump valve in imported sludge pump house
<i>Anaerobic Digester Feed (ADF)</i>	From the feed well, at the top of digester N°3.
<i>Digested Sludge (DS)</i>	From pipe valve
<i>Centrifuge liquors (CL)</i>	From pipe feeding the centrate well, at rear of polymer storage building
<i>Centrifuge cake (CK)</i>	From cake compound area, beneath cake hopper

Table 4.2 List of determinants and how they were measured

<i>Description</i>	<i>Conditions</i>	<i>Units (sludge samples)</i>
<i>Biochemical Oxygen Demand (BOD)</i>	Sample is dosed with allythiourea (ATU) to inhibit nitrification and incubated for 5 days.	mg L ⁻¹
<i>BOD filtered (BOD.sol)</i>	As above, but sample filtered through 0.45 mm filter.	mg L ⁻¹
<i>Chemical Oxygen Demand (COD)</i>	Small scale tube method with photometric measurement	mg L ⁻¹
<i>Phosphorus reactive (P.sol)</i>	Determination using colorimetric analysis on Aqua 800 analyser	mg L ⁻¹
<i>Phosphorus total (P.tot)</i>	Conversion of phosphorus compounds to soluble reactive phosphorus by acid peroxide digestion	mg L ⁻¹
<i>Nitrate as N (NO₃-N)</i>	Determination using colorimetric analysis on Aqua 800 analyser	mg L ⁻¹
<i>Ammoniacal Nitrogen (NH₄-N)</i>	Determination using colorimetric analysis on Aqua 800 analyser	mg L ⁻¹ (%)
<i>Kjeldahl Nitrogen (TKN)</i>	Conversion of nitrogenous compounds to ammonia by acid/peroxide digestion	mg L ⁻¹ (mg Kg ⁻¹)
<i>Total Oxidised Nitrogen (TON)</i>	As above, TON is TKN minus NH ₄	mg L ⁻¹
<i>Suspended solids (SS)</i>	Determined gravimetrically following GFC filter paper filtration	mg L ⁻¹
<i>Magnesium total (Mg.tot)</i>	Not Known	mg L ⁻¹
<i>Magnesium Dissolved (Mg.sol)</i>	Filtered through 0.45 mm filter paper	mg L ⁻¹ (mg Kg ⁻¹)
<i>Loss on ignition (VS)</i>	Dried sample burned in furnace at 550°C	%
<i>Dry Solids (DS)</i>	Sample dried at 105°C overnight	%
<i>Volatile Acids (VFA)</i>	Not Known	mg L ⁻¹
<i>Alkalinity as CaCO₃ (Alk)</i>	Determination using colorimetric analysis on Aqua 800 analyser	mg L ⁻¹ (mg Kg ⁻¹)
<i>Calcium Dissolved (Ca.sol)</i>	Filtered through 0.45 mm filter paper	mg L ⁻¹ (mg Kg ⁻¹)

Table 4.3 Details of sample analysis

<i>Sample</i>	<i>Analysis</i>	<i>pH</i>
<i>Crude Sewage</i>	BOD, BOD.sol, COD, SS, TKN, NH ₄ , P.tot, P.sol, Mg.tot, Mg.sol and Ca.sol	Bulk Fluid
<i>Settled Sewage</i>	BOD, BOD.sol, COD, SS, TKN, NH ₄ , P.tot, P.sol, Mg.tot, Mg.sol and Ca.sol	Bulk Fluid
<i>Effluent A</i>	COD, SS, NH ₄ -N, NO ₃ -N, P.tot, P.sol, Mg.tot, Mg.sol, Ca.sol,	Sample
<i>Effluent C</i>	COD, SS, NH ₄ -N, NO ₃ -N, P.tot, P.sol, Mg.tot, Mg.sol, Ca.sol,	Bulk
<i>Humus</i>	SS, TKN, NH ₄ -N, P.tot, P.sol, Mg.tot, Mg.sol, , Ca.sol, Alk,	Sample
<i>BNR Lanes</i>	TON, NO ₃ -N, NH ₄ -N, NO ₂ -N, P.tot, P.sol, Mg.sol, Alk,	Bulk
<i>PFT Liquor</i>	BOD, BOD.sol, NH ₄ -N, SS, Mg.tot, P.tot, P.sol, Mg.sol, Ca.sol, VFA, Alk.	Sample
<i>PFT sludge</i>	NH ₄ -N, P.tot, Mg.tot, DS, VS, VFA, Alk	Sample
<i>RAS</i>	SS, NH ₄ -N, P.tot, Mg.tot, P.sol, Mg.sol, Ca.sol, Alk,	Bulk
<i>BSAS</i>	P.tot, Mg.tot, NH ₃ -N, DS, Alk	Bulk
<i>TSAS</i>	TKN, NH ₄ -N, P.tot, Mg.tot, DS, VS, VFA, Alk,	Sample
<i>Belt Thickener Liquors</i>	BOD, BOD.sol, SS, NH ₄ -N, P.tot, P.sol, Mg.tot, Mg.sol, Ca.sol, VFA, Alk	Sample
<i>Imports</i>	TKN, NH ₄ -N, P.tot, Mg.tot, DS, VS, Alk	Sample
<i>AD Feed</i>	TKN, NH ₄ -N, P.tot, Mg.tot, DS, VS, Alk,	Sample
<i>Digested Sludge</i>	NH ₄ -N, P.tot, Mg.tot, VFA, DS, VS, Alk	Sample
<i>Centrifuge Liqour</i>	NH ₄ -N, P.tot, Mg.tot, DS, Alk	Bulk
<i>Centrifuge Cake</i>	TKN, NH ₄ -N, P.tot, Mg.tot, DS, VS, Alk,	
<i>Lagoon Sludge</i>	SS, NH ₄ -N, P.tot, P.sol, Mg.tot, Mg.sol, Ca.sol	Sample

4.2.3 Conversion of units

For the analysis of sludge, some of the determinants were expressed as mg Kg⁻¹. In order for loads to be calculated (kg d⁻¹) of X, the units had to be converted into mg L⁻¹. Conversion was done by taking into account the DS content of the sample and also the

density. The specific gravity was taken as 1.03 for sludge which had a DS content of less than 5% and 1.05 for sludge which had a DS content greater than 5% (Metcalf and Eddy, 1991).

4.2.4 Flow rates

To calculate the daily loads of each of the determinants, the flow rates of the corresponding stream had to be determined. Initially the SCADA system from Slough STW was used to ascertain flow rates, but on closer inspection the flows did not seem accurate. Flow rates were therefore determined from other sources. Flow to works (FTW) i.e. crude sewage, and effluent A were determined from remote loggers (Warren Jones and Mobrey respectively). The other flows were determined from daily effluent stream and sludge stream log-sheets (DESL and DSSL respectively). Details of how the flow rates were calculated are listed below:

<i>Crude</i>	Mobrey remote logger.
<i>Effluent A</i>	Warren Jones remote logger. The data for effluent A was incomplete, so missing values were calculated as follows; the percentage of the FTW that effluent A consisted of was calculated, then the average percentage was used to calculate the flow of effluent A from the FTW.
<i>Effluent C</i>	Calculated by deducting Effluent A from FTW.
<i>PFT feed</i>	The hours run by the PFT pumps (on stream A and C) are recorded on the DESL. The pump capacities were: PFT A $60 \text{ m}^3 \text{ hr}^{-1}$ PFT C $5 \text{ m}^3 \text{ hr}^{-1}$ Flows were then calculated by multiplying pump capacity by hours run. Total PFT feed was determined by addition of PFT A and PFT C.
<i>PFT sludge</i>	Recorded in $\text{m}^3 \text{ d}^{-1}$ in the DSSL.
<i>PFT liquors</i>	Calculated by deducting PFT sludge from PFT feed.

<i>Blended SAS</i>	Recorded in $\text{m}^3 \text{d}^{-1}$ in the DSSL. Also recorded as SAS pump hours run in DESL. Flows also determined by multiplying pump capacity by hours run. Pump capacities were: SAS A $162 \text{ m}^3 \text{hr}^{-1}$ SAS C $39.6 \text{ m}^3 \text{hr}^{-1}$ Figures for both methods varied on a daily basis, but the average flows for each method were similar.
<i>Thickened SAS</i>	Recorded in $\text{m}^3 \text{d}^{-1}$ in DSSL.
<i>Belt thickener liquors</i>	Determined by deducting thickened SAS from blended SAS.
<i>Imports</i>	Recorded in $\text{m}^3 \text{d}^{-1}$ in DSSL.
<i>AD Feed</i>	Calculated by adding all the sludge streams together ie PFT sludge, imports and thickened SAS.
<i>Digested sludge</i>	Calculated using the hours run recorded in the DSSL and multiplying by the pump capacity ($37.8 \text{ m}^3 \text{hr}^{-1}$).
<i>Centrifuge feed</i>	Recorded in $\text{m}^3 \text{d}^{-1}$ in data sheets for the centrifuge.
<i>Centrifuge cake</i>	Calculated using the average DS content of the cake
<i>Centrate liquors</i>	Calculated by deducting centrifuge cake from centrifuge feed.

The loadings were calculated by multiplying the concentration of the determinant by the flow on the day the sample was taken. All flow rates and loadings were then averaged and the standard deviation of the data derived.

4.2.5 Struvite precipitation potential

The struvite precipitation potential (SPP) for each sampling point was then calculated using a computer model called Struvite (Version 3.1). R.E Loewenthal and I.R Morrison, from the Department of Civil Engineering, University of Cape Town, developed the model. The model was developed for the Water Research Commission, South Africa and is based on work done by Lowenthal *et al.*, (1994).

4.3 Pilot plant

A bench-scale pilot plant was operated to see if struvite could be crystallised from the centrate liquors. The bench-scale reactor was constructed using a Water Research Council (WRC) porous pot apparatus. The apparatus consisted of a porous vessel (BTSK346) inside an impermeable vessel (BTSK347). A diagram of the bench scale rig can be seen in Figure 4.1 and a photograph in Figure 4.2.

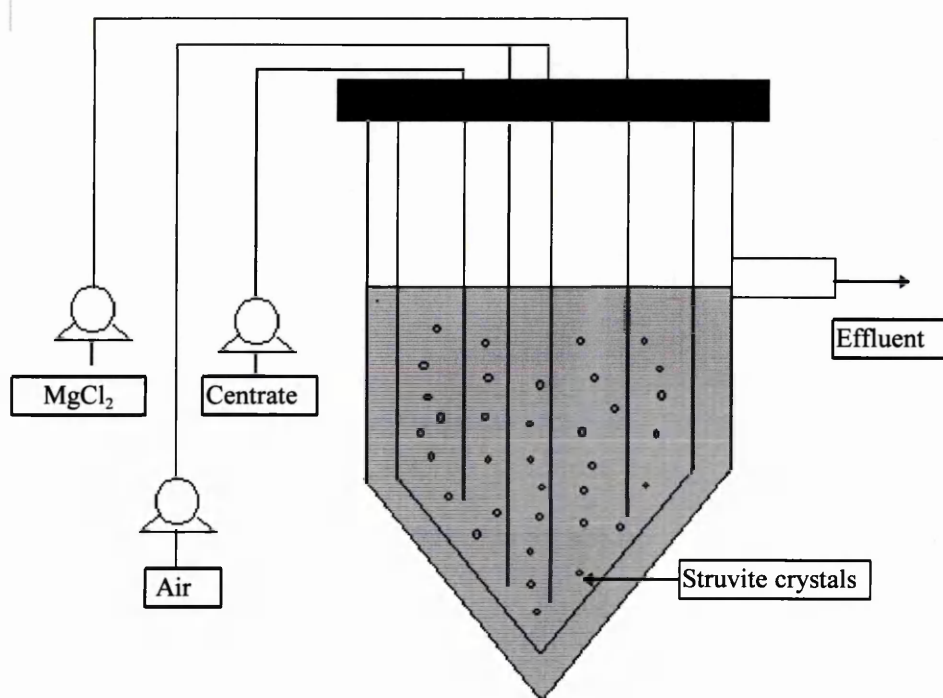


Figure 4.1 Diagram of Pilot Plant



Figure 4.2 Bench-scale pilot plant

Both vessels were supplied by Bird and Tole Ltd., UK (see Appendix D for contact details). Two peristaltic pumps (Watson and Marlow) were used to feed centrate liquors and magnesium chloride into the reactor. The flow rates of the two feeds can be seen in Table 4.4. Aeration was supplied by an aquarium aeration unit, which consisted of a pump and two aeration stones. The aeration stones had to be periodically soaked in 0.5M hydrochloric acid to remove struvite deposits.

Table 4.4 **Reactor conditions**

<i>Parameter</i>	<i>Value</i>	<i>Units</i>
<i>Volume</i>	3.5	Litres
<i>Centrate Feed</i>	7	ml min ⁻¹
<i>Chemical Feed</i>	12	ml min ⁻¹
<i>Total Feed</i>	19	ml min ⁻¹
<i>HRT* of centrate only</i>	8.31	Hours
<i>HRT of centrate + MgCl₂</i>	3.07	Hours
<i>Aeration</i>	220 (x2)	ml min ⁻¹

*Hydraulic Retention Time

4.3.1 Pilot plant feed

The reactor was fed with centrate liquors obtained from Slough STW. The liquors were collected in 25L plastic containers and stored at room temperature. The pH of the liquors were recorded using a Jenway 100 pH probe and then adjusted to 9.0, using 20% sodium hydroxide solution (Hays Chemicals). The date the samples were obtained and the day the pH of the sample was adjusted were recorded. Samples of the liquors prior to pH adjustment and after pH adjustment were taken and sent to the Thames Water Centre Laboratories for analysis. Samples were taken before and after pH adjustment to determine if raising the pH affected the chemical composition of the liquors. The analysis performed by the laboratories are listed in Table 4.5

The reactor was also fed with magnesium chloride, which was obtained from NedMag chemicals. The magnesium chloride was in a liquid form, of purified quality, at a concentration of 400 Kg m⁻³. Solutions of the required concentration of magnesium

were prepared using deionised water and tested with Dr Lange kit LCK 326 to verify the amount of magnesium present. Deionised water was used to prevent the addition of extra magnesium and calcium ions, due to the harness of the water in the Thames region.

4.3.2 Analysis

The effluent from the reactor was sampled on a daily basis (apart from weekends), after at least four HRTs. A sample of effluent was sent to Thames Water Centre Laboratories for analysis (Table 4.5).

Table 4.5 Laboratory analysis of centrate liquors

<i>Determinant</i>	<i>Units</i>
<i>TKN</i>	mg L ⁻¹
<i>NH₄-N</i>	mg L ⁻¹
<i>Tot.P</i>	mg L ⁻¹
<i>P.sol</i>	mg L ⁻¹
<i>Tot.Mg</i>	mg L ⁻¹
<i>Mg.sol</i>	mg L ⁻¹
<i>Ca</i>	mg L ⁻¹
<i>Alk.</i>	mg L ⁻¹
<i>SS</i>	mg L ⁻¹

On the spot analysis was carried out on the effluent samples for pH, ammoniacal nitrogen (NH₄-N), soluble phosphorus (P-PO₄), total phosphorus (P.tot) and total magnesium (Mg.tot). Spot analyses were carried out using Dr Langer test kits. The test kits used are shown in Table 4.6.

The results of the test kits were read using a Lasa 100 machine. The test kits were used according to the manufacturers instructions.

Table 4.6 Tests used for spot analysis

<i>Test Kit N°</i>	<i>Determinant</i>	<i>Range mg L⁻¹</i>
<i>Ammonium LCK 303</i>	NH ₄ -N	2-47
<i>Magnesium LCK 326</i>	Mg.tot (I)	0.5-50.0
<i>Phosphorus LCK 350</i>	PO ₄ -P	2-20
<i>Phosphorus LCK 350</i>	P.tot	6-60
<i>Phosphorus LCK 348</i>	PO ₄ -P	0.5-5.0
<i>Phosphorus LCK 348</i>	P.tot	1.5-15

5.0 Results

5.1 Flows

The daily flow rates through Slough STW are summarised in Table 5.1. Flows were obtained from daily log-sheets, as detailed in Chapter 4. Flow rates highlighted in red are second generation data. The method in which they were obtained is also detailed in Chapter 4. Complete tables of the flow data can be seen in Appendix A.

It was assumed that the flow meters were regularly calibrated and located in positions to give accurate results.

Table 5.1 Average flows of various streams

<i>Stream</i>	<i>Crude Sewage $m^3 d^{-1}$</i>	<i>Settled Sewage $m^3 d^{-1}$</i>	<i>Flow to BNR $m^3 d^{-1}$</i>	<i>Flow to AS $m^3 d^{-1}$</i>	<i>Effluent A $m^3 d^{-1}$</i>	<i>Effluent C $m^3 d^{-1}$</i>
<i>Average</i>	66022.55	68269.05	51201.79	17067.26	49984.55	20423.19
<i>Standard Dev.</i>	10556.12	4908.9	3681.68	1227.23	3588.22	4492.00
<i>Sample Size</i>	64	31	31	31	34	34

<i>Stream</i>	<i>PFT Feed $m^3 d^{-1}$</i>	<i>PFT Liquor $m^3 d^{-1}$</i>	<i>PFT Sludge $m^3 d^{-1}$</i>	<i>Blended SAS $m^3 d^{-1}$</i>	<i>Thickened SAS $m^3 d^{-1}$</i>	<i>Belt Liquor $m^3 d^{-1}$</i>
<i>Average</i>	552.72	337.95	221.81	1186.44	164.75	1021.69
<i>Standard Dev.</i>	150.61	140.97	85.97	348.44	50.46	303.03
<i>Sample Size</i>	60	59	62	61	61	61

<i>Stream</i>	<i>Imports $m^3 d^{-1}$</i>	<i>Digester Feed $m^3 d^{-1}$</i>	<i>Digested Sludge $m^3 d^{-1}$</i>	<i>Centrifuge Feed $m^3 d^{-1}$</i>	<i>Centrifuge Liquor $m^3 d^{-1}$</i>	<i>Cake 21.5% DS $m^3 d^{-1}$</i>
<i>Average</i>	162.58	537.81	596.25	456.44	392.75	63.69
<i>Standard Dev</i>	98.29	147.55	204.67	223.68	192.47	31.21
<i>Sample Size</i>	63	63	61	61	27	27

The flow results show that 75% of the flow to treatment is going through treatment stream A and 30% of the flow is going through stream C. The belt thickener liquors constitute the majority of the liquors recycled to the head of the works. The thickener liquors are 66% of the return flow, the centrate liquors 25% and the PFT liquors 5%.

The return liquors are about 3% of the total flow to works. The sludge stream at Slough is about 2% of the total flow to the works.

5.2 Wastewater characteristics

Sampling for the mass balance was conducted from the 28th April to the 12th of June. Composite samples were taken up until the 21st of June. Full results of the on-site sampling can be seen in Appendix A. An on-site sampling log book is also included in Appendix B.

It should be noted that on the 15th May, Slough STW began dosing the crude sewage with ferric chloride, to combat odour problems and reduce complaints from surrounding communities. The dosing level was 600ml min⁻¹, which equates to 0.01ml ferric per litre of crude. Samples were taken before and after the dosing regime, there was no visible difference in the results.

5.2.1 Influent and effluent streams

The crude sewage into the works, the settled sewage and the effluent from treatment stream A and C were sampled using automated sampling devices. The analysis of these four streams are summarised in Table 5.2.

Table 5.2 Characteristics of influent and effluent streams

Crude Sewage						
	<i>COD</i> <i>Kg d⁻¹</i>	<i>BOD</i> <i>Kg d⁻¹</i>	<i>BOD.sol</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>SS</i> <i>Kg d⁻¹</i>
<i>Average</i>	29572.6	7797.2	1588.7	1059.1	2018.3	24965.7
<i>Standard Dev.</i>	11865.5	3319.7	997.2	181.6	756.2	18258.9
<i>Sample Size</i>	28	28	28	28	26	28
<i>mg L⁻¹</i>	442.6	116.7	24.6	16.1	31.5	370.6
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	707.9	377.8	591.2	1059.1	7819.6	22899.5
<i>Standard Dev.</i>	302.8	44.3	130.4	181.6	943.5	4574.5
<i>Sample Size</i>	27	28	27	27	27	22
<i>mg L⁻¹</i>	10.5	5.7	8.9	7.8	117.6	359.8

Table 5.2 continued

Settled Sewage						
	<i>COD</i> <i>Kg d⁻¹</i>	<i>BOD</i> <i>Kg d⁻¹</i>	<i>BOD.sol</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>SS</i> <i>Kg d⁻¹</i>
<i>Average</i>	17896.0	4060.3	1408.4	1273.4	1607.8	8873.7
<i>Standard Dev.</i>	9170.0	2062.9	1077.2	327.1	240.7	7299.5
<i>Sample Size</i>	30	31	31	31	26	30
<i>mg L⁻¹</i>	328.4	76.9	28.1	23.9	30.3	160
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	385.8	305.7	430.2	410.3	5937.4	19772.3
<i>Standard Dev.</i>	161.5	55	38.7	31.7	454.1	4260.3
<i>Sample Size</i>	29	31	29	29	30	23
<i>mg L⁻¹</i>	8.0	5.7	8.0	7.7	111.2	356.2

Effluent C						
	<i>COD</i> <i>Kg d⁻¹</i>	<i>SS</i> <i>Kg d⁻¹</i>	<i>TON</i> <i>Kg d⁻¹</i>	<i>N-NO₂</i> <i>Kg d⁻¹</i>	<i>N-NO₃</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>
<i>Average</i>	639.0	213.4	377.5	6.4	371.0	13.5
<i>Standard Dev.</i>	313.6	331.6	58.7	5.2	58.3	19.9
<i>Sample Size</i>	21	21	21	21	21	21
<i>mg L⁻¹</i>	34.4	17.4	20.5	0.4	20.2	0.8
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	111.6	104.0	149.9	144.8	2042.2	3694.8
<i>Standard Dev.</i>	15.2	13.2	18.2	16.6	239.4	977.2
<i>Sample Size</i>	21	21	21	21	20	17
<i>mg L⁻¹</i>	6.0	5.6	8.1	7.8	109.0	198.7

Effluent A						
	<i>COD</i> <i>Kg d⁻¹</i>	<i>SS</i> <i>Kg d⁻¹</i>	<i>TON</i> <i>Kg d⁻¹</i>	<i>N-NO₂</i> <i>Kg d⁻¹</i>	<i>N-NO₃</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>
<i>Average</i>	2957.5	1526.4	357.8	21.7	342.8	71.7
<i>Standard Dev.</i>	2249.7	2046.7	68.7	17.7	63.3	99.6
<i>Sample Size</i>	22	22	17	22	18	21
<i>mg L⁻¹</i>	58.0	29.3	7.3	0.43	7.0	1.4
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	67.2	30.7	333.7	315.3	5581.6	12862.7
<i>Standard Dev.</i>	47.8	22.4	33.5	36.3	417.5	904.1
<i>Sample Size</i>	22	22	22	22	21	13
<i>mg L⁻¹</i>	1.3	0.6	6.7	6.3	112.4	267.8

Magnesium and calcium levels were relatively low for a hard water area. Expected levels of magnesium and calcium are 150 mg L⁻¹, as opposed to the 117 mg L⁻¹ calcium and the 8.9 mg L⁻¹ magnesium found in the crude. TKN levels in the crude are also low. Typically TKN levels are greater than 40 mg L⁻¹, the crude at Slough has an average TKN of 31.5mgL⁻¹.

Of the total phosphorus entering the works 50% is soluble, increasing to 71% after primary treatment. The soluble phosphorus levels in the final effluent from treatment stream A are much lower than phosphorus levels in the final effluent from treatment stream C. The average concentration of phosphorus in the effluent of treatment stream C is 6 mg L⁻¹, whereas in the effluent of treatment stream A the average phosphorus concentration is 1.3 mg L⁻¹.

5.2.2 BNR lanes

The Bardenpho process at Slough consists of four lanes. These lanes were sampled to see how the BNR performed. At present the recirculation pump is only operating at 50% capacity and 50% of the mixing in the anaerobic zone is switched off. The results of the BNR sampling are shown in Table 5.3.

Table 5.3 Characteristics of BNR lanes

BNR Lane 1						
	<i>Tot.P</i> <i>mg L⁻¹</i>	<i>P.sol</i> <i>mg L⁻¹</i>	<i>Mg.sol</i> <i>mg L⁻¹</i>	<i>TON</i> <i>mg L⁻¹</i>	<i>N-NH₄</i> <i>mg L⁻¹</i>	<i>Alk</i> <i>mg L⁻¹</i>
<i>Average</i>	34.3	3.3	9.2	4.8	3.2	262.7
<i>Standard Dev.</i>	71.7	4.1	3.9	2.5	1.0	4.5
<i>Sample Size</i>	5	5	5	5	5	5

BNR Lane 2						
	<i>Tot.P</i> <i>mg L⁻¹</i>	<i>P.sol</i> <i>mg L⁻¹</i>	<i>Mg.sol</i> <i>mg L⁻¹</i>	<i>TON</i> <i>mg L⁻¹</i>	<i>N-NH₄</i> <i>mg L⁻¹</i>	<i>Alk</i> <i>mg L⁻¹</i>
<i>Average</i>	33.4	2.3	8.2	5.8	2.1	260.0
<i>Standard Dev.</i>	71.6	3.8	2.3	2.5	1.0	10.4
<i>Sample Size</i>	5	5	5	5	5	5

Table 5.3 continued

BNR Lane 3						
	<i>Tot.P</i> <i>mg L⁻¹</i>	<i>P.sol</i> <i>mg L⁻¹</i>	<i>Mg.sol</i> <i>mg L⁻¹</i>	<i>TON</i> <i>mg L⁻¹</i>	<i>N-NH₄</i> <i>mg L⁻¹</i>	<i>Alk</i> <i>mg L⁻¹</i>
<i>Average</i>	33.6	5.8	8.8	6.5	1.0	252.7
<i>Standard Dev.</i>	71.3	11.9	4.1	3.2	0.4	9.3
<i>Sample Size</i>	5	5	5	5	5	3

BNR Lane 4						
	<i>Tot.P</i> <i>mg L⁻¹</i>	<i>P.sol</i> <i>mg L⁻¹</i>	<i>Mg.sol</i> <i>mg L⁻¹</i>	<i>TON</i> <i>mg L⁻¹</i>	<i>N-NH₄</i> <i>mg L⁻¹</i>	<i>Alk</i> <i>mg L⁻¹</i>
<i>Average</i>	29.2	4.4	8.6	4.3	3.12	276.3
<i>Standard Dev</i>	58.8	7.1	2.7	2.6	1.4	2.5
<i>Sample Size</i>	5	5	5	5	5	3

In lanes 1 and 2 soluble phosphorus constitutes less than 10% of the total phosphorus. In lanes 3 and 4, the soluble phosphorus concentration is less than 20%; almost double the concentration found in lanes 1 and 2. The lower soluble phosphorus levels in lane 1 and 2 suggests these two lanes are more efficient at phosphorus removal. The ammonium levels in lanes 1 and 4 are slightly high, at over 3 mg L⁻¹, than the ammonium in lanes 2 and 3. Lane 3 has low ammonium levels, 1 mg L⁻¹, indicating that the aeration in lane 3 is sufficient, but could be increased in the other lanes. Magnesium levels in all four lanes are similar, at around 9 mg L⁻¹ . Magnesium levels in lane 2 are slightly lower than the other three lanes at just over 8 mg L⁻¹ .

5.2.3 Return activated sludge

The return activated sludge (RAS) from both the activated sludge (AS) plant and the BNR plant were sampled. The results from both types of RAS are compared in Table 5.4

Table 5.4 Characteristics of RAS from AS and BNR plant

Activated Sludge Plant							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	15.0	3.0	21.1	3.1	1.9	0.7	78.8
<i>Standard Dev.</i>	12.9	1.3	1.2	1.3	2.6	1.2	46.6
<i>Sample Size</i>	5	5	5	5	5	5	3
<i>mg L⁻¹</i>	64.3	11.5	21.1	10.5	5.4	117.2	252

BNR Plant							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	114.8	8.7	28.4	16.1	2.0	82.5	294.4
<i>Standard Dev.</i>	84.8	9.1	20.1	15.5	2.7	65.4	290.7
<i>Sample Size</i>	2	2	2	2	2	2	2
<i>mg L⁻¹</i>	163.0	10.1	40.3	19.9	1.8	113.5	357.5

The total phosphorus in the RAS from the BNR plant is approximately 7.5 times higher than the phosphorus in the RAS from the AS. The soluble fraction of phosphorus in the BNR RAS is approximately 7% of the total phosphorus. The soluble fraction of phosphorus in the AS RAS is roughly 20%. Magnesium levels in RAS from the BNR is slightly higher than the magnesium levels found in the activated sludge RAS. Calcium levels in the BNR RAS are more than 100% higher than in the AS RAS. Alkalinity is also higher in the BNR RAS than the AS RAS.

5.2.4 Other sludge streams

A total of seven samples were taken for each of the sludge streams. The characteristics of the sludge streams are summarised in Tables 5.5- 5.9

Humus sludge was also sampled, but the results have not been included in this section, as they were not used for the mass balance. The analysis of the humus sludge can be seen in Appendix A.

The PFT streams are summarised in Table 5.5.

Table 5.5 PFT streams

PFT Feed							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>D.S</i> <i>%</i>	<i>Alk.</i> <i>Kg d⁻¹</i>
<i>Average</i>	121.7	334.3	49.7	17.8	357.4	2.24	20.0
<i>Standard Dev.</i>	137.4	386.2	44.7	16.6	302.5	2.71	23.2
<i>Sample Size</i>	6	6	6	5	5	6	4

PFT Sludge							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>	<i>D.S</i> <i>%</i>	<i>Alk.</i> <i>Kg d⁻¹</i>
<i>Average</i>	138.6	189.9	29.9	12.7	218.0	4.4	17.6
<i>Standard Dev.</i>	150	99.3	14.9	2.7	89.7	1.0	12.8
<i>Sample Size</i>	7	7	5	7	7	7	4

PFT Liquor							
	<i>BOD</i> <i>Kg d⁻¹</i>	<i>BOD.sol</i> <i>Kg d⁻¹</i>	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>
<i>Average</i>	402.7	125.2	20.9	9.1	37.2	3.8	3.6
<i>Standard Dev.</i>	284.5	79.4	16.1	5.57	46.9	2.9	1.2
<i>Sample Size</i>	6	6	6	6	5	6	6
	<i>Ca</i> <i>Kg d⁻¹</i>	<i>S.S</i> <i>Kg d⁻¹</i>	<i>VFA</i> <i>Kg d⁻¹</i>	<i>Alk.</i> <i>Kg d⁻¹</i>			
<i>Average</i>	52.7	1783.9	223.5	138.6			
<i>Standard Dev.</i>	21.5	1646.5	139.1	74			
<i>Sample Size</i>	6	6	5	4			

The PFT feed was the most variable sample. The analysis for the PFT feed was not used in the final mass balance. For the mass balance, the PFT feed was calculated by deducting the settled sewage results from the crude sewage results. The concentration of total phosphorus in the PFT sludge is higher than the concentration in the PFT liquor. The soluble phosphorus concentration in the PFT liquor is 44% of the total phosphorus concentration. Approximately 11% of the magnesium entering the PFTs, remains in the PFT sludge. The PFT liquors contain 88% of the magnesium entering the PFTs

The combined surplus activated sludge (SAS) from both the AS and BNR plant was sampled. It was not possible to obtain separate samples of AS and BNR SAS.

However the concentration of components in the AS SAS and BNR SAS will be the same as the concentration of components in the AS RAS and BNR RAS, these results can be seen in Appendix A. The analysis of the blended SAS is summarised in Table 5.6.

Table 5.6 SAS streams

Blended SAS					
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	DS %	<i>Alk.</i> <i>Kg d⁻¹</i>
<i>Average</i>	446.7	92.1	82.9	1.5	5.6
<i>Standard Dev.</i>	96.2	26.6	34.5	1.2	4.5
<i>Sample Size</i>	7	6	7	7	50
<i>mg L⁻¹</i>	453.7	96.8	90.1		10.3

Thickened SAS							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	DS %	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	375.0	2.35	626.8	73.1	83.1	6.5	10.4
<i>Standard Dev.</i>	101.5	1.01	334.8	10.5	27.6	0.4	6.2
<i>Sample Size</i>	6	6	6	4	6	6	4
<i>mg L⁻¹</i>	2214.8	14.2	3785.1	388.3	481.9		50.7

Belt Thickener Liquor							
	<i>BOD</i> <i>Kg d⁻¹</i>	<i>BOD.sol</i> <i>Kg d⁻¹</i>	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>P.sol</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>Mg.sol</i> <i>Kg d⁻¹</i>	<i>Ca</i> <i>Kg d⁻¹</i>
<i>Average</i>	120	2.07	29.1	15.7	11.9	11.4	120.7
<i>Standard Dev.</i>	91.2	1.04	10.8	6.0	2.0	2.6	7.7
<i>Sample Size</i>	5	5	6	6	6	6	6
<i>mg L⁻¹</i>			27.1	14.2	10.7	10.1	120.7
	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>SS</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>				
<i>Average</i>	1.8	405.8	345.6				
<i>Standard Dev.</i>	0.9	238.7	54.0				
<i>Sample Size</i>	6	6	4				
<i>mg L⁻¹</i>	1.6	396.5	285.8				

The blended SAS is thickened from 1.5% dry solids to 6.5% dry solids by the belt press thickeners. The majority of the phosphorus in the thickened SAS is insoluble; less than

1% of the total phosphorus in the thickened SAS is soluble. In the belt thickener liquors, the concentration of soluble phosphorus is 52% of the total phosphorus concentration. The majority of the magnesium in the belt thickener liquors is soluble. Most of the phosphorus and magnesium in the blended SAS is removed in the thickened SAS.

The imported sludge analysis is summarised in Table 5.7

Table 5.7 Imported sludge

Imports							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>DS</i> <i>%</i>	<i>VS</i> <i>%</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	81.6	204.4	74.0	22.7	4.7	76.8	19.5
<i>Standard Dev.</i>	92	223.6	109.4	23.1	1.2	2.5	27.9
<i>Sample Size</i>	7	7	5	7	7	7	5

The average phosphorus load in the imported sludge is approximately 82 Kg d⁻¹. The load for all the determinants varies greatly as the flow of imported sludge to Slough STW is variable. During the sampling period the flow of imported sludge ranged from 5 m³ d⁻¹ to 386 m³ d⁻¹.

The Thickened SAS, imports and PFT sludge are combined and fed into anaerobic digesters. The analysis of the digester streams are summarised in Table 5.8.

Table 5.8 Digester influent and effluent

Digester Feed							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>TKN</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>DS</i> <i>%</i>	<i>VS</i> <i>%</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	603.1	1473.5	607.1	103.2	3.8	74.2	59.3
<i>Standard Dev.</i>	97.6	121.4	113.4	13.1	1.0	2.1	35.4
<i>Sample Size</i>	6	6	4	6	7	6	4
<i>mg L⁻¹</i>	1066.0	2485.6	1000.8	173.9			102.4

Table 5.8 continued

Digested Sludge							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>DS</i> <i>%</i>	<i>VS</i> <i>%</i>	<i>VFA</i> <i>Kg d</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	610.4	679.3	93.1	2.8	70.2	57.2	49.2
<i>Standard Dev.</i>	217.6	215.8	39.3	0.4	1.2	19.3	12.3
<i>Sample Size</i>	7	7	7	7	7	6	5
<i>mg L⁻¹</i>	951.0	1166.0	152.5			57.2	98.8

The average phosphorus load into the digester is 603 Kg d⁻¹, similar to the phosphorus load in the digested sludge. About 23% of the flow from the digester is put into the sludge lagoons. The lagoons are used to store sludge when the centrifuge is not working. The centrifuge feed is approximately 77% of the digested sludge. The loads of magnesium and phosphorus into the digester are similar to loads of magnesium and phosphorus coming out of the digester

The digested sludge is dewatered via centrifugation. The analysis of the centrifuge streams are summarised in Table 5.9.

Table 5.9 Centrifuge streams

Centrifuge Feed*							
	<i>Tot.P</i> <i>Kg d⁻¹</i>	<i>N-NH₄</i> <i>Kg d⁻¹</i>	<i>Tot.Mg</i> <i>Kg d⁻¹</i>	<i>DS</i> <i>%</i>	<i>VS</i> <i>%</i>	<i>VFA</i> <i>Kg d⁻¹</i>	<i>Alk</i> <i>Kg d⁻¹</i>
<i>Average</i>	470.0	523.0	72.0	2.8	70.2	57.2	38.0
<i>Sample Size</i>	7	7	7	7	7	6	5

*Based on 77% of the digested sludge

Table 5.9 continued

Centrifuge Liquor							
	BOD <i>Kg d⁻¹</i>	BOD.sol <i>Kg d⁻¹</i>	Tot.P <i>Kg d⁻¹</i>	P.sol <i>Kg d⁻¹</i>	Tot.Mg <i>Kg d⁻¹</i>	Mg.sol <i>Kg d⁻¹</i>	N-NH ₄ <i>Kg d⁻¹</i>
<i>Average</i>	82.2	21.1	57.5	34.2	18.5	2.8	221.8
<i>Standard Dev.</i>	102.4	14.2	16.2	9.2	27.2	1.2	62.6
<i>Sample Size</i>	5	5	5	5	5	5	5
<i>mg L⁻¹</i>	280.2	66.6	167.0	94.9	43.9	7.4	615.2
	Ca <i>Kg d⁻¹</i>	SS <i>Kg d⁻¹</i>	VFA <i>Kg d⁻¹</i>	Alk <i>Kg d⁻¹</i>			
<i>Average</i>	21.3	249.1	4.2	992.3			
<i>Standard Dev.</i>	17.2	168.9	1.2	173.2			
<i>Sample Size</i>	5	5	4	4			
<i>mg L⁻¹</i>	55.8	3140.0	10.5	2580.3			

Centrifuge Cake							
	Tot.P <i>Kg d⁻¹</i>	TKN <i>Kg d⁻¹</i>	Tot.Mg <i>Kg d⁻¹</i>	N-NH ₄ <i>Kg d⁻¹</i>	DS %	VS %	Alk <i>Kg d⁻¹</i>
<i>Average</i>	352.5	666.6	55.6	283.2	22.6	65.0	30.6
<i>Standard Dev.</i>	165.6	305.3	26.3	255.5	1.3	2.8	10.3
<i>Sample Size</i>	5	5	5	4	5	5	4
<i>mg L⁻¹</i>	6531	12405	1049	4477			482.2

The soluble phosphorus in the centrifuge liquors constitutes 59% of the total phosphorus load. 75% of the total phosphorus into the centrifuge is held in the centrifuge cake. There is six times more phosphorus in the centrifuge cake than in the centrifuge liquor. There is three times more magnesium in the centrifuge cake than in the centrifuge liquor.

5.3 Magnesium, ammonia and phosphorus through Slough STW

The following graphs plot the levels of phosphorus, magnesium and ammonia through Slough STW. The areas where the highest level of all three components occurs should correspond to the area which has the most potential to form struvite. Figure 5.1 is based on total phosphorus, which gives a misleading result as all the phosphorus present is not necessarily available for struvite formation. Only the soluble fraction can form struvite. Figure 5.2 is based on soluble phosphorus levels. Soluble phosphorus data was

not available for all the sampling sites, as the Thames Water Quality Centre Laboratories could not perform soluble phosphorus analysis on the thicker sludge streams. The soluble phosphorus levels in the digested sludge and the blended SAS were determined from one sample. The sample was filtered and the filtrate tested for P-PO₄ using Dr Lange kit LCK 350. The sampling sites were allocated locations numbers, these are listed in Table 5.10

Table 5.10 Sampling location numbers

N ^o	Location	N ^o	Location
1	PFT Feed	10	Digested Sludge
2	PFT Sludge	11	Crude Sewage
3	PFT Liquor	12	Settled Sewage
4	BSAS	13	Effluent C
5	TSAS	14	Effluent A
6	BTL	15	BNR lanes
7	Centrate	16	Humus
8	Imports	17	RAS
9	AD Feed		

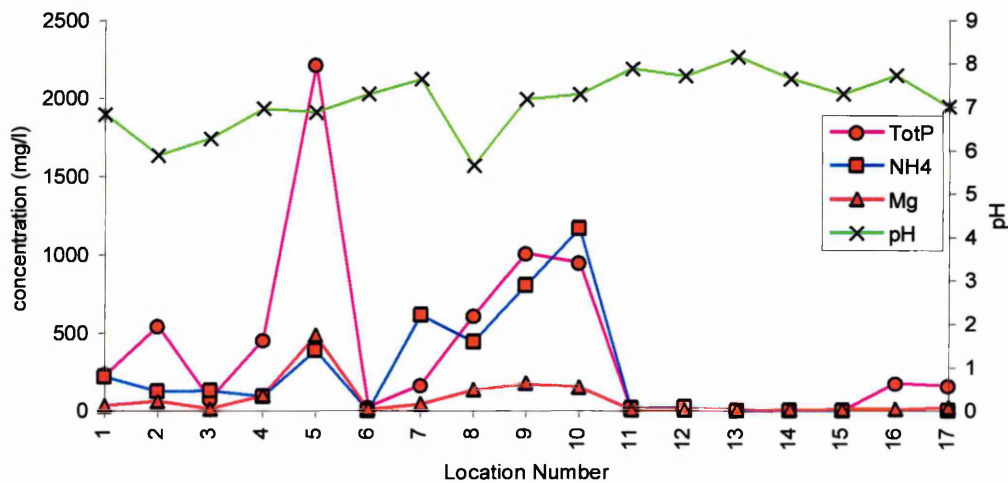


Figure 5.1 Concentration of magnesium, total phosphorus and ammonia through Slough STW

Figure 5.1 shows that locations 5, 8, 9 and 10 have the highest amount of total phosphorus. The location numbers correspond to thickened SAS, imports, anaerobic digester feed and digested sludge, respectively. These locations could theoretically form struvite, but the pH for location 8, 9 and 5 is relatively low i.e. under the pH of 7.0, for struvite to form. Considering only the concentrations of phosphorus and magnesium and the pH, location 10, i.e. digested sludge is probably the most likely place for struvite formation to occur.

Figure 5.2 indicates that location 7 and 10, which corresponds to the centrate stream and the digested sludge, have the highest potential to form struvite. The average pH of the centrifuge liquor stream is 7.64, which is higher than the average pH of 7.29 in the digested sludge stream.

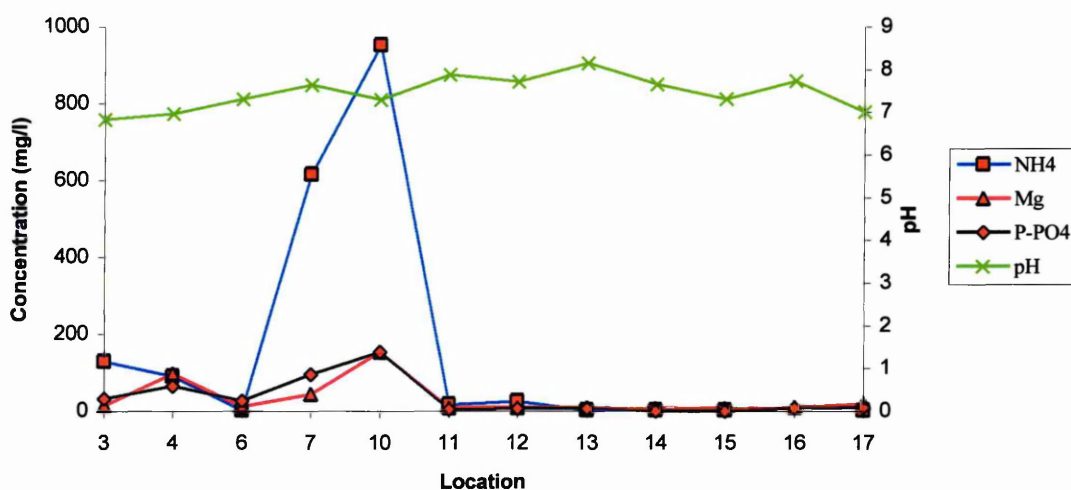


Figure 5.2 Concentration of magnesium, soluble phosphorus and ammonia through Slough STW

5.4 Mass balance across Slough STW

A mass balance of total phosphorus, TKN and magnesium through Slough STW is shown in Figure 5.3. As previously mentioned the PFT feed was calculated using crude sewage and settled sewage results. The settled sewage concentrations for stream C were assumed to be the same as the concentrations for stream A. Loads for settled sewage in

stream C were then calculated using previously determined flow data. The data for the lagoons was based on the difference in flows for the digested sludge and the flow onto the centrifuge. The flow difference was found to be 23%, the loading into the lagoon was then calculated from this figure. The load recycled to the head of the works was calculated by the addition of all the return liquors. The flow to the works prior to the addition of return liquors was calculated by deducting the return liquors from the crude sewage data. Calculated results on the mass balance are indicated by purple boxes as opposed to grey boxes, which indicate results were based on sampling data.

The mass balance indicates that 26% of the phosphorus load to the head of the works is due to the return liquors. Magnesium in the return liquors adds 20% to the magnesium load into the works. The majority of the phosphorus and magnesium is found in the centrifuge cake.

SPP is also included in the mass balance and was calculated using a computer model, based on the work by Lowenthal *et al.*, (1994). A positive SPP indicates there is a potential to form $X \text{ mgL}^{-1}$ of struvite, whereas a negative SPP denotes no potential for struvite to form. The data used to obtain the SPP results is shown in Table 5.11.

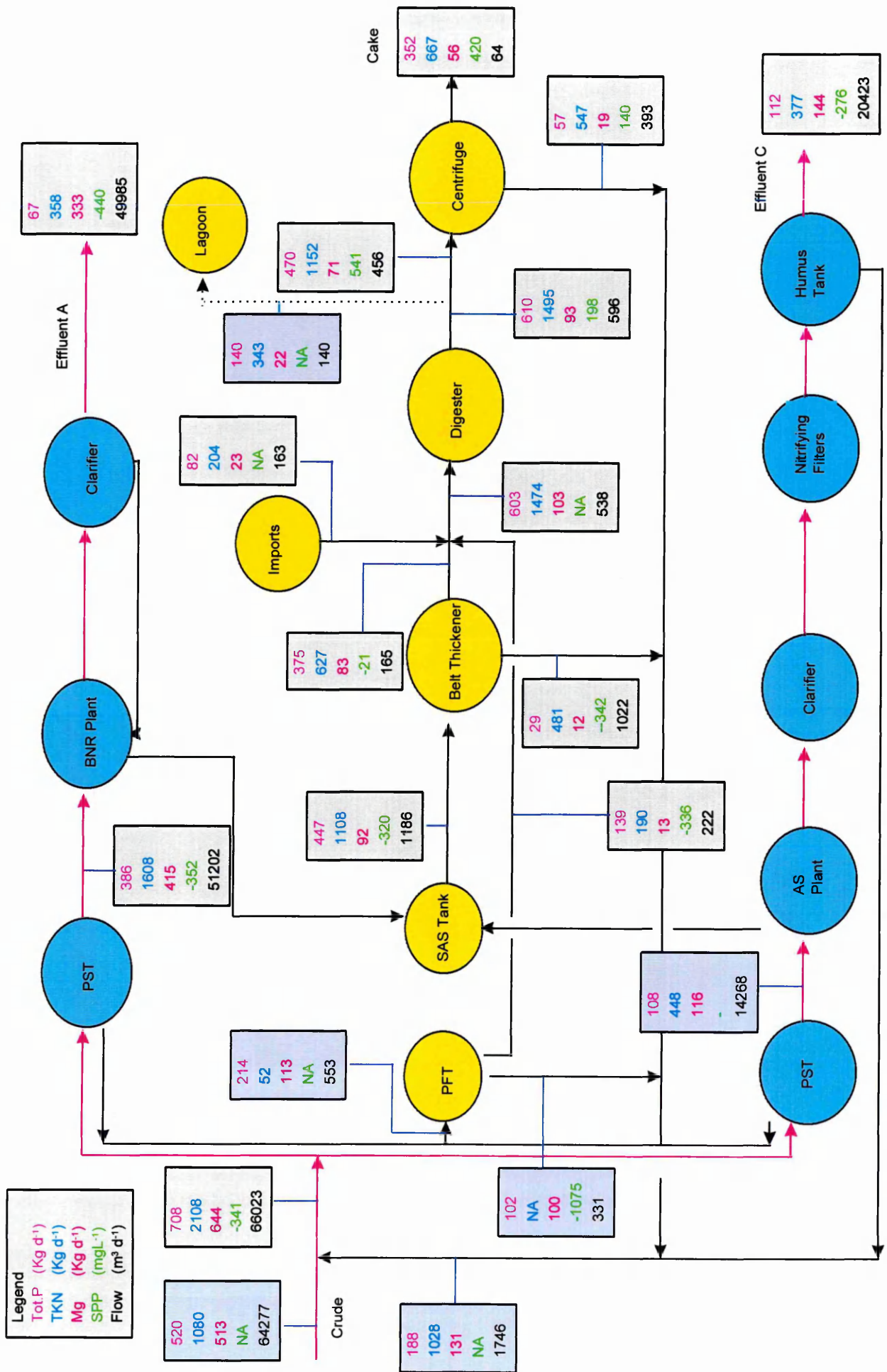


Figure 5.3 Mass Balance of phosphorus, ammonia and magnesium at Slough STW

Table 5.11 Data used to calculate SPP of various streams

<i>Stream</i>	<i>P-PO₄</i> <i>mg L⁻¹</i>	<i>NH₄</i> <i>mg L⁻¹</i>	<i>Mg</i> <i>mg L⁻¹</i>	<i>Ca</i> <i>mg L⁻¹</i>	<i>Alk</i> <i>mg L⁻¹</i>	<i>pH</i>	<i>Temp</i> <i>mg L⁻¹</i>	<i>SPP</i> <i>mg L⁻¹</i>
<i>PFT Feed</i>	NA	220	33	644	39.5	6.9	18.4	NA
<i>PFT Sludge</i>	32.2 ^a	123	61	982	63.8	5.9	19.5	-336
<i>PFT Liquor</i>	32.2	129	13	185	478.8	6.3	18.8	-1075
<i>Blended SAS</i>	65.0 ^b	90	96.8	NA	10.3	7	18.3	-320
<i>Thickened SAS</i>	14.2 ^c	389	482	NA	50.7	6.9	18.3	-21
<i>Belt Liquor</i>	14.2	1.6	11	121	285.8	7.3	17.2	-342
<i>Imports</i>	NA	441	134	NA	133	5.7	18.4	NA
<i>Digester Feed</i>	NA	1166	153	NA	98.8	7.3	26.8	NA
<i>Digested Sludge</i>	154 ^d	1166	153	NA	98.8	7.3	26.8	198
<i>Centrifuge Liquor</i>	94.9	615	44	56	2580	7.6	24.1	140
<i>Centrifuge Cake</i>	94.9 ^e	4477	1049	NA	482	7.0	NA	420
<i>Crude Sewage</i>	5.7	16.1	8.9	117.6	360	7.9	14	-341
<i>Settled Sewage</i>	5.7	23.9	8.04	111.2	356	7.7	14	-352
<i>Effluent C</i>	5.6	0.8	8.06	109.0	199	8.2	13.4	-276
<i>Effluent A</i>	0.6	1.4	6.7	112.4	268	7.6	13	-440

Notes

NA Data not available

a Used P-PO₄ concentration of PFT Liquor, should be the sameb P-PO₄ concentration of this stream could not be measured by laboratories. Data base on one sample filtered and analysed using Dr Lange kit LCK 350c Used P-PO₄ concentration of Belt Thickener Liquor, should be the samed P-PO₄ concentration of this stream could not be measured by laboratories. Data base on one sample filtered and analysed using Dr Lange kit LCK 350e Used P-PO₄ concentration of Centrifuge liquor, should be the same

The digested sludge, centrifuge liquor and centrifuge cake are identified by the Lowenthal *et al.*, (1994) model as streams which have the potential to form struvite. These streams all have high concentrations of soluble phosphorus. The centrifuge cake

has the highest SPP, as it has the highest magnesium concentration of any of the streams. The digested sludge also has a high SPP which could due to the high concentration of phosphorus. The centrifuge liquor also has a positive SPP, though at 140 mg L^{-1} , it is not as high as the other two streams. The magnesium concentration in the centrifuge liquors is more than 50% less than the magnesium concentration in the other two SPP positive streams.

The thickened SAS has the highest magnesium concentration of all the streams, but has a negative SPP. The pH of the thickened SAS is less than 7.0, so the potential for this stream to form struvite is low. If the pH of the thickened SAS stream increased to 7.5, the SPP would increase from -21 mg L^{-1} to 51 mg L^{-1} .

The blended SAS also has a high soluble phosphorus and magnesium concentration but a low SPP. The pH of the blended SAS is relatively low at 7.0, but the pH would have to increase to 8.5 for the SPP to increase from -320 mg L^{-1} to 16 mg L^{-1} .

5.5 Possible ways to reduce the struvite precipitation potential

5.5.1 Dilute digested sludge with belt thickener liquors

The belt thickener liquors could be redirected and used to dilute the digested sludge. If the digested sludge was diluted with belt thickener liquors, the following wastewater characteristics would be achieved:

P-PO ₄	66.6 mg L^{-1}	Ca	74.8 mg L^{-1}
Alkalinity	244 mg L^{-1}	Mg	64.8 mg L^{-1}
NH ₄	420 mg L^{-1}		

The struvite potential of this combined stream would be -63 mg L^{-1} , assuming a combined pH of 7.0. However if the pH were to increase up to 7.5, the SPP of this stream would increase to 70 mg L^{-1} . The combined stream has a lower SPP than the digested sludge only, even if the pH is 7.5.

5.5.2 Dilute centrifuge liquor with belt thickener liquor

The belt thickener liquors could be used to dilute the centrifuge liquors in order to reduce the SPP of the centrifuge liquor stream. The wastewater characteristics of this combined stream would be:

P-PO ₄	35.3 mg L ⁻¹	NH ₄	158 mg L ⁻¹
Alkalinity	945 mg L ⁻¹	Mg	21.5 mg L ⁻¹

The SPP of this stream would be -477 mg L⁻¹ assuming a pH of 7.0. If the pH rose to 7.5, the SPP would be -78 mg L⁻¹. The pH would have to increase to 8.5 before struvite would form in this stream (25 mg L⁻¹).

5.5.3 Lower the pH of digested sludge.

The digested sludge could be dosed with acid to decrease the pH and thereby decrease the potential for struvite to form. If the pH of the digested sludge was reduced from 7.3 to 6.2 the SPP would drop from 198 mg L⁻¹ to -6 mg L⁻¹. The amount of acid required to lower the pH to 6.2 would be 3.29 mMol L⁻¹ of strong acid.

5.5.4 Side-stream treatment to remove phosphorus

Another possible solution to the formation of struvite at Slough STW would be to precipitate the phosphorus from the centrifuge liquor as struvite, in a side-stream process. This would lower the amounts of phosphorus recycled around the works and would reduce the amount of struvite formed upstream of the process.

This option was investigated further in a series of bench-scale experiments.

5.6 Bench-scale struvite precipitation using centrifuge liquors

Experiments were conducted to determine whether struvite could be produced from the centrifuge liquor stream. Centrifuge liquor was collected from Slough and stored at room temperature. The pH of the centrifuge liquor was raised to 9.0, using sodium hydroxide. Centrifuge liquor samples were analysed before and after pH adjustment. Table 5.12 shows the average composition of centrifuge liquors before and after pH adjustment.

Table 5.12 Analysis of centrate liquor before and after pH adjustment

(mgL ⁻¹)	<i>Tot.P</i>	<i>P.sol</i>	<i>Tot.Mg</i>	<i>Mg.sol</i>	<i>N-NH₄</i>	<i>TKN</i>	<i>Ca</i>	<i>Alkalinity as (CaCO₃)</i>	<i>pH</i>
<i>Before</i>									
<i>Average</i>	99.6	92.1	13.15	11.5	530.5	547.0	26.0	4888.0	7.5
<i>After</i>									
<i>Average</i>	100.8	85.6	5.9	1.7	574.8	654.0	6.0	2322.5	9.0

Levels of soluble phosphorus, magnesium and calcium dropped after raising the pH to 9.0. Raising the pH must caused the magnesium and calcium in the sample to react with phosphorus, forming precipitates. The ratio of calcium : magnesium in the centrifuge liquor is roughly 2 : 1. This decreases to a 1 : 1 ratio after the pH has been raised. This reduction in the ratio indicates that more calcium is reacting with the phosphorus in the sample than magnesium. The concentration of total phosphorus remained the same.

The magnesium levels in the centrifuge liquor samples were too low to remove the remaining phosphorus as struvite. The pilot plant was therefore dosed with magnesium chloride (MgCl₂) to provide a source of magnesium ions and maximise struvite production.

5.6.1 Struvite crystallisation

The pilot plant was started on the 7th July, using centrifuge liquors and a dose of 252 mg L⁻¹ of MgCl₂. Crystals were seen on the surface of the porous pot, by the 8th of

July. Samples of crystals were taken and analysed by x-ray diffraction (XRD) at the laboratories at Cranfield university. The results of the XRD can be seen in Figure 5.4. The crystals produced were validated to be struvite and were of a high purity.

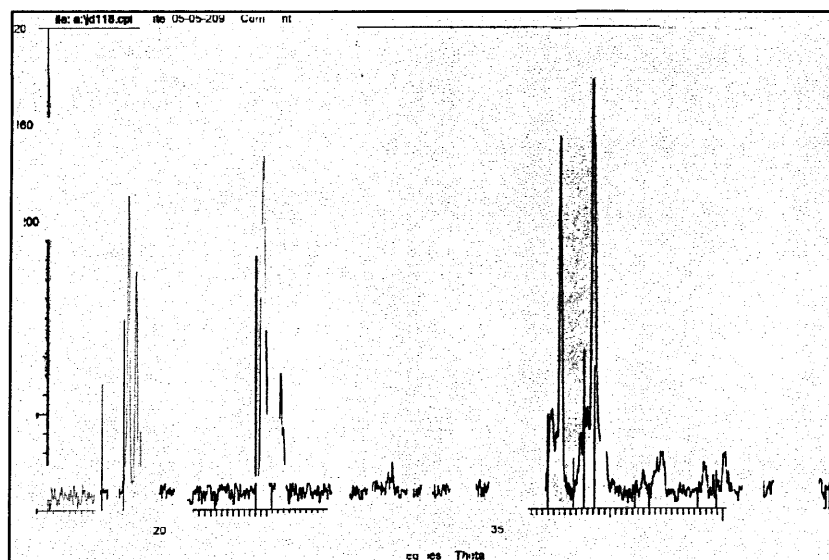


Figure 5.4 XRD of crystals produced in pilot plant

5.6.2 Optimum magnesium dose

Once it was established that struvite could be formed from the centrifuge liquors at Slough STW, the magnesium dose to the pilot plant was altered to determine an optimum dosing regime. Figure 5.5 shows the influent and effluent concentrations of ammonia, phosphorus and magnesium when the pilot plant was dosed with 252 mg L^{-1} of MgCl_2 .

The dosing regime equated to a magnesium : phosphorus (Mg : P) ratio of approximately 3.5 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 96%. The soluble phosphorus was reduced by 97% and the ammonium by 70%. The ratio of $\text{Psol} : \text{NH}_4 : \text{Mg}$ removed in the pilot plant was 2.8 : 32 : 2.8 (mM L^{-1}). The 1:1 ratio of P : Mg shows that the phosphorus is probably being removed as struvite. The mass of struvite formed was 0.69 g L^{-1} (assuming one mole of struvite weighs 245g i.e. water of crystallisation is taken into account). On a plant the size of Slough STW, which has an

average centrifuge liquor flow of 393 m^3 , this would be equivalent to 271 Kg d^{-1} . On a yearly basis approximately 100 tons of struvite could be formed with this dosing regime.

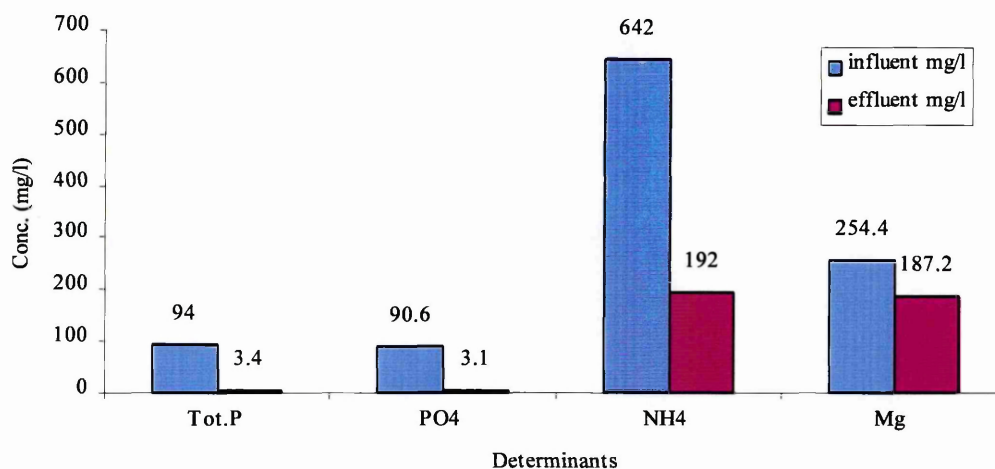


Figure 5.5 Influent and effluent concentrations of struvite components with a magnesium addition of 252 mg L^{-1}

The ammonium removal was greater than the requirement for struvite. The surplus ammonium is probably being removed from the reactor by air stripping. The ammonia is being volatilised and converted into a gaseous form by the high pH in the reactor and the air flow. Ammonium removal by air stripping is a method used in treatment works for the reduction of nitrogen from wastewater.

The dose of magnesium was reduced to 136 mg L^{-1} , to see how this would effect the phosphorus removal and if struvite would still be produced. The results for this experiment are shown in Figure 5.6.

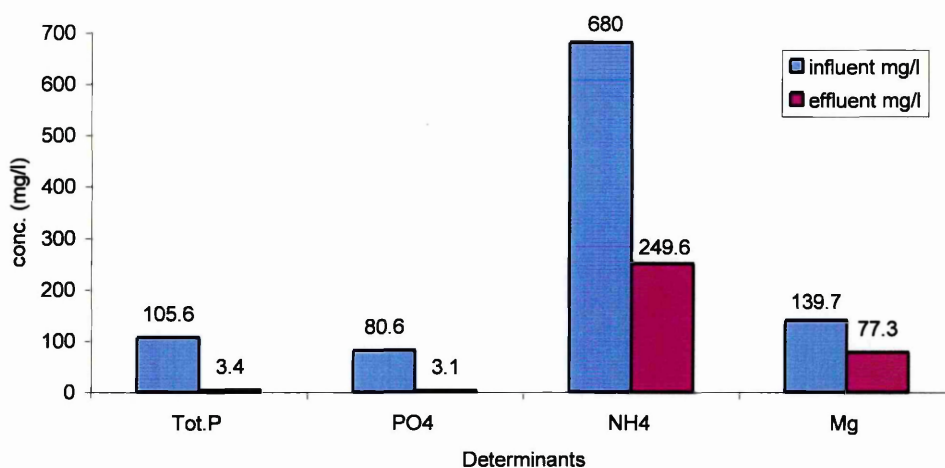


Figure 5.6 Influent and effluent concentrations of struvite components with a magnesium addition of 136 mg L^{-1}

The dosing regime equated to a Mg : P ratio of approximately 1.7 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 97%. The soluble phosphorus was reduced by 96% and the ammonium by 63%. The ratio of $\text{P}_{\text{sol}} : \text{NH}_4 : \text{Mg}$ removed in the pilot plant were 2.5 : 31 : 2.6 (mM L^{-1}). The approximate 1:1 ratio of P : Mg shows that the phosphorus is being removed as struvite. The ammonium removal was far greater than the requirement for struvite. At this dosing regime 2.5 mM L^{-1} of struvite was formed, equating to 0.61 g L^{-1} . At full scale the production of struvite could be approximately 241.5 Kg d^{-1} , or 88 tons a year.

The magnesium dose was reduced to 82.7 mg L^{-1} to see how this would effect phosphorus removal. The results of this experiment are shown in Figure 5.7

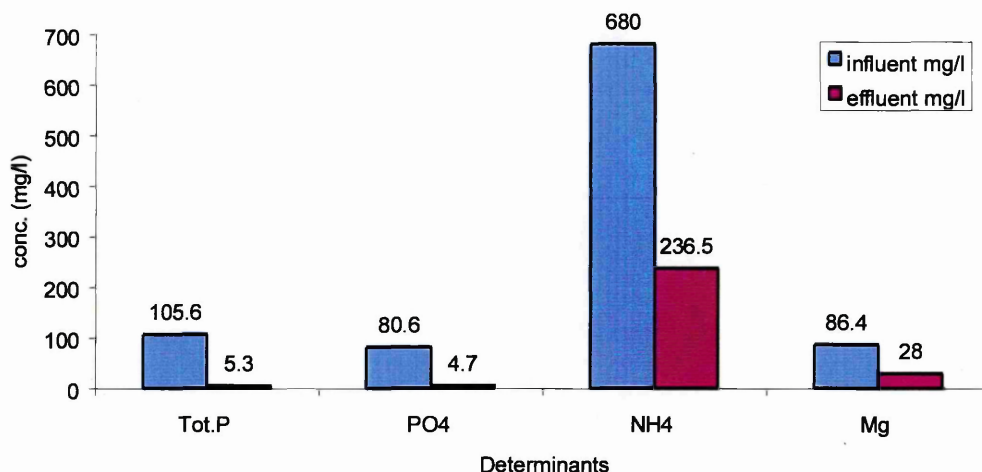


Figure 5.7 Influent and effluent concentrations of struvite components with a magnesium addition of 82.7 mg L^{-1}

The dosing regime equated to a Mg:P ratio of approximately 1.05 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 95%. The soluble phosphorus was reduced by 94% and the ammonium by 65%. The ratio of $\text{P}_{\text{sol}} : \text{NH}_4 : \text{Mg}$ removed in the pilot plant was 2.45 : 32 : 2.42 (mM L^{-1}). The approximate 1:1 ratio of P : Mg shows that the phosphorus was removed as struvite. The ammonium removal was far greater than the requirement for struvite.

The pilot plant was still producing struvite at the lower dosing regime, so the dose was reduced further. The magnesium dose was decreased to 62.1 mg L^{-1} . The results of this experiment are shown in Figure 5.8.

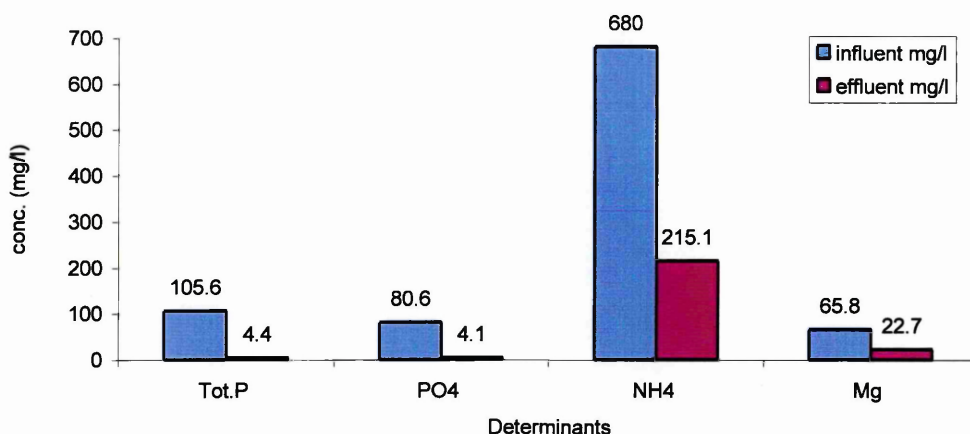


Figure 5.8 Influent and effluent concentrations of struvite components with a magnesium addition of 62.1 mg L^{-1}

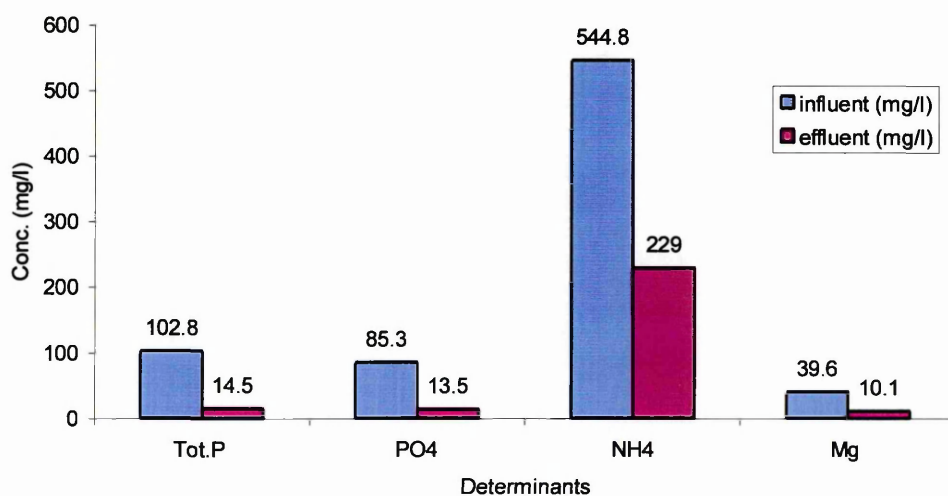
The dosing regime equated to a Mg : P ratio of approximately 0.8 : 1 (including Mg present in the centrifuge liquors after pH adjustment). The total phosphorus concentration was reduced by 95%. The soluble phosphorus was reduced by 94% and the ammonium by 68%. The molar ratios of $\text{P}_{\text{sol}} : \text{NH}_4 : \text{Mg}$ removed in the pilot plant were 2.5 : 33 : 1.8. The phosphorus removal is similar to the removal achieved when dosing with 82.7 mg L^{-1} magnesium, but the phosphorus is not being removed as only struvite. There is a surplus of 0.7 mM L^{-1} phosphorus being removed which can not be accounted for by struvite production.. Table 5.13 summarises analysis performed by the Thames Water Quality Centre Laboratories on the pilot plant effluent. Table 5.13 shows that at a dose of 62.1 mg L^{-1} Mg, the calcium concentration in the effluent is less than one. The low calcium concentration indicates that almost all the calcium in the influent has been removed by the pilot plant. The average influent calcium concentration was 6 mg L^{-1} (Table 5.12). The calcium concentration equates to 0.15 mM L^{-1} of calcium. If it were to be assumed that this calcium formed hydroxyapatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$), this would only account for 0.09 mM L^{-1} of phosphorus removed as hydroxyapatite i.e. 0.6 mM L^{-1} of phosphorus is unaccounted for.

Table 5.13 Other analysis performed by Thames Laboratories on pilot plant effluent

<i>Mg added mg L⁻¹</i>	<i>Ca mg L⁻¹</i>	<i>Alk mg L⁻¹</i>	<i>SS mg L⁻¹</i>	<i>TKN mg L⁻¹</i>
0	<3.0	3144.0	94.0	NA
39.62	<1.0	2199.0	56.0	NA
62.1	<1.0	1217.0	16.5	174.5
82.7	<3.0	193.8	30.0	269.7
136	7.0	720.0	51.0	190.0
252	8.0	662.0	48.0	182.0

The additional phosphorus removal could have been due to a bacterial contamination that was observed, during the run of the pilot plant. The contamination was high enough to form a visible bio-film in the tubing of the reactor and in the reactor itself. The growth of the bio-film could explain the additional phosphorus removal.

The magnesium dose to the pilot plant was reduced again to evaluate if phosphorus removal could still be achieved. The removal of phosphorus is an important factor when considering the load recycled back to the head of the works and the extra load to the BNR plant. The magnesium dose was reduced to 36.3 mg L⁻¹. The results of this experiment are shown in Figure 5.9

**Figure 5.9** Influent and effluent concentrations of struvite components with a magnesium addition of 36.3 mg L⁻¹

The total phosphorus concentration was reduced by 88%. The soluble phosphorus was reduced by 94% and the ammonium by 72%. The ratio of $\text{P}_{\text{sol}} : \text{NH}_4 : \text{Mg}$ removed in the pilot plant was 2.3 :23 :1.2 (mM L^{-1}). Phosphorus removals were still good at low doses of magnesium, but the phosphorus is not removed only as struvite.

The magnesium dose was removed and the pilot plant run with only centrifuge liquors and aeration, to see what level of phosphorus removal could be achieved. The results of this experiment are shown in Figure 5.10.

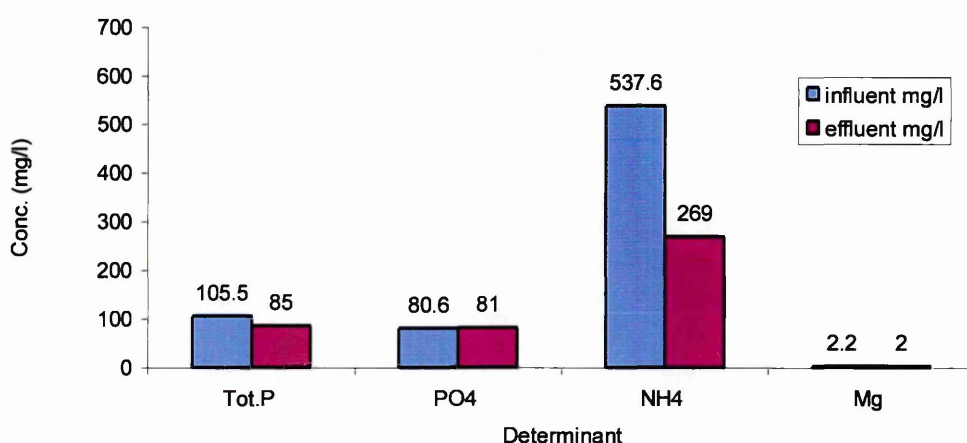


Figure 5.10 Influent and effluent concentrations of struvite components with no magnesium addition

With no magnesium added, the total phosphorus removal in the pilot plant was 19%. There was no soluble phosphorus removal and the amount of magnesium that went into the plant (from the centrifuge liquors) was also present in the pilot plant effluent. The ammonium removal was 50%.

The results shown in Figures 5.5 - 5.10 are summarised in Figures 5.11-5.13. Figure 5.11 shows the percentage phosphorus and ammonia removals with increasing magnesium dose. Figure 5.12 shows the molar removal of soluble phosphorus and ammonia, with the molar usage of magnesium and Figure 5.13 shows only the molar phosphorus removal and magnesium usage, with increasing dose of magnesium.

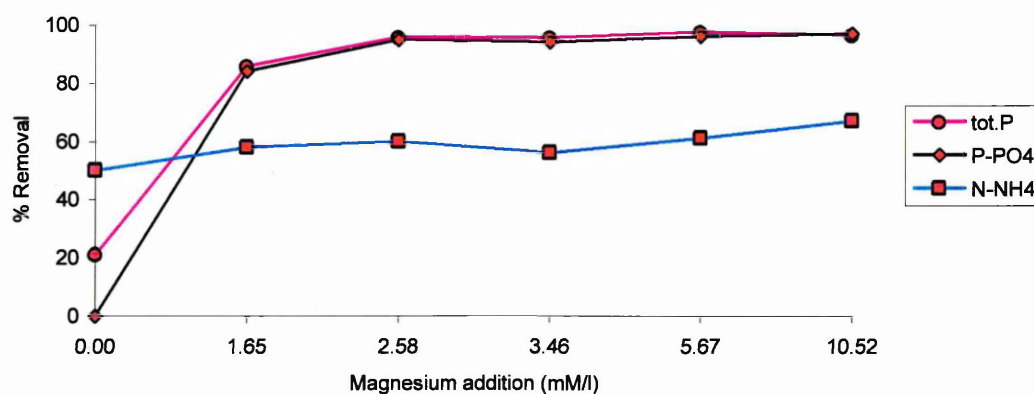


Figure 5.11 Percentage removal of phosphorus and ammonia with increasing magnesium dose.

Figure 5.11 shows that phosphorus removal increases with magnesium addition. The level of phosphorus removal reaches approximately 97% at a magnesium molar addition of 5.7 mM L^{-1} , but does not go higher than this, even though the magnesium dose is doubled.

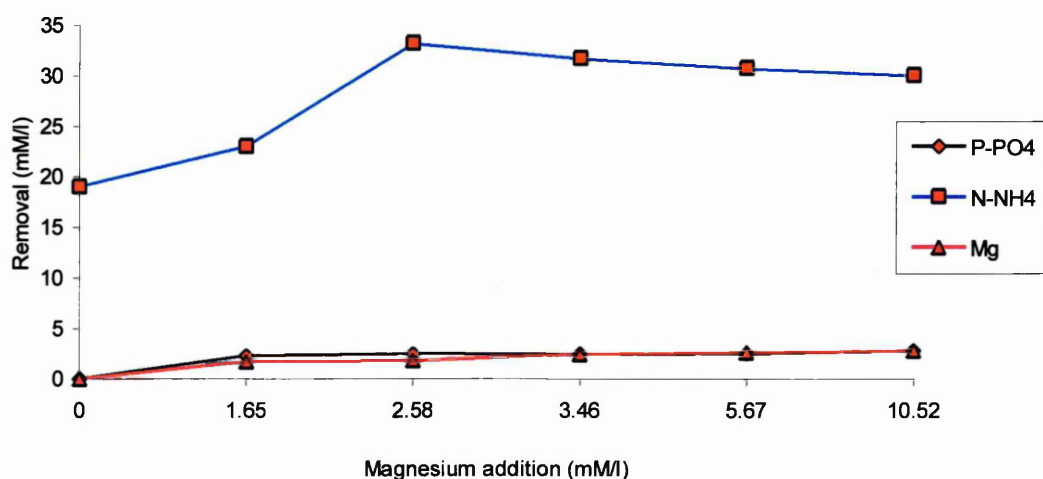


Figure 5.12 Molar removal of phosphorus and ammonia and molar usage of magnesium against molar addition of magnesium

Figure 5.12 shows that the molar removal of ammonia exceeds the molar removals of phosphorus and the molar usage of magnesium. Figure 5.13 shows the same results as Figure 5.12, but the ammonia removal has not been included.

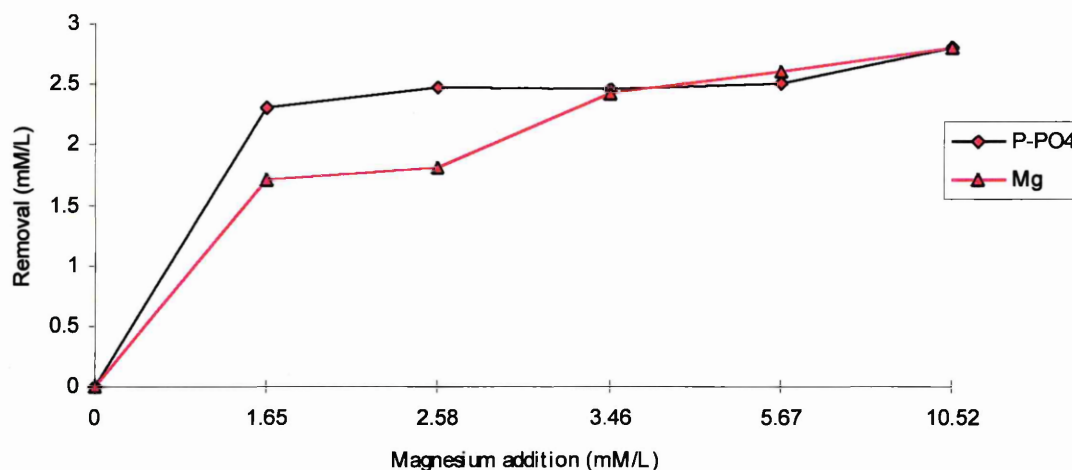


Figure 5.13 Molar removal of phosphorus and molar usage of magnesium against molar addition of magnesium

Figure 5.13 shows that at high dosages of magnesium, the phosphorus is probably removed as struvite. This can be seen as the lines for phosphorus and magnesium are the same at higher doses of magnesium. At magnesium doses below 3.4 mM L^{-1} , phosphorus is still removed, but not solely as struvite.

5.7 Costs

The costs of a pilot plant, with a capacity to treat all of the average centrifuge liquor flow was estimated. The costs were based on the addition of chemicals only and did not take into account the civil engineering of a side-stream phosphorus removal process. The cost to build a full-scale struvite crystallisation plant, based on the Phosnix process would be in the region of £200,000 (personal communication, Thames Water Engineering).

The annual chemical cost of phosphorus removal as struvite is shown in Figure 5.14

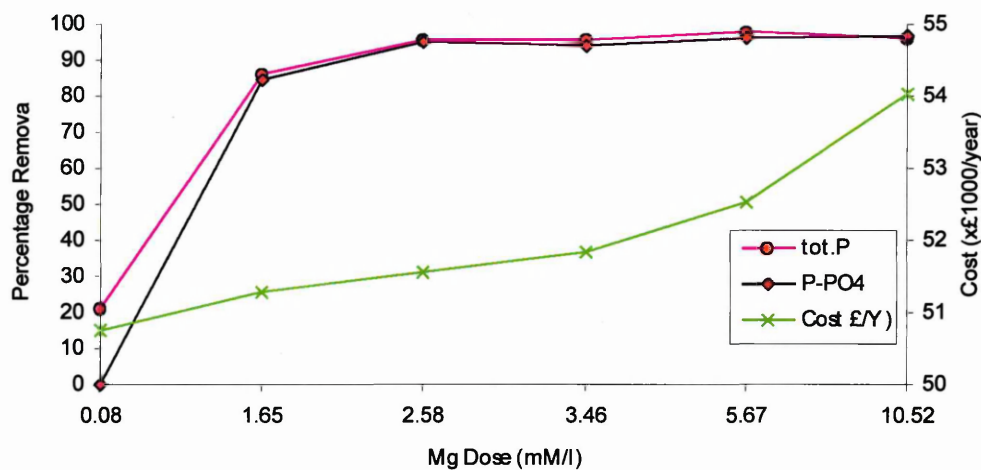


Figure 5.14 Estimated annual chemical cost of phosphorus removal by struvite precipitation

As the percentage phosphorus removal increases the cost of chemical addition also increases. Between a magnesium dose of 2.6 to 10.5 mM L⁻¹ (62-253 mgL⁻¹) the percentage phosphorus removal ranges between 96-97% i.e. there is no difference in phosphorus removal. In terms of phosphorus removal there is no benefit to be gained by increasing the magnesium dose above 62 mgL⁻¹. However in terms of struvite production the magnesium dose needs to be around 83 mgL⁻¹ (3.5 mM L⁻¹ Mg). This increase in dose, increases the cost from £51,500 to £52,000. The increase in cost, in terms of increasing magnesium dose is small. The majority of the chemical costs can be attributed to the addition of sodium hydroxide, to raise the pH.

The cost of sodium hydroxide was based on the amount required to raise the pH of the centrifuge liquors from 7.5 to 9.0, during the bench-scale work. The amount of sodium hydroxide required was around 150 ml per 25 litres. Considering the flow of centrifuge liquors at Slough STW a dose of 2.36 m³d⁻¹ of sodium hydroxide would be required to raise the pH to 9.0 at full-scale. Assuming the cost of sodium hydroxide is £59 ton⁻¹, the daily cost of sodium hydroxide addition would be £139, or £50,735 per year.

Table 5.14 summarises the calculations used to derive the costs of chemical addition. The calculations were based on the average flow of centrifuge liquors i.e. $393 \text{ m}^3\text{d}^{-1}$

Table 5.14 Cost of chemical addition

<i>Mg Dose</i> (mg L^{-1})	<i>Daily Mg Requirement</i> (Kg d^{-1})	<i>Mg Requirement</i> (tonnes y^{-1})	<i>Cost of Mg</i> (£90 ton^{-1}) (£ y^{-1})	<i>Cost of NaOH</i> (£59 ton^{-1}) (£ y^{-1})	<i>Total Cost of chemicals</i> (£ y^{-1})
0	0	0	0	50760	50760
40	16	5.7	511	50760	51272
62	24	8.9	800	50760	51561
83	33	11.9	1071	50760	51832
136	53	19.59	1755	50760	52515
253	99	36.2	3258	50760	54019

Table 5.15 summaries the amount of struvite that could be produced at full-scale at each of the dosing regimes used during the bench-scale work. The percentage removals of phosphorus are also included in the table. The amount of struvite produced is based on the amount magnesium used in the reactor. By using the magnesium results it is assumed that all the magnesium used in the reactor is due to the formation of struvite. Daily struvite production rates were based on average centrifuge liquor flows.

Table 5.15 Possible production of struvite at full-scale

<i>Mg dose</i> mg L^{-1}	<i>Bench-scale production of struvite</i> mML^{-1}	<i>Full-scale production of struvite</i> Kg d^{-1}	<i>Full-scale production of struvite</i> ton y^{-1}	<i>Possible income from struvite*</i> £ y^{-1}	<i>Tot. Phosphorus removal</i> %
0	0	0	0	0	19
36	1.2	116	42	8,400	88
62	1.8	173	63	12,600	95
83	2.4	231	84	16,800	95
136	2.6	250	91	18,200	97
252	2.8	272	99	19,800	96

* Based on a price of £200 per tonne

6.0 Discussion

6.1 Wastewater characteristics

Previous work at conducted at Slough STW, by Williams (1999), found the wastewater characteristics detailed in Table 6.1.

Table 6.1 Previous wastewater characteristics at Slough STW

<i>Stream</i>	<i>SS mg L⁻¹</i>	<i>P.sol mg L⁻¹</i>	<i>Tot.P mg L⁻¹</i>	<i>Ammonia mg L⁻¹</i>	<i>Flow m³ d⁻¹</i>	<i>P. Load Kg d⁻¹</i>
<i>Settled Sewage</i>	125	8.7	11.7	34	59000	690
<i>SAS</i>	9,000	190	350	50	700	245
<i>Belt Thickener Liquor</i>	250	190	200	50	600	120
<i>Digested sludge</i>	28,500	70	800	750	300	240
<i>Centrifuge Liquor</i>	270	80	110	750	250	28

The soluble and total phosphorus levels (5.7 and 8.0 mg L⁻¹ respectively) in the settled sewage determined by this study were slightly lower than the levels found by Williams (1999). The difference could be attributed to variations in the composition of industrial discharge to Slough STW, during the respective sampling periods. The decrease in phosphorus concentrations may also be due to increased infiltration of ground water into the sewer pipes.

The surplus activated sludge (SAS) from the BNR plant had higher levels of total phosphorus than previously determined by the Williams study (453.7 mg L⁻¹ compared to 350 mg L⁻¹). The higher phosphorus concentration in the SAS could be because the BNR had been modified since the first study was conducted. When this current study was undertaken the mixing in the anaerobic zone had been optimised to facilitate phosphorus release and subsequent uptake (Williams and Beresford, 1998). The total phosphorus concentration in the SAS would therefore increase, as more phosphorus is accumulated by the biomass.

The soluble phosphorus level in the SAS is now lower, at 65 mg L⁻¹ than the previous study (190 mg L⁻¹). The reduction in soluble phosphorus could be due to a number of factors. The recirculation in the BNR lanes operated at 50% capacity during this work. The reduction in recirculation would increase the concentration of nitrates in the SAS. The nitrates would provide a source of oxygen, thereby reducing the tendency for the SAS to go anaerobic. The flow rate of the SAS has also increased since the previous work (1186 m³ compared to 700 m³) so the hydraulic retention time in the SAS buffer tank has decreased. Jardin and Popel (1996) and Pitman (1999) have both shown that hydraulic retention times in storage facilities affect the amount of phosphorus released from the sludge. When the SAS is subjected to anaerobic conditions e.g. due to long retention times, the phosphorus stored as polyphosphate chains is hydrolysed and released (Levin and Shapiro, 1965). It should be noted that the soluble phosphorus content of the SAS in this study was based on the results of one grab sample. However, the soluble phosphorus content of the belt thickener liquors (15.7 mg L⁻¹ compared to 190 mg L⁻¹) also confirms the attenuated release in phosphorus.

The total phosphorus in the anaerobic digester feed averages 1066 mg L⁻¹ and the soluble phosphorus concentration averages 95 mg L⁻¹ (based on centrifuge liquor data). This gives a phosphorus release of 9%. The degree of phosphorus solubilisation at Slough is lower than figures reported by Murakami *et al.*, (1987) and Knocke *et al.*, (1988). Both authors found a phosphorus release of 60%. However, Wedi and Wilderer (1994) also found a relatively low phosphorus release of 4-10% at full-scale. During laboratory trials on the same sludge, Wedi and Wilderer found a release of 20%. They explained the difference by concluding the phosphorus was released during digestion, but became chemically bound in the sludge. This refixation of phosphorus could explain the relatively low concentrations of phosphorus in the centrifuge liquor (167.0 mg L⁻¹) compared to the phosphorus levels in the centrifuge cake (6531 mg L⁻¹). The phosphorus released in the anaerobic digesters at Slough STW could have been refixed as struvite and other phosphates, which were held in the sludge and removed with the centrifuge cake.

6.1.2 Phosphorus Recycle

The mass balance conducted at Slough STW demonstrated that 26% of the phosphorus entering the works was due to the phosphorus feedback i.e. phosphorus in the return liquors. This compares well with the 20% detected by Pitman *et al.*, (1991), and the 20-50% range given by Munch and Barr (unpublished). Other authors have found phosphorus feedback as high as 40% (Jardin and Popel, 1994). It should be noted that Jardin and Popel's figure was determined during a pilot study and the recycle percentage range given by Munch and Barr was based on an estimation, which assumed sludge flow to be 1% of the total flow to treatment.

The phosphorus feedback could be reduced by optimising the solids capture in the belt thickeners. Popel and Jardin, (1993) estimated that less than 5% of the phosphorus feedback is due to thickening processes. This work agrees with the figure, as 4.1% of the phosphorus feedback at Slough STW is due to the belt thickeners.

The phosphorus feedback will impact on the performance of the BNR plant at Slough. At present there is no consent for phosphorus at Slough STW, but a consent of 1 mg L^{-1} will be implemented by the year 2004. Currently Slough STW is not reaching this consent, averaging a phosphorus discharge of 1.3 mg L^{-1} .

6.1.3 Reducing the struvite precipitation potential

The mass balance conducted at Slough STW identified streams which had a positive struvite precipitation potential (SPP). These streams were identified as the digested sludge, centrifuge liquor and centrifuge cake. The SPP of these streams could be reduced by various methods. One method is to dilute the digested sludge with the belt thickener liquors, giving a combined stream which has a lower SPP. This method was used by Borgerding (1972) at the Hyperion treatment plant, Los Angeles, where digested sludge was diluted with secondary effluent in a 1:1 flow ratio. Diluting the digested sludge would not be suitable at Slough STW as the digested sludge is dewatered via centrifugation. Diluting the sludge would increase the hydraulic load on the centrifuge and cake formation would be difficult.

The dilution options presented in Chapter 5, may reduce the formation of struvite, but they do not address the problem of recycling nutrients to the head of the works and increasing the nutrient load onto the BNR.

Booker *et al.*, (1999) suggested dosing digested sludge with acid to decrease the pH below 7.5, reducing the potential for struvite to form. The pH of the digested sludge at Slough STW, would have to be dropped to 6.2 to reduce the struvite precipitation potential to a negative, in accordance with the model devised by Lowenthal *et al.*, (1994). The digested sludge could be dosed with ferric chloride to fix the phosphorus in the sludge and remove it in the cake. Maimas *et al.*, (1994) determined a dose of 100Kg ferric chloride per tonne of total solids. At Slough STW, the typical dry solids content of anaerobic digester feed is 4% and flow rate of feed is about 560 m³ d⁻¹. This equates to a total solids load of around 22.4 tonnes. Assuming a cost of £50 per tonne of ferric chloride, the cost of dosing digesters to prevent struvite formation is £112 per day, or £41,000 per annum. This method does not however provide an avenue for recycling phosphorus, which crystallisation of struvite in a sidestream process does.

The stream identified as suitable for the sidestream precipitation of struvite, at Slough STW was the centrifuge liquor stream. This is in accordance with a number of authors who have used digested sludge supernatant as feed, during pilot studies into struvite crystallisation (Battistoni *et al.*, 1998, Salutsky *et al.*, 1972, Momberg and Oellerman, 1992).

6.2 Bench-scale struvite formation.

The experiments conducted during this work showed that struvite could be rapidly crystallised from the centrifuge liquors at Slough. Struvite crystals were produced within 24 hours of starting the pilot plant. Raising the pH of the liquors to 9.0 was an effective method of forming struvite. Magnesium in the storage containers was removed before even entering the reactor. A pH of 9.0 was found to be optimum by Siegrist *et al.*, (1992).

It was found that 95% of the total phosphorus could be removed from the centrifuge supernatant as struvite, by the addition of at least a 1.05 : 1 molar ratio of magnesium to phosphorus i.e. a magnesium dose of about 83 mg L⁻¹. This ratio of 1.05 : 1 was also found by Fujimoto *et al.*, (1991). Other authors, Siegrist *et al.*, (1992) and Salutsky *et al.*, (1972), found a higher ratio of 1.3 : 1 was required to guarantee phosphorus removal as struvite. The lower ratio necessary for struvite precipitation during this series of experiments was probably due to the lack of any competing reactions. When the pH of the centrifuge liquor was raised to 9.0 in the storage containers, 77% of the calcium was removed, before entering the reactor. On average 6 mg L⁻¹ of calcium entered the reactor. At a dosing regime of 83 mg L⁻¹ this equates to a 0.04 : 1 molar ratio of calcium : magnesium. Hwang and Choi (1998) found that for effective struvite formation, the ratio of calcium to magnesium should be less than 1. Mustovo *et al.*, (2000) found that the ratio of magnesium : calcium should be greater than 0.6. In this case, the ratio of magnesium : calcium is 23 :1. Before the addition of sodium hydroxide to raise the pH, the molar ratio of calcium : magnesium was 1.18 : 1. A soluble phosphorus removal of 7% was observed on raising the pH, before the centrifuge liquor was fed into the reactor. Most of this phosphorus was probably removed as calcium phosphates.

At full-scale the presence of calcium should be taken into consideration when determining an ideal magnesium dose. The centrifuge liquors were batch pH adjusted prior to being fed into the reactor. At full-scale it is more likely that pH correction will occur within the reactor, so the calcium ions will not have been removed and will be competing with the magnesium ions. A ratio of 1.3 : 1 (magnesium : phosphorus) is probably more suitable at full-scale. Also, by batch treating the centrifuge liquors it was possible to settle out the suspended solids in the liquor, prior to the pilot plant. If the suspended solids were allowed to enter the pilot plant they may have caused clogging of tubing and increased the organic content of the struvite produced. It may be beneficial to add a unit process prior to the reactor at full-scale, to remove suspended solids.

Ammonia removals during the bench-scale trials exceeded the requirement for struvite precipitation. The additional ammonia removal was due to air stripping i.e. the ammonium was converted to ammonia gas, due to the aeration and elevated pH. It is unclear if this volatilisation of ammonium would cause a problem during a full-scale struvite crystallisation process at Slough STW. The legislative consequences of ammonia release in the UK may have to be considered, before deciding on a full-scale phosphorus sidestream process.

6.3 Cost considerations.

Calculations were done to determine the yearly cost of chemical addition at full-scale. From these calculations it was deduced that the 97% of the total chemical cost was due to the addition of sodium hydroxide. The alkalinity in wastewater is generally high, so there is a large buffering capacity which needs to be overcome. If a full-scale plant is to be viable the cost required for pH correction needs to be addressed.

Some authors have used magnesium hydroxide as a source of magnesium ions and to raise the pH. Salutsky *et al.*, (1972) achieved 90% phosphorus recovery with magnesium hydroxide addition, but at a temperature of 25°C. Munch and Barr (unpublished) also used magnesium hydroxide as a dual function chemical and obtained an average of 94% phosphorus removal as struvite. However, using magnesium hydroxide to serve both functions means that the magnesium dose or the pH can not be optimised independently of each other. The Phosnix process uses magnesium hydroxide, but also has sodium hydroxide addition to control the pH. The sodium hydroxide requirement is less with magnesium hydroxide, than with magnesium chloride (Taruya *et al.*, 2000). An advantage of using magnesium chloride over magnesium hydroxide is that magnesium chloride disassociates faster than magnesium hydroxide, resulting in shorter reaction times. A shorter reaction time means a smaller full-scale reactor can be constructed as the hydraulic retention time can be reduced.

Some authors have managed to crystallise phosphorus from wastewater without the addition of any chemicals. Battistoni *et al.*, (1997) removed 80% of phosphorus from

belt press liquors, from a treatment plant that had nitrification, denitrification and anaerobic digestion. The liquors were aged and air stripped to remove carbon dioxide. The pH was raised from 7.9 to 8.3-8.6 and the phosphorus was removed as struvite. The liquor had a Mg : P ratio of 3.7 : 1, so did not require magnesium addition. However, when the work was repeated with centrate liquor from a biological nutrient removal plant, phosphorus removal was achieved as a mixture of struvite and hydroxyapatite. The Mg : P ratio had decreased to 0.22 : 1 and was no longer sufficient to exclusively form struvite (Battistoni *et al.*, 1998).

If we assume that the optimum dose to remove over 90% of the phosphorus in the centrifuge liquor (as struvite) is 83 mg L⁻¹, the annual chemical cost of a full-scale plant would be almost £52,000. The amount of struvite that was formed at bench-scale during this dosing regime, was 2.4 mM L⁻¹. This would equate to 231 Kg d⁻¹ of struvite at full-scale. On a yearly basis, 84 tonnes of struvite could be recovered. The sale of struvite could bring in a yearly revenue of approximately £17,000 (struvite from the Phosnix process is sold for \$280 a tonne).

The revenue that could be generated from the sale of struvite is a third of the cost of chemical addition. However, the sale of struvite is not the only factor under consideration. Costs of production have to be offset against the revenue lost through increased pumping costs, lost man hours, expensive pipe replacements, possible excavation work if pipes are located underground, STW downtime due to blockages. These factors are difficult to quantify financially. Also, if by having a side-stream treatment, operational problems due to struvite formation are removed, it would become possible to have an unmanned site.

7.0 Conclusions

- Modifications to the BNR plant and shorter hydraulic retention times in the buffer tank have meant the SAS has less opportunity to become anaerobic and release phosphorus. Consequently soluble phosphorus levels in the belt thickener liquors are lower than previously determined.
- The anaerobic digesters solubilise 9% of the total phosphorus content in the feed.
- The majority of phosphorus is bound in the centrifuge cake.
- 26% of the phosphorus load to treatment is due to phosphorus feedback.
- The centrifuge liquor is the most suitable stream for sidestream treatment.
- At bench-scale, struvite can be formed rapidly by raising the pH to 9.0 and a magnesium addition of at least 1.05 : 1 magnesium : phosphorus. A magnesium addition lower than the 1.05 : 1 ratio will result in a mixture of struvite and hydroxyapatite. At full-scale a magnesium dose of 1.3 : 1 is recommended.
- 97% phosphorus removal as struvite can be achieved.
- Chemical costs of a full-scale struvite crystallisation plant will be at least £50,000 per annum. The addition of sodium hydroxide to raise the pH, accounts for 97% of this cost.
- Revenue of £16,000-20,000 can be generated from selling the struvite produced.

8.0 Further Work

- Evaluate the use of magnesium hydroxide as a source of magnesium and base addition. Raising the pH of centrifuge liquors by sodium hydroxide is expensive, so by using a dual function chemical cost savings can be made.
- Investigate the effects of lower pH on the system effectiveness. Some pilot studies have been carried out on digested sludge supernatant, with no pH correction. Again, by eliminating the requirement for sodium hydroxide, cost savings can be achieved. Preliminary studies have been started in this area, giving 80% phosphorus removal. As yet, the purity of the product is unknown.
- Examine methods to increase the size of the struvite crystals produced. At present, the product resembles a powder. A more granular product would be desirable, as it would be easier to handle.
- Look at possible ways of releasing the phosphorus bound in the centrifuge cake and placing it in the centrifuge liquors. By increasing the phosphorus content of the centrifuge liquors, the yield of struvite could be increased.
- Scale-up the bench work to an on-site pilot plant.

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Flow Data for Slough STW

	Treatment to Works	Settled Sewage	Flow of SS to BNR (75% split)	Flow of SS to AS	Effluent A RHS	Effluent A LHS	Total Eff. A	% A of FTW	Effluent C
Date	m ³	m3	m3d-1	m3d-1	m ³	m ³	m ³		m ³
28-Apr	77356.67	76632.67	57474.50	19158.17	34473.00	20628.16	55101.16		22255.51
29-Apr	77585.22	76878.97	57659.23	19219.74	41228.00	14035.95	55263.95		22321.27
30-Apr	75636.68	75283.93	58462.95	18820.98	39906.00	13970.01	53876.01		21760.67
01-May	74792.31	74109.96	55582.47	18527.49	38610.00	14664.56	53274.56		21517.75
02-May	73696.98	72951.88	54713.91	18237.97	38822.00	13672.36	52494.36		21202.62
03-May	70523.10	70085.60	52564.20	17521.40	41503.00	8730.60	50233.60		20289.50
04-May	68789.92	68055.57	51041.68	17013.89	44016.00	4983.06	48999.06		19790.86
05-May	69312.77	68599.97	51449.98	17149.99	43617.00	5754.49	49371.49		19941.28
06-May	69459.47	68699.02	51524.27	17174.76	44329.00	5146.98	49475.98		19983.49
07-May	68936.19	68356.54	51267.41	17089.14	43086.00	8313.00	51399.00	74.56	17537.19
08-May	68201.16	67452.31	50589.23	16863.08	42721.00	8267.00	50988.00	74.76	17213.16
09-May	68100.57	67537.32	50652.99	16884.33	42613.00	8227.00	50840.00	74.65	17260.57
10-May	66340.83	65523.68	49142.76	16380.92	42019.00	8194.00	50213.00	75.69	16127.83
11-May	66853.42	66439.02	49829.27	16609.76	43362.00	8311.00	51673.00	77.29	15180.42
12-May	64786.25	64624.75	48468.56	16156.19	41349.00	8042.00	49391.00	76.24	15395.25
13-May	63180.01	62572.46	46929.35	15643.12	38985.00	7800.00	46785.00	74.05	16395.01
14-May	63794.75	63261.60	47446.20	15815.40	38904.00	7838.00	46742.00	73.27	17052.75
15-May	64820.74	64157.89	48118.42	16039.47	39622.00	7876.00	47498.00	73.28	17322.74
16-May	63391.96	62877.91	47158.43	15719.48	38909.00	7740.00	46649.00	73.59	16742.96
17-May	61130.91	60596.01	45447.01	15149.00	37138.00	7647.00	44785.00	73.26	16345.91
18-May	66864.77	66088.37	49566.28	16522.09	40270.00	8092.00	48362.00	72.33	18502.77
19-May	65061.94	64600.94	48450.71	16150.24	39208.00	7884.00	47092.00	72.38	17969.94
20-May	63710.96	63070.46	47302.85	15767.62	36200.00	7647.00	43847.00	68.82	19863.96
21-May	73560.34	73180.59	54885.44	18295.15	41200.00	8297.00	49497.00	67.29	24063.34
22-May	64723.74	64279.89	48209.92	16069.97	37301.00	7793.00	45094.00	69.67	19629.74
23-May	62970.12	62308.67	46731.50	15577.17	37084.00	7767.00	44851.00	71.23	18119.12
24-May	67845.77	67251.57	50438.68	16812.89	37591.00	7996.00	45587.00	67.19	22258.77
25-May	65631.32	65062.37	48796.78	16265.59	39836.00	8098.00	47934.00	73.04	17697.32
26-May	76451.47	75947.32	56960.49	18986.83	39778.00	8318.00	48096.00	62.91	28355.47
27-May	76856.86	76040.26	57030.20	19010.07	43932.00	8631.00	52563.00	68.39	24293.86

Appendix A

Flow Data for Slough STW

	Treatment to Works	Settled Sewage	Flow of SS to BNR (75% split)	Flow of SS to AS	Effluent A RHS	Effluent A LHS	Total Eff. A	% A of FTW	Effluent C
	m ³	m ³	m3d-1	m3d-1	m ³	m ³	m ³		m ³
28-May	91518.33				45996.00	9106.00	55102.00	60.21	36416.33
29-May	85413.77				45926.00	8950.00	54876.00	64.25	30537.77
30-May	82131.92					8866.00	58502.57		23629.35
31-May	74432.13	73813.08	55359.81	18453.27	nd	9125.00	53018.01		21414.12
01-Jun	76631.45								
02-Jun	76923.74								
03-Jun	73895.86								
04-Jun	69178.60								
05-Jun	65905.76								
06-Jun	65808.62								
07-Jun	65866.52								
08-Jun	65842.61								
09-Jun	65862.74								
10-Jun	64331.10								
11-Jun	63092.95								
12-Jun	61869.77								
13-Jun	60866.98								
14-Jun	61072.09								
15-Jun	59161.80								
16-Jun	62443.29								
17-Jun	61844.12								
18-Jun	61504.43								
19-Jun	56544.97								
20-Jun	60530.36								
21-Jun	58029.05								
22-Jun	58185.45								
23-Jun	57053.38								
24-Jun	56310.75								
25-Jun	6210.27								
26-Jun	57271.02								

Flow Data for Slough STW

Treatment to Works	Settled Sewage	Flow of SS to BNR (75% split)	Flow of SS to AS	Effluent A RHS	Effluent A LHS	Total Eff. A	% A of FTW	Effluent C
m ³	m3	m3d-1	m3d-1	m ³	m ³	m ³		m ³
27-Jun	58778.87							
28-Jun	57032.22							
29-Jun	57987.05							
30-Jun	65547.94							
Average	66022.55	51201.79	17067.26	40610.44	9012.09	49984.55	71.23	20423.19
SD	10556.12	3681.68	1227.23	2846.38	3023.84	3588.22	4.45	4492.00
Number	64.00	31.00	31.00	32.00	34.00	34.00	23.00	34.00

Flow Data for Slough STW

	PFT Feed "A" (capacity 60m3/hr)	PFT Feed "A" m3/d	PFT Feed "A" hrs run	PFT Feed "C" (capacity 5m3/s)	PFT Feed "C" m3/d	PFT Feed C	Total PFT Feed m3/d	PFT Outlet Liquors m3	PFT Outlet Sludge m3	SAS A (capacity 45 l/s) Hrs run	SAS "A" (Pumps) Hrs run	SAS C (Pumps) Hrs run	SAS "C" (pumps) m3/d	Total SAS (pumps) m3/d
28-Apr	11.55	693.00		6.20	31.00	724.00	405.00	319.00	319.00	5.48	887.76	5.90	233.64	1121.40
29-Apr	11.27	676.20		6.01	30.05	706.25	339.25	367.00	367.00	5.10	826.20	5.90	233.64	1059.84
30-Apr	5.37	322.20		6.11	30.55	352.75	112.75	240.00	240.00	5.71	925.02	5.90	233.64	1158.66
01-May	10.92	655.20		5.43	27.15	682.35	430.35	252.00	252.00	5.58	903.96	5.90	233.64	1137.60
02-May	11.93	715.80		5.86	29.30	745.10	406.10	339.00	339.00	5.90	955.80			955.80
03-May	6.79	407.40		6.02	30.10	437.50	219.50	218.00	218.00	3.22	521.64	11.01	436.00	957.64
04-May	11.77	706.20		5.63	28.15	734.35	547.35	187.00	187.00	6.75	1093.50	0.40	15.84	1109.34
05-May	11.42	685.20		5.52	27.60	712.80	540.80	172.00	172.00	6.35	1028.70	3.94	156.02	1184.72
06-May	12.17	730.20		6.05	30.25	760.45	537.45	223.00	223.00	8.59	1391.58	4.91	194.44	1586.02
07-May	9.22	553.20		5.29	26.45	579.65	422.65	157.00	157.00	8.39	1359.18	5.06	200.38	1559.56
08-May	11.99	719.40		5.89	29.45	748.85	598.85	150.00	150.00	4.46	722.52	6.65	263.34	985.86
09-May	8.90	534.00		5.85	29.25	563.25	407.25	156.00	156.00	5.03	814.86	5.99	237.20	1052.06
10-May	13.16	789.60		5.51	27.55	817.15	664.15	153.00	153.00	6.03	976.86	6.05	239.58	1216.44
11-May	6.56	393.60		4.16	20.80	414.40	252.40	162.00	162.00	3.98	644.76	8.04	318.38	963.14
12-May	2.50	150.00		2.30	11.50	161.50	35.50	126.00	126.00	1.68	272.16			272.16
13-May	9.55	573.00		6.91	34.55	607.55	291.55	316.00	316.00	5.78	936.36	4.27	169.09	1105.45
14-May	8.40	504.00		5.83	29.15	533.15	174.15	359.00	359.00	8.13	1317.06	4.28	169.49	1486.55
15-May	10.58	634.80		5.61	28.05	662.85	295.85	367.00	367.00	8.46	1370.52	5.55	219.78	1590.30
16-May	8.40	504.00		2.01	10.05	514.05	174.05	340.00	340.00	4.78	774.36	1.11	43.96	818.32
17-May	8.68	520.80		2.82	14.10	534.90	252.90	282.00	282.00	8.27	1339.74	4.93	195.23	1534.97
18-May	12.48	748.80		5.52	27.60	776.40	398.40	378.00	378.00	8.33	1349.46	5.26	208.30	1557.76
19-May	7.59	455.40		1.12	5.60	461.00	316.00	145.00	145.00	7.64	1237.68	8.70	344.52	1582.20
20-May	10.24	614.40		5.22	26.10	640.50	314.50	326.00	326.00	8.37	1355.94	5.39	213.44	1569.38
21-May	5.84	350.40		5.87	29.35	379.75	53.75	326.00	326.00	8.16	1321.92	4.56	180.58	1502.50
22-May	6.89	413.40		6.09	30.45	443.85	131.85	312.00	312.00	8.00	1296.00	5.00	198.00	1494.00
23-May	10.53	631.80		5.93	29.65	661.45	392.45	269.00	269.00	8.45	1368.90	4.99	197.60	1566.50
24-May	9.40	564.00		6.04	30.20	594.20	327.20	267.00	267.00	5.23	847.26	10.54	417.38	1264.64
25-May	8.98	538.80		6.03	30.15	568.95	335.95	233.00	233.00	5.93	960.66	5.90	233.64	1194.30
26-May	7.90	474.00		6.03	30.15	504.15	307.15	197.00	197.00	5.25	850.50	5.90	233.64	1084.14
27-May	13.14	788.40		5.64	28.20	816.60	584.60	232.00	232.00	6.46	1046.52	5.82	230.47	1276.99

Appendix A

Flow Data for Slough STW

	PFT Feed "A"		PFT Feed "C"		Total PFT	PFT Outlet		SAS "A"		SAS "C"		Total SAS
Date	(capacity 60m3/hr)		(capacity 5m3/s)			Feed	Liquors	Sludge	(capacity 45 l/s)	(Pumps)	(pumps)	
	hrs run	m3/d	Hrs run	m3/d	m3/d	m3	m3	Hrs run	Hrs run	m3/d	m3/d	
28-May	10.63	637.80	NR	NR	NR		127.00	6.19	1002.78	5.98	236.81	1239.59
29-May	14.33	859.80	NR	NR	NR		142.00	8.06	1305.72	8.64	342.14	1647.86
30-May	9.00	540.00	NR	NR	NR		181.00	6.40	1036.80	3.17	125.53	1162.33
31-May	9.98	598.80	4.05	20.25	619.05	485.05	134.00	8.04	1302.48	4.83	191.27	1493.75
01-Jun												0.00
02-Jun	7.99	479.40	0.85	4.25	483.65	383.65	100.00	4.20	680.40	0.52	20.59	700.99
03-Jun	11.28	676.80			676.80	585.80	91.00	5.67	918.54	6.36	251.86	1170.40
04-Jun	11.76	705.60	5.27	26.35	731.95	512.95	219.00	5.92	959.04			959.04
05-Jun	8.95	537.00	6.14	30.70	567.70	244.70	323.00	2.56	414.72	7.06	279.58	694.30
06-Jun	6.50	390.00	5.90	29.50	419.50	152.50	267.00	7.36	1192.32	4.91	194.44	1386.76
07-Jun	6.10	366.00	6.03	30.15	396.15	224.15	172.00	6.22	1007.64	11.35	449.46	1457.10
08-Jun	8.52	511.20	6.01	30.05	541.25	364.25	177.00	6.31	1022.22	4.23	167.51	1189.73
09-Jun	10.39	623.40	6.32	31.60	655.00	508.00	147.00	8.42	1364.04	4.62	182.95	1546.99
10-Jun	10.19	611.40	4.04	20.20	631.60	436.60	195.00	8.76	1419.12	5.31	210.28	1629.40
11-Jun	8.24	494.40	6.00	30.00	524.40	362.40	162.00	8.69	1407.78	5.55	219.78	1627.56
12-Jun	6.52	391.20	5.21	26.05	417.25	277.25	140.00	7.16	1159.92	5.00	198.00	1357.92
13-Jun	8.82	529.20	3.52	17.60	546.80	329.80	217.00	6.09	986.58	3.07	121.57	1108.15
14-Jun	6.41	384.60	3.01	15.05	399.65	269.65	130.00	4.23	685.26	3.96	156.82	842.08
15-Jun	4.97	298.20	3.01	15.05	313.25	226.25	87.00	4.02	651.24	3.91	154.84	806.08
16-Jun	9.16	549.60	3.01	15.05	564.65	316.65	248.00					
17-Jun	11.04	662.40	2.82	14.10	676.50	274.50	402.00	8.05	1304.10	5.26	208.30	1512.40
18-Jun	3.45	207.00	3.01	15.05	222.05		300.00	7.31	1184.22	2.94	116.42	1300.64
19-Jun	8.91	534.60	3.01	15.05	549.65	353.65	196.00	7.65	1239.30	4.80	190.08	1429.38
20-Jun	2.69	161.40	0.67	3.35	164.75	115.75	49.00	2.19	354.78	0.74	29.30	384.08
21-Jun	9.30	558.00	0.21	1.05	559.05	559.05		4.51	730.62	0.03	1.19	731.81
22-Jun	11.65	699.00	2.63	13.15	712.15	390.15	322.00	4.26	690.12	0.70	27.72	717.84
23-Jun	10.23	613.80	2.30	11.50	625.30	263.30	362.00	1.93	312.66	0.03	1.19	313.85
24-Jun	9.41	564.60	2.30	11.50	576.10	360.10	216.00	4.14	670.68	0.81	32.08	702.76
25-Jun	8.06	483.60	3.01	15.05	498.65	356.65	142.00	7.43	1203.66	4.01	158.80	1362.46
26-Jun	8.25	495.00	3.22	16.10	511.10	400.10	111.00	7.78	1260.36	3.94	156.02	1416.38

Flow Data for Slough STW

	PFT Feed "A" (capacity 60m3/hr)	PFT Feed "A" hrs run	PFT Feed "A" m3/d	PFT Feed "C" (capacity 5m3/s)	PFT Feed "C" hrs run	PFT Feed "C" m3/d	Total PFT Feed	PFT Outlet Liquors	PFT Outlet Sludge	SAS A (capacity 45 l/s) Hrs run	SAS "A" m3/d	SAS C (Pumps) Hrs run	SAS "C" (pumps) m3/d	Total SAS (pumps) m3/d
27-Jun	6.50		390.00	3.01		15.05	405.05	165.05	240.00	7.76	1257.12	3.73	147.71	1404.83
28-Jun	7.04		422.40	3.01		15.05	437.45	261.45	176.00	4.92	797.04			797.04
29-Jun	7.21		432.60	3.01		15.05	447.65	265.65	182.00	4.72	764.64	3.49	138.20	902.84
30-Jun	7.24		434.40	3.01		15.05	449.45	224.45	225.00			0.36	14.26	14.26
Average	8.97		537.94	4.44		22.21	552.72	337.95	221.81	6.17	999.73	4.78	189.23	1142.20
SD	2.51		150.45	1.75		8.73	150.61	140.97	85.97	1.86	301.59	2.52	99.95	396.35
Number	63.00		63.00	59.00		59.00	60.00	59.00	62.00	61.00	61.00	58.00	58.00	63.00

Flow Data for Slough STW

	BSAS	TSAS	BTL	Imports	Digester Feed (P+S+I)	Digested Sludge (capacity 37.8m3 Hrs run	Digested Sludge (pumps)	Centrifuge Feed	ADF-Cent.F	DS-Cent.F	Centrate	Cake (21.5%DS)
Date	Total SAS m3/d	SAS Out (Sludge) m3/d	SAS Out (liquors) m3/d		m3/d		m3/hr	m3/d				
28-Apr	953.00	136.00	817.00	285.00	740.00	23.65	893.97	nd				
29-Apr	1151.00	172.00	979.00	256.00	795.00	23.19	876.58	393.00	402.00	483.58	338.16	54.84
30-Apr	1139.00	164.00	975.00	89.00	493.00	21.37	807.79	618.00	-125.00	189.79	531.77	86.23
01-May	1099.00	153.00	946.00	6.00	411.00	11.88	449.06	122.00	289.00	327.06	104.98	17.02
02-May	954.00	148.00	806.00	64.00	551.00	13.11	495.56	333.00	218.00	162.56	286.53	46.47
03-May	965.00	107.00	858.00	386.00	711.00	22.43	847.85	nd				
04-May	1159.00	172.00	987.00	256.00	615.00	21.89	827.44	nd				
05-May	1089.00	170.00	919.00	161.00	503.00	16.81	635.42	nd				
06-May	1534.00	229.00	1305.00	168.00	620.00	20.20	763.56	554.00	66.00	209.56	476.70	77.30
07-May	1542.00	217.00	1325.00	58.00	432.00	14.19	536.38	286.00	146.00	250.38	246.09	39.91
08-May	1038.00	128.00	910.00	5.00	283.00	13.05	493.29	444.00	-161.00	49.29	382.05	61.95
09-May	1058.05	151.00	907.05	256.00	563.00	19.82	749.20	421.00	142.00	328.20	362.26	58.74
10-May	1108.00	145.00	963.00	174.00	472.00	15.70	593.46	122.00	350.00	471.46	104.98	17.02
11-May	997.00	128.00	869.00	225.00	515.00	9.94	375.73	310.00	205.00	65.73	266.74	43.26
12-May	218.00	28.00	190.00	177.00	331.00	9.09	343.60	231.00	100.00	112.60	198.77	32.23
13-May	992.00	176.00	816.00	146.00	638.00	22.07	834.25	113.00	525.00	721.25	97.23	15.77
14-May	1573.00	283.00	1290.00	110.00	752.00	23.37	883.39	699.00	53.00	184.39	601.47	97.53
15-May	1540.00	247.00	1293.00	5.00	619.00	13.88	524.66	453.00	166.00	71.66	389.79	63.21
16-May	904.00	149.00	755.00	210.00	699.00	20.69	782.08	nd				
17-May	1561.00	241.00	1320.00	178.00	701.00	18.42	696.28	165.00	536.00	531.28	141.98	23.02
18-May	1516.00	215.00	1301.00	181.00	774.00	21.96	830.09	668.00	106.00	162.09	574.79	93.21
19-May	1624.00	218.00	1406.00	235.00	598.00	21.62	817.24	336.00	262.00	481.24	289.12	46.88
20-May	1534.00	202.00	1332.00	269.00	797.00	21.70	820.26	758.00	39.00	62.26	652.23	105.77
21-May	1507.00	198.00	1309.00	18.00	542.00	15.58	588.92	451.00	91.00	137.92	388.07	62.93
22-May	1518.00	213.00	1305.00	99.00	624.00	16.46	622.19	nd				
23-May	1538.00	182.00	1356.00	221.00	672.00	19.66	743.15	991.00	-319.00	-247.85	852.72	138.28
24-May	1385.00	146.00	1239.00	241.00	654.00	21.75	822.15	699.00	-45.00	123.15	601.47	97.53
25-May	1165.00	123.00	1042.00	323.00	679.00	18.60	703.08	565.00	114.00	138.08	486.16	78.84
26-May	1157.00	142.00	1015.00	243.00	582.00	19.24	727.27	668.00	-86.00	59.27	574.79	93.21
27-May	1201.00	154.00	1047.00	215.00	601.00	16.15	610.47	495.00	106.00	115.47	425.93	69.07

Flow Data for Slough STW

	BSAS	TSAS	BTL	Imports	Digester Feed (P+S+I)	Digested Sludge (capacity 37.8m3 Hrs run	Digested Sludge (pumps)	Centrifuge Feed	ADF-Cent.F	DS-Cent.F	Centrate	Cake (21.5%DS)
	Total SAS m3/d	SAS Out (Sludge) m3/d	SAS Out (liquors) m3/d		m3/d		m3/hr	m3/d				
28-May	1243.00	171.00	1072.00	62.00	360.00	11.17	422.23	292.00	68.00	130.23	251.26	40.74
29-May	1737.00	225.00	1512.00	3.00	370.00	4.08	154.22	nd				
30-May	1150.00	143.00	1007.00	235.00	559.00	23.22	877.72	731.00	-172.00	146.72	629.00	102.00
31-May	1483.00	184.00	1299.00	297.00	615.00	16.56	625.97	406.00	209.00	219.97	349.35	56.65
01-Jun												
02-Jun	784.00	117.00	667.00	278.00	495.00	23.90	903.42					
03-Jun	1161.00	155.00	1006.00	162.00	408.00	22.22	839.92					
04-Jun	935.00	147.00	788.00	111.00	477.00							
05-Jun	549.00	66.00	483.00	4.00	393.00	14.80	559.44					
06-Jun	1446.00	191.00	1255.00	242.00	700.00	20.60	778.68					
07-Jun	1512.00	170.00	1342.00	248.00	590.00	16.00	604.80					
08-Jun	1149.00	149.00	1000.00	261.00	587.00	15.76	595.73					
09-Jun	1548.00	224.00	1324.00	162.00	533.00	14.14	534.49					
10-Jun	1538.00	220.00	1318.00	274.00	689.00	14.50	548.10					
11-Jun	1531.00	211.00	1320.00	72.00	445.00	11.39	430.54					
12-Jun	1552.00	199.00	1353.00	5.00	344.00	9.14	345.49	nd	nd	nd	nd	nd
13-Jun	1054.00	135.00	919.00	156.00	508.00	7.94	300.13					
14-Jun	837.00	103.00	734.00	164.00	397.00	10.15	383.67					
15-Jun	781.00	97.00	684.00	188.00	372.00	20.26	765.83					
16-Jun				177.00	425.00	21.22	802.12					
17-Jun	1509.00	237.00	1272.00	120.00	759.00	12.95	489.51					
18-Jun	1275.00	203.00	1072.00	209.00	712.00	17.40	657.72					
19-Jun	1422.00	218.00	1204.00	12.00	426.00	9.58	362.12					
20-Jun	395.00	62.00	333.00	141.00	252.00	9.94	375.73					
21-Jun	706.00	120.00	586.00		120.00							
22-Jun				20.00	342.00	8.25	311.85					
23-Jun	316.00	55.00	261.00	104.00	521.00	8.21	310.34	nd	nd	nd	nd	nd
24-Jun	707.00	145.00	562.00	54.00	415.00	4.17	157.63					
25-Jun	1445.00	199.00	1246.00	7.00	348.00	9.00	340.20					
26-Jun	1477.00	187.00	1290.00	77.00	375.00	8.69	328.48					

Flow Data for Slough STW

	BSAS	TSAS	BTL	Imports	Digester Feed (P+S+I)	Digested Sludge (capacity 37.8m3 Hrs run	Digested Sludge (pumps)	Centrifuge Feed	ADF-Cent.F	DS-Cent.F	Centrate	Cake (21.5%DS)
	Total SAS m3/d	SAS Out (Sludge) m3/d	SAS Out (liquors) m3/d		m3/d		m3/hr	m3/d				
27-Jun	1425.00	177.00	1248.00	152.00	569.00	9.16	346.25					
28-Jun	1315.00	178.00	1137.00	269.00	623.00	9.37	354.19					
29-Jun	919.00	116.00	803.00	289.00	587.00	14.67	554.53					
30-Jun	753.00	109.00	644.00	265.00	599.00	16.29	615.76					
Average	1186.44	164.75	1021.69	162.58	537.81	15.77	596.25	456.44	121.67	210.64	392.75	63.69
SD	348.44	50.46	303.03	98.29	147.55	5.41	204.67	223.68	201.07	194.44	192.47	31.21
Number	61.00	61.00	61.00	62.00	63.00	61.00	61.00	27.00	27.00	27.00	27.00	27.00

Crude Sewage Data for Slough STW

Date	Flow m ³	COD mg/l	COD kg/d	BOD mg/l	BOD kg/d	BODs mg/l	BODs kg/d	%sol	N-NH ₄ mg/l	N-NH ₄ kg/d	TKN mg/l	TKN kg/d	SS mg/l	SS kg/d	Tot.P mg/l	Tot.P kg/d
28-Apr	77356.67	350.00	27074.83	48.40	3744.06	23.00	1779.20	47.52	12.70	982.43	25.30	1957.12	195.00	15084.55	9.70	750.36
29-Apr	77585.22	318.00	24672.10	108.60	8425.75	17.00	1318.95	15.65	13.10	1016.37	26.50	2056.01	213.00	16525.65	8.60	667.31
30-Apr	76536.68	476.00	36003.06	148.20	11209.36	10.00	766.37	6.75	14.50	1096.73	32.70	2473.32	577.00	43642.36	11.57	875.27
01-May	74792.31	498.00	37246.57	122.80	9184.50	20.00	1495.85	16.29	15.50	1159.28	33.30	2490.58	372.00	27822.74	11.33	847.55
02-May	73696.98	622.00	45839.52	167.60	12351.61	26.00	1916.12	15.51	12.50	921.21	54.60	4023.86	724.00	53356.61	26.26	1935.28
03-May	70523.17	542.00	38223.52	142.20	10028.38	14.00	987.32	9.85	14.20	1001.43	40.50	2856.19	1098.00	77434.36	11.00	775.82
05-May	69312.77	305.00	21140.39	67.30	4664.75	9.00	623.81	13.37	16.00	1109.00	25.30	1753.61	208.00	14417.06	9.54	661.11
06-May	69459.47	538.00	37369.19	208.90	14510.08	23.00	1597.57	11.01	16.60	1153.03	23.30	1606.21	496.00	34451.90	10.00	694.46
07-May	68936.19	399.00	27505.54	76.20	5252.94	16.00	1102.98	21.00	13.80	951.32	23.30	1606.21	174.00	11994.90	7.87	542.63
08-May	68201.16	624.00	42557.52	159.40	10871.26	39.00	2659.85	24.47	13.90	948.00	31.10	2121.06	372.00	25370.83	14.31	975.62
09-May	68100.57	336.00	22881.79	85.20	5802.17	9.00	612.91	10.56	13.70	932.98	24.10	1641.22	286.00	19476.76	14.16	964.30
13-May	63180.01	407.00	25714.26	139.90	8838.88	13.00	821.34	9.29	19.30	1219.37	49.60	3133.73	646.00	40814.29	14.27	901.58
14-May	63794.75	709.00	45230.48	114.60	7310.88	21.00	1339.69	18.32	17.10	1090.89	41.60	2653.86	480.00	30621.48	11.82	753.80
15-May	64820.74	606.00	39281.37	188.90	12244.64	26.00	1685.34	13.76	16.80	1088.99	34.40	2229.83	408.00	26446.86	9.78	633.88
16-May	63391.96	884.00	56038.49	107.80	6833.65	31.00	1965.15	26.76	14.10	893.83	42.10	2668.80	1054.00	66815.13	13.95	884.51
19-May	65061.94	586.00	38126.30	148.50	9661.70	9.00	585.56	6.06	9.60	624.59	39.20	2550.43	360.00	23422.30	9.71	631.62
20-May	63710.96	655.00	41730.68	147.50	9397.37	13.00	828.24	8.81	15.90	1013.00	36.70	2338.19	500.00	31855.48	13.33	849.27
21-May	73560.34	390.00	28688.53	145.00	10666.25	15.00	1103.41	10.34	13.40	985.71	28.60	2103.83	273.00	20081.97	7.76	570.90
22-May	64723.74	513.00	33203.28	205.60	13307.20	1.00	64.72	0.49	25.70	1663.40	30.60	1980.55	252.00	16310.38	7.77	503.16
10-Jun	63401.26	532.00	33729.47	81.00	5135.50	35.00	2219.04	43.21	22.04	1397.43	25.40	1585.09	136.00	8487.12	7.71	480.83
11-Jun	62405.3	221.00	13791.57	59.40	3706.87	36.00	2246.59	60.61	18.43	1150.07	25.40	1585.09	136.00	8487.12	7.71	480.83
12-Jun	61178.08	399.00	24410.05	107.50	6576.64	65.00	3976.58	60.47	20.00	1223.44	33.00	2018.88	218.00	13336.82	7.91	484.16
16-Jun	61519.82	288.00	17717.71	81.80	5032.32	16.00	984.32	19.56	15.87	976.57	20.60	1267.31	140.00	8612.77	7.46	458.63
17-Jun	60794.68	219.00	13314.03	49.80	3027.58	17.00	1033.51	34.14	15.05	914.90	23.70	1440.83	132.00	8024.90	8.14	494.87
18-Jun	60545.25	184.00	11140.33	52.30	3166.52	26.00	1574.18	49.71	17.32	1048.52	20.60	1247.23	98.00	5933.43	7.24	438.47
19-Jun	54745.62	217.00	11879.80	65.60	3591.31	31.00	1697.11	47.26	19.35	1059.27	27.90	1527.40	116.00	6350.49	7.79	426.25
20-Jun	59103.14	240.00	14184.75	94.10	5561.61	53.00	3132.47	56.32	17.08	1009.30	22.50	1329.82	106.00	6264.93	8.49	501.73
21-Jun	57553.1	336.00	19337.84	142.80	8218.58	76.00	4374.04	53.22	17.81	1024.96	25.00	1438.83	186.00	10704.88	7.13	410.53
Average		442.64	29572.61	116.68	7797.23	24.64	1588.65	25.44	16.12	1059.14	31.47	2018.29	370.84	24965.67	10.54	707.92
SD		173.71778	11865.546	46.8185	3319.722	17.09497	997.2044	18.85168	3.258288	181.5752	8.861998	756.1646	265.5337	18258.88	3.94822	302.8042
Number		28	28	28	28	28	28	28	28	28	26	27	28	28	27	0

Crude Sewage Data for Slough STW

Date	Flow m ³	Psol. mg/l	%sol P kg/d	Tot.Mg mg/l	MgsoL. mg/l	kg/d	%sol Mg kg/d	Ca mg/l	kg/d	Alk mg/l	pH	Temp
28-Apr	77356.67	5.70	440.93	58.76	7.80	603.38	7.20	556.97	92.31	8973.37		
29-Apr	77585.22	5.30	411.20	61.62	8.00	620.68	7.40	574.13	92.50	9387.81		
30-Apr	75636.68	5.60	423.57	48.39	9.90	748.80	7.90	597.53	79.80	9000.76		
01-May	74792.31	5.20	388.92	45.89	9.00	673.13	7.90	590.86	87.78	9199.45		
02-May	73696.98	6.00	442.18	22.85	14.70	1083.35	8.00	589.58	54.42	9359.52		
03-May	70523.1	4.80	338.51	43.63	8.30	585.34	8.30	585.34	100.00	9732.19		
05-May	69312.77	6.40	443.60	67.10	8.40	582.23	8.30	575.30	98.81	120.00	8317.53	8.23
06-May	69459.47	5.90	409.81	59.01	9.10	632.08	8.20	569.57	90.11	115.00	7987.84	8.31
07-May	68936.19	5.90	406.72	74.97	8.00	551.49	7.70	530.81	96.25	123.00	8479.15	8.06
08-May	68201.16	6.20	422.85	43.34	9.00	613.81	7.20	491.05	80.00	117.00	7979.54	8.21
09-May	68100.57	6.50	442.65	45.90	10.00	681.01	8.10	551.61	81.00	118.00	8035.87	8.03
13-May	63180.01	6.10	385.40	42.75	10.70	676.03	7.50	473.85	70.09	110.00	6949.80	8.34
14-May	63794.75	5.80	370.01	49.09	9.50	606.05	7.60	484.84	80.00	111.00	7081.22	8.32
15-May	64620.74	6.00	388.92	61.36	8.80	570.42	7.40	479.67	84.09	110.00	7130.28	8.25
16-May	63391.96	6.10	386.69	43.72	10.30	652.94	7.80	494.46	75.73	117.00	7416.86	8.03
19-May	65061.94	4.80	312.30	49.44	8.30	540.01	7.80	507.48	93.98	111.00	7221.88	7.24
20-May	63710.96	5.20	331.30	39.01	10.90	694.45	8.00	509.69	73.39	115.00	7326.76	7.25
21-May	73560.34	5.00	367.80	64.42	7.50	551.70	7.00	514.92	93.33	104.00	7650.28	7.14
22-May	64723.74	4.90	317.15	63.03	8.70	563.10	7.60	491.90	87.36	114.00	7378.51	14.00
10-Jun	63401.26	5.93	375.97							404.00	25614.11	
11-Jun	62405.3	5.01	312.65	65.02	7.50	488.04	7.90	493.00		132.00	8237.50	
12-Jun	61178.08	6.21	379.92	78.47	7.90	483.31	7.90	483.31		116.00	7096.66	
16-Jun	61519.82	5.08	312.52	68.14	8.20	504.46	8.00	492.16		119.00	7320.86	
17-Jun	60794.88	6.01	385.38	73.83	7.90	480.28	7.80	474.20		114.00	6930.59	
18-Jun	60545.25	5.72	346.32	78.98	7.70	486.20	7.80	472.25		113.00	6841.61	
19-Jun	54745.62	6.05	331.21	77.70	8.10	443.44	8.00	437.96		122.00	6678.97	
20-Jun	59103.14	6.94	410.18	81.75	7.40	437.36	7.70	455.09		115.00	6796.86	
21-Jun	57553.1	5.46	314.24	76.55	7.80	448.91	7.60	437.40		115.00	6618.61	
Average		5.71	377.82	58.69	8.87	591.19	7.76	515.37	84.79	117.59	7819.64	7.88
SD		0.55698	44.26582	15.19232	1.534726	130.3857	0.329508	49.24217	11.33387	7.012403	943.5475	0.505159
28	28	28	28	27	27	27	27	27	19	27	22	13
												4

Settled Sewage Data for Slough STW (Stream A)

Date	Flow	COD mg/l	COD kg/d	BOD mg/l	BOD kg/d	%sol	N-NH4 mg/l	N-NH4 kg/d	TKN mg/l	TKN kg/d	SS mg/l	SS kg/d	Tot.P mg/l	Tot.P kg/d
28-Apr	57474.503	137	7874.007	29.1	1672.508		13	747.1685	20.1	1155.238	73	4195.639	5.63	323.5814
29-Apr	57659.228	197	11358.87	4	230.6369	13	749.57	325	20.6	1187.78	79	4555.079	7.179	413.9356
30-Apr	56462.948	241	13607.57	89.2	5036.495	23	1298.648	25.78475	17.9	1010.687	86	4855.813	6.567	370.7922
01-May	55582.47	324	18008.72	115.1	6397.542	40	2223.299	34.75239	21.7	1206.14	98	5447.082	7.165	398.2484
02-May	54713.91													
03-May	52564.2													
04-May	51041.677													
05-May	51449.978	244	12553.79	61.4	3159.029									
06-May	51524.265	208	10717.05	43.2	2225.848	14	721.3397	32.40741	22.3	1148.991	82	4224.99	8.438	434.7617
07-May	51287.405	336	17225.65	83.9	4301.335	26	1332.953	30.98927	20.2	1035.602	116	5947.019	7.598	389.5297
08-May	50589.233	356	18009.77	109.8	5554.698	40	2023.569	36.42987	24.4	1234.377	140	7082.493	9.011	455.8596
09-May	50652.99			106.8	5409.739	25	1266.325	23.40824	22.6	1144.758	86	4356.157	8.197	415.2026
10-May	49142.76	325	15971.4	120.3	5911.874	51	2506.281	42.39401			bm		6.96	342.0336
11-May	49829.265													
12-May	48468.563													
13-May	46929.345	307	14407.31	105.3	4941.66	36	1689.456	34.18803	24.6	1154.462	110	5182.228	9.583	449.7239
14-May	47446.2	335	15894.48	110.2		40			32.7	1551.491	131	6215.452	10.72	508.6233
15-May	48118.418	415	19969.14	88.1	4239.233	78			21.1	1015.299	31.6	1520.542	8.166	
16-May	49566.278	217	10755.88	46.9	2324.658	5	247.8314	10.66098	26.2	1298.636	40.4	2002.478	101	5006.194
17-May	48450.705	190	9205.634	50.4	2441.916	16	775.2113	31.74603	34.4	1666.704	29.7	1438.986	79	3827.606
18-May	47302.845	277	13102.89	94.6	4474.849	17	804.1484	17.9704	45.6	2157.01	38.1	1802.238	120	5676.341
19-May	54885.443	211	11580.83	47.4	2601.57	11	603.7399	23.20675	18.3	1004.404	34.5	1893.548	99	5433.659
20-May	48209.918	313	15089.7	109.4	5274.165	23	1108.828	21.02377	37.7	1817.514	146	7038.648	7.976	384.5223
21-May	58269	269	15674.36	69.6	4055.522	19	1107.111	27.29885	24	1398.456	28.8	1678.147	82	4778.058
22-May	58269	284	16548.4	29.9	1742.243	8	466.152	26.75585	16.924	986.1446	23.7	1380.975	102	5943.438
23-May	58269	374	21792.61	36.3	2115.165	27	1573.263	74.38017	26.074	1519.306	38.4	2237.53	238	13868.02
24-May	58269	136	7924.584	20	1165.38	14	815.768	70	23.953	1395.717	26.3	1532.475	48	2796.912
25-May	58269	192	11187.65	51	2971.719	42	2447.298	82.35294	23.166	1349.86	27.6	1608.224	88	5127.672
26-May	58269													0
27-May	58269	356	20743.76	115.2	6712.589	69	4020.561	59.89583	14.884	855.622	23.6	1375.148	216	12586.1
28-May	58269	430	25055.67	51.3	2989.2	8	466.152	15.59454	11.938	695.6153	286	16664.93	286	16664.93
29-May	58269	466	27153.35	145.7	8489.793	80	4661.52	54.90734	25.427	1481.606	32.6	1899.569	284	16548.4
30-May	58269	777	45275.01	92.6	5395.709	28	1631.532	30.23758	27.742	1616.499	518	30183.34	518	30183.34
31-May	58269	645	37583.51	141.8	8262.544	35	2039.415	24.68265	28.707	1672.728	428	24939.13	428	24939.13
32-May	58269	632	36826.01	61.6	3589.37	5	291.345	8.116883	19.297	1124.417			9.594	559.0328
Average		328.3571	17896.35	76.9	4060.25	28.10345	1408.419	44.71282	23.92455	1273.358	30.3	1607.773	160.2857	8.027963
SD		152.4013	9170.239	37.67577	2062.937	20.70601	1077.187	59.14575	7.171139	327.1146	5.020913	240.6915	121.969	7299.487
Number		30	30	31	30	31	29	29	31	31	26	26	30	29
														31

Appendix A

Settled Sewage Data for Slough STW (Stream A)

Date	Flow	Psol. mg/l	Psol. kg/d	%sol P	Tot.Mg mg/l	Tot.Mg kg/d	Mgsol. mg/l	Mgsol. kg/d	%sol Mg	Ca mg/l	Ca kg/d	Alk mg/l	Alk kg/d	pH	Temp
28-Apr	57474.5	4	229.898	71.04796	7.2	413.8164	7.2	413.8164	100	104	5977.348				
29-Apr	57659.23	5.5	317.1258	76.61234	7.6	438.2101	7.5	432.4442	98.68421	112	6457.833				
30-Apr	56482.95	5	282.3147	76.13827	7.9	446.0573	7.7	434.7647	97.46835	115	6493.239				
01-May	55582.47	6.1	339.0531	85.13608	7.9	439.1015	7.7	427.985	97.46835	115	6391.984				
02-May	54713.91														
03-May	52564.2														
04-May	51041.68														
05-May	51449.98	8.3	427.0348	84.88443	8.2	421.8898	8.2	421.8898	100	108	5556.598			8.03	
06-May	51524.27	6.5	334.9077	77.03247	8.6	443.1087	7.7	396.7368	89.53488	120	6182.912			8.18	
07-May	51287.41	6.2	317.8579	81.80042	8.2	420.3927	8.1	415.266	98.78049	113	5793.217			7.94	
08-May	50589.23	6.8	344.0068	75.46332	8.7	440.1263	8.2	414.8317	94.25287	115	5817.762	401	23047.28	7.77	
09-May	50652.99	6.2	314.0485	75.63743	7.9	400.1586	8.7	440.681	110.1266	111	5622.482	393	22660.08	7.76	
10-May	49142.76	5.2	255.5424	74.11264	7.4	363.6564	7.7	378.3993	104.0541	117	5749.703	315	17785.83	7.48	
11-May	49829.27									109	5431.39				
12-May	48468.56														
13-May	46929.35	7.5	351.9701	78.26359	8.6	403.5924	7.8	366.0489	90.69767	115	5396.875	364	19133.37	7.82	
14-May	47446.2	8.4	398.5481	78.35821	8.7	412.7819	7.8	370.0804	89.65517	113	5361.421	388	19804.17	7.91	
15-May	48118.42	6.4	307.9579		8.6	413.8184	7.6	365.7	88.37209	116	5581.736	347	17853.14	7.58	
18-May	49566.28	5.7	282.5278	74.34459	7.7	381.6803	7.4	366.7905	96.1039	108	5353.158	224	11331.99	7.55	14
19-May	48450.71	4.2	203.493	68.98817	8.3	402.1409	7.8	377.9155	93.9759	121	5882.535	324	16411.57	7.61	14
20-May	47302.85	6.7	316.9291	74.91055	8.4	397.3439	7.9	373.6925	94.04762	110	5203.313	352	17298.25	7.42	14
21-May	54885.44	5.2	285.4043	69.50942	8.2	450.0806	7.2	395.1752	87.80488	105	5762.971	231	11510.56	7.54	14
22-May	48209.92	5.2	250.6916	65.19559	8.1	390.5003	7.7	371.2164	95.06173	108	5206.671	297	14395.16	7.41	14
10-Jun	58269	5.71	332.716		7.3	425.3637	7.8	454.4982		107	6234.783	359	20918.57		
11-Jun	58269	4.51	262.7932		8.2	477.8058	7.5	437.0175		111	6467.859	345	20102.81		
12-Jun	58269	6.23	363.0159		8.6	501.1134	8.2	477.8058		117	6817.473	397	23132.79		
13-Jun	58269	5.5	320.4795		7.9	460.3251	7.6	442.8444		111	6467.859	383	22317.03		
14-Jun	58269	5.31	309.4084		6.1	355.4409	6.6	384.5754		108	6293.052	490	28551.81		
15-Jun	58269														
16-Jun	58269	4.93	287.2862		7.7	448.6713	7.2	419.5368		111	6467.859	331	19287.04		
17-Jun	58269	3.18	185.2954												
18-Jun	58269	6.79	395.6465		8.4	489.4596	7.6	442.8444		106	6176.514	385	22433.57		
19-Jun	58269	4.91	286.1008												
20-Jun	58269	5.3	308.8257		8.6	501.1134	7.4	431.1906		106	6176.514	370	21559.53		
21-Jun	58269	4.36	254.0528		8.2	477.8058	7.3	425.3637		102	5943.438	452	26337.59		
	53673.16	5.718276	305.6866	75.75503	8.044444	430.2043	7.67037	410.3374	95.89382	111.2143	5937.446	356.1905	19772.26	7.714286	14
	4311.343	1.199711	55.00084	5.26454	0.582655	38.66033	0.410267	31.66794	5.753975	4.802446	454.0976	61.54805	4260.26	0.238995	0
35		37	31	31	29	29	29	29	29	20	30	23	23	16	7

Appendix A

Effluent C Data for Slough STW

Date	Flow m ³	COD mg/l	COD kg/d	SS mg/l	SS kg/d	TON mg/l	TON kg/d	N-NO ₂ mg/l	N-NO ₂ kg/d	N-NO ₃ mg/l	N-NO ₃ kg/d	N-NH ₄ mg/l	N-NH ₄ kg/d	ToTP mg/l	kg/d	
05-May	19941.28	46	917.2989	18.5	368.9137	22.4	446.6847	0.15	2.991192	22.3	444.6905		2.5	49.8532	6.665	132.9086
07-May	17537.19	36	631.3388	6	105.2231	17.8	312.162	0.822	14.41557	17	298.1322	4.2	73.6562	4.815	84.44157	
08-May	17213.16	33	568.0343	5.6	96.3937	20.4	351.1485	0.424	7.29838	20	344.2632	2.9	49.91816	5.612	96.60025	
09-May	17260.57	40	690.4228	13.6	294.7438	22	379.7325	0.392	6.766143	21.6	372.8283	1.5	25.89086	6.245	107.7923	
10-May	16127.83	36	580.6019	9.6	154.8272	22.8	367.7145	0.206	3.322333	22.6	364.489	0.9	14.51505	6.373	102.7827	
11-May	15180.42	21	318.7888	12	182.165	22.1	335.4873	0.119	1.80847	22	333.9692	0.4	6.072168	6.432	97.64046	
13-May	16395.01	43	704.9854	8.5	139.3576	24.2	396.7592	1.387	22.73988	22.8	373.8062	0.2	3.279002	6.085	99.76364	
14-May	17052.75	36	613.899	5.5	93.79013	22.5	383.6869	0.865	14.75063	21.6	368.3394	0.3	5.115825	6.392	109.0012	
15-May	17322.74	29.8	516.2177	6	103.9364	25.6	443.4621	0.48	8.314915	25.1	434.8008	0.3	5.196822	7.045	122.0387	
16-May	16742.96	37	619.4895	6.5	108.8292	24.6	411.8768	0.271	4.537342	24.3	406.8539	0.3	5.022888	7.055	118.1216	
17-May	16345.91	35	572.1069	19	310.5723	21.6	353.0717	0.197	3.220144	21.4	349.8025	0.7	11.44214	6.65	108.7003	
18-May	18502.77	33	610.5914	11	203.5305	22	407.0609	0.519	9.602938	21.5	397.8096	0.1	1.850277	6.887	127.4286	
19-May	17969.94	27	485.1884	7.5	134.7746	22.4	402.5267	0.32	5.750381	22.1	397.1357	0.1	1.796994	5.8	104.2257	
20-May	19863.96	28	556.1909	13	258.2315	20.8	413.1704	0.253	5.025582	20.5	407.2112	0.1	1.986396	6.486	128.8376	
21-May	24063.34	25	601.5835	10.5	252.6651	21.3	512.5491	0.252	6.063962	21	505.3301	0.2	4.812668	6.401	154.0294	
16-Jun	20423	65.7	1341.791	78	1592.994	14.9	304.3027	0.238	4.860674	14.7	300.2181	0.1	2.0423	5.64	115.1857	
17-Jun	20423	72.6	1482.71	66.5	98.6002	12.4	253.2452	0.191	3.900793	12.2	249.1606	0.582	11.88619	5.082	103.7897	
18-Jun	20423	41.9	855.7237	37.5	32.08964	21.2	432.9676	0.1	2.0423	21.1	430.9253	0.1	2.0423	5.511	112.5512	
19-Jun	20423	10	204.23	9	1.83807	18.2	371.6986	0.1	2.0423	18.1	369.6563	0.1	2.0423	4.964	101.3798	
20-Jun	20423	16.8	343.1064	17.5	6.004362	16.3	332.8949	0.1	2.0423	16.2	330.8526	0.1	2.0423	5.398	110.2434	
21-Jun	20423	10	204.23	5	1.02115	15.4	314.5142	0.127	2.593721	15.3	312.4719	0.1	2.0423	5.155	105.2806	
Average		34.41905	638.9776	17.44286	213.3572	20.51905	377.4627	0.357762	6.38514	20.1619	371.0832	0.751524	13.45268	6.033	111.5592	
SD		15.22999	313.6165	19.70331	331.559	3.433019	58.74927	0.320432	5.263581	3.332488	58.28158	1.116203	19.9196	0.697613	15.22133	
Number		21	21	21	21	21	21	21	21	21	21	21	21	21	21	0

Effluent C Data for Slough STW

Date	Flow m ³	Psol mg/l	Psol kg/d	%sol P	Tot.Mg mg/l	Tot.Mg kg/d	Mgsol. mg/l	Mgsol. kg/d	%sol Mg	Ca mg/l	Ca kg/d	Alk mg/l	Alk kg/d	pH	Temp
05-May	19941.28	6.5	129.6183	97.52438	8	159.5302	8.5	169.5009	106.25	110	2193.541				
07-May	17537.19	4.7	82.42479	97.61163	7.9	138.5438	8.1	142.0512	102.5316	113	1981.702				8.3
08-May	17213.16	5.5	94.67238	98.00428	7.9	135.984	8.2	141.1479	103.7975	111	1910.681				8.5
09-May	17260.57	6	103.5634	96.07686	7.7	132.9084	7.9	136.3585	102.5974	117	2019.487	221	3814.586		8.4
10-May	16127.83	6.1	98.37976	95.7163	7.7	124.1843	7.7	124.1843	100	117	1886.956	201	3241.694		8.2
11-May	15180.42	5.9	89.56448	91.72886	7.8	118.4073	8.3	125.9975	106.4103	104	1705.081	197	3229.817		8.23
13-May	16395.01	5.7	93.45156	93.67297	8.2	134.4391	7.5	122.9626	91.46341	105	1790.539	206	3512.867		8.31
14-May	17052.75	6.2	105.7271	96.99625	8	136.422	7.6	129.6009	95	105	1790.539	206	3512.867		8.31
15-May	17322.74	6.8	117.7946	96.52236	8.5	147.2433	7.5	129.9206	88.23529	105	1818.888	200	3464.548		8.37
16-May	16742.96	6.8	113.8521	96.38554	8.5	142.3152	7.7	128.9208	90.58824	105	1758.011	203	3398.821		8.41
17-May	16345.91	5.6	91.5371	84.21053	8	130.7673	7.4	120.9597	92.5	99	1618.245	192	3136.415		7.88
18-May	18502.77	6	111.0166	87.12066	8.6	159.1238	8	148.0222	93.02326	104	1924.288	208	3848.576		7.74
19-May	17969.94	5.8	104.2257	100	8.1	145.5565	8.1	145.5565	100	110	1976.693	205	3683.838		7.72
20-May	19863.96	5.7	113.2246	87.88159	8.2	162.8845	7.8	154.9389	95.12195	108	2145.308	247	4906.398		7.84
21-May	24063.34	5.7	137.161	89.04859	7.9	190.1004	7.5	180.4751	94.93671	101	2430.397	21.3	512.5491		7.84
16-Jun	20423	5.4	110.2842	95.74488	8.3	169.5109	7.6	155.2148	91.56627	112	2287.376	228	4656.444		
17-Jun	20423	4.8	98.0304	94.451	7.9	161.3417	7.6	155.2148	96.20253	108	2205.684	220	4493.06		
18-Jun	20423	4.74	96.80502	86.0098	8.2	167.4686	7.7	157.2571	93.90244	112	2287.376	199	4064.177		
19-Jun	20423	4.74	96.80502	95.48751	7.5	153.1725	7.7	157.2571	102.6667	115	2348.645	206	4207.138		
20-Jun	20423	4.77	97.41771	88.36606	8.3	169.5109	7.9	161.3417	95.18072	113	2307.799	211	4309.253		
21-Jun	20423	4.8	98.0304	93.11348	8.2	167.4686	7.5	153.1725	91.46341	110	2246.53	212	4329.676		
		5.630952	103.9803	93.41302	8.066667	149.8515	7.8	144.7645	96.83037	108.95	2042.16	198.6647	3694.815	8.152	13.42
		0.673349	13.2241	4.531884	0.28519	18.20062	0.301662	16.56514	5.485941	5.052097	239.3533	47.59686	977.2133	0.268147	0.044721
21	21	21	21	21	21	21	21	21	21	20	20	17	17	15	5

Effluent A Data for Slough STW

Date	Flow m³	Psol mg/l	Psol kg/d	%sol	Tot.Mg mg/l	Tot.Mg kg/d	Mgsol. mg/l	Mgsol. kg/d	%sol	Ca mg/l	Ca kg/d	Alk mg/l	Alk kg/d	pH	Temp
28-Apr	55101.16	1.3	71.6315	34.52855	7.5	413.2587	7	385.7081	93.33333	110	6061.127				
29-Apr	55283.95	1.2	66.31674	33.41688	7	386.8477	6.8	375.7949	97.14286	112	6189.563				
30-Apr	53876.01	0.7	37.71321	39.17399	6.8	366.3568	6.9	371.7444	101.4706	115	6195.741				
01-May	53274.56	0.9	47.94711	51.57593	6.9	367.5945	7	372.9219	101.4493	110	5860.202				
02-May	52494.36	1.5	78.74154	99.33775	7.4	388.4583	1	52.49436	13.51351						
03-May	50233.6	1.4	70.32705	91.56311	6.9	346.6119	7.6	381.7754	110.1449	122	6128.5				
04-May	49999.06	0.4	19.59962	36.83241	6.5	318.4939	6.5	318.4939	100	118	5781.889			7.76	
05-May	49371.49														7.5
06-May	49475.98	0.8	39.58078	66.28003	6.5	321.5939	6.7	331.4891	103.0769	113	5590.786	281	13902.75	7.94	
07-May	51399	0.6	30.8394	59.52381	6.3	323.8137	6.5	334.0935	103.1746	119	6116.481	280	14391.72	7.85	
08-May	50988	0.5	25.494	44.80287	6.3	321.2244	6.6	336.5208	104.7619	108	5506.704	271	13817.75	7.76	
09-May	50840	0.4	20.336	30.93581	6.7	340.628	6.9	350.796	102.9851	115	5846.6	268	13625.12	7.82	
10-May	50213	0.3	15.0639	30.21148	6.3	316.3419	6.9	346.4697	109.5238	111	5573.643			7.78	
11-May	51673	0.3	15.5019	30.76923	6.4	330.7072	7	361.711	109.375	110	5684.03			7.8	
12-May	49391														
13-May	46785	0.4	18.714	56.81818	6.9	322.8165	6.3	294.7455	91.30435	110	5146.35	284	13286.94	7.91	
14-May	46742	0.6	28.0452	54.24955	6.6	308.4972	6	280.452	90.90909	113	5281.846	271	12667.08	7.92	
15-May	47498	0.4	18.9992	46.18938	6.5	308.737	6	284.988	92.30769	108	5129.784	272	12919.46	7.94	
16-May	46649	0.2	9.3298	23.44666	7	326.543	6.5	303.2185	92.85714	114	5317.966	280	13061.72	7.88	
17-May	44785														
18-May	48362	0.4	19.3448	54.05405	6.2	299.8444	6.3	304.6806	101.6129	115	5561.63	246	11897.05	7.28	13
19-May	47092	0.3	14.1276	38.31418	7.5	353.19	6.6	310.8072	88	109	5133.028	255	12008.46	7.32	13
20-May	43847	0.2	8.7694	26.73797	6.8	298.1596	6.2	271.8514	91.17647	110	4823.17	266	11683.3	7.13	13
21-May	49497	0.2	9.8994	25.54278	5.9	292.0323	5.6	277.1832	94.91525	103	5098.191	242	11978.27	7.18	13
22-May	45094	0.2	9.0188	29.7619	6.4	288.6016	6.4	288.6016	100	115	5185.81	266	11995	7.27	13
		0.6	30.69732	45.63939	6.695455	333.6524	6.331818	315.2973	95.13794	112.381	5581.574	267.8462	12862.66	7.649412	13
		0.411733	22.37404	20.17119	0.423677	33.46026	1.266937	69.33643	19.35645	4.283412	417.5063	13.17729	904.1547	0.295603	0
25	25	22	22	22	22	22	22	22	22	21	21	21	13	17	5

Effluent A Data for Slough STW

Date	Flow m ³	COD mg/l	COD kg/d	SS mg/l	SS kg/d	TOTN mg/l	TOTN kg/d	N-NO2 mg/l	N-NO2 kg/d	N-NO3 mg/l	N-NO3 kg/d	N-NH4 mg/l	N-NH4 kg/d	TotP mg/l	TotP kg/d
28-Apr	55101.16	164	9036.59	133	7328.454			1.572	86.61902				5	275.5058	3.765
29-Apr	55263.95	183	10113.3	145	8013.273			0.693	38.29792				3.9	215.5294	3.591
30-Apr	53376.01	82.5	4444.771	45	2424.42			0.621	33.457				2.1	113.1396	1.7869
01-May	53274.56	59	3143.199	29.5	1571.6			0.68	36.2267				1.4	74.58439	1.745
02-May	52494.36	37	1942.291	22	1154.876			0.362	19.00296				5	262.4718	1.51
03-May	50233.6	57	2863.315	32	1607.475			0.584	29.33642				0.4	20.09344	1.529
04-May	48999.06	50	2449.953	21.6	1058.38			0.293	14.35672				0.4	19.59962	1.086
05-May	49371.49							0.298	14.7127						
06-May	49475.98	39	1929.563	13.6	672.8733			0.455	22.51157				6	296.8559	1.207
07-May	51399	44	2261.556	12.4	637.3476			0.399	20.5082						1.008
08-May	50988	63	3212.244	19.2	978.9696			0.239	12.18613				1.1	56.0868	1.116
09-May	50840	35	1779.4	9.6	488.064			7.2	366.048				1	50.84	1.293
10-May	50213	29	1456.177	19.5	979.1535			0.119	5.975347				0.1	5.0213	0.993
11-May	51673	46	2376.958	7	361.711			0.121	6.252433				0.1	5.1673	0.975
12-May	48391														
13-May	46785	40	1871.4	6.5	304.1025			0.189	8.842365				0.2	9.357	0.704
14-May	46742	36	1692.712	20	934.84			0.5	23.371				0.7	32.7194	1.106
15-May	47498	44	2089.912	17	807.466			0.243	11.54201				0.2	9.4996	0.866
16-May	46649	56	2612.344	19.5	909.6555			0.155	7.230595				0.1	4.6649	0.853
17-May	44785														
18-May	48362	39	1886.118	11	531.982			0.456	22.05307				0.3	14.5086	0.74
19-May	47092	39	1836.588	16	753.472			0.155	7.29926				0.1	4.7092	0.783
20-May	43847	56	2455.432	11	482.317			0.728	31.92062				0.5	21.9235	0.748
21-May	49497	34	1682.898	16	791.952			0.384	19.00685				0.2	9.8994	0.783
22-May	45094	43	1939.042	17.5	789.145			0.146	6.583724				0.1	4.5094	0.672
Average		57.97727	2957.535	29.26818	1526.433			0.426909	21.69512				1.37619	71.74697	1.311814
SD		39.39981	2249.699	36.60507	2046.702			0.322812	17.74746				1.888625	99.57571	0.83253
Number	25	22	22	22	22	17	17	22	22	18	18	21	21	22	22
															0

BNR Data for Slough STW

Date	Flow per lane m ³	BNR 1 TotP mg/l	BNR 2 TotP mg/l	BNR 3 TotP mg/l	BNR 4 TotP mg/l	BNR 1 Psol kg/d	BNR 2 Psol kg/d	BNR 3 Psol kg/d	BNR 4 Psol kg/d
03-May	13141.05	162.6	2136.314	161.5	2121.872	161	2115.932	134.2	1763.306
10-May	12285.69	0.98	12.03998	0.465	5.712846	1.518	18.64968	1.03	12.65426
15-May	12029.60438	1.704	20.49845	0.896	10.77853	0.908	10.92288	0.784	9.43121
19-May	12112.67625	1.947	23.58338	1.131	13.69944	1.25	15.14085	1.531	18.54451
25-May	12199.19438	4.027	49.12616	2.963	36.14621	3.193	38.95203	8.32	101.4973
Average		34.25	448.3124	33.38	437.6418	33.58	439.9196	29.17	381.0866
SD		71.74	943.7231	71.61	941.5855	71.25	936.9815	58.79	773.6288

Date	Flow per lane m ³	BNR 1 Mgsol mg/l	BNR 2 Mgsol mg/l	BNR 3 Mgsol mg/l	BNR 4 Mgsol mg/l	BNR 1 TON kg/d	BNR 2 TON kg/d	BNR 3 TON kg/d	BNR 4 TON kg/d
03-May	13141.05	16.1	211.5709	12.2	160.3208	16.1	211.5709	13.4	176.0901
10-May	12285.69	7.1	87.2284	7.3	89.68554	7.2	88.45697	7.4	90.91411
15-May	12029.60438	7.1	85.41019	6.7	80.59835	6.5	78.19243	7.3	87.81611
19-May	12112.67625	7.8	94.47887	7.4	89.6338	7.2	87.21127	7.6	92.05634
25-May	12199.19438	7.7	93.9338	7.4	90.27404	6.9	84.17444	7.4	90.27404
Average		9.16	114.5244	8.2	102.1025	8.78	109.9212	8.62	107.4301
SD		3.893	54.39791	2.255	32.79238	4.102	56.96211	2.674	38.41341

Date	Flow per lane m ³	BNR 1 N-NO ₂ mg/l	BNR 2 N-NO ₂ mg/l	BNR 3 N-NO ₂ mg/l	BNR 4 N-NO ₂ mg/l	BNR 1 N-NO ₃ kg/d	BNR 2 N-NO ₃ kg/d	BNR 3 N-NO ₃ kg/d	BNR 4 N-NO ₃ kg/d
03-May	13141.05	1.6	21.02568	1.5	19.71158	0.7	9.198735	1.3	17.08337
10-May	12285.69	6.8	83.54269	6.5	79.85699	6.4	78.82842	7.4	90.91411
15-May	12029.60438	1.7	20.45033	7.1	85.41019	7.6	91.42499	0.1	1.20296
19-May	12112.67625	3.8	46.02817	3.1	37.5493	3.9	47.23944	3.1	37.5493
25-May	12199.19438	4.7	57.33621	5.9	71.97525	7.4	90.27404	2.9	35.37766
Average		3.72	45.67662	4.82	58.90066	5.2	63.35312	2.96	36.42548
SD		2.181	26.52331	2.407	28.74253	2.915	35.13705	2.769	33.86043

Appendix A

Date	Flow per lane m ³	BNR 1		BNR 2		BNR 3		BNR 4		BNR 1		BNR 2		BNR 3		BNR 4		
		N-NH ₄	mg/l	kg/d	N-NH ₄	mg/l	kg/d	N-NH ₄	mg/l	kg/d	Alk	mg/l	kg/d	Alk	mg/l	kg/d	Alk	mg/l
03-May	13141.05	2	26.2821	0.3	3.942315	1.2	15.76926	1.3	17.08337									
10-May	12285.69	3	38.85707	2.6	31.94279	0.9	11.05712	3.5	42.99992									
15-May	12029.60438	2.5	30.07401	2.3	24.056921	0.3	3.609881	2.1	25.26217	263	3183.786	265	3187.845	259	3115.668	279	3356.26	
19-May	12112.67625	4.3	52.08451	2.9	35.12676	1	12.11268	4.3	52.08451	267	3234.085	267	3234.085	257	3112.958	276	3343.099	
25-May	12199.19438	4.3	52.45654	2.9	35.37766	1.5	18.29879	4.4	53.67646	258	3147.392	248	3025.4	242	2952.205	274	3342.579	
Average		3.22	39.55084	2.14	26.08975	0.98	12.18935	3.12	38.22128	262.7	3181.754	260	3149.11	252.7	3060.277	276.3	3347.313	
SD		1.047	12.2145	1.092	13.1987	0.444	5.591317	1.372	16.34501	4.509	46.05472	10.44	109.602	9.292	93.60269	2.517	7.752777	

		BNR 1	BNR 2	BNR 3	BNR 4	BNR 1	BNR 2	BNR 3	BNR 4
Date	Flow per lane	pH	pH	pH	pH	Temp	Temp	Temp	Temp
	m ³								
03-May	13141.05	7.82	7.85	7.61	7.67				
10-May	12285.69	7.45	7.56	7.41	7.5	22.3	19.8	21.4	21.2
15-May	12029.60438	6.85	6.92	7	6.98	16.2	16.2	16.2	16.2
19-May	12112.67625	7.1	7.11	7.08	7.14	16.8	16.8	16.7	16.7
25-May	12199.19438								
Average		7.305	7.36	7.275	7.3225	18.43	17.6	18.1	18.03333
SD		0.422	0.422769	0.285	0.317739	3.362	1.92873	2.869	2.753785

PFT Feed Data for Slough STW

Date	Flow m ³	TotP mg/kg		TKN mg/kg	mg/l	kg/d	N-NH ₄ %D.S	mg/ml	kg/d	Mg mg/kg	mg/ml	kg/d	Ca mg/kg	mg/l	kg/d	D.S %	V.S %		
03-May	437.50	23000.00	207.67	90.86	24000.00	216.70	94.81	0.42	37.92	16.59	1480.00	13.36	5.85	28871.90	260.69	114.05	0.93	9029.13	81.80
10-May	817.15	6600.00	58.31	47.65	30600.00	270.35	220.92	0.60	53.01	43.32	1366.00	12.07	9.86	41770.50	369.04	301.56	0.91	8934.95	83.20
19-May	461.00	8780.00	542.14	249.93	28190.00	1740.66	802.45	0.41	253.17	116.71	1377.00	85.03	39.20	22876.00	1412.54	651.18	6.36	61747.57	76.00
25-May	568.95	13210.00	16.67	9.49	27390.00	34.57	19.67	4.02	50.74	28.87	na	na	na	na	na	0.13	1262.14	79.70	
12-Jun	417.25	400.00	0.62	0.26	36000.00	55.92	23.33	0.30	4.66	1.94	3511.00	5.45	2.28	47045.10	73.08	30.49	0.16	1553.40	70.20
23-Jun	625.30	11000.00	530.78	331.89	28000.00	1351.07	844.82	0.30	144.76	90.52	1062.00	51.24	32.04	22865.10	1103.30	689.89	4.97	46252.43	82.50
Average		10498.33	226.03	121.68	29030.00	611.55	334.33	1.01	219.61	49.66	1759.20	33.43	17.84	32685.72	643.73	357.44	2.24	21779.94	78.90
SD		7536.88	251.36	137.40	4020.02	739.69	386.19	1.48	389.11	44.74	991.66	33.99	16.64	11134.92	580.97	302.52	2.71	26300.01	4.99
Number	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	6	6	6	6

Date	Flow		Alk	mg/kg	mg/l	kg/d	pH	Temp
	m ³	m ³						
03-May	437.50							
10-May	817.15							
19-May	461.00	1577.00	97.38	44.89	6.81	19.00		
25-May	568.95	328.00	0.41	0.23	7.03	17.00		
12-Jun	417.25	530.41	0.82	0.34	7.49	18.20		
23-Jun	625.30	1147.76	55.38	34.63	6.00	16.01		
Average		895.29	38.50	20.02	6.83	17.55		
SD		573.21	46.98	23.17	0.62	1.32		
Number	4	4	4	4	4	4		

PFT Sludge Data for Slough STW

	Flow	Tot.P		TKN		N-NH ₄		Mg		Ca		
Date	mg/kg	mg/ml	kg/d	mg/kg	mg/ml	kg/d	%DS	kg/d	mg/kg	mg/ml	kg/d	kg/d
03-May	218.00	17000.00	643.69	140.32	643.69	140.32			1064.00	40.29	8.78	18073.80
10-May	153.00	8600.00	470.95	72.06	29420.00	1611.10			1366.00	74.80	11.45	23020.70
15-May	367.00	8820.00	240.62	88.31	30160.00	822.81	0.30	30.04	1477.00	40.29	14.79	23802.00
19-May	145.00	6880.00	302.87	43.92	22150.00	1004.28	0.30	136.02	2017.00	91.45	13.26	23498.30
25-May	233.00	11000.00	405.83	94.56	34000.00	1254.37	0.30	110.68	1814.00	66.92	15.59	27757.80
12-Jun	140.00	9600.00	429.67	60.15	3400.00	152.17	0.30	134.27	1571.00	70.31	9.84	24163.90
23-Jun	362.00	26000.00	1300.00	470.60	10000.00	500.00	0.30	152.91	820.00	41.00	14.84	22168.10
Average		12528.57	541.95	138.56	20875.71	855.49	0.30	123.15	1447.00	60.73	12.65	23212.09
SD		6779.62	358.03	149.58	11341.49	486.34	0.00	27.55	412.76	20.40	2.67	2873.09
Number		7	7	7	7	7	5	5	7	7	7	7

	Flow	DS		VS		Alk		pH		Temp	
Date	mg/kg	%	mg/l	%	mg/kg	mg/ml	kg/d				
03-May	218.00	3.90	37864.08	85.40							
10-May	153.00	5.75	55825.24	81.90							
15-May	367.00	2.81	27281.55	81.60	3345.00	91.26	33.49	5.85	22.60		
19-May	145.00	4.67	45339.81	82.10	968.00	43.89	6.36	6.81	17.60		
25-May	233.00	3.80	36893.20	76.50	1092.00			5.57	16.20		
12-Jun	140.00	4.61	44757.28	79.40	1295.37	57.98	8.12	5.43	22.90		
23-Jun	362.00	5.25	50970.87	87.40	1238.31	61.92	22.41	5.79	18.00		
Average		4.40	42704.58	82.04	1587.74	63.76	17.60	5.89	19.46		
SD		0.98	9545.62	3.60	990.63	19.90	12.80	0.54	3.08		
Number		7	7	7	5	4	4	5	5		

PFT Liquor data for Slough STW

Date	Flow	BOD	BODs	TotP	Psol	N-NH ₄	TotMg	Mgsol.	Ca	
	m ³	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	kg/d
03-May	219.50	503.30	110.47	473.00	103.82	35.03	7.69	22.50	4.94	140.00
11-May	252.40	1644.50	415.07	120.00	30.29	85.05	21.47	27.40	6.92	168.00
15-May	295.85	2352.00	695.84	475.00	140.53	159.73	47.25	61.10	18.08	271.00
19-May	316.00									
25-May	335.95	2000.10	671.93	738.00	247.93	58.41	19.62	32.39	10.88	
12-Jun	277.25	433.90	120.30	373.00	103.41	29.60	8.21	17.36	4.81	142.00
23-Jun	263.30	8260.40	2174.96	8260.40	2174.96	146.06	38.46	76.69	20.19	269.00
Average		1386.76	402.72	435.80	125.20	73.56	20.85	32.15	9.13	185.33
SD		875.04	284.48	222.44	79.43	52.92	16.06	17.12	5.57	67.21
number		6	6	6	6	6	6	6	6	5

Date	Flow	SS	VFA	Alk	pH	Temp
	m ³	mg/l	kg/d	mg/l	kg/d	
03-May	219.50	775.00	170.11			
11-May	252.40	7280.00	1837.47	582.00	146.90	
15-May	295.85	14300.00	4230.66	1409.00	416.85	21.40
19-May	316.00					
25-May	335.95	3220.00	1081.76	511.00	171.67	16.70
12-Jun	277.25	720.00	199.62	252.00	69.87	18.77
23-Jun	263.30	12090.00	3183.30	1186.00	312.27	18.30
Average		6397.50	1783.82	788.00	223.51	18.79
SD		5823.67	1646.51	487.47	139.13	1.95
Number		6	6	5	4	4

Humus Sludge Data for Slough STW

Date	TKN mg/l	TotP mg/l	Psol mg/l	TotMg mg/l	Mgsol mg/l	Ca mg/l	SS mg/l	Alk mg/l	pH	Temp
03-May	421	24.48	10.2	19.1	9.8	9.8	125	5160		
10-May	670.2	12.235		13.3	8.3	8.3	154	17600		
15-May	140	79.562		48.5	11.2	11.2	170	3180	263	8.07
19-May	724.8	446.586	8.8	37.2	7.7	7.7	217	15810	217	7.97
25-May	837.8	375.659	9.3	16	9.4	9.4	14.7	5440	394	8.1
12-Jun		129.378	5.25							19.2
Average	558.76	177.9833	8.3875	26.82	9.28	9.28	133.1167	10638.33	297.5	7.7375
SD	279.3695	186.7127	2.170397	15.30709	1.362718	1.362718	68.04382	6891.674	75.99342	0.620826
Number	5	6	4	5	5	5	6	6	4	4

BNR and AS RAS Data for Slough STW

Date	Flow m3	Tot.P mg/l	kg/d	Psol. mg/l	kg/d	Tot.Mg mg/l	kg/d	Mgsol. mg/l	kg/d	N-NH ₄ mg/l	kg/d	Ca mg/l	kg/d	Alk mg/l	kg/d	pH	Temp	SS mg/l
03-May		2.81	0.53	2.71	0.51	22.20	4.20	12.10	2.29	14.80	2.80	120.00	22.68					
10-May		112.79	21.32	11.40	2.15	22.40	4.23	10.50	1.98	2.60	0.49	125.00	23.63			7.50		
15-May		109.13	20.62	19.10	3.61	19.70	3.72	10.20	1.93	5.60	1.06	111.00	20.98	299.00	56.51	7.47	20.80	
19-May		2.68	0.51	12.30	2.32	20.30	3.84	9.80	1.85	1.70	0.32	123.00	23.25	278.00	52.54	6.81	16.50	
25-May		94.24	17.81	12.20	2.31	21.10	3.99	9.80	1.85	2.50	0.47	107.00	20.22	180.00	34.02	7.33	17.50	
26-May																		
Average	189.00	64.33	12.16	11.54	2.18	21.14	4.00	10.48	1.98	5.44	1.03	117.20	22.15	252.33	47.69	7.28	18.27	
SD		56.65	10.71	5.83	1.10	1.17	0.22	0.95	0.18	5.44	1.03	7.82	1.48	63.52	12.00	0.32	2.25	
Number		5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	3.00	3.00	4.00	3.00	

AS

Date	Flow m3	Tot.P mg/l	kg/d	Psol. mg/l	kg/d	Tot.Mg mg/l	kg/d	Mgsol. mg/l	kg/d	N-NH ₄ mg/l	kg/d	Ca mg/l	kg/d	Alk mg/l	kg/d	pH	Temp	SS mg/l
12-Jun		150.63	150.63	13.06	13.06	37.20	37.20	23.30	23.30	3.31	3.31	111.00	111.00	431.00	431.00	7.01	18.60	
23-Jun		175.46	175.46	7.14	7.14	43.40	43.40	16.40	16.40	0.20	0.20	116.00	116.00	284.00	284.00	7.15		4040.00
Average	1000.00	163.05	163.05	10.10	10.10	40.30	40.30	19.85	19.85	1.76	1.76	113.50	113.50	357.50	357.50	7.08	18.60	4040.00
SD		17.56	17.56	4.19	4.19	4.38	4.38	4.88	4.88	2.20	2.20	3.54	3.54	103.94	103.94	0.10		
Number		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1

BNR

[illegible]

Thickened SAS Data for Slough STW

Date	Flow m ³ /d	TotP mg/kg	mg/l	kg/d	Psol mg/l	kg/d	TKN mg/kg	mg/l	kg/d	N-NH4 %DS	mg/l	kg/d	TotMg mg/kg	mg/l	kg/d
03-May	107.00	42000.00	2800.00	299.60	14.00	1.50	67000.00	4466.67	477.93				7742.00	516.13	55.23
10-May	145.00	35000.00	2206.67	319.97	26.20	3.80	84000.00	5296.00	767.92				6810.00	429.35	62.26
15-May	247.00	36000.00	2094.86	517.43	11.20	2.77	70470.00	4100.68	1012.87	0.59	343.32	84.80	8672.00	504.63	124.64
19-May	218.00	35570.00	2137.59	465.99	7.60	1.66	67100.00	4032.39	879.06	0.50	300.48	65.50	7193.00	432.27	94.23
25-May	123.00	35000.00	2086.67	256.66	10.50	1.29	74000.00	4411.81	542.65	0.86	512.72	63.07	8451.00	503.84	61.97
12-Jun	199.00	29700.00	1963.03	390.64	15.47	3.08	61000.00	403.18	80.23	0.60	396.57	78.92	7641.00	505.03	100.50
Average		35545.00	2214.80	375.05	14.16	2.35	61445.00	3785.12	626.78	0.64	388.27	73.07	7751.50	481.88	83.14
SD		3914.91	297.55	101.52	6.51	1.01	27834.20	1716.87	334.84	0.16	91.81	10.47	713.76	39.82	27.61
number		6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	4.00	4.00	4.00	6.00	6.00	6.00

Date	Flow m ³ /d	DS %	mg/l	VS %	Alk mg/kg	mg/l	kg/d	pH	Temp
03-May	107.00	7.00	66666.67	78.30					
10-May	145.00	6.62	63047.62	79.80				6.97	
15-May	247.00	6.11	58190.48	77.80	847.00	56.47	13.95	7.06	19.30
19-May	218.00	6.31	60095.24	72.20	515.00	32.47	7.08	6.84	16.10
25-May	123.00	6.26	59619.05	70.30	489.00	28.46	3.50	6.64	18.70
12-Jun	199.00	6.94	66095.24	81.70	1423.00	85.52	17.02	6.89	18.90
Average		6.54	62285.71	76.68	818.50	50.73	10.39	6.88	18.25
SD		0.37	3548.69	4.46	434.71	26.28	6.19	0.16	1.45
Number		6	6	6	4	4	4	5	4

TSAS gives high result for SPP due to the use of TotP instead of sol.P .
Used the results of the Belt press sol.P for TSAS as they will be the same

Assume S.G 1.05 as D.S> 5%

Blended SAS Data for Slough STW

Date	Flow m ³ /d	TotP mg/kg	mg/l	kg/d	TotMg mg/kg	mg/l	kg/d	N-NH4 % D.S	mg/l	kg/d	DS %	mg/l	Alk mg/kg	mg/l	kg/d	pH	Temp
03-May	965.00	58000	580.00	559.70	8229.00	82.29	79.41	0.38	38.00	36.67	1.03	10000					
10-May	1108.00	34000	336.70	373.06				0.92	91.11	100.95	1.02	9902.9				7.31	
15-May	1540.00	27000	304.08	468.28	3788.00	42.66	65.70	0.59	66.45	102.33	1.16	11262	288.00	3.24	4.99	7.31	19.60
19-May	1624.00	33250	348.64	566.19	7508.00	78.72	127.85	0.30	31.46	51.09	1.08	10485	99.40	1.04	1.69	6.83	16.80
25-May	1165.00	36000	335.53	390.90	7976.00	74.34	86.61	1.28	119.30	138.99	0.96	9320.39	255.00	2.38	2.77	6.98	17.80
12-Jun	1552.00	34000	297.09	461.08	9031.00	78.91	122.47	0.56	48.93	75.94	0.90	8737.86	412.84	3.61	5.60	7.11	19.10
23-Jun	316.00	24000	973.98	307.78	5514.00	223.77	70.71	0.58	235.38	74.38	4.18	40583	1018.34	41.33	13.06	6.22	
Average		35179	453.72	446.71	7007.67	96.78	92.12	0.66	90.09	82.91	1.48	14327	414.68	10.32	5.62	6.96	18.33
SD		10953	249.08	96.23	1968.29	63.90	26.63	0.34	71.14	34.45	1.20	11605	355.44	17.36	4.45	0.41	1.27
Number		7	7	7	6	6	6	7	7	7	7	7	5	5	5	6	4

BSAS P levels are really high, this is because they are based on total P which includes P in the cells. This is misleading as cellular P is not available for struvite ppt, what you need is soluble P. The samples need to be filtered and the filtrate is tested for soluble P

Belt Thickener Liquor Data for Slough STW

Date		BOD	BOD	BODs	kg/d	TotP	kg/d	Psol	kg/d	TotMg	kg/d	Mgsol	kg/d	Ca	kg/d
03-May	858.00	240.20	206.09	2.00	1.72	44.01	37.76	14.00	12.01	14.00	12.01	11.70	10.04	123.00	105.53
10-May	963.00	193.60	186.44	4.00	3.85	46.08	44.38	26.20	25.23	14.30	13.77	14.30	13.77	120.00	115.56
15-May	1293.00	26.20	33.88	1.00	1.29	18.12	23.43	11.20	14.48	8.40	10.86	7.80	10.09	129.00	166.80
19-May	1406.00	74.60	104.89	1.00	1.41	14.58	20.50	7.60	10.69	9.10	12.79	8.50	11.95	128.00	179.97
25-May	1042.00	65.60	68.36	2.00	2.08	15.86	16.52	10.50	10.94	8.20	8.54	7.40	7.71	109.00	113.58
12-Jun	1353.00					23.70	32.06	15.47	20.93	10.10	13.67	10.90	14.75	115.00	155.60
23-Jun	261.00														
Average		120.04	119.93	2.00	2.07	27.06	29.11	14.16	15.71	10.68	11.94	10.10	11.38	120.67	139.51
sd		91.77	74.39	1.22	1.04	14.29	10.78	6.51	6.02	2.77	1.99	2.68	2.62	7.71	31.75
number		5	5	5	5	6	6	6	6	6	6	6	6	6	6

Date		IN-NH4	SS	Alk	kg/d	pH	Temp
03-May	858.00	2.00	865.00	nd		7.40	17.20
10-May	963.00	2.50	704.00	nd		7.50	17.10
15-May	1293.00	1.10	172.00	288.00	372.38	7.53	17.50
19-May	1406.00	0.50	214.00	300.88	381.03	6.85	16.90
25-May	1042.00	1.20	264.00	275.09	283.42	7.30	16.70
12-Jun	1353.00	2.48	160.00	312.00		7.20	17.80
Average		1.63	396.50	285.75	345.61	7.30	17.20
sd		0.82	307.00	19.16	54.03	0.25	0.40
number		6	6	4	3	6	6

Struvite ppt potential -92. V.low. Could be due to p

Imports Data for Slough STW

Date	Flow m3	TotP mg/kg	mg/l	kg/d	TKN mg/kg	mg/l	kg/d	N-NH4 %DS	mg/l	kg/d	Mg mg/kg	mg/l	kg/d	DS %	mg/l	VS %
03-May	386	1800.00	91.03	35.14	30000.00	1517.14	585.62				2098.00	106.10	40.95	5.31	50571.43	80.70
10-May	174	17000.00	442.33	76.97	46000.00	1196.99	208.26				3777.00	98.28	17.10	2.68	26019.42	76.20
15-May	5	17000.00	919.62	4.60	52060.00	2816.20	14.08	1.00	87.12	0.44	3382.00	182.95	0.91	5.68	8711.91	78.30
19-May	235	15100.00	524.83	123.34	40250.00	1398.98	328.76	0.72	250.25	58.81	2100.00	72.99	17.15	3.58	34757.28	74.50
25-May	323	14600.00	757.81	244.77	4500.00	233.57	75.44	1.39	721.48	233.04	3519.00	182.65	59.00	5.45	51904.76	73.90
12-Jun	5	18310.00	920.73	4.60	56110.00	2821.53	14.11	1.40	704.00	3.52	3220.00	161.92	0.81	5.28	50285.71	77.00
23-Jun	104	23000.00	710.10	73.85	55000.00	1698.06	176.60	1.88	580.43	60.36	3209.00	99.07	10.30	3.18	30873.79	73.60
Average		13968.33	609.39	81.57	38153.33	1664.05	204.38	1.13	440.71	73.95	3016.00	134.15	22.65	4.66	37041.75	76.77
sd		6115.23	322.17	92.09	18872.35	1002.35	223.65	0.33	321.17	109.40	733.41	47.58	23.09	1.23	17370.40	2.51
number		7	7	7	7	7	7	5	5	5	7	7	7	7	7	7

Date	Flow m3	Alk mg/kg	mg/l	kg/d	pH	Temp
15-May	5	2753.00	148.92	0.74	5.51	21.30
19-May	235	2076.00	72.16	16.96	6.81	17.10
25-May	323	3558.00	184.68	59.65	5.16	15.30
12-Jun	5	2509.00	126.17	0.63	5.13	19.90
23-Jun	104	3865.11	119.33	12.41	5.21	18.20
Average			132.98	19.50	5.65	18.40
SD			622.50	47.16	0.79	2.71
Number			5	5	5	5

Anaerobic Digester Feed Data for Slough STW

Date	Flow m ³ /d	TotP mg/kg	mg/l	kg/d	TKN mg/kg	mg/l	kg/d	N-NH ₄ %DS	mg/l	kg/d	Mg mg/kg	mg/l	kg/d	DS %	mg/l	VS %
03-May	711.00	35000.00	1087.38	773.13	65000.00	2019.42	1435.81				4733.00	147.04	104.55	3.20	31067.96	76.40
10-May	472.00	26000.00	1027.38	484.92	70000.00	2766.02	1305.56				5391.00	213.02	100.55	4.07	39514.56	74.30
15-May	619.00	28000.00	956.89	592.32	73000.00	2494.76	1544.25	3.43	1172.19	725.59	5726.00	195.68	121.13	3.52	34174.76	74.60
19-May	598.00	31450.00	989.30	591.60	79720.00	2507.70	1499.60	2.90	912.23	545.52	5343.00	164.87	98.59	3.24	31456.31	71.50
25-May	679.00	31000.00	933.01	633.51	81000.00	2437.86	1655.31	3.31	996.21	676.43	5566.00	164.33	111.58	3.10	30097.09	72.10
12-Jun	344.00														0.00	
23-Jun	521.00	19000.00	1042.29	543.03	49000.00	2688.00	1400.45	1.65	922.72	480.74	2886.00	158.32	82.48	5.76	55922.33	76.50
Average		28408.33	1006.04	603.09	69620.00	2485.63	1473.50	2.82	1000.84	607.07	4940.83	173.88	103.15	3.82		74.23
SD		5548.01	57.30	97.63	11744.04	260.68	121.41	0.81	120.19	113.44	1061.81	25.07	13.05	1.02		2.10
Number		6	6	6	6	6	6	4	4	4	6	6	6	6	7	6

Date	Flow m ³ /d	Alk mg/kg	mg/l	kg/d	pH	Temp
15-May	619.00	829.00	28.33	17.54	7.80	
19-May	598.00	3014.00	94.81	56.70	7.02	30.10
25-May	679.00	2882.00	86.74	58.90	6.80	26.50
23-Jun	521.00	3638.86	199.62	104.00	7.01	25.60
Average		2590.97	102.37	59.28	7.21	26.00
SD		1220.15	71.27	35.35	7.17	27.05
Number		4	4	4	4	2.07

Digested Sludge Data for Slough STW

Date	Flow m ³ /d	TotP mg/kg	mg/l	kg/d	N-NH ₄ %DS	mg/l	kg/d	Mg mg/kg	mg/l	kg/d	DS %	mg/l	VS %	VFA mg/l
03-May	847.85	46000.00	1134.37	961.78	4.25	1048.06	888.60	6255.00	154.25	130.78	2.54	24660.19	71.40	88.00
10-May	593.46	30380.00	1038.23	616.15	3.46	1182.45	701.73	6093.00	208.23	123.57	3.52	34174.76	71.50	28.00
15-May	524.66	32520.00	817.74	429.04	4.63	1164.24	610.84				2.59	25145.63	70.40	52.00
19-May	817.24	33220.00	832.11	680.03	4.51	1129.69	923.22	5517.00	138.19	112.94	2.58	25048.54	67.90	57.00
25-May	703.08	35300.00	908.20	638.54	4.53	1165.49	819.43	5693.00	146.47	102.98	2.65	25728.16	70.20	63.00
12-Jun	345.49	34400.00	975.22	336.93	4.42	1253.05	432.92	5179.00	146.82	50.73	2.92	28349.51	70.40	55.00
23-Jun	310.34				4.42	1218.72	378.21	4395.00	121.18	37.61	2.84	27572.82	69.80	
Average		35303.33	950.98	610.41	4.32	1165.96	679.28	5522.00	152.52	93.10	2.81		70.23	57.17
sd		5505.65	122.92	217.63	0.40	65.65	215.83	675.33	29.54	39.28	0.35		1.20	19.32

Date	Flow m ³ /d	Alk mg/kg	mg/l	kg/d	pH	Temp
03-May	847.85					
10-May	593.46				7.39	
15-May	524.66	3417.00	85.92	45.08	7.46	31.80
19-May	817.24	3457.00	86.59	70.77	6.81	26.00
25-May	703.08	2550.00	65.61	46.13	7.35	28.00
12-Jun	345.49	4390.19	124.46	43.00	7.36	28.20
23-Jun	310.34	4771.86	131.57	40.83	7.34	20.00
Average						
		3717.21	98.83	49.16	7.29	26.80
SD		878.27	28.06	12.25	0.24	4.34
Number		5	5	5	6	5

Centrifuge Liquor Data for Slough STW

Date	Flow m3	BOD mg/l	BOD kg/d	BODs mg/l	TotP kg/d	Psol mg/l	TotMg kg/d	Mgsol mg/l	N-NH ₄ mg/l	kg/d
11-May	266.74	986.70	263.20	163.00	43.48	76.63	19.34	6.70	472.00	125.90
19-May	289.12	214.40	61.99	54.00	15.61	50.76	39.26	5.40	818.90	236.76
25-May	486.16	76.90	37.39	9.00	4.38	73.03	42.25	7.70	481.90	234.28
12-Jun	392.76	69.10	27.14	54.00	21.21	45.80	31.53	10.80	540.92	212.45
23-Jun	392.753	53.70	21.09	53.00	20.82	41.19	38.82	6.50	762.39	299.43
Average		280.16	82.16	66.60	21.10	57.48	34.24	7.42	615.22	221.77
sd		400.21	102.40	57.26	14.24	16.24	9.22	2.06	163.52	62.63
Number		5	5	5	5	5	5	5	5	5

Date	Flow m3	Ca mg/l	kg/d	SS mg/l	VFA mg/l	Alk mg/l	pH	Temp
11-May	266.74	60.00	16.00	1309.00	349.17		7.92	
19-May	289.12	52.00	15.03	1580.00	456.80	2667.00	7.71	24.00
25-May	486.16	106.00	51.53	373.30	181.48	2054.00	7.83	24.00
12-Jun	392.76	39.00	15.32	627.50	246.45	2559.00	7.84	24.30
23-Jun	392.753	22.00	8.64	30.00	11.78	3041.00	7.80	
Average		55.80	21.31	783.96	249.14	2580.25	7.64	24.10
sd		31.53	17.16	646.32	168.86	407.11	0.48	0.17
number		5	5	5	4	4	5	3

Struvite ppt potential 171mg/l (struvite model)

Centrifuge Cake Data for Slough STW

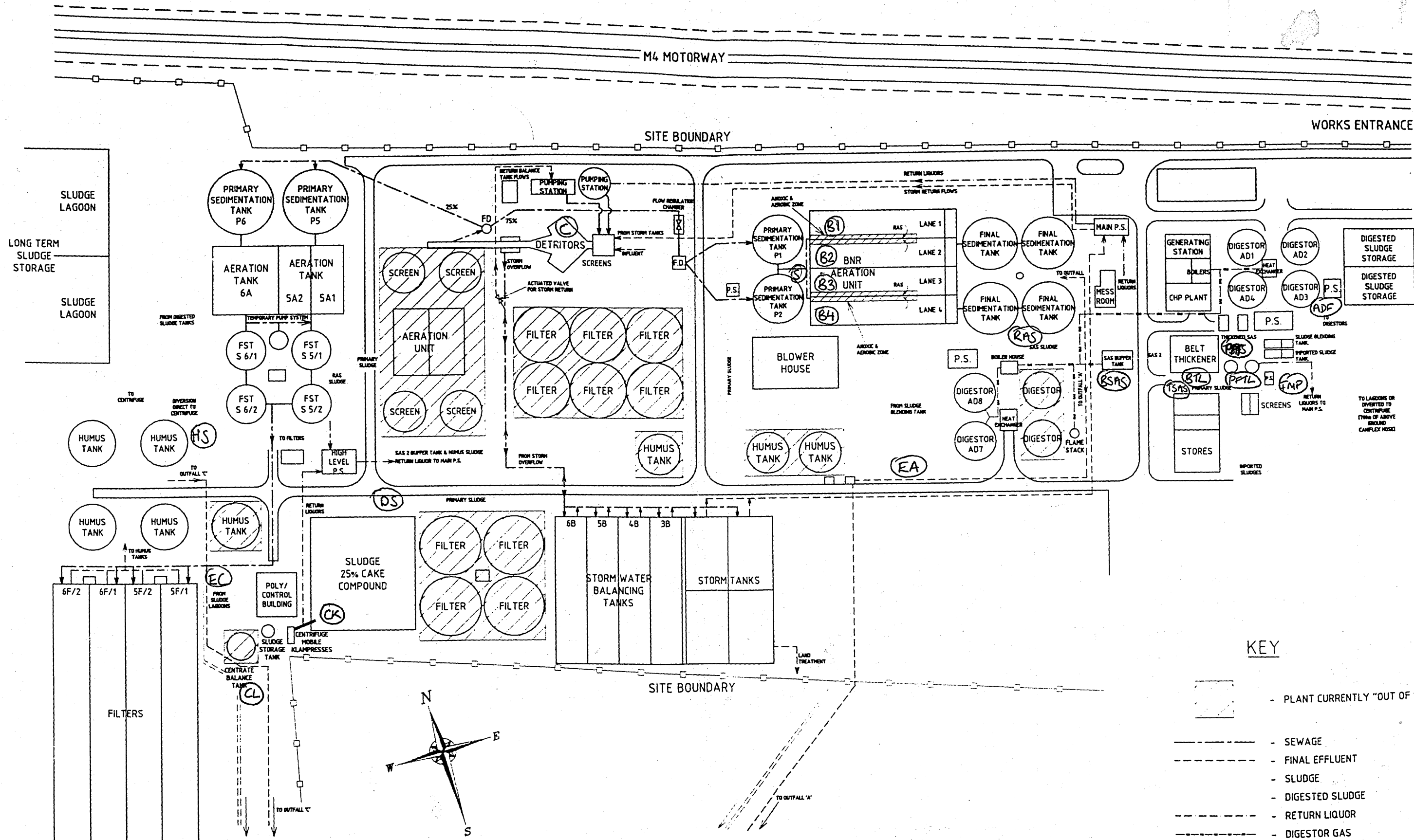
	Flow	TotP			TKN				Mg				DS		VS	N-NH ₄			Alk		
	m ³ /d	mg/kg	mg/l	kg/d	mg/kg	mg/l	kg/d	mg/kg	mg/l	kg/d	%	%	%	mg/l	%	%DS	mg/l	kg/d	mg/kg	mg/l	kg/d
Date																					
03-May	17.02	32000.00	6534.10	111.23	65000.00	13272.38	225.94	5925.00	1209.83	20.60	21.44	204190	68.20								
10-May																					
16-May																					
19-May	46.88	27480.00	5760.33	270.07	48200.00	10103.64	473.70	4984.00	1044.74	48.98	22.01	209619	63.50	1.37	2871.78	134.64	2330.00	488.41			22.90
25-May	78.84	27000.00	5554.29	437.88	55000.00	11314.29	891.99	5719.00	1176.48	92.75	21.60	205714	62.80	1.30	2674.29	210.83	2445.00	502.97			39.65
12-Jun	63.69	27610.00	6350.30	404.44	55260.00	12709.80	809.47	3423.00	787.29	50.14	24.15	230000	67.90	4.52	10396.00	662.11	2675.00	615.25			39.18
23-Jun	63.69	37000.00	8457.14	538.63	64000.00	14628.57	931.68	4496.00	1027.66	65.45	24.00	228571	62.80	0.86	1965.71	125.19	1409.93	322.27			20.53
Average	54.02	30218.00	6531.23	352.45	57492.00	12405.74	666.56	4909.40	1049.20	55.58	22.64	215619	65.04	2.01	4476.95	283.19	2214.98	482.23			30.57
SD		4296.07	1150.06	165.56	7004.59	1751.82	305.32	1009.05	166.65	26.34	1.33	12642.12	2.76	1.69	3965.17	255.50	555.54	120.76			10.27
Number		5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4		4

On-site Diary

Date	Comments
28 th April	Automated samplers put in place for crude, settled sewage, effluent A and Effluent C. Programmes set for 12am-12am.
4 th May	Sampler for crude fine. Settled sewage not catching the bottles correctly, sample is being lost. Sampler arm may be too short for the sampler. Sampler for effluent C is not picking up sample, may be due to coiling of sampling tube around gaurd rail. Swapped settled sewage sampler for effluent C, as more important to get settled sewage data than effluent C. Cleaned samplers before exchanging
5 th May	Reprogrammed settled sewage sampler. Weight on the end of tube too large and became entangled in the cleaning brush on the bridge arm. Changed the base unit on the effluent C sampler. Changed sampler batteries
10 th May	Digester pump not working, whole of the plant backed up. Unable to get samples for PFT sludge, PFT feed, PFT liquor and centrate liquor.
12 th May	Pumps to inlets not working, crude diverted to other pumping stations
15 th May	Centrifuge pump not working due to struvite build up. PFT feed and humus sludge weak. Ferric dosing started 600ml/min
17 th May	Sample tube for settled sewage was removed from the basin. Reset programme.
19 th May	No PFT liquor as PFT not switched on. PFT sludge and feed significantly thicker than usual. May be overdosing ferric.
25 th May	Centrifuge not working properly, cake forming in large lumps. PFT feed very thin
12 june	Digester gas pipes changed for larger diameter pipes, to reduce the back pressure of gas and prevent digester overflowing
13 th June	Feed and effluent pipes on digester changed

On-site Diary

14 th June	SAS belts not working. MLSS in BNR up to 6000.



A	First Issue	Auth.	Chd.	Appd.	Date
		JH S			28/01/00
Description	Auth.	Chd.	Appd.	Date	

Notes
1. ALL PIPELINES ARE SCHEMATIC AND DO NOT IN ANY WAY REPRESENT ACTUAL LOCATIONS.

Thames Water Utilities Engineering

LAING

Laing Limited
Bedford Road
St. Martin
Huntingdon
Cambridgeshire
PE19 2SJ

Client	THAMES WATER
Asset/Works	
Area/Location	
Scale 1:10	NOT TO SCALE
Datum	LOCAL

Project	SLOUGH W.W.T.W.
Title	SCHEMATIC SITE LAYOUT.

Hyder	HYDER CONS. P.O. Box 4 Penryn Road Nelson CF46 5YA Tel: +44 (0)1753 644101 Fax: +44 (0)1753 644102
Location Code	SLOUGH
Project Code	NE01883
Drawing No.	1007

Contact Addresses

American Sigma Inc.

11601 Maple Ridge Road
Medina
NY 14103
USA
Unitika Phosnix process

Hideo Katsuura

Manager
Engineering Department
Unitika Ltd.
Osaka
Japan

E.mail : yasunori-ueno@lab.unitika.co.jp

Bird and Tole Ltd.

Bledlow Ridge
High Wycombe
Bucks
HP14 4AJ
United Kingdom

Tel: 01494 481342

NedMag

NedMag Industries
PO Box 241 (Billitonweg 1)
9604 AE
Veendam
The Netherland

E.mail : sales@nedmag.nl

Dr Bruno Lange GmbH

40549 Dusseldorf
Germany

UK Contact No. : 01256 333403

MAGNESIUM CHLORIDE



Liquid Purified Quality

Product description

nedMag C[®] liquid P.Q. is a clear liquid, which is used in many industries for a wide variety of applications, including:

- magnesium metal
- animal feed supplements
- de-icing fluids
- oxychloride cements
- drilling mud
- textiles
- detergents
- dust suppressants
- sugar

Packaging

nedMag C[®] liquid P.Q. is available in containers of 1 m³, in road tankers up to 25 m³ and in ship loads.

Storage and handling

nedMag C[®] liquid P.Q. is mildly corrosive to mild steel and aluminium. The preferred materials for storage and handling equipment are carbon steel, polypropylene, polyethylene and polyester.

Chemical composition

		Typical	Specification
MgCl ₂	%	32	30 min.
MgSO ₄	%	0.25	0.40 max.
Mg	%	8.25	
KCl	%	0.30	0.45 max.
NaCl	%	0.40	0.45 max.
Br	%	0.40	0.50 max.
As	mg/l		0.05 max.
Cd	mg/l		0.1 max.
Cr	mg/l		0.3 max.
Cu	mg/l		0.5 max.
Fe	mg/l	0.5	1 max.
Hg	mg/l		0.01 max.
Ni	mg/l		1 max.
Pb	mg/l		0.5 max.
Zn	mg/l		0.3 max.

Physical properties

pH	4 - 6
Density kg/m ³	1290 - 1330

February 1998
Rev. 5



NEDMAG INDUSTRIES Mining & Manufacturing B.V.
Head office: P.O. Box 241 (Billitonweg 1), 9640 AE Veendam · The Netherlands
Tel: +31 598 651911 Fax: +31 598 651205
Trade register, Groningen 02331543, VAT no. NL 004927084B01



Appendix C

No:

CATEGORY 1 COSHH ASSESSMENT

COMPANY : Thames WaterDESIGNATED COSHH AREA : Manor Farm Pilot HallPRODUCT / TRADE NAME : Sodium Hydroxide (NaOH)COSHH SUBSTANCE(S) : Sodium Hydroxide (20%).

CHIP CLASSIFICATION :

Very Toxic (T+) ☐Toxic (T) ☐Harmful (Xn) ☐Irritant (Xi) ☒Corrosive (c) ☒

OTHER CLASSIFICATIONS :

Oxidising (O) ☐☐Extremely Flammable (F+) ☐☐Highly Flammable (F) ☐☐Flammable ☐☐Explosive (E) ☐☐Sensitising by inhalation (Xn) ☐☐Sensitising by skin contact (x) ☒☒Carcinogenic category 1 (T) ☐☐Carcinogenic Category 2 (T) ☐☐Carcinogenic category 3 (Xn) ☐☐Mutagenic category 1 (T) ☐☐Mutagenic category 2 (T) ☐☐Mutagenic category 3 (Xn) ☐☐Dangerous for the environment (N) ☐☐

OCCUPATIONAL EXPOSURE LIMITS (source EH40/):

Substance

MEL / OES

ppm / mg m-3

8-hr-TWA / 15 minute reference period

NaOH

OES

2 mg/m³

STEL

PRODUCT USE (including means of application) :

Dosed by pump, pipette, measuring cylinderAverage quantity use <4l per day (total)Number of persons regularly exposed : 2-5Approximate duration of daily exposure : <30 mins

HAZARDS :

What are the hazards ? (copy of product safety data sheet to be attached)

Corrosive to skin, irritant to eyes (severe), inhalation may affect respiratory and digestive tracts. High exposure may cause chronic effects

How are the substances hazardous ?

Such as bronchitis, pneumonitisInhalation ☒Ingestion ☒Absorbed through the skin ☐Injected into the body ☐

LIMITATIONS AND PROHIBITIONS (What should not be done with the product ?) :

General : Protect eyes and skin, minimise inhalation (ventilate area)Incompatible Materials : Acids, ammonia, metals, many organic compounds, red/white phosphorusStorage restrictions : Well ventilated area, min temp 25°C, max 50°C, UseLimitations of Means of Application : Minimise handling where possibleStainless steel, Nickel, Cast iron, polypropylene, thermoplastics

No:

CONTROL MEASURES :

Engineering Controls Required ? :

YES/NO

If yes, specify : _____

Non-Engineering Controls Required ? :

YES/NO

If yes, specify : Wear chemical goggles, PVC suit, rubber footwear, gloves

Written Safe System of Work (including hygiene precautions) required ? :

YES/NO

If yes, copy must be attached.

Personal Protective Equipment required ? :

YES/NO

If yes, specify (including appropriate commodity codes from the Thames Water Personal Protective Equipment

Catalogue, PS5406A) : Waterproof PVC suit, rubber footwear, gloves (not disposal), chemical goggles, breathing apparatus in unventilated areas.**RISK ASSESSMENT :**Substitutes : Mild alkalis (eg $Mg(OH)_2$) for pH correctionAdditional Information : Use near to safety shower, Avoid contact with eyes, skin. In the case of contact with skin, eyes - wash ~~ee~~ with copious amounts of water - seek medical attention

Special First Aid Requirements ? :

YES/NO

If yes, copy must be attached.

Local First Aiders Informed ? :

YES/NO

Employee Information and Instruction carried out ? :

YES/NO

Further consultation with designated safety adviser required ? :

YES/NO

Safe for use ? :

YES/NO

ASSESSMENT REVISION :

This assessment is / is not a review or update of a previous assessment (* delete as appropriate)

Previous Assessment Serial Number _____

Dated 08/06/00**REQUIREMENT FOR REVIEW :**This assessment must be reviewed before 08/06/05 (not to exceed 5 years of date of completion), or immediately if there is any evidence that it is no longer valid, or immediately where there has been a significant change in the work to which this assessment relates.

SIGNED ON BEHALF OF THE AFOREMENTIONED THAMES WATER GROUP COMPANY :

A. ClarkDate 08/06/00

Trained COSHH Assessor

No:

CATEGORY 1 COSHH ASSESSMENT

COMPANY : Thames Water
DESIGNATED COSHH AREA : Manor Farm Pilot Hall
PRODUCT / TRADE NAME : Magnesium Chloride
COSHH SUBSTANCE(S) : MgCl₂

CHIP CLASSIFICATION :

Very Toxic (T+) ☐ Toxic (T) ☐ Harmful (Xn) ☐ Irritant (Xi) ☐ Corrosive (c) ☐

OTHER CLASSIFICATIONS :

Oxidising (O) ☐ Extremely Flammable (F+) ☐ Highly Flammable (F) ☐
Flammable ☐ Explosive (E) ☐ Sensitising by inhalation (Xn) ☐
Sensitising by skin contact (x) ☐ Carcinogenic category 1 (T) ☐ Carcinogenic Category 2 (T) ☐
Carcinogenic category 3 (Xn) ☐ Mutagenic category 1 (T) ☐ Mutagenic category 2 (T) ☐
Mutagenic category 3 (Xn) ☐ Dangerous for the environment (N) ☐

OCCUPATIONAL EXPOSURE LIMITS (source EH40/):

Substance MEL / OES ppm / mg m-3 8 hr TWA / 15 minute reference period

Non-hazardous.

PRODUCT USE (including means of application):

Dosing via pump or pipette

Average quantity use 10L per month

Number of persons regularly exposed : 1

Approximate duration of daily exposure : 15 mins per day (max)

HAZARDS :

What are the hazards ? (copy of product safety data sheet to be attached)

Deliberate ingestion can cause abdominal cramps, minor skin irritations may be possible

How are the substances hazardous ?

Inhalation ☐ Ingestion ☒ Absorbed through the skin ☐ Injected into the body ☐

LIMITATIONS AND PROHIBITIONS (What should not be done with the product ?):

General : Wear gloves, goggles, lab coat.

Incompatible Materials : Heat, >160°C evolves toxic chloride gas.

Storage restrictions : Keep cool and sealed.

Limitations of Means of Application : Low temperatures (<160°C)

No:

CONTROL MEASURES :

Engineering Controls Required ? :

YES ☒ NO

If yes, specify : _____

Non-Engineering Controls Required ? :

☒ YES ☐ NOIf yes, specify : Gloves, goggles, Lab coat.Written Safe System of Work (including hygiene precautions) required ? : YES ☒ NO

If yes, copy must be attached.

Personal Protective Equipment required ? :

☒ YES ☐ NOIf yes, specify (including appropriate commodity codes from the Thames Water Personal Protective Equipment Catalogue, PS5406A) : Gloves, goggles, Lab coat.**RISK ASSESSMENT :**Substitutes : NoneAdditional Information : Avoid contact with eyes + skin, Do not ingest, Do not heat.

Special First Aid Requirements ? :

YES ☒ NO

If yes, copy must be attached.

Local First Aiders Informed ? :

YES ☒ NO

Employee Information and Instruction carried out ? :

☒ YES ☐ NOFurther consultation with designated safety adviser required ? : YES ☒ NO

Safe for use ? :

☒ YES ☐ NO**ASSESSMENT REVISION :**

This assessment is / is not a review or update of a previous assessment. (* delete as appropriate)

Previous Assessment Serial Number _____

Dated 06/06/00**REQUIREMENT FOR REVIEW :**This assessment must be reviewed before 06/06/05 (not to exceed 5 years of date of completion), or immediately if there is any evidence that it is no longer valid, or immediately where there has been a significant change in the work to which this assessment relates.**SIGNED ON BEHALF OF THE AFOREMENTIONED THAMES WATER GROUP COMPANY :**F. ClarkDate 06/06/00

Print name

Trained COSHH Assessor