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ENVIRONMENT AGENCY

ENVIRONMENT PROTECTION SECTION
CORNWALL AREA

REPORT

TAMAR LAKES PROJECT 2001:
Initial assessment of nutrient data to identify pollution sources, assess the effect of Tamar Lakes on the downstream water quality and to recommend future monitoring requirements.

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140

CONTENTS

APPENDICES

EXECUTIVE SUMMARY

This study has been undertaken to analyse existing data, collected from the Tamar Lakes catchment to identify and assess:

a) Pollution sources directly to the lakes and the upstream catchment.
b) The input of key nutrients into Tamar Lakes, including any apparent temporal trends.
c) Any impact the lakes may have on the downstream stretches of the river Tamar.
d) Future requirements for a detailed monitoring program of both lakes and catchment.

The Tamar Lakes catchment comprises *ca.* 17 km^2 of agricultural land, some 5 km^2 of which drain directly into the Upper and Lower Tamar lakes (UTL & LTL). The river Tamar upstream and downstream of the lakes has a River Quality Objective (RQO) of River Ecosystem (RE) classification 2 and is subject to EC Freshwater Fish Directive (salmonid) (FFD). Regular breaches of the RE classification have occurred since designation in 1996. The UTL is subject to both EC FFD and a EC Abstraction Directive for potable water. Failures of the EC FFDs in the UTL have occurred in 1994, 1997 & 1999. The Lower Tamar Lake has an EC Freshwater Fish Directive (cyprinid) designation and has remained compliant in all years except 1997. A total of 13 sites in the Tamar Lakes catchment have been routinely monitored on a monthly basis.

There are no significant non-agricultural nutrient inputs within the catchment. Several inputs to both the catchment and the lakes have been identified which have nutrient concentrations high enough to cause eutrophication and severe algal blooms within the lakes. These take the form of both chronic and acute pollution sources, some of which require further identification. The highest nutrient concentrations entering the lakes were from a small feeder to the Upper Tamar Lake, NGR SS2860912792. The highest nutrient concentrations entering the Lower Tamar Lake were from the Newlands feeder during a rainfall event. Nutrient loadings to the lakes could not be calculated due to the lack of flow data. No trends in nutrient concentration into or out of the lakes were evident over the sampling period.

The lakes have had a significant deleterious effect on the downstream water quality through the development of algal blooms which have continued to proliferate downstream. The induced breakdown of algal cells in river water samples has caused elevated biochemical oxygen demand (BOD) determinations, which have resulted in un-representative breaches of the RE 2 classification. Future trends in the trophic status of the lakes are difficult to predict from these data. However, the majority of parameters measured, appear to be relatively stable.

Any future monitoring program should involve targeted investigations to isolate remaining pollution sources and to assess the impact of wet weather events on nutrient loading to the lakes. This should include the monitoring of key sites and the gathering of accurate flow data. Once the loading of nutrients into the lakes has been addressed, determination of sediment nutrient status and cycling capacity within the lakes could also be undertaken.

1 INTRODUCTION

1.1 BACKGROUND

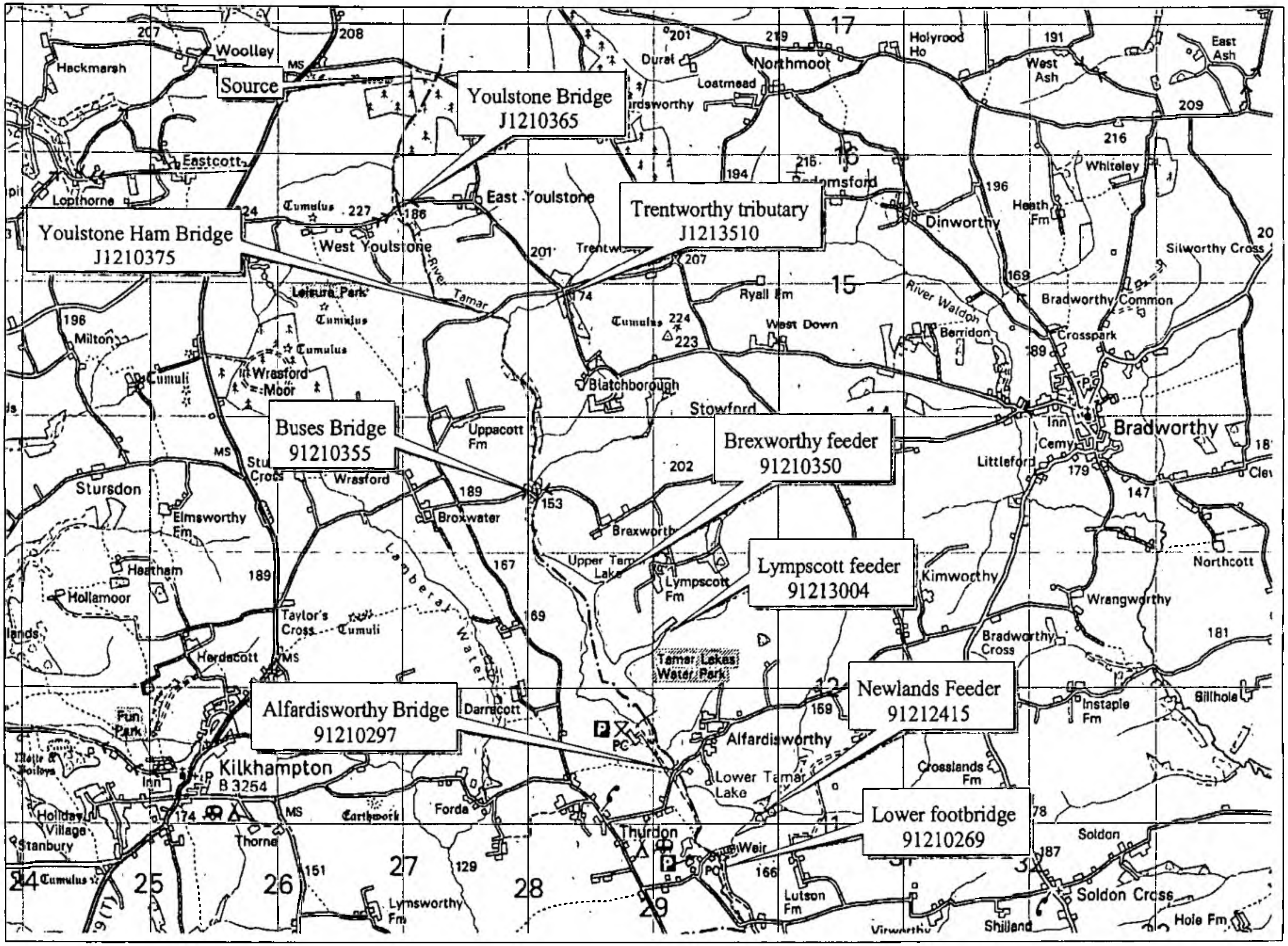
1.1.1 The upper reaches of the River Tamar, including the Upper Tamar Lake (UTL) and Lower Tamar Lake (LTL), drain an agricultural catchment of some 17 km^2. Approximately 5 km^2 of this, drains directly into the lakes. The catchment contains no known significant non-agricultural nutrient sources. Since its construction in 1975, the UTL has continually been impacted by agricultural nutrient enrichment. This has resulted in annual algal blooms, typical of hypereutrophic surface waters. (1, 2)

1.1.2 The River Tamar upstream and downstream of the lakes includes several EC Freshwater Fish Directive (salmonid) (FFD) (78/659/EEC) sites and has been given a River Quality Objective (RQO) of River Ecosystem (RE) classification 2. Historically, EC directive failures have occurred upstream of the lakes due to elevated ammonium (NH_4^+). Downstream of the lakes, Biochemical Oxygen Demand (BOD) has regularly exceeded the RE2 standard of 4 mg l^{-1} since designation (appendix 3). The UTL is also subject to EC FFD and has suffered failures in 1994 for NH_4^+, 1997 for pH and 1999 for dissolved oxygen(3). The LTL is subject to the less stringent FFD (cyprinid) and suffered a failure in 1997 for pH(3).

1.2 OBJECTIVES

a) To review of archive nutrient and sanitary data from the Tamar Lakes catchment.
b) To assess key nutrient input to the lakes, including any temporal trends.
c) To quantify the impact of the lakes on the river Tamar downstream LTL.
d) To define future requirements for detailed investigative programmes of both lakes and catchment to identify pollution sources impacting the lakes.

Figure 1. Tamar Lakes catchment showing routine sampling points



2. METHODS

2.1 Data have been collated and compared to identify specific sources of pollution in the catchment.
Sampling has been carried out on a monthly basis several sites in the (fig.1 & appendix 1). Consistent, comparable data exist for these sites from Jan 1998 to Sept 2001, except for March – June 2001 when foot and mouth restrictions applied. A limited wet weather survey was also carried out in April 2000 in which three samples were taken from each site during a single day.

2.2 Comparable monthly monitoring data have been analysed to investigate trends in nutrient concentration over time and compared to assess any impact the lakes may have had on water quality between entering and leaving the lakes.
Regular, monthly monitoring of key nutrient and sanitary determinands has been undertaken since 1990 (except 1993 & 1994) for the River Tamar upstream of UTL, at Buses Bridge (URN 91210355), which forms the principle input to UTL, and below LTL at the Lower Footbridge (URN 9122069).

2.3 To compare nutrient concentrations in river water entering and leaving the lakes, data have been analysed using two-way analysis of variance (ANOVA)$^{(5)}$. Where significant differences were returned, these were followed by a Tukey-Kramer test for least significant difference (LSD)$^{(5)}$. Where significant intra year differences between sites have been masked by large inter year variation, individual t tests have also been used. Specific relationships between variables have been investigated using Spearman's Rank correlation coefficients$^{(5)}$.
In comparisons between nutrient concentrations entering and leaving the lakes, high values, indicative of specific major pollution events, which can be identified as outliers $^{(4)}$, have been excluded from the data in order that underlying trends are not obscured. However, where data have been analysed to identify specific pollution sources these outliers have been included.

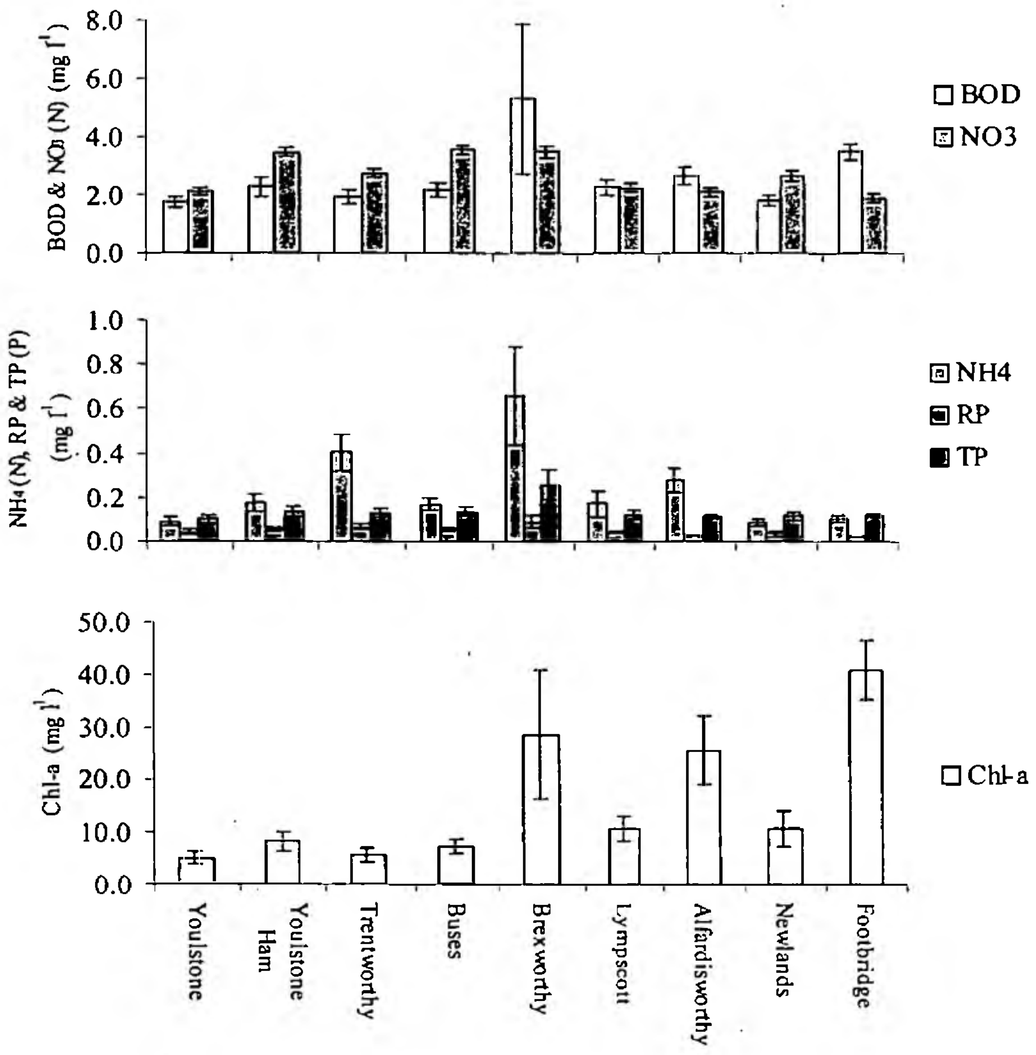
3. RESULTS

3.1 Sources of nutrients impacting the Tamar Lakes:-

3.1.1 Routine monitoring

A significant increase in mean annual NO_3^- ($P < 0.01$) and NH_4^+ ($P < 0.05$) concentration (fig. 2) from 2.11 +/- 0.12 mg l^{-1} to 3.48 +/- 0.17 mg l^{-1} was evident between Youlstone Bridge and Youlstone Ham Bridge (fig. 1). No increase in total phosphorus (TP), reactive phosphorus (RP) or BOD was evident between these sites. The Trentworthy Tributary which joins the main river channel downstream of Youlstone Ham Bridge had a significantly higher ($P < 0.01$) NH_4^+ concentration (0.4 +/- 0.08 mg l^{-1}) than the upstream sites. Total P and RP were not elevated at the Trentworthy Tributary site. No significant change in concentration for any determinands was evident between Youlstone Ham Bridge and Buses Bridge. Brexworthy Feeder, which discharges directly into UTL, had the highest annual mean value for BOD, NH_4^+ and TP (5.32, 0.66 and 0.257 mg l^{-1} respectively) of any site in the catchment. Mean annual Chlorophyll A (Chl-a) concentration in the Brexworthy feeder was 28.62 mg l^{-1} which was higher than any other input to the lakes or the catchment. The variance for these parameters in the Brexworthy feeder was significantly greater ($P < 0.001$) than at any other site (fig.2). Mean annual BOD, NH_4^+, RP, TP and Chl-a in the Lympscott feeder were not significantly different from the main input to UTL at Buses Bridge. However, NO_3 concentration in the Lympscott feeder (2.3 +/- 0.16 mg l^{-1}) was significantly ($P < 0.05$) lower than at Buses Bridge. Nutrient and BOD concentrations at Alfardisworthy Bridge, between the lakes, were not significantly different than at Buses Bridge. However, Chl-a concentration had increased significantly ($P < 0.01$). Nutrient inputs to LTL via the Newlands feeder stream were not significantly different from the main input below Alfardisworthy except for NH_4^+ which was significantly ($P < 0.01$) lower.

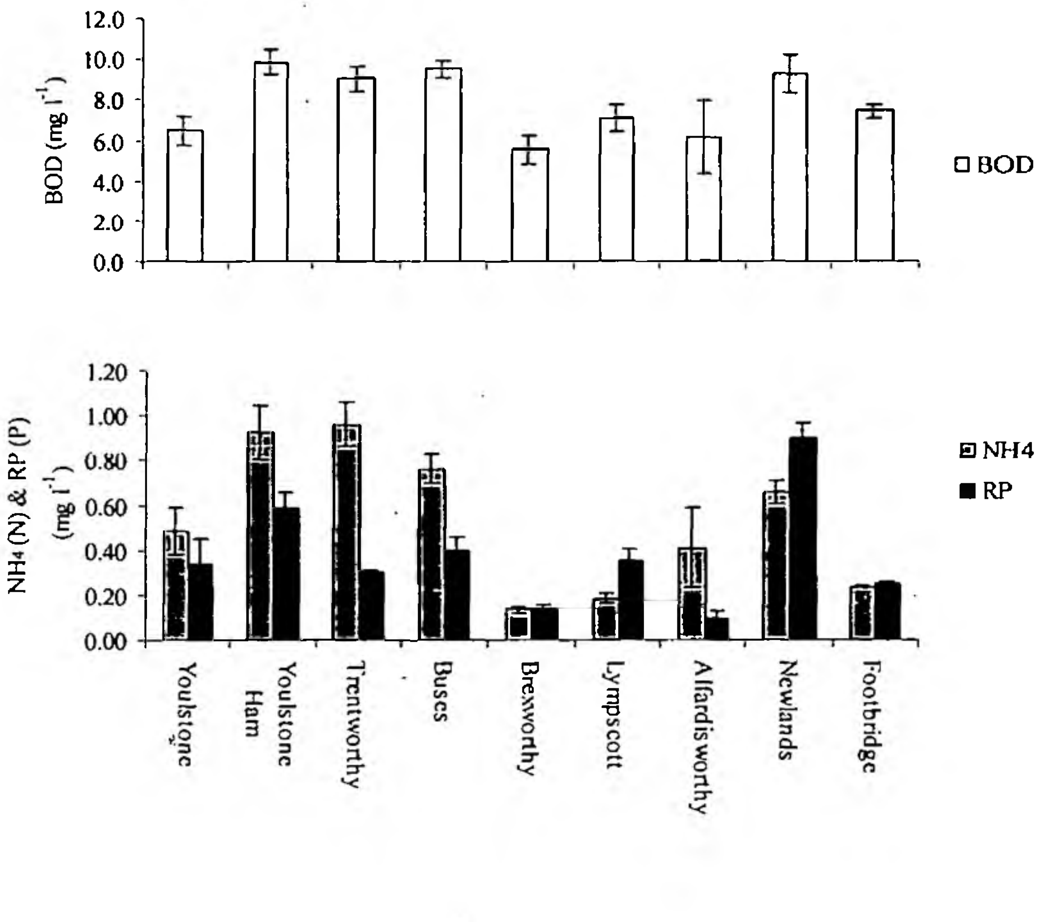
Figure 2. Nutrients, BOD and Chlorophyll-a at routine monitoring sites, Tamar Lakes catchment since Jan 1998 (mg l^{-1} +/- s.e. n = 39).



3.1.2 Effects of wet weather on the catchment

Nutrient concentrations in river water entering the lakes were greatly increased during the rainfall event monitored in this study. Statistical comparison between the wet weather survey of 03/04/00 and annual averages is complicated, primarily due to excessive differences in sample size and unequal variances in the data. Notwithstanding this, BOD concentration at the four sites upstream of UTL was between three and four times higher during the wet weather event than the annual average (Fig. 3). Ammonium and RP showed similar or even greater increases. In contrast to this, the Brexworthy feeder had reduced NH_4^+ and RP concentrations and relatively unchanged BOD, making this source the least polluted of all inputs to the catchment during this event. In the Lympscott feeder, NH_4^+ concentrations remained unchanged while BOD concentrations increased threefold over the annual average from 2.3 +/- 0.28 mg l^{-1} to 7.1 +/- 0.69 mg l^{-1} and RP concentration increased eightfold from 0.043 +/- 0.005 to 0.36 +/- 0.048 mg l^{-1}. No significant difference in BOD concentration was evident between Buses Bridge and Alfardisworthy. However, RP concentration was significantly less ($P = 0.013$) at Alfardisworthy. In the Newlands Feeder to LTL, NH_4^+ concentration was 0.65 +/- 0.053 mg l^{-1} which was a 7.7 fold increase over the annual average. Reactive P in the Newlands Feeder had increased 25 fold during the wet weather survey from 0.036 +/- 0.009 mg l^{-1} to 0.90 +/- 0.053 mg l^{-1}. This was the highest RP concentration of any site within the catchment. Total P was not determined during the wet weather survey.

Figure 3. BOD, ammonia and reactive phosphorus at Tamar Lakes catchment sites during a wet weather survey (mg l^{-1} +/- s.e. n = 3).



3.2 Comparison of nutrient, Chl-a and BOD concentrations between entering and leaving the lakes

3.2.1 Phosphorus

RP inputs were significantly greater than outputs ($P < 0.05$) in all years except 1990, 1995, and 1998. No significant difference in TP concentration was found between sites for any single year, or over the 1998 to 2000 period as a whole (Fig. 5). Further, no significant change in TP concentration occurred over this period.

Reactive P data (Fig.4) were available since 1990 (except 1993 & 1994) and TP (Fig.5) since March 1998 for both Buses Bridge and Lower Footbridge sites. No significant trends were apparent over the period for either determinand. Mean RP concentration in river water entering the lakes at Buses Bridge was 0.061 +/- 0.006 mg l^{-1} over the period as a whole. This was significantly greater than the 0.027 +/- 0.002 mg l^{-1} RP concentration in the river water leaving the lakes at the Lower Footbridge site. Individual t-tests revealed that

Figure 4. Mean annual reactive phosphorus concentration. Buses Bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 10<>12).

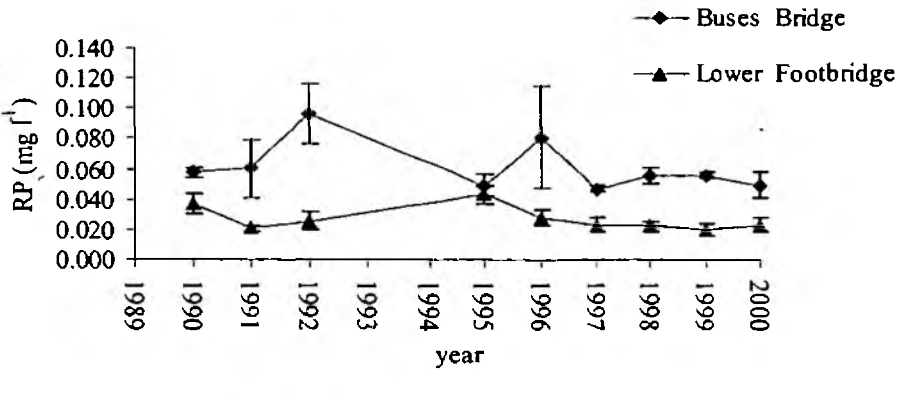
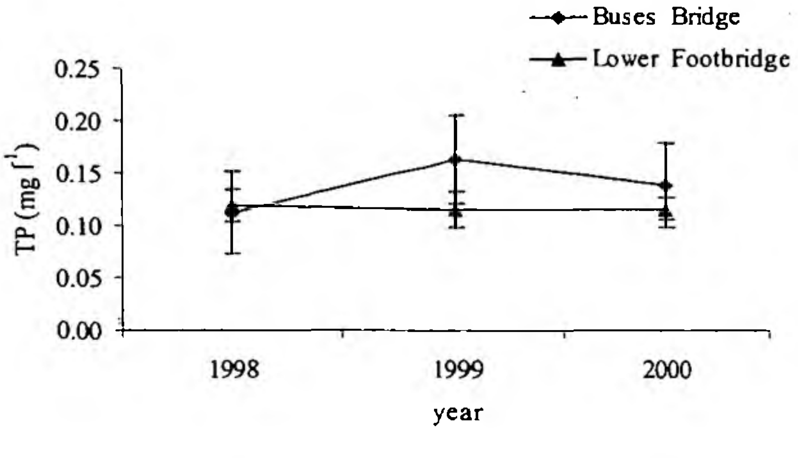


Figure 5. Mean annual total phosphorus concentration. Buses Bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 10<>12).



3.2.2 Nitrogen

No significant difference in NH$_4^+$ concentration (Fig. 6) was identified between Buses Bridge and Lower Footbridge in any single year. However, NH$_4^+$ concentration at Buses Bridge over the period 1990 to 2000 as a whole was 0.14 +/- 0.02 mg l^{-1}, significantly greater ($P < 0.01$) than 0.09 +/- 0.01 mg l^{-1} at the Lower Footbridge site. Nitrate (NO$_3^-$) concentration at Buses Bridge was significantly greater ($P < 0.05$) than at the Lower Footbridge in every year except 1990. Principle nitrogen components, NO$_3^-$ and NH$_4^+$ data were available and have been analysed for the period 1990 to 2000 (except years 1993 and 1994). Mean NO$_3^-$ concentration at Buses Bridge over the period 1990 to 2000 (Fig. 7) was 3.54 +/- 0.10 mg l^{-1}. This was significantly greater ($P < 0.01$) than the 1.96 +/- 0.12 mg l^{-1} in river water leaving the lakes at the lower footbridge.

Figure 6. Mean annual ammonia concentration. Buses Bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 10<>12).

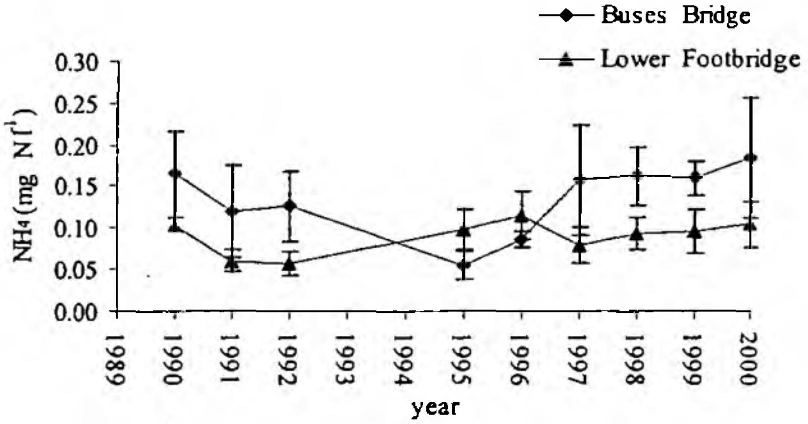
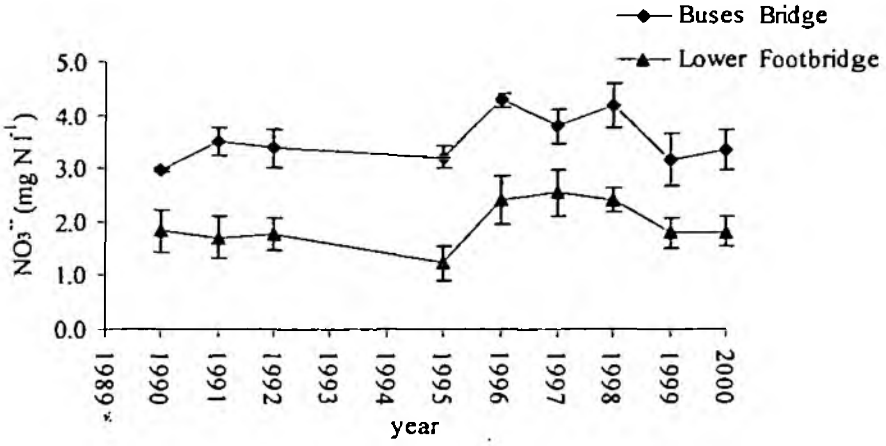


Figure 7. Mean annual nitrate concentration, Buses Bridge and Lower Footbridge. (mg l^{-1} +/- s.e. n = 10<>12).



3.2.3 Chlorophyll-a

During the years 1998 to 2000 when Chl-a data were available, no significant change occurred in the mean annual concentration at either site (Fig. 8). Mean annual Chl-a concentration leaving the lakes was significantly greater than that entering in both 1998 and 2000 ($P < 0.01$) and 1999 ($P = 0.012$). The highest recorded Chl-a concentration entering the lakes during this period from Buses Bridge was 32.3 mg l^{-1} in July 1999. This was followed, in August 1999, by the highest concentration leaving the lakes of 88.8 mg l^{-1}. At the Lower Footbridge site, mean monthly Chl-a concentration showed a distinctive seasonal pattern (Fig. 9) increasing through the summer months and decreasing towards winter. This was not the case at Buses Bridge where the highest mean monthly concentration was in December.

Figure 8. Mean annual chlorophyll-a concentration, Buses bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 10<>12).

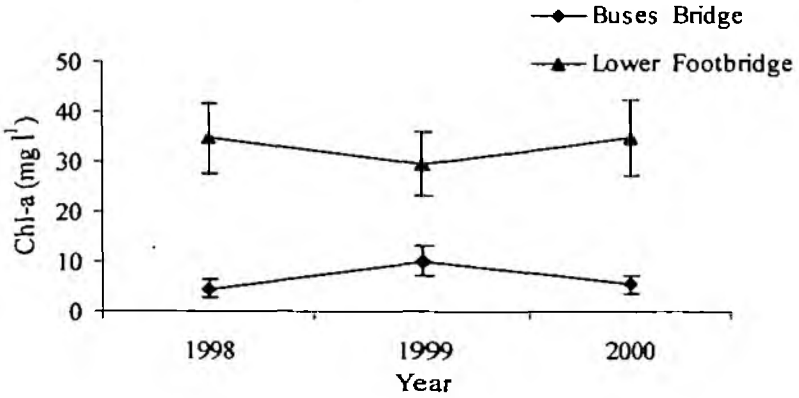
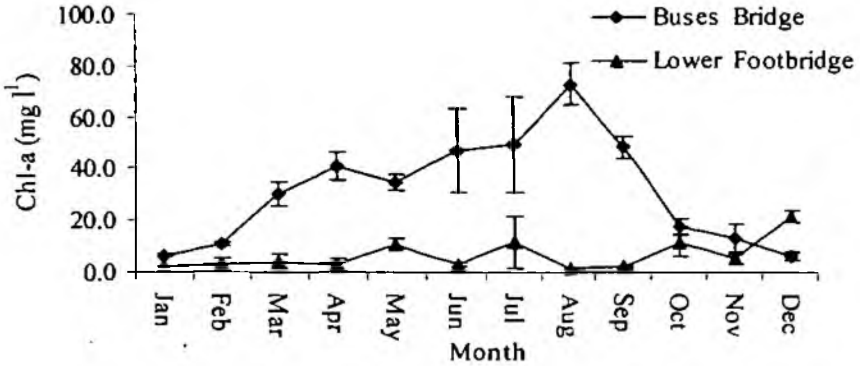


Figure 9. Mean monthly chlorophyll-a concentration, Buses Bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 3)



3.2.4 Biochemical oxygen demand

Two way ANOVA indicated that mean annual BOD (Fig. 10) was significantly greater ($P < 0.01$) leaving the lakes at the Lower Footbridge site than entering the lakes at Buses Bridge in 1995 and 1996. Over the period 1990 to 2000 as a whole mean BOD entering UTL at Buses Bridge was 1.89 +/- 0.124 mg l^{-1} which was significantly less ($P < 0.01$) than 3.12 +/- 0.164 mg l^{-1} leaving the lakes at the Lower Footbridge site. In a similar fashion to Chl-a, BOD showed a distinctive seasonal pattern at the Lower Footbridge which was not reflected at Buses Bridge (Fig. 11). Mean BOD was significantly higher ($P < 0.05$) at Buses Bridge than Lower Footbridge every month from April to October.

Figure 10. Mean annual BOD, Buses Bridge and Lower Footbridge. (mg l^{-1} +/- s.e. n =10<>12).

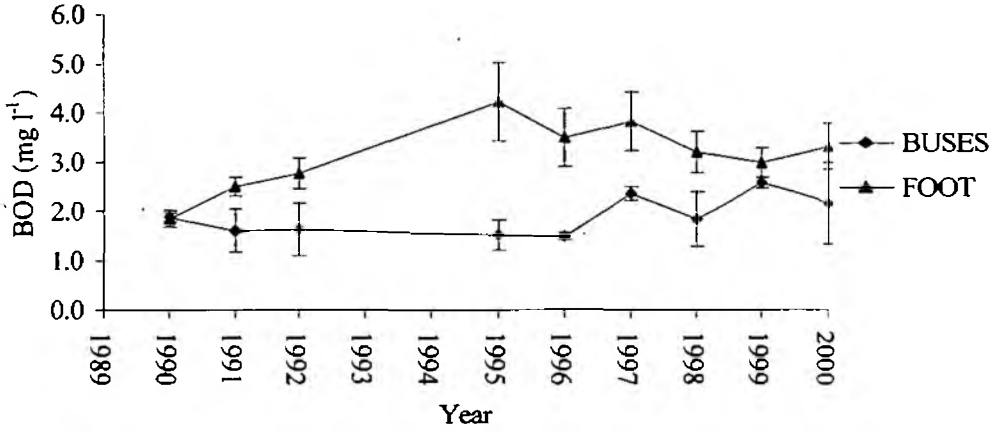
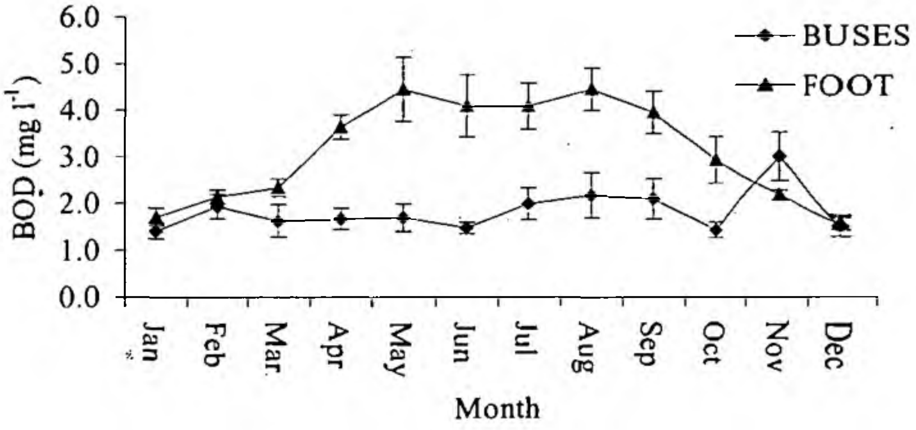


Figure 11. Mean monthly BOD 1990 – 2000, Buses Bridge and Lower Footbridge (mg l^{-1} +/- s.e. n = 9)



4. DISCUSSION

No flow measuring has been undertaken as part of the historic monitoring programme Without such data, estimation of nutrient loadings to the lakes has not been possible. However, the data available have been sufficiently comprehensive to; identify some specific, potential sources of pollution and high risk areas, to assess the possible impact of the lakes on the River Tamar downstream of the LTL outfall and to outline the principle components of targeted investigations and a remedial management strategy for the catchment.

4.1 Sources of pollution in the Tamar Lakes catchment

4.1.1 In the analysis of data from the catchment sites upstream of UTL (Fig. 1), a significant, but as yet unidentified, source of NO_3^- pollution has been indicated between Youlstone Bridge and Youlstone Ham Bridge. During the wet weather survey, a significant increase in RP, NH_4 and BOD was also found between these sites. Two tributaries join the main river channel between Youlstone Bridge and Youlstone Ham Bridge and these should be investigated to isolate the source. Elevated NH_4^+ concentrations in the Trentworthy Tributary may be due to a point source of mink farming effluent from Woodview Farm. However, work to prevent contamination from this site has been undertaken and previous investigative work has failed to positively identify this site as the cause. Several tributaries join the main river channel between Youlstone Ham Bridge and Buses Bridge. These do not significantly alter the concentration of nutrients entering UTL below Buses Bridge. However, the degree to which they increase loadings is not determinable without accurate flow data taken across a range of wet weather conditions.

4.1.2 The Brexworthy Feeder (91210350 Fig. 1) issues from a point downhill of a row of settling ponds on Lympscott Farm. This is by far the most polluted input into the Tamar Lakes. The mean annual P concentration (0.257 mg l^{-1}, Fig .2) is several times that required to cause severe eutrophication(1,2,6). Mean annual NH_4^+ concentration is also above the 90%ile RE2 classification of the main river channel. Unfortunately, without accurate flow data, loadings to UTL from this source cannot be calculated and its likely impact on the lake ecosystem cannot be estimated. The variance in data from this site was significantly higher than at all other sites, suggesting that nutrient inputs occur in sporadic acute events. The reduced concentrations during the wet weather survey (Fig.3) compared to all other sites suggests that nutrient input from this site is not rainfall related but a management issue. Chlorophyll-a concentrations at this site were *ca.* 3 times that of the upstream river sites. Sampling of the site takes place where there is flow in the stream bed and not in the standing lake water. This suggests that algae may be proliferating in a standing body of water prior to discharge into the lake. A second feeder stream enters UTL close to this monitoring site. This is the actual Brexworthy feeder which issues from Brexworthy farm. No data are available from this input.

4.1.3 Nutrient concentrations in the Lympscott feeder were similar to those of Buses Bridge and probably represent general runoff from the surrounding farmland. During the wet weather survey, nutrient concentrations were not elevated to the same degree as the upstream sites. However, mean annual TP concentration is still high enough to cause eutrophication in a standing water body(1,2,6). The Alfardisworthy Bridge sampling point (91210297 Fig.1) is poorly situated, downstream of a tributary which flows past the Lower Alsworthy Farm buildings. Consequently, any inputs from this source cannot be separated from water leaving UTL. The sampling site is also downstream of an area of standing water which may alter the NH_4^+ and Chl-a concentrations.

4.1.4 Mean annual nutrient and BOD concentrations in the Newlands feeder to LTL (Fig.2) are similar to those of the main inputs to both lakes. However, during the wet weather survey, increases in RP concentration were greater than any other input. Total P was not determined during the wet weather survey. During the year as a whole TP concentrations were, on average, three times higher than RP. This highlights the potential for massive acute loadings from this input during wet weather events. Precipitation was 12 mm each day for the two days prior to the survey and 13 mm on the day. This is not excessive rainfall for the area and without knowing the increase in flow over this period the full impact of such events can not be estimated. Clearly, there is a need for further, more detailed surveys of wet weather events, throughout the year, which must include harmonised flow monitoring. Longer term flow monitoring of all inputs to the lakes must also be carried out to calculate back ground loadings to the lakes.

4.2 The trophic status of Tamar Lakes and their effect on the downstream river water quality

4.2.1 Phosphorus concentration entering UTL via the main river channel at Buses Bridge has been sufficient to cause the lakes to become eutrophic (1,2,6) in every year since monitoring began in 1976 Severe algal blooms have been evident since the UTL was built. The difference in RP concentration between entering and leaving the lakes over the 1990 to 2000 sampling period would suggest that the lakes are acting as an effective sink for P. However, the more recent TP data collected between 1998 and 2000 would appear to contradict this assumption. No significant difference was identified between TP entering and leaving the lakes during this period. This would suggest that a proportion of RP underwent a transformation into organic P (OP) form, as biological material, rather than being retained in the lake sediments. This could suggest that little net accumulation of P has occurred in the sediments during their development. This has important implications for any future recovery program as it indicates that internal loading of P, from the sediments, is less likely to be the major driving force behind elevated P concentrations and consequent algal blooms in the lakes. However, this cannot be confirmed without detailed, intact sediment core analysis, including their capacity to release P under anaerobic conditions which could be undertaken at a future date.

4.2.2 No significant difference in NH_4^+ concentration between input and output from the lakes was identified during any one year. However, over the 1990 to 2000 period as a whole, ammonia concentration at the lower footbridge site was significantly lower than at the Buses Bridge site. Such mass balances do not enable inferences to be drawn regarding the fate of ammonia in the water column, as ammonia cycling is known to be rapid and complex(1). These data suggest only that ammonia utilisation slightly outweighs its production from the breakdown of biological material within the lakes.

4.2.3 Nitrate concentration was significantly reduced during retention in the lakes. What proportion of this was due to denitrification in the sediments or to nitrate uptake for biological assimilation is impossible to say. A clearer picture of nitrogen cycling in the lake sediments could be gained by carrying out denitrification assays on intact sediment cores. Such data could be extrapolated to estimate denitrification capacity and give a clearer picture of nitrogen cycling in the lakes as a whole.

4.2.4 Mean annual Chl-a concentration increased three to eight fold between Buses Bridge and Lower Footbridge during the 1998 to 2000 sampling period, indicating the scale of algal production within the lakes. When viewed monthly, a clear seasonal pattern was evident at the outflow from the lakes (Fig.9). This was not the case in the River Tamar upstream of the lakes, where no trend was evident. In a Spearman's Rank correlation test between Chl-a and TP above the lakes at Buses Bridge, a highly significant coefficient of $r_s = 0.70$ was returned. This was not reflected at the lower footbridge site ($r_s = 0.17$) where the seasonal pattern of Chl-a concentration did not correlate with the stable TP concentration. This suggests that, unlike the situation in the lakes, algal production in the river, upstream of the UTL, occurs as a direct consequence of agricultural enrichment. This assumption is enhanced by a significant correlation ($r_s = 0.64$) between Chl-a concentration and mean rainfall over the previous 3 days, suggesting agricultural runoff is the likely principle cause. No comparative algology has been carried out on samples upstream and downstream of the lakes to assess the impact of the lakes on the algal community structure.

4.2.5 The River Tamar upstream and downstream of the lakes has been designated as RE 2, requiring BOD levels to remain below 4.0 mg l^{-1} (90%ile). Elevated BOD levels in the downstream stretches of the river have caused regular failure since designation (appendix 3). A very highly significant correlation ($r_s = 0.87$) exists between BOD and Chl-a at the Lower Footbridge site. No such correlation was found between Chl-a and soluble BOD (filtered) (see appendix 2), suggesting that most of the BOD is due to the degradation of algal cells during the BOD assay. In the upstream site, these correlations were both found to be highly significant ($r_s = 0.70$ & $r_s = 0.63$ respectively). Dissolved BOD is a good indicator of agricultural pollution and its correlation with Chl-a at the upstream site adds further confirmation to the direct effect of agricultural run-off on the production of algae in the upstream stretches of river.

4.2.6 The United Nations Environment Program (UNEP)$^{(6)}$ developed a tri-parameter probability distribution using mean P, Chlorophyll and Secchi depth, to estimate the degree of eutrophication in lakes and reservoirs. Inserting data from the Tamar lakes into the model returns a probability in the region of 0.5 between eutrophic and hypereutrophic states for all three parameters. Evidence suggests that severe algal blooms have occurred since UTL was first built. This, together with the above evidence, indicates that nutrient concentrations in the waters entering the lakes from agricultural enrichment have been the principle cause of eutrophication and that internal loading has been of lesser importance. However, the capacity for internal loading from the sediments has not been assessed and is likely to increase over time.

4.2.7 A successful lake remediation plan would require a rationalised monitoring program, aimed at identifying individual pollution sources and high risk areas. Accurate flow measurements across a range of weather conditions together with harmonised nutrient and sanitary determination would enable loadings to be assessed and modelled. Once identified, individual nutrient inputs and high risk areas must be tackled wherever possible and farmers must be encouraged to continue improving best practice in sensitive areas likely to effect river water quality. Over the longer term, as remedial action in the catchment is taken, monitoring must continue to assess the success of such action.

5. CONCLUSIONS

5.1 Several inputs to both the lakes and the surrounding catchment have elevated nutrient concentrations capable of causing eutrophication.

5.2 The impact of the lakes on the downstream stretches of the River Tamar has been threefold:

a) To buffer the effects of specific pollution events occurring upstream of Buses Bridge.
b) To reduce the concentration of nitrate and ammonia.
c) To greatly increase the algal biomass entering the river at the Lower Footbridge site, resulting in BOD failure.

5.3 According to the UNEP the Tamar Lakes can be classified between eutrophic and hypereutrophic. Notwithstanding the short duration over which TP and Chl-a concentrations have been measured, no increasing trends in nutrient concentrations were evident over the sampling period (1998 to 2000).

5.4 Agricultural enrichment is the principle cause of eutrophication in the Tamar Lakes. Hence, improving farming practices to reduce nutrient inputs to the upstream catchment must be the principle aim of any management strategy. Development of such a strategy will require;

over the short term:

a) Implementation of targeted investigations to identify and tackle remaining pollution sources.
b) Accurate flow measurements to assess nutrient loadings to the lakes.

over the longer term:

c) Detailed analysis of sediment nutrient status and cycling capacity.
d) Implementation of a targeted programme to monitor the nutrient input to the lakes and assess the impact of nutrient reduction on the biological communities over a prolonged period.

6 BIBLIOGRAPHY

1. UNEP-IETC (1999). *Planning and management of lakes and reservoirs, an integrated approach to eutrophication.* IETC Technical Publication Series, issue 11. Osaka/Shiga. 375 p.

2. Harper, D. (1992). *Eutrophication of freshwaters: Principles, problems and restoration.* Chapman and Hall. London. 327 p.

3. Moss, K. (2001) *Report on 1999 EC directive compliance and other national reporting commitments.* EA South West Regional report.

4. Kangi, G.K. (1993) *Statistical tests.* Sage, London, p 45 & 171.

5. Fowler, J. & Cohen, L. (1995) *Practical statistics for field biology.* John Wiley & Sons, Chichester. 227p.

6. UNEP-IETC (1999). *Planning and management of lakes and reservoirs, an integrated approach to eutrophication.* IETC Technical Publications Series, Issue 11, Osaka/Shiga. 375p.

Appendix 1

Sampling points, drivers and determinands, Tamar Lakes catchment.

SITE NAME	SITE NO (URN)	SAMPLING PERIOD	DRIVER	FRQ.	ANALYSIS
R Tamar at Youlstone Bridge	J1210365	Jan 1998 - Present	Operational - Further investigation into trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
R Tamar at Youlstone Ham Bridge	J1210375	Jan 1998 - Present	Operational - Further investigation into trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
Trentworthy Trib to R Tamar	J1213510	Jan 1998 - Present	Operational - Further investigation into trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
R Tamar at Buses Bridge	91210355	Apr 1976 - Present	Routine Freshwater Fish Directive Site FF directive failure investigation	Monthly	Sanitary (inc solids), metals, nitrate, D.O., temp (Filtered BOD, nutrients and chl-a Apr 1997)
Brexworthy Feeder to UTL	91210350	Apr 1992 - Present	FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
Lympscott Feeder to UTL	91213004	Apr 1992 - Present	Operational - LEAP Action to determine trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
UTL at Dam - Surface	91210318	Jan 1991 - Present	Routine Freshwater Fish Directive Site FF directive failure investigation	Monthly	Sanitary (inc solids), metals, nitrate, D.O., temp (Filtered BOD, nutrients and chl-a Apr 1997)
UTL at Dam - Mid Depth	91210322	Apr 1997 - Present	Operational - LEAP Action to determine trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
UTL at Dam - Bottom	91210311	Apr 1991 - Present	Operational - LEAP Action to determine trophic status of UTL. FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
R Tamar prior to LTL	91210297	Feb 1992 - Present	FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
Newlands Feeder to LTL	91212415	Feb 1992 - Present	FF directive failure investigation	Monthly	BOD, filtered BOD, nutrients, solids, Chl-a, D.O., temp
LTL at Dam - Surface	91210289	Aug 1991 - Present	Routine Freshwater Fish Directive Site FF directive failure investigation	Monthly	Sanitary (inc solids), metals, D.O., temp (Filtered BOD, nutrients and chl-a Mar 1998)
R Tamar at Footbridge below LTL	91210269	May 1985 - Present	Routine GQA Site RE failure	Monthly	Sanitary (inc solids), metals, D.O., temp (Filtered BOD, nutrients and chl-a Mar 1998)

Appendix 2

List of technical abbreviations.

BOD Biochemical Oxygen Demand

The amount of oxygen used by microorganisms in the process of breaking down organic matter in water. Samples can be filtered to remove particulate matter such as algal cells, thus measuring soluble BOD.

Chl-a Chlorophyll A

A key photosynthetic molecule which is easily measured colourimetrically and gives a quantitative measurement of planktonic algae.

TP Total phosphorus

Soluble and insoluble, organic and inorganic phosphorus forms measured by digesting the sample prior to phosphorus determination.

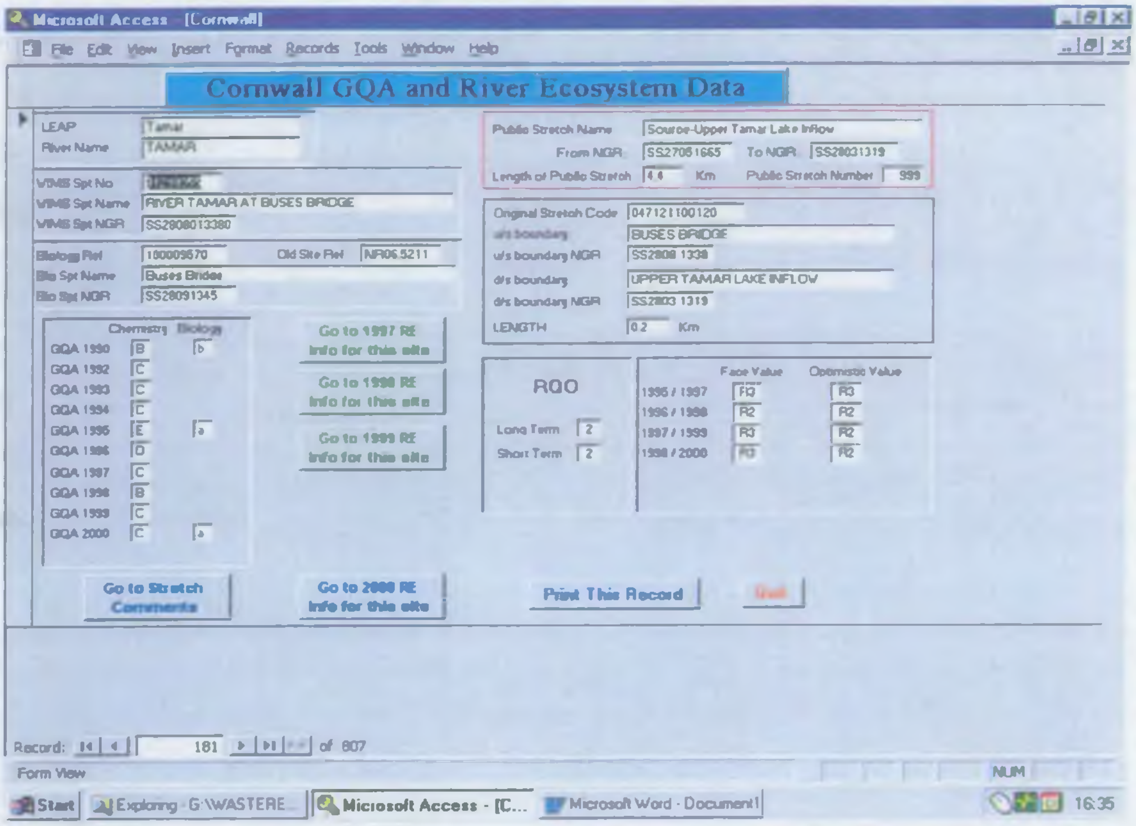
RP Reactive phosphorus

Soluble and labile orthophosphate (PO_4^{3-}).

Appendix 3.

River Quality Objective compliance for a) Buses bridge and b) Lower Footbridge sites.

a) Buses bridge



Cornwall GQA and River Ecosystem Data

LEAP: Tamar
River Name: TAMAR
VIMS Spt No: [redacted]
VIMS Spt Name: RIVER TAMAR AT BUSES BRIDGE
VIMS Spt NGR: SS2808013380
Biology Ref: 100009570
Old Site Ref: NR06.5211
Bio Spt Name: Buses Bridge
Bio Spt NGR: SS28091345

	Chemistry	Biology
GQA 1990	B	b
GQA 1992	C	
GQA 1993	C	
GQA 1994	C	
GQA 1995	E	a
GQA 1996	D	
GQA 1997	C	
GQA 1998	B	
GQA 1999	C	
GQA 2000	C	a

Public Stretch Name: Source-Upper Tamar Lake Inflow
From NGR: SS27061665
To NGR: SS28031319
Length of Public Stretch: 4.4 Km
Public Stretch Number: 999

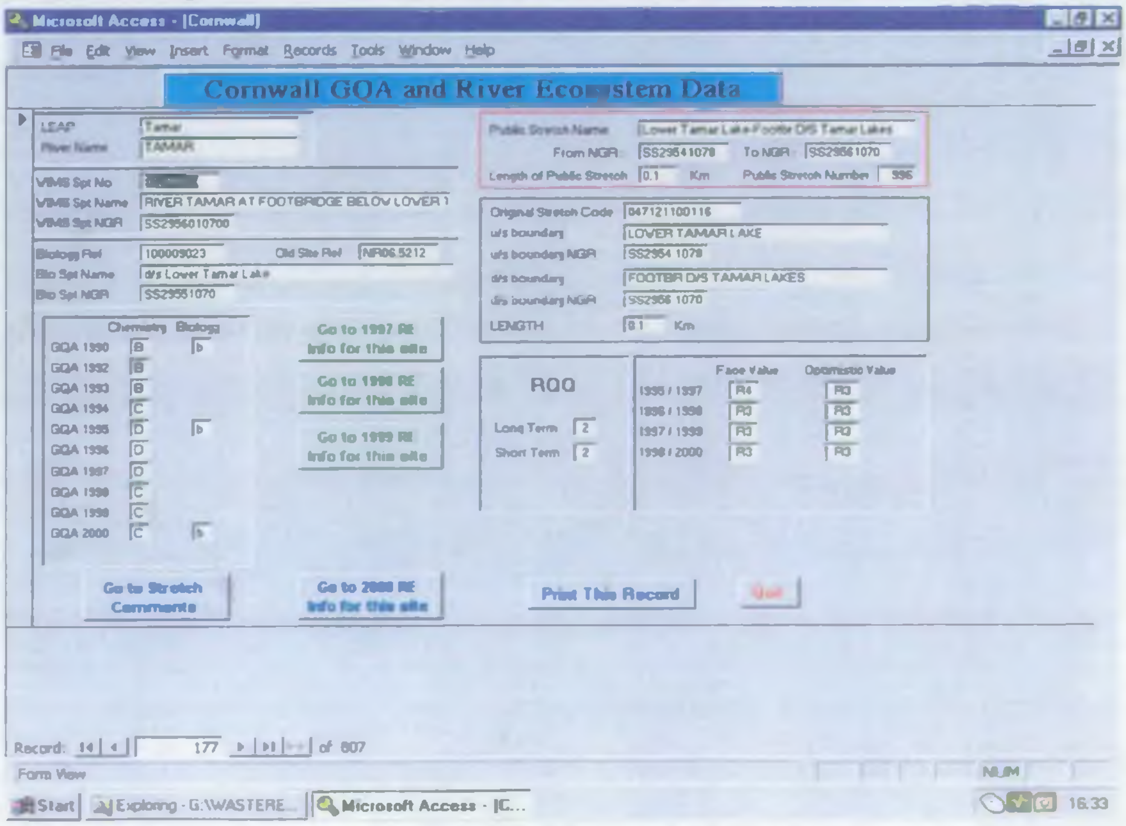
Original Stretch Code: 047121100120
u/s boundary: BUSES BRIDGE
u/s boundary NGR: SS2808 1338
d/s boundary: UPPER TAMAR LAKE INFLOW
d/s boundary NGR: SS2803 1319
LENGTH: 0.2 Km

RQO
Long Term: 2
Short Term: 2

	Face Value	Optimistic Value
1995 / 1997	R3	R3
1996 / 1998	R2	R2
1997 / 1999	R3	R2
1998 / 2000	R3	R2

Record: 181 of 807

b) Lower Footbridge sites



Cornwall GQA and River Ecosystem Data

LEAP: Tamar
River Name: TAMAR
VIMS Spt No: [redacted]
VIMS Spt Name: RIVER TAMAR AT FOOTBRIDGE BELOW LOWER T
VIMS Spt NGR: SS2956010700
Biology Ref: 100009023
Old Site Ref: NR06.5212
Bio Spt Name: d/s Lower Tamar Lake
Bio Spt NGR: SS29551070

	Chemistry	Biology
GQA 1990	B	b
GQA 1992	B	
GQA 1993	B	
GQA 1994	C	
GQA 1995	D	b
GQA 1996	D	
GQA 1997	D	
GQA 1998	C	
GQA 1999	C	
GQA 2000	C	b

Public Stretch Name: Lower Tamar Lake-Footbr D/S Tamar Lakes
From NGR: SS29541078
To NGR: SS29561070
Length of Public Stretch: 0.1 Km
Public Stretch Number: 996

Original Stretch Code: 047121100116
u/s boundary: LOWER TAMAR LAKE
u/s boundary NGR: SS2954 1078
d/s boundary: FOOTBR D/S TAMAR LAKES
d/s boundary NGR: SS2956 1070
LENGTH: 0.1 Km

RQO
Long Term: 2
Short Term: 2

	Face Value	Optimistic Value
1995 / 1997	R4	R3
1996 / 1998	R3	R3
1997 / 1999	R3	R3
1998 / 2000	R3	R3

Record: 177 of 807