# Basingstoke and Deane Borough Council
# Basingstoke Water Cycle Study

## Phase 2 final report
## 2009

# Appendix B

# Water Quality Model Calibration and Validation Report

# Basingstoke and Deane Borough Council

Phase 2 water cycle study

Water quality model calibration and validation report
February 2009

## Halcrow Group Limited

# Basingstoke and Deane Borough Council

Phase 2 water cycle study

Water quality model calibration and validation report
February 2009

## Halcrow Group Limited

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# Basingstoke and Deane Borough Council

Phase 2 Water Cycle Study

## Contents Amendment Record

This report has been issued and amended as follows:

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# 1 Introduction

## *1.1 Objectives of water quality modelling*

As part of the evidence base for the Basingstoke WCS, a detailed water quality assessment was carried out to assess the current water quality in the catchment, and to assess the potential impact of growth on water quality.

To this end water quality modelling was undertaken for the whole of the Loddon catchment, to include the River Loddon (from where it comes out of culvert to the Loddon at Blackwater), Bow Brook and Vyne Stream. This included three Sewage Treatment Works (STW) in the catchment; Basingstoke, Sherfield-on-Loddon and Sherborne St John. Sherborne St John STW discharges to the Vyne Stream, which joins the Bow Brook about 4.5km upstream of the confluence with the Loddon. Approximately 0.5km before the confluence with the Loddon, Sherfield-on-Loddon STW discharges to the Bow Brook. Basingstoke STW is located to the north-east of Basingstoke town, and discharges to the River Loddon approximately 3.5km upstream of the confluence with the River Lyde.

## *1.2 Modelling approach*

For the Basingstoke detailed WCS water quality analysis was undertaken using two modelling packages:

- STAVRoS – a rainfall-driven stochastic model, and;
- ISIS-quality – a semi-deterministic process water quality model.

STAVRoS is a water quality modelling package, which is used to assess the impact of continuous and intermittent discharges on receiving watercourses. The model is rainfall-driven, and includes an urban and rural hydrological response to rainfall. Urban runoff quality is controlled by a build-up and washoff model, whereas diffuse rural runoff is controlled by a stochastic process (based on mean and standard deviation). Discharges from STW are based on the known mean and standard deviation final effluent concentrations. STAVRoS models BOD, ammonia and orthophosphate.

ISIS-quality is an add-on package of the ISIS software. The model is driven by inputs (at flow-time and concentration-time boundaries). ISIS-quality is a full

process based model, and can represent the complex interactions of pollutants in rivers, dissolved oxygen processes and the cycling of nitrogen and phosphorus. The principal pollutants considered in the ISIS-quality model for Basingstoke WCS were:

- ammoniacal nitrogen;
- total oxidised nitrogen (nitrite and nitrate);
- un-ionised ammonia
- pH;
- temperature;
- dissolved oxygen;
- total BOD;
- orthophosphate;
- adsorbed phosphorus, and;
- suspended sediments.

# 2 Model conceptualisation

## *2.1 Conceptualisation of STAVRoS*

### *2.1.1 River reaches*

In STAVRoS rivers are represented by discrete river reaches which receive flow and quality from upstream and diffuse inputs, and route flow and loads to downstream reaches. The river reaches were determined by the location of tributaries and major point source inputs to the rivers. The location of the river reaches are illustrated in Table 1. For each river reach a catchment area was extracted from the FEH CD-ROM.

| River reach in STAVRoS | Location of river reach | Sampling point | Comments |
|---|---|---|---|
| Loddon1 | Loddon at Pyots Bridge to upstream Basingstoke STW | Loddon @ Pyots Bridge | Divided into 2 reaches to reflect change in geology |
| Loddon2 | Basingstoke STW to confluence with Lyde | Loddon @ Blackwater | |
| Loddon3 | Confluence with Lyde to confluence with Bow Brook | Loddon @ Long Bridge | |
| Loddon4 | Confluence with Bow Brook to Loddon (Stratfield Arm) | Loddon @ Stratfield Arm | Sampling point not operating since 2001 |
| Loddon5 | Loddon (Stratfield Arm) to Loddon above Blackwater | Loddon above Blackwater | |
| Lyde | Lyde at Deanland Farm to confluence with Loddon | Lyde @ Deanland Farm | Divided into 2 reaches to reflect change in geology |
| Vyne1 | Head of Vyne to upstream Sherborne STW | | |
| Vyne2 | Sherborne STW to confluence with Bow Brook | Vyne d/s of Sherborne STW | |
| Bow Brook1 | Head of Bow Brook to confluence with Vyne | | |
| Bow Brook1a | Confluence with Vyne to upstream Sherfield STW | Bow Brook @ Bow Bridge | |
| Bow Brook2 | Sherfield STW to confluence with Loddon | | |

**Table 1 Location of river reaches in STAVRoS**

Diffuse runoff quality from the hydrological river catchment in STAVRoS is determined by a stochastic process (based on mean and standard deviation). For the upstream river reaches the assumed runoff quality was based on observed water quality data, where available. Diffuse inputs were added to downstream river reaches during the calibration process to achieve a good calibration against observed data.

*2.1.2* *Urban areas*

To represent runoff from Basingstoke urban area, a runoff unit was conceptualised in STAVRoS. The runoff unit was conceptualised to flow to Basingstoke STW, and flow was then discharged to the Loddon. The catchment area and runoff parameters which contributed to runoff from the Basingstoke urban area was taken from an InfoWorks model of the catchment. The catchment areas used in STAVRoS are illustrated in Table 2. Runoff quality from the urban area is based on a build up/washoff model. The buildup rate is determined by a buildup rate in kg/ha/day. The washoff load is determined by the intensity of rainfall and the washoff rate, and the parameters used are illustrated in Table 2.

| Parameter | Soil Class 1 | Soil Class 4 |
|---|---|---|
| Impermeable area | 25.16 | 10.95 |
| Permeable area | 59.25 | 61.23 |
| Moisture depth parameter | 200 | |
| Effective Impervious Area (IF) | 0.75 | |
| Build up rate (BOD) kg/ha/day | 0.3 | |
| Washoff rate (BOD) mg/l | 900 | |
| Build up rate (Amm) kg/ha/day | 0.02 | |
| Washoff rate (Amm) mg/l | 35 | |

**Table 2 Parameters used to represent urban areas**

DWF for Basingstoke STW was calculated based on the population, consumption, trade and infiltration from an InfoWorks model of the catchment (see Table 3). For both Sherfield and Sherborne there was no information on catchment areas draining to the STW. As a result only the foul flow (DWF) draining to these STW was modelled. The DWF for Sherborne was based on the consented DWF of 1,430m$^3$/day. For Sherfield STW the flow consent is based on Flow to Full Treatment (FFT), and a DWF was back calculated from the FFT consent.

| Parameter | Basingstoke | Sherfield | Sherborne |
|---|---|---|---|
| Population | 96255 | 4740 (assumed) | 3600 (assumed) |

| | | | |
|---|---|---|---|
| Consumption (l/h/d) | 155 | 180 (assumed) | 180 |
| Trade ($m^3$/d) | 13820 | 0 | 0 |
| Infiltration (% of PG) | 0 | 97 (assumed) | 120 (assumed) |
| DWF ($m^3$/d) | 28734 | 1680 (assumed from FFT which is 5,262) | 1430 |

**Table 3 DWF parameters for STAVRoS model**

Foul flow quality is based on a load rate in g/head/day. For BOD this was assumed to be 60 g/h/day, for ammonia 8 g/h/day, and orthophosphate 2 g/h/day. All values were taken from literature for drainage modelling[1].

## *2.2 Conceptualisation of ISIS*

For the ISIS-quality modelling the number of river reaches were increased to improve the representation of water quality processes and stability of the ISIS model. River reaches were conceptualised into discrete units of 1000m or less. Information on bed elevation and channel geometry was assumed from information gathered from map data and site visits.

ISIS is not a rainfall driven model, and therefore all inputs need to be defined through flow-time or concentration-time boundary files. The flow inputs for ISIS were extracted from the STAVRoS model, as was water quality information for BOD, ammonia and orthophosphate. To represent the other pollutants in ISIS upstream quality inputs were specified based on observed data. Further loads were added during calibration to account for additional diffuse pollution from the rural catchment.

Process rates for the water quality modelling were established in the ISIS model based on literature data[2]

## *2.3 Representation of STW final effluent*

The models were conceptualised to have the same flow and quality inputs to ensure consistency between the models. However there was a key difference between STAVRoS and ISIS in the representation of final effluent quality from the three STWs.

---

[1] Butler, D., and Davies, J.W., (2000). Urban Drainage, published by E & FN Spon

[2] George, L., *et al.,* (1985). Rates, Constants and Kinetics Formulations in Surface Water Quality Modelling, U.S. Environmental Protection Agency

- In STAVRoS final effluent is represented by a mean and standard deviation. During a simulation a random pick is taken daily based on the mean and standard deviation. This approach ensures that the model predicts the correct average load from the STW, but cannot represent daily variations in STW performance.

- In ISIS final effluent is represented as a time series. Evidence from the observed data indicated that temporal variations in final effluent quality strongly influenced downstream water quality. Therefore the time series for ISIS used the observed STW sample data, and used a linear interpolation between sample points. The main advantage of this approach is that daily variations in STW performance, and hence water quality impacts, can be represented. This is illustrated in Figure 1.

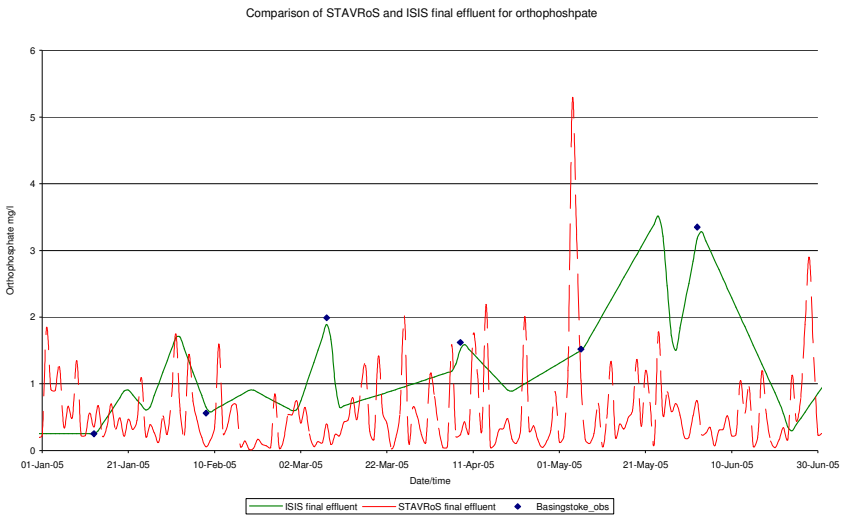



**Figure 1 Representation of final effluent from Basingstoke STW**

# 3 Model calibration

## *3.1* *Sewer calibration*

Flow arriving at Basingstoke STW was calibrated in STAVRoS against the InfoWorks model. As the summary statistics in Table 4 illustrate the runoff generated in STAVRoS closely matched the runoff in InfoWorks.

| | InfoWorks | STAVRoS | % error |
|---|---|---|---|
| Mean ($m^3/s$) | 0.339 | 0.351 | 3.46% |
| 5%ile low flow ($m^3/s$) | 0.184 | 0.169 | -8.07% |
| 99%ile flow ($m^3/s$) | 0.543 | 0.535 | -1.39% |

**Table 4 Calibration of flow arriving at Basingstoke STW**

The primary aim when calibrating sewer quality is to generate realistic and representative quality in both foul flow and stormwater runoff. In STAVRoS average BOD concentrations in foul flow were 200 mg/l, whereas average ammonia concentrations were 25 mg/l. This compares well to literature data, which suggests average BOD should be 200-400 mg/l, and average ammonia should be 30-85 mg/l[3]. Stormwater quality is represented by a buildup and washoff model. During dry weather pollutant loads buildup based on the buildup rate, and when rainfall occurs this load is assumed to be washed off the surface into the sewer.

## *3.2* *River Flow calibration*

River flow was calibrated in STAVRoS, and the final calibration was used as input to the ISIS model. Catchment areas for each river reach were taken from FEH. During calibration parameters which affect the volume and timing of runoff from the catchment were adjusted to achieve a good fit against both mean and 95%ile low flow data, and continuous time series data at Loddon above Blackwater.

Table 5 illustrates the calibration of river flow against observed data throughout the catchment. As shown, for all reaches on the Loddon and Lyde the model predicted both mean and 95%ile flows within 10% of observed data. There is significant uncertainty with regards to the flow estimates on Bow Brook, in particular the 95%ile low flows were not considered representative.

[3] Butler, D., and Davies, J.W., (2000). Urban Drainage, published by E & FN Spon

| River reach name | STAVRoS | | Observed | | % error | |
|---|---|---|---|---|---|---|
| | Mean (m3/s) | 95%ile low flow (m3/s) | Mean (m3/s) | 95%ile low flow (m3/s) | Mean | 95%ile low flow |
| BowBrook1 | 0.352 | 0.127 | 0.281 | 0.001 | 25.10% | N/A |
| Loddon1 | 0.347 | 0.140 | 0.370 | 0.142 | -6.20% | -1.35% |
| Loddon2 | 0.696 | 0.449 | 0.746 | 0.475 | -6.62% | -5.45% |
| Lyde1 | 0.572 | 0.417 | 0.567 | 0.416 | 0.82% | 0.08% |
| Loddon3 | 1.285 | 0.873 | 1.327 | 0.875 | -3.22% | -0.18% |
| Loddon5 | 1.713 | 1.012 | 1.608 | 0.944 | 6.55% | 7.18% |

**Table 5 Comparison of observed and modelled river flows**

In addition to this data the model results at the downstream end of the Loddon were compared to time series data at the same location. The results showed that for the most part the model was able to predict both the timing and volume of peak river flows. The model also predicts the rising and recessing limb of the flow hydrograph well against the observed data, as well as accurately predicting the baseflow in the river. For some storm events the model did under-predict peak flows, but overall the time series results indicate a good flow calibration for the Loddon catchment.

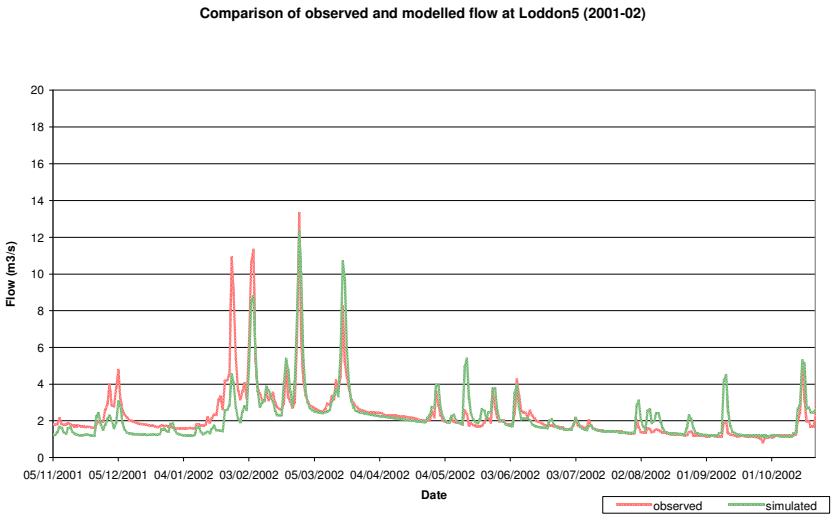



**Figure 2a Illustration of observed and modelled flow on the Loddon**

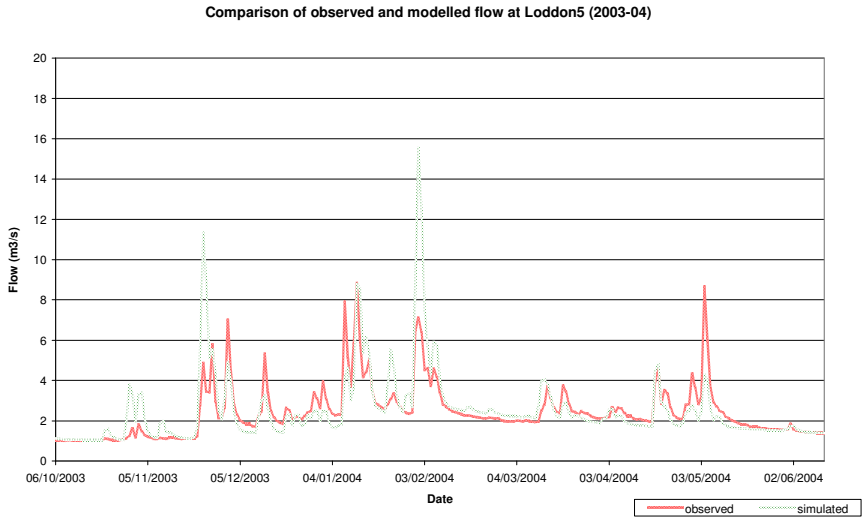



**Figure 3b Illustration of observed and modelled flow on the Loddon**

## *3.3 River quality calibration*

### *3.3.1 STAVRoS*

Initially water quality was calibrated in STAVRoS. The assumed diffuse loads were then extracted as inputs to ISIS. To calibrate water quality in STAVRoS (for BOD, ammonia, and phosphate) upstream quality was assumed to be the same as the nearest sampling point. Model results were then compared to the observed data. Where STAVRoS under-predicted water quality additional load was added to the model until a good calibration was achieved. Similarly where STAVRoS over-predicted water quality decay was added to the model to achieve a good calibration.

As shown in Appendix A the STAVRoS model was very well calibrated against the observed sampling data. For most reaches predicted water quality was within 5% of the observed sampling data. The only exceptions to this were:

- BOD – Vyne downstream of Sherborne STW and Loddon at Long Bridge under-predicted by 6% and 10%, respectively;
- Ammonia – Loddon at Blackwater over-predicted by 6%, and;
- Phosphate – Bow Brook at Bow Bridge over-predicted by 14%, and Loddon at Long Bridge under-predicted by 7%.

For all reaches the model predicted water quality in the same WFD classification as the observed data.

*3.3.2* *ISIS*

The diffuse sources of pollution for BOD, ammonia and phosphate were extracted from STAVRoS and added as concentration-time boundaries to the ISIS model. For the additional pollutants modelled in ISIS, but not in STAVRoS, concentration-time boundary files were created for all the upstream inputs (i.e. upstream of Loddon, Lyde, Bow Brook and Vyne Stream) and for the inputs from Basingstoke, Sherfield and Sherborne STWs, based on available observed data. Process rates including decay, nitrification, denitrification, adsorption were adjusted in ISIS to achieve a good calibration against the observed data for all pollutants.

Appendix A illustrates the calibration of ISIS for all pollutants modelled. The results indicate overall a good calibration was achieved for the majority of pollutants. However, as ISIS is a process-based water quality model the calibration does not match observed data as closely as STAVRoS, where calibration can be achieved by adjusting diffuse pollution and decay.

The calibration of BOD in ISIS is excellent at three of the four sampling points along the Loddon. Immediately downstream of Basingstoke STW the model over-predicts BOD by approximately 30%, but the model predictions remain in the same WFD classification as the observed data. ISIS under-predicts BOD in Bow Brook and the Vyne by 15% and 20%, respectively. In Bow Brook the model predicts BOD to be in the same WFD classification (high) as the observed data. However, due to the under-prediction on the Vyne ISIS predicts the river to be in good ecological status for BOD, whereas the observed data indicates it is currently moderate. As a result caution should be applied when using ISIS to predict consents from Sherborne STW to meet WFD standards.

As ISIS represents the interaction between BOD and DO the model under-predicts DO where BOD is over-predicted, and vice versa. However the ISIS model predicts DO within 10% of the observed data at all reaches except downstream of Basingstoke STW (-20%) and on the Bow Brook upstream of Sherfield (+17%).

ISIS represents the nitrogen cycle, and thus the calibration should consider the four major pollutants; ammoniacal nitrogen, un-ionised ammonia, nitrite and

nitrate. On the Vyne, Bow Brook and Lyde the predicted total ammonia predicts very well against the observed data. On the Loddon the model over-predicts Ammoniacal nitrogen at the Keepers Cottage and Blackwater sampling points. For all the sampling points ammoniacal nitrogen is predicted to be in the same WFD classification (high) as the observed data. Un-ionised ammonia is formed from total ammonia when pH and temperature conditions permit. As temperature and pH[4] increase the amount of un-ionised ammonia also increases. ISIS under-predicts un-ionised ammonia along the middle reaches of the Loddon, and this is mainly because temperature in these reaches is also under-predicted. However, in all reaches the predicted and observed un-ionised ammonia is significantly lower than the 90% target for RE1-RE3 reaches (0.021 mg/l).

Nitrites are formed due to oxidation of Ammoniacal nitrogen. Further oxidation leads to the production of nitrates. Predicted levels of both nitrite and nitrate in all river reaches compare well against the observed sampling data. Both nitrites and nitrates are over-predicted in the lower reaches of the Loddon and at the Vyne (downstream of Sherborne STW), but the overall calibration of total oxidised nitrogen (sum of nitrite and nitrate) is considered to be satisfactory.

Orthophosphate in ISIS is well calibrated against observed data in all of the river reaches. At the sampling point at Keepers Cottage the predicted orthophosphate is less than the observed data. However at this sampling point there is one high sample (1.82 mg/l) which causes the mean to be skewed. As discussed, daily variations in STW performance appear to significantly influence the downstream water quality in the Loddon. This was particularly evident for orthophosphate, and the assumed concentration-time boundary was based on observed sampling points, and linearly interpolated between these points. As illustrated in Appendix A modelling the temporal variations in STW discharge allow calibration of water quality against specific samples, as well as against the summary statistics of samples.

In the ISIS model the presence of suspended solids is important in the phosphate cycle, as orthophosphate is adsorbed to sediment particles to form adsorbed phosphorus. Generally, the model predicts suspended solids well compared to the observed data, but there is some over-prediction in the Loddon at Long Bridge and Blackwater.

[4] For all sampling points the model predicts mean pH within 2% against observed data

# 4 Conclusions

For the detailed water cycle study two water quality models of the Loddon catchment were conceptualised and calibrated. STAVRoS is a rainfall-driven model which uses stochastic processes to generate water quality from the urban and rural catchments. ISIS-quality is a process-based water quality model, and is able to model a wider range of pollutants and represents in-river water quality processes.

Given that STAVRoS and ISIS represent fundamentally different approaches to water quality modelling there were inevitably differences in the conceptualisation and representation. However, as far as was possible, differences in the models were kept to a minimum, and any differences were due to the different approaches within the software.

The calibration of STAVRoS was excellent for BOD, ammonia and phosphate. To achieve a good calibration in STAVRoS diffuse loads were added where appropriate, and simple first order decay was used to reduce in-river loads.

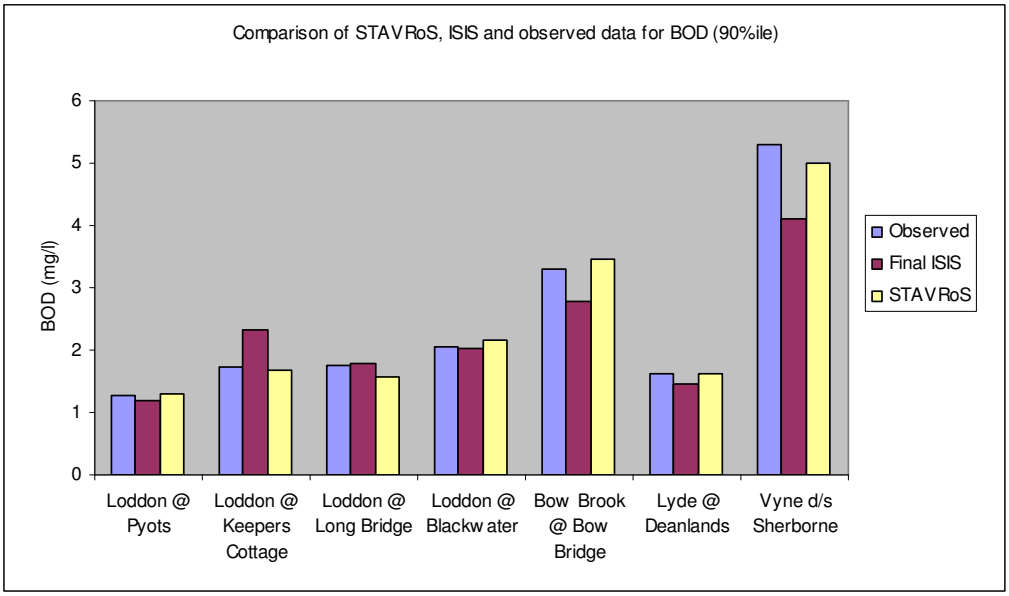
ISIS is a process-driven model, and represents the interaction between pollutants (e.g. BOD-DO, and nitrogen cycle). Overall, the calibration of water quality against observed data was satisfactory and the model was considered fit for purpose.

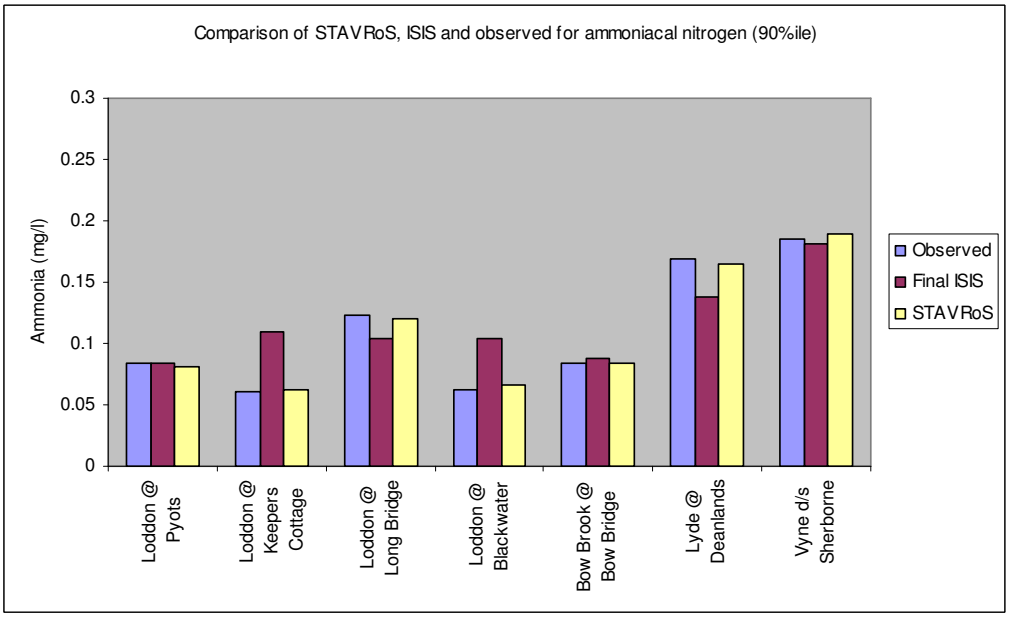
The table below summarises the main features of STAVRoS and ISIS and illustrates their potential uses for water quality modelling

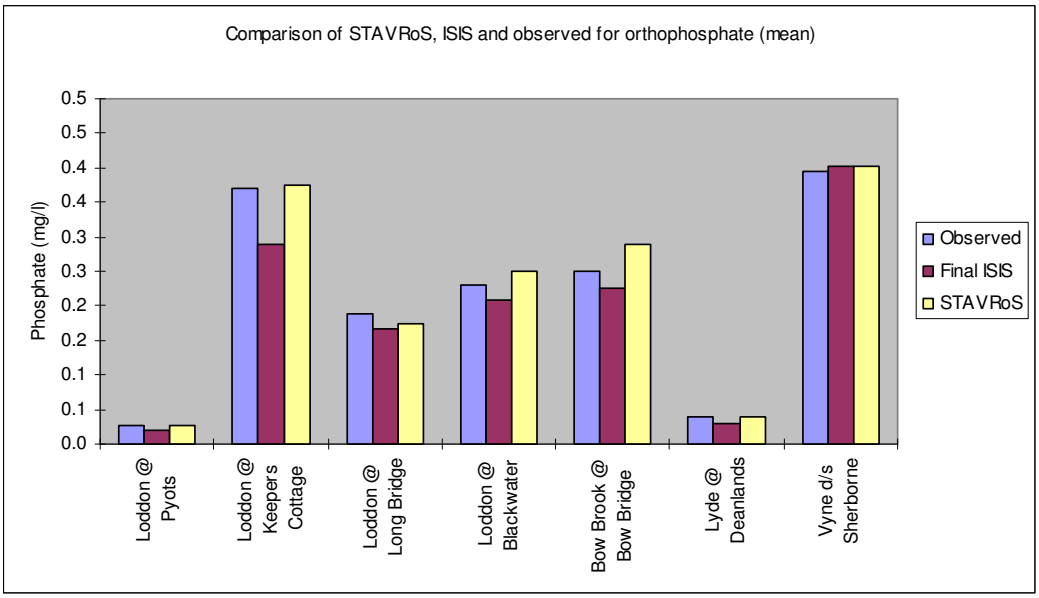
| Model | Advantages | Disadvantages |
|---|---|---|
| ISIS | • Represents interaction between pollutants<br>• Represents time of travel in rivers<br>• Includes broader range of pollutants<br>• Represents temperature and can therefore examine summer/winter effects and effects of climate change<br>• Suitable for representing temporal variations in STW final effluent and impact in quality | • Cannot generate urban runoff or storm overflows within the modelling software<br>• Calibration not as close as with other software which use more black-box approaches<br>• Complex modelling approach which requires large modelling effort to conceptualise and calibrate |
| STAVRoS | • Rainfall-driven model | • Calibration achieved by adding loads from |

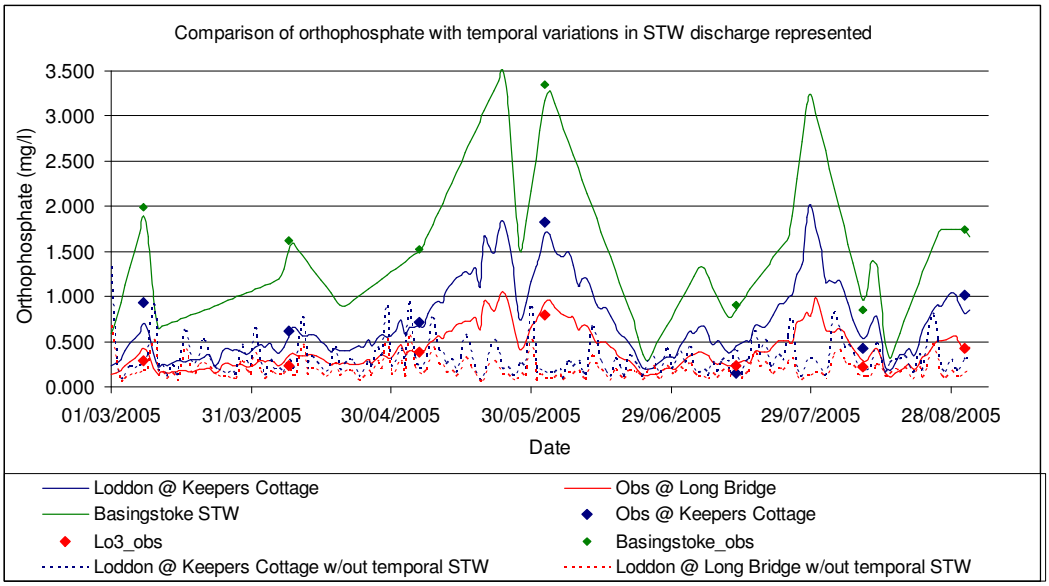
| | | |
|---|---|---|
| | • Generates urban runoff flow and quality<br>• Can represent storm tank overflows and impacts on watercourses<br>• Simplified model – simple to conceptualise and calibrate<br>• Suitable for assessing likely consents at STW | 'diffuse' sources or adjusting decay rates<br>• Does not represent interaction between pollutants<br>• Represents STW final effluent as mean and standard deviation, therefore cannot represent the impact of temporal variations |

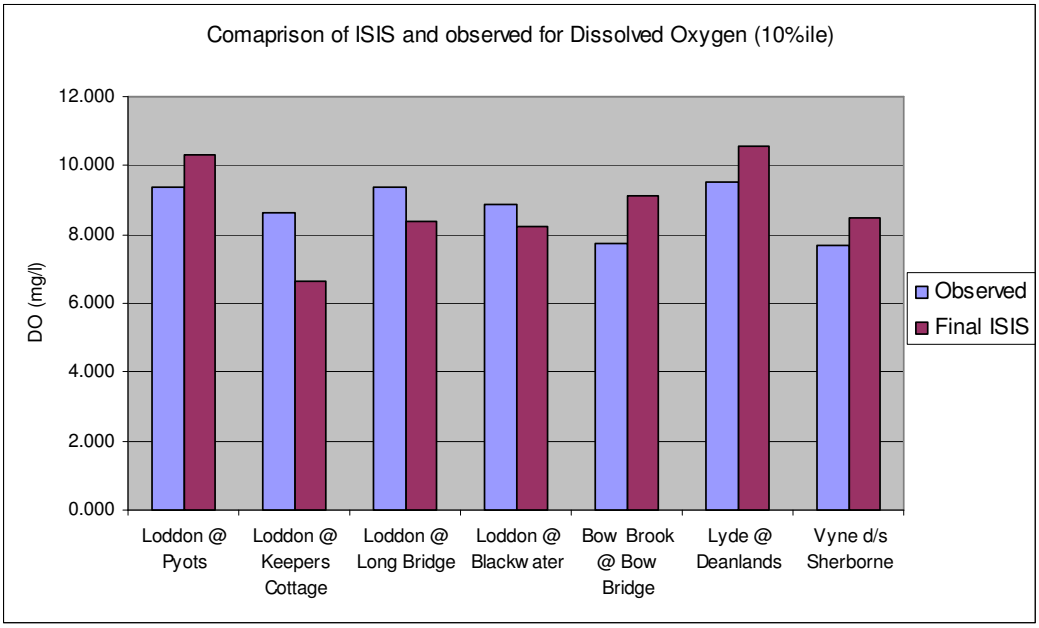
# A Water quality calibration graphs

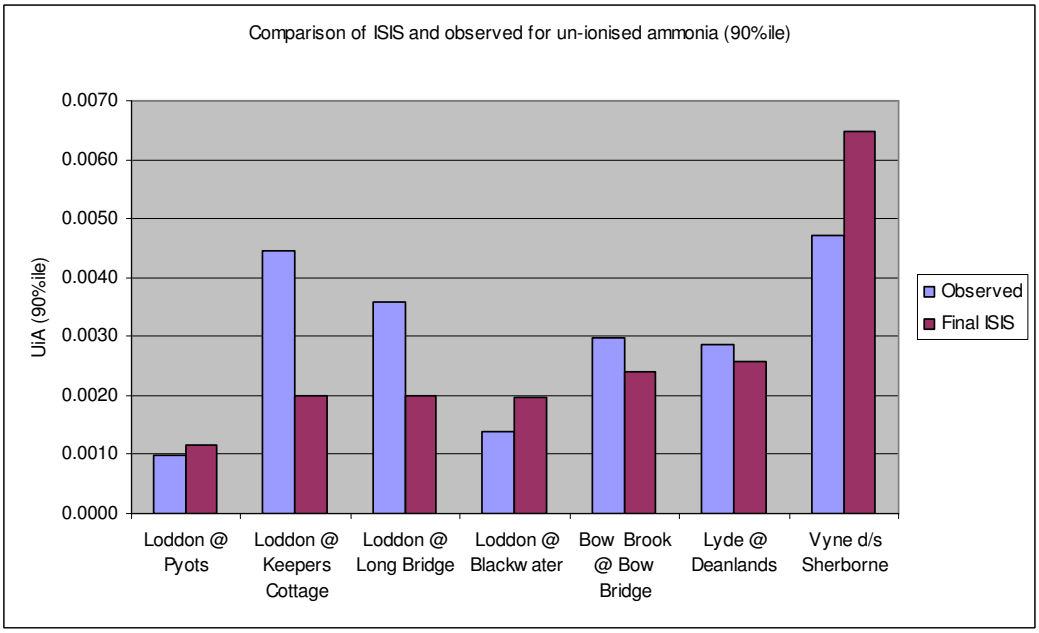


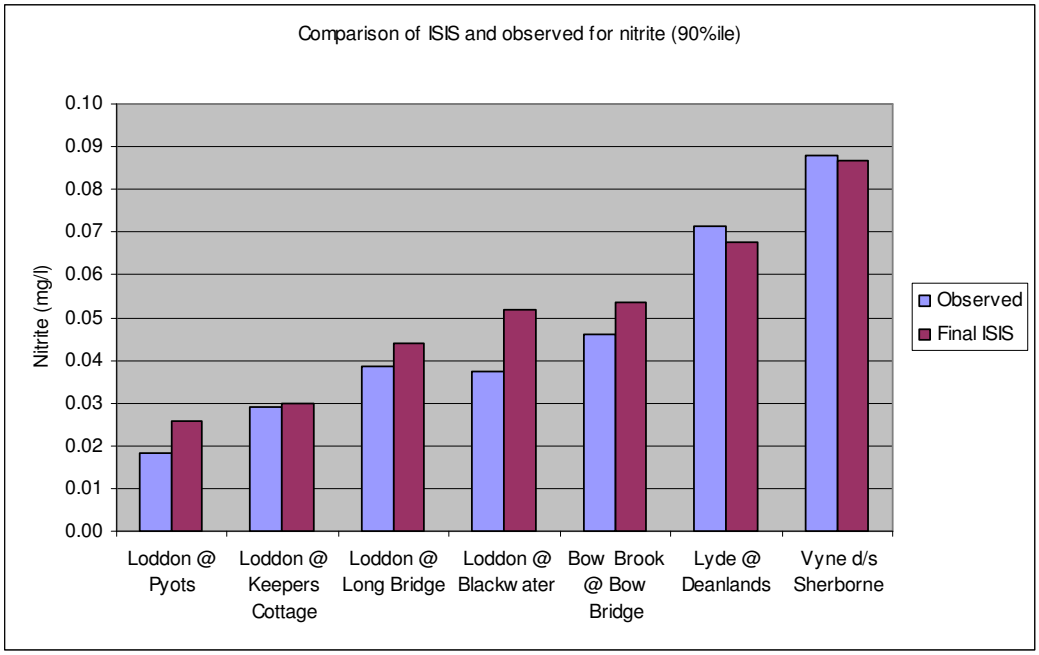



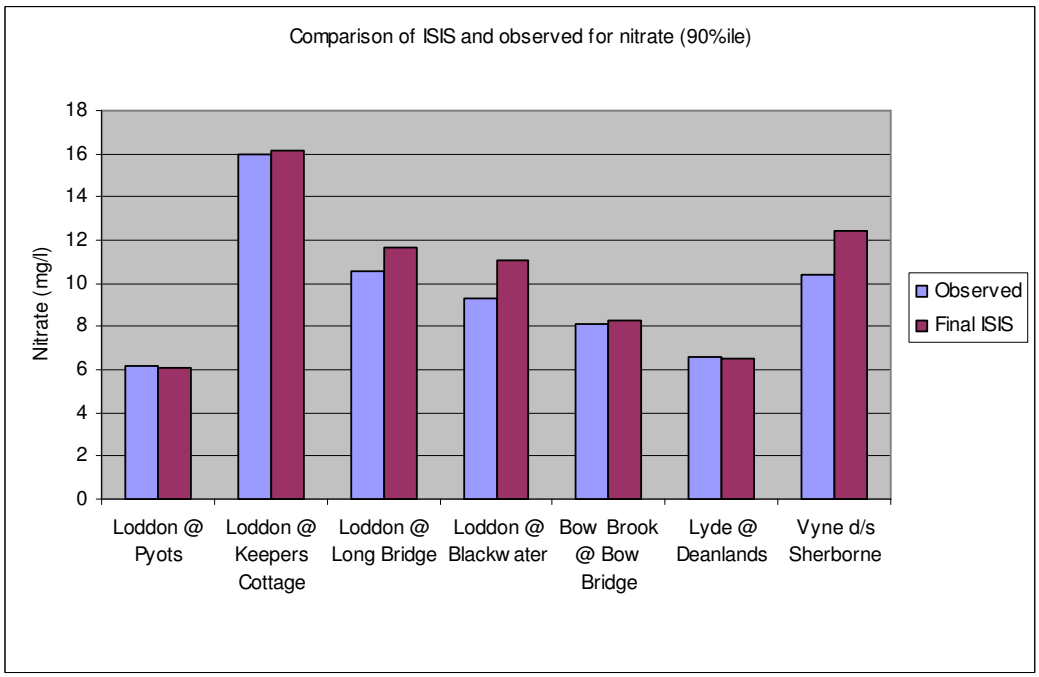

Comparison of STAVRoS, ISIS and observed for orthophosphate (mean)
Phosphate (mg/l)
0.5
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackwater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS
STAVRoS

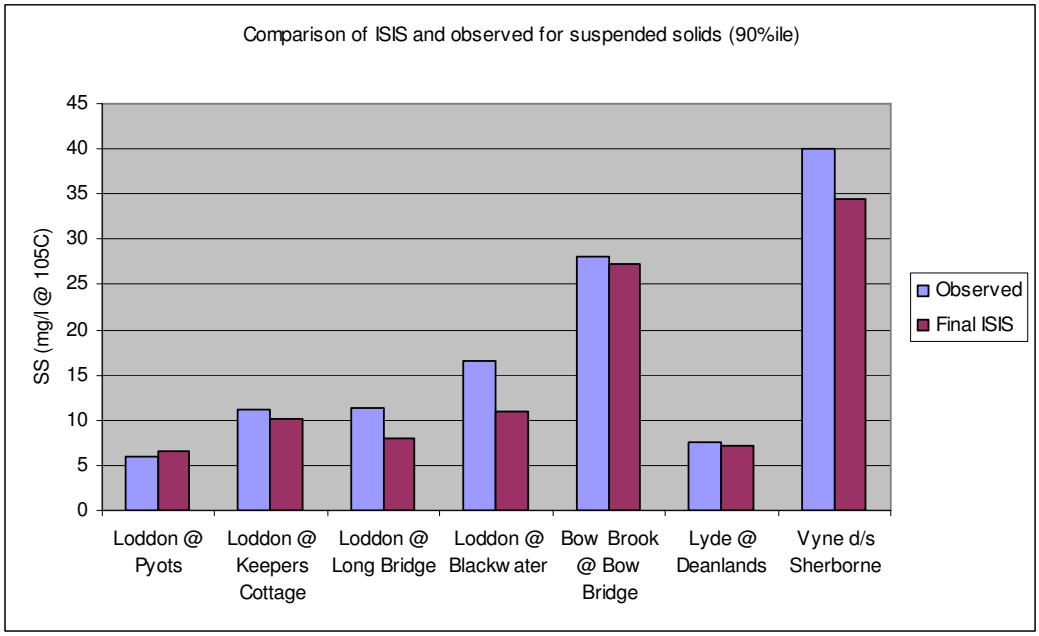

Comparison of orthophosphate with temporal variations in STW discharge represented
Orthophosphate (mg/l)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
01/03/2005
31/03/2005
30/04/2005
30/05/2005
29/06/2005
29/07/2005
28/08/2005
Date
Loddon @ Keepers Cottage
Basingstoke STW
Lo3_obs
Loddon @ Keepers Cottage w/out temporal STW
Obs @ Long Bridge
Obs @ Keepers Cottage
Basingstoke_obs
Loddon @ Long Bridge w/out temporal STW

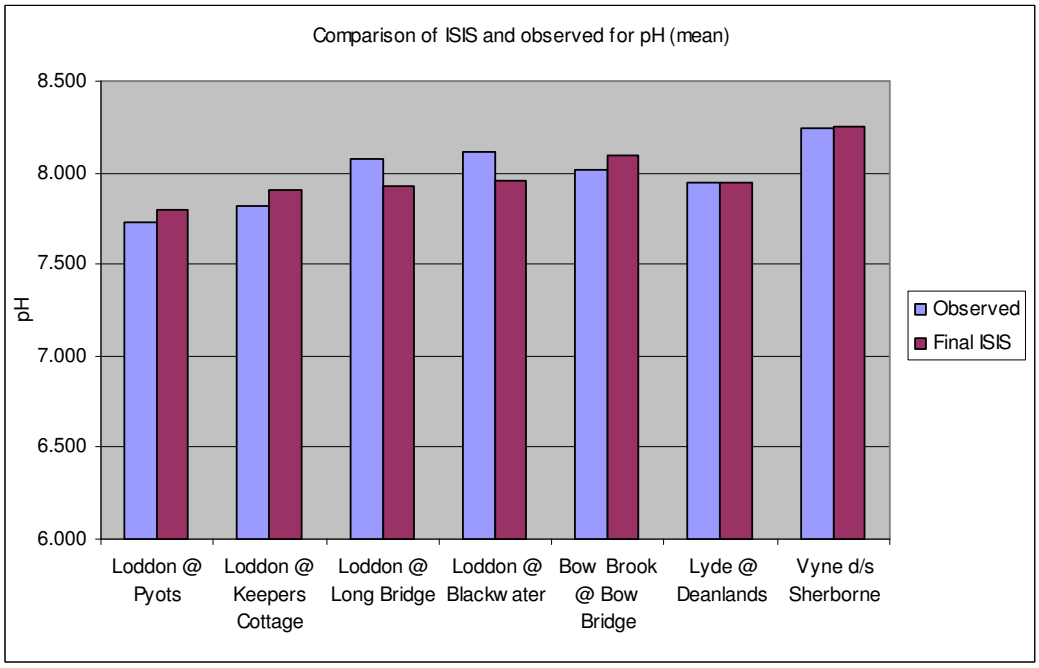

Comaprison of ISIS and observed for Dissolved Oxygen (10%ile)
DO (mg/l)
12.000
10.000
8.000
6.000
4.000
2.000
0.000
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS

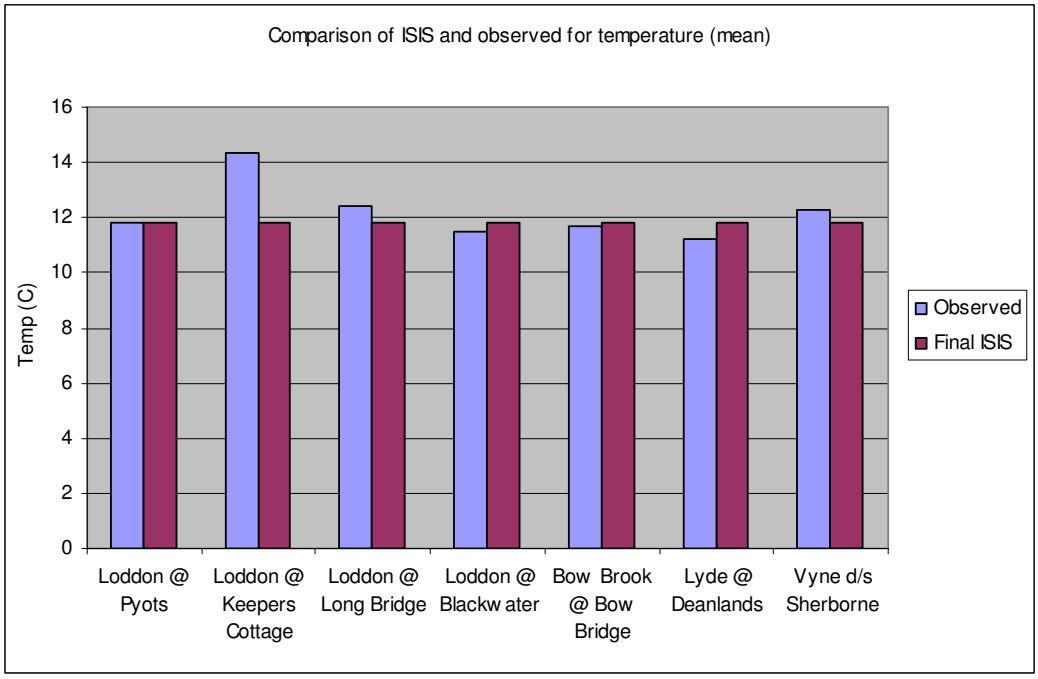

Comparison of ISIS and observed for un-ionised ammonia (90%ile)
UiA (90%ile)
0.0070
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS


Comparison of ISIS and observed for nitrite (90%ile)
Nitrite (mg/l)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS


Comparison of ISIS and observed for nitrate (90%ile)
Nitrate (mg/l)
18
16
14
12
10
8
6
4
2
0
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS


Comparison of ISIS and observed for suspended solids (90%ile)
SS (mg/l @ 105C)
45
40
35
30
25
20
15
10
5
0
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS


Comparison of ISIS and observed for pH (mean)
pH
8.500
8.000
7.500
7.000
6.500
6.000
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS


Comparison of ISIS and observed for temperature (mean)
Temp (C)
16
14
12
10
8
6
4
2
0
Loddon @ Pyots
Loddon @ Keepers Cottage
Loddon @ Long Bridge
Loddon @ Blackw ater
Bow Brook @ Bow Bridge
Lyde @ Deanlands
Vyne d/s Sherborne
Observed
Final ISIS