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Efficacy of Anglian Water's Slug-it-Out Scheme

Review of the water quality evidence from the first two years of the scheme

Authors: **Greg Smith (University of Exeter)**

Brett Day (University of Exeter)

Ruth Welters (University of East Anglia)

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Summary

The Slug-it-Out Scheme

Slug-it-Out is a payments for ecosystem services (PES) scheme developed by Anglian Water with help from the Universities of Exeter and East Anglia. The scheme's objective is to eliminate raw water pollution problems resulting from agricultural application of the slug pesticide metaldehyde.

The first year of the Slug-it-Out scheme ran over the autumn and winter of 2015/16 (henceforth, 2015) and focussed on farmers in the natural catchments of six Anglian Water reservoirs; Pitsford, Hollowell, Ravensthorpe, Alton, Ardleigh and Grafham. In the second year of the scheme (2016), Rutland Water was also included.

Slug-it-Out was implemented through an intensive programme of engagement in which farmers were offered payments in return for a commitment to stop using metaldehyde. The scheme pioneered an innovative format for those payments that combined a;

- *participation payment* paid to all farmers joining the scheme
- *product substitution payment* that covered the additional costs of switching to an alternative slug pesticide (ferric phosphate), and
- *performance bonus* received only if raw water quality was observed to improve to a level conforming with regulatory standards.

Over its first two years, Slug-it-Out trial achieved remarkable success in engaging farmers; indeed, every eligible farmer in each of the trial catchments joined the scheme and committed to stop using metaldehyde. In 2015, for example, an estimated 1,613 kg of metaldehyde was removed from the farmed landscape. The purpose of the report summarised here, however, is to assess the degree to which that engagement translated into delivery on the scheme's primary objective; the delivery of improvements in raw water quality.

Measuring Metaldehyde Pollution

To build an evidence base from which to assess the efficacy of the scheme, Slug-it-Out was accompanied by a detailed programme of water quality sampling and testing. Regular measures of metaldehyde concentrations (reported in µg/l or parts per billion) were made in the year preceding the scheme and throughout the 2015 and 2016 trials, samples being taken

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from (a) the feeder streams that drain each reservoir's natural catchment and (b) river offtakes outside the natural catchments where water is abstracted to replenish each reservoir.

Frequent measurements were made at each sampling location, though to provide consistent data series that might be compared across sampling locations, the analyses reported in this document are based on an interpolation of the raw data which uses the observed measurements to 'fill in' the likely concentration levels for each day of the risk period (defined as the 184 days from 1st August to 31st January).

While the concentration data provides the core statistics upon which the assessment of the efficacy of Slug-it-Out is based, the report also makes use of two other measures of pollution.

First, the data series at each sampling location are examined to see whether the scheme has had any impact on the frequency of occurrence of 'pollution events'. We define pollution events as spikes in raw water concentrations in which the levels of metaldehyde pollution exceed the 0.1µg/l regulatory standard imposed on drinking water.

Second, a program of hydrological modelling was undertaken in order to estimate a time series of flow data through the natural catchment feeder. Multiplying flow by metaldehyde concentrations provides an estimate of the quantity of metaldehyde entering the reservoir through a sampling point. These 'flux' measures actually capture the key quantity of concern for Anglian Water; that is to say, the rate at which the natural catchment is contributing to pollution levels in Anglian Water reservoirs. Calculation of measures of metaldehyde flux complete the picture of raw water pollution at any sampling point.

Testing for the Impact of Slug-it-Out

Establishing the impact of the Slug-it-Out scheme requires differentiating changes resulting directly from the scheme from other factors that might concurrently impact on metaldehyde pollution levels (for example, crop rotation or weather patterns). To that end, this report adopts a classic experimental approach based on comparing test cases with control cases. In this study, the test consists of measures of metaldehyde pollution taken from sampling locations in the natural catchments during the Slug-it-Out trials in 2015 and 2016. Those measures can be compared to two possible controls, namely;

- *Control A*: the same sampling points in the year previous to the trial (2014 for all reservoirs except for Rutland where the control year is 2015). While these measures provide perfect geographic control ensuring comparisons are not skewed by

differences in the characteristics of each catchment, they fail to provide temporal control. Differences in the weather between the test and control years, for example, might result in divergence between the test and control measures of pollution.

- *Control B*: sampling points in the river offtakes used for reservoir replenishment over the same period as the test measures in the natural catchments. Since each river offtake draws water drained from land that is close to, but outside the reservoir's catchment, these measures provide an approximate geographic control and also a reasonable temporal control.

Findings

As might be expected, the data series for the 10 natural catchment feeder streams in the 7 reservoirs and the 7 river abstraction locations that act as controls show quite varied patterns of metaldehyde pollution measurements. Figure A, for example, shows the metaldehyde concentration data for Pitsford Water in 2014 and in the two years of the trial (2015 & 2016).
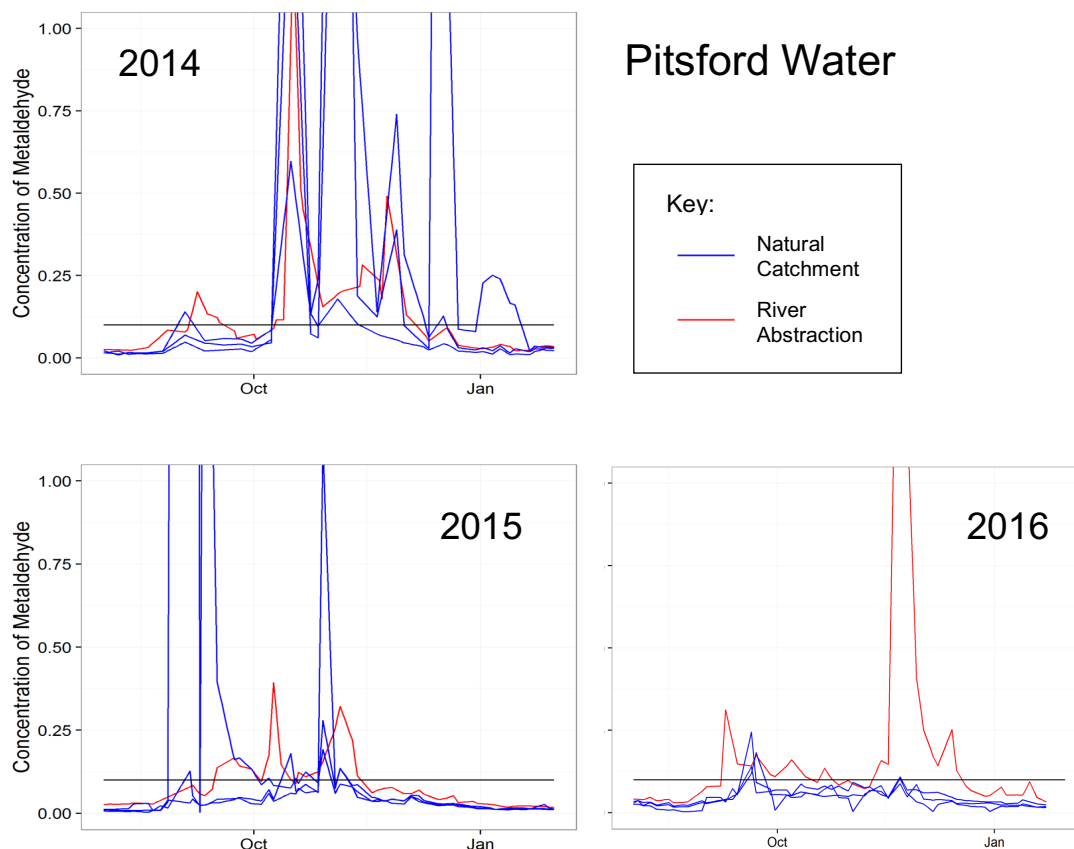

Figure A: Metaldehyde concentration times series for Pitsford Water prior to Slug-it-Out (2014) and in the first two years of the scheme (2015 and 2016)

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What is very clear from the Pitsford data is that there are some rather significant changes in the patterns of metaldehyde pollution over the three years. In 2014, the year before Slug-it-Out, we observe significant pollution spikes both in the three reservoir feeder streams draining the natural catchment (blue lines) and in the River Nene abstraction location outside the reservoir catchment (red line). Indeed, the horizontal line drawn on the graph at the 0.1µg/l level of concentrations shows that the raw river water both in and outside the Pitsford catchment breeches the regulatory standard for drinking water on numerous occasions. In the first year of the scheme, 2015, there are still breeches of the 0.1µg/l level both within and without the natural catchment, but in both cases the frequency of those breeches has reduced substantially.[1] In 2016, the concentration data in the natural catchment shows a uniform fall, with only the occasional and marginal breech of the 0.1µg/l level. Importantly, the opposite pattern is shown in the 2016 data for water quality outside the Pitsford catchment. Indeed, it is that pattern of falling pollution within the natural catchment where the Slug-it-Out scheme has been implemented coupled with rising metaldehyde pollution in river water drained from areas outside the scheme which provides the strongest evidence of an independent impact of the scheme on water quality.

The main report provides a detailed analysis of the water quality data series for each reservoir. For the purposes of this summary, however, we aggregate the data across all seven reservoirs in Slug-it-Out so as to provide an overview of the overall efficacy of the scheme.

Considering first the aggregated data on the frequency of pollution events (breeches of the 0.1µg/l level) we observe a pattern very similar to that already described for the specific case of Pitsford Water. In the year before Slug-it-Out (2014) our interpolation of the data suggests that the 0.1µg/l level was exceeded for some 19% of the risk period. To be clear, that means 19% of the interpolated concentration measurements taken from each of the natural catchment feeder streams for the Slug-it-Out reservoirs was above the 0.1µg/l level. Removing the interpolated measures and focusing on just the raw sample observations that percentage is a little lower, 15%. In the first year of the scheme, 2015, exceedances in the natural catchment feeder streams falls to 11% in the interpolated data (and 10% for raw sample observations) before falling further to just 5% in the interpolated data (and 3% for

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[1] Detailed follow-up work from the Anglian Water farm engagement team managed to pinpoint the causes of the pollution events within the natural catchment, which hailed from inappropriate handling of metaldehyde on farm premises rather than application of the pesticide in the Pitsford catchment.

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raw sample observations). Accordingly, we observe between a four- or five-fold decline in metaldehyde pollution events associated with introduction of the Slug-it-Out scheme.

While that finding is certainly promising, it does not on its own prove an independent effect of Slug-it-Out. It remains possible that the reduction in pollution events is merely an artefact of general trends in farming or differences in conditions from 2014 to 2016 that happen to coincide with the introduction of Slug-it-Out. To test that hypothesis, we turn to the control data measuring the frequency of exceedances in rivers located near to the reservoirs but outside the Slug-it-Out scheme. Again using aggregated data we observe 41% exceedances in 2014, 27% in 2015 and 40% in 2016 (the equivalent figures for the raw sample observations are 46%, 28% and 47% respectively). Observe, that the same pattern in the aggregated data mirrors that seen in the Pitsford data when examined on its own; pollution events decline in 2015 but increase again in 2016. The fact that pollution events increase in 2016 in areas outside the Slug-it-Out scheme but decline in areas inside the scheme is strong evidence for a substantive impact of the scheme on metaldehyde pollution.

Figure B allows a more detailed examination of the aggregated concentration data. The data here are presented in terms of the proportion of days during the risk period in which the measurements exceeded each level of concentration. Reading from the left, the graph starts with a concentration level of 0 and, not surprisingly, at that concentration the lines, plotting data for the natural catchments and the river abstractions in each year, record a value of 1. In other words, for every day of the risk period concentrations were at least zero. Moving along the x axis the concentration levels increase and the lines plot out the proportion of days in which levels of pollution of that concentration or greater were observed. Of course the lines fall from left to right because at each progressively higher level of pollution we have fewer days in which that level was exceeded. While the graph in Figure B is truncated at a concentration of at 0.5μg/l, if we were to progress out to ever higher concentrations we would find that each of the lines eventually falls to zero at the peak concentration observed for those sampling points.

The advantage of this presentation of the data is that if provides a simple way to compare the data across treatments. For example, the vertical dashed line highlights the 0.1μg/l level of metaldehyde concentration that we take to represent a pollution event. Scanning vertically up this line we see that there were 19% exceedances of that pollution concentration in the natural

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catchments in 2014, 11% in 2015 and 5% in 2016; which of course is the data discussed previously.

Figure B: Aggregated metaldehyde concentration data

Looking at the blue lines in Figure B, notice that within the natural catchment the 2015 line (dashed) always lies below the 2014 line (solid). That indicates that 2015 (the first year of SiO) was a categorically better year for metaldehyde pollution than 2014. That same pattern repeats itself for concentrations in the river abstraction sampling locations outside the Slug-it-Out scheme; again, the red dashed line for 2015 is always below the red solid line for 2014. Since both the control and the test show a reduction in metaldehyde in 2015 compared to 2014 that comparison fails to distinguish between the hypothesis that Slug-it-Out was responsible for reductions in metaldehyde in the reservoir natural catchments or the alternative that 2015 was, for example, just a generally low pressure year for slugs and hence lower metaldehyde use.

Figure B also plots the data for 2016. The proportion of days with high metaldehyde levels in 2016 in the natural catchments (blue dotted line) is generally lower than those seen in 2014 and 2015 in the natural catchments. In other words, it is not just the number of high pollution events that had declined in streams draining the Slug-it-Out reservoirs but a general fall in pollution concentrations in the natural catchments of those reservoirs.

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Notice also that the data for 2016 for river abstractions from outside the Slug-it-Out catchments increases across the range of concentrations when compared to the 2015 observations at those same locations. Our interpretation of this data is that across the wider farmed landscape metaldehyde pollution worsened from 2015 to 2016, a trend that was reversed in areas participating in the Slug-it-Out scheme where metaldehyde pollution levels showed substantial falls. While it is impossible to make definitive statements, there is very good reason to believe that the improvements in water quality in the natural catchments of the Slug-it-Out reservoirs can be directly attributed to the changes in farm practices brought about by the Slug-it-Out scheme.

The final set of pollution measurements examined in the report concern measures of metaldehyde flux; that is to say, measures of the quantities of metaldehyde transported from the natural catchments into the reservoir through the feeder streams. Again, for the purposes of this summary we aggregate the flux data over all Slug-it-Out reservoirs. Again the data describe a very clear trend. In 2014, the year before the scheme, some 463.7g of metaldehyde entered the reservoirs from the natural catchments. In the first year of the scheme, 2015, that figure fell to 113.6g and fell further still in 2016 to 32.8g.

To understand the significance of that 93% fall in metaldehyde export to the reservoirs consider the data just for Pitsford Water. Imagining that the 17.5 mill m^3 reservoir began today without any metaldehyde pollution then at the rate of metaldehyde export from the natural catchment seen in 2014 (and presuming no replacement of water or decay of metaldehyde in the reservoir) then it would take just over 9 years for metaldehyde pollution of the Pitsford reservoir to accumulate to a level that exceeded the 0.1μg/l regulatory threshold. Taking the levels of export seen in 2016 under the Slug-it-Out scheme the period of accumulation required to reach that same threshold is 270 years.

Conclusions

Analysis of water quality data associated with the Slug-it-Out scheme provides strong and convincing evidence to support the contention that the scheme has delivered very substantial reductions in the quantity of metaldehyde being exported from the natural catchments of Anglian Water reservoirs to the reservoirs themselves. Our best estimates suggest that compared to the base year of 2014, the Slug-it-Out scheme of 2016 delivered a 74% reduction in the frequency of pollution events exceeding the 0.1μg/l level in the reservoir's natural catchments and a 93% reduction in the quantities of metaldehyde entering the reservoirs from those natural catchments.

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Introduction

This report provides an update on the effectiveness of Anglian Water's Slug-it-Out (SiO) scheme for 2015/16 (henceforth 2015) and 2016/17 (henceforth 2016).

The data upon which this analysis is based consists of a times series of measurements of metaldehyde concentrations observed in samples taken from water courses feeding 6 reservoirs over the course of 2014 (the year preceding the scheme), 2015 and 2016. Five of those reservoirs were in the 2015 SiO scheme while the sixth, Rutland Water, only entered the scheme in 2016.

For each reservoir the data records water quality in two different types of feed to the reservoir. The first are measurements taken from water courses draining the NC of the reservoir; that is, draining land that has been included in the SiO scheme. We describe these as Natural Catchment (NC) measurements. The second are measurements taken from rivers near to the reservoir from which water is abstracted to replenish the reservoir. These rivers are not fed by the NC of the reservoir and hence the land they drain, while in the same region, is not included in the SiO scheme. We describe these as river abstraction (RA) measurements.

The data allows us to make numerous comparisons each of which provide insights into the effectiveness of the SiO scheme. One comparison is to contrast measurements from the NC in each reservoir the year before SiO with measurements in the two years of the scheme. That comparison perfectly controls for the individual characteristics of each catchment but may be subject to temporal confounding. A second comparison is to contrast measurements from the NC of the reservoirs in the scheme in 2015 with those in Rutland Water which was not in the scheme. That comparison controls well for temporal issues, but may be confounded by the differing characteristics of the catchments being compared. A final set of comparisons contrast measurements from each NC with those from the nearby RA location. While there are some differences in the nature of the water courses in the NC and at the RA location, this comparison does a reasonable job of controlling for both spatial and temporal confounding. While no one comparison has the characteristics of a perfect experiment, each has its merits. We intend to examine all three forms of comparison in building up the weight of evidence to support or refute an impact of the SiO scheme on levels of metaldehyde pollution in Anglian Water reservoirs.

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To measure the effectiveness of the scheme we examine information from the NC of each of the six reservoirs in the SiO scheme using both metaldehyde concentration data and estimates of metaldehyde 'flux'. While identifying the level of metaldehyde pollution in the streams and rivers feeding the reservoirs, the concentration data does not provide a clean picture of the quantity of pollution reaching the reservoir. For example, high metaldehyde concentrations in a low flow river may bring relatively little pollution to the reservoir while low concentrations in a high flow river might be delivering large quantities of metaldehyde to the reservoir. To account for this potential confounding, we combine the metaldehyde concentration data with estimated daily flows to give a measure of metaldehyde 'flux'. Flux is the measure that describes the total quantity of pollutant passing a sampling location over some period of time. In our case the flux measures estimates the quantity of metaldehyde being exported from the land to the reservoir, the quantity that ultimately determines the levels of pollution concentration in the reservoir.

The report is divided into 6 parts with each part relating an analysis of the data from one of the reservoirs included in the SiO scheme. Section A provides a detailed investigation of data from the Pitsford reservoir, a section that also develops the analyses of concentrations and fluxes used in discussion of data for each of the other reservoirs. Section B summarises the results from the Hollowell/Ravensthorpe reservoir, Section C Alton reservoir, Section D Ardleigh reservoir, Section E Grafham reservoir and Section F Rutland reservoir. A detailed discussion of the hydrological flow modelling used in the calculation of flux measures is provided in an Appendix.

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A. Pitsford Reservoir

Introduction

Pitsford reservoir is supplied from two sources –abstraction from the River Nene catchment (371 km^2) at Duston Mill and directly from its NC (46 km^2) with feeder streams including those at Holcot (NC1), Scaldwell (NC2) and Walgrave (NC3). Accordingly, in the analysis that follows we take the data from Duston Mill on the River Nene as our control sample and compare that to measurements in the three NC sampling locations which drain land in the Pitsford catchment subject to the SiO intervention.

Figure 1. Map of the Pitsford Catchment (Map provided by Anglian Water)

Data

The data used in the analyses records metaldehyde concentrations taken at the different sampling location at intervals over the 6 months from August to the end of January, That period represents the risk period over which metaldehyde might be used in agricultural production;

While the metaldehyde concentration samples used in the analysis provide a detailed picture of pollution levels, the data required pre-processing. In particular, measurements were not taken at the same frequency at all sampling locations and the interval between measurements varied. Those features of the data make it difficult to compare across sampling locations using simple averages or counts of the raw data. To provide a consistent data series for each sampling

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location we instead interpolate the data, using the observed data points to 'fill in' the likely concentration levels for each day of the risk period. The analysis reported subsequently uses linear interpolation although alternatives such as spline interpolation might also be used.

Results: Concentrations

The plots shown in Figure 1 map out the interpolated concentration for each day of the risk period at the different sampling locations for 2014, 2015 and 2016. All the graphs have the same scale for metaldehyde concentration on the y axis; the three left-hand side graphs plot the metaldehyde against the date on the x axis; the three graphs on the right-hand side reorganise the data ranking the observations of metaldehyde concentrations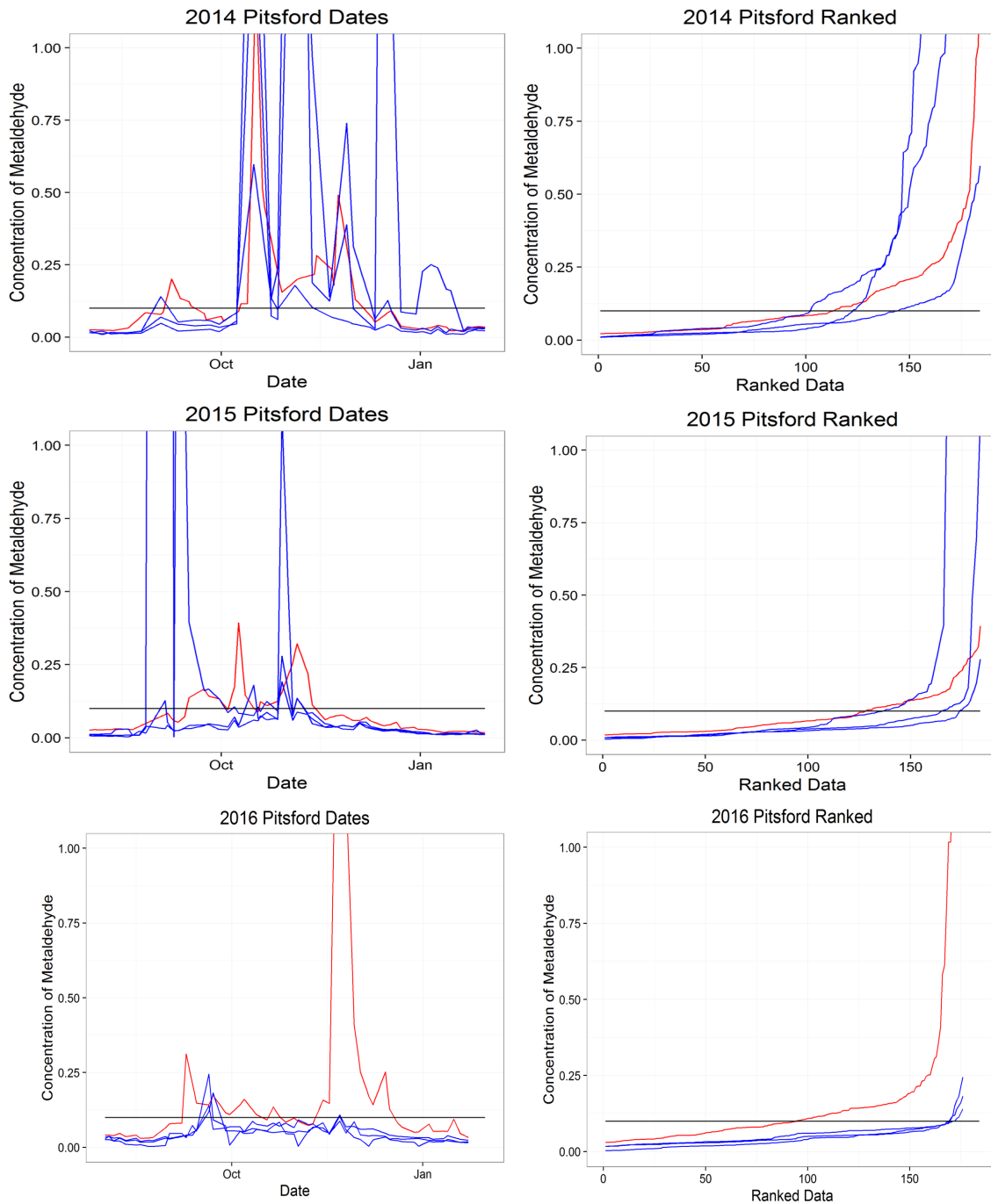 from lowest to highest. The EU regulatory limit for metaldehyde concentrations in drinking water is 0.1µg/l and this is plotted for reference on the graphs. In the graphs, data for the three NC sampling locations are plotted in blue while those from the RA sampling location is plotted in red.

In 2014, the year before the SiO scheme began, we observe multiple high metaldehyde concentration peaks both in the NC and also in the RA control. The levels of pollution are more easily visualised in the ranked data on the right-hand side. Here we see that for all three NC sampling locations and the RA sampling location, the 0.1µg/l threshold is exceeded for around a third of the risk period. The data from the first year of the SiO scheme, 2015, are shown in the graphs in the next row. The first thing to note is that there is a noticeable reduction in the number of metaldehyde concentration peaks. Again the frequency of metaldehyde pollution events is easier to assess from the ranked data in the right hand side graph. For the three NC sampling locations, each now being fed by land completely in the SiO scheme, we see a marked decline. Only a fifth of days in the risk period show metaldehyde levels above the regulatory limit.

At first sight, that could be taken as clear evidence of a positive impact of SiO. A difficulty with that interpretation arises when one compares the concentration data from inside the Pitsford catchment to that observed in areas outside the catchment and not in the SiO scheme. In particular, the red line plotting metaldehyde levels in the RA sampling location on the River Nene, also shows evidence of a significant fall in metaldehyde pollution from 2014 to 2015. Accordingly, it is not possible to categorically attribute the improvements seen within the Pitford catchment to SiO. An alternative explanation that could equally explain the data is that

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the levels of metaldehyde use fell across the region (perhaps as a result of changing weather conditions) independent of the SiO scheme.

Blue = NC, Red = River Abstraction / Intake.

Figure 2. Metaldehyde concentrations for 2014, 2015 and 2016

That ambiguity is somewhat resolved by data from the second year of the SiO scheme, 2016. Notice here that within the Pitsford catchment the NC sampling locations show a very substantial decline in metaldehyde concentration peaks, with only a handful of days registering minor exceedances of the regulatory limit. In contrast pollution events in the control location

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on the River Nene exhibit persistently high levels of metaldehyde, returning to the levels seen in 2014. That pattern of data clearly points to a significant difference in metaldehyde pollution within the Pitsford NC that can, with reasonable certainty, be attributed to the SiO scheme.

To explore the metaldehyde concentrations further we summarise the Pitsford data in Table 1. The table shows the number of days the metaldehyde concentration was above the 0.1µg/l threshold, the maximum metaldehyde concentration for the year and the mean and median metaldehyde concentrations.

Table 1. Metaldehyde Concentration Summary Statistics for Pitsford Catchment.

Concentration Measure	Year	Duston Mill River Nene	Holcot Stream	Scaldwell Brook	Walgrave Brook
Number of Days above 0.1µg/l threshold (actual measurements above threshold)	2014	71 (21)	82 (14)	41 (5)	62 (8)
	2015	57 (16)	11 (2)	20 (4)	48 (12)
	2016	82 (23)	7 (2)	4 (2)	7 (2)
Maximum (µg/l)	2014	1.25	5.46	0.60	2.36
	2015	0.39	0.28	1.11	19.90
	2016	2.32	0.18	0.14	0.25
Mean (µg/l)	2014	0.14	0.50	0.08	0.28
	2015	0.08	0.04	0.06	0.82
	2016	0.18	0.05	0.05	0.04
Median (µg/l)	2014	0.08	0.08	0.05	0.03
	2015	0.06	0.03	0.03	0.04
	2016	0.09	0.04	0.05	0.03

Observe that in the Pitsford catchment in 2014, metaldehyde levels were high in both the NC and the surrounding region. Concentrations in the Holcot peaked at 5.46µg/l, the Scaldwell peak was 0.60µg/l, 2.36µg/l at Walgrave and 1.25µg/l on the River Nene. Likewise, the number of days when the metaldehyde concentration was above the 0.1µg/l threshold also registers as relatively high, ranging from 82 days in Holcot Stream to 41 days in Scaldwell Brook.

Despite implementation of SiO in 2015, each sampling location again witnessed significant peaks in 2015; 0.28µg/l at Holcot, 1.11µg/l at Scaldwell, 19.90µg/l at Walgrave and 0.39µg/l on the River Nene (see Box 1 for a discussion of the high metaldehyde peak). Looking in more detail, the reduction in maximum metaldehyde concentration on the River Nene together with a reduction in the number of days above the threshold suggests a fall in metaldehyde pollution across the wider region.

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If metaldehyde leaching into watercourses was generally lower in 2015 then we might expect metaldehyde levels in the NC to be have fallen at least as significantly if not more extensively as a result of the additional effects of the SiO scheme. The NC data, however, paints a somewhat inconclusive picture. First consider the peak concentration data. While the peak in Holcott shows a substantial fall of equivalent magnitude to that seen in the River Nene control location, the peaks observed in the Scaldwell Brook and Walgrave Brook in 2015 are very much larger than those in 2014. Clearly the SiO scheme did not eliminate all metaldehyde pollution events in the catchment of the Pitsford in 2015. The impacts of those peaks are also reflected in the average concentration data. Again, the Holcot experiences a fall in average concentrations of some 92%, a level which, as expected, exceeds the 43% fall seen in the River Nene control. The fall in the Scaldwell, however, is only 25% and the Walgrave experiences an almost 200% increase in average concentrations. While the significant peaks observed at those two sampling location, particularly the single high peak event in the Walgrave, partially explains this finding, the average concentrations data do not comprehensively support a clear effect for SiO. Things ae somewhat clearer when considering the number of days above the 0.1μg/l threshold, Here we observe a 20% fall in the River Nene control samples, which is exceeded by the 87% fall in the Holcot, 68% in the Scaldwell and 23% in the Walgrave. Overall the summary statistics for 2015 provide good evidence of a SiO impact in the Holcot, with increasingly less convincing support for an effect in the Scaldwell and Walgrave.

A very much more convincing story is told by the data from the second year of the SiO scheme. In 2016 all three NC sampling locations have lower readings for peak metaldehyde concentrations and across all three locations only a handful of days exceed the 0.1μg/l threshold. For the RA sampling point on the Nene River the picture is very different with 2016 showing substantial increases in metaldehyde pollution for all statistics. Since the control suggests an increase in metaldehyde pollution over the general region, the falls in pollution observed in the Pitsford catchment are strong evidence of the impact of the SiO scheme.

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Box 1: Investigation into the High Metaldehyde Peak in the Pitsford Catchment

On the 11th September 2015, routine sampling identified a significant metaldehyde exceedance had occurred on the 5th September. Although levels rapidly declined, a repeating pattern of exceedances was observed associated with rainfall events for the following 2 weeks. Throughout this period field drains were not flowing, suggesting a point source was responsible for the observations. Further investigation identified that only oilseed rape had been planted in the catchment, with most of the winter wheat land either not harvested or fallow.

On the 14th September a detailed catchment walk over identified high levels of metaldehyde at the top of the Walgrave brook in the vicinity of a farmyard. Although fully engaged with the SiO trial, in the follow-up interview the landowner confirmed that he had employed four additional staff to service his contract pelleting commitments for land outside the natural catchment. Therefore, metaldehyde pellets were being handled and stored within the SiO trial area although not applied to land there. Whilst no product spillage had been reported, in 2016 this farmer has agreed to: run the contract pelleting from another yard, store any metaldehyde out of the catchment, and let Anglian Water give all operators a half day training session before harvest.

A follow-up catchment flow survey calculated that the maximum volume of water entering the reservoir from the brook would total 0.35Ml during the 2 day peak (5&6 September). This related to 0.003% of the current Pitsford storage and theoretically increased the raw water metaldehyde level in Pitsford by 0.000561µg/l. Whilst the sample results were high, due to low flow the actual impact on water quality would have been negligible.

Another way to describe the same data which has some presentational advantages is to express the levels of pollution in terms of the proportion of days during the risk period in which the measurements exceeded each level of concentration. An example of such a plot is shown in Figure 3.
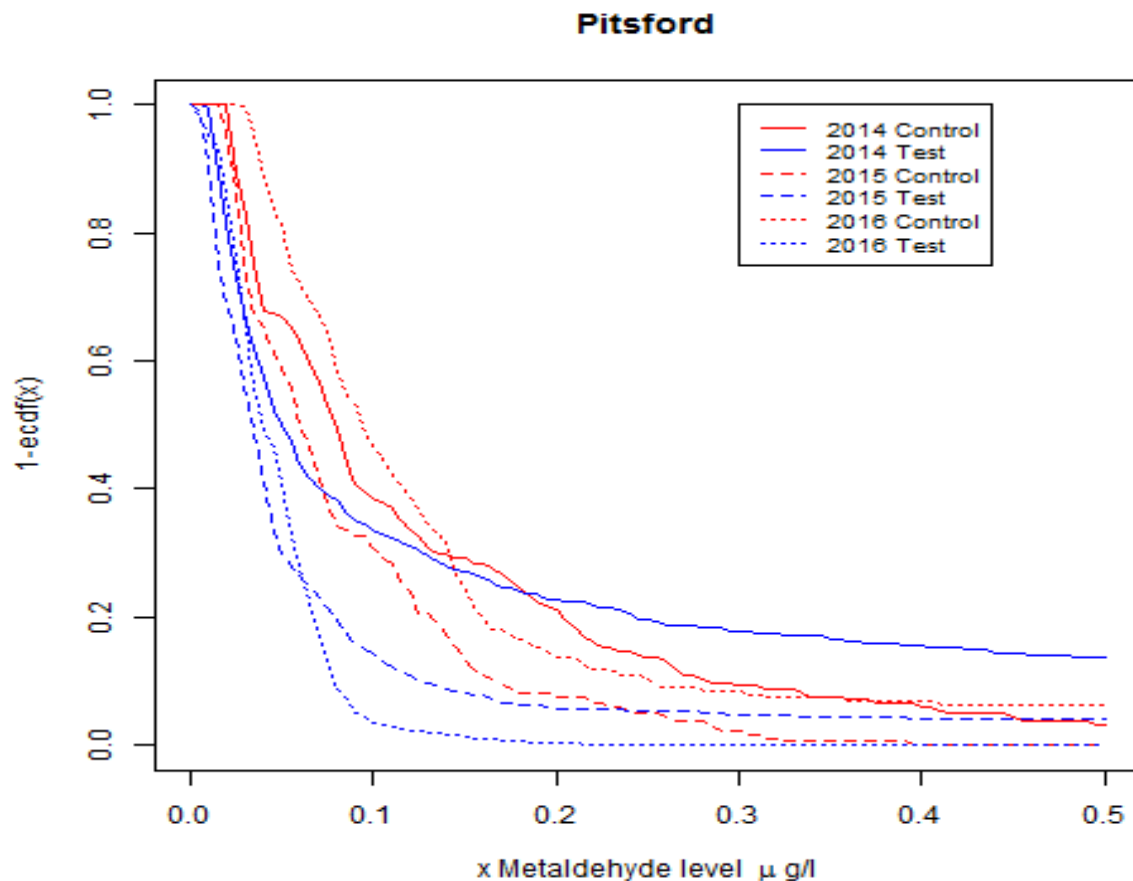
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Pitsford

Figure 3. Complementary cumulative density function for 2014 2015 and 2016

Reading from the left, the graph starts with a concentration level of 0 and, not surprisingly, at that concentration the lines, each plotting data from a sampling location in a particular year, record a value of 1. In other words, for every day of the risk period concentrations were at least zero. Moving along the *x* axis the concentration levels increase and the lines plot out how the proportion of days with that concentration or greater decline. While the graph in Figure 3 is truncated at a concentration of at 0.5μg/l, if we were to progress out to ever higher concentrations we would that the line for each sampling location eventually falls to zero at the peak concentration observed for that sampling point. The advantage of this presentation of the data is that if provides a simple way to compare the data across treatments. For example, taking the regulatory concentration limit of 0.1μg/l we can scan vertically upwards to see the proportion of days exceeding that level in each sampling location. So the location showing the highest levels of exceedances of that limit was the RA location on the River Nene in 2016. There some 55% of observations exceeded the regulatory limit over the risk period. In contrast the lowest levels of exceedances were seen in the NC sampling locations in the same year,

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2016. Here less than 5% of observations exceed the limit. Generally, lines on the graph that fall away to zero fastest are those showing the lowest pollution levels.

Since the data is presented simply in terms of the proportion of observations exceeding some concentration level, the presentation in Figure 3 also allows us to easily combine data. Indeed, that is what has been done in Figure 3, where data from the three NC sampling locations has been pooled and plotted out as the blue lines.

Looking at the blue lines in Figure 3, notice that within the NC the 2015 line (dashed) always lies below the 2014 line (solid). That indicates that 2015 (the first year of SiO) was a categorically better year for metaldehyde pollution than 2014. That same pattern repeats itself for concentrations in the RA sampling location on the River Nene; again, the red dashed line for 2015 is always below the red solid line for 2014. Since both the control and the test show a reduction in metaldehyde in 2015 compared to 2014 that comparison fails to distinguish between the hypothesis that SiO was responsible for reductions in metaldehyde in the Pitsford NC or the alternative that 2015 was just a generally low pressure year for slugs and hence lower metaldehyde use.

Figure 3 also plots the data for 2016. The proportion of days with high metaldehyde levels in 2016 in the NC (blue dotted line) is lower than all other lines including 2014 and 2015 in the NC and the 2016 in the wider catchment. The fact that the levels of metaldehyde concentrations were higher in the wider catchment than previous years and that those in the NC were lower than previous years is strong evidence that the SiO scheme had a positive effect on reducing metaldehyde concentrations in 2016.

Results: Flux

The concentration data alone is not sufficient to establish how the quantities of metaldehyde entering the reservoir are changing over time; that calculation also requires information on the level of flows. Conclusions based just on the concentration data may be misleading; high levels of metaldehyde concentrations measured in a tributary experiencing very low flow conditions may make barely any contribution to pollution entering the reservoir. To examine the absolute quantities of metaldehyde passing through the sampling locations, we combine the concentration data with estimated daily flows to give a measure of metaldehyde 'flux'. Flux describes the total quantity of pollutant passing each measurement point over some period of time. The estimation of water flows at the different sampling locations was done using the SWAT model parameterised for the rainfall and land uses observed in the SiO catchments. Details of that hydrological modelling exercise are provided in the Appendix.

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Data on metaldehyde fluxes in the NC of the Pitsford reservoir and the RA sampling location on the River Nene are summarised in Table 2. The table shows the mean metaldehyde flux over the course of the risk period measured in micrograms/sec and an estimate of the total metaldehyde delivered by each river over that same period measured in grams. The metaldehyde flux (µg/s) is calculated as concentration (µg/l) multiplied by flow (m^3/s) giving total metaldehyde.

Table 2. Metaldehyde Flux Summary Statistics for Pitsford Catchment.

Flux Measure	Year	Duston Mill River Nene	Holcot Stream	Scaldwell Brook	Walgrave Brook
	2014	192.68	6.51	2.10	3.36
Mean (µg/s)	2015	32.78	0.21	0.73	1.59
	2016	72.34	0.08	0.25	0.15
	2014	3063.14	103.48	33.46	53.42
Total (g)	2015	521.20	3.26	11.68	25.27
	2016	1099.97	1.07	3.39	2.05

Observe that in the Pitsford catchment in 2014, metaldehyde fluxes were relatively high in both the NC and the wider catchment with average fluxes of 6.51µg/s at Holcot, 2.10µg/s at Scaldwell, 3.36µg/s at Walgrave and 192.68µg/s on the River Nene.

Mirroring the concentration data, metaldehyde fluxes in 2015 were lower than 2014 in both the NC and the wider catchment with average fluxes of 0.21µg/s at Holcot, 0.73µg/s at Scaldwell, 1.59µg/s at Walgrave and 32.78µg/s on the River Nene. The average fluxes on the River Nene represent an 83% reduction compared to the 2014. Accordingly, strong evidence for a SiO effect in 2015 would require metaldehyde flux reductions in the NC sampling points to achieve at least that level of reduction. In Holcot we observe an impressive 97% reduction in average metaldehyde fluxes, however, in Scaldwell and Walgrave the reductions are more modest at 65% and 53%. Again the data does not provide enough information to clearly identify an independent SiO effect in 2015.

In 2016 metaldehyde fluxes again showed sharp falls in the NC with average fluxes of 0.08µg/s at Holcot, 0.25µg/s at Scaldwell, 0.15µg/s at Walgrave. In contrast, fluxes in the control location on the River Nene, outside the scheme area, showed a significant increase more than doubling from 2015 levels to 72.34µg/s. The average metaldehyde fluxes in 2016 compared to 2014 show a combined reduction of greater than 90% in the NC (99% in Holcot, 88% in

Scaldwell and 96% in Walgrave) and a reduction of 62% in the wider catchment. Compared to 2015 the average fluxes represent a combined reduction of 73% in the NC (62% in Holcot, 66% in Scaldwell and 91% in Walgrave) and an increase of 121% in the wider catchment.

The 2016 data provides particularly strong evidence that the SiO scheme prevented metaldehyde from entering the watercourses of the NC and therefore reduced metaldehyde pollution levels in Pitsford reservoir. Overall, the metaldehyde flux results match the conclusions of the metaldehyde concentration results for Pitsford.

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B. Hollowell and Ravensthorpe Reservoir Catchments

Introduction

The combined area of the Hollowell/Ravensthorpe NC is 22.1km^2; consisting of 13 arable farms. The reservoirs are fed by the NC only without additional river abstraction. Accordingly in this trial location, we do not have a good control sampling location to act as a comparison point to data collected in the NC.

Results: Concentration

Table 3 summarises metaldehyde concentrations in the Hollowell/Ravensthorpe trial area detailing the number of days that metaldehyde concentrations were above the 0.1µg/l threshold, as well as the maximum, mean and median metaldehyde concentration over the risk period.

Table 3. Metaldehyde Concentration Summary Statistics for Hollowell/Ravensthorpe Catchment.

Concentration Measure	Year	Ravens Coton Mill	Ravens Res.	Hollowell Crow Hill	Hollowell Res.
Number of Days above 0.1µg/l threshold (actual measurements above threshold)	2014	42 (6)	108 (25)	15 (1)	122 (22)
	2015	0 (0)	29 (9)	0 (0)	33 (10)
	2016	0 (0)	0 (0)	0 (0)	4 (1)
Maximum (µg/l)	2014	3.17	0.28	1.58	0.19
	2015	0.05	0.12	0.09	0.16
	2016	0.06	0.07	0.05	0.12
Mean (µg/l)	2014	0.18	0.13	0.09	0.11
	2015	0.01	0.09	0.01	0.08
	2016	0.02	0.05	0.02	0.07
Median (µg/l)	2014	0.02	0.16	0.02	0.12
	2015	0.01	0.08	0.01	0.08
	2016	0.01	0.05	0.01	0.07

Observe that in the Hollowell/Ravensthorpe catchment in 2014, metaldehyde levels were high in both the NC tributaries and in the reservoirs themselves. All sampling points see levels above the 0.1µg/l threshold with peaks of 3.17µg/l at Coton Mill, 0.28µg/l at Ravensthorpe Reservoir, 1.58µg/l at Crow Hill and a peak of 0.19µg/l at Hollowell Reservoir. Likewise we observe a substantial number of days when the metaldehyde concentration was above the 0.1µg/l threshold; 42 and 15 days in the two NC tributaries and 122 and 108 days in the two reservoirs.

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Following implementation of the SiO scheme the metaldehyde concentration data shows significant falls across all measures. In both 2015 and 2016 the NC sampling locations did not record any exceedances of the regulatory limit of 0.1µg/l. Similarly, in 2015 mean metaldehyde concentrations in the NC tributaries fell from from 0.18µg/l at Crow Hill and 0.09µg/l Coton Mill to 0.01µg/l. Paralleling that observation, the levels of metaldehyde concentrations observed in the reservoirs themselves fell in 2015 and 2016 as did the number of days above the regulatory threshold. The concentration data suggest a substantial SiO scheme effect, reflected in falling levels of metaldehyde pollution both in the NC tributaries and in the reservoirs they feed.

Figure 4 plots the same data in the proportions format; the graph details the proportion of time that pollution levels at a sampling location take values greater than a particular concentration. Note that the test data here is the pooled data from the NCs of Hollowell and Ravensthorpe.
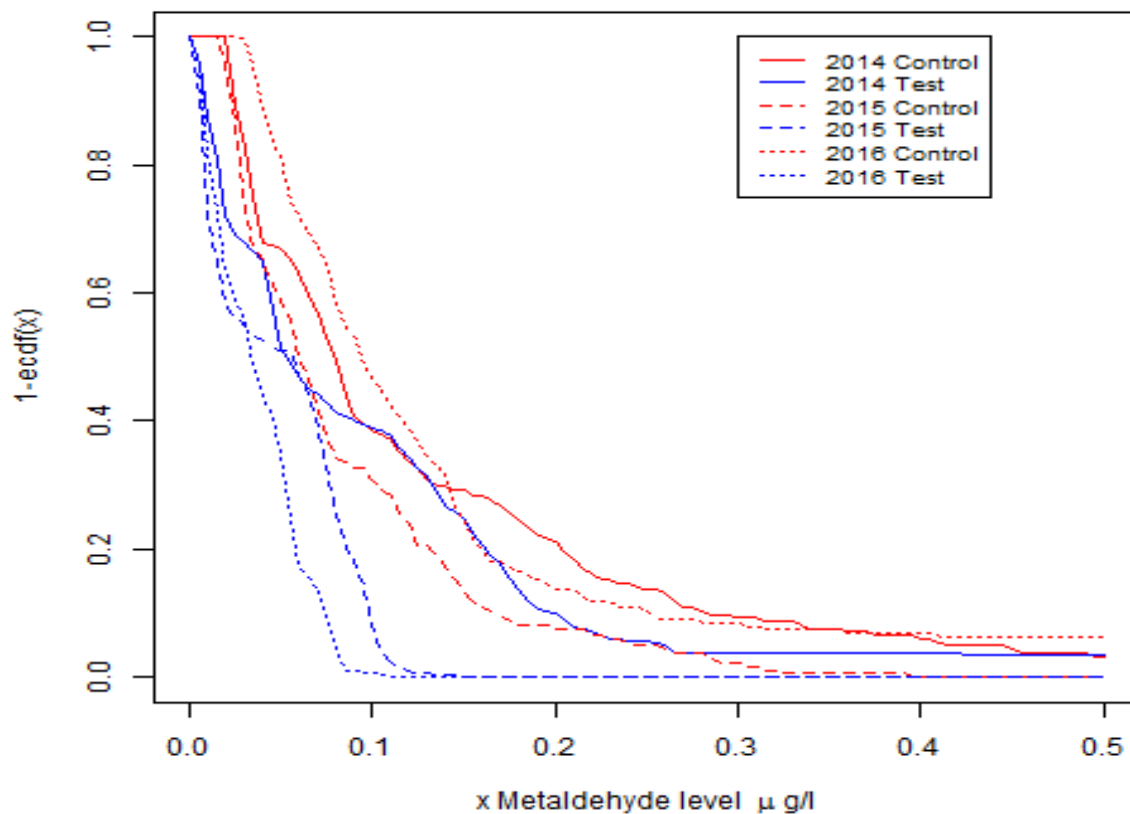

Figure 4. Complementary cumulative density function for 2014 2015 and 2016

As Hollowell/Ravensthorpe reservoirs are only supplied by the NC, for convenience we add a control comparison by showing the Pitsford River Nene abstraction alongside the combined NC test measurements.

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Figure 4 clearly shows the substantial fall in metaldehyde concentrations observed in the two years of the SiO scheme compared to the pre-scheme levels measured in 2014. The blue dashed line (test 2015) and blue dotted line (test 2016) are below that of the blue solid line (test 2014).

Results: Flux

The metaldehyde fluxes are summarised in Table 4. The table shows the mean metaldehyde flux and an estimate of the total metaldehyde exported from the land to the NC streams. The metaldehyde flux (μg/s) is calculated as concentration (μg/l) multiplied by flow (m^3/s) and the total metaldehyde is in grams.

Observe that in the Hollowell/Ravensthorpe NC in 2014, average metaldehyde fluxes were 6.51μg/s at Coton Mill and 2.92μg/s at Crow Hill and total exported metaldehyde was 103.49g at Coton Mill and 46.43g at Crow Hill. In 2015, average metaldehyde fluxes were lower than 2014 (0.13μg/s at Coton Mill and 0.11μg/s at Crow Hill) with lower total exported metaldehyde of 2.14g and 1.70g. The average fluxes represent reductions of 98% and 96% compared to the 2014 with similar reductions in the total exported metaldehyde. In 2016, the metaldehyde fluxes reduced again (0.07μg/s at Coton Mill and 0.05μg/s at Crow Hill) along with lower total exported metaldehyde of 1.10g and 0.78g. The average fluxes represent reductions of 99% and 98% compared to 2014.

Table 4. Metaldehyde Flux Summary Statistics for Pitsford Catchment.

Flux Measure	Year	Ravens Coton Mill	Hollowell Crow Hill
	2014	6.51	2.92
Mean (μg/s)	2015	0.13	0.11
	2016	0.07	0.05
	2014	103.49	46.43
Total (g)	2015	2.14	1.70
	2016	1.10	0.78

Overall, the metaldehyde flux results match the conclusions of the metaldehyde concentration results for Hollowell and Ravensthorpe. There is strong evidence of a substantial fall in metaldehyde levels in the catchment as a result of the SiO scheme. Ravensthorpe and Hollowell are the simplest and smallest of the catchments and this could have contributed to the clear results observed. Indeed, farm advisors reported the small size of the catchments and small numbers of farmers, along with very little non-agricultural infrastructure (like industry or villages) made it easy to engage with farmers.

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C. Alton Reservoir Catchment

Introduction

Alton reservoir is supplied from three sources –abstraction from the River Gipping catchment at Sproughton, abstraction from the Mill River at Bucklesham and from the Alton NC through Tattingstone Brook. In this case, therefore, we have two controls and one sampling location in the NC.

The Alton NC consists of 22 arable farms, managed by 20 farm businesses with a total of 1967.1ha of arable land. Soils are characterised by a large proportion of sandy loam soils to the south and clay loam soils towards the north of the catchment – providing good growing conditions for a wide range of crops including winter wheat, oilseed rape, winter barley, sugar beet, potato and spring barley.

Results: Concentration

The metaldehyde concentration data for Alton is summarised in Table 5. Observe that previous to SiO implementation, metaldehyde levels were low in the NC and the River Mill but high in the River Gipping. In 2014, in the NC, there was only one exceedance of the regulatory 0.1µg/l threshold with a maximum metaldehyde concentration of 0.10µg/l and mean of 0.02µg/l. In the wider catchment in 2014 there were an estimated 2 days above the regulatory threshold in the River Mill and 56 days in the River Gipping. The maximum metaldehyde concentration was 0.11µg/l and 1.97µg/l with means of 0.02µg/l and 0.15µg/l.

Following implementation of the SiO scheme in 2015, the data in Table 5 seems to suggest that metaldehyde levels in the NC actually increased in 2015. The number of days of exceedances of regulatory limit rose to 19 days and the mean increased to 0.06µg/l. The opposite pattern reveals itself in 2016, Metaldehyde levels dropped in the NC with the number of exceedances falling to zero and the mean concentrations reducing to 0.01µg/l.

In the control rivers the trend in metaldehyde concentrations is generally downwards. At the River Gipping sampling location, mean metaldehyde concentration decreases in 2015 to 0.08µg/l and then to 0.07µg/l in 2016. In the Mill River the mean metaldehyde concentration stays at 0.02µg/l in 2015 and then increases to 0.03µg/l in 2016. These data suggest that metaldehyde pollution in the Alton NC was already low and that concentrations increased slightly in the first year of SiO before falling back to very low levels in 2016.

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Table 5. Metaldehyde Concentration Summary Statistics for Alton Catchment.

Concentration Measure	Year	Tattingstone Brook	Mill River, Bucklesham	River Gipping
Number of Days above 0.1µg/l threshold (actual measurements above threshold)	2014	1 (1)	2 (1)	56 (12)
	2015	19 (5)	0 (0)	37 (9)
	2016	0 (0)	11 (3)	26 (8)
Maximum (µg/l)	2014	0.10	0.11	1.97
	2015	0.69	0.05	0.66
	2016	0.04	0.23	0.55
Mean (µg/l)	2014	0.02	0.02	0.15
	2015	0.06	0.02	0.08
	2016	0.01	0.03	0.07
Median (µg/l)	2014	0.01	0.02	0.04
	2015	0.04	0.02	0.04
	2016	0.00	0.02	0.04

Figure 5 plots the concentration data in proportions format. The graph mirrors the story told by the summary concentration data. The blues lines represent the NC sampling location at Tattingstone Brook and the red lines the control locations on the River Mill and Gipping. Clearly metaldehyde concentrations in the Alton NC were already low in 2014 (solid blue line). Perhaps surprisingly, those levels increased in the first year of SiO (dashed blue line) before dropping to very low levels in 2016 (dotted blue line).. At the 0.1µg/l threshold only a very small proportion of days were over that regulatory threshold in 2014 this increased to approximately 10% of days in 2015 before dropping to no exceedances of that threshold in 2016. In the control sampling locations, the red lines show a decrease in 2015 and 2016 (dashed and dotted lines) compared to 2014 (solid line).

Results: Flux

The metaldehyde fluxes are summarised in Table 6. The table shows the mean metaldehyde flux and an estimate of the total metaldehyde exported from the land to the NC streams.
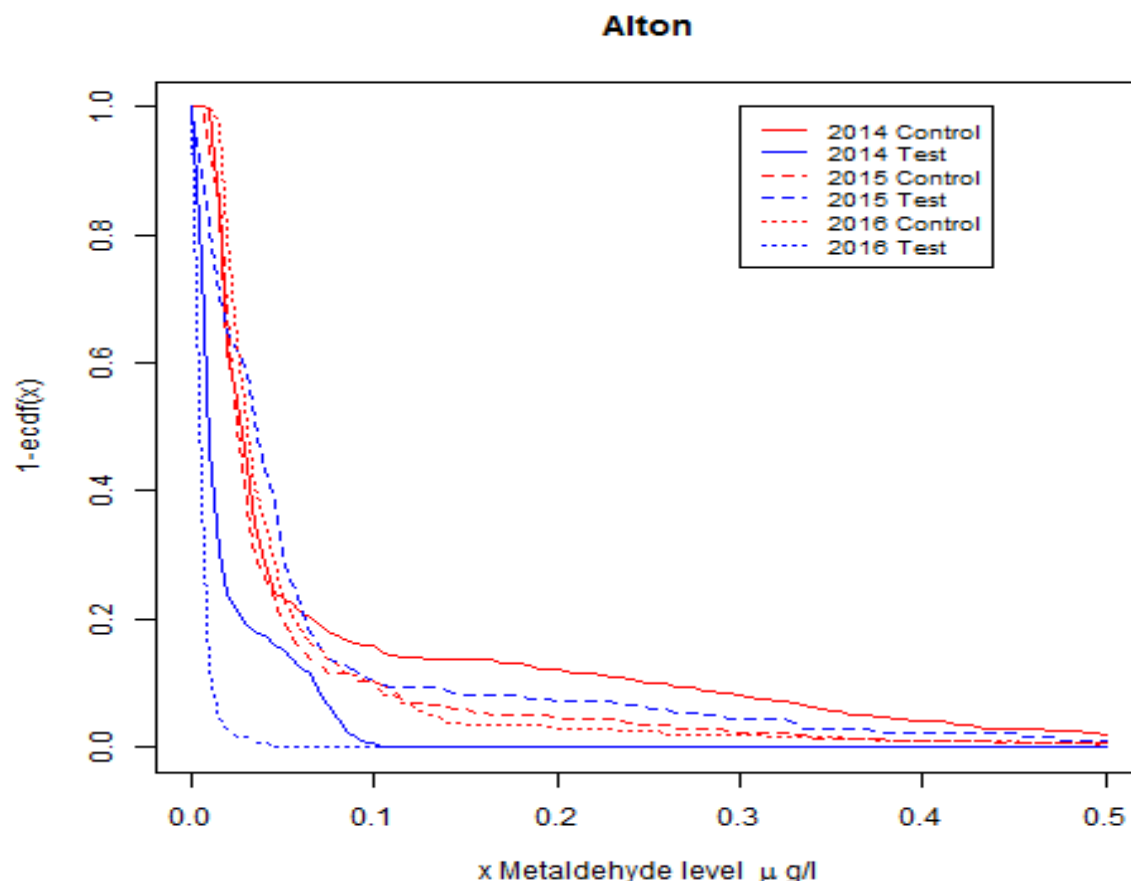
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Figure 5. Complementary cumulative density function for 2014 2015 and 2016

Observe that in the Alton NC in 2014, average metaldehyde fluxes was 1.31µg/s with total exported metaldehyde estimated to be 20.77g. In 2015 and 2016, average metaldehyde flux was significantly lower at 0.56µg/s in 2015 and 0.06µg/s in 2016 with similar reductions in the total exported metaldehyde falling to 8.95g in 2015 and 0.99g in 2016. The average fluxes for 2015 represent reductions of 57% compared to 2014 with further reductions of 89% in 2016 compared to 2015.

Overall, the metaldehyde fluxes show reductions in the metaldehyde entering the NC streams and rivers in 2015 and 2016 compared to the year before SiO was active (2014). This is in contrast to the concentration data where the concentrations appeared to increase in 2015 before dropping in 2016. To explain this one has to look at the estimated stream flows for the years of the scheme versus the year before the scheme. In the Alton NC 2014 average stream flow was 0.062m³/s in 2015 this dropped to 0.015m³/s and 0.008m³/s in 2016. These differences in the stream flow mask the effect of the SiO scheme in the concentration data because higher flows at a lower metaldehyde concentration meant that more metaldehyde entered the NC streams in 2014 compared to 2015.

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Table 6. Metaldehyde Flux Summary Statistics for Alton Catchment.

Flux Measure	Year	Tattingstone Brook
Mean (μg/s)	2014	1.31
	2015	0.56
	2016	0.06
Total (g)	2014	20.77
	2015	8.95
	2016	0.99

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D. Ardleigh Reservoir Catchment

Introduction

Ardleigh reservoir is supplied from two sources – abstraction from the River Clone catchment at East Mills and from two tributaries of the NC, the Northern and Western Salary Brooks.

The Ardleigh NC is 14.2km^2; consisting of 14 arable farms, managed by 13 farm businesses with a total of 815.5 ha land (100 fields) under arable farming. Soils are characterised by a large proportion of well drained clay loam – providing good growing conditions for a wide range of crops including winter wheat, oilseed rape, spring barley and potato.

Results: Concentration

The metaldehyde concentration data is summarised in Table 7. Observe that in the Ardleigh catchment in 2014 (before SiO), metaldehyde levels were low in the NC but relatively high in the wider catchment. In 2014, in the NC, in the North Salary Brook there were no exceedances of the regulatory 0.1µg/l threshold with a maximum metaldehyde concentration of 0.09µg/l and mean of 0.04µg/l. In the Western Salary Brook the pattern of concentrations is somewhat different. In 2014 there were an estimated 16 days above the regulatory threshold with a maximum metaldehyde concentration of 0.18µg/l and mean of 0.05µg/l. In the contral sampling location on the River Colne there were an estimated 80 days above the regulatory threshold in 2014 with a peak metaldehyde concentration of 2.02µg/l and mean of 0.17µg/l.

In 2015 and 2016 metaldehyde concentrations observed at the NC sampling locations reveal little conspicuous evidence of a response to implementation of the SiO scheme. Mean levels stay roughly the same in both the North and West Salary Brooks. Peak concentrations at those sampling points rise in 2015 before falling back again in 2016 a similar pattern to that observed in the measure of days exceeding the 0.1 µg/l threshold. In the control sampling location the pattern of data is similar to that observed in the control locations for the other reservoirs; mean concentrations decrease in 2015 to 0.06µg/l and then increases in 2016 to 0.21µg/l.

The concentration suggests that metaldehyde levels in the Ardleigh NC were low prior to SiO implantation and that the scheme did little to affect further reductions in metaldehyde levels.

Table 7. Metaldehyde Concentration Summary Statistics for Ardleigh Catchment.

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Concentration Measure	Year	North Salary Brook	West Salary Brook	River Colne
Number of Days above 0.1µg/l threshold (actual measurements above threshold)	2014	0 (0)	16 (2)	80 (25)
	2015	7 (1)	18 (5)	32 (8)
	2016	1 (1)	12 (3)	54 (24)
Maximum (µg/l)	2014	0.09	0.18	2.02
	2015	0.14	0.23	0.35
	2016	0.11	0.19	2.28
Mean (µg/l)	2014	0.04	0.05	0.17
	2015	0.04	0.05	0.06
	2016	0.05	0.05	0.21
Median (µg/l)	2014	0.03	0.03	0.06
	2015	0.04	0.04	0.05
	2016	0.05	0.04	0.06

Figure 6 shows the concentration data in proportion format, with the blue lines plotting out the combined NC data (the North and Western Salary Brooks) and the red lines plotting out the control data from the River Colne abstraction point.

Figure 6 supports evidence from the summary concentration data, indicating that metaldehyde concentration levels were already low in the Ardleigh NC and remained so after the implementation of SiO. This can be seen by comparing the blue solid line (2014) to the blue dashed and dotted lines (2015 and 2016). At the 0.1µg/l threshold all years for the NC show that only a very small proportion of days were over that regulatory threshold. In the wider catchment the red lines show an increase in 2016 compared to 2015 but a reduction overall compared to 2014.
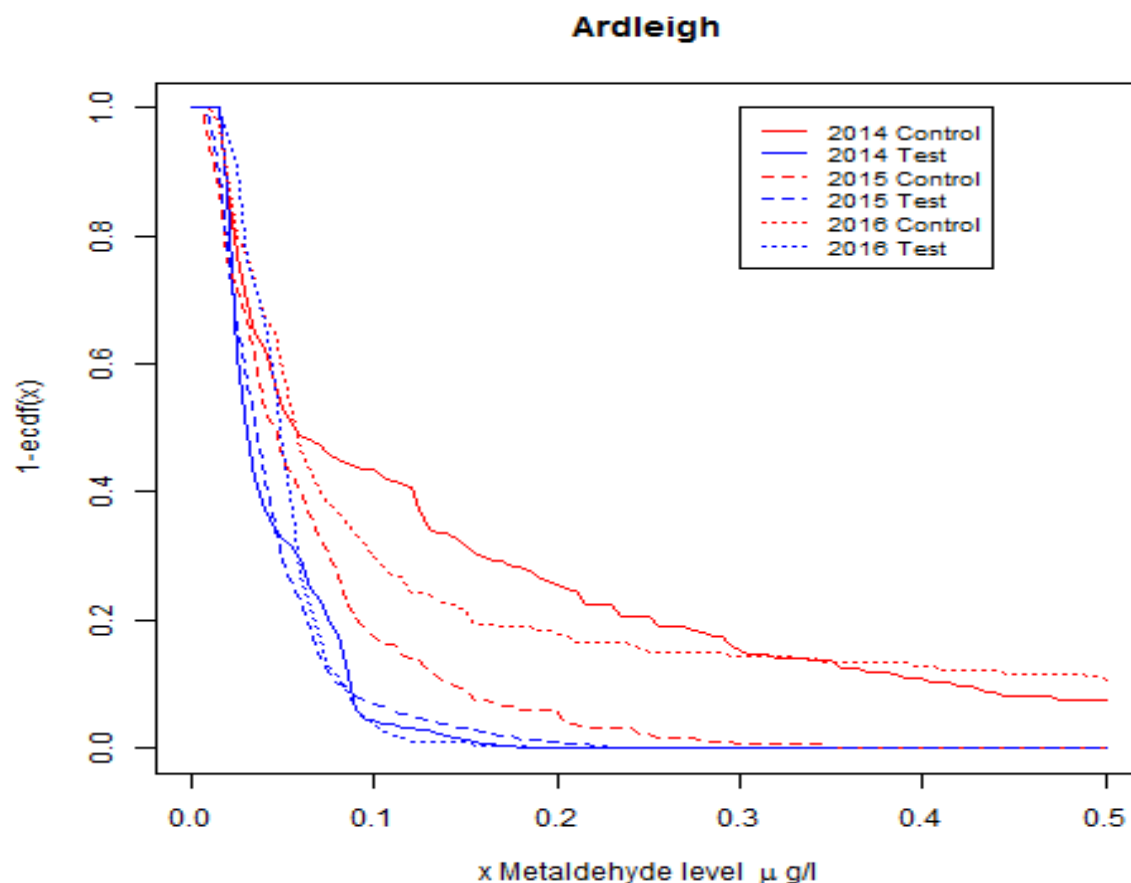
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Figure 6. Complementary cumulative density function for 2014 2015 and 2016

Results: Flux

The metaldehyde fluxes are summarised in Table 8. Observe that in the Ardleigh NC in 2014, average metaldehyde fluxes were 0.35µg/s for North Salary Brook and 0.41µg/s for Western Salary Brook, with total exported metaldehyde of 5.54g and 6.33g. In 2015 and 2016, average metaldehyde fluxes were significantly lower 0.03µg/s to 0.11µg/s as were the total exported metaldehyde of 0.42g to 1.52g. The average fluxes for 2015 represent reductions of 83% to 73% compared to 2014 with further reductions of 50% and 45% in 2016.

Overall, the metaldehyde fluxes show reductions in the metaldehyde entering the NC streams and rivers in 2015 and 2016 compared to the year before SiO implementation. This is in contrast to the concentration data where the concentrations appeared to be similar across all three years. To explain this one has to look at the estimated stream flows for the years of the scheme versus the year before the scheme. In the Ardleigh NC 2014 average stream flow was 0.009m³/s in the North Salary Brook and 0.011m³/s in Western Salary Brook. These average stream flows reduced to 0.002m³/s and 0.003m³/s in 2015 and 0.001m³/s and 0.001m³/s in 2016. It is apparent that these substantial differences in stream flows between 2014 and 2015/16

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mask the effect of the SiO scheme in the concentration data. Higher flows at similar concentrations result in significantly less metaldehyde entering the reservoir from the NC streams following SiO implementation.

Table 8. Metaldehyde Flux Summary Statistics for Ardleigh Catchment.

Flux Measure	Year	North Salary Brook	Western Salary Brook
	2014	0.35	0.41
Mean (μg/s)	2015	0.06	0.11
	2016	0.03	0.06
	2014	5.54	6.33
Total (g)	2015	0.89	1.52
	2016	0.42	0.85

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E. Grafham Reservoir Catchment

Introduction

Grafham reservoir is supplied from two sources – abstraction from the River Great Ouse catchment at Offord which supplies over 95% of the reservoirs water and a feed from the NC through Diddington Brook. The total area of the Grafham NC is 19.5km^2 consisting of 12 arable farms, managed by 11 farm businesses with a total land area of 1,111ha under arable farming. Soils are mainly clay – providing good growing conditions for a wide range of crops including winter / spring wheat, oilseed rape, linseed, winter/spring barley, peas and spring beans.

Sampling of the NC at Grafham only commenced in 2015, therefore no figures exist for metaldehyde concentration in the NC prior to the implementation of SiO. In addition, low flow events prevented sampling of Diddington Brook on numerous occasions through 2016. Given the limited information on metaldehyde concentrations for 2016, results for that year should be treated with caution.

Results: Concentration

Metaldehyde concentrations for the Grafham sampling locations are summarised in Table 9.

While no data is available for the NC in 2014, the RA sampling location on the Great Ouse records an estimated 98 days of exceedances of the regulatory threshold with a maximum metaldehyde concentration of 1.01 µg/l and mean of 0.26 µg/l. The pattern of change in concentrations in the control over 2015 and 2016 mirrors that seen in the controls for other reservoirs. The concentration measures fall sharply in 2015 before increasing again in 2016.

Data for concentrations in the NC data from 2015 and 2016 show a very mixed pattern. The number of exceedances of the 0.1 µg/l threshold increases from 2015 to 2016. Mean metaldehyde concentrations remain low and constant at 0.06 µg/l in 2015 and 0.07µg/l in 2016. Peak concentration falls from 0.46 µg/l to 0.15 µg/l from 2015 to 2016. .

Since a comparison for 2014 does not exist for the NC and the sampling data in 2016 is limited by the frequency of low flow events it is difficult to draw definitive conclusions from this data as to whether the SiO scheme had a measurable effect on metaldehyde pollution in the Grafham reservoir NC.

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Table 9. Metaldehyde Concentration Summary Statistics for Grafham Catchment.

Concentration Measure	Year	Diddington Brook	River Great Ouse
Number of Days above 0.1µg/l threshold (actual measurements above threshold)	2014		98 (43)
	2015	21 (3)	59 (18)
	2016	50 (1)	78 (39)
Maximum (µg/l)	2014		1.10
	2015	0.42	0.29
	2016	0.15	2.36
Mean (µg/l)	2014		0.26
	2015	0.06	0.09
	2016	0.07	0.26
Median (µg/l)	2014		0.11
	2015	0.04	0.08
	2016	0.06	0.10

The proportion plot in Figure 7 shows concentrations in the NC at Diddington Brook as blue lines and the control samples taken from the Great River Ouse as the red lines. The Great River Ouse data shows concentrations falling from 2014 to 2015 followed by increases in 2016. The concentration data for Diddington Brook shows generally low levels of metaldehyde pollution in both 2015 and 2016. The sampling difficulties caused by low flows in 2016 prevent satisfactory comparison across those two years. Overall, the data does not provide sufficient data to provide meaningful conclusions on the impact of the SiO scheme on metaldehyde pollution in the Grafham reservoir.
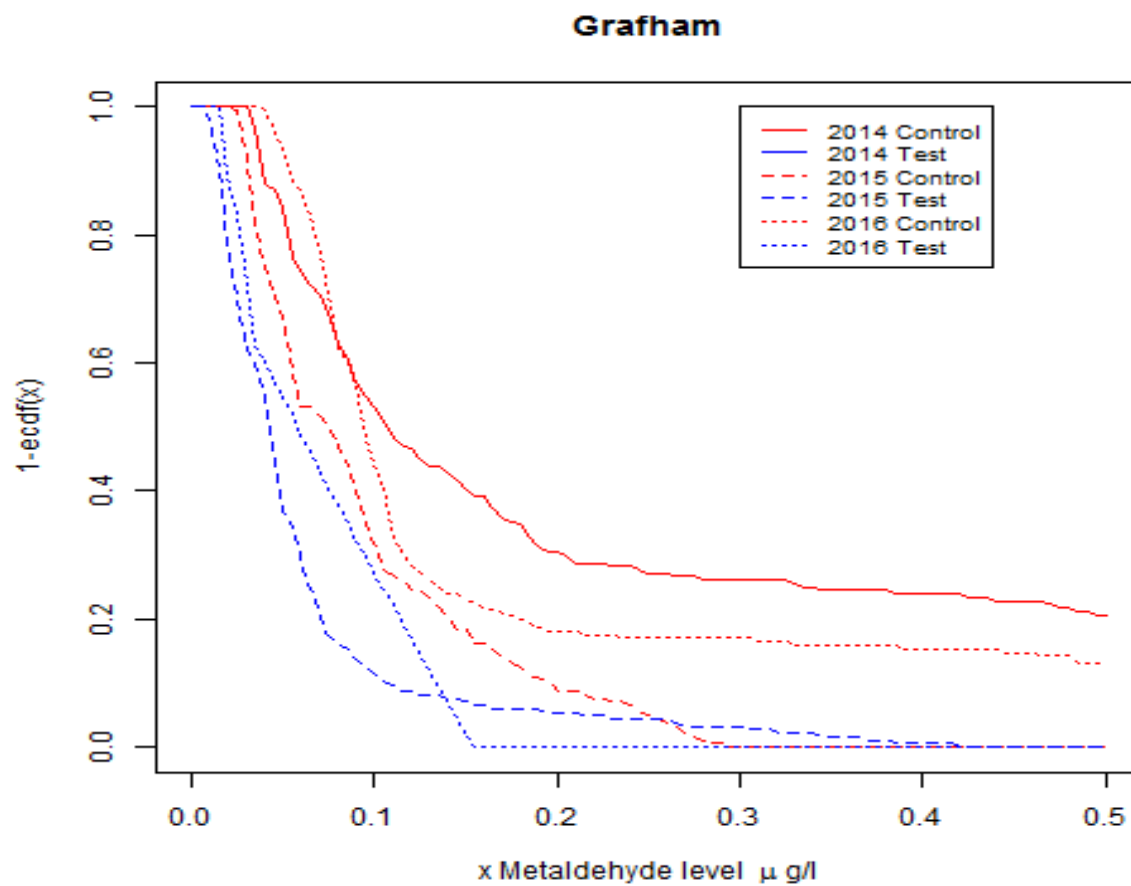
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Figure 7. Complementary cumulative density function for 2014 2015 and 2016

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F. Rutland Reservoir Catchment

Introduction

The SiO scheme was expanded to Rutland in 2016/17. In this case, therefore, results for both 2014/15 (2014) and 2015/16 (2015) are pre-intervention and there is just one year of results whilst the SiO scheme was active (2016). Data is available from the River Gwash which feeds the reservoir from the NC as well as from abstraction points on the River Welland at Tinswell and the River Nene at Wansford which act as control observations for the NC.

Results: Concentration

Metaldehyde concentration data for Rutland is summarised in Table 10. In 2014 and 2015 (before SiO), metaldehyde levels are generally high in both the NC and the control sampling locations. All three locations witness numerous exceedances of the 0.1µg/l threshold with peaks of between 1.04µg/l and 1.86µg/l in the NC and of between 0.65µg/l and 1.75µg/l in the control locations. The mean metaldehyde level in the NC was 0.11 in 2014 and 0.13 in 2015 with the wider catchment registering similarly high average measurements ranging between 0.11µg/l and 0.26µg/l.

Following implementation of the SiO scheme in 2016, exceedances of 0.1µg/l threshold fall sharply from the 55 days estimated for 2014 the 60 days estimated for 2015 down to just 4 days. Average metaldehyde concentrations in the Gwash also fall significantly reducing to 0.05µg/l in 2016 with a peak concentration of just 0.12µg/l. In contrast, in the control locations outside the SiO scheme, metaldehyde levels are observed to increase in 2016. The number of days of above the regulatory threshold, the maximum concentrations and the mean metaldehyde levels all rose substantially when compared to 2015. Taking these two results together, a substantial reduction in the NC at the same time as a substantial increase in the wider catchment provides very strong evidence that the SiO scheme resulted in lower metaldehyde concentrations in the Rutland NC.

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Table 10. Metaldehyde Concentration Summary Statistics for Rutland Catchment.

Concentration Measure	Year	Gwash NC	Welland at Tinwell	Nene at Wansford
Number of Days above 0.1μg/l threshold (actual measurements above threshold)	2014	55 (8)	93 (24)	124 (30)
	2015	60 (18)	82 (26)	77 (26)
	2016	4 (1)	120 (62)	129 (69)
Maximum (μg/l)	2014	1.04	1.05	1.75
	2015	1.86	1.68	0.65
	2016	0.12	2.58	4.44
Mean (μg/l)	2014	0.11	0.20	0.26
	2015	0.13	0.17	0.11
	2016	0.05	0.24	0.25
Median (μg/l)	2014	0.04	0.10	0.13
	2015	0.05	0.09	0.08
	2016	0.03	0.13	0.12

Figure 8 presents the data in terms of proportion of days exceeding each level of metaldehyde concentration. The blue lines represent the NC on the Gwash and the red lines represent the control measurements taken from the Rivers Welland and Nene.

Comparing the NC data for 2016 (blue dotted line) with that for the pre-scheme measurements for 2014 (blue solid line) and 2015 (blue dashed line), we observe substantive falls in metaldehyde pollution levels in the Gwash. At the 0.1 μg/l threshold, for example, the 2016 data show only a very small proportion of days exceeding the regulatory threshold compared to almost a third of days exceeding the threshold in the two year's measurements prior to the SiO scheme. In contrast, the 2016 data for the control locations shows no overall fall in concentrations. Indeed metaldehyde pollution in 2016 was categorically higher in the control locations in 2016 than it was in 2015. This evidence supports the conclusions that the SiO scheme substantially reduced metaldehyde levels in the NC in 2016. Importantly that reduction in metaldehyde runs counter to the increases seen in the wider catchment, a finding that provides strong evidence that it is the SiO scheme rather than some other driver (e.g. changing weather) causing the reduction in metaldehyde in the NC of Rutland Water.
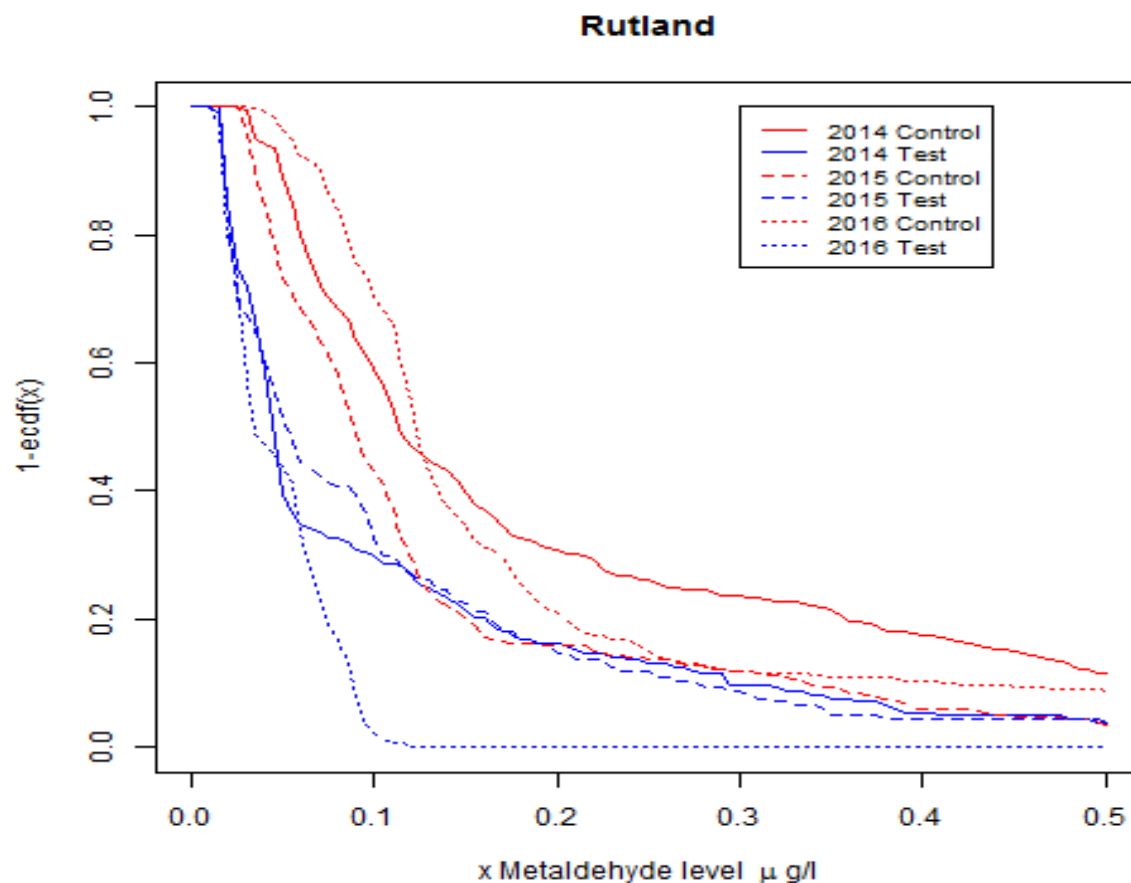
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Figure 8. Complementary cumulative density function for 2014 2015 and 2016.

Results: Flux

Data on estimated metaldehyde fluxes for Rutland Water are summarised in Table 11. Observe that in the Rutland NC in 2014, average metaldehyde fluxes were 5.71µg/s and total exported metaldehyde was 90.82g. In 2015, average metaldehyde fluxes were lower than 2014 (3.66µg/s) with lower total exported metaldehyde of 58.24g. In 2016, the metaldehyde fluxes reduced substantially again to 1.46µg/s, along with lower total exported metaldehyde of 22.13g. The average fluxes seen in the 2016 data represent reductions of 74% compared to 2014 and 60% compared to 2015.

Overall, the flux data documents a significant fall in the metaldehyde entering the reservoir from the NC streams following implementation of the SiO scheme in 2016. Note that there is some divergence between the flux and concentration data regarding 2015. In particular the concentration data appears to show that 2015 (compared to 2014) had similar or slightly higher metaldehyde concentrations, whereas, once we take into account estimates of the flow in the

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river metaldehyde fluxes appear lower in 2015. Although this result does not change the conclusions for Rutland it is an indication that the concentration data does not provide the whole story regarding measurements of the amount of metaldehyde entering the reservoir.

Table 11. Metaldehyde Flux Summary Statistics for Rutland Catchment.

Flux Measure	Year	Gwash NC
	2014	5.71
Mean (μg/s)	2015	3.66
	2016	1.46
	2014	90.82
Total (g)	2015	58.24
	2016	22.13

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Appendix: Estimating Streamflow Using SWAT in the Pitsford Reservoir Catchment, UK.

The intention of this appendix is to simulate daily streamflow data for the catchment of Pitsford Reservoir, UK. The model used in this endeavour is the Soil and Water Assessment Tool (SWAT), its ArcGIS plugin (ArcSWAT) and its calibration tool SWATCUP. In particular, we aim to simulate daily streamflow data for the three locations where regular metaldehyde concentration sampling has been undertaken as part of Anglian Water's SiO metaldehyde reduction scheme.

The resulting streamflow data will be used to calculate metaldehyde fluxes (the mass of metaldehyde transported in the streams) for those sampling locations in the Pitsford catchment (which are typically low flow streams). By converting the metaldehyde concentration data to metaldehyde flux data we will be able to compare the level of metaldehyde in those low flow streams in the Pitsford catchment to the metaldehyde level in another sampling location, a high flow river (the River Nene) used to supply the Pitsford reservoir through pumped abstraction.

Study Area

The study was conducted in the Pitsford reservoir catchment located in Northamptonshire, UK (Figure 1A). The total area of the NC is approximately 46km^2 with a total of 3143ha under arable cultivation and an average annual rainfall of approximately 660mm.
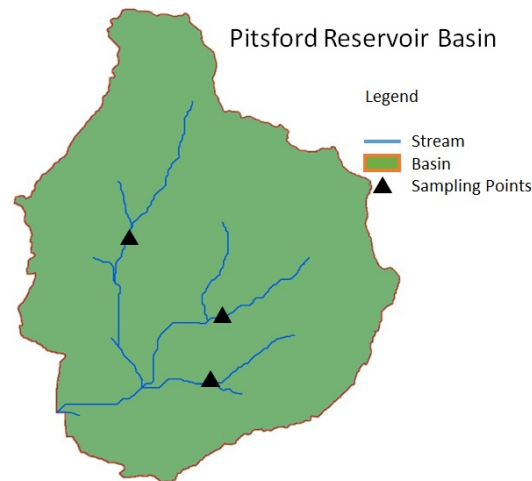
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Figure 1A. The study Region, Pitsford Reservoir Catchment

Model and Data

Soil and Water Assessment Tool (SWAT)

The SWAT model (Arnold and Fohrer, 2005; Arnold et al., 1998) is a watershed-scale model which operates on a daily time step. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields (e.g., fertilizer and pesticides) in large complex watersheds with varying soils, land uses and management conditions over long periods of time. It is continually being developed and was the product of four decades of modelling efforts by USDA-Agricultural Research Service, USDA-Natural Resources Conservation Service, and Texas A&M University. It has gained international acceptance as an interdisciplinary watershed modelling tool and is currently being used in close to 100 countries with over 1000 published peer-reviewed articles.

The main data requirements for SWAT modelling are Digital Elevation Model (DEM), land-use, soil and climate data.

Digital Elevation Model (DEM)

A DEM is a digital representation of the terrain's surface created from elevation data. As the topographic condition of the basin determines the direction and movement of water, a DEM is a vital requirement for SWAT. The DEM used in this study was the Ordnance Survey 'Terrain 5' for Great Britain, a grid of heighted points with regular 5 metre post spacing, see Figure 2A(a). The DEM was downloaded through the geospatial data service for academics 'Digimap' http://digimap.edina.ac.uk/.

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Land use

Land use data used in this study was the LandCoverMap 2007 (LCM2007) (CEH 2007). It is derived from satellite images and digital cartography and gives land cover information for the entire UK. The Land use data was downloaded through the geospatial data service for academics 'Digimap' http://digimap.edina.ac.uk/. The land use categories in LCM2007 were associated to their closest SWAT land uses (Table 1A); for the Pitsford catchment there are a total of 11 LCM2007 land uses and seven SWAT land uses, see Figure 2A(b).

LCM2007	SWAT
Broadleaved Woodland	Deciduous Forest (FRSD)
Coniferous Woodland	Evergreen Forest (FRSE)
Arable and Horticulture	Agriculture Generic (AGRL)
Improved Grassland	Grasslands/Herbaceous (RNGE)
Rough grassland	Grasslands/Herbaceous (RNGE)
Neutral Grassland	Grasslands/Herbaceous (RNGE)
Calcareous Grassland	Grasslands/Herbaceous (RNGE)
Acid grassland	Grasslands/Herbaceous (RNGE)
Fen, Marsh and Swamp	Emergent/Herbaceous Wetlands (WETN)
Heather	No Classification (NOCL)
Heather grassland	Grasslands/Herbaceous (RNGE)
Bog	Emergent/Herbaceous Wetlands (WETN)
Montane Habitats	No Classification (NOCL)
Inland Rock	South Western Range Rock (SWRN)
Saltwater	Water (WATR)
Freshwater	Water (WATR)
Supra-littoral Rock	No Classification (NOCL)
Supra-littoral Sediment	No Classification (NOCL)
Littoral Rock	No Classification (NOCL)
Littoral sediment	No Classification (NOCL)
Saltmarsh	Emergent/Herbaceous Wetlands (WETN)
Suburban	Urban Medium Density (URML)
Urban	Urban Medium Density (URML)

Table 1A. LandCoverMap2007 to SWAT classifications

Soil

Soil data used in this study was the Harmonised World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009). The Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) combined regional and

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national soil information with the information already contained within the 1:5,000,000 scale FAO-UNESCO Digital Soil Map of the World, to create the comprehensive Harmonized World Soil Database (HWSD). Three soil classifications are present in the Pitsford catchment as shown in Figure 2A(c).

Climate Data

Climate data used in this study is a combination of The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) 1979 through 2014 and *Anglian Water Rainfall Data 2014-2017 (Ref?)*. Climate data for precipitation, wind speed, temperature, solar radiation and relative humidity were downloaded from https://globalweather.tamu.edu/ with equivalent data for 2014, 2015 and 2016 appended from the weather station at Pitsford School (located 1km south of Pitsford reservoir) http://www.northantsweather.org.uk/.
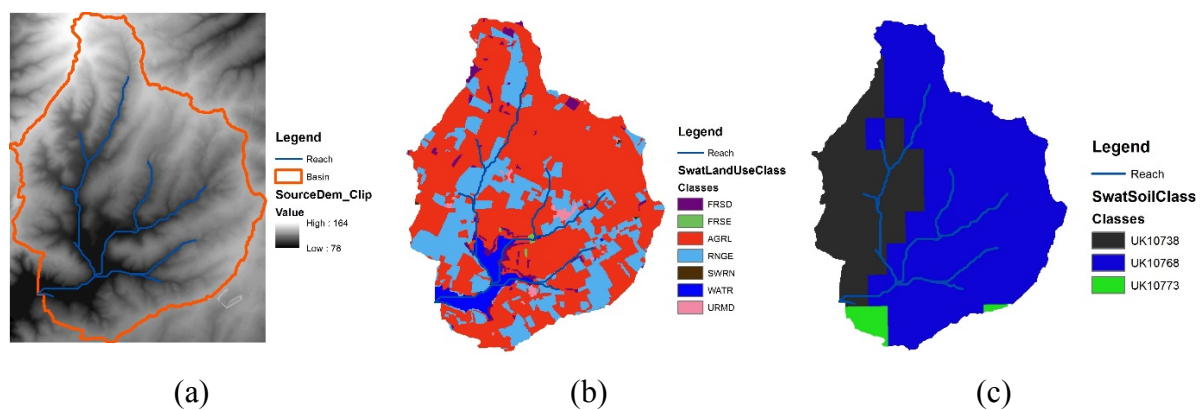

(a)   (b)   (c)

Figure 2A. Input data for SWAT Pitsford (a) DEM, (b) land use and (c) Soil data.

Results

Calibration - River Nene

To ensure that the hydrological model accurately reflects the local hydrological conditions the model needs to be compared to measured data. Since flow data is not available for the Pitsford NC we instead use data from the wider River Nene catchment. In particular, we compare flows on the River Nene as close as possible to the Duston Mill intake. The DEM, land-use and soil input for this model are depicted in Figure 3A.
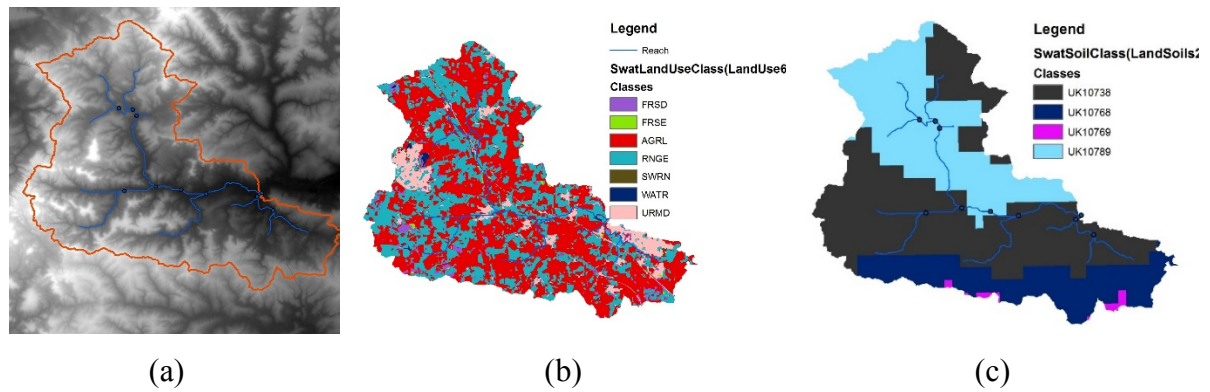
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<div align="center">(a)   (b)   (c)</div>

Figure 3A. Input data for SWAT River Nene (a) DEM, (b) land use and (c) Soil data.

The modelled streamflow was calibrated against the gauge point 032807 from the Environment Agency - Lincolnshire and Northamptonshire. We obtained the flow data from the National River Flow Archive which provides daily flow data from 1939 to 2015.

The River Nene SWAT model was run from January 1st 1990 to December 31st 2014. The first ten years were used to calibrate the model with results only outputted from January 1st 2000. Figure 4A shows the uncalibrated SWAT model against the gauged data for 2010 onwards. Observe that the model reasonably estimates the streamflow on the River Nene but divergences are clearly visible between the modelled and gauged flow data.
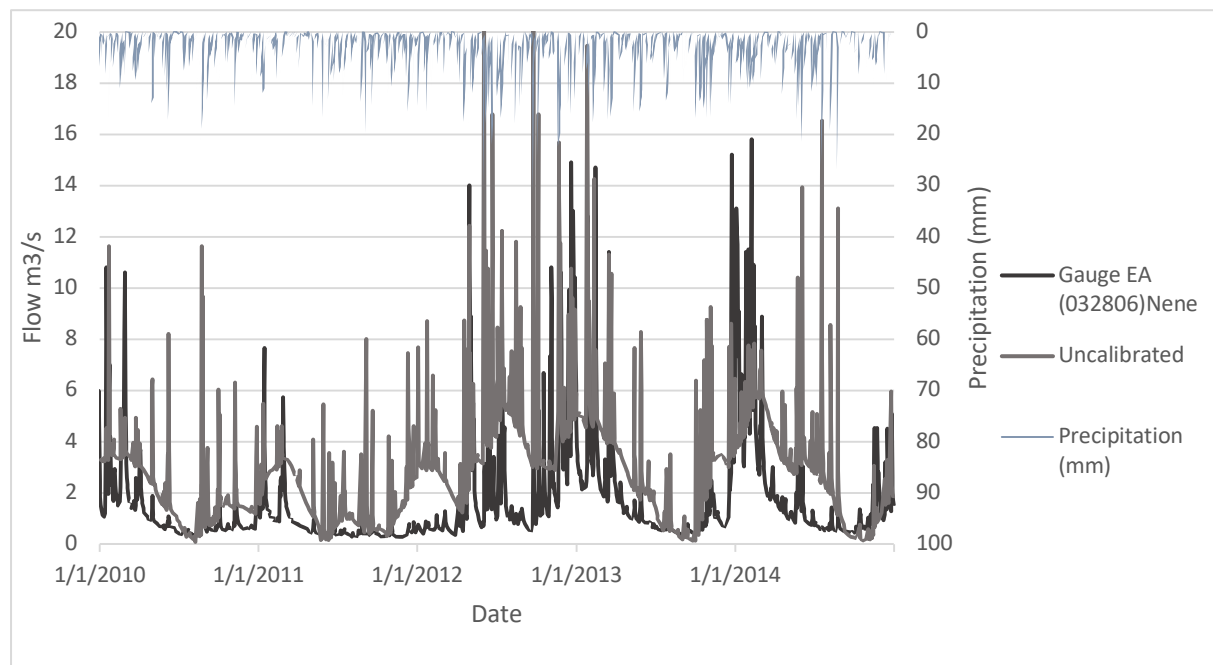

Figure 4A. River Nene Gauge Flow and Uncalibrated SWAT Model Flow.

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To provide a better fit between the gauged and model data we use SWATCUP to calibrate the parameters of the model. The parameters that were calibrated are listed in Table 2A. The optimisation program SUFI-2 (Sequential Uncertainty Fitting Ver.2) (Abbaspour *et al.* 2007) in SWAT-CUP (SWAT Calibration and Uncertainty Procedures) (Abbaspour 2007) is employed for the calibration.

Table 2A. Description of SWAT input parameters selected for calibration.

Parameter Name	Description	Initial Range		Final Parameters	
		Min	Max	B281	D179
r__CN2.mgt	Curve number for moisture condition II	-0.4	0.2	-0.050	-0.133
r__SOL_AWC(1).sol	Soil available water storage capacity	-0.2	0.2	-0.143	-0.253
r__SOL_K(1).sol	Soil hydraulic conductivity	-1	0.1	-0.889	-0.959
r__SOL_ALB().sol	Moist soil albedo	-0.2	0.2	0.096	0.137
v__ALPHA_BF.gw	Baseflow alpha factor	0.1	0.8	0.425	0.524
v__GW_DELAY.gw	Groundwater delay time	10	450	162.14	33.617
v__GWQMN.gw	Threshold depth of water in the shallow aquifer	1	1000	535.75	576.77
v__GW_REVAP.gw	Revap coefficient	0.02	0.2	0.175	0.165
v__ESCO.hru	Soil evaporation compensation factor	0.1	0.8	0.177	0.271
v__CH_N2.rte	Manning's n value for the main channel	-0.01	0.3	0.084	0.081
v__CH_K2.rte	Main channel conductivity	-0.01	250	99.942	136.42
v__REVAPMN.gw	Threshold water in shallow aquifer	10	150	97.890	98.426
v__SURLAG.bsn	Surface runoff lag coefficient	1	24	13.200	10.626
v__OV_N.hru	Manning's n value for overland flow	0	0.8	0.431	0.794

Figure 5A shows two calibrated SWAT model against the gauged data. Visually the two calibrated models estimate the streamflow well on the River Nene with only small divergences between the modelled and gauged flow data. To measure the fit of the model to the gauged data we use two common measures for hydrological models: Nash-Sutcliffe and R^2. The range of Nash-Sutcliffe lies between 1.0 (perfect fit) and $-\infty$. An efficiency of less than zero indicates that the mean of the observed time series would have been a better predictor than the model (Krause *et al.* 2005). R^2 is the proportion of variability in the data accounted for by the model and ranges from 1.0 (perfect fit) to 0. The calibrated model has a Nash Sutcliffe of 0.5 and R^2 of 0.52 which are both considered a 'good' level of fit in the hydrological literature.
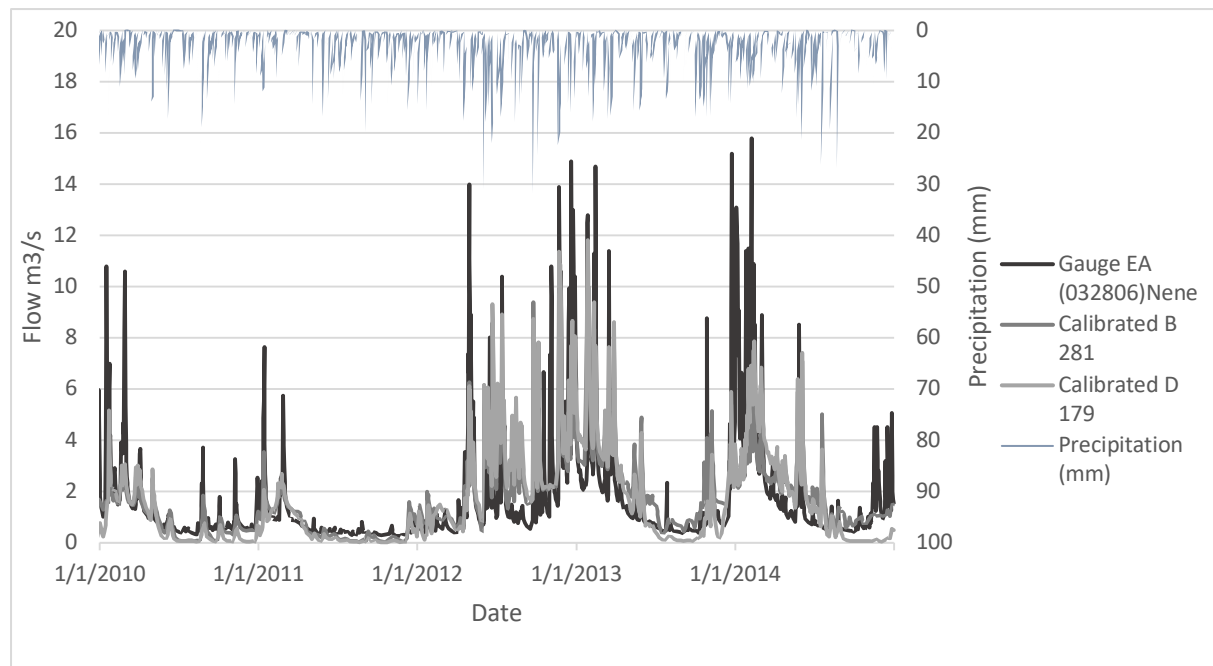
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Figure 5A. River Nene Gauge Flow and Calibrated SWAT Model Flow.

Pitsford NC

To estimated streamflow in the Pitsford NC we run the SWAT model with three sets of parameters—one set of uncalibrated parameters and two sets of calibrated parameters (taken from the best fitting models of the flow in the River Nene).

The SWAT model estimates flow from January 1st 1990 to January 31st 2017. The first twenty years were used to calibrate the model with results only outputted for the 7 years from January 1st 2010 to January 31st 2017.

Sampling Point 1: Scaldwell Brook

Results for daily streamflow at Scaldwell Brook are shown in Figure 6A from January 1st 2014 to January 31st 2017, the dark line represents the uncalibrated SWAT model and the two grey lines the calibrated models. The estimated streamflow for Scaldwell Brook is typically low, with flows above 1m³/s only occurring during a small number of large rain events. The average streamflow during the seven year period from 2010 was 0.08m³/s (calibrated) to 0.14m³/s (uncalibrated) with a maximum of 1.76m³/s (uncalibrated) and a minimum of 0.00m³/s (uncalibrated). During the SiO scheme (August 2015 to January 2017) the average streamflow was 0.02m³/s (calibrated) to 0.06m³/s (uncalibrated) with a maximum of 1.46m³/s (uncalibrated) and a minimum of 0.00m³/s (uncalibrated).
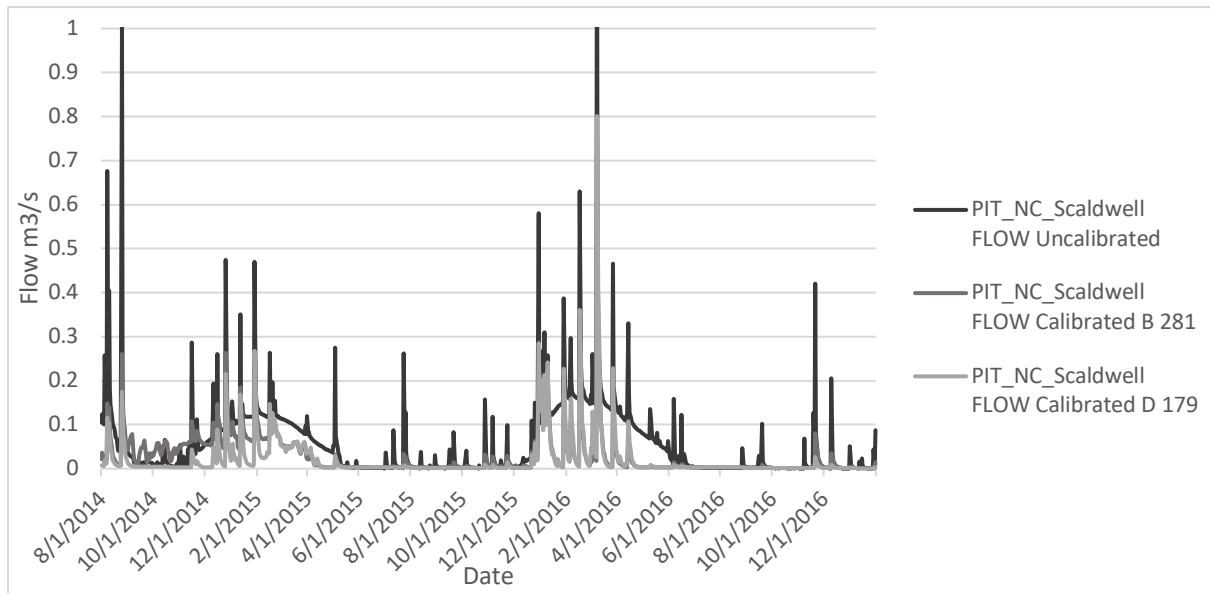
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Figure 6A. Scaldwell Brook Daily Streamflow.

Sampling Point 2: Walgrave Brook

Results for daily streamflow at Walgrave Brook are shown in Figure 7A from January 1st 2014 to January 31st 2017, the dark line represents the uncalibrated SWAT model and the two grey lines the calibrated models. The estimated streamflow for Walgrave Brook is typically lower than Scaldwell, with flows above 1m³/s only occurring once during the seven years. The average streamflow during the seven year period from 2010 was 0.06m³/s (calibrated) to 0.09m³/s (uncalibrated) with a maximum of 1.07m³/s (uncalibrated) and a minimum of 0.00m³/s (uncalibrated). During the SiO scheme (August 2015 to January 2017) the average streamflow was 0.02m³/s (calibrated) to 0.04m³/s (uncalibrated) with a maximum of 0.89m³/s (uncalibrated) and a minimum of 0.00m³/s (uncalibrated).
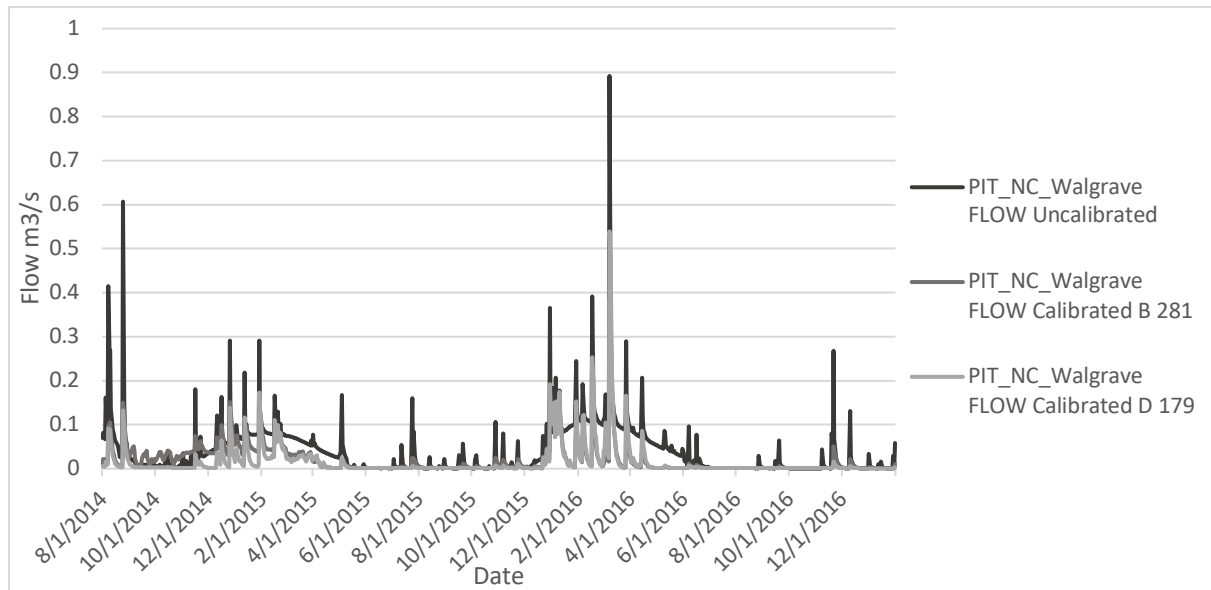
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Figure 7A. Walgrave Brook Daily Streamflow and Precipitation.

Sampling Point 3: Holcot Stream

Results for daily streamflow at Holcot Stream are shown in Figure 8A from January 1st 2014 to January 31st 2017, the dark line represents the uncalibrated SWAT model and the two grey lines the calibrated models. The estimated streamflow for Holcot Stream is typically lower than both Scaldwell and Walgrave, with no flows above 1m^3/s. The average streamflow during the seven year period from 2010 was 0.03m^3/s (calibrated) to 0.05m^3/s (uncalibrated) with a maximum of 0.60m^3/s (uncalibrated) and a minimum of 0.00m^3/s (uncalibrated). During the SiO scheme (August 2015 to January 2017) the average streamflow was 0.01m^3/s (calibrated) to 0.02m^3/s (uncalibrated) with a maximum of 0.50m^3/s (uncalibrated) and a minimum of 0.00m^3/s (uncalibrated).

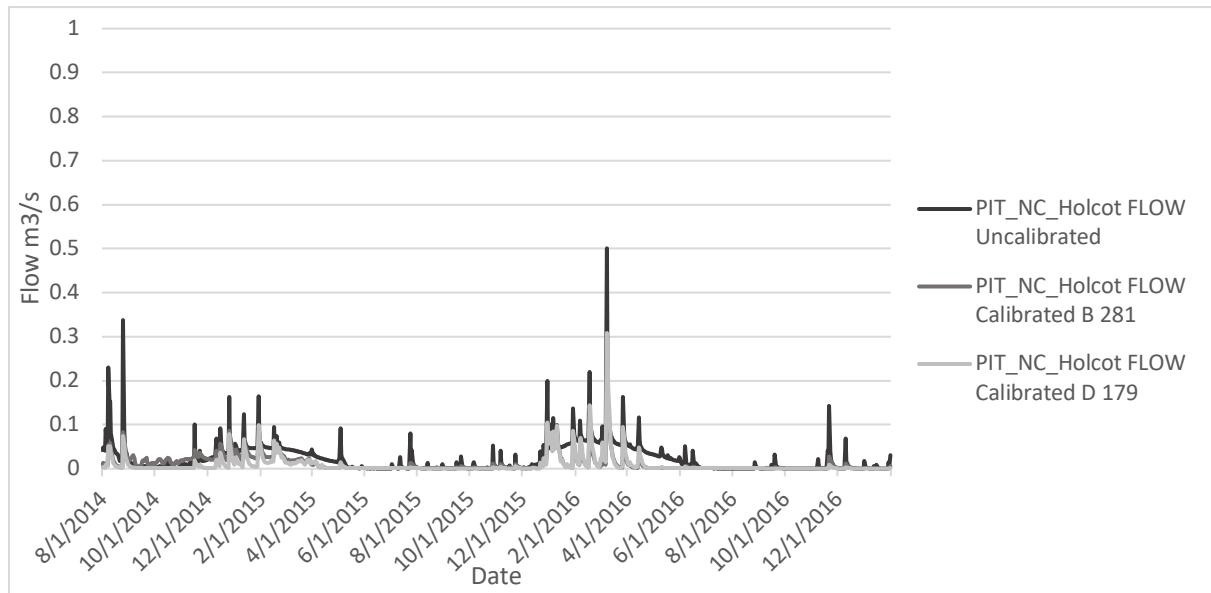University of Exeter, University of East Anglia and Anglian Water,

Figure 8A. Holcot Stream Daily Streamflow and Precipitation.