Test lowering of Mereway Weir November 2017 to November 2018

Draft Report, August 2019 Version 1

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Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH
Email: enquiries@environment-agency.gov.uk
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Introduction

The lower River Crane frequently runs dry for weeks or months at a time downstream of the tilting weir at Mereway Road. We have been investigating a solution to this low flow issue since 2013.

This investigation is closely integrated with two related projects:

The replacement of Mereway Weir, scheduled for delivery in 2019/20. The weir dates from the 1930s and is nearing the end of its lifespan. The results of this investigation will inform the design of a replacement weir to ensure that flows are regulated more sensitively than the existing structure.

The Crane Valley Partnership (CVP) Landscape Vision for the Lower River Crane, published in 2017. This ambitious vision aims to restore and enhance 3km of the lower River Crane running through Richmond and Hounslow. It is a major restoration project, with potential to deliver great benefits for the community. The feasibility study for the restoration project was completed early in 2019. Without improved flow, the restoration of the river channel will not be viable.

The flow in the lower Crane can be increased by altering the settings of Mereway Weir, which diverts flow along the lower arm of the Duke of Northumberland's River (DNR). Constructed in the 16th century, this artificial channel splits off from the River Crane upstream of Mereway Weir.

In the past, flow in the DNR has been favoured to the detriment of the Crane. This was believed to be largely because of the water supply requirements for Thames Water's abstraction on the DNR at Mogden Sewage Treatment Works (STW). The abstraction provides water for the cooling of Mogden STW power house. However, previous phases of this investigation have demonstrated that the Thames Water abstraction at Mogden is not the main limiting factor on the diversion of more flow to the River Crane in most circumstances.

Extensive data analysis, followed by a one-day test of altered level settings at Mereway Weir in October 2016, indicated that flow could be reduced in the DNR without compromising the abstraction. However, a longer-term test was required in order to assess the effects of lower flows in the DNR on its ecological and amenity value, and to ensure that the abstraction requirements could still be supplied during long dry spells.

Therefore a final investigation took place over the space of a year from November 2017 to November 2018. In this third and final report of our hydrology investigation, we document the results of that test and make recommendations for the future management of Mereway Weir to maintain improved water levels in the lower Crane.

Aims of this report:

- Analyse the hydrological and ecological data, fixed point photographs and gauge board data collected throughout the year of the test.
- Assess whether there were any negative impacts on the abstractions caused by reducing levels in the DNR.
- Assess whether there were any negative impacts on the DNR and if they can be mitigated.
- Provide recommendations toward the design and settings of a replacement weir and a new fish passage on the lower Crane.

Background information

Location and key sites

Mereway Weir is located on Mereway Road in Twickenham. It regulates the division of flows between the Lower River Crane and the DNR. There are two abstraction points on the DNR and flow gauging stations on both rivers.

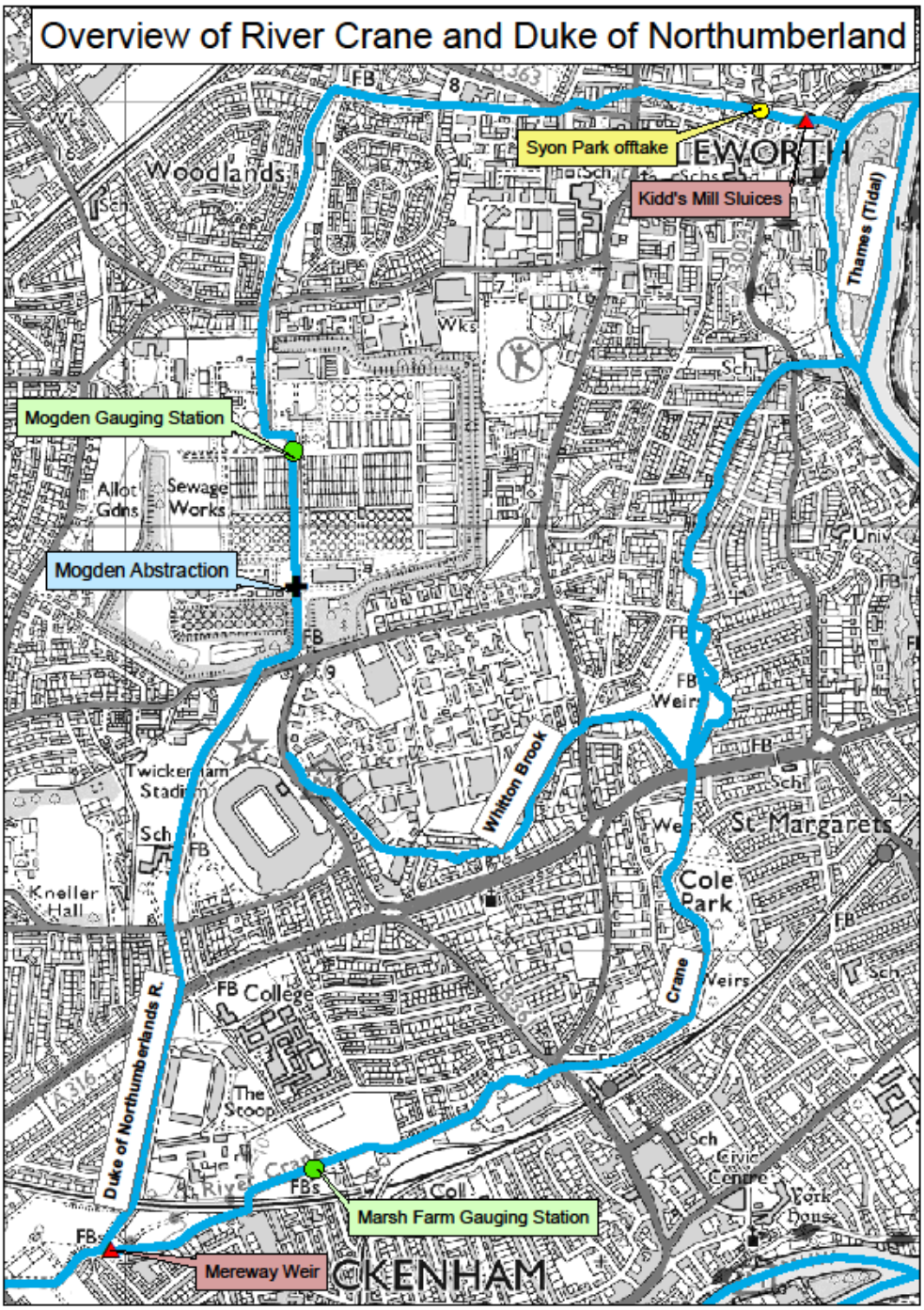

Figure 1. Map of River Crane and Duke of Northumberland's River showing sites being discussed.

Operation of Mereway Weir

The tilting weir at Mereway Road is designed to regulate the water level in the DNR. When water levels are rising the weir will adjust itself when levels upstream of Mereway exceed a set Upper Limit (UL). Every time the weir hits this threshold the weir tilts and lowers, releasing more water to the Lower River Crane. When the upstream levels are falling, the weir rises each time levels hit a set Lower Bound (LB). The range between the two level settings is called the deadband. This is a range of levels at which the weir will remain stationary and not raise or lower itself.

During flood events, the weir may lower until it lies flat on the riverbed. During these events the water level in the River Crane significantly increases while the water level in the DNR usually fluctuates by only a few centimetres.

Flow diverted to the River Crane during dry spells can be increased in two ways: by resetting the lower threshold, or by opening the penstock on a bypass channel. In both cases, flood risk will be unchanged as the way the weir operates during periods of high flow remains unchanged.

Review of possible options to improve the flow in the River Crane

The first hydrology report on this issue (dated February 2016) found that the level thresholds used until November 2017 for Mereway Weir have ensured that there is sufficient flow to feed the abstractions on the DNR in all flow conditions. However, for most of the time there is some 'spare water' which could be diverted to the Lower River Crane without impacting the abstractions on the DNR.

The key recommendation from this report was to undertake a test lowering of Mereway Weir while gathering flow data along the DNR and lower Crane.

Mereway Weir levels test 18th October 2016

On October 18th 2016, Mereway Weir was lowered to allow more water to go down the River Crane. This was done in two stages: a first lowering at 11:00 and a second at 14:00. The weir was then returned to automatic operation at 16:00.

During the test three flow gaugings were carried out on the DNR, while gauge board readings and fixed point photographs were taken every 30 mins. The abstraction at Mogden STW and Syon Park's abstraction at Kidd's Mill were also monitored.

After analysis of the data collected on the day we found positive results for all the potential showstoppers:

- The abstractions from the DNR continued to operate.
- Flow and habitat on the DNR were not significantly affected.
- No additional issues were identified for fish passage on the DNR.

The test also demonstrated significant potential benefits to the lower River Crane. The recommendation following the investigation was to carry out a further long-term test of the lowering of Mereway Weir levels, with ecological monitoring of the DNR and the lower Crane.

One Year Test (November 2017 to November 2018)

On 29th November 2017, Mereway Weir settings were changed to significantly increase low and medium flows in the Lower River Crane. This is considered the start date of the test investigation. However, from November 11th the bypass channel was open much more than usual, resulting in a significant increase in the flow in the Lower River Crane before the test officially started.

Some adjustments of the Upper Limit and Lower Bound settings were required in the beginning until the optimum settings were found. The first setting proved ineffective because the Lower Bound was not low enough, and flow ceased over the weir within a few hours. On the 13th December the settings were adjusted, but this resulted in the weir being unable to reach equilibrium, and caused flow to increase and decrease in regular pulses throughout each day. Finally on the 31st January 2018, the weir settings were adjusted again. This resulted in a stable flow regime with a constant flow over the weir. This final setting has the Upper Limit at 9.63 mAOD, and the Lower Bound at 9.53 mAOD. These settings were retained throughout the period of the test and up until present.

The test was planned for 12 months, with the weir settings to remain in place unless a showstopper had been identified during the review of the data collected throughout the investigation. The data collected is presented and analysed in this report.

Interpretation of data collected

Data available

- River Crane at Cranford gauging station (3660TH) – day mean flow data from 1977 to present. This gauging station is approximately 8.5km upstream of Mereway Weir.
- River Crane at Twickenham (Marsh Farm) gauging station (3680TH) – day mean flow data from 1977 to present. The river is quite wide here, the channel gets very weedy during the summer and at the low flows measured by the gauging station may be slightly overestimated.
- Duke of Northumberland's River at Mogden gauging station (3695TH) – day mean flow data from 1977 to present. This gauging station is downstream of Thames Water's Mogden abstraction. The low flows measured at this gauge may also be slightly overestimated.
- Mogden abstraction data from 1999 to present.
- Level data upstream and downstream of Mereway Weir from July 2010.
- Logged level data from logger installed between Mereway Weir and the railway bridge on the DNR from October 2016 to December 2018.
- Flow gaugings carried out at 5 sites on the DNR and 1 on the Crane from November 2017 to November 2018.
- Gauge board readings from 5 locations along the DNR, and 5 locations on the Crane, collected monthly.
- Fixed point photographic evidence along the DNR and the River Crane, taken monthly by volunteers.
- Fish survey data from surveys carried out on the DNR and the River Crane in 2017 and 2018.
- Invertebrate surveys carried out in spring and autumn in 2017 and 2018 on both rivers.
- Habitat surveys carried out along both rivers in 2015 and 2018.

Hydrological conditions

Rainfall data shows that summer 2018 was very dry. By analysing the summer months (April to September) we found that summer 2018 was the 6th driest summer on record for North London, and the driest since 2003. The record goes back to 1910.

Figure 2 shows the surplus/deficit plots of areal rainfall vs the long term average (1961-90) for the North London Areal Unit. Red indicates lower than average monthly rainfall and blue indicates higher than average monthly rainfall. We can see that for the months leading up to the test and for several months throughout the test, rainfall was significantly below average. Early summer 2018 was particularly dry with just 0.2mm of rain recorded between 30 May 2018 and 27 July 2018 at the Heathrow Rain Gauge.

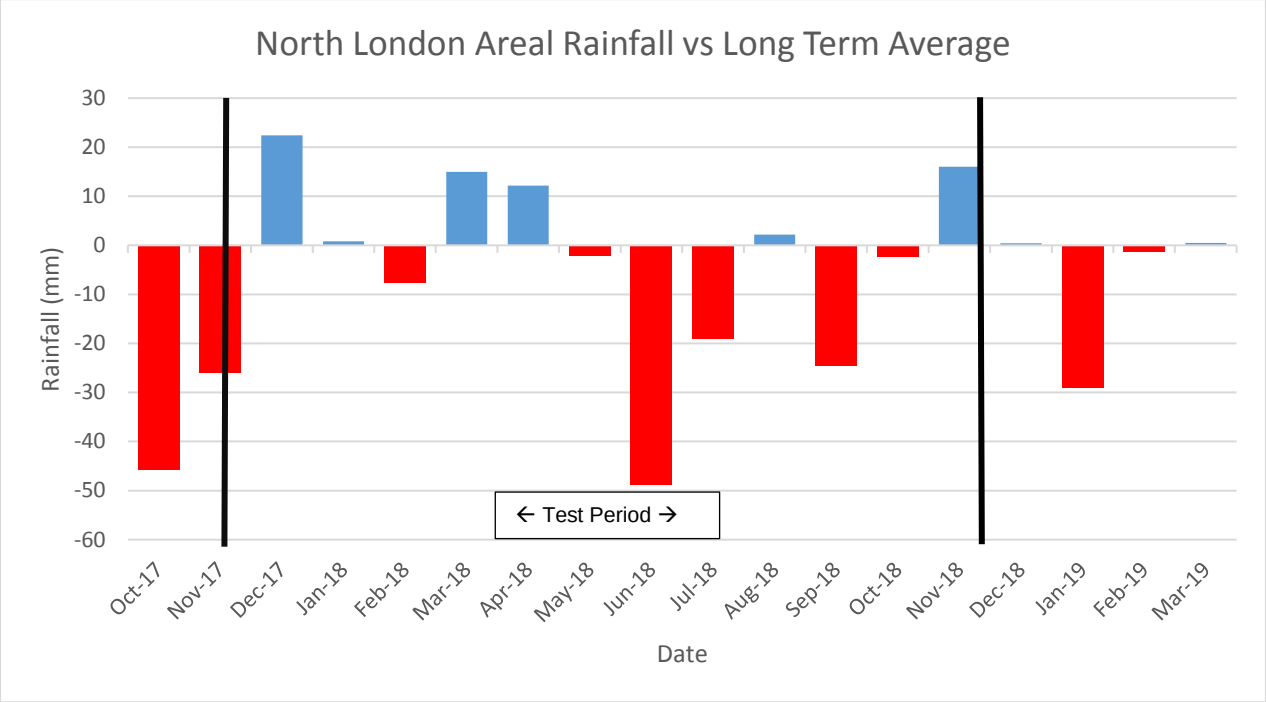

Figure 2. North London Areal Unit surplus/deficit rainfall vs the long term average.

Testing during such a dry summer gives us good confidence that the results from this test are suitable to assess hydrological and ecological conditions in future dry years.

Analysis of results - Duke of Northumberland's River

Abstraction on the DNR

There are two locations on the DNR where a legal right exists to abstract water from the River. We therefore need to ensure that sufficient water remains in the DNR to support these abstractions. The two abstractions are:

- One for cooling Thames Water's Mogden Sewage Treatment Work (STW)
- One at the bottom of the DNR used to top up water levels for the fishing lakes at Syon Park.

In order to protect abstraction volumes a low flow alarm was installed at Mogden Gauging Station to alert the Environment Agency when flows in the DNR fall below a certain level. There are two settings on the alarm; one is set well above the required flow as an early warning so flows can be reviewed to see if they are falling and identify whether there is a risk of falling further. The second is set to identify very low flows at Mogden Gauging Station. If this level is reached Environment Agency staff will review whether action needs to be taken to ensure abstraction can continue at Mogden and Syon Park. During the test period the early warning alarm 0.1m^3/s was reached on a number of occasions, but never with a significant falling trend. In total, river flow was below the early warning alarm for 1% of the test period. Flow never reached the low flow alarm level of 0.05 m^3/s, the lowest flow recorded was 0.096 m^3/s. This shows that the chosen settings protected the required quantities of water for abstraction across the flow regime.

We have contacted both abstractors following the test and whilst both noticed a reduction in flow, this did not cause them to be unable to abstract water at any point during the year of the test.

Hydrological Analysis

The following hydrological analysis was carried out using flow data from the gauging station at Mogden Sewage Treatment Works (STW) on the DNR, and from spot flow gauging carried out monthly.

Flow Duration Curves (FDC)

River flows change naturally throughout the year, so we use flow statistics to capture flow variability from high to low flow conditions. Flow duration curve statistics are expressed as the percentage of time that flow is exceeded. A Q95 is the flow in a river which is exceeded on average for 95% of the time. A Q95 is normally taken as a low flow, whereas a Q30 is usually a relatively high winter flow.

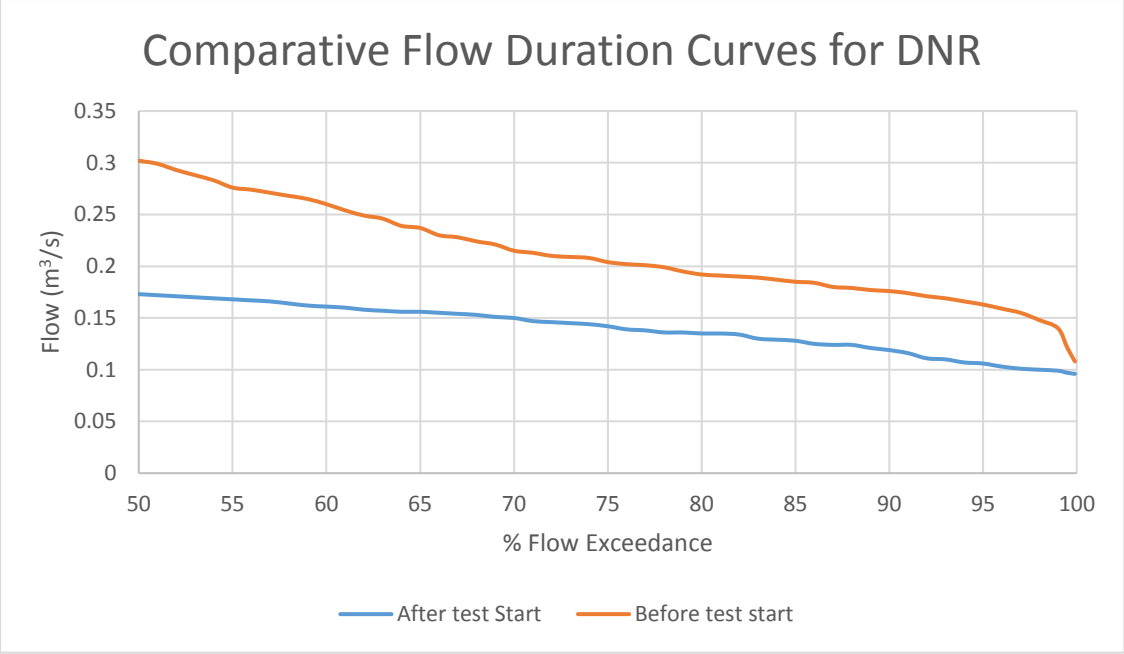

Figure 3 Flow duration curves for Mogden Gauging Station on the DNR for the year before the test (Nov 2016 - Nov 2017) and for the test period (Feb 2018 – Dec 2018). The graph is focussed on med - low flows Q50-Q100.

Figure 3 compares flows in the year before test start and then for the 11 months from Feb 2018 to December 2019. Dec 2017 and Jan 2018 are excluded because the settings on the weir were not operating as expected during these periods resulting in anomalous flows. The graph shows only Q50 and above to focus in on the periods of lower flow during the year. As expected, flows were lower after February 2018, on average by around 0.06m^3/s. Some of this difference may be explained by the drier weather conditions in 2018. However, most of the change is due to the change in levels settings at Mereway Weir, as evidenced by the corresponding increase in flows in the Lower Crane (see Figure 25).

The setting of Mereway Weir needs to ensure enough water is present in the DNR to fulfil the abstraction requirements of Thames Water and Syon Park. The flow measured at Mogden gauging station is downstream of the Thames Water abstraction, and therefore shows us the flow that is passed on downstream to the remainder of the DNR and to the Syon Park abstraction. Flows remained above 0.1m^3/s for 99% of the test and only fell marginally below this level. The test can therefore be considered to be an assessment of the impact on the DNR of reducing flow to 0.1m^3/s. Given the dry weather experienced we would consider that if the abstractions and ecology remained functional and healthy during the test period, then the test will have successfully proven that it is appropriate to continue with the new flow regime and with a minimum target flow of 0.1m^3/s for Mogden GS.

Spot Flow Gauging

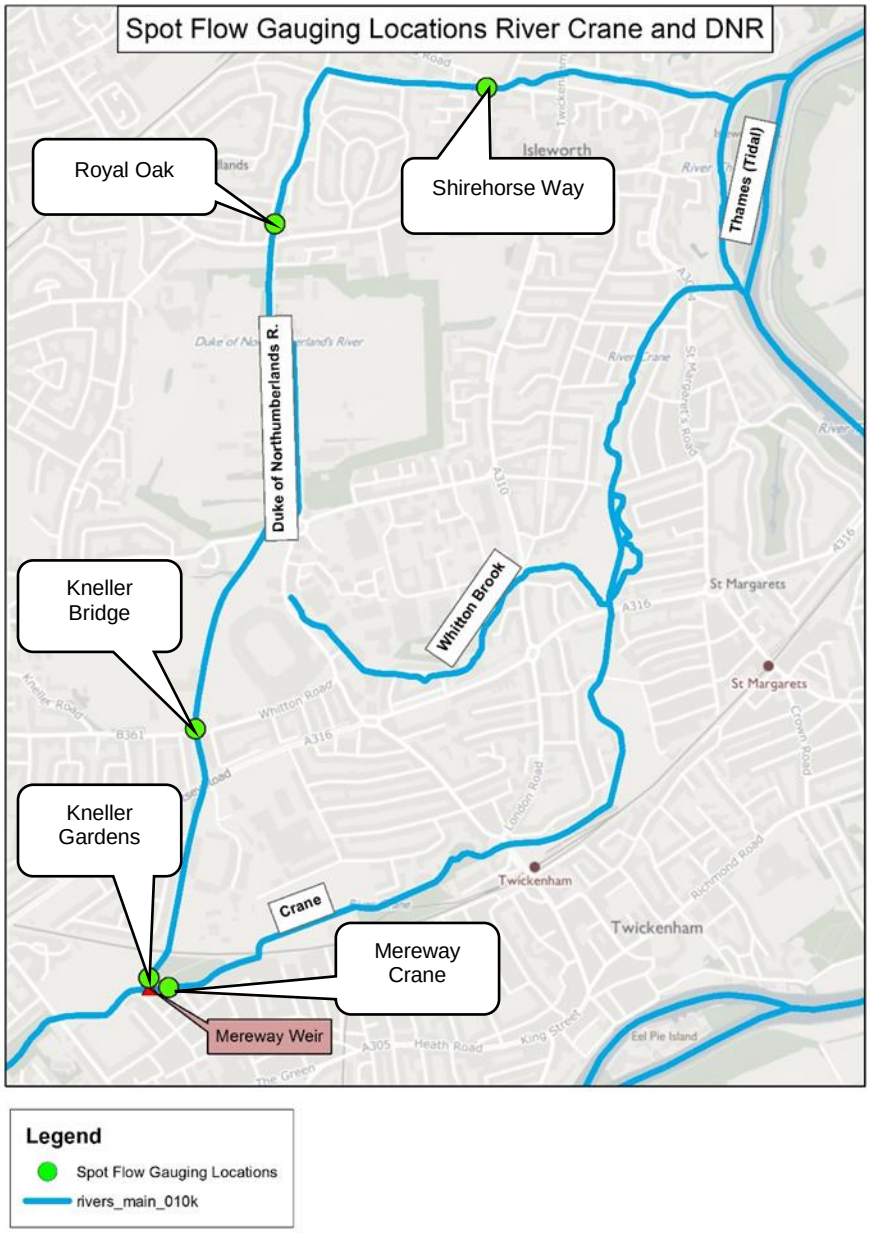

Figure 4: Map of spot flow gauging locations in the study area.

Spot flow gauging was carried out at 4 points along the DNR every month from the 17th August 2017 until 23rd October 2018. This data can be used to assess how flow velocity has changed in the DNR. The locations selected for spot flow gauging are areas of differing habitat and in different reaches of the DNR. There is also one spot gauging location on the Lower River Crane. Spot gauging is useful allows us to ground-truth the gauging station data, but is limited as it's only at one point and at one point in time. For this project, it was also useful to measure flow velocities. Velocities are particularly useful in determining the changes in the flow regime and the associated impacts and changes for habitats for fish and invertebrates. Gauging stations do not measure velocity directly.

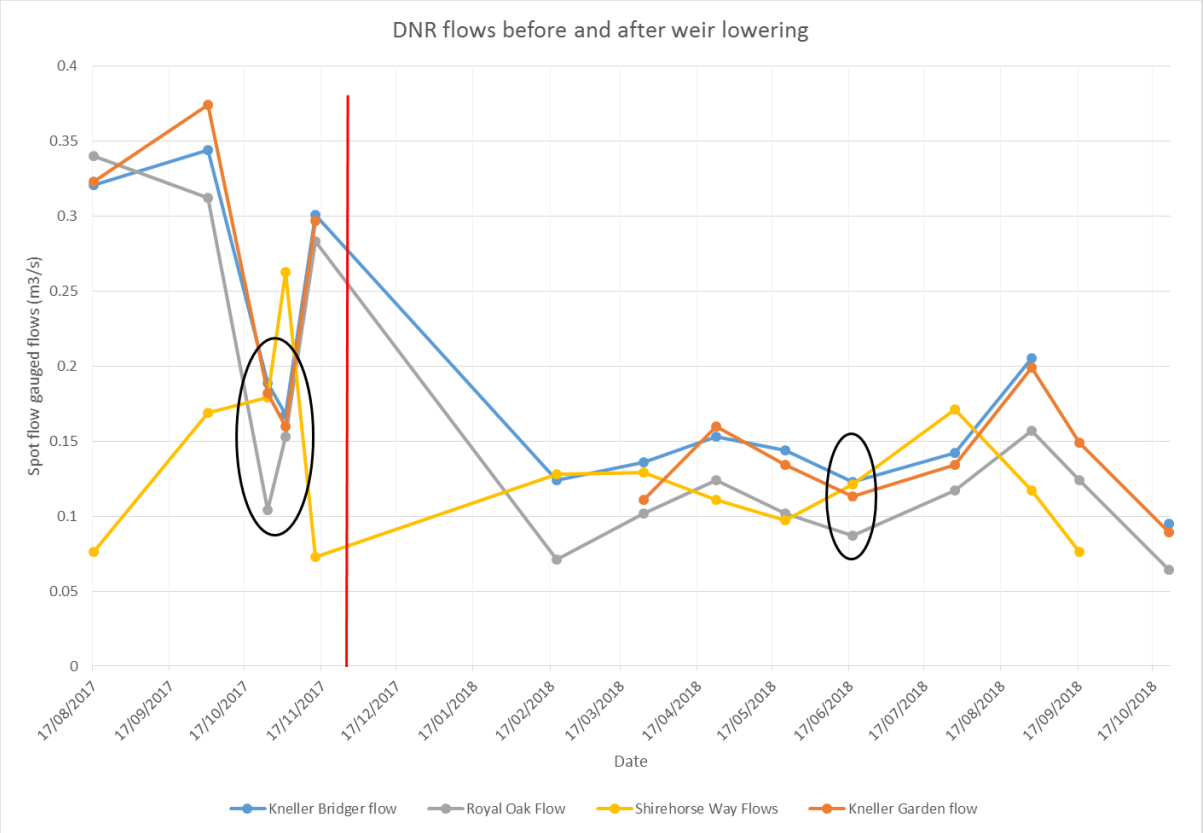

Figure 5. Average flows of DNR from before and after the lowering of Mereway Weir. The red line represents the start of the test period. The points circled represent similar periods of low flow measured upstream at Cranford gauging station before and after the test start as shown in figure 6.

Comparing periods of similar flows and weather conditions from before and after the test, at first glance the velocities look averagely lower after the test start date. Some of this difference can be explained by the relatively drier conditions in much of 2018 compared to autumn 2017. The flows gauged in the DNR during periods of low flow, as measured at Cranford gauging station, before and after the test (Nov 2017 and June 2018) are compared below in figures 5 and 6. Table 1 shows the percentage reduction in flows. It is important to note that the spot flow gauging shows only a snapshot of the flow at the time of measurement on any given day. The gauging station data is continuous data collected every 15 minutes and is averaged over 1 day to give the average daily flow and shows the average daily flow for the river at that point.

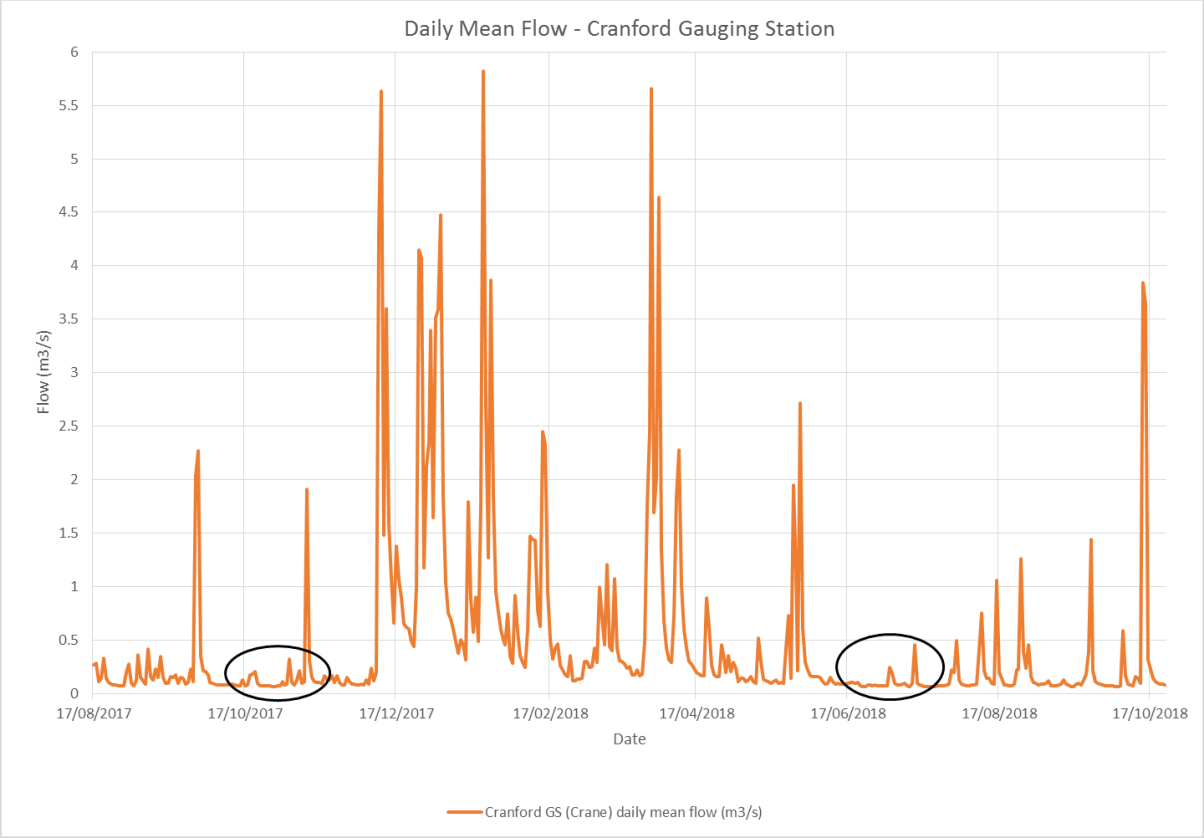

Figure 6. Daily mean flow measured at Cranford gauging station. The circled areas highlight similar periods of low flow before and after the test.

The dates spot flow gaugings were carried out during the periods of low flow highlighted in figure 6 were 26/10/2017 and 18/06/2018. On these days the daily mean flow measured at Cranford gauging station was 0.069 m3/s and 0.099 m3/s respectively.

Site	26/10/2017 - before test (m3/s)	18/06/2018 - during test (m3/s)	Difference in flow (cumecs)	Percentage Reduction
Kneller Gardens	0.182	0.113	0.069	38%
Kneller Bridge	0.189	0.123	0.066	35%
Royal Oak	0.104	0.087	0.017	16%
Shirehorse Way	0.169	0.097	0.072	43%

Table 1. Table comparing gauged flows on the DNR during periods of low flow before and after the lowering of Mereway Weir.

The spot gauging data confirms that there is a significant drop in flow on the DNR during dry periods. This is as expected, given the aim of the test was to try ensure more flow was diverted to the lower River Crane at low flows. This investigation will seek to determine whether this reduction in flow had a negative impact on the ecology of the DNR.

Hydrographs

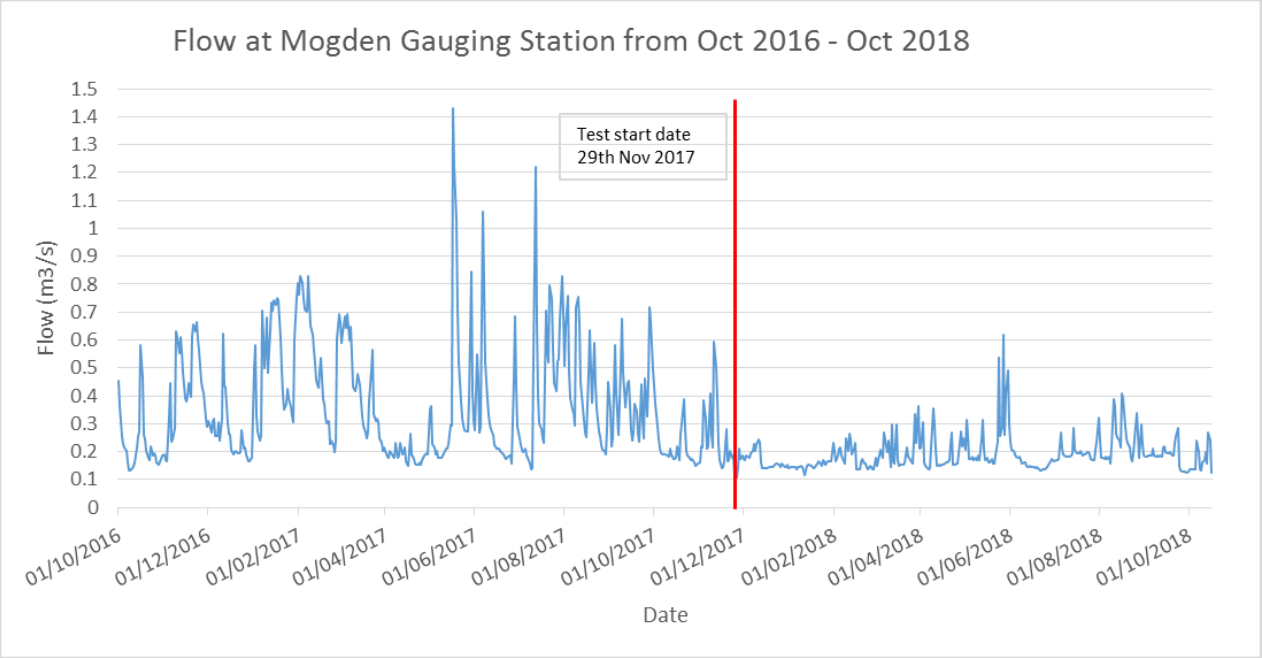

Figure 7: Graph of average daily flow at Mogden Gauging Station on the Duke of Northumberland's River.

Figure 7 shows the flows of the DNR at Mogden gauging station for the year before and after the lowering of Mereway Weir. After the weir was lowered, peak flows are noticeably reduced with flows only once exceeding 0.5m^3/s in 2018 despite being regularly reached in 2016 and 2017. Flows during drier periods are more similar, generally falling between 0.1 and 0.2m^3/s both before and after the test, although before the test low flows are often in the upper end of this range. After the test start flows during drier periods are more in the lower to mid areas of this range. Using daily flow figures (the average flow for each day) the flow in the DNR never fell below 0.1m^3/s.

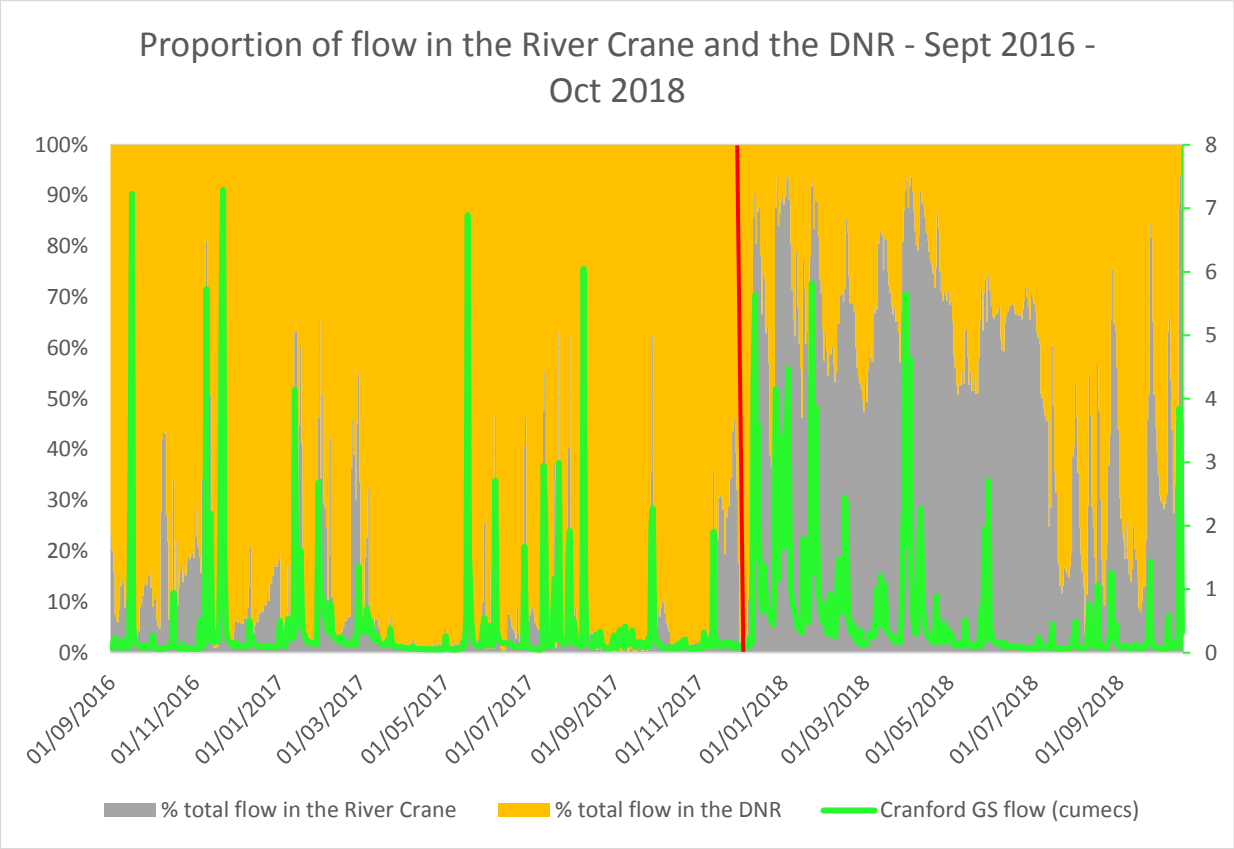

Figure 8. The split in flow between the River Crane and the DNR from September 2016 to September 2018. The red line marks the start of the test, when the weir was first lowered. The green line shows the flow as measured at Cranford gauging station upstream of the weir.

Figure 8 shows the proportion of flow in the River Crane compared to the DNR. The settings of the weir before the test clearly favoured the DNR, and left the River Crane virtually dry on many occasions. After test start the split of flows between the two rivers is more even, although the Crane seems to be favoured during the higher winter flows with the DNR being favoured in the lower summer flows. It is clear, when compared to the flow at Cranford gauging station that this increase in flow in the Crane is not a result of increased rainfall during the test period. Enhanced protection of the DNR will be appropriate under some conditions as the abstractors have a legal right to take water. However, much of the variability is believed to be due to the lack of fine control at Mereway Weir. It is expected that when the structure is upgraded a more consistent split between the two rivers could be achieved to meet the balance of needs.

Gauge boards and fixed point photography on the DNR

Throughout the investigation, volunteers and Environment Agency staff collected monthly fixed point photographs to monitor flow and habitat change on the River Crane and the DNR. Photographs were also taken of each gauge board to monitor changes in water level. The two rivers were divided into 8 reaches, and each reach was taken on by a volunteer or small group of volunteers.

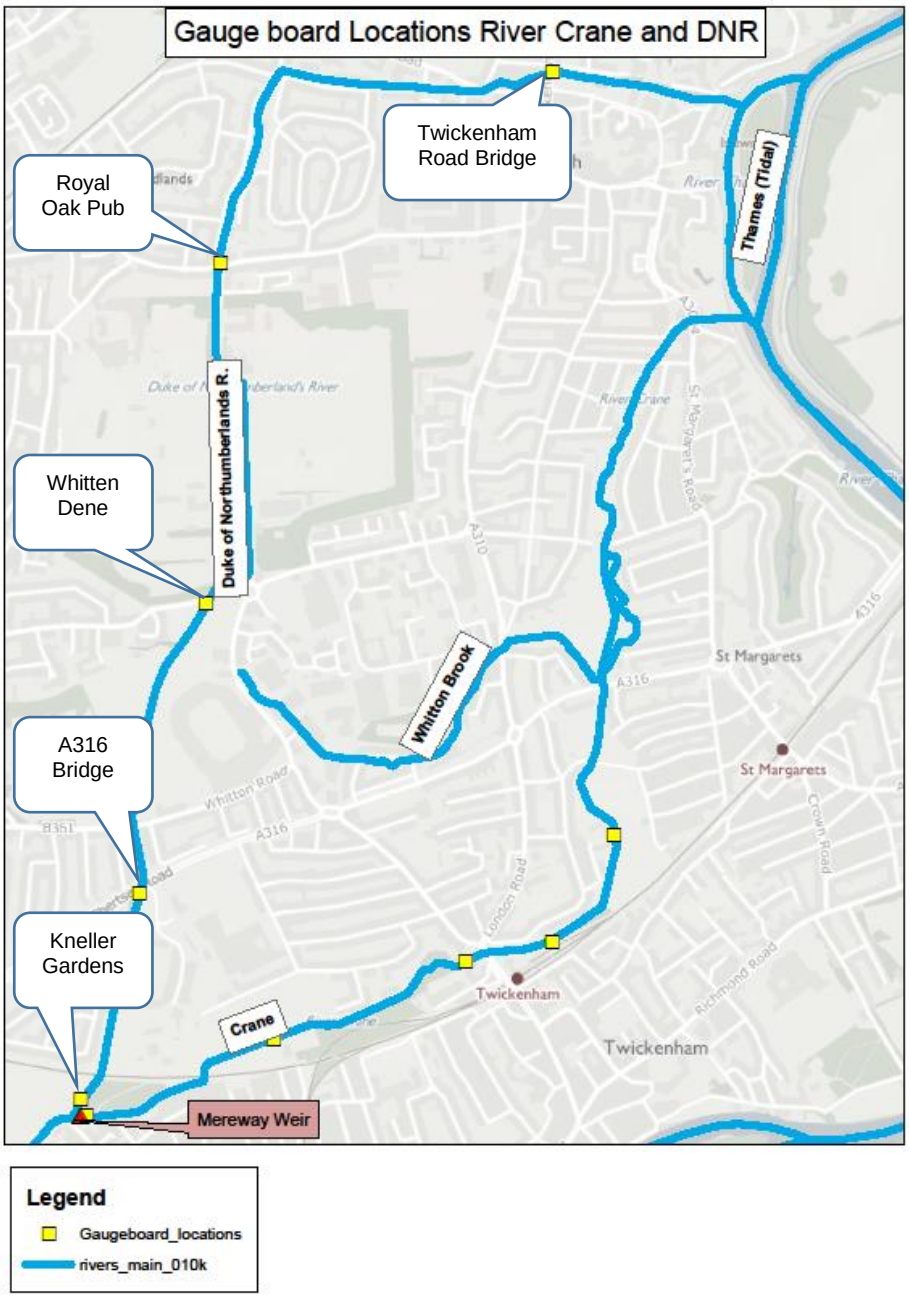

Figure 9. Map of gauge board locations along the DNR and River Crane.

The gauge board readings from the boards along the DNR show minimal change throughout the year. Additionally, the range of levels recorded were in keeping with levels seen in the October 2016 test. All boards, except Royal Oak Pub show a slight increase in levels at the end of June. This is likely to be a result of the level at Mereway Weir rising (and thereby

favouring flow into the DNR) as the flows from the upper Crane reduced during the drier months.

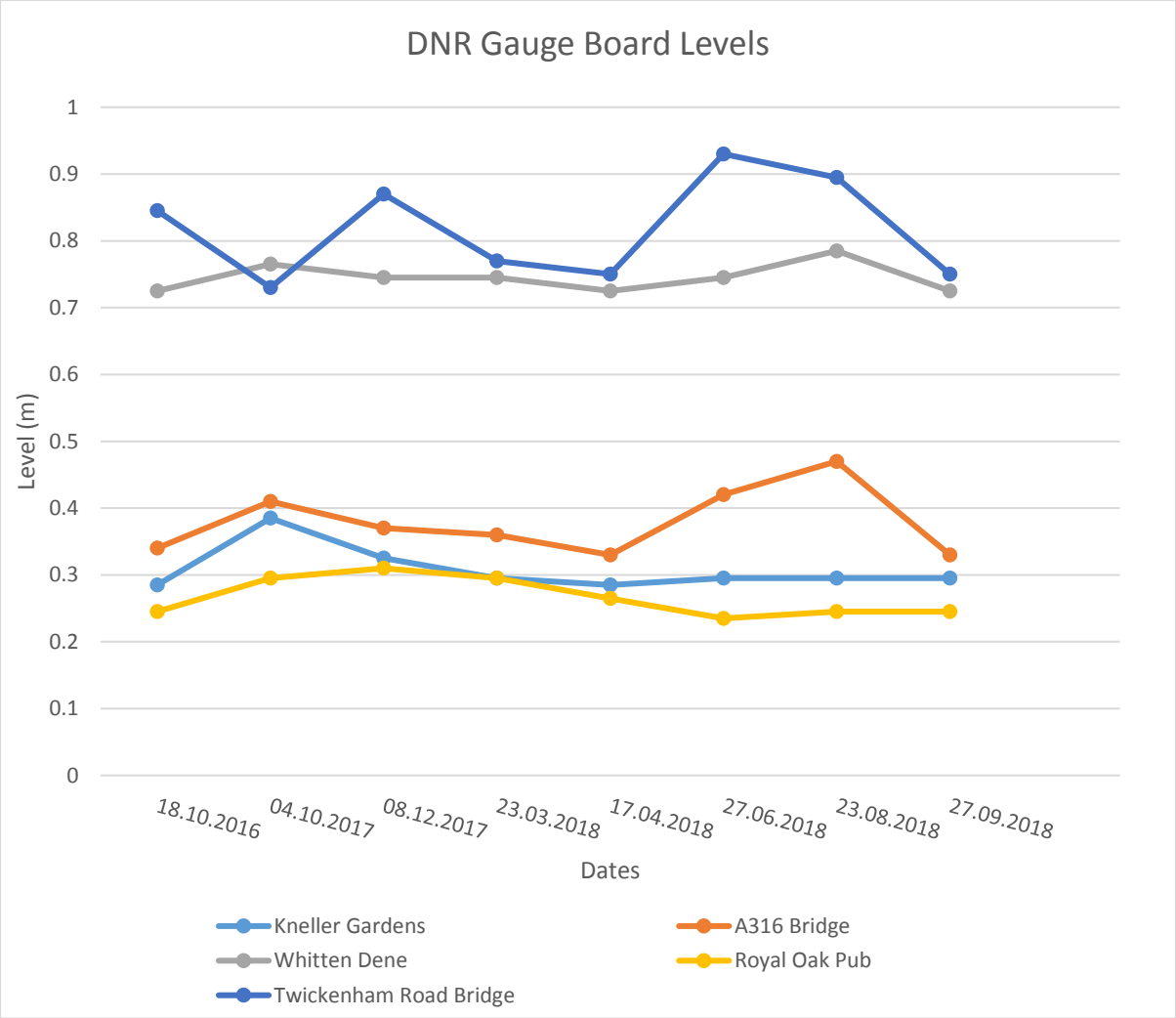

Figure 10. Gauge board levels on the DNR. The first point is the date of the one day test carried out in 2016.

Fixed Point Photography

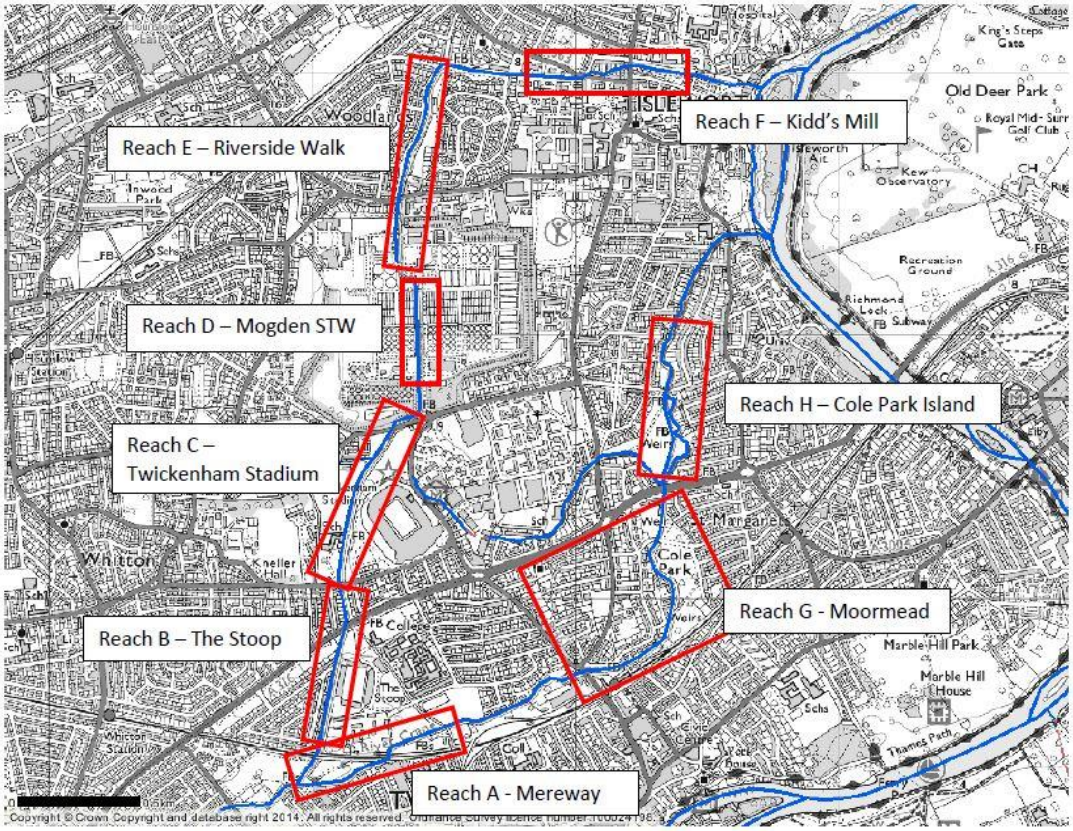

Figure 11. Map of the reaches used for fixed point photography, done by volunteers.

The photographs give us an overview of how each river reacted to the change in weir levels throughout the year. The photographs were collected during a period of prolonged dry weather, meaning that any low-flow impacts on the DNR would have likely been increased. The photos indicate that there has been no significant change in both biodiversity and morphology since the lowering of Mereway Weir, in the observed year. Warmer and drier weather over the summer increased the amount of marginal vegetation and macrophyte growth, with limited impact on change in morphology. It should be noted that in-channel improvement works for the Duke of Northumberland's River Improvement Works Project (London Wildlife Trust, London Borough of Hounslow and Crane Valley Partnership) in March 2018 at Riverside Walk (Reach E), greatly improved the morphology and habitat in this area.

Figure 12: Before and after photographs of a location in reach Reach C upstream of Kneller Road on 04/10/17 (Before) and 09/10/18 (After).

The vast majority of sites showed expected patterns of changes throughout the year, with few noticeable differences between 2017 and 2018. For example in Figure 12 the vegetation that has established in the summer season, is visible in both pictures. This common reed helps to narrow the channel. Flow appears consistently low both before and after the Mereway Weir lowering. The flow velocity in the channel is still low and channel likely over-wide. It is therefore likely that the lowering of the weir has not had a significant impact on the flow conditions within this reach, where the reeds naturally narrow the channel to increase flow velocities.

Figure 13: Before and after photographs of a location in reach C near Twickenham Stadium on 16/08/17(Before) and 10/08/18 (After).

The only reach with a clear difference between 2017 and 2018 was in the area near Twickenham Stadium as shown in Figure 13. The DNR is over-wide with uniform sediment deposition across the channel at this location. There is a significant difference between the morphology of this reach from 2017 to 2018. Reeds exist on the bank in both photos but they are much more established in August 2018. Unbranched Bur-reed has grown in the centre of the DNR, which is likely due to the uniform sediment deposition. These changes may be due to reduced peak flows in the DNR, but will also be affected by the warmer and drier than average summer.

Urban River Survey (2015 – 2018)

Urban River Surveys (URS) were carried out on the River Crane and the DNR before and after the change in flows to record changes in habitat. URS is a scientific assessment developed by Queen Mary University of London which records information on the physical structure of 500m stretches of urban rivers and their margins. URS uses indices calculated from survey data to assess the relative physical quality of individual surveyed stretches within the range achievable in an urban environment. Surveys were carried out for from June to September in 2015, 2016 and 2017 before the test, and in August 2018 in the summer after the test start. Six sample reaches were used for the DNR, starting upstream to downstream: Stoop Memorial, Chase Bridge, Rugby Football Union, Mogden Sewage Treatment Works, Old Brewery and Silver Hall Park.

The individual stretches of river surveyed cover the majority of the DNR from Mereway Weir to Silver Hall Park. More information on the technique and the full results for the River Crane and DNR can be viewed on the URS website[1]. In general very little difference was found between the two surveys for the majority of criteria measured under URS.

[1] https://urbanriversurvey.org/

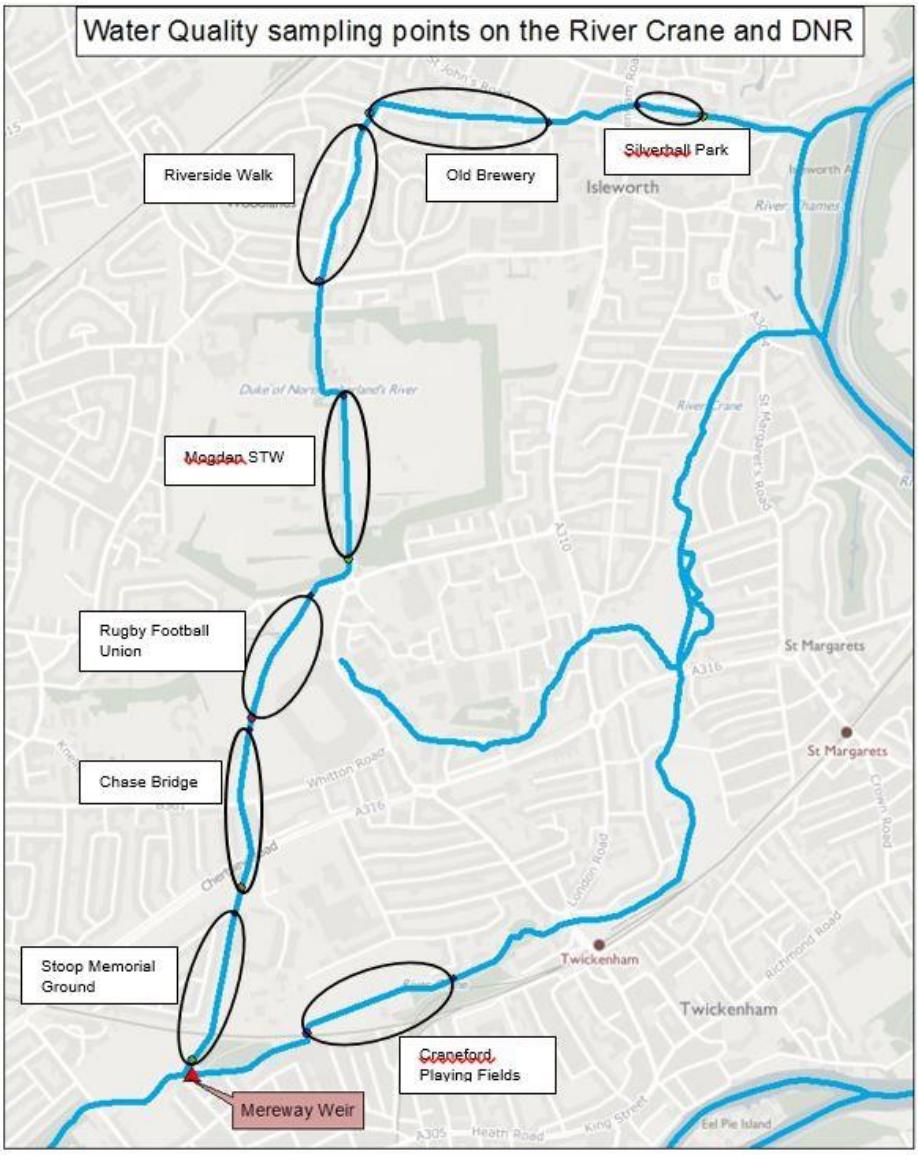

Figure 14. Urban River Survey reaches on the DNR and River Crane

Dominant Flow Type

One assessment criterion which may have been expected to change is the dominant flow type. However, we found no change in the before and after surveys with all sites recording a dominant flow type of 'smooth'. This is as expected, given that the DNR is a low gradient artificial channel.

Stretch Habitat Quality Index (SHQI)

Another key measure is the Stretch Habitat Quality Index (SHQI), which provides an overall score by combining the Materials, Physical Habitat and Vegetation Classes scores. Higher scores indicate more artificial influences on the river (less natural). We found that SHQI scores stayed the same in the after survey except for three reaches:

- The reach running past Twickenham Stadium, recorded a score of 8 in 2015, rising to 11 in 2018, due to loss of bank side connected tree cover decreasing from Moderate to Low. This is likely due to changes in tree cover and riparian vegetation that have occurred between 2015 and 2018 as part of the Duke of Northumberland River Improvement Project, carried out by the Crane Valley Partnership.

- The survey reach near Mogden STW improved from a 15 in 2015 to a 12 in 2018, due to Physical Habitat improving from Stable to Semi-natural. The reach near the Twickenham Stoop Memorial also improved from an 8 in 2015 to a 7 in 2018, going from Semi-natural Moderately Active to Semi-natural Active, indicating an increased number of varied habitat types. In both these reaches marginal vegetation seems to have narrowed the channel and thereby increased the diversity of flow habitats. This could be a further result from the work carried out as part of the Duke of Northumberland River Improvement Project. A reduction in high flows following the test could helped this marginal vegetation, or may be due to plants becoming more established thereby enabling further narrowing. This is likely to be a positive change for the river increasing habitat diversity and providing shelter for fish fry.

Based on this data our conclusion is that the URS data does not show a significant impact on habitat quality due to the reduction of flow in the DNR.

Water Quality

Our standard water quality monitoring for the DNR involves spot sampling to monitor priority substances. Spot sampling is carried out monthly at several sites along the River Crane and DNR. For this investigation 3 sites' data was analysed, one upstream of Mereway Weir, and two sites downstream of the weir on the Crane and DNR.

To improve our understanding of water quality during the test period we installed a real time water quality monitor (called a sonde) at Shirehorse Way (see Figure 15). We also analysed data collected for the Citizen Crane project and from Environment Agency spot sampling in order to gain the best possible understanding of water quality on the DNR.

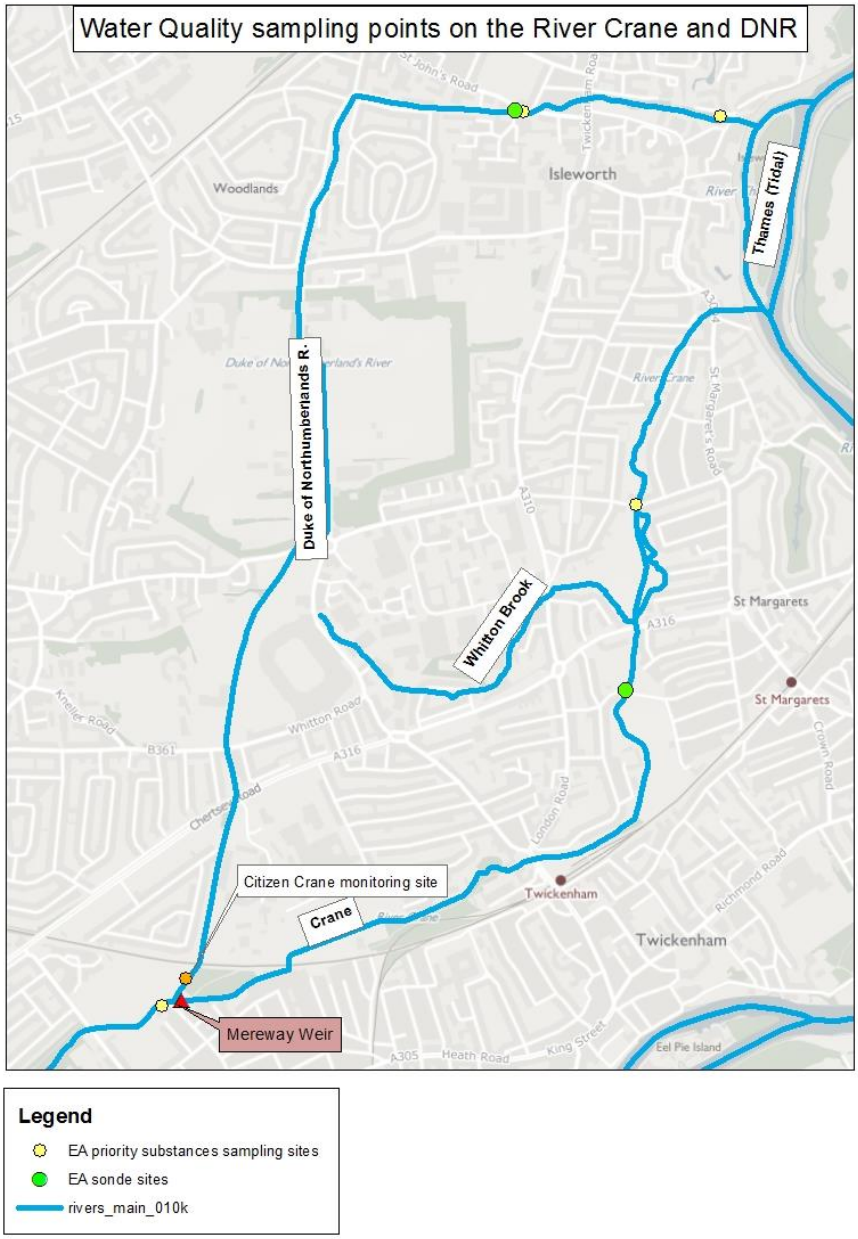

Figure 15. Locations of the monitoring sites on both rivers used to monitor water quality parameters.

Sonde Water Quality Data

Real time water quality data was collected from November 2017 to October 2018. The parameters measured by the Shirehorse Way sonde are shown in Table 2.

Temperature	Affects aquatic species growth and development, reproductive success, and disease resistance.
Conductivity	Useful indicator of water quality, as many minerals and runoff from fertilizers produce ions that affect the conductivity (not measured for WFD)
pH	Changes in pH can cause gill irritation in fish and impact hatching success. Extreme pH can stress or kill fish. Influenced by run-off or discharges.
Ammonium	Hazardous to fish and macro-invertebrates. Main source is organic matter (e.g. sewage).

Turbidity	Useful indicator of water quality due to the presence of suspended particles. High turbidity can impact the dissolved oxygen in water, and can cause sediment build up when particles settle to the bottom (not measured for WFD).
Dissolved Oxygen DO%	Measure of the amount of oxygen dissolved in the water. Added from the atmosphere and through photosynthesis process in plants and algae. Impacted by temperature, and organic matter due to respiration of microbes breaking down organic matter. Varies diurnally, seasonally, and with depth.

Table 2. Table of parameters measured by the sonde installed on Shirehorse Way.

A comparison to the Water Framework Directive (WFD) standards can be used to indicate whether the water quality at each site is high, good, moderate, poor or bad. A reference of the WFD water quality standards is available in Appendix 2. Please note these standards are only used for comparison purposes and do not form an official WFD classification.

On the DNR there is limited water quality data prior to the test start, but from the data available it doesn't appear that the reduction in flow has significantly influenced the water quality. In general the trend of ammonium on the DNR is of good WFD status. There were some spikes in ammonium (see Figure 16) over the winter (between 09/12/2017 and 04/03/2018), but more variable conductivity readings (see figure 45 in Appendix 2) suggest that these may have been linked to wet weather.

Dissolved oxygen readings show that the DNR also suffers from algal blooms in warmer weather. The diurnal variations however, are less severe than in the Crane, ranging between 30% and 135%. Given that there is unlikely to be a significant difference in nutrient levels between the two watercourses, this is likely to be due to the differences in river morphology and habitat (in particular the more natural bed and banks in the DNR compared to concrete in the River Crane).

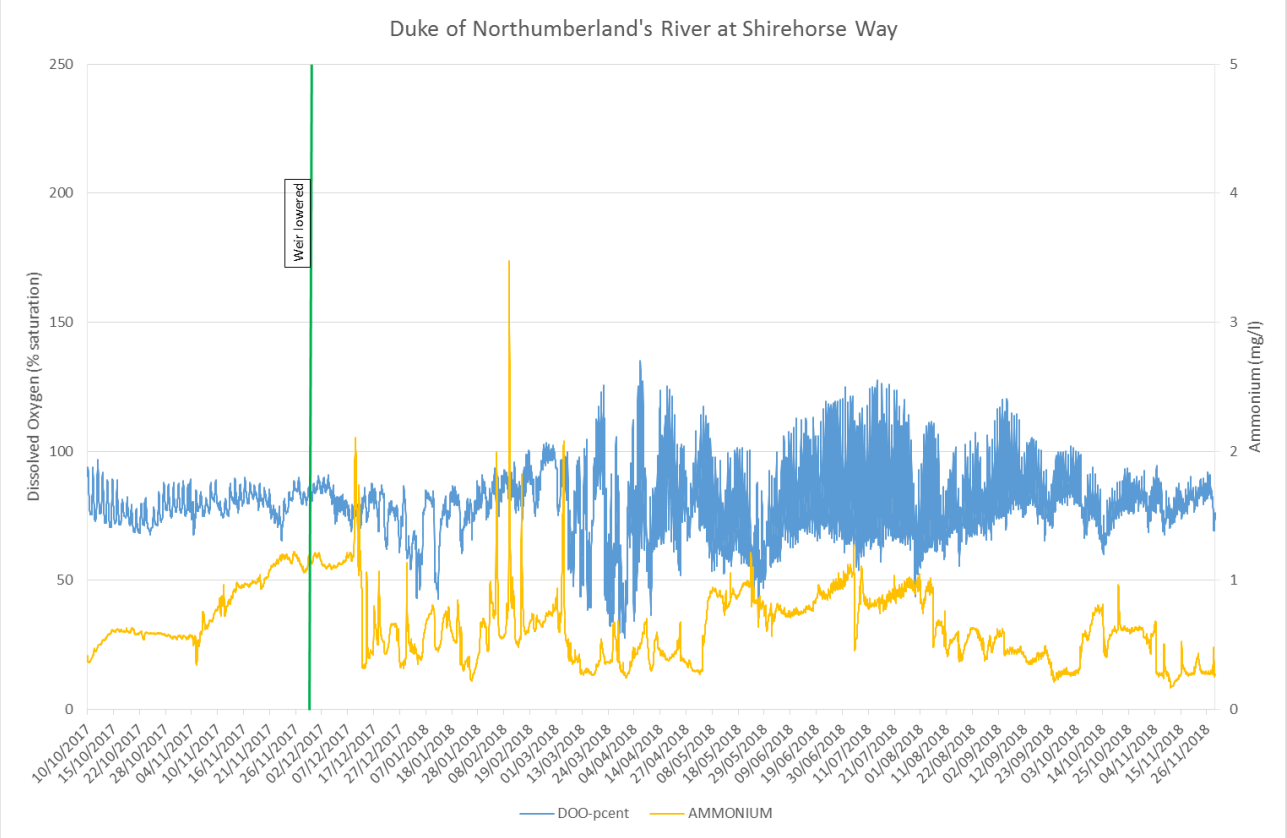

Figure 16. Dissolved Oxygen (% saturation) and Ammonium (mg/l) recorded in the DNR from October 2017 to November 2018.

Monitoring Water Quality Data

Spot sampling data has been collected over the past four years by the Citizen Crane Project. The last year's data fall within the time period of the Mereway Weir investigation, while the previous three years show the water quality before the lowering of the weir. One Citizen Crane sites falls within the zone of influence of the Lower Crane Flow Improvement Project: Kneller Gardens (Citizen Crane Site 12).

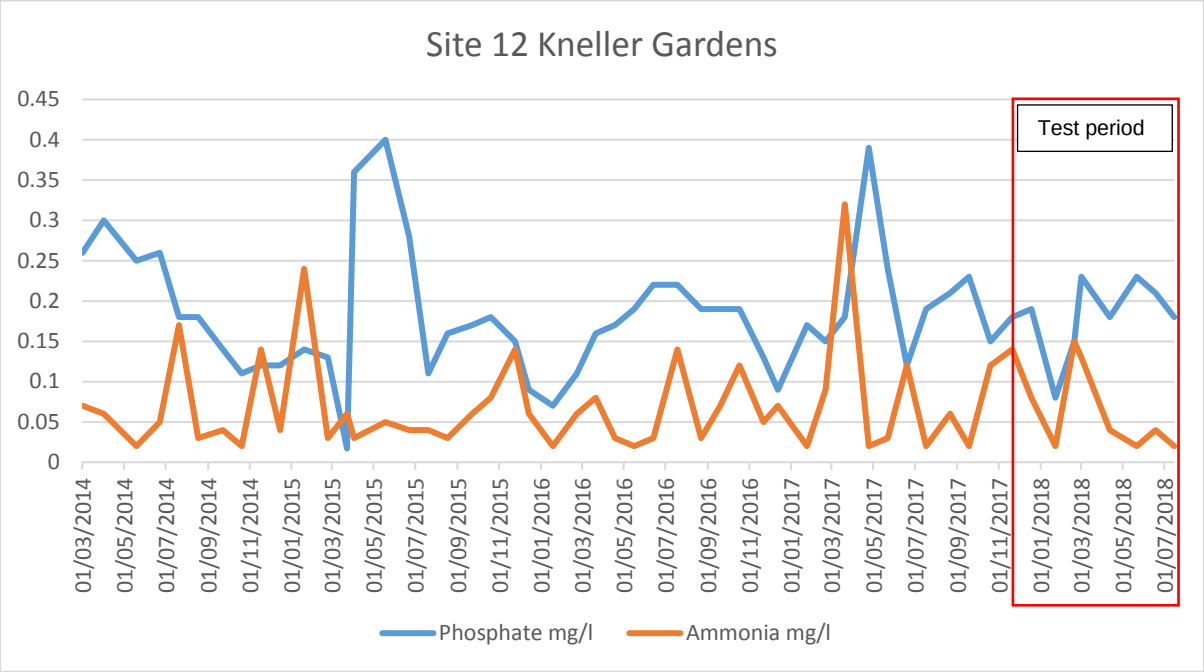

Figure 17. Citizen Crane monitoring data, showing Phosphate (mg/l) and Ammonia (mg/l) for the 3 years prior to test period and the test period.

Figure 17 shows how levels vary with each determinant at the Kneller Gardens sampling point on the DNR. Following the changes to Mereway Weir the data seems to follow a similar pattern and remains within similar ranges to the data collected before the test start.

A statistical analysis (S-Test and T-Test) of the data was carried out to assess if any changes in water quality could be attributed to the changes made at Mereway Weir. This analysis found no statistical difference between the sample data before and after the test start.

Analysis of Environment Agency spot sampling priority substances monitoring data

We have used spot sampling at Environment Agency monitoring points along the course of the DNR and the River Crane to understand the potential impact on other priority substances (As defined under the Water Framework Directive (2000/60/EC)). The data shows that most determinants, such as poly aromatic hydrocarbons, mercury and tributyl tin were below the limit of detection. There were occasionally small spikes in one or more determinants, but on the whole concentrations of these parameters remained very low. Suspended solids were variable, with spikes in the dataset, most likely attributed to periods of increased flow due to rainfall events. This would likely account for any spikes seen in the priority substances data. Our analysis did not find any evidence of a change in these water quality parameters following the change in level setting at Mereway Weir.

Conclusion

The data collected from the sondes and spot sampling sites does not appear to show a deterioration in the water quality of the DNR. While there were some issues with algal blooms in the warmer summer period, a similar trend was seen on the Crane, but the DNR's oxygen levels were rarely supersaturated. This shows the DNR's morphology, and flow regime are still more resilient than the Crane to environmental factors or pollution incidents. Similarly, from the sampling for the priority substances, there was no evidence of a change, or that those water quality parameters were impacted by the lowering of the weir. As a result it can be concluded that the lowering of Mereway Weir has not caused any negative impacts on the water quality of the DNR.

Ecology

Macroinvertebrate samples were collected in November 2017, prior to the 1-year test, to gather baseline ecological data. Samples were then taken in 2018, during the test, to assess the impact of the change in flow and water level upon the macroinvertebrate community. Samples were collected in the spring and autumn, in line with standard Environment Agency sampling procedure, and were analysed in our ecology lab in Welwyn Garden City.

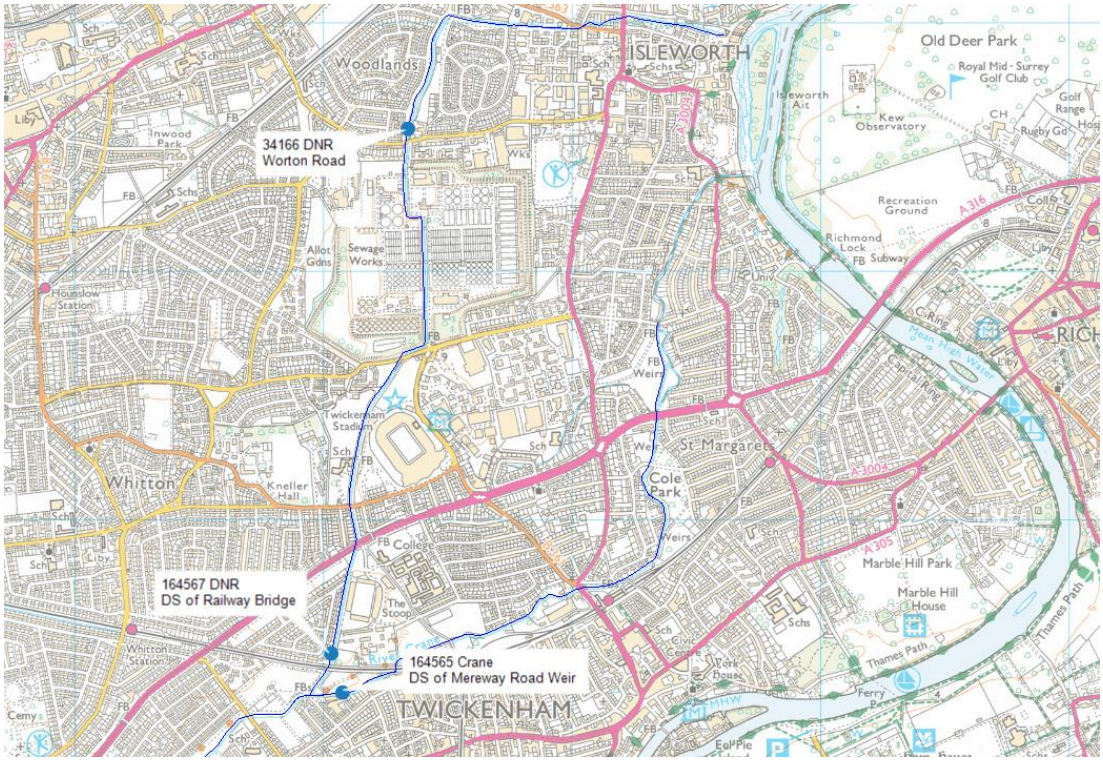

Figure 18. Location of macroinvertebrate sample sites on the DNR and River Crane.

Site ID	River	Site Name	Grid Reference
164565	CRANE	DS Mereway Road Weir	TQ1507673314
164567	DNR	DS of Railway Bridge	TQ1508073430
34166	DNR	Worton Road	TQ1530075500

Table 3. macroinvertebrate sample sites and names on the DNR and River Crane.

Two sites on the DNR were sampled for macroinvertebrates, there were 34166 'Worton Road' and 164567 'DS of Railway Bridge'.

The WHPT NTaxa is a classification method which measures the number of taxa (species) attributing to an assessment, according to the requirements of the Water Framework Directive

(WFD) (for more information please see Appendix 3). On the DNR there is substantial variation in WHPT NTaxa at both sites (see figure 18). For 'DS of Railway Bridge', Ntaxa appears to be lower in 2018, compared to 2017, with a significant drop to a value of 16 in April 2018. For 'Worton Road', NTaxa falls in October 2017 (prior to the change in water level), and remains low in May 2018.

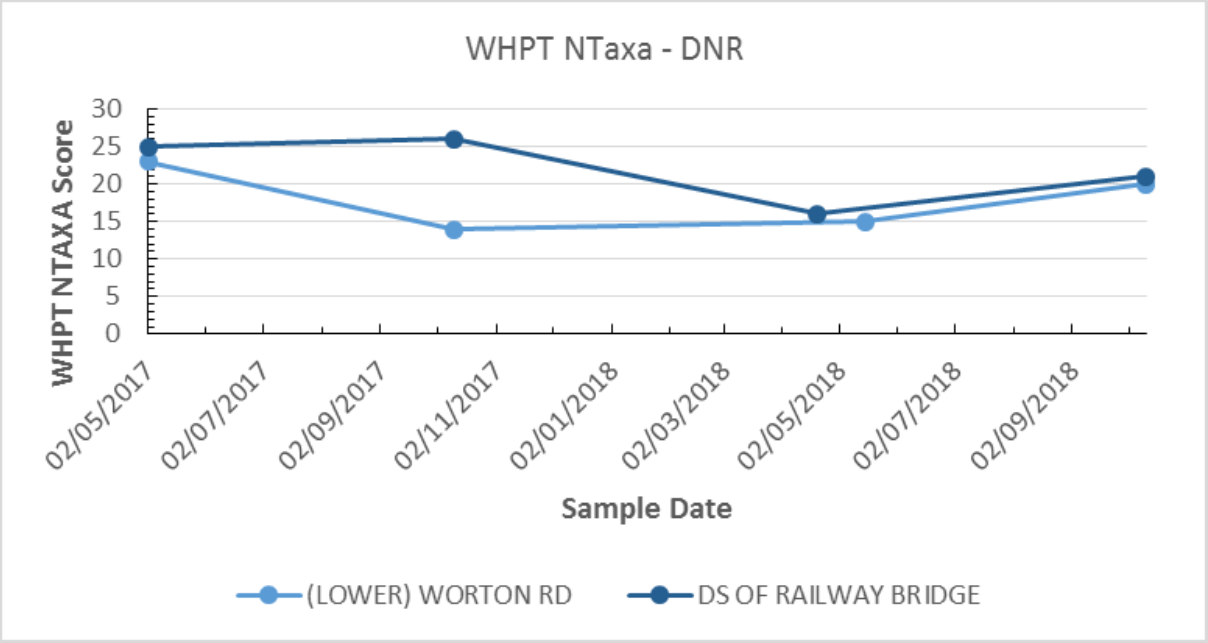

Figure 19. WHPT NTaxa at both sites on the DNR

PSI (Proportion of Sediment-sensitive Invertebrates) score describes the relationship between river ecology and fine sediment, using macro-invertebrates which have different sediment sensitivity ratings. PSI scores are moderately low for both sites, with the majority of scores falling within the 'Moderately Sedimented' boundary (see Figure 19). Low PSI scores would be expected for the DNR as it is an artificial river, which lacks gradient, and doesn't receive high flows.

For both sites, there is a drop-off in PSI score from spring 2018 to autumn 2018 – with 'Worton Road' falling from 'Slightly Sedimented' to 'Moderately Sedimented' and 'DS of Railway Bridge' falling from 'Moderately Sedimented' to 'Sedimented'. This data indicates that sediment is likely impacting upon the invertebrate community of the DNR – particularly at the 'DS of Railway Bridge' site. However, the data does not suggest that the reduction in flow in the DNR during the test is exacerbating the effects of this, as the 2018 during-test PSI scores are not significantly lower than the 2017 pre-test PSI scores.

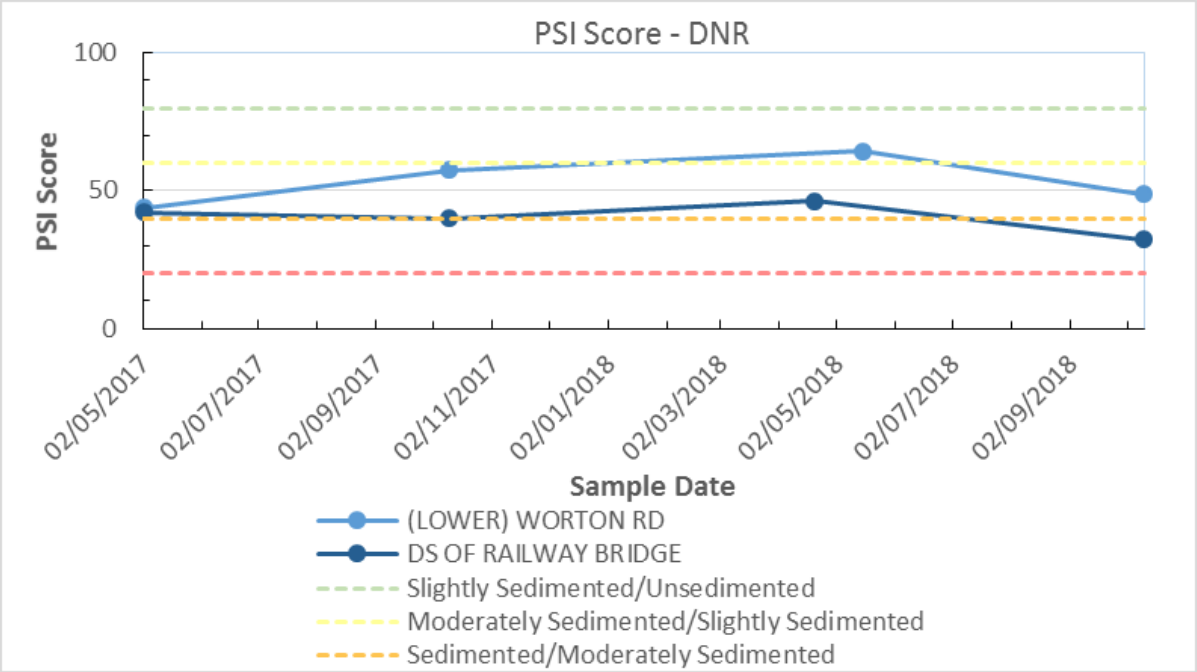

Figure 20. PSI (Proportion of Sediment-sensitive Invertebrates) Scores for the DNR

LIFE (Lotic-invertebrate Index for Flow Evaluation) score are derived using the relationship between species abundance and ecological association with different flows. This can be used to assess how the macro-invertebrate community might be changing due to flow pressure. On the DNR, LIFE scores show relatively little variation for both sites (figure 20). The samples at 'Worton Road' were found to have high LIFE scores, indicating that the invertebrate community found here includes species which have a preference for relatively fast flow and well oxygenated water. The spring 2018 sample from 'DS Railway Bridge' contained species which are slow-flow specialists - in particular, an individual specimen of *Molanna angustata* was identified. *M. angustata* is a slow-flow specialist, primarily found in lakes, canals and slow rivers. In conjunction with this habitat-preference, this species also requires relatively good water quality.

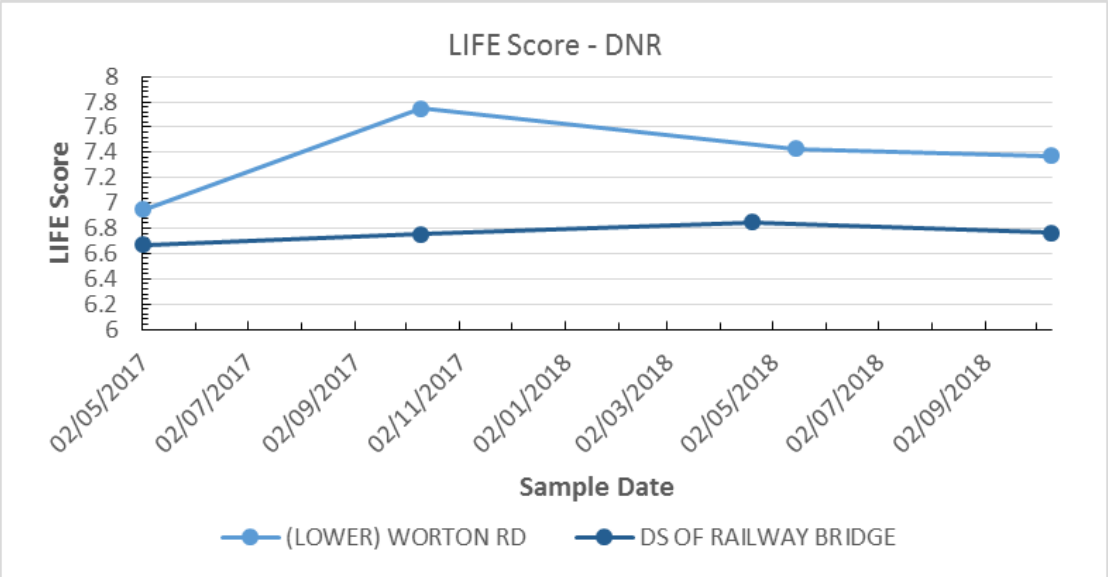

Figure 21. LIFE score of samples collected from DNR 2017-2018

Historical Worton Road data

We hold historical macroinvertebrate monitoring data for the 'Worton Road' site (see Appendix 4). Comparison of the 2017 and 2018 samples to this did not demonstrate any significant fall in indices, and shows scores to follow a relatively normal pattern for this site:

- **ASPT (average score per taxon)**: is an index for assessing pollution stress in rivers using macroinvertebrates. The ASPT equals the average of the tolerance scores of all macroinvertebrate families found, and ranges from 0 to 10. The ASPT at Worton Road generally hovers around the Moderate/Good range from 1990-2006. The results from 2017/2018 sampling are higher, and scores are more within the Good range.

- **NTaxa**: Ntaxa scores fluctuate quite a bit from 1990-2006. A similar range of NTaxa is observable for the 2017/18 sampling.

- **PSI**: From 1990-2006, PSI scores generally fall into the Sedimented boundary. 2017/2018 scores range between Moderately Sediment to Slightly Sediment, so are improving upon the historic scores.

- **LIFE (lotic-invertebrate index for flow evaluation)**: From 1990-2006, LIFE scores generally fall within the range which would indicate low sensitivity to flow. 2017/2018 LIFE scores fall within a range which would indicate moderate to high sensitivity to flow, so this shows an improvement on the historic scores, and indicates presence of more species with a preference for faster flows in 2017/2018. Life scores are derived using the relationship between species abundance and ecological association with different flows.

Conclusion

The study period has coincided with a period of prolonged dry weather, resulting in natural low-flow conditions. This may have had an effect upon the composition and diversity of the invertebrate community of the DNR, thereby making it more difficult to detect any potential effects of the Mereway test. To better understand the long-term effects of the water-level change upon the invertebrate community of the DNR, it would be advisable to continue macroinvertebrate monitoring to obtain a larger dataset for an improved analysis to be carried out.

On the whole, no significant impacts upon the invertebrate community were definitively observed during the study period, and it appears that the lowering of flow in the DNR has not had a significant adverse effect.

Fisheries Data

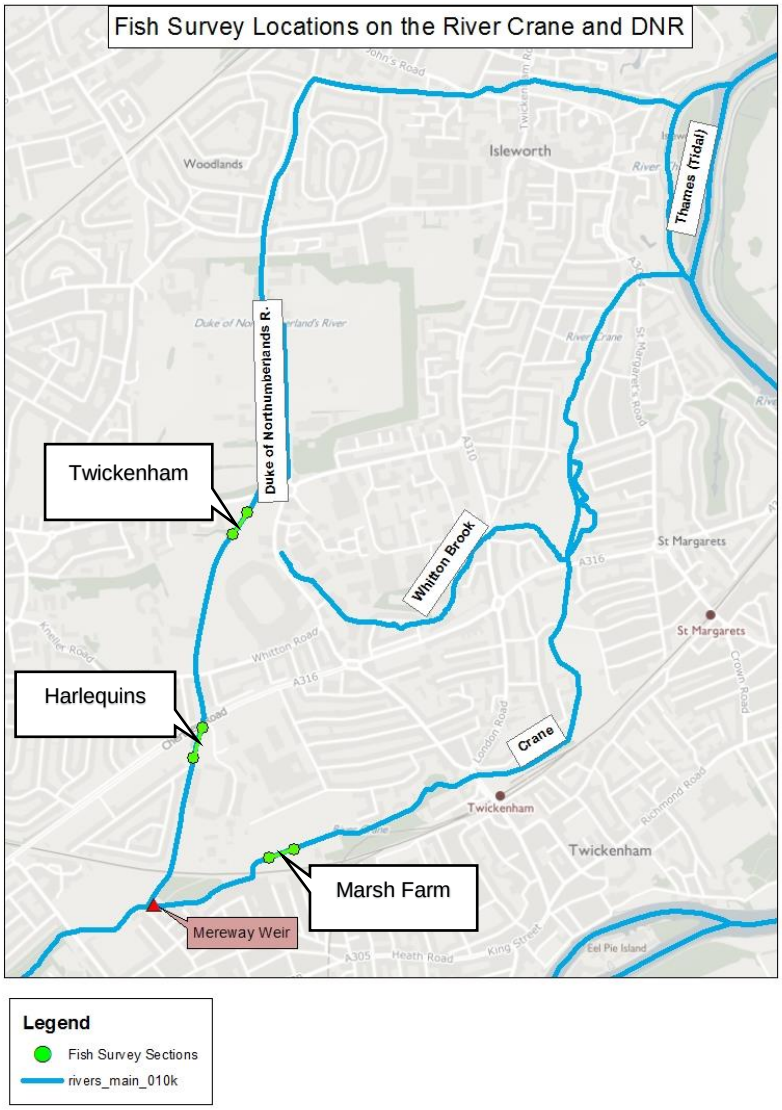

Figure 22. Locations of fish survey sections on the DNR and River Crane.

There were two control sites used to monitor the effect of lowering the weir on the DNR, with one monitoring site used on the River Crane. Minor fish species such as stone loach, and minnow are surveyed by estimating, by eye, abundance based on numbers observed. These abundancies are given as 1-9, 10-99 or 100-999. This method is used as electric fishing is not always effective on these smaller species, and to prevent having to catch and count potentially hundreds of fish. The major fish species are surveyed by catching, measuring and counting each fish. This also allows us to estimate biomass per species.

Harlequins

The water levels had changed between 2017 and 2018 (please see Table 4). There was however, no obvious decrease in the quality of available habitat or substrate within the surveyed section after the weir was lowered.

Table 4. Change in level of water at fish survey site on DNR at Harlequins Stadium.

Year	Left bank	Middle channel	Right bank
2017	0.5m	0.47m	0.39m
2018	0.32m	0.38m	0.36m

This variation in water depth had no negative effect on the resident fish population. In fact, the density and biomass for this section increased between 2017 and 2018, see figure 23. The large increase in density is due to a rise in numbers of dace and gudgeon. This fluctuation is unsurprising given their shoaling and migratory behaviour. The overall increase in biomass appears to be less drastic than the difference in density, because of the size of fish which were found within the section. 2018 produced a lot of juvenile fish indicating there has been a successful spawning nearby. Bullhead, stone loach, and minnows were all found in similar abundances in both years (10-99, 1-9 and 100-999 respectively).

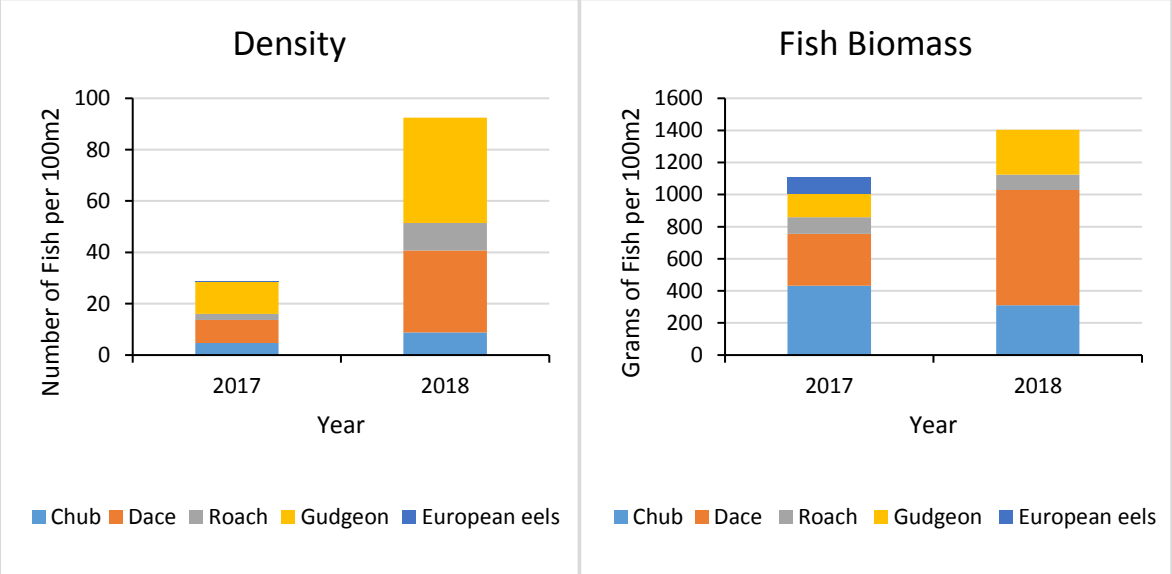

Figure 23. Density and Biomass graphs comparing 2017 and 2018 fish surveys at the Harlequins site.

Twickenham

The water levels had also changed between 2017 and 2018 at this site (please see Table 5). Similar to the Harlequins site, there had been no obvious decrease in the quality of available habitat or substrate after the lowering of the weir.

Table 5. Change in level of water at fish survey site on DNR at Twickenham.

Year	Left bank	Middle channel	Right bank
2017	0.59m	0.69m	0.60m
2018	0.46m	0.55m	0.48m

This variation in water depth had no negative effect on the diversity of fish within this section, however, there was an obvious decrease in density and biomass of fish present between 2017 and 2018. This fluctuation is unsurprising given their shoaling and migratory behaviour. With very little blocking migration in the surrounding area it is very likely that the majority of fish may have migrated to a different part of the river. There was still a variety of fish sizes

indicating that this part of the river is still able to support these species throughout their various life stages.

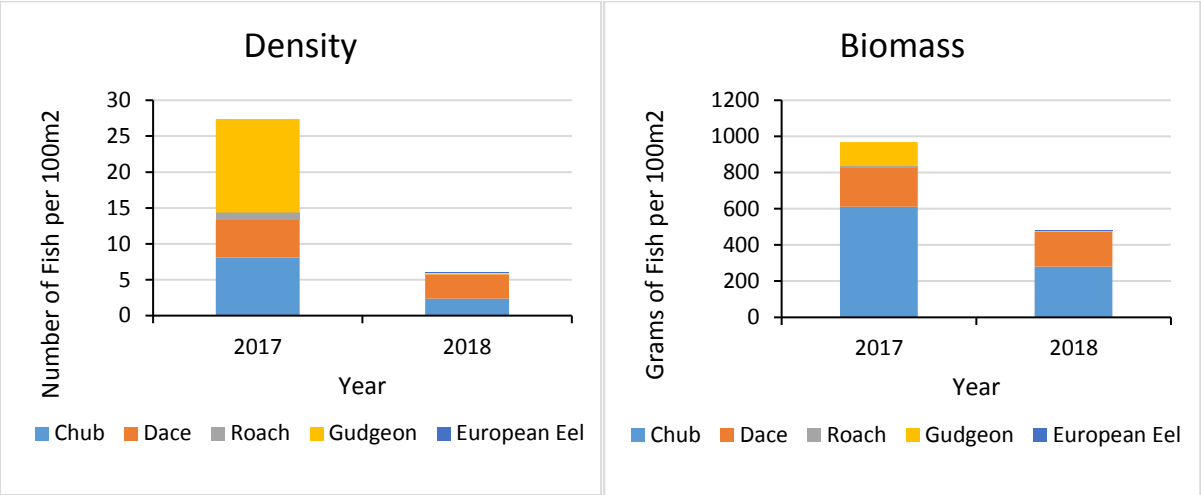

Figure 24. Density and Biomass graphs comparing 2017 and 2018 fish surveys at the Twickenham site.

Future Look

The flow data collected does not suggest that the changes to the flow split will have a significant negative impact upon the fish species in the DNR. The ability for robust conclusions to be drawn from the data is limited as the gauging sites represent velocities at a single site. Therefore the data has to be interpreted as the channels will have the potential to support the required water velocity, accepting that there could be significant local variability in this.

For cyprinid fish communities, it is the characteristics of the river flow which have greater relevance to understanding the bearing that the flow is likely to have on the resilience and sustainability of the fish communities present. Higher flows help create and maintain important habitats necessary for all life stages, aid downstream dispersal and can act as cues for migration. Periods of lower flow assist in strong juvenile development, provide conditions suitable for foraging and refuge. Water depth and wetted widths are also factors which will contribute to the long-term sustainability of fish populations. The DNR has lower variability in river discharge than the river Crane, while having greater habitat diversity. The habitat diversity present in the DNR is a key factor in the resilience of the fish in the river. Once a certain flow is maintained in the DNR, these habitats should continue to support these fish populations.

Recommended minimum flow for the Duke of Northumberland

Flow in the DNR is gauged downstream of the Mogden abstraction, therefore a minimum flow value calculated at Mogden excludes the Mogden abstraction. The minimum flow figure has been calculated based on the evidence from the test, summarised above, where a flow of 0.1m³/s at Mogden GS left strong flows at Kidds Mill, downstream of Syon Park abstraction. It is important to note that the test was carried out over a period of prolonged dry weather, with a particularly dry period experienced in the summer of 2018.

Below it can be seen that the flow as measured at Mogden GS (pictured left), allowed for good flows at Kidds Mill weir (pictured right). Maintaining the flow at Mogden GS above 1.0m^3/s during a dry year has maintained a healthy habitat in the DNR.

Figure 25. Flow over weir at Mogden STW and over Kidds Mill weir on 23rd August 2018.

The abstraction licence at Mogden STW allows 0.0556m^3/s on average. The average abstraction over the period Jan 2017 to March 2018 was 0.03m^3/s following an equipment upgrade at Mogden STW in July 2017. Peak abstraction over the same period was 0.1m3/s which only lasted for one day.

Mogden's gauging weir impounds a body of water from which the abstraction takes place. This body of water provides resilience for the channel to cope with the short periods of higher abstraction rates by buffering the impact, as the reduction in storage will partially offset reduction in flow. As abstraction very rarely rises above 0.03m^3/s, we can use a conservative abstraction estimate of 0.04m^3/s in our calculations. Adding this to the downstream target flow (0.1m^3/s) gives us a target flow 0.14m^3/s upstream of the Mogden abstraction. This ensures sufficient flow to allow abstraction at a higher rate by Thames Water when needed. Peak abstraction rates (0.1m^3/s) are very rarely used and can only be sustained under the terms of the abstraction licence for short periods. The maximum recent abstraction rate still enables a flow of at least 0.04m3/s to pass down the lower DNR and onto the Syon Park abstraction. For the majority of the time a flow of 0.1m^3/s will be retained to pass through Mogden GS and further downstream. Additionally, if Thames Water were to take their maximum average of 0.0556m^3/s, this would still leave 0.0844m^3/s passing beyond Mogden GS.

The recommended minimum flow for the DNR is therefore proposed as 0.14m^3/s between Mereway Weir and the Mogden abstraction. This will leave at least 0.1m^3/s between the Mogden abstraction and the confluence with the Thames except during peak abstraction periods. These periods are short in duration and buffered by storage in the system. Our judgement is that, as these periods are rare and short in duration, they are unlikely to have a significant environmental impact. If this judgement is incorrect the issue will be picked up by our low flow alarms enabling us to consider if action is required to improve flows. We will also engage with Thames Water to understand when periods of peak abstraction are likely.

Analysis of results - River Crane

Hydrological Analysis

The following hydrological analysis was carried out using flow data from Marsh Farm gauging station on the River Crane, and at Cranford (8km upstream of Mereway Weir).

Flow Duration Curves (FDC)

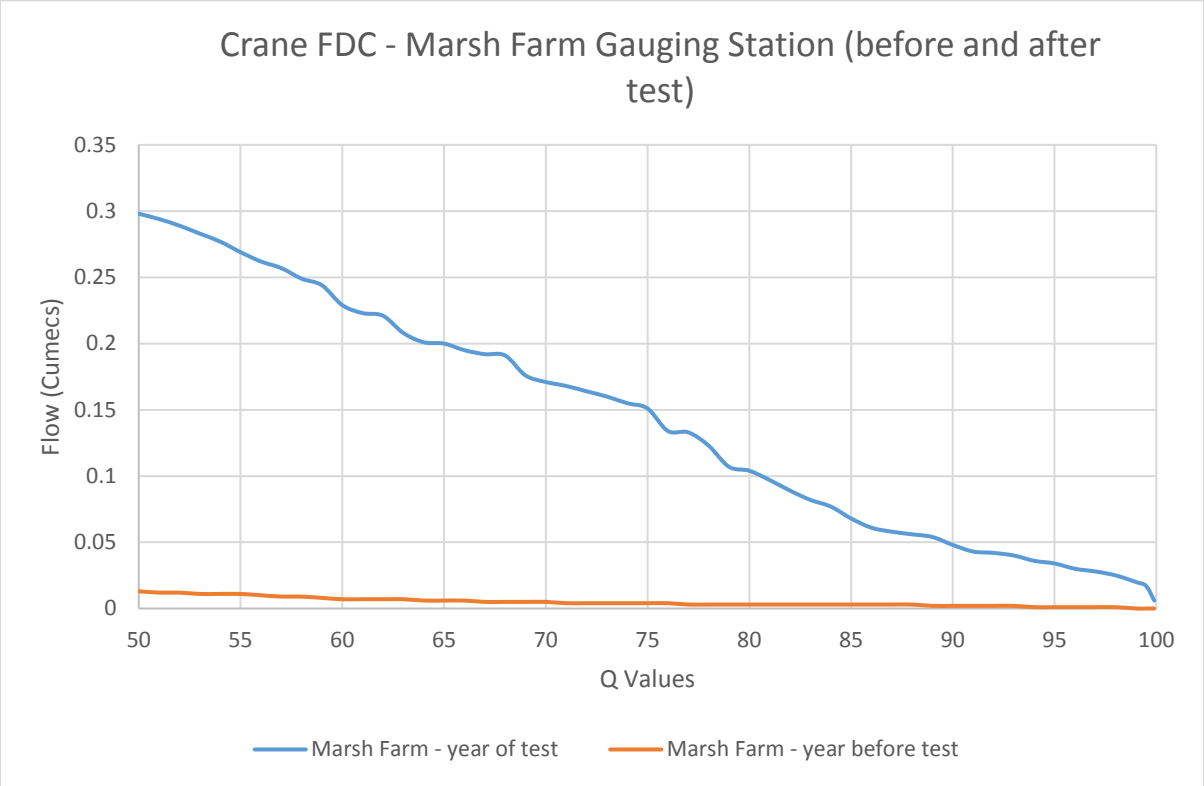

Figure 26. Flow duration curves for Marsh Farm Gauging Station on the River Crane for the year before the test (Nov 2016 - Nov 2017) and for the test period (Feb 2018 – Dec 2018). The graph is focussed on med - low flows Q50-Q100.

The Flow Duration Curves (FDC's) for the River Crane show a major improvement in flows after Mereway Weir was lowered. Prior to lowering, the Q50 value, which is the median flow, was 0.013 m^3/s, whereas after the Q50 value was 0.298 m^3/s.

Hydrographs

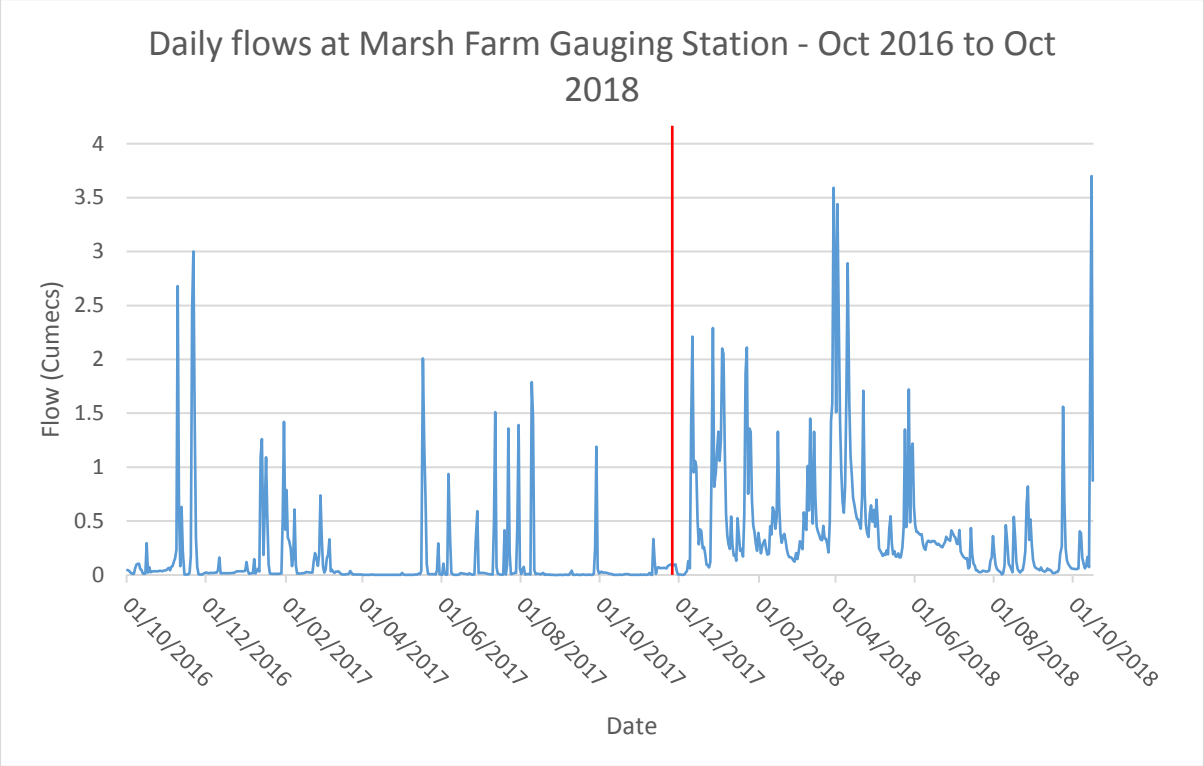

Figure 27. Daily flows measured at Marsh Farm gauging station before and after the lowering of Mereway Weir. The red line represent the start of the test period.

A clear increase in the flows after the test start can be seen in figure 27. Baseflow is significantly increased in winter, whilst in summer the increase in baseflow is smaller, yet is still a very significant increase compared to summer 2017.

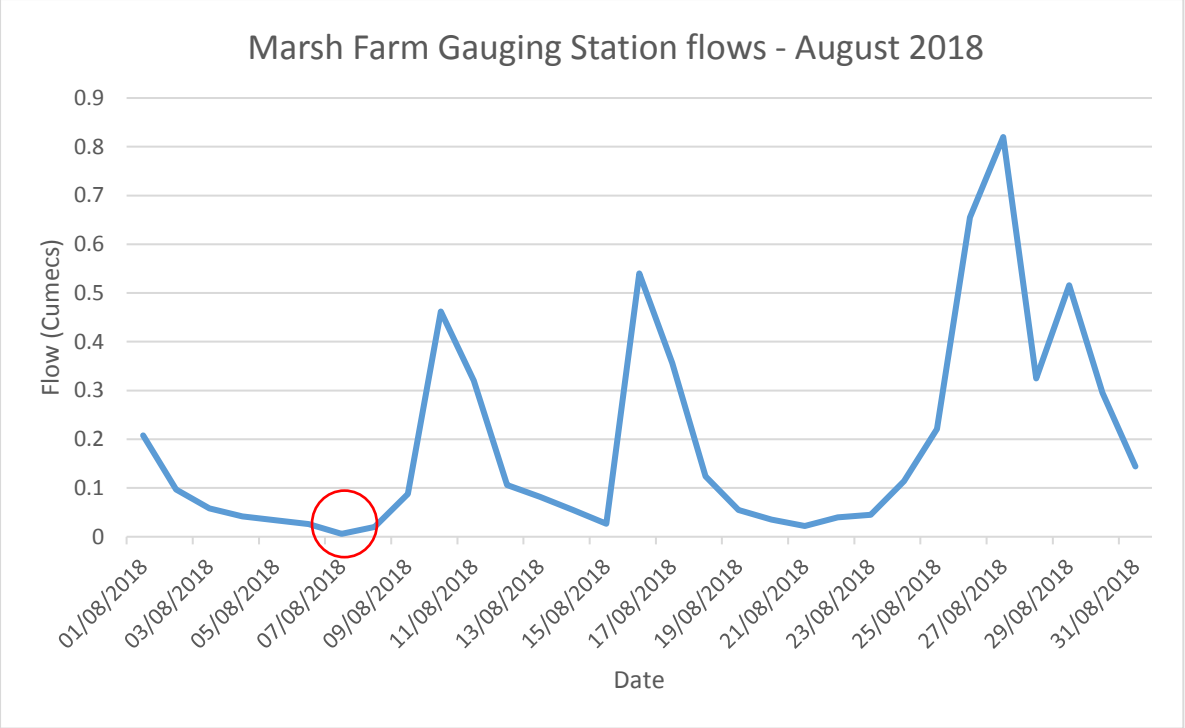

Figure 28. Flow gauged at Marsh Farm gauging station in August 2018, towards the end of the prolonged dry weather period experienced over summer.

Towards the end of the prolonged dry weather period on 8th August 2018 (circled in red in figure 28), the flows were extremely low, and appear to have dropped below the lower bound of the weir's deadband, causing it to rise in response. This resulted in no water being passed over the weir and down the Crane. Fortunately the problem was fixed quickly by lowering the weir to the lower end of the 'dead band', and no detrimental impacts on the fish downstream were recorded. These issues are due to the age of the current weir and are not expected to continue after the weir is replaced.

Gauge boards and fixed point photography on the River Crane

Gauge Boards

The gauge board locations on the Crane can be seen in Figure 9. There is more variation in levels seen in the River Crane than the DNR, throughout the year. The drop seen in June 2018 corresponds with the slight increase seen in the levels recorded on the DNR in the same month. This is likely due to the settings at Mereway Weir causing it to overcompensate during the prolonged dry weather. As the water levels decreased upstream of the weir, this caused the weir to move to its highest level to protect flows down the DNR. There was still flow available to go down the Crane, even during the dry weather period experienced in 2018. Fixed point photography also shows that the Crane, although extremely low during the driest months, never ran dry throughout the test.

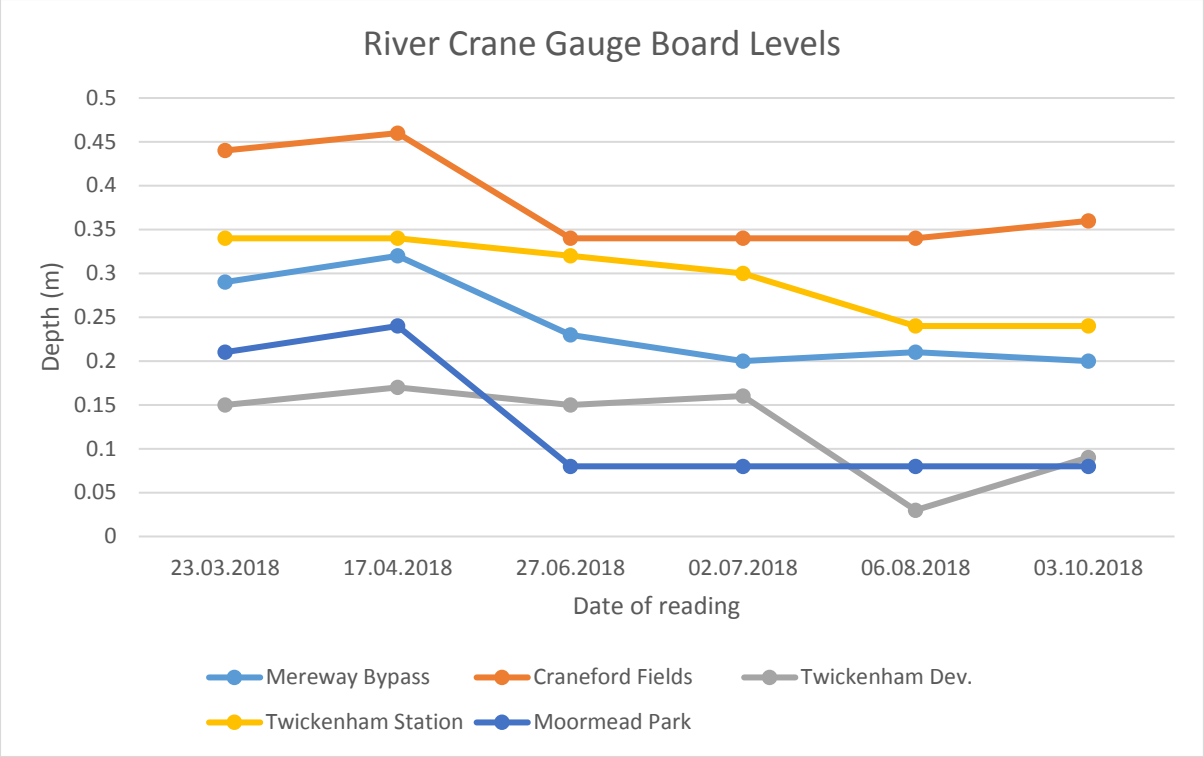

Figure 29. Gauge board levels of the River Crane during the test period. There is no data from before the test as there was no flow in the River Crane before the start of the test.

Fixed Point Photography

Figure 30. Before and after photos of Reach A on the River Crane. (Picture on left taken 04/10/2017, and picture on right taken 02/10/2018).

The Crane showed signs of improvement throughout the spring and summer. There is a noticeable increase in levels post-lowering on the River Crane. During the summer months of 2017, the reach shown above was partially dry, exposing concrete bed. Fixed point photography indicated that the bed was consistently wet during the test period. Filamentous algae is visible in the late summer months, likely due to the drier and warmer than average summer. This would be exacerbated by the overwide channel, and the lack of tree cover on the River Crane. The vegetation growth in the DNR, which works to narrow the channel in spring and summer, would help increase velocity and prevent this algal growth.

Figure 31. Photo of Reach A in the River Crane taken 27/06/2018 showing filamentous algae growth.

Urban River Survey (2015 – 2018)

Dominant Flow Type

Crane Playing Fields scored “no perceptible flow” in 2015 and “smooth flow” in 2018 post Mereway Weir Adjustments. Looking at the pictures in figure 30, it can be shown that this improvement is a direct result of the weir lowering.

Further downstream, Cole Park Island scored “no perceptible flow” for both the 2017 and 2018 surveys, both for the natural and concreted sections. The concrete section of this reach is tidal, so the “no perceptible flow” may have been a result of the stage of the tide at which the survey was done.

Stretch Habitat Quality Index (SHQI)

The Crane Playing Fields improved from a Poor in 2015 to a Below Average in 2018. This can be most likely attributed to the change from Semi Natural Stable (SNS) in 2015 to Semi Natural Active (SNA) in 2018. Semi Natural Stable has a flow dominated by glides, with no evidence of pool formation. Semi Natural Active in contrast, is characterised by extensive riffle influenced flow patterns, some pool formation.

Unsurprisingly, the concreted section of Cole Park Island scored (worse) than the naturalised section, due to being heavily modified. The natural section showed an improvement, scoring Average in 2015 and Good in 2018.

Water Quality

Sonde Water Quality Data

There is limited water quality data prior to the lowering of Mereway Weir. However, results from 14/10/17 to 11/11/17 indicate that the river was stagnant at this location, given the dissolved oxygen (DO) fell to zero and conductivity, pH and turbidity were all stable (see Appendix 2). Following the lowering of the weir, DO levels initially fell. This may have been due to the oxygen demand from sediment being remobilised by the opening of the weir, or due to a ‘slug’ of stagnant water passing down the river. After this initial drop, from 08/12/17 onwards the continued flow recovered DO levels to a level high enough for fish to live comfortably.

There were some spikes in ammonium over the winter, but conductivity readings suggest these were associated with wet weather and associated sewage pollution.

Moving into spring and summer of 2018 the spikes in ammonium became lower, but the diurnal variation in DO became increasingly extreme, until it swung between a max of 227% and a min of 9% in July. This is due to algal activity caused by eutrophication, and probably

exacerbated by lack of flow. The fish population was likely able to survive by finding pockets of river with faster flowing water downstream of weirs, where DO level would have been better. In winter 2018 DO levels became more stable, around 95%, a level of high status when compared to WFD standards.

Overall it appears that the lowering of Mereway Weir has significantly improved water quality in the lower Crane by restoring continuous flow. However, in summer water quality is seriously impacted by algal blooms. Habitat restoration is likely to be key to resolving this issue – as we see from the DNR where the same water flowing through a more natural reach does not produce algal blooms.

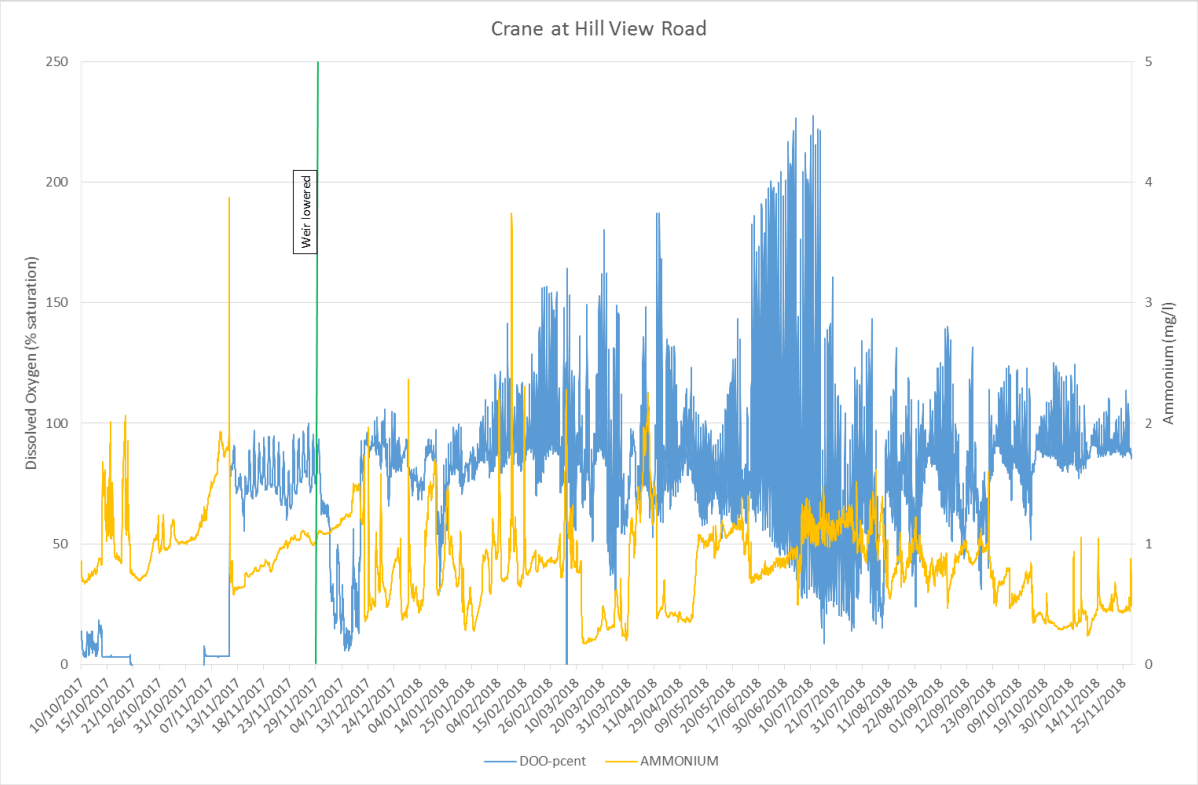

Figure 32.Dissolved Oxygen (% saturation) and Ammonium (mg/l) recorded in the DNR from November 2017 to November 2018.

Ecology

One site was sampled on the river Crane, this was 164565 'DS of Mereway Road Weir'. Unfortunately, due to high river levels during the sampling season, no sample could be taken in spring 2017. On the whole, the invertebrate community of the river Crane appears relatively poor.

Results

A considerable drop in WHPT Ntaxa is observable from 2017 to 2018 (see figure 33) but, as only one sample was taken in 2017, it is not possible to make accurate comparison or reach any certain conclusions from this. Although Ntaxa does fall in 2018, the quality of the species found within the October 2018 sample is better than would generally be expected for the river Crane – including caddisflies such as *Athripsodes cinereus*, *Hydroptila sp.*, *Goera pilosa*, and *Mystacides azurea*.

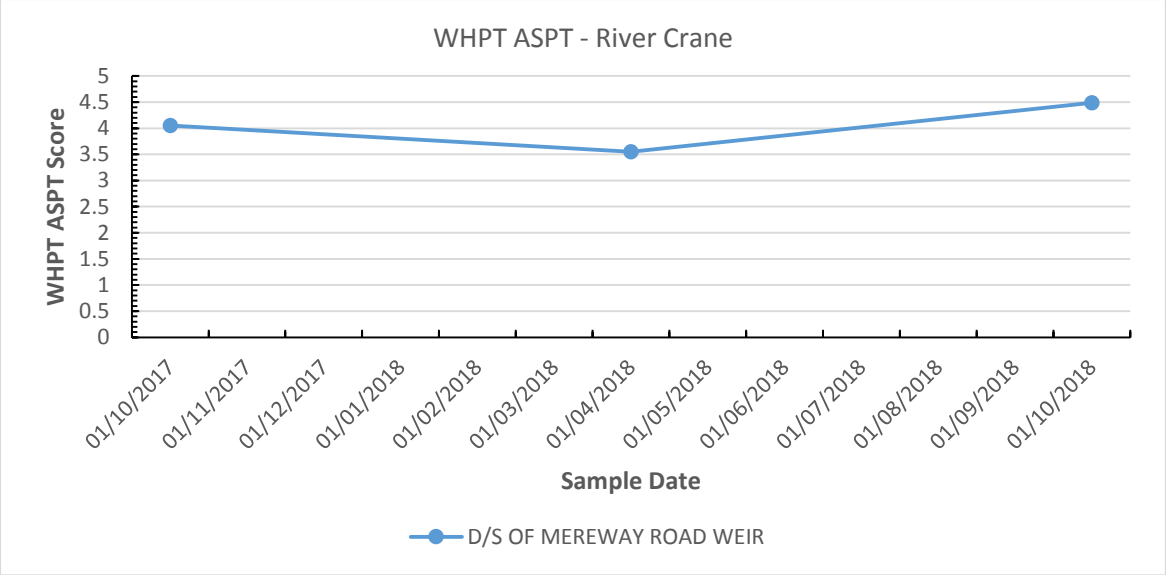

Figure 33. WHPT NTaxa scores on the River Crane

PSI and LIFE scores were found to be low for the River Crane, and the samples analysed were dominated by generalist non biting midges (*Chironomidae* family) and gastropod species which do not require fast-flowing or highly oxygenated water. However, it is likely that the low PSI and LIFE scores observed are a product of the poor habitat quality, and thus poor invertebrate diversity of the River Crane, rather than a product of high-sediment loads and poor flow conditions, as low invertebrate diversity will likely cause low scores across other indices including PSI and LIFE.

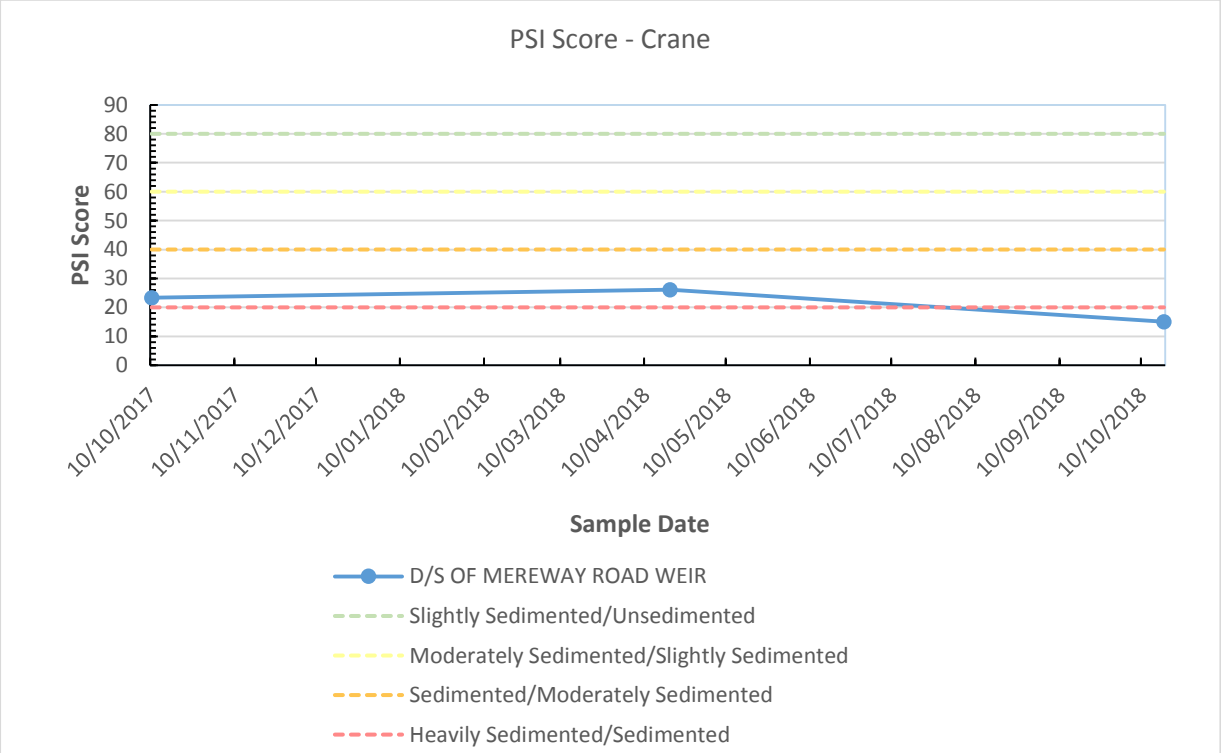

Figure 34. PSI (Proportion of Sediment-sensitive Invertebrates) Scores for the River Crane

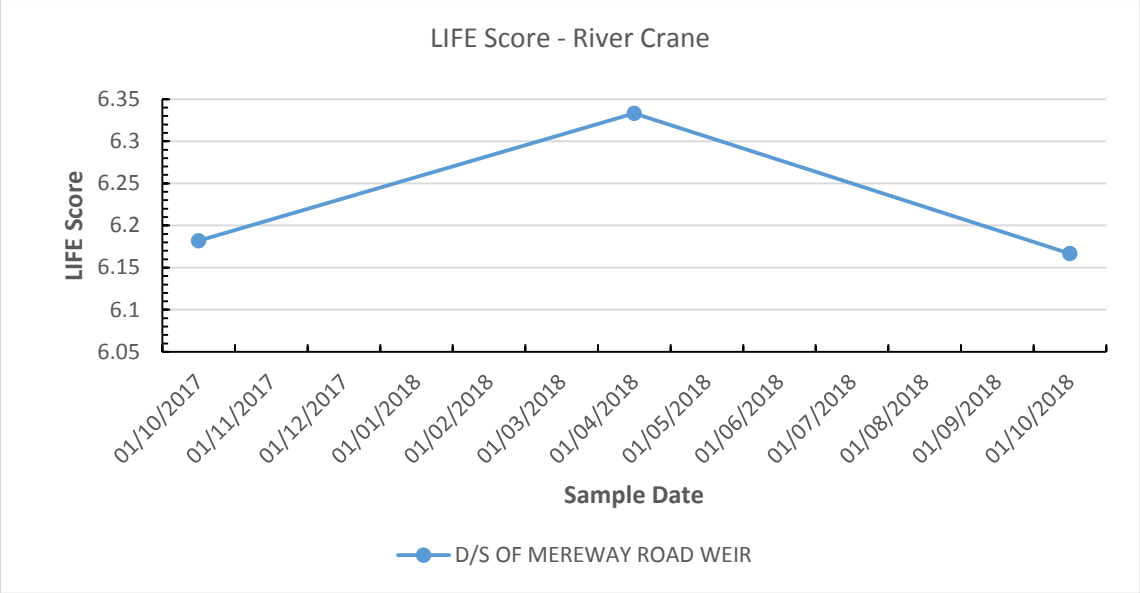

Figure 35. LIFE (lotic-invertebrate index for flow evaluation) scores for the River Crane.

Conclusions

From the samples taken, the macroinvertebrate community of the River Crane appears relatively poor. The community exhibits low diversity (low Ntaxa), which is a reflection on the poor habitat diversity and quality within the river channel, and is dominated by generalist species and species typical of poor-quality urban environments, such as non biting midges (*Chironomidae*) and gastropods. However, several species of caddis fly and mayfly were found amongst the three samples, including species such as *Athripsodes cinereus, Mystacides azurea, Tinodes waeneri, Goera pilosa,* and*, Ephemera danica*. Though their abundance is not high, their presence in the river Crane does reflect its ability to support these groups, which all require relatively good water quality. As such, this does suggest the Crane's potential to support a more diverse invertebrate community, following enhancement in habitat and continued enhancement in flow.

Fisheries Data

One site was used for fish surveying on the River Crane, at Marsh Farm. The major issue affecting the fish population within this section of the River Crane was the lack of a consistent flow of water throughout most of the year.

Table 6. Change in level of water at fish survey site on the Crane at Marsh Farm.

Year	Left Bank	Middle	Right Bank
2017	0.14 m	0.16 m	0.13 m
2018	0.22 m	0.24 m	0.23 m

In 2017 the river both immediately upstream and downstream of the survey area consisted of a small trickle flow and dry concrete river bed (see figure 36). Since the weir was lowered there has been a more constant flow of water through the survey section in particular.

Figure 36. (from top left to bottom right) photos from the 2017 fish survey. (A) A photo of the River Crane downstream of the survey section, (B) a photo of the middle of the survey section, (C) a photo of the top of the survey section.

Since the weir was lowered there has been a more constant flow of water through the survey section in particular. Both upstream and downstream of the survey site had flowing water with no concrete bed exposed when the survey was conducted in 2018.

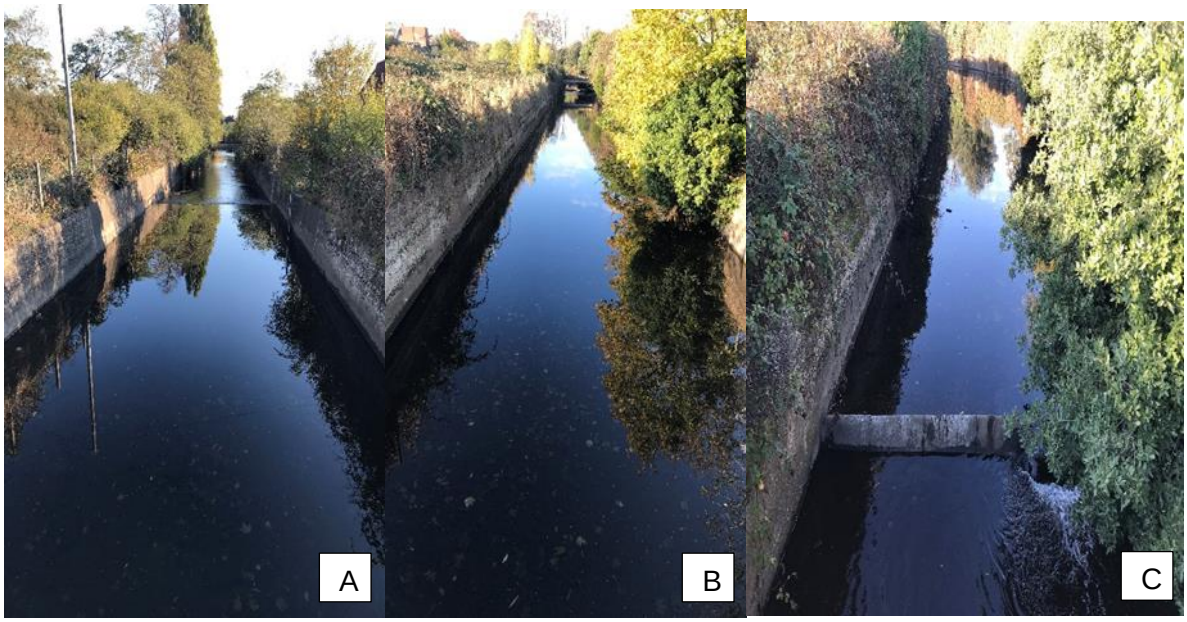

Figure 37. (from left to right) Photos of the fish survey site during the 2018 survey (A) a photo downstream of the survey section, (B) a photo of the middle of survey section, (C) a photo of the top of the survey section.

The changes in water level and flow consistency have resulted in a considerable rise in fish species diversity, overall fish density and overall fish biomass (see figure 38). The 2017 survey only produced 5 fish, 3 stone loach and 2 three-spine stickleback. In 2018 these species were abundant with stone loach numbers estimated between 100-999 individuals and stickleback estimated as 10-99 individuals. Other minor species found in 2018 were bullhead (10-99) and

minnow (10-99). Dace, roach and chub were found in a variety of sizes indicating that they were able to utilise this section of river throughout their various life stages.

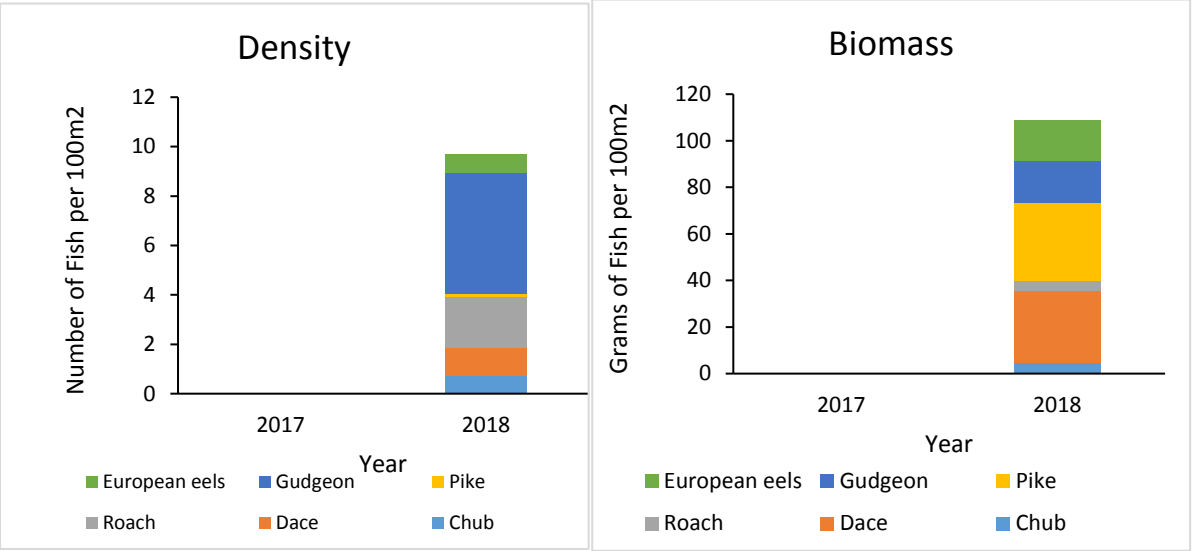

Figure 38. Density and Biomass of major fish species graphs comparing 2017 and 2018 surveys at Marsh Farm. No major species were found in the River Crane in the 2017 survey, resulting in 2017 on the graphs being blank.

Overall the fish population in the Lower River Crane demonstrates a dramatic improvement following the change in level settings at Mereway Weir. Just five fish from two species were found in 2017, but in 2018 hundreds of fish from 8 different species were found.

Future Look

The modifications to the flow split have resulted in changes to the low flow conditions within the River Crane. These changes have allowed fish to be present for longer periods of the year than before the weir was lowered. For the benefits of the alterations to the flow regime to be fully realised, supplementary work should be delivered within the River Crane to ensure that the habitats are present for fish populations to thrive and be resilient in future. The habitat improvements would need to allow the flows within the channel to interact with the habitat requirements of the different fish species found in the river.

Fish need to be able to migrate to areas of slack water when the risk of flood conditions occur which would otherwise risk displacing the fish downstream. Flow at critical velocities can displace juvenile fish, e.g. water velocities for newly hatched roach and dace need to be below 2cm/s, which increases as the larvae grow. Water velocities greater than this will displace the juvenile fish, effectively removing them from the population. The River Crane is the preferred route for fluvial flood flows, and large sections of the River Crane are canalised within a concrete channel, significantly increasing the risk of this occurring.

If the habitat in the Crane downstream of Mereway Weir is improved to support fish then it should be expected that the fish species present will be similar to that found in the fish community upstream of the weir in the Crane.

Water Framework Directive (WFD)

Duke of Northumberland's River

The Duke of Northumberland River is designated as an artificial waterbody under WFD, titled the 'Lower Duke of Northumberland River'. The ecological status of the river is classified as Moderate Ecological Potential. It is a requirement under WFD that any change to the water

body does not cause deterioration or prevent the water body from meeting its objectives. Despite the reduced flow regime, the monitoring of fish, macroinvertebrates and water quality have shown that no deterioration was recorded during the year-long test period.

River Crane

The River Crane is 13.7 km in length, running from above Cranford to where the river becomes tidal after the Cole Park allotments. All WFD classifications are based on sampling points on the river upstream of Mereway Weir. Downstream of Mereway Weir, the River Crane acts as a flood relief channel with impoverished flow and habitat. Poor habitat and low base flow within this part of that channel will have the greatest impact on ecology. This is not captured in the current WFD classifications.

Overall the River Crane is classified as Poor Ecological Status. The Hydrological Regime is classified as Does Not Support Good, however flow is not attributed as a 'Reason for Not Achieving Good' (RNAG) for the other elements. Mereway Weir does act as a barrier to fish migration upstream, with barriers considered an RNAG for fish in this water body. The new weir design, recommended as a result of this project, will include fish passage to allow free movement of fish upstream of this point. As the new weir setting has not impacted the flow regime upstream of the weir, it can be concluded that the lowering of Mereway Weir will not cause deterioration to the WFD classification of the Crane. The improved flow regime downstream of the weir will improve the habitat within this section and increase the ecological resilience of this water body, with the fish easement expected to improve the fish element.

Discussion & Conclusions

Duke of Northumberland's River

- Fish surveys carried out before and during the test showed an improvement in density and biomass of fish surveyed at one site, and a decrease at another site as a result of migration to different parts of the river. The variety of fish sizes surveyed however, indicates that this part of the river is still able to support the species throughout their various life stages. Overall the decrease in flow has not been a negative impact on fish populations in the DNR.
- Flow and sediment may be having an adverse effect on the invertebrate community at one sampling site, but as there was no significant difference between 2017 and 2018 PSI and LIFE scores, this issue cannot be attributed to the lowering of Mereway Weir. Comparisons of the 2017 and 2018 samples with historical data from Worton Road showed no significant fall in indices. As a result no significant impacts upon the invertebrate community were definitively observed during the study period.
- Statistical analysis carried out on the four years of spot sampling data showed no statistical difference in the data during the test year. Similarly water quality data collected from the sondes and spot sampling sites does not appear to show a deterioration in the DNR over the test period, allowing us to conclude that water quality in the DNR was not negatively impacted by the lowering of the weir.

Additional Considerations

Elver Pass at Kidd's Mill - The elver pass at Kidd's Mill requires a flow of 0.5 l/sec. As the abstraction for Syon Park will be protected by the setting of Mereway Weir, there will always be enough water above Kidd's Mill weir for the elver pass. This was confirmed throughout the investigation. On the one occasion when no flow was passing over Kidd's Mill weir as a result of the tilting weir being raised, there was still enough water above the weir to pump over the elver pass. Once the pound had filled, flow resumed over the weir.

River Crane

- Hydrological monitoring has shown a clear improvement in the River Crane. An increase in flows was recorded after the test start, and some flow remained in the channel for the entire test period, although levels went extremely low during the dry summer period.
- Water quality data has shown an apparent improvement in the Lower Crane in the flow that has been restored. In summer, however, water quality is seriously impacted by algal blooms causing extreme spikes in DO.
- October 2018 sampling showed that the macroinvertebrate community is relatively poor, with low habitat diversity and quality negatively impacting species diversity. The intermittent nature of the flow in the Crane before the test period means that there is limited ecology data prior to lowering of the weir.
- The improvements recorded in fish populations during the test period have been extremely positive. There was a considerable rise in species diversity, overall fish density and overall fish biomass.

Additional Considerations

Crane tidal gates - No impact was recorded on the Crane Tidal gates. The changes to flow are well within the normal operation of these gates and high flow events will not be altered by the proposed changes at Mereway Weir.

Flood Risk - Under the current operating regime the tilting weir lies flat on the bed of the river under flood conditions. Any change to the target levels will not change how the weir operates under flood conditions, therefore no alteration to flood risk is expected.

Climate Change - Climate change is predicted to lead to drier summers which could lead to increased pressure on the flow and ecology of the lower Crane and DNR. However, it is likely that the increased flow in the Lower Crane alongside habitat restoration will greatly improve the resilience of this river to the impacts of climate change. The DNR will remain well protected from extremely dry conditions because Mereway Weir will continue to protect flows during very dry periods. More marginal plants may also help to improve resilience to extreme events.

Conclusion and Recommendation

Overall the investigation has confirmed that changing the split of water down the DNR and River Crane has not adversely impacted the DNR while significantly improving the River Crane. Given the dry weather experienced during the test period, the analysis of the data collected has shown that the lowering of Mereway Weir has been a success. In addition, the abstractions from the DNR have been protected throughout the test period.

Based on the success of the investigation it is recommended that the current flow split between the two rivers is maintained. The recommended minimum flow of 0.14m3/s in the DNR has been maintained at the test band setting for Mereway Weir of 9.53mAOD – 9.63mAOD. As a result, this level setting will be maintained until the new weir is installed, and used to inform the design of the new weir replacement. It is hoped we will continue to see improvements in all aspects of the River Crane, while continuing to maintain the ecology of the DNR.

Further Recommendations

- Continue invertebrate monitoring on the DNR for next 2 years. This will allow an improved analysis of the impact of reducing the flow in the DNR on the ecology.

- Carry out habitat enhancement and morphological works along the lower Crane, downstream of Mereway Weir through the Crane Valley Partnership's Lower River Crane Restoration Project, including the creation of backwaters, and depth variations in the channel for fish spawning and refuge. This is recommended to increase biodiversity of the river, but also to increase the amenity value of the river to the local community.

Acknowledgements

We are extremely grateful to all the volunteers who took part in the investigation, collecting vital test data and taking photos.

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Jordan Hambidge

Phil Belfield

Patrycja Meadows

Jonathan Smith

Jordan Rowling

Chris Martin

Ross Biddle

Rosalind Brown

Appendix

Appendix 1. Hydrology

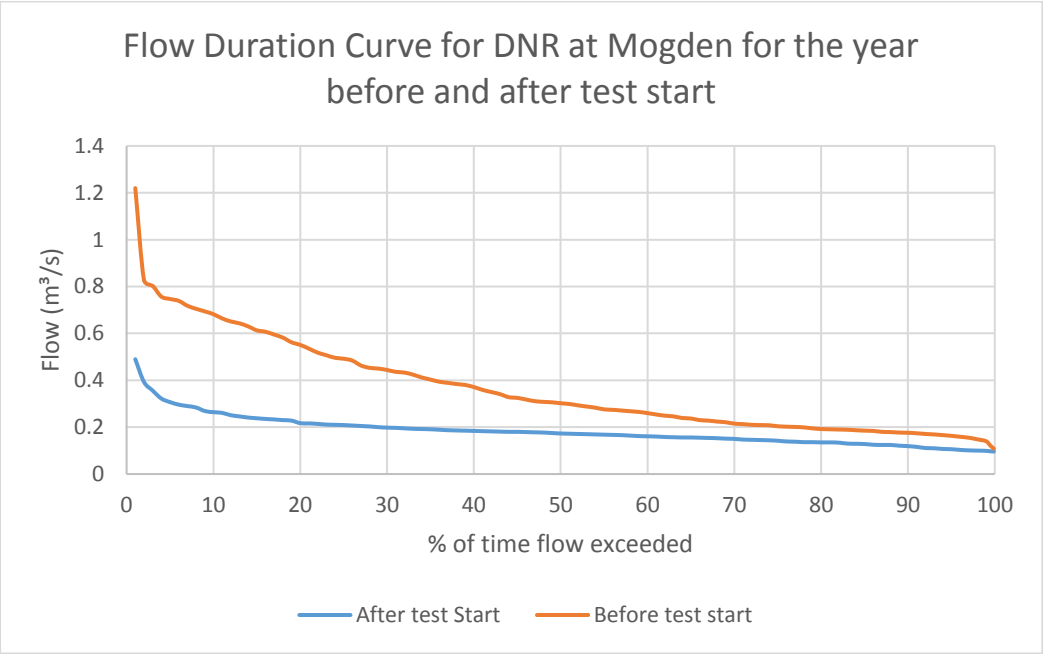

Figure 39. Flow duration curves for Mogden Gauging Station on the DNR for the year before the test (Nov 2016 - Nov 2017) and for the test period (Feb 2018 – Dec 2018).

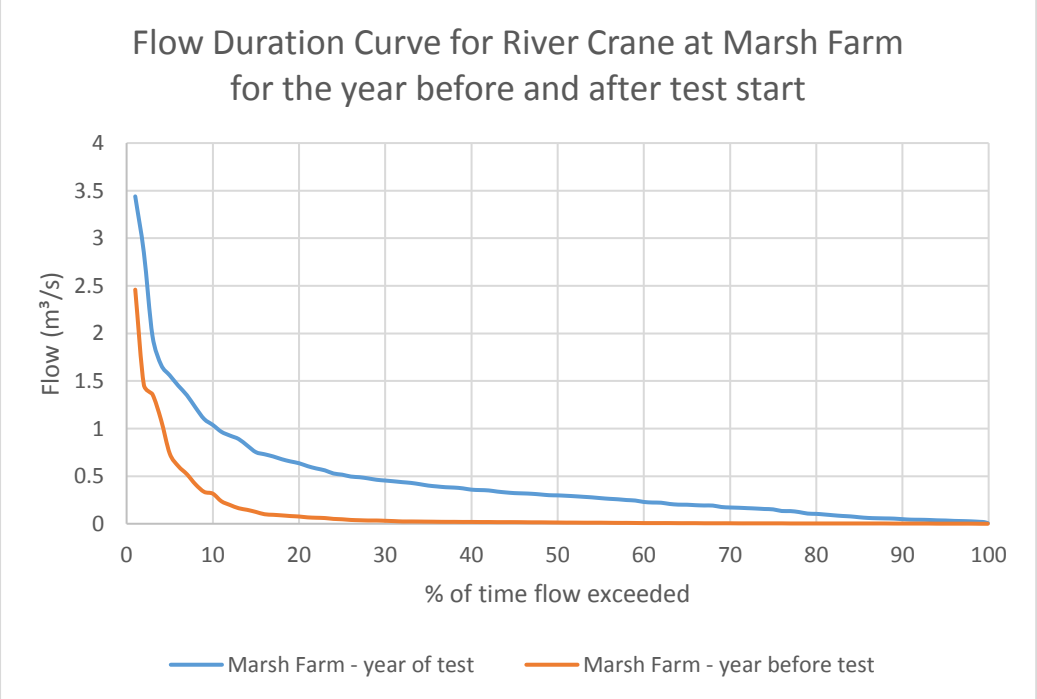

Figure 40. Flow duration curves for Marsh Farm Gauging Station on the DNR for the year before the test (Nov 2016 - Nov 2017) and for the test period (Feb 2018 – Dec 2018).

Appendix 2. Water Quality

Reference Water Framework directive (WFD) water quality standards

Please note these standards are only used for comparison purposes and do not form an official WFD classification.

EQS Standards & simplified typologies - WFD 2016 Cycle 2							
Element	**Statistic**	**Typology**	**HIGH**	**GOOD**	**MODERATE**	**POOR**	**BAD**
Ammonia (mg/l)	90 %ile	0 = Canals	0.3	0.6	1.1	2.5	>2.5
		2 = Lowland high alkalinity	0.3	0.6	1.1	2.5	>2.5
Dissolved Oxygen (% sat)	10 %ile	0 = Canals	70	60	54	45	<45
		2 = Lowland high alkalinity	70	60	54	45	<45
pH	High-Good: 5 & 95%ile; Mod-Poor 10%ile	All waters	> 6 & < 9	> 6 & < 9	4.7	4.2	<4.2
Temperature (degC)	98%ile	0 = Rivers not in salmonid water bodies and canals	25	28	30	32	>32

Figure 41. Water Framework Directive (WFD) water quality standard.

Water quality data and interpretation

27th of October – 26th of November 2017

Crane Hill View Road

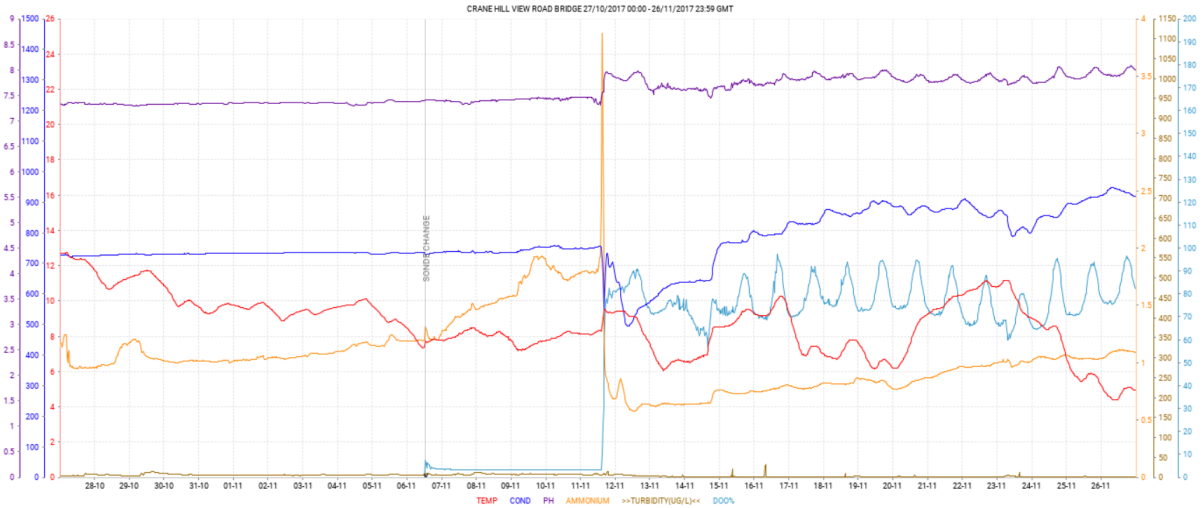

Figure 42. Water quality data collected by sonde on the Crane between 27th October - 26th November 2017. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

DNR Shirehorse Way Bridge

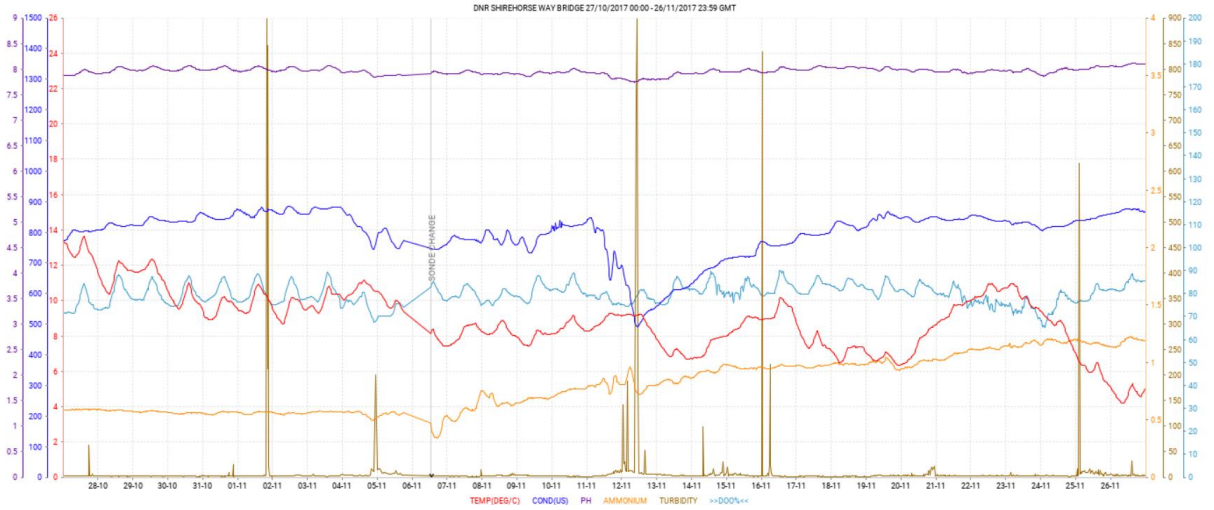

Figure 43. Water quality data collected by sonde on the DNR between 27th October - 26th November 2017. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

The graphs above cover the time period from the 28th of October, when the sondes were first deployed, to the 26th of November 2017. The water quality at the Crane Hill view Road site is poor to start with. Dissolved oxygen levels are very low and have very little fluctuation in concentration with some readings as low as 1% saturation. From the 11th of November onwards there is an increase in dissolved oxygen, to a level of high status when compared to WFD standards, with a diurnal fluctuation in concentration. A potential cause of the improvement of dissolved oxygen concentration on the River Crane may be due to the opening of one of the relief channels on the Mereway Weir on the 11th November. Throughout the same time period the Shirehorse Way site on the Duke of Northumberland's River (DNR) has a higher dissolved oxygen concentration with similar ammonium concentrations as found in the River Crane. There are peaks in turbidity at the DNR site which are not found in the River Crane. These are not prolonged and some are attributed to high flows or rainfall especially when there is river water dilution resulting in a decrease in conductivity.

15th January 2018 – 14th February 2018

Crane Hill View Road

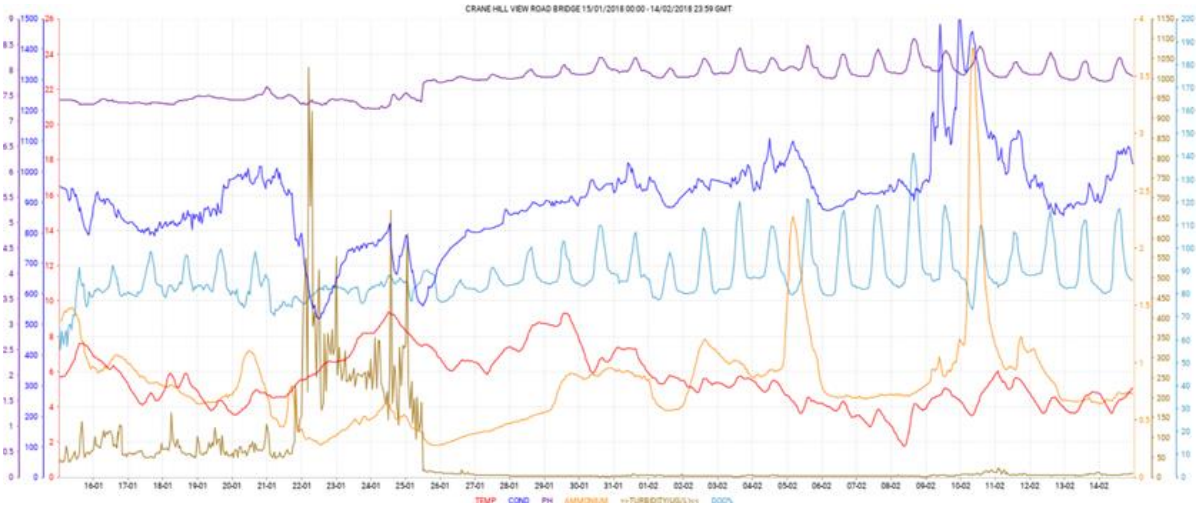

Figure 44. Water quality data collected by sonde on the Crane between 15th January – 14th February 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

DNR Shirehorse Way Bridge

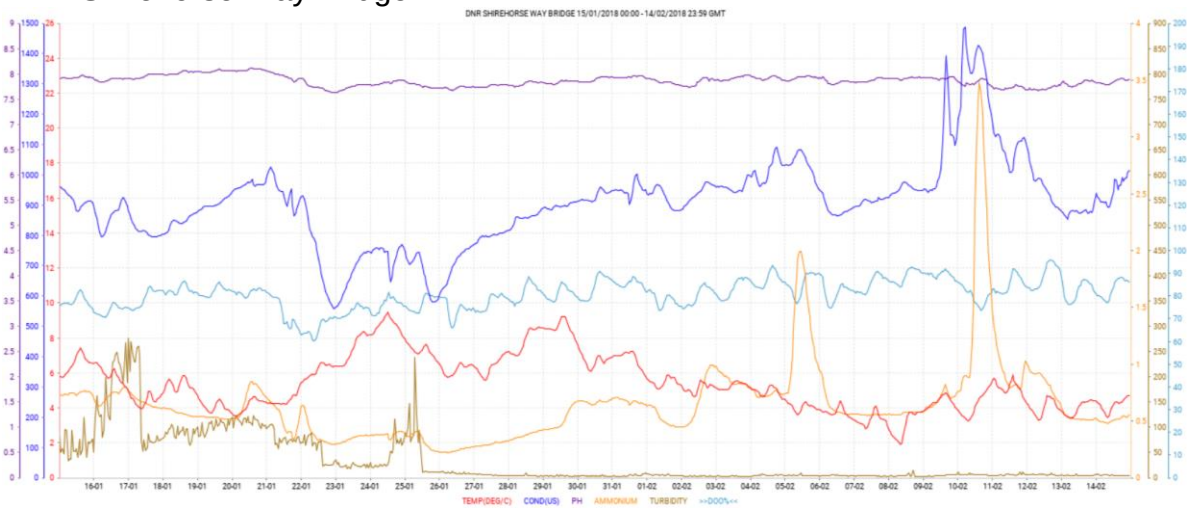

Figure 45. Water quality data collected by sonde on the DNR between 15th January – 14th February 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

From the 15th of January 2018 to 14th of February 2018 dissolved oxygen levels in both the River Crane and the Duke of Northumberland's River are high maintaining a concentration of between 80 and over 100 percent saturation throughout. On the River Crane there are times when the dissolved oxygen concentrations are supersaturated at well above 100 percent saturation meaning conditions are eutrophic. At both sites there were dilution events such as rain which affected water quality, the biggest impact being from the 22nd of January 2018 to 25th of January 2018. The main impacts due to these dilution events were prolonged increase in turbidity due to sediment mobilisation and a decrease in conductivity as river water becomes more dilute due to an increase in water volume. At both sites there are two peaks in ammonium, one on the 5th of February 2018 and one on the 10th of February 2018. These peaks in ammonium are accompanied by an increase in conductivity. The peaks in ammonium are indications of a pollution incident upstream of the Mereway Weir as the peaks are detected at both sonde sites.

19th April 2018 – 19th May 2018

Crane Hill View Road

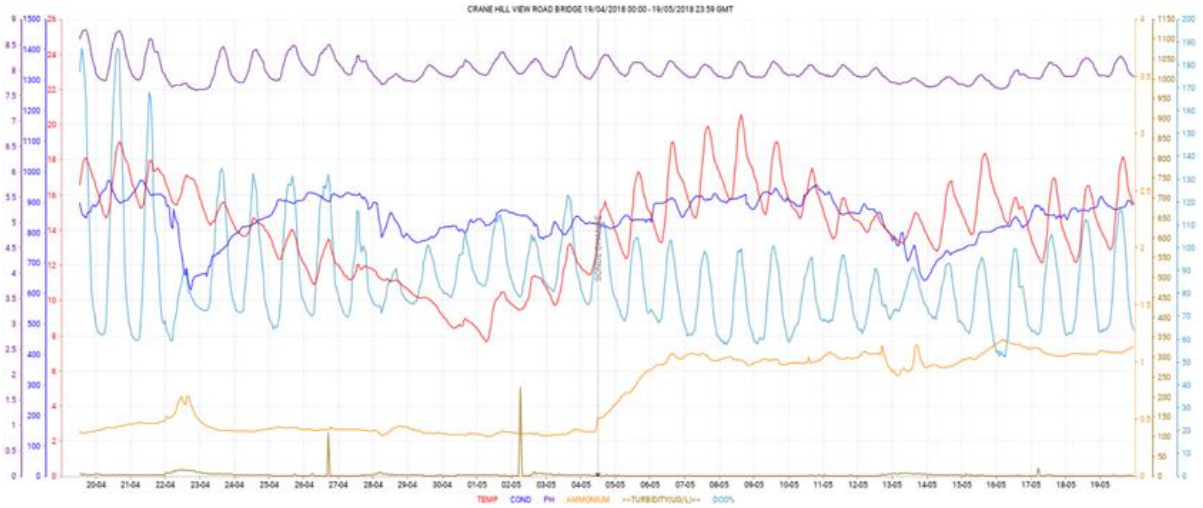

Figure 46. Water quality data collected by sonde on the Crane between 19th April – 19th May 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

DNR Shirehorse Way Bridge

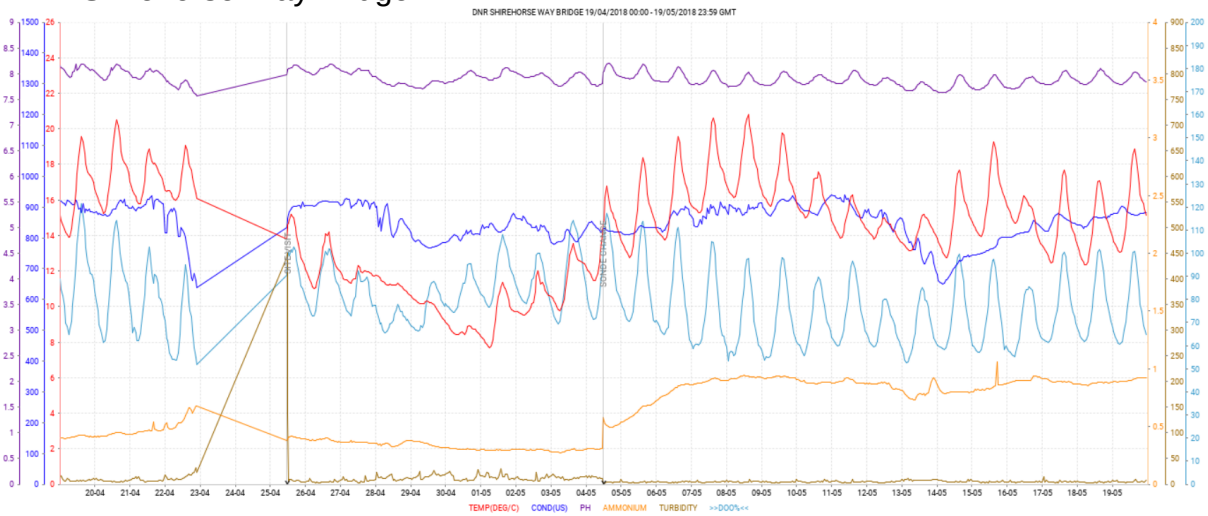

Figure 47. Water quality data collected by sonde on the DNR between 19th April – 19th May 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

The diurnal trend in dissolved oxygen concentrations at the Crane at Hill View Road sonde is more exaggerated in this time frame, going into supersaturated levels especially at the start of the data set. The ammonium concentration increases after the sonde change on the 4th of May 2018 but this is more than likely due to recalibration of the ammonium probe.

There is a similar trend in dissolved oxygen concentrations at the Duke of Northumberland's River (DNR) although the dissolved oxygen concentrations are rarely supersaturated. On the 23rd of April 2018 there was an issue with the sonde on the DNR which is the reason for no data from the 23rd to the 25th of April 2018. All other determinants mimic what was found at the Crane sonde including the recalibration of the ammonium probe.

24th July 2018 – 23rd August 2018

Crane Hill View Road

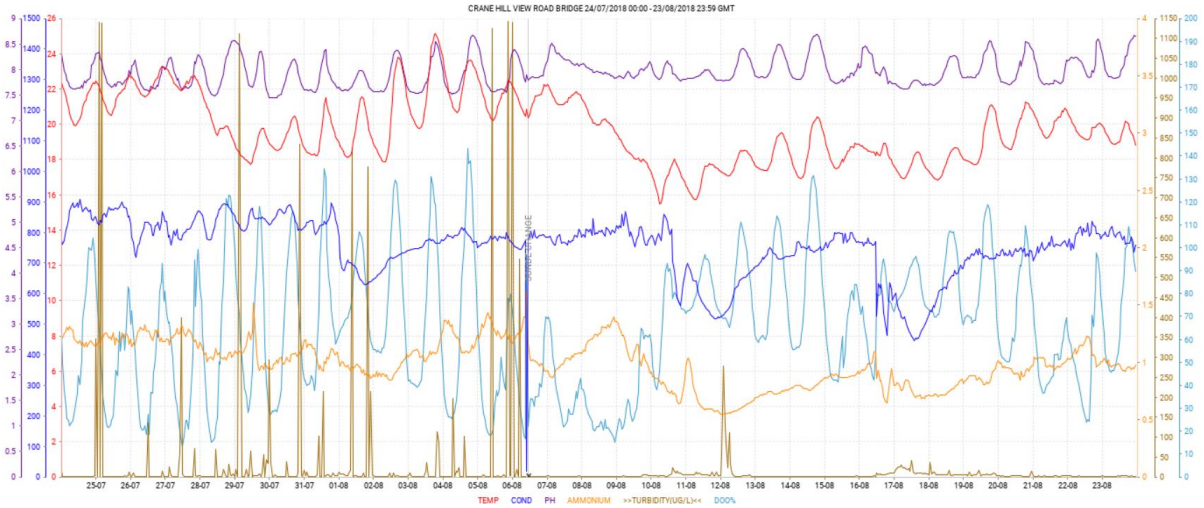

Figure 48. Water quality data collected by sonde on the Crane between 24th July – 23rd August 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

DNR Shirehorse Way Bridge

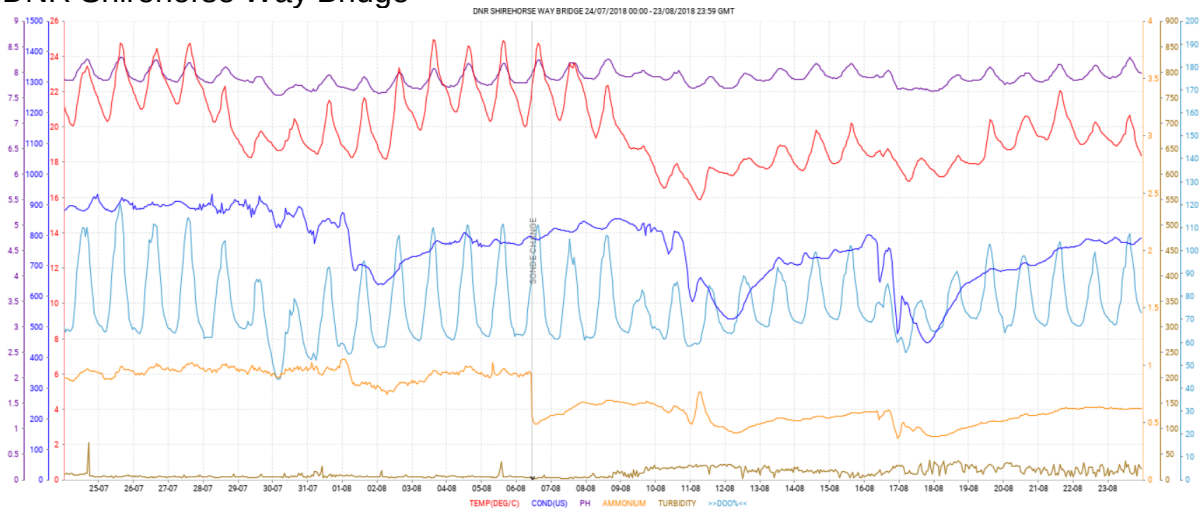

Figure 49. Water quality data collected by sonde on the DNR between 24th July – 23rd August 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

Turbidity at the Crane at Hill View Road sonde fluctuates greatly from 25th of July to the 6th of August although these peaks are not as numerous after the sonde was changed on the 7th of August. Due to this the reason for some of these peaks may have been interference with the turbidity probe as opposed to turbidity increase in the river water. Similar to the previous timeline there are big variances in the dissolved concentration through the timeline. The dissolved oxygen levels are particularly poor when at its lowest concentration of under 30% saturation which would be bad when compared to WFD classification. The highest concentration at above 120 percent saturation indicate supersaturation due to eutrophic conditions. Ammonium remains at around 1mg/l (good under WFD classification) throughout the time frame with some minor peaks. The conductivity decreases at various points most significantly on the 11th and 17th of August 2018 due to dilution of the river water through increased flow.

Again the trends found at the Duke of Northumberland's River (DNR) are similar to the ones found on the River Crane especially conductivity, temperature, pH. However the peaks in turbidity are not found on the DNR probe and dissolved oxygen levels are more steady and at a higher/better quality. The dissolved oxygen levels do not indicate the same level of supersaturation and don't decrease to levels as low as what was found on the River Crane. Ammonium levels are lower in the DNR but still at good WFD status. Some of the ammonium peaks found on the River Crane are visible on the DNR data also, more specifically the ones found on the 11th and 16th of August 2018.

22nd September 2018 – 22nd October 2018

Crane Hill View Road

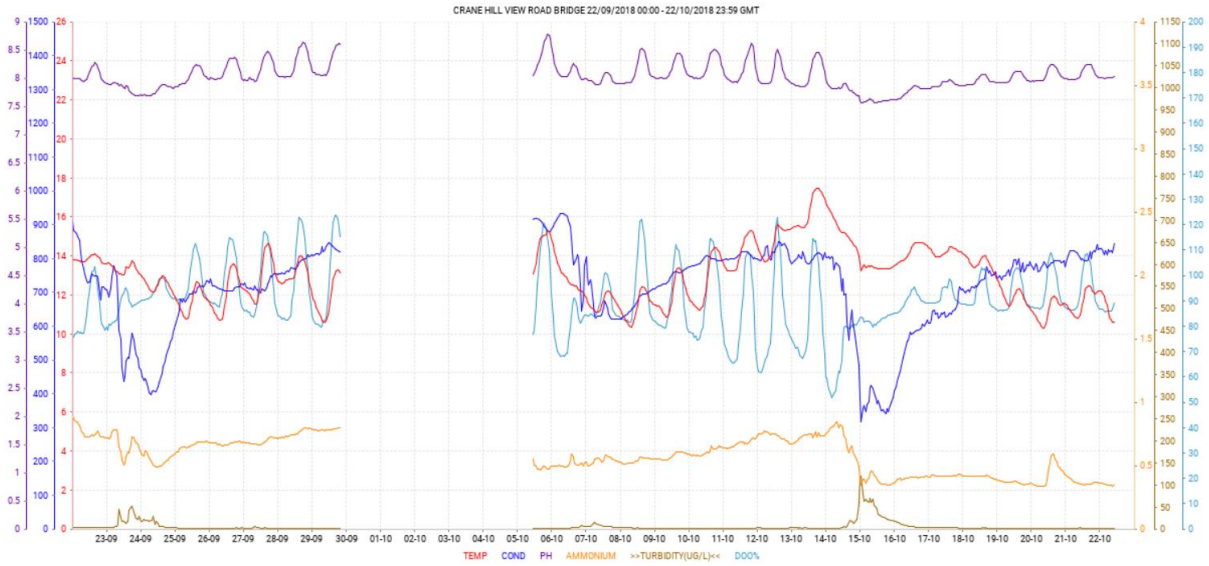

Figure 50. Water quality data collected by sonde on the Crane between 22nd September – 22nd October 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

DNR Shirehorse Way Bridge

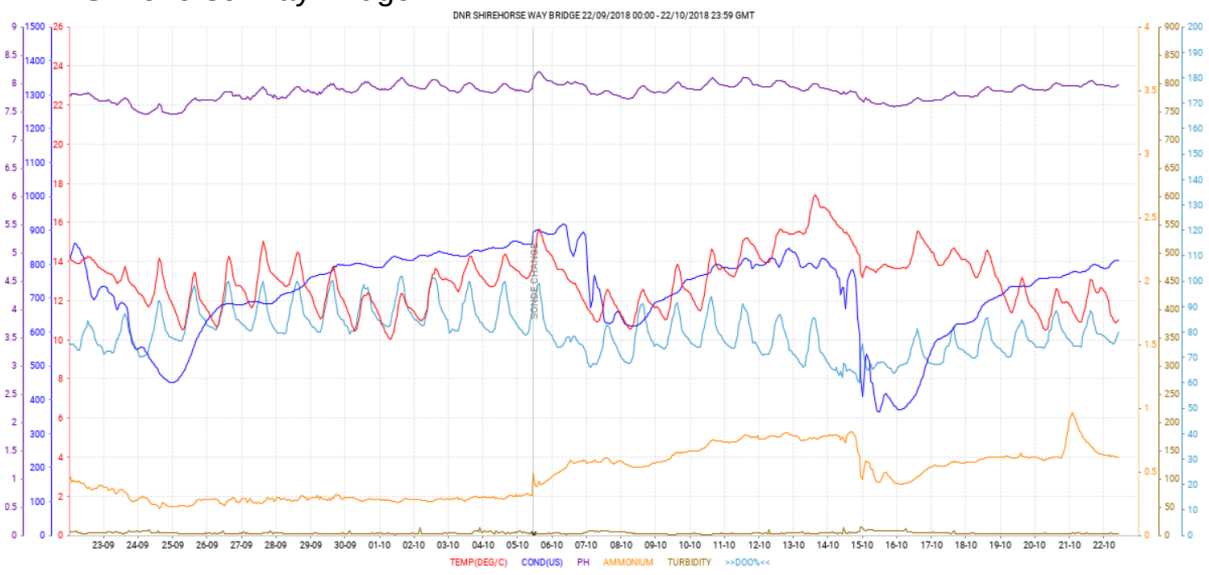

Figure 51. Water quality data collected by sonde on the DNR between 22nd September – 22nd October 2018. Standard determinants were temperature, conductivity, phosphate, ammonium, turbidity and dissolved oxygen were monitored.

With the most recent data there is a slight stabilisation/improvement in dissolved oxygen concentration at the Crane at Hill View Road sonde. The conductivity at both sites decreases at various points on each graph is response to rainfall events, the ammonium can also be seen decreasing too after these rainfall events.

The dissolved oxygen levels at the Duke of Northumberland's River site is also less variable with a slight improvement in concentrations compared to the previous timeline.

Appendix 3. Explanation of Indices

Macro-invertebrates

BMWP

The Biological Monitoring Working Party (BMWP) score has been the accepted index for assessing pollution stress in rivers using macroinvertebrates in the United Kingdom since the early 1980s. Although it will detect a wide range of aquatic stressors, the index is based specifically on organic pollution. Each invertebrate family is assigned a score from 1 – 10 according to their tolerance/sensitivity to organic pollution; higher scores indicating less tolerance/greater sensitivity. The BMWP score is the sum of the values of the BMWP families recorded in the sample. Full results are shown in Table A2.

ASPT

The average score per taxon (ASPT) is the BMWP score divided by the number of scoring families in the sample (N-Taxa). ASPT provides a standardised index of pollution stress facilitating robust comparisons between samples and locations.

LIFE

The Lotic-invertebrate Index for Flow Evaluation (LIFE) provides a semi quantitative description of the macroinvertebrate community based on mean current velocities (Extence, Balbi & Chadd, 1999). It therefore provides an index of low flow stress experienced by the river ecosystem and the sensitivity of the macroinvertebrate communities to any reductions in mean current velocity. Species level LIFE scores were calculated for comparisons between sampling locations and sampling occasions as species level data provides greater precision than family level data for assessing the effects of current velocity changes (Extence *et al*. 1999).

Macro-invertebrates have particular velocity preferences. This means that as flow is altered it can affect the macro-invertebrate community. This can either be directly due to the changes in velocity patterns, or indirectly through associated habitat change.

Generally as flows decline:

- taxa associated with slower flows appear/increase in abundance
- taxa associated with faster flows disappear/decrease in abundance

LIFE scores reflect this change and we can use this principle to assess how the macro-invertebrate community might be changing due to flow pressure.

Macro-invertebrates are allocated to 1 of 6 flow groups which reflects the flow conditions they prefer. The LIFE flow groups are shown in the table below.

Flow group	Description
I	taxa primarily associated with rapid velocities

II	taxa primarily associated with moderate to fast velocities
III	taxa primarily associated with slow or sluggish velocities
IV	taxa primarily associated with usually slow and standing waters
V	taxa primarily associated with standing waters
VI	taxa frequently associated with drying or drought impacted sites

Table 7. LIFE flow groups of macro-invertebrates

WHPT (Walley Hawkes Paisley Trigg)

WHPT was introduced as the basis for the UK's river invertebrate status classification under the Water Framework Directive in the second River Basin Management Plans published in 2015 (including the draft plans published in 2014). It replaces the Biological Monitoring Working Party (BMWP) indices that were used since the 1980 National River Quality Survey. WHPT is a revision of BMWP (it was originally known as revised BMWP). Like BMWP, WHPT can be expressed as a score (the sum of values for each taxon in a sample), as an average score per taxon (ASPT) and as the number of scoring taxa (N-taxa). WFD status is based on ASPT and Ntaxa.

The new index was introduced to improve the accuracy of invertebrate assessments and the compliance of the UK's river invertebrate status classification with the Water Framework Directive, which requires abundance to be taken into account (see the normative definitions in Annex V of the Water Framework Directive). It makes better use of data that is already being collected.

In England and Wales, you should use a global bias value of 1.68 for WHPT-Ntaxa. This is based on audit results from all Environment Agency laboratories in 2010. Bias for WHPT is greater than for BMWP because the additional families used by WHPT (mainly Diptera) cause a disproportionately greater number of laboratory errors.

status boundary	EQR WHPT-ASPT	EQR WHPT-Ntaxa
High/Good	0.97	0.80
Good/Moderate	0.86	0.68
Moderate/Poor	0.72	0.56
Poor/Bad	0.59	0.47

PSI

The Proportion of Sediment-sensitive Invertebrates (PSI) metric (Extence *et al.* 2011) describes the impact on the macro-invertebrate community of fine sediments (defined as less than 2mm in size) deposited on the river bed.

The technique offers an alternative to direct physical and visual methods of assessing sedimentation, which can be expensive and difficult to apply. It also provides an indication of

the ecological impact of fine sediment, this depends on conditions over a period of time, not just conditions at a single time of observation.

Appendix 4. Ecology

Duke of Northumberland River

Results

The WHPT ASPT (Average Score Per Taxon) of the samples collected in 2018 has not significantly changed following the lowering of the Mereway Weir in November 2017 – with scores remaining stable since October 2017 (see figure 2). All samples from both sites were found to have an ASPT of roughly 4.7-5.4. This is a relatively good score, and indicates that water quality is not impacting upon the macroinvertebrate community of the DNR.

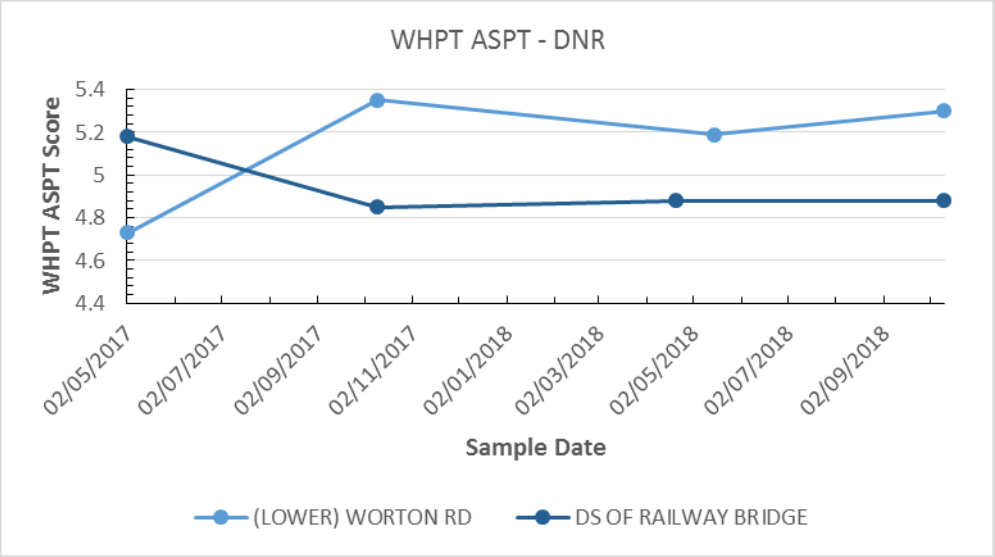

Figure 52. WHPT ASPT (average score per taxon) of samples collected at two sites on the DNR 2017- 2018.

LIFE (Lotic-invertebrate Index for Flow Evaluation) scores show relatively little variation for both sites (see figure 5). The samples collected at 'Worton Road' were found to have high LIFE scores, indicating that the invertebrate community found here includes species which have a preference for relatively fast flow and well oxygenated water. The invertebrate community of 'DS of Railway Bridge' was found to have a lower LIFE score for all samples taken during the study period. The spring 2018 sample from 'DS Railway Bridge' (collected on 20/04/18) contained species which are slow-flow specialists – in particular, an individual specimen of *Molanna angustata* was identified. *M. angustata* is a slow-flow specialist, primarily found in lakes, canals and slow rivers. In conjunction with this habitat-preference, this species also requires relatively good water quality.

River Crane

Results

ASPT scores are relatively low throughout the study period and fall around 3.5-4.5 (see figure 6) – as would be expected for a watercourse such as the Crane, which generally does not have the high quality habitat or water quality to support high-scoring invertebrate taxa. On the whole, the 2018 ASPT scores do not appear to differ significantly to the 2017 ASPT score.

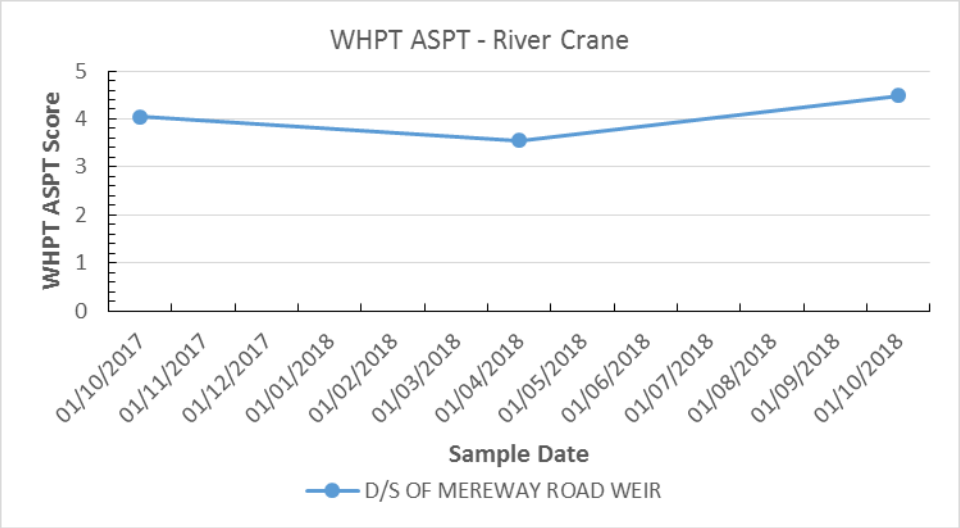

Figure 53. WHPT ASPT of samples collected from river Crane 2017-2018

4a. Raw data

SITE_ID	SAMPLE_DATE	PSI	BMWP_SCORE	SCORING_TAXA	ASPT	LIFE_F	WHPT	NTaxa
164567	02-May-17	42.22	118	22	5.36	6.67	5.176	25
164567	10-Oct-17	40	129	25	5.16	6.75	4.85	26
164567	20-Apr-18	46.15	82	15	5.47	6.85	4.875	16
164567	10-Oct-18	32.26	96	18	5.33	6.76	4.881	21
34166	23-May-90	18.92	73	17	4.29	6	3.512	17
34166	15-Aug-90	14.29	74	18	4.11	5.88	3.939	18
34166	03-Oct-90	20.51	85	20	4.25	5.94	3.865	20
34166	08-May-91	18.52	73	16	4.56	6.21	4.247	17
34166	28-Aug-91	23.26	76	19	4	5.94	3.57	20
34166	25-Nov-91	23.91	82	19	4.32	6	3.675	20
34166	01-Oct-92	24	90	20	4.5	6	4.064	22
34166	18-Oct-93	26.67	80	18	4.44	6.06	4.061	18
34166	27-Apr-95	29.79	111	23	4.83	6.27	4.458	24
34166	18-Sep-95	23.08	102	22	4.64	6.09	4.025	24
34166	10-Nov-97	26.83	86	19	4.53	6.39	4.086	21
34166	27-Apr-98	25	85	18	4.72	6.18	4.145	20
34166	05-Oct-98	29.55	83	19	4.37	6.53	3.971	21
34166	22-Jul-99	24.49	100	22	4.55	6.26	3.936	25
34166	10-May-00	29.27	102	20	5.1	6.42	4.548	21
34166	23-Oct-00	24.44	99	21	4.71	6.25	4.164	22
34166	30-May-03	23.81	104	22	4.73	6.33	4.335	23
34166	25-Nov-03	27.78	81	18	4.5	6.22	4.11	20
34166	27-Apr-06	30.77	61	14	4.36	6.25	3.971	14
34166	10-Oct-06	24.14	76	17	4.47	6.33	4.078	18
34166	02-May-17	43.9	102	20	5.1	6.95	4.735	23
34166	10-Oct-17	57.58	73	14	5.21	7.75	5.35	14
34166	15-May-18	64.29	71	13	5.46	7.43	5.193	15
34166	10-Oct-18	54.05	86	17	5.06	7.38	5.3	20
164565	10-Oct-17	23.4	103	22	4.68	6.18	4.046	24
164565	19-Apr-18	26.09	45	12	3.75	6.33	3.546	13
164565	18-Oct-18	15	63	14	4.5	6.17	4.486	14

Figure 54. Raw data for all sites sampled on DNR and Crane in 2017-2018

4b. Worton Road – Historical Data Graphs

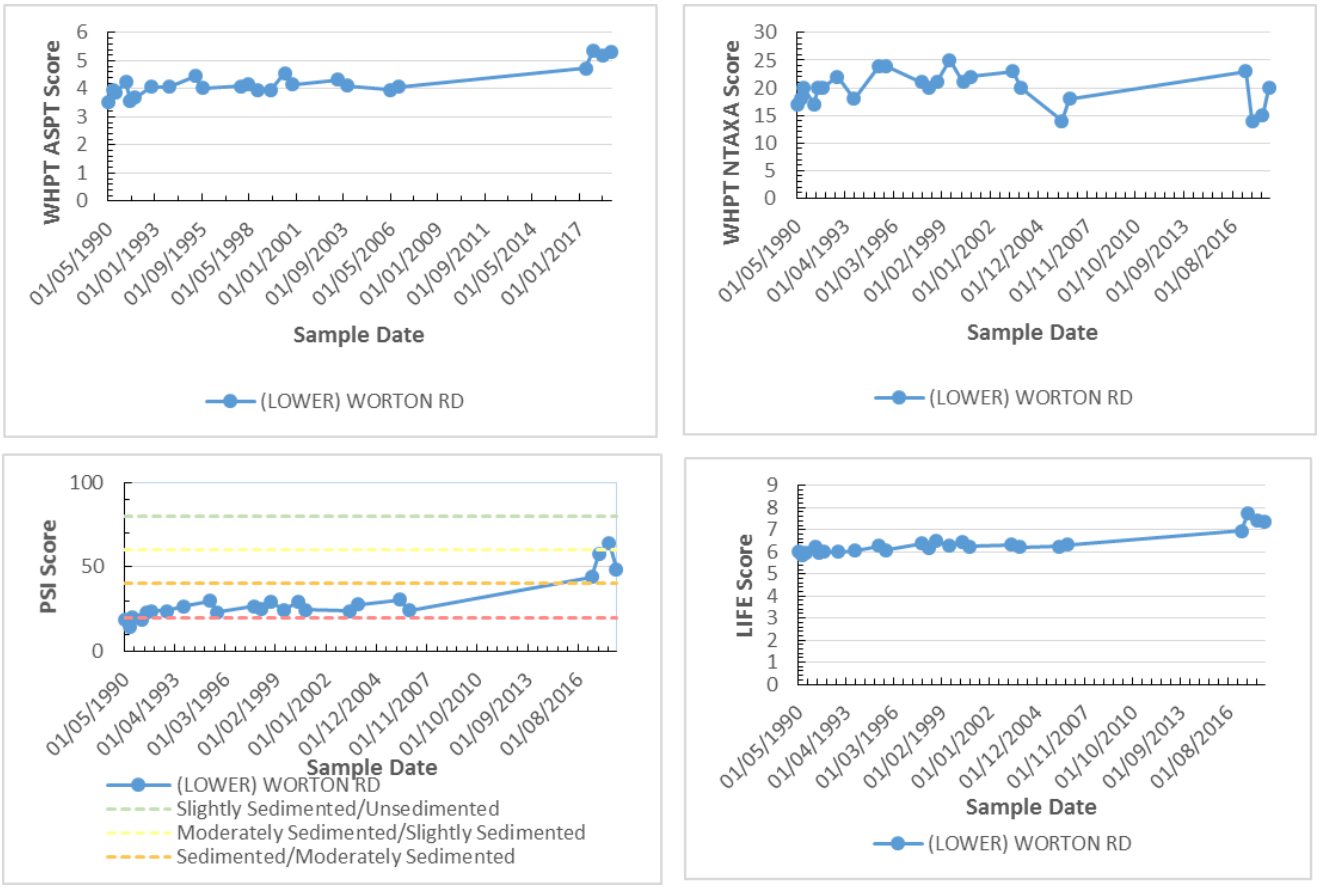

Figure 55.WHPT ASPT, WHPT NTAXA, PSI Score, and LIFE Score for Worton Road side – historical record.