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GFT's annual water quality monitoring report on behalf of Peatland Action

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Summary

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Background

Galloway Fisheries Trust (GFT) have been actively involved in recent years with encouraging and supporting peatland restoration in South West Scotland. GFT's interest in this work is associated with the potential water quality benefits from peatland restoration particularly to help address acidification problems.

In November 2019, Peatland Action agreed to fund an annual Water Quality Monitoring (WQM) program, monitoring peatland restoration sites within the region under the guidance of Emily Taylor, Galloways' local Peatland Officer. Currently, there is a three-year restoration project running at Tannylaggie on the River Bladnoch catchment and it was agreed that GFT would gather baseline data at this location and further spot sample pH data across the Upper River Bladnoch catchment by collecting water samples. In addition to this, data was also collected from sites across the Upper Cree catchment to provide baseline which may help direct future peatland restoration in the catchment.

Main findings

- There is a significant issue with low pH in and around the Dargoal Burn. This watercourse is having a negative impact on Polbae Burn and the River Bladnoch.

- It is important to consider the impacts on various water quality parameters on the overall health of a waterbody, e.g. Dissolved Oxygen, fDOM, temperature and conductivity.

- Many of these parameters impact each other and these relationships can highlight potential causes of poor water quality.

- There is one primary outflow from the restoration area that allows for precise and localised water quality monitoring.

- Water quality outputs can differ significantly within a watercourse depending on instream habitat, water flows and so the location of the sondes needs to be considered to ensure data is not biased.

- Spot sampling on the Bladnoch highlights the ranges of pH within the catchment and how these are affected by high and low flows. Differences in the worst affected areas are still notable in lower flows.

- The pH data collected across the Upper Cree catchment suggested areas of pH below the critical point, even out-with the most acidic periods of high flow. Further monitoring in this area is crucial to aid the direction of potential restoration in the future.

- This study has provided a crucial insight into water quality pre-restoration and will allow comparisons to be made in years following restoration.

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1 INTRODUCTION

Across Scotland, seventeen river catchments are affected by acidification, four of which are in Galloway (Rivers Cree, Bladnoch, Kirkcudbrightshire Dee and Water of Fleet) (Environment Agency, 2015). Degrading peatlands is one of the key drivers of this acidification and poor water quality in Galloway.

Globally, peatlands cover only approximately 3% of the lands surface (Limpens *et al.*, 2008) however have accumulated between 270 and 450 Pg. of carbon (Pg. = petagrams, 1 Pg. = 1 trillion kilograms) which represents 20 - 30% of the world's estimated global soil carbon pool (Gorham, 1991; Turunen *et al.*, 2002; Trenberth & Smith, 2005). There is approximately 2.9 million hectares of peatland in the UK. However, the majority (~ 2.6 million hectares) of this peat is found in Scotland (Holden *et al*., 2004). These peatlands are predominantly blanket peat and represent around 10 - 15% of the world's blanket peat resource (Holden *et al*., 2004).

Functional peatland is a globally important resource which acts as an effective carbon store, as the rate of production and accumulation of organic material is greater than the rate organic material is degraded and exported (Wallage *et al*., 2006; Martin-Ortega *et al*., 2014). Functioning peatland is also crucial for maintaining water quality, as healthy peatland stores Dissolved Organic Carbon (DOC), humic acids, nutrients which can lead to eutrophication and atmospherically deposited pollutants which can lead to acidification of surface waters (GFT, 2018; Martin-Ortega *et al*., 2014; Stimson *et al*., 2017).

The current state of Scotland's peatlands is widely publicised. Peatlands cover nearly a quarter of Scotland and contain over half of the Scottish soil carbon. It is suggested that over half of the blanket bog and more than 90% of lowland raised bogs are now degraded releasing greenhouse gases into the atmosphere and DOC into the water systems (Artz *et al.*, 2018). Functioning peatland is crucial for maintaining water quality, as healthy peatland stores DOC, humic acids, nutrients which can lead to eutrophication and atmospherically deposited pollutants which can lead to acidification of surface waters (Martin-Ortega *et al*., 2014; Stimson *et al*., 2017).

Many of these peatlands have lost their natural vegetation through a mix of human interference and natural influences (Wosten *et al.*, 2006). Vast areas have been drained to convert them for use in forestry, agriculture and peat extraction (Peacock *et al.*, 2018). Afforested peatlands account for around 25% of human-affected peatlands worldwide (Muller *et al.*, 2015).

Forest-to-bog conversions are now underway with the aim of increasing carbon storage and returning ecosystems to their natural state (Muller *et al*., 2015). Forest-to-bog restoration is particularly important in the Dumfries and Galloway (D&G) area as it has highly acidified catchments, a large area of commercial forestry planted on deep peat and a growing interest from forestry owners, forest managers and the GFT in undertaking peatland restoration to improve water quality for wild fisheries.

GFT have been actively involved in recent years with encouraging and supporting peatland restoration in SW Scotland. GFT's interest in this work is associated with the potential water quality benefits from peatland restoration particularly to help address acidification problems. GFT have undertaken feasibility studies (supported by Peatland Action) in the upper Luce, Bladnoch and Water of Fleet catchments which all have water quality problems associated with heavily drained deep peats. These studies have included water quality monitoring data collection. The reduced water quality in these areas has had an economic impact and has reduced biodiversity with the loss of key native species including Atlantic salmon.

Work undertaken by GFT has focussed on how best to monitor water quality influenced by drained / degraded peatlands. There are many reasons to monitor water quality when considering peatland restoration including:

- To assist in prioritising areas for peat restoration to determine where water quality could be most improved.
- To collect information to inform peatland restoration feasibility studies.
- To monitor the longer-term water quality benefits from peatland restoration.
- To monitor for any short-term deterioration in water quality during restoration works. Being aware of any concerns, particularly if protected sites are present downstream, allowing mitigation action to be taken quickly to address the situation.

In November 2019, Peatland Action agreed to fund an annual WQM program, monitoring peatland restoration sites within the region under the guidance of Emily Taylor, the regions Peatland Officer. Currently, there is a three-year restoration project just starting at Tannylaggie on the River Bladnoch catchment and it was agreed that GFT would gather baseline data at this site.

2 WATER QUALITY AS A DRIVER OF PEATLAND RESTORATION

To begin with, all emphasis was put on carbon storage as being the main driver of peatland restoration. However, WQM is also an important consideration and a fundamentally important aspect of peatland restoration.

2.1 Impacts of degrading peatlands on water quality

The primary cause of the deterioration of Scotland's peatlands is the alterations in land use. Some sites have been heavily drained to allow for agricultural expansion by improving the grazing quality of the uplands (Artz *et al.*, 2018). Others have been drained to increase the productivity of the land for timber production and forestry expansion. It was also considered that by lowering the water table it would reduce the downstream flood risk by creating a moisture deficit (Wallage *et al.,* 2006). Along with the lowered water table, pressures from over-grazing and burning are continuing to threaten the condition of many peatland areas. Large areas of bare and damaged peat can negatively and chronically affect the delivery of water related ecosystem services (Bonn *et al.,* 2010; Nisbet *et al.,* 2014).

Degradation of peatlands have several direct and in-direct negative effects on water quality. These include changes in pH, metal concentrations, dissolved organic carbon, colour and the concentration of Fine Particulate Organic Matter (FPOM) (Martin-Ortega *et al.*, 2014).

The primary concern is the increased concentration of DOC that is exported from the peat systems and into the surrounding watercourses. DOC is the carbon contained within organic matter in a solution that can pass through a 0.45 µm filter (Koehler *et al.,* 2009). Increased carbon load from DOC entering the water contributes to acidification along with increasing water temperatures and reducing light penetration (Peacock *et al.*, 2018). The mobilization of toxic metals that have been sequestered over time is a concern, transforming peatlands from sinks into sources of toxic metals (Rothwell *et al.*, 2010). Elevated metal concentrations have been linked to acidification and the toxic effect of specific metals such as Aluminium and Iron are linked to low pH.

Increased levels of suspended sediment when bare peat erodes can have a negative impact on benthic habitat and increases the biological oxygen demand (BOD) of a watercourse (Ramchunder *et al.*, 2012; Martin-Ortega *et al.*, 2014). FPOM can smother the river base, starving the inhabitants of oxygen. This is of greatest concern where there are salmonid eggs deposited in the gravel. Smothering the eggs with sediment impacts the oxygen transfer across their membrane leading to delayed hatching and often complete egg loss. The decomposition of FPOM leads to an increased BOD which can reduce the dissolved oxygen concentration (DO) of a watercourse. DO is a key parameter that needs to be considered as sudden changes can result in the mortality of salmonids.

2.2 Impact of acidification on fisheries

Upland river catchments within West Galloway are notoriously acidic and are therefore particularly sensitive to further changes. Salmonid populations within these watercourses are under threat and are showing declines in historical densities. Salmonids exist in freshwater between pH 5 and 9 with successful recruitment of young between pH 6 and 9 (Hendry & Cragg-Hine, 2000). Monitoring carried out as part of this project in the Upper Bladnoch and catchments have indicated pH regularly decreases to below pH 5.

Early life stages of fish are more sensitive to acidification therefore there is a higher mortality rate in younger fish (Baker *et al.,* 1996). Being unable to increase the population size due to increased mortality at a young age is thought to be an important factor contributing to the extinction of fish populations (Jeffries *et al.,* 2003). A shift in the age and size structure of a population is a resulting effect of decreased population which occurs when acidification increases the mortality of eggs and alevins. Acidification disrupts the enzyme chorionase from working correctly which would prevent alevins from emerging from the eggs and developing correctly (Peterson *et al.,* 1980).

It has been suggested that the reduced number of young fish could be because of a reduction in egg deposition. This can result from disruption to the spawning behaviour or the reproductive physiology of maturing adults (Schofield, 1976). Sub lethal acid stress can inhibit the growth and development of embryos and can cause malformation. When a female is exposed to low pH the eyeing rate of embryos is seen to decrease significantly. Even when an embryo is cultured in neutral pH, if the male or female has previously been exposed to acidic water the malformation rate of the embryo is increased. This can be caused by disruption of the endocrine system in mature adults as plasma levels of sex steroids and gonadotrophin were seen to be very high leading to malformation of the future embryos (Ikuta, 2000).

One of the most sensitive species which are most at risk in Galloway are Atlantic salmon (*Salmo salar*). They are particularly sensitive to acidification during the transformation into smolts before migrating from freshwaters into salt water. Magee *et al.,* (2003) experimented on the effects of episodic acidification on salmon smolts and found an increase in plasma potassium and a decrease in plasma sodium and chloride leading to the fish being unable to stay hypo-osmotic when transferred into saltwater leading to increased mortality. When salmon were introduced to acidic conditions and increased $AL^{3}+$ in freshwater they experienced reduced feeding and growth, altered migratory behaviour, gill damage, osmoregulatory and endocrine disruption and eventually death.

Indirect responses to acidification can also be seen to be problematic even if the acidification itself is not lethal. It is seen that acid stress depresses the immune system in fish. This reduced immune system can lead to death caused by common bacteria and viruses that would normally have been attacked and killed by the fish's immune system (Ikuta *et al.,* 2000).

3 WATER QUALITY MONITORING

WQM is used as a guide to help direct peatland restoration and is used to support peatland restoration at various stages. WQM is generally split into three critical phases: baseline, during restoration and post-restoration.

3.1 Stages of monitoring water quality

3.1.1 Baseline

When monitoring peatland restoration, it is vital to have pre-restoration baseline data. The lack of such data is currently a major problem limiting what is known about the success of peatland restoration (Lunt *et al*., 2010). Determining whether changes seen in a watercourse are due to the restoration activity or are the natural temporal changes which would occur regardless is key. It would be impossible otherwise to pin specific changes to specific activities. Where funds allow, pre-restoration monitoring should be in place for up to two years prior to restoration (O'Brien *et al*., 2007). For regular monitoring to be a realistic target, any amount of pre-restoration monitoring would be preferable to none. GFT would recommend a minimum of a month and this should include at least one flood event.

3.1.2 During restoration

Monitoring WQ during the restoration period itself is a useful tool in determining the impacts the restoration activity is having. Peatland restoration methods can be split into three main categories: water management, re-vegetation and vegetation management. The aim of restoration is to restore hydrological function, vegetation cover and active peat forming vegetation (Lunt *et al.*, 2010).

The sections below detail the different impacts that can occur from the different types of restoration.

<u>Forest-to-bog restoration</u>

Forest-to-bog is a key restoration technique being used in Dumfries and Galloway. Understanding the implications of the techniques involved and the expected changes in water chemistry is important when planning a monitoring program. If a site is felled to waste, trees are cut and either mulched on site or used to block the ditches. If trees are felled and removed from site, management of the site post felling includes stump flipping and ground smoothing. Research into the effects of ground smoothing is limited as it is a relatively new technique however there has been monitoring looking at the more commonly seen forest-to-bog techniques. Gaffney, (2016) researched the combined effects of conifer felling and drain blocking on open peatlands. They studied the effects this had on pore, surface, stream, and river water quality in the short-term (0 - 1 years) post restoration where the effects of the restoration are disturbance related. The results from this study found significant increases in DOC, phosphate, potassium and ammonium in pore and surface water but the only increases seen in streams was a significant increase in iron and phosphate, but these had no significant impact on rivers. There was also no significant increase in aquatic carbon export.

Gaffney *et al.,* (2018) studied differences in pore and surface water chemistry across restoration sites of different ages (0 - 17 years since restoration). These were compared to afforested and open bog controls and provided an insight into recovery rates. They also considered which pore and surface water chemistry variables were the most useful indicators of restoration recovery.

Looking primarily at surface water results and focusing on data collected immediately following restoration, results concluded that DOC increased dramatically following restoration. This was thought to be as a result of stimulated enzyme activity that is often observed in drought-rewetting cycles (Fenner *et al.*, 2011). In addition, brash decomposition will have contributed considerably to the increased DOC concentrations. Along with DOC, brash and conifer needle decomposition are thought to be linked to spikes in Aluminium and Zinc concentrations seen in surface and pore water samples following felling. Only slight increases in pH were noted in the year following restoration and no mention was made of the immediate pH response to restoration disturbance within this study. It was noted however that a legacy effect is seen in recovery rates of pH. Forestry can acidify soils with the formation of an acid humus layer (Nisbet & Evans, 2014). In coastal areas, aerial scavenging of atmospheric Sulphur and Nitrogen has a greater impact due to the sea salt deposition. Forests enhance sea salt disposition, which through cation exchange displace acid cations in the soil, which contributes to the acidity of surface waters (Fowler *et al.,* 1989; Evans *et al.,* 2001; Nisbet & Evans, 2014; Gaffney *et al.*, 2018).

Gaffney *et al.*, (2018) suggested that shallow pore water was most disturbed by restoration, likely to be as a result of continued water table fluctuation, physical disturbance of surface peat by harvesting machinery and vertical leaching from decomposing brash and tree material.

It was concluded that the restoration process itself affected many water chemistry variables but most of which recovered within eleven years, except Ammonium, Zinc and DOC which remained elevated compared to control bogs (i.e. in pristine condition). Other variables including pH and water table depth (WTD) did not completely recover exhibiting what Gaffney *et al., (*2018) described as a 'legacy effect' of drainage and afforestation. Gaffney *et al.*, (2018) recommend monitoring WTD, pH, conductivity, Calcium, Ammonium, Phosphate, Potassium, DOC, Aluminium and Zinc as key variables.

Muller *et al.*, (2015) also investigated the effect of felling practices on water chemistry. One of the key focuses of this was the difference between outputs from two different techniques. The main method involved felling trees using a hydraulic shear. Once felled the trees were placed into the furrows and then pushed down as necessary and driven over. The concern with this technique is that despite being compressed into furrows, decomposition still takes many years. Therefore, Muller *et al.*, (2015) investigated differences between this technique and an alternative restoration method, mulching. Following mulching, the ground surface becomes covered with splintered remains from the felled trees. This debris is expected to decompose quicker than sheared trees, speeding up the restoration of the bog. The aim was to determine the short-term impact of these forest-to-bog restoration techniques, particularly looking at water quality further down the catchment in drainage streams and receiving streams. Water quality monitoring was carried out through a mix of water sample collection for laboratory analysis and the use of a YSI 556 multi-probe system. Measurements and samples were taken every nine days.

Sharp increases in concentrations of Potassium, Aluminium, DOC and Phosphorus were recorded in samples collected near felling activity. It was stressed by the authors that the quantities of elements leached from the felled forestry plots and transported into the nearby stream were minimal. The increased concentrations seen as a result of felling activity was only found in the zone of disturbance and was buffered out before reaching nearby watercourses. The study suggested that the main source of DOC and Potassium was the decomposing biomass, which showed much higher levels in the mulched site, however not the Aluminium and Phosphorus. It indicated that the source of Aluminium and Phosphorus in samples was the disturbance of mineral soils that took place when heavy machinery was used to shear or mulch the trees.

Both these studies agree that the restoration technique produces a significant effect however, the effects appear to be localised and impacts downstream are minimal.

Ditch blocking

There have been varying opinions surrounding the impacts of ditch blocking as a technique and a notable lack of consistent behaviours between systems (Martin-Ortega *et al.*, 2014). There are evidence-based reports that show a reduction in DOC and colour in water systems following ditch blocking (Wallage *et al.*, 2006; Armstrong *et al.*, 2010; Anderson *et al.*, 2011). However, Worrall *et al.*, (2007) and Gibson *et al.*, (2009) both noted increases in DOC after restoration. Worrall *et al.*, (2007) stated that you may see temporary increases in DOC in the first few years after restoration as a result of systems 'flushing' out accumulated DOC when water tables are raised. Monteith *et al.*, (2007) suggest that these levels are relative to the site and are modified by other long-term drivers such as acid deposition and other site-specific factors.

Peacock *et al.*, (2018) claim that ditch blocking had no effect on DOM quality in the four years since restoration was completed. They also say they found no short-term deterioration in water quality during the restoration period.

It has been noted by Martin-Ortega *et al.,* (2014) that there are limited reports of the impact of restoration on surface water acidity, sulphate, nitrate, and metal concentrations so it is key that further monitoring is carried out.

As with forest-to-bog restoration, ditch blocking requires the use of heavy machinery and will therefore cause some physical disturbance to the site.

Re-vegetation and vegetation management

Direct water quality effects of re-vegetation and vegetation management are limited. The primary concern is the addition of fertiliser and lime to bare peat to encourage the reformation of peat forming vegetation.

Liming may be used as part of a re-vegetation program to alter the pH of the soils. Bare peat with low water tables are less able to neutralise acid deposition (Gorham *et al.,* 1987) therefore the pH of the soil is often not suitable for plant re-establishment. Fertilisation may also be used as bare peat is commonly low in major nutrients, especially Phosphorus and Potassium which are both required for plant growth (Finér & Laine, 1998; Stimson *et al.*, 2017).

Several studies have linked liming to increased DOC concentrations (Grieve, 1990a, 1990b; Andersson and Nilsson, 2001). A study by Stimson *et al.*, (2017) carried out a four-year study looking into the direct effects of lime and fertiliser on water quality. They found short-term elevated concentrations of Calcium and Phosphate for all applications compared to a control. Potassium showed similar patterns however it was not as consistent and there was no response in Nitrates. The evidence suggested that apart from Potassium in the first year of application, most products applied remained within the catchment. The study concluded that revegetation with lime and fertiliser application lead to no detectable change in DOC concentration over a four-year monitoring period. It was noticed however that the treatment produced a significant short-term suppression of colour and DOC concentration in drainage catchments. The most notable direct effect on water quality was the export of phosphate in the first year, which was above recommended levels.

3.1.3 Post restoration

Post-restoration monitoring is useful in evaluating the benefits of peatland restoration; however, it can take many years before any significant improvements are notable. Annual monitoring is recommended to gauge changes over time. Water quality data can provide evidence that peatland restoration is beneficial to the environment and support future project proposal.

3.2 Multi-parameter sonde for water quality monitoring

The EXO 1 Sonde was the multi-parameter instrument used in this study to collect water quality data. It uses four inter-changeable sensors and an integrated pressure transducer. Users can define what data is collected and how often. Data is stored on the sonde until transferred either to a PC or the EXO handheld device (a portable computer). Its battery life is approximately 90 days however this can be reduced depending on sampling frequency and external factors such as temperature. *Figure 1* is a diagram courtesy of Xylem Analytics labelling the various features of this sonde.

Figure 1: EXO 1 Sonde displaying the anatomy of the instrument. Diagram courtesy of Xylem Analytics

3.2.1 How it works

The sonde can gather constant monitoring data or to be used to spot sample. Depending on which sensors are being used, calibration is required either monthly or quarterly. If the handheld device is available, this can be done in the field, otherwise the sondes need to be calibrated on a PC. Each sensor measures its parameter via a variety of electrochemical, optical, or physical detection methods.

When deploying a sonde to constantly monitor a site over a period of time, readings can be taken as often as required, up to every two seconds. Advanced settings also allow less frequent readings to be taken until a trigger reading is measured, for example, if a certain depth is recorded and then readings could be set to automatically increase in frequency. This would allow more detailed data to be collected under flood conditions.

If the handheld device is available, spot samples can be collected. A single reading can be taken and stored on the handheld and then transferred onto a PC when required. Spot sampling is useful to gather data over a large area in a short period of time however it is not an accurate representation of the water quality of a watercourse. Water quality may average at an acceptable level, however regarding fish health, it is the short-term pulses and flushes seen during periods of high flows and flood events that are a concern. If the pH drops considerably in a flood event it may cause fish kills. In the long term, low water quality conditions are more likely to trigger behavioural responses in salmonids, such as avoidance.

3.2.2 What data can it collect?

The sonde was set to collect data every 15 minutes. The sensors used were pH, temperature/conductivity (two in one), dissolved oxygen (DO) and fDOM (fluorescent dissolved organic matter). Depth is automatically recorded using the integral pressure transducer. Other sensors are available for example, turbidity and total algae.

3.2.3 Advantages of using a Sonde

These instruments are highly accurate and recognised globally. The sondes allow the user to define exactly what it monitors with interchangeable sensors. Data collected is relative and can be compared within samples to show relationships between parameters, e.g. depth data can be compared to pH to show the effect of flood events on the pH of the watercourse over a period of time. The sonde can either be deployed to gather temporal data over long periods of time or to gather spatial data through spot sampling.

Only one day a month was required for maintenance and downloading data and it can be calibrated in the field if necessary. Sondes are incredibly robust and can withstand a lot of pressure and impact. One of the greatest advantages of the sondes is their mobility. They can be moved very easily and quickly with minimal cost. Compared to previous constant monitoring equipment which took three days to set up, this accessibility changes the way in which monitoring can be utilised.

3.2.4 Disadvantages of using Sonde

The sondes are relatively expensive to buy. Up to £10,000 per unit and additional costs for the handheld computer, they are an investment. Insurance is also costly due to the high-risk nature of its use. Servicing and maintenance costs range from £700-£1000 annually and buffering solutions are costly too with the amount required depending on how frequently the equipment is used.

For some parameters, the sonde can only detect change, it cannot quantify the specific components of a parameter. For example, fDOM sensors will detect an increase or decrease in DOM concentration in a sample but without more detailed laboratory analysis the exact components of the sample are unknown.

There are other parameters which it cannot record such as Nitrates, DOC content and heavy metal content. For this level of detail, laboratory analysis would be required.

3.2.5 Framework

For the sondes to remain in-situ and have a level of protection against flood damage, GFT with the help of the supplier designed a housing framework that holds the sonde in place.

The framework seen in *Figure 2* is made up of three spiked posts, one drainage pipe, a length of chain and jubilee clips to hold it all together. Holes are drilled in the bottom of the pipe to allow water to flow through and cable ties are used at the bottom to stop the sonde falling out the other end of the pipe. By using simple and cheap materials it has been possible to put together a mobile structure that costs no more than £100 and takes around an hour to construct with two people.

When building a framework, it is important that the banks are stable and not likely to be washed away. Using natural features such as large boulders or cuts in the banking to provide some extra protection is key. It is also essential to consider water height in low flows. The sonde must be placed so it always remains under the water surface or the equipment could get damaged.

Figure 2: GFT's framework which is used to house and protect the sondes whilst deployed in the field

3.2.6 Data output

Data collected on the sonde is configured in two ways. The software produces an excel file containing the raw data (*Figure 3*) and produces graphs to be created and exported (*Figure 4*). The raw data can be used out carry out statistical analysis and the graphs can provide a visual representation of the data, which can show trends and relationships between parameters.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	KOR Export File																				
2																					
3	File Created:10/03/2020 14:56:30																				
4																					
5	Sonde ID	Sonde 15L101810																			
6	User ID	YSI																			
7	Site	Deployment Site																			
8	Template	EXO_Default 15min																			
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11																					
12	Devices List:																				
13	Name	SN	Firmware	Corresponding Data Column(s)																	
14	Data Collection Device			1;2;3;4;5																	
15	EXO1 Sonde	15L103267	1.0.73	6;7																	
16	Optical DO	15L100938	3.0.0	8;9																	
17	fDOM	15K103455	3.0.0	10;11																	
18	pH	15L103269	3.0.0	12;13																	
19	Conductivity/Temp	15H102194	3.0.5	14;15;16;17;18;19																	
20	Depth Non-Vented 0-10m	15L101810	3.0.0	20;21																	
21																					
22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
23	Date (MM/DD/YYYY)	Time (HH:MM:SS)	Time (Fract. Sec)	Site Name	Fault Code	Battery V	Cable Pwr V	ODO % sat	ODO mg/L	fDOM RFU	fDOM QSU	pH	pH mV	Temp °C	Cond µS/cm	SpCond µS/cm	Sal psu	nLF Cond µS/cm	TDS mg/L	Press psi a	D
24	03/04/2020	14:30:00	0	Deployment Site	0	2.6	0	81	10.58	39.92	119.46	4.04	153.6	4.138	48	79.8	0.04	80.9	52	0.681	
25	03/04/2020	14:45:00	0	Deployment Site	0	2.6	0	82.4	10.76	39.96	119.57	4.04	153.9	4.138	47.8	79.4	0.04	80.5	52	0.678	
26	03/04/2020	15:00:00	0	Deployment Site	0	2.6	0	82.8	10.79	39.95	119.55	4.05	153.3	4.181	48.2	80.1	0.04	81.2	52	0.679	
27	03/04/2020	15:15:00	0	Deployment Site	0	2.6	0	82.8	10.8	39.92	119.45	4.05	152.9	4.219	49	81.3	0.04	82.4	53	0.676	
28	03/04/2020	15:30:00	0	Deployment Site	0	2.6	0	83	10.81	39.8	119.09	4.06	152.6	4.242	50.3	83.3	0.04	84.4	54	0.673	
29	03/04/2020	15:45:00	0	Deployment Site	0	2.6	0	83.3	10.84	39.72	118.86	4.07	152.3	4.264	51.5	85.2	0.04	86.4	55	0.672	
30	03/04/2020	16:00:00	0	Deployment Site	0	2.6	0	83	10.8	39.62	118.56	4.07	152.1	4.267	52.9	87.6	0.04	88.8	57	0.67	
31	03/04/2020	16:15:00	0	Deployment Site	0	2.6	0	83.5	10.87	39.6	118.5	4.07	152	4.264	53.8	89	0.04	90.2	58	0.668	
32	03/04/2020	16:30:00	0	Deployment Site	0	2.6	0	83.7	10.9	39.58	118.44	4.07	152	4.265	54.4	90	0.04	91.2	59	0.666	
33	03/04/2020	16:45:00	0	Deployment Site	0	2.6	0	83.9	10.91	39.51	118.23	4.07	152	4.265	54.8	90.7	0.04	91.9	59	0.668	
34	03/04/2020	17:00:00	0	Deployment Site	0	2.6	0	84	10.93	39.42	117.96	4.07	152	4.265	55.2	91.4	0.04	92.6	59	0.668	
35	03/04/2020	17:15:00	0	Deployment Site	0	2.6	0	83.9	10.92	39.32	117.66	4.07	152	4.261	55.5	91.9	0.04	93.2	60	0.669	
36	03/04/2020	17:30:00	0	Deployment Site	0	2.6	0	84.1	10.95	39.19	117.28	4.07	152	4.253	55.8	92.4	0.04	93.6	60	0.669	
37	03/04/2020	17:45:00	0	Deployment Site	0	2.6	0	84.1	10.95	39.06	116.88	4.07	152	4.234	56	92.9	0.04	94.1	60	0.667	

Figure 3: Excel output of raw data collected on the sonde. This data was collected from the bottom site at Dargoal Burn and was used to produce the tables in Appendix 1 and the graphs presented throughout the report.

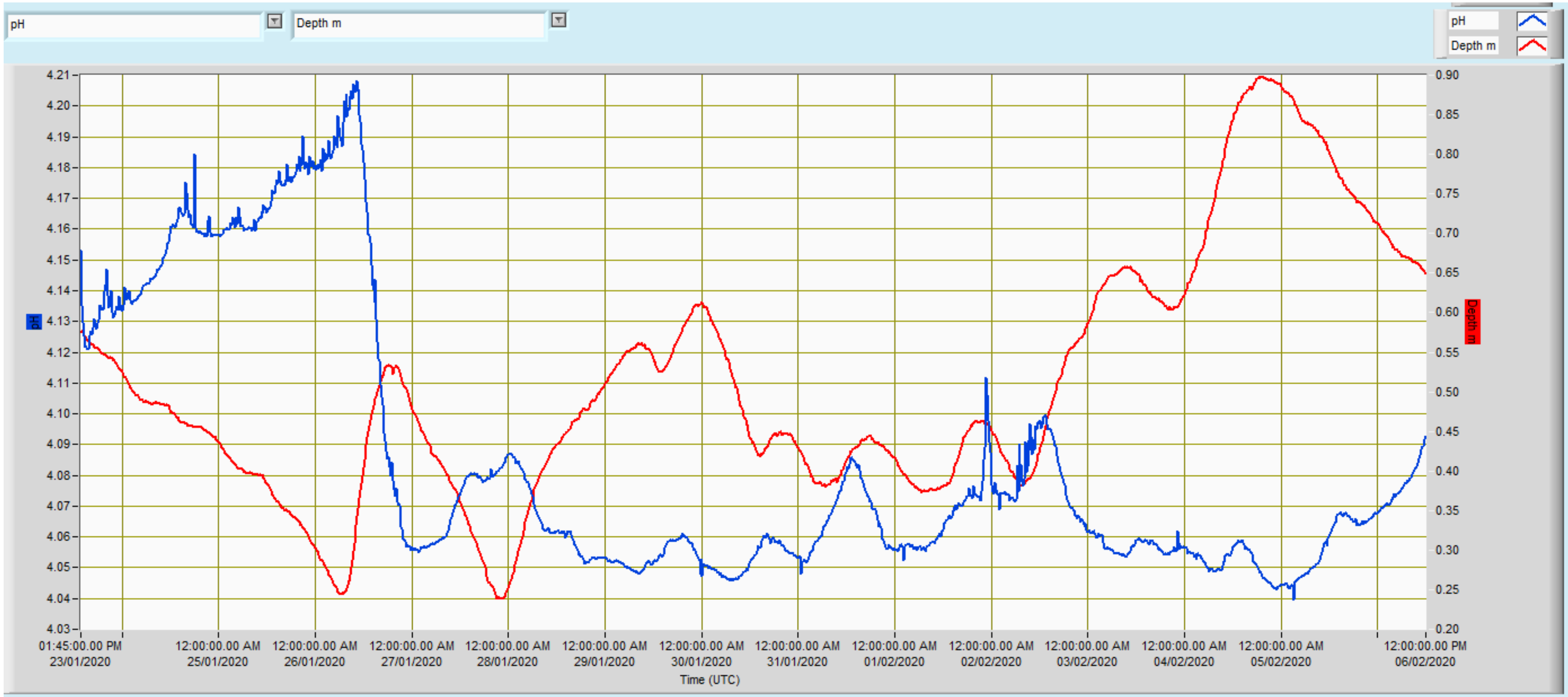

Figure 4: Graph output from the KOR software looking at the relationship between depth (red line) and pH (blue line). This graph has been produced using raw data detailed in Figure 3.

4 TANNYLAGGIE AND THE RIVER BLADNOCH

The River Bladnoch is a medium sized, low lying catchment which has been designated a Special Area of Conservation (SAC) under the European Commission’s Habitats Directive for Atlantic salmon (GFT, 2018).

One of the major land use of the upper River Bladnoch catchment is conifer afforestation, with 71% of the catchment planted (*Figure 5*) (Helliwell *et al.*, 2001). A study conducted by Helliwell *et al* in 2001 investigated water quality of the Rivers Bladnoch, Cree and Luce catchments. The results of this study demonstrated that the Rivers Bladnoch and Cree, which drain afforested areas, were significantly more acidic than the River Luce which drains adjacent moorland. Therefore, it was concluded that extensive forestry plays an import role in exacerbating acidification through dry and occult deposition in these catchments (Helliwell *et al*., 2001). Afforestation not only decreases pH and increases aluminium in soils and surface waters but may also result in reduced light levels (Essex & Williams, 1992). Heavy shading, as a result of dense forestry being planted next to burns, reduces riparian vegetation, increases bankside erosion, and leads to reduced biodiversity and burns productivity (Broadmeadow & Nisbet, 2004).

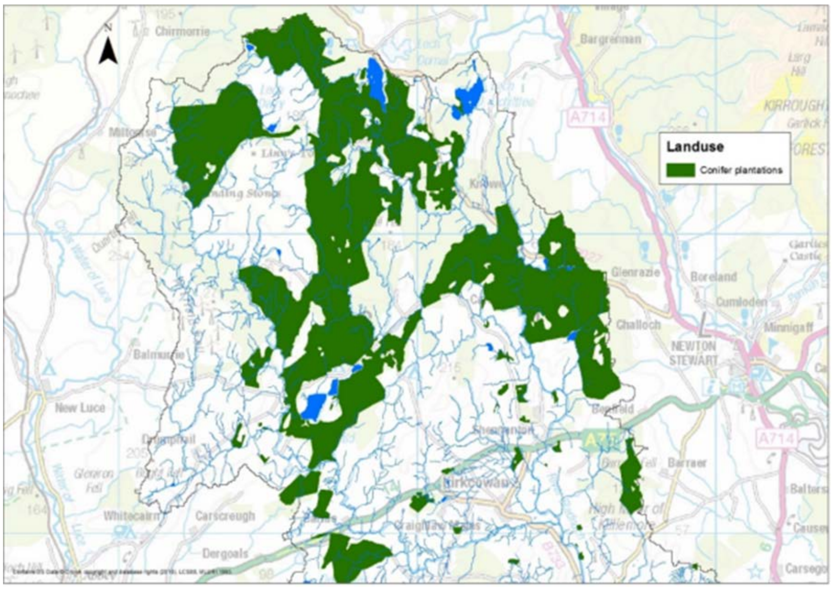

*Figure 5: Afforested area of upper River Bladnoch catchment, with 71% of the catchment being planted (*Helliwell *et al*., 2001*)*

Tannylaggie is an area of forestry located within the River Bladnoch catchment, which is the site of a three-year, forest-to-bog restoration project, led by Forestry and Land Management Scotland (FLMS). This project aims to restore up to 300 Ha of deep peat through felling trees, stump flipping and ground smoothing. Peat depth measurements in *Figure 6* highlight the approximate area due to be restored.

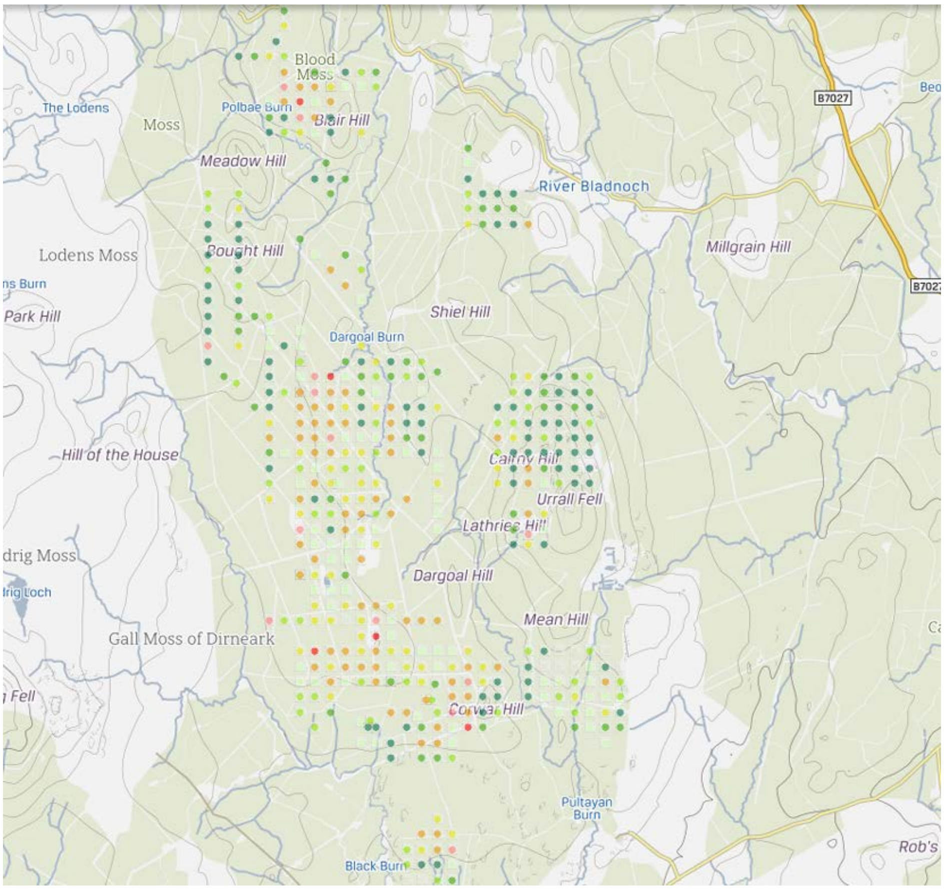

Figure 6: Peat depth map for Tannylaggie restoration

Concerns about this location have been raised in the past due to the conditions of the Dargoal Burn which runs through the restoration site and feeds into the River Bladnoch. The Dargoal Burn has been classified as one of the most acidified watercourse in Galloway with acid pulses dropping pH to as low as 3.8. Previous studies have shown that this watercourse is having a knock-on-effect on water quality further downstream (GFT, 2018).

This project aimed to gather baseline water quality data from the Dargoal Burn and surrounding catchment, to allow a comparison during and post restoration.

5 METHODS

GFT collected WQM data between the 30th December 2019 and the 17th March 2020. Two methods were used to collect data. Spot samples were gathered to collect spatial differences within the Bladnoch catchment and constant monitoring EXO 1 multi-parameter sondes were deployed to gather temporal changes within the vicinity of the restoration at Tannylaggie.

5.1 Constant monitoring

GFT and Emily Taylor considered the area due to be restored and the location of the sondes were agreed in early December following the confirmation of the project. Three sondes were deployed for a period of two and a half months. As highlighted in *Figure 7* by the yellow line, there is one primary outflow of drainage water from the restoration site (all drains within restoration site are coloured red). This single outflow allows a concise monitoring point for this restoration area, which is important in collecting accurate, representative data.

This project collected baseline data from three locations within the vicinity of the restoration and focused on providing comparable data which allows for changes as a result of the restoration to be identified. Monitoring was focused around the primary outflow identified in *Figure 7*, sondes were placed above the inflow, in the inflow and downstream of the inflow (*Figure 8*). *Table 1* provides the OS grid references of the deployment locations, along with the Site ID's which are referred to throughout this report.

Table 1: Grid references of the constant monitoring sites at Tannylaggie on the Dargoal Burn

Location	**Site ID**	**Grid Reference**
Above the inflow	Site 1	227694 570938
In the inflow	Site 2	227602 570976
Below the inflow	Site 3	227655 571132

The top two sondes remained in-situ for the whole study period however the lowest sonde, which was monitoring downstream of the inflow, was required to test the regular water samples that were collected around the catchment. The sonde was removed at approximately 1pm on the sampling days and returned at 10am the following day. Comparable data has been adjusted accordingly.

The framework was built as detailed in section 3.2.5 and will remain in place to allow for future monitoring.

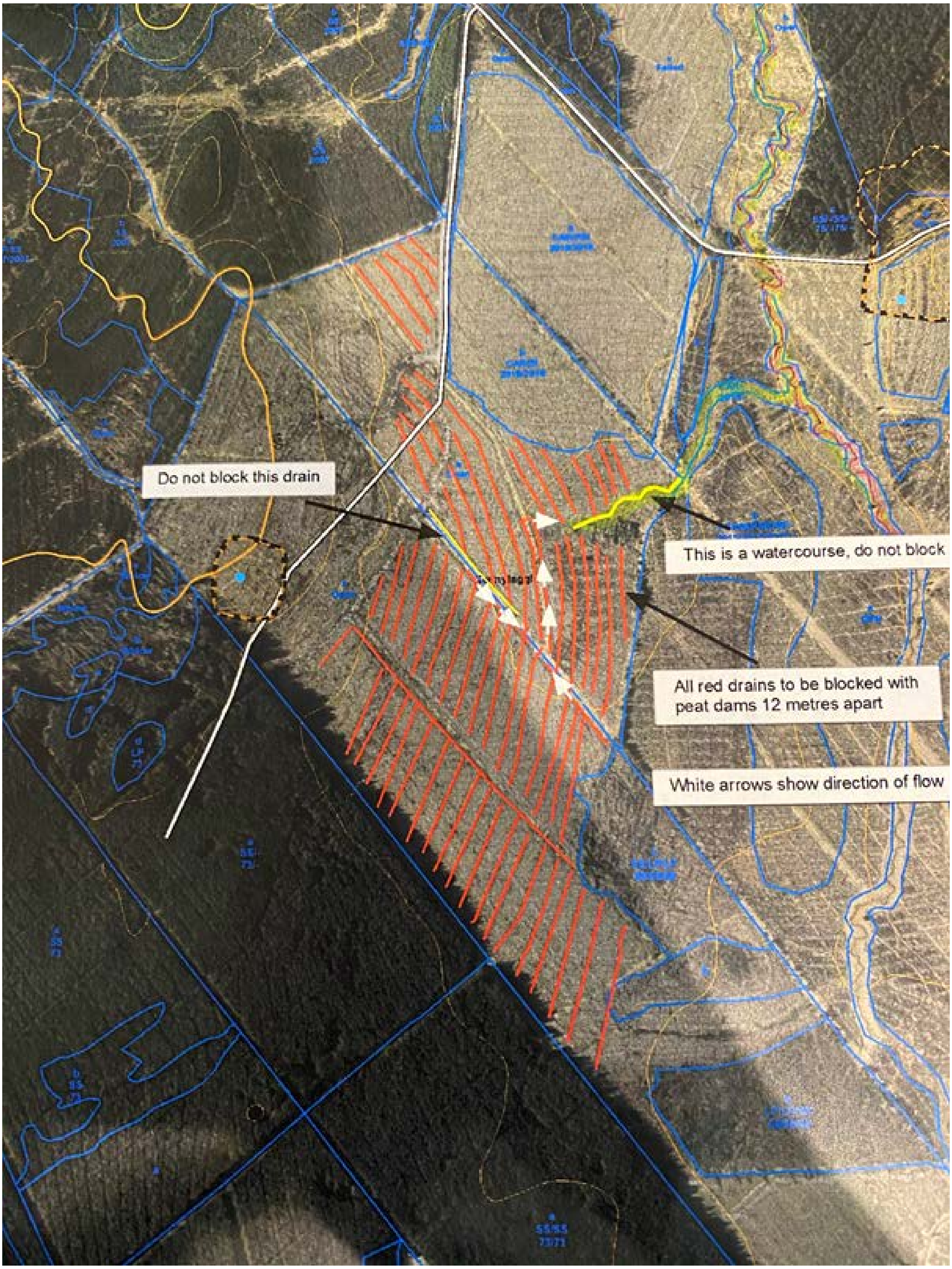

Figure 7: Drainage map of the site, highlighting the primary inflow burn feeding off the restoration site (yellow line). The red lines are indicating the drains visible in the site.

Figure 8: Locations of the sondes at Tannylaggie

5.2 Water sampling

As part of a report looking into the recovery of the Upper Bladnoch catchment from acidification (GFT, 2018) GFT carried out a monitoring program between 16/12/17 and the 14/04/18. It was decided to utilise this historical data and continue monitoring at the same sites as part of this project.

Water samples were collected throughout the Upper Bladnoch catchment throughout the duration of the study period. These were not dictated by weather or flow rates and aimed to gather data at random intervals. The purpose of this was to gather spatial data showing differences in pH throughout the catchment and to highlight the extent of the effect high flows have on different water bodies at various points in the system. By noting the river flows on each day, it allowed comparisons to be made.

The variation in the data collected highlights the importance in constant monitoring to get a true representation of the lower ranges of pH in any given area.

Samples were collected from the riverbank. The sample bottles were rinsed three times with river water. The sample bottle was dipped completely under water and capped whilst still underwater in order to eliminate any air from the sample bottle. The water had to be deeper than the sample bottles and free of surface scum and debris.

Samples were kept in the boot of the truck where temperature was lowest, and once all samples were collected these were then taken straight back to the office and tested.

Samples were tested using the EXO 1 sonde. Before taking a reading, a small amount of the sample due to be read was poured into a jug and swirled. This was then poured over the pH sensor to ensure any water droplets from the previous sample would be rinsed away. The sample was then poured into the jug and the sonde was held in the water for two minutes. This method was standardised across all sampling events. Samples of previously similar pH levels were read at the same time to reduce the fluctuations of the pH sensor readings which reduced the amount of time required for the readings to settle.

Figure 9: GFT staff collecting a water sample on the River Bladnoch

6 RESULTS

6.1 Constant monitoring

Appendix 1 provides tables of all the data gathered over the monitoring period. The raw data from each site has been grouped into months, and minimum, maximum, and average data has been presented. These tables will be referred to within this data summary. Graphs have been produced to give a visual representation of the relationships between key parameters and to show the fluctuations as a result of changing water levels. Due to the number of comparable data sets within this study, key time periods, parameters and relationships have been chosen to be displayed in graph form.

pH

Constant water quality monitoring was used to highlight key periods when pH fell below 5, the critical pH below which is detrimental for juvenile salmonid survival. It has been demonstrated that a high number of mortalities of juvenile salmonids are expected when pH falls below pH 5 (Peterson *et al*., 1980).

Site 1

During the study period between the 30th December 2019 and 17th March 2020, the average pH ranged between 6 and 6.07. The minimum pH of 5.59 was recorded in January (recorded 23/01/2020) and the maximum pH of 6.19 was recorded in February (recorded 11/12/2017). During the study period, pH was recorded above the critical pH for juvenile salmonids (pH 5) consistently throughout the study. *Figure 10* is a time series graph showing the relationship between pH and depth which highlights the fluctuations of pH in response to changing water levels.

Site 2

During the study period between the 30th December 2019 and 17th March 2020, the average pH ranged between 4.02 and 4.2. The minimum pH of 3.95 was recorded in February (recorded 13/02/2020) and the maximum pH of 4.56 was recorded in January (recorded 02/01/2020). During the study period, pH was recorded below the critical pH for juvenile salmonids (pH 5) consistently throughout the study. *Figure 11* is a time series graph showing the relationship between pH and depth which highlights the fluctuations of pH in response to changing water levels.

Site 3

During the study period between the 30th December 2019 and 17th March 2020, the average pH ranged between 4.02 and 4.05. The minimum pH of 3.78 was recorded in March (recorded 12/03/2020) and the maximum pH of 4.21 was recorded in January (recorded 26/01/2020). During the study period, pH was recorded below the critical pH for juvenile salmonids (pH 5) consistently throughout the study. *Figures 12 and 13* are time series graph showing the relationship between pH and depth which highlights the fluctuations of pH in response to changing water levels. *Figure 12* is during January, and *Figure 13* is the whole study period.

As displayed in *Figure 14* where all sites are compared against each other and a benchmark of pH 5, there were notable differences between Site 1 and Site 2 and 3. Even during flood events, the pH at Site 1 is significantly higher than at Sites 2 and 3.

Constant monitoring data picked up acid flushes each month with pH dropping and recovering in a relatively short period of time. These flushes are what kill salmonid eggs that may be present within the substrate of a watercourse and are often missed with spot sampling alone. Although fish are not present within the watercourses monitored in this study, poor water quality higher up in the catchment can have an impact on watercourses lower in the catchment which will contain fish. As can be seen from the graphs, pH and depth are correlated. As depth increases, as a result of increased precipitation from rain or snow melt, a greater volume of pollutants are deposited into surface waters and pH decreases (in other words becomes more acidic). The graphs displaying pH have been produced from the time period 12th December to 22nd January, as it is the only period that all three sondes were recording without disruption and this allows a comparison between sites.

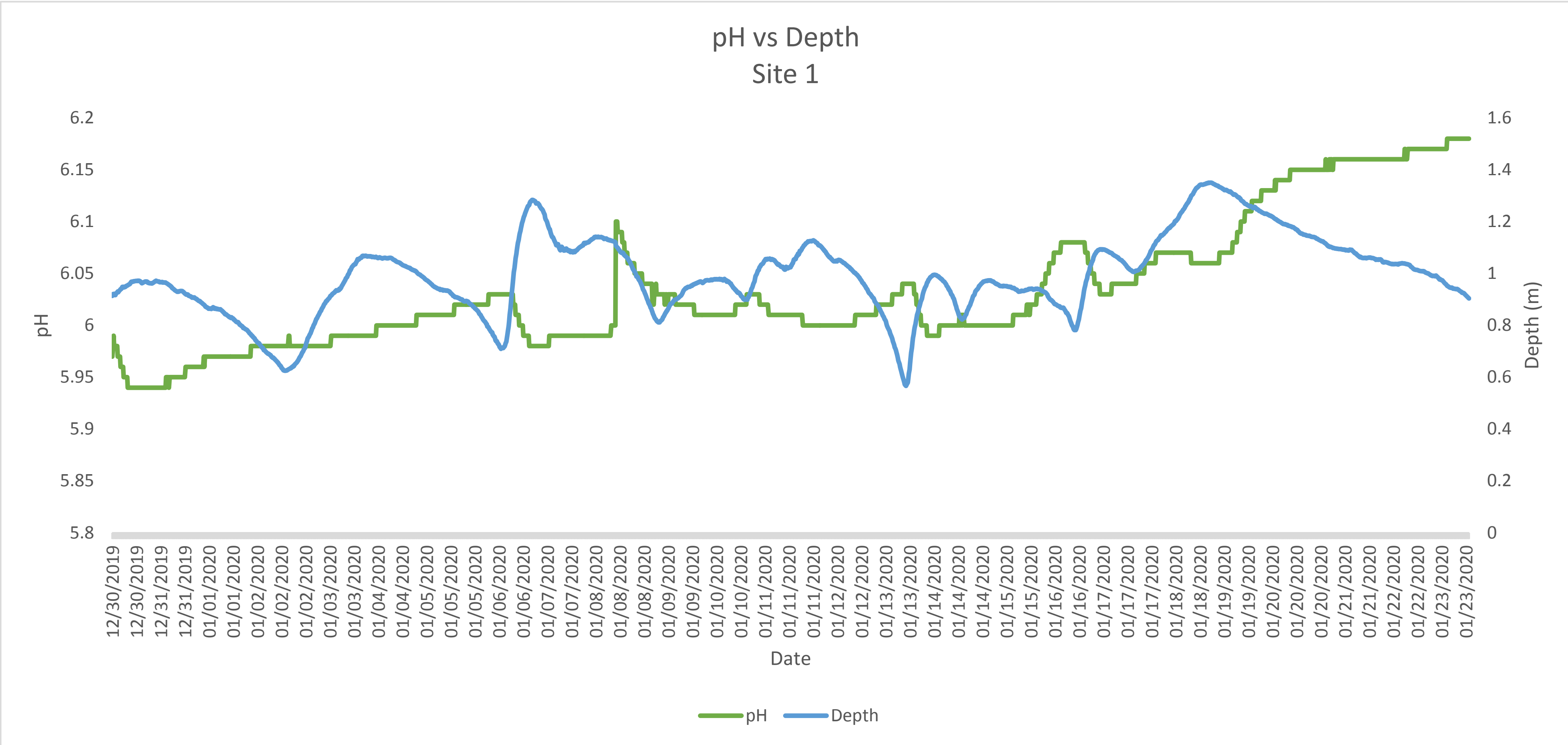

Figure 10: Time series graph from constant monitoring of pH (green line) and Depth (blue line) between 30/12/2019 and 23/01/2020 on the Dargoal Burn at Site 1, Grid Ref: 227694 570938 .Site 1 is located ***above*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

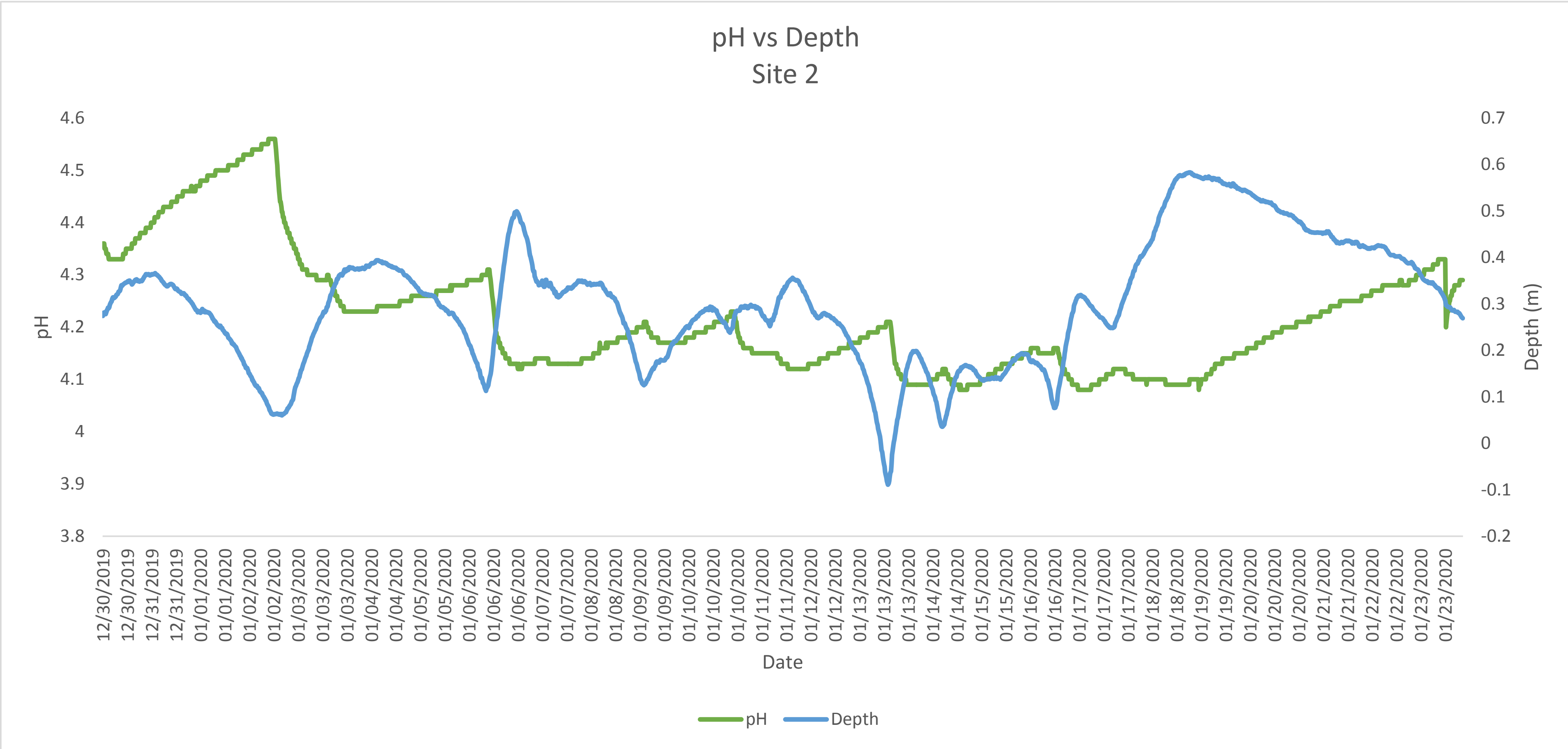

*Figure 11: Time series graph from constant monitoring of pH (green line) and Depth (blue line) between 30/12/2019 and 23/01/2020 on the Dargoal Burn at Site 2, Grid Ref: 227602 570976. Site 2 is located **in** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

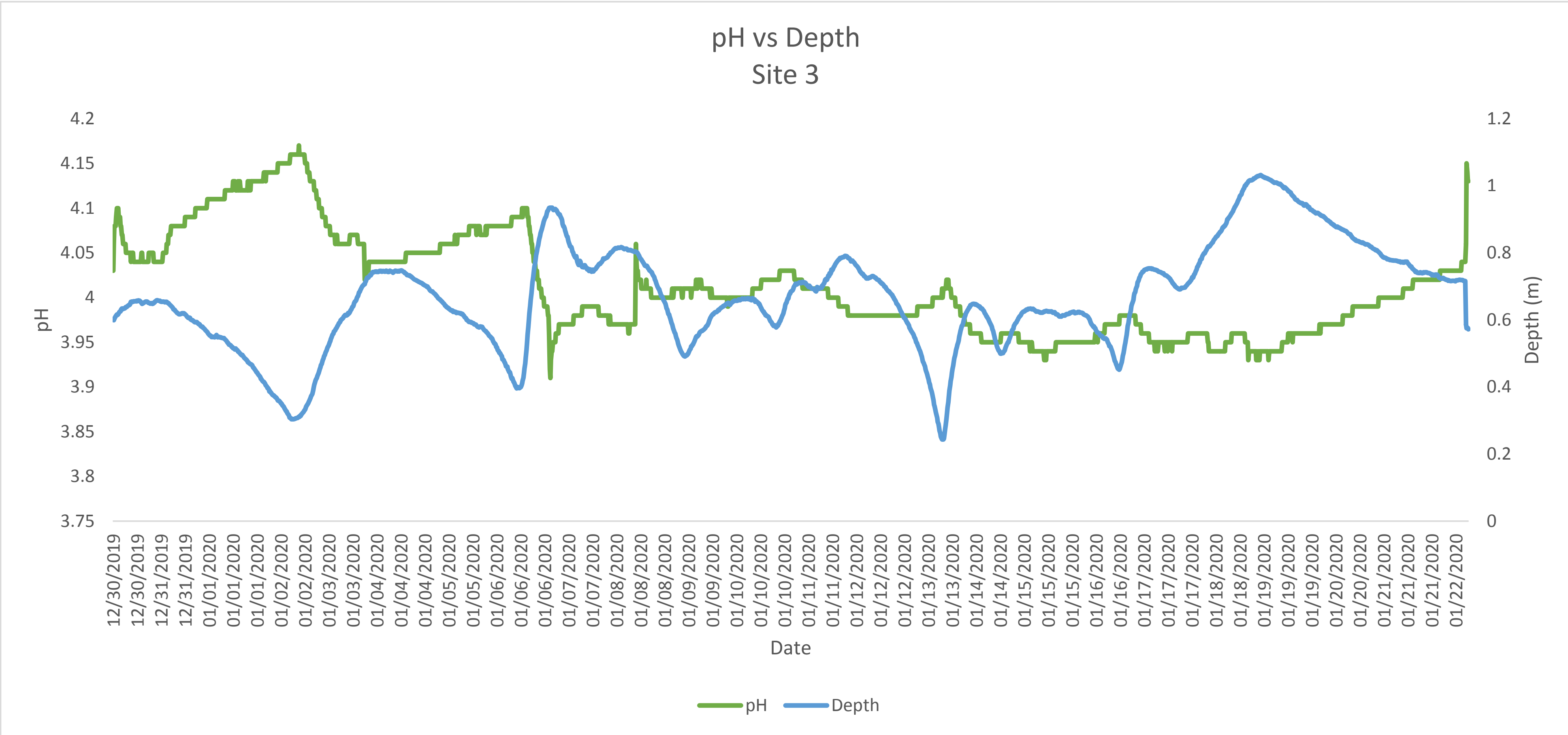

*Figure 12: Time series graph from constant monitoring of pH (green line) and Depth (blue line) between 30/12/2019 and 22/01/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located **in** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

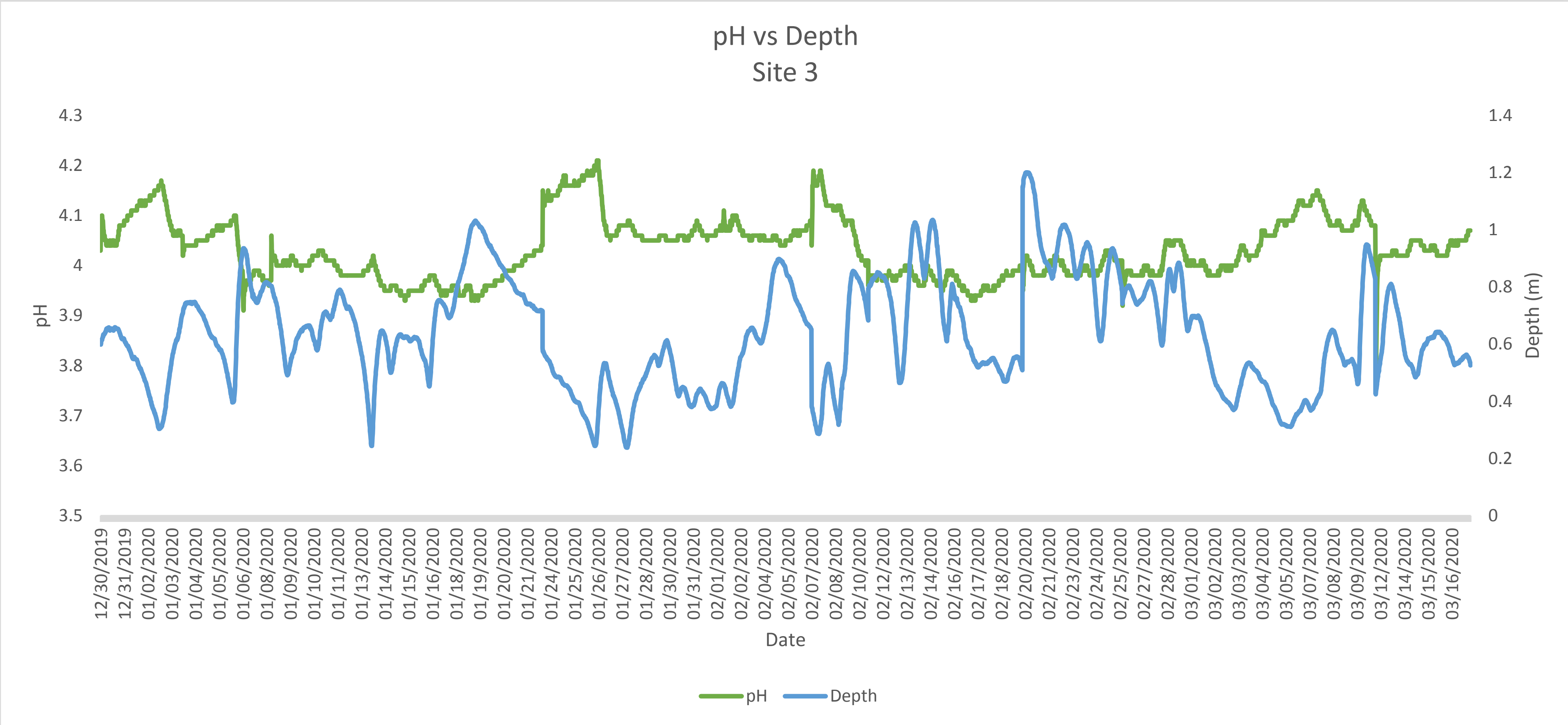

Figure 13: Time series graph from constant monitoring of pH (green line) and Depth (blue line) across the whole study period between 30/12/2019 and 16/03/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located ***below*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

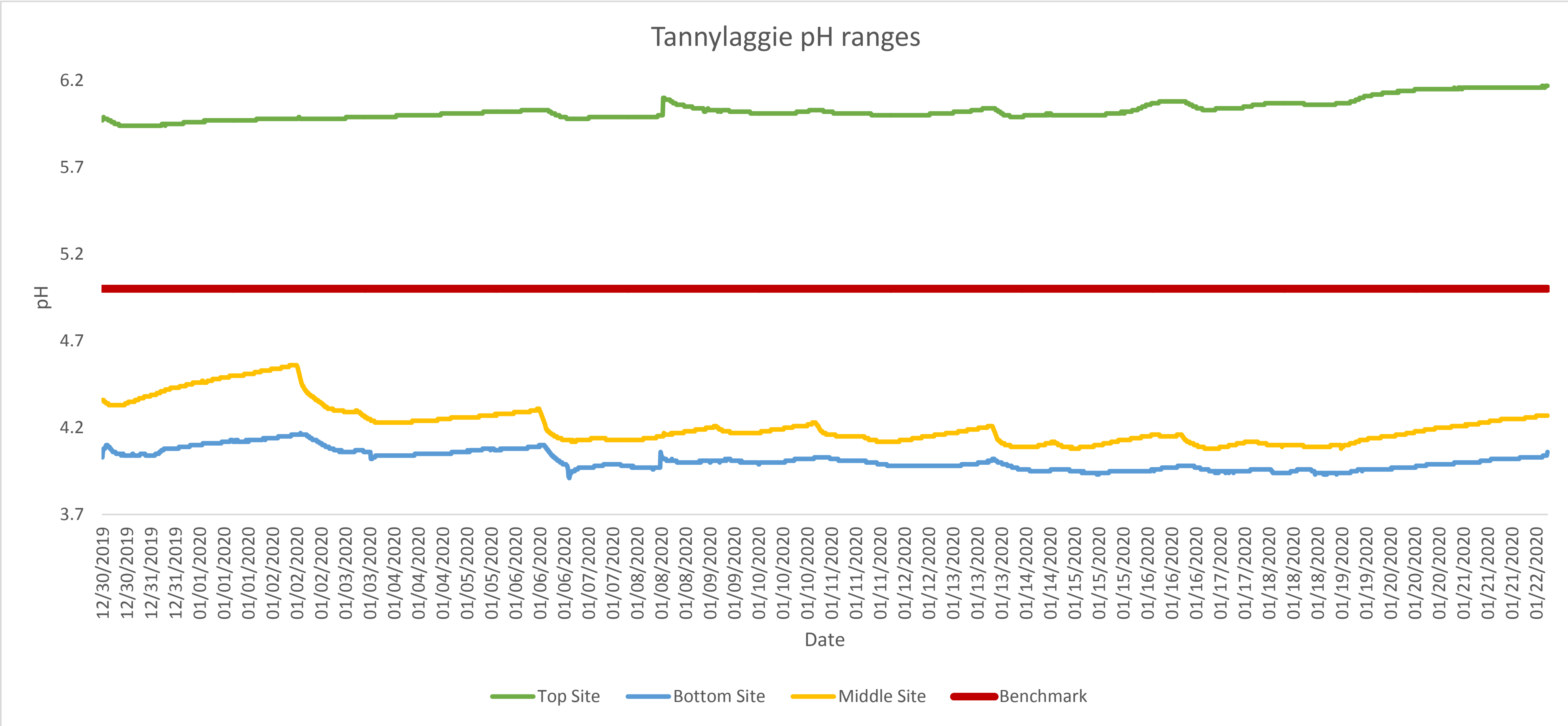

Figure 14: Time series graph from constant monitoring of pH between 30/12/2019 and 22/01/2020. Graph displaying pH values at Site 1, 2 and 3 on the Dargoal Burn. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes. Red line is the critical pH below which is detrimental to juvenile salmonids.

Dissolved oxygen

Constant water quality monitoring was used to gather baseline data on the natural fluctuations of DO within the waterbodies surrounding the restoration area before any work was carried out to allow for comparisons to be made in the future as in indicator of the health of the water body. Data collected was compared against a suggested scale of DO concentrations and their effect on trout eggs, juveniles and adults (*Figure 31*).

Unfortunately, one of the sondes dissolved oxygen sensors was not reading properly for the duration of the study period (Site 1). Due to the time restrictions and the delay that would result from sending a sonde away, it was not possible to get this fixed. However, DO measurements were still gathered from the bottom and middle sites which could be impacted by the restoration site.

<u>Site 2</u>

The diurnal fluctuations of DO throughout the study period remained stable and fluctuations were closely correlated to daily temperature changes. DO concentrations were positively correlated to lowering water temperatures, as water temperature decreased, DO concentrations increased. DO concentrations were positively correlated with depth, as depth increased, DO concentrations also increased. DO concentrations were also positively correlated to decreasing temperature. This was apparent across the study period. Average DO concentrations ranged between 9.6 and 10mg/L throughout the duration of the study. The minimum DO concentration of 8.29 mg/L was recorded in January (recorded on 07/01/2020) and the maximum DO concentration of 11.6 mg/L was recorded each month throughout the study.

During the study period, DO concentrations considered stressful for salmonid eggs (between 7 and 9 mg/L) 11% of the time and were below optimal (11mg/L) 97% of the time. DO concentrations were considered optimal for juvenile and adults 100% of the time.

<u>Site 3</u>

The diurnal fluctuations of DO throughout the study period remained stable and fluctuations were closely correlated to daily temperature changes which can be seen in in *Figure 16*. DO concentrations were positively correlated to lowering water temperatures, as water temperature decreased, DO concentrations increased. As *Figure 15* indicates, DO concentrations were positively correlated with depth and as depth increased, DO concentrations also increased. Average DO concentrations ranged between 9.8 and 10.4mg/L throughout the duration of the study. The minimum DO concentration of 8.5 mg/L was recorded in January (recorded on 24/01/2020) and the maximum DO concentration of 11.6 mg/L was recorded in February (recorded on 13/02/2020).

During the study period, DO concentrations considered stressful for salmonid eggs (between 7 and 9 mg/L) 4.4% of the time and were below optimal (11mg/L) 95% of the time. DO concentrations were considered optimal for juvenile and adults 100% of the time.

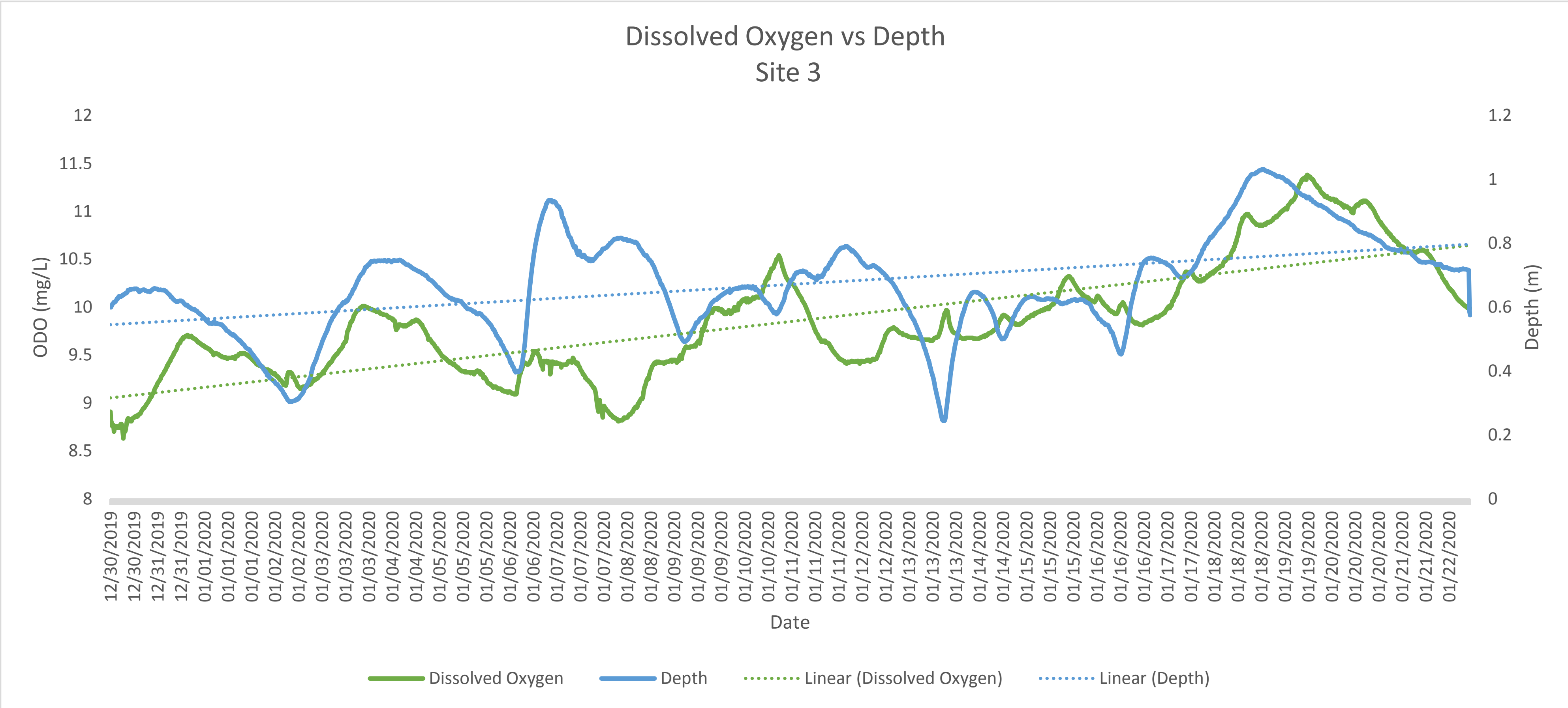

Figure 15: Time series graph from constant monitoring of Optical Dissolved Oxygen (green line) and Depth (blue line) between 30/12/2019 and 22/01/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located ***below*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

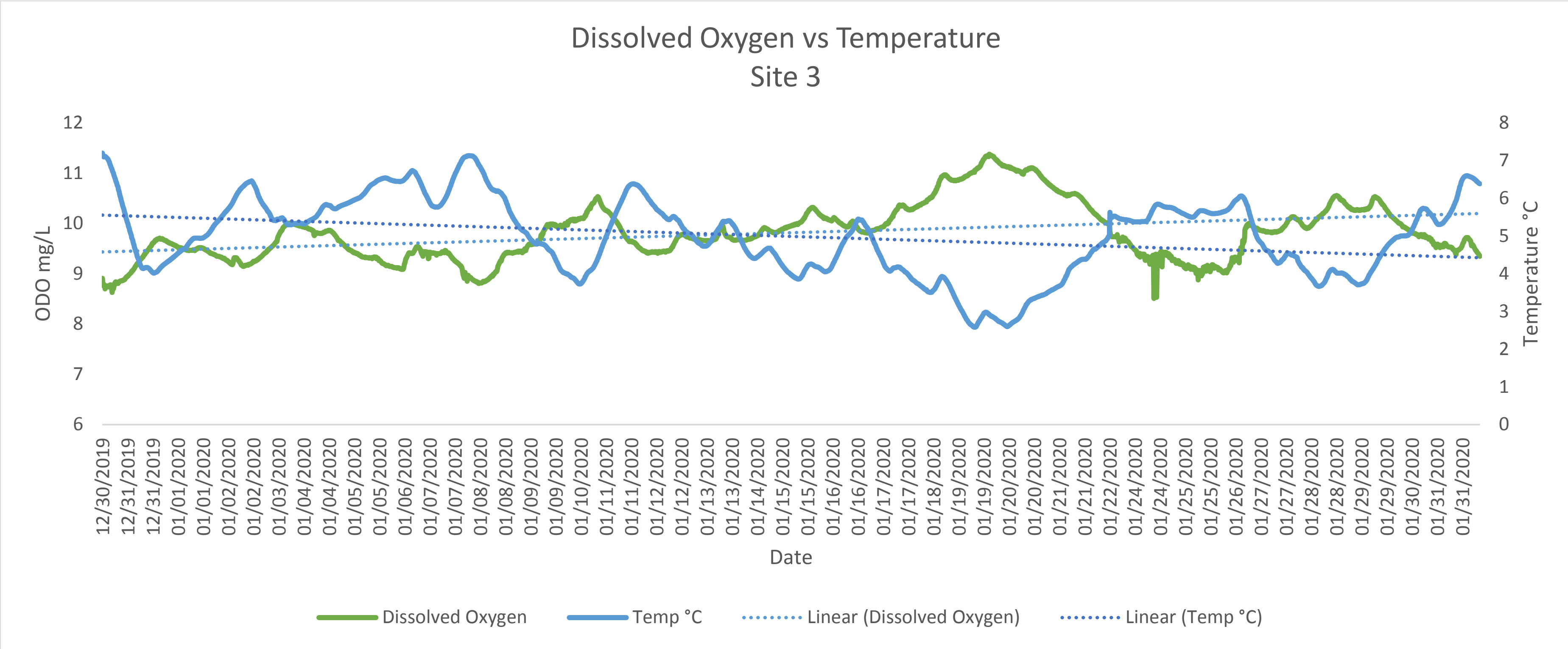

*Figure 16: Time series graph from constant monitoring of Optical Dissolved Oxygen (green line) and temperature (blue line) between 30/012/2019 and 30/01/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located **below** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

fDOM

Colored Dissolved Organic Matter (CDOM) refers to organic matter in water that absorbs strongly in the ultraviolet (UV) spectrum. Fluorescent Dissolved Organic Matter (fDOM) refers to the fraction of CDOM that fluoresces (Fondriest Environmental, 2014b).

Constant water quality monitoring was used to measure the levels of CDOM/FDOM to understand their trends because they can have a significant effect on aquatic ecosystems. The standard unit to present fDOM in is Quinine Sulphate Units (QSU).

<u>Site 1</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum concentration of fDOM (82.9 QSU) was recorded in January (recorded 30/12/2020) and the maximum concentration of fDOM (305.71 QSU) was recorded in March (recorded 04/03/2020). Average concentrations of fDOM ranged between 231.5 and 293.5 QSU during the study period. Site 1 presented the highest fDOM concentrations of all three sites averaging 69% higher than Site 2 and 56% higher than Site 3.

<u>Site 2</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum concentration of fDOM (18.5 QSU) was recorded in February (recorded 24/02/2020) and the maximum concentration of fDOM (168.9 QSU) was recorded in January (recorded 30/01/2020). Average concentrations of fDOM ranged between 46.8 and 124 QSU during the study period. The fDOM concentrations during February were considerably lower than the other months however this correlates with increased water levels on a regular basis during this period.

Figure 20 is a time series graph highlighting a period of significantly spiking fDOM concentrations which potentially is resulting in increasing temperature. This period is where the highest concentration of fDOM was recorded throughout the study at Site 2.

<u>Site 3</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum concentration of fDOM (103.9 QSU) was recorded in February (recorded 30/12/2020) and the maximum concentration of fDOM (133.2 QSU) was recorded in February (recorded 04/03/2020). High fDOM concentrations are correlating with low water levels across all months. Average concentrations of fDOM ranged between 113.6 and 122.6 QSU during the study period.

Figure 17 is a time series graph showing the relationship between fDOM and depth at Site 3. This graph highlights the diurnal fluctuation of fDOM and indicates that there is a negative correlation between fDOM and depth, as the depth of the water increases, the concentration of fDOM decreases. Diurnal fluctuations can be seen in closer detail in *Figure 18*. These fluctuations are apparent across all sites throughout the study. *Figure 19* displays the negative correlation between temperature and fDOM concentration, as the temperature decreases, the concentration of DOM also decreases. This correlation is also apparent across all sites throughout the study period.

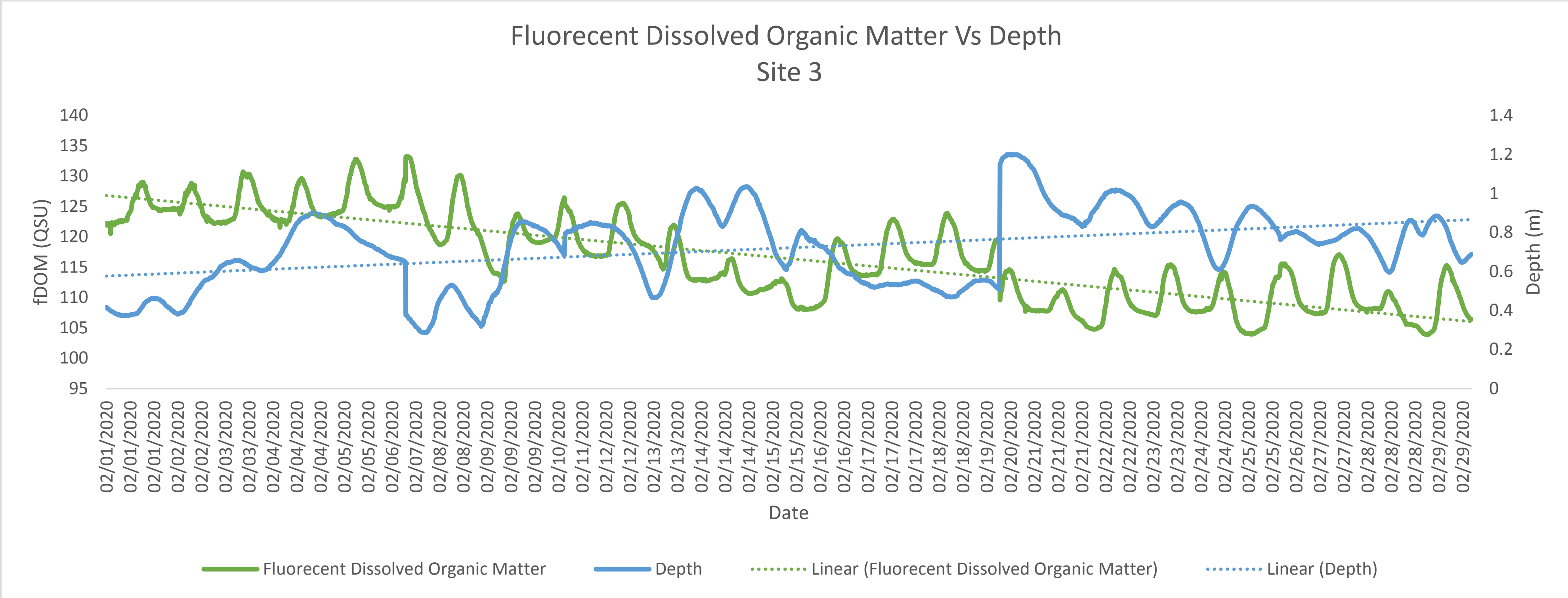

*Figure 17: Time series graph from constant monitoring of Fluorescent Dissolved Organic Matter (green line) and Depth (blue line) between 01/02/2019 and 29/02/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located **below** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

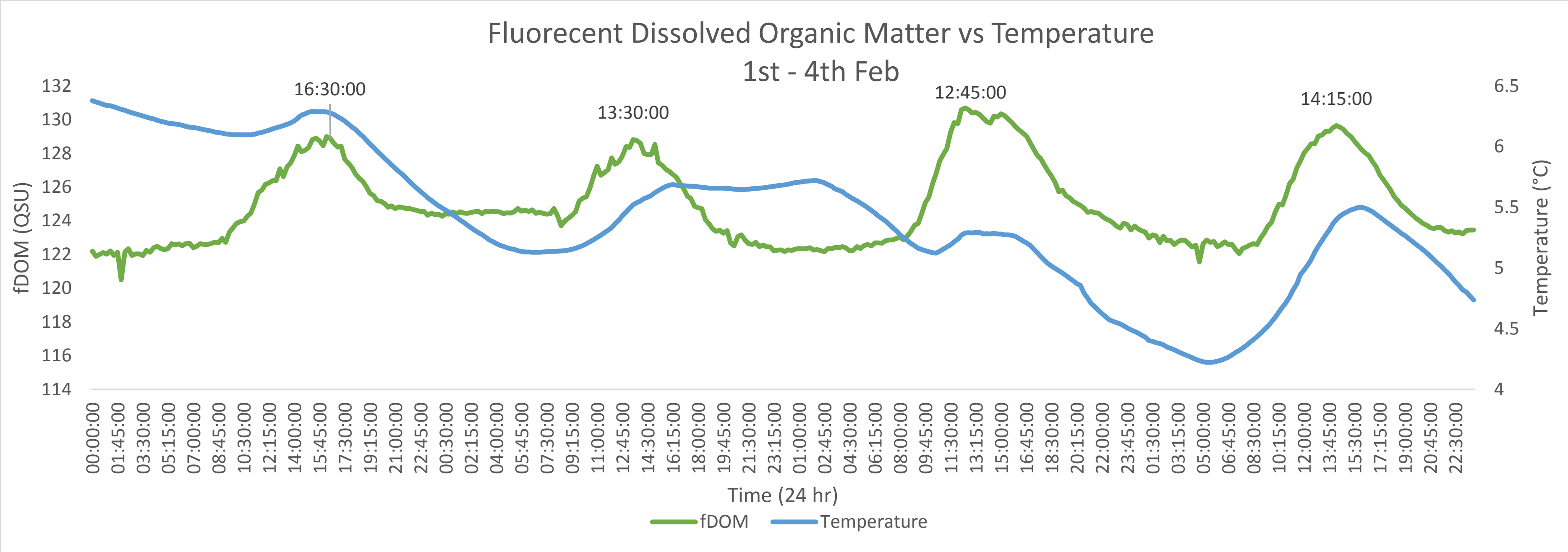

Figure 18: Time series graph from constant monitoring of Fluorescent Dissolved Organic Matter and temperature between midnight 01/02/2019 and midnight 04/02/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located ***below*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes. This graph is displaying data collected at 15-minute intervals to highlight the natural daily fluctuations in fDOM concentrations recorded as a result of temperature.*

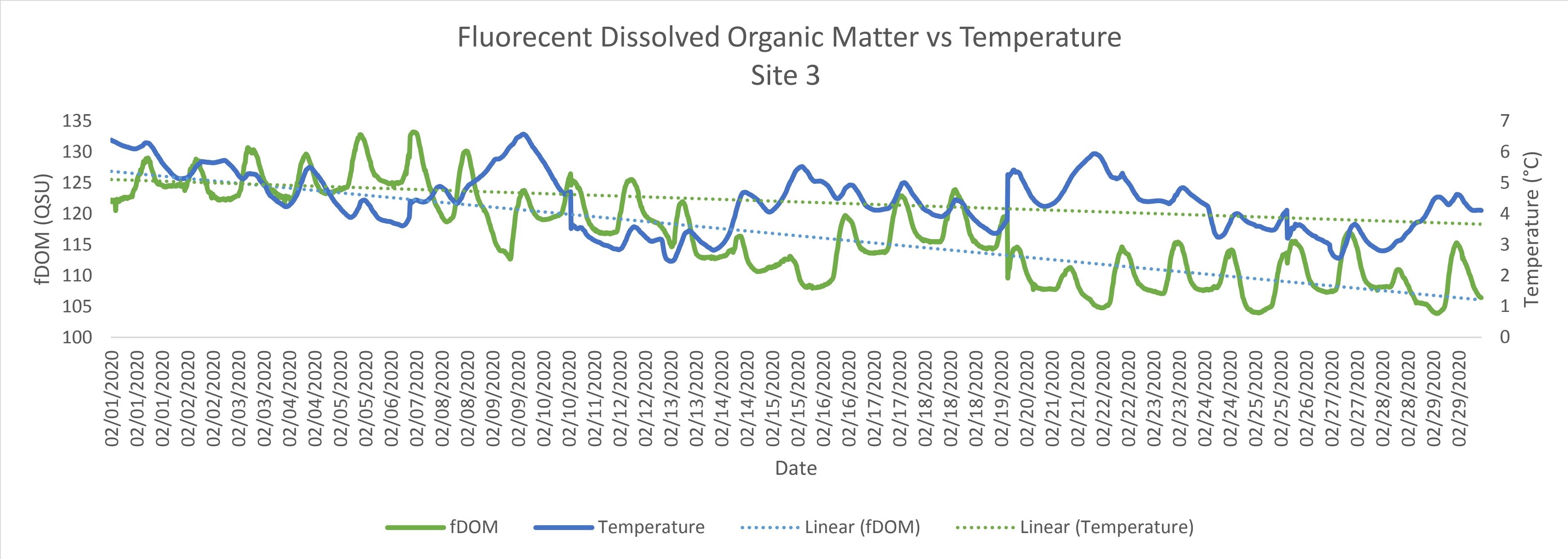

*Figure 19: Time series graph from constant monitoring of Fluorescent Dissolved Organic Matter and temperature between 01/02/2019 and 29/02/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located **below** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

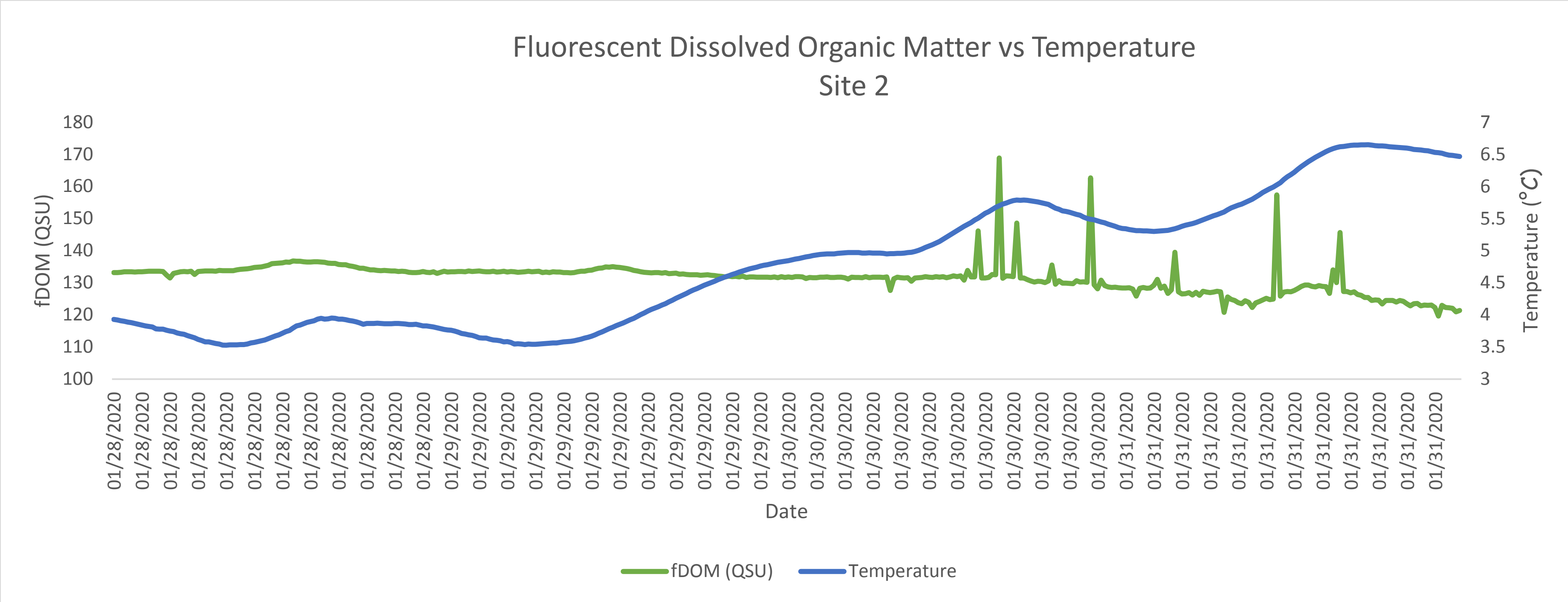

Figure 20: Time series graph from constant monitoring of Fluorescent Dissolved Organic Matter and temperature between 28/01/2020 and 31/01/2020 in the Dargoal Burn at Site 2, Grid Ref: 227602 570976. Site 2 is located ***in*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

Temperature

Temperature is a significant factor to consider when assessing water quality. In addition to its own effect, temperature influences several other parameters and is a key driver in the natural fluctuations of these factors and can alter the physical and chemical properties of water (Fondriest Environmental, 2014). Considering this, temperature should be considered when monitoring factors such as DO, pH and fDOM, along with some other factors which are not being monitored as part of this study. These relationships will be further discussed in Section 6.

<u>Site 1</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum temperature of 5.6°C was recorded in February (recorded 15/02/2020) and the maximum temperature of 6.8°C was recorded in January (recorded 01/01/2020). Average temperature ranged between 6.1 and 6.4°C during the study period. The water temperature at site one was significantly more stable than Site 2 and Site 3 with a maximum fluctuation of only 1.2°C.

<u>Site 2</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum temperature of 2.1°C was recorded in March (recorded 05/03/2020) and the maximum temperature of 7.3°C was recorded in January 2020 (recorded 07/01/2020). Average temperature ranged between 4.2 and 5°C during the study period. A maximum fluctuation of 5.2°C was recorded during this study period.

<u>Site 3</u>

During the study period between the 30th December 2019 and 17th March 2020 the minimum temperature of 2.2°C was recorded in March (recorded 05/03/2020) and the maximum temperature of 7.1°C was recorded in January 2020 (recorded 07/01/2020). Average temperature ranged between 4.4 and 5°C during the study period. A maximum fluctuation of 5.1°C was recorded during this study period.

Figure 21 is a time series graph showing the fluctuating temperature throughout January which was the month where the largest fluctuation was seen during the study. It indicates there is a positive correlation between depth and temperature. Where depth decreases, temperature increases.

Figure 18 and *19,* which can be found in the fDOM section within this data summary, highlight the influence that temperature has on DOM concentrations within Site 3 during February. Diurnal fluctuations can be seen, as the daily temperature drops, so does the concentration of fDOM. There is a negative correlation between the two parameters over the entire period of study at each site. Site 1, although more stable, presents the same fluctuations at a smaller scale.

Figure 16, which can be found in the DO section within this data summary, highlighted the relationship between DO and temperature during the month of January. Colder temperatures result in higher DO levels within the watercourse.

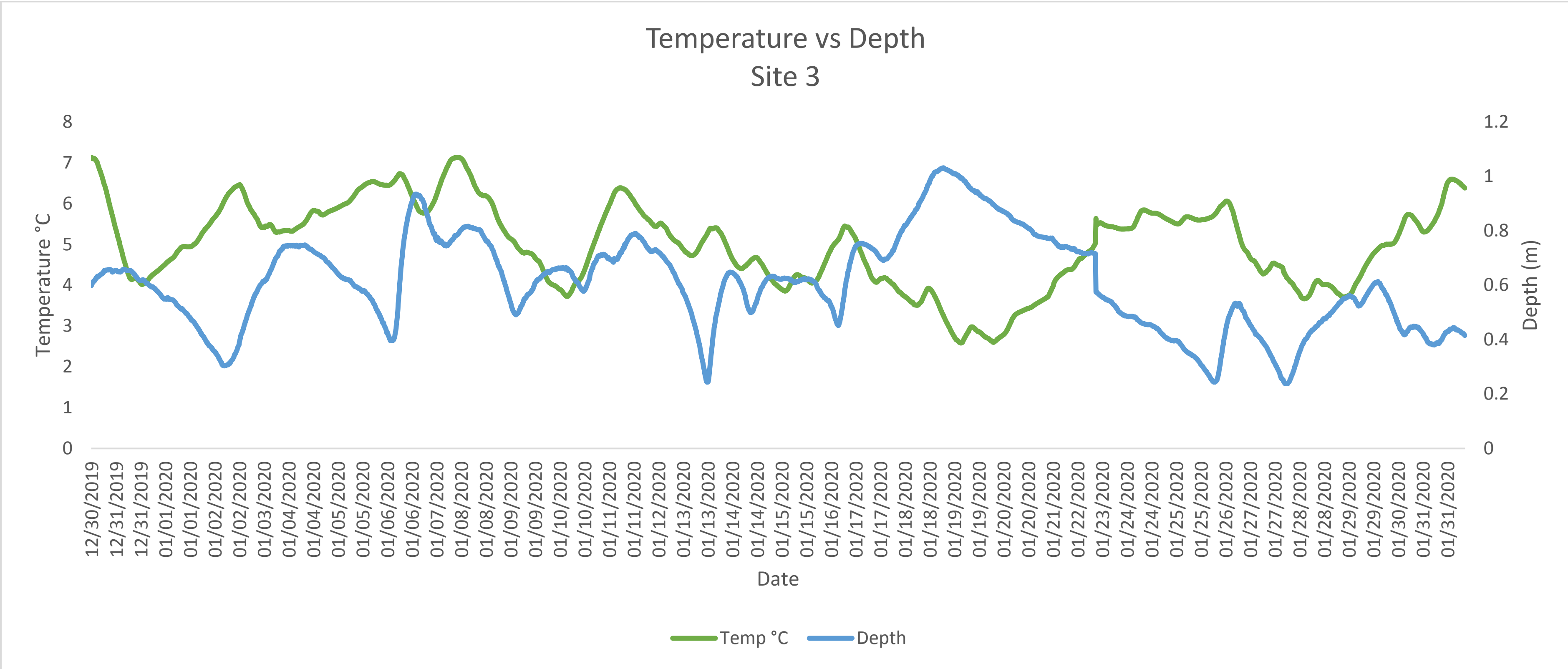

*Figure 21: Time series graph from constant monitoring of Temperature between 30/12/2019 and 31/01/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located **below** the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

Specific Conductivity

Specific conductance is a conductivity measurement made at or corrected to 25°C. This is the standardised method of reporting conductivity. All measurements contained within this report have been corrected.

Site 1

During the study period between the 30th December 2019 and 17th March 2020 the minimum Specific conductivity at this site was 121.5 µS/cm. This was recorded in December (recorded 30/12/2019) and the maximum specific conductivity of 245.8 µS/cm was recorded in February (recorded 26/02/2020). Average specific conductivity ranged between 178 and 219.6 µS/cm during the study period. Specific conductivity was higher at Site 1 than both Site 2 and 3.

Site 2

During the study period between the 30th December 2019 and 17th March 2020 the minimum Specific conductivity of 55.4 µS/cm was recorded in January (recorded 02/01/2020) and the maximum specific conductivity of 111.9 µS/cm was recorded in March (recorded 03/03/2020). Average specific conductivity ranged between 73.6 and 89.1 µS/cm during the study period.

Site 3

During the study period between the 30th December 2019 and 17th March 2020 the minimum Specific conductivity at this site was 65 µS/cm. This was recorded in January (recorded 26/01/2020) and the maximum specific conductivity of 117.3 µS/cm was recorded in February (recorded 17/02/2020). Average specific conductivity ranged between 81 and 98.8 µS/cm and during the study period.

Figure 22 is a time series graph showing data collected during the month of February. This graph is highlighting the natural fluctuations of specific conductivity and how this is in response to varying water levels. Specific conductivity increases in higher flows, and deceases as water levels drop.

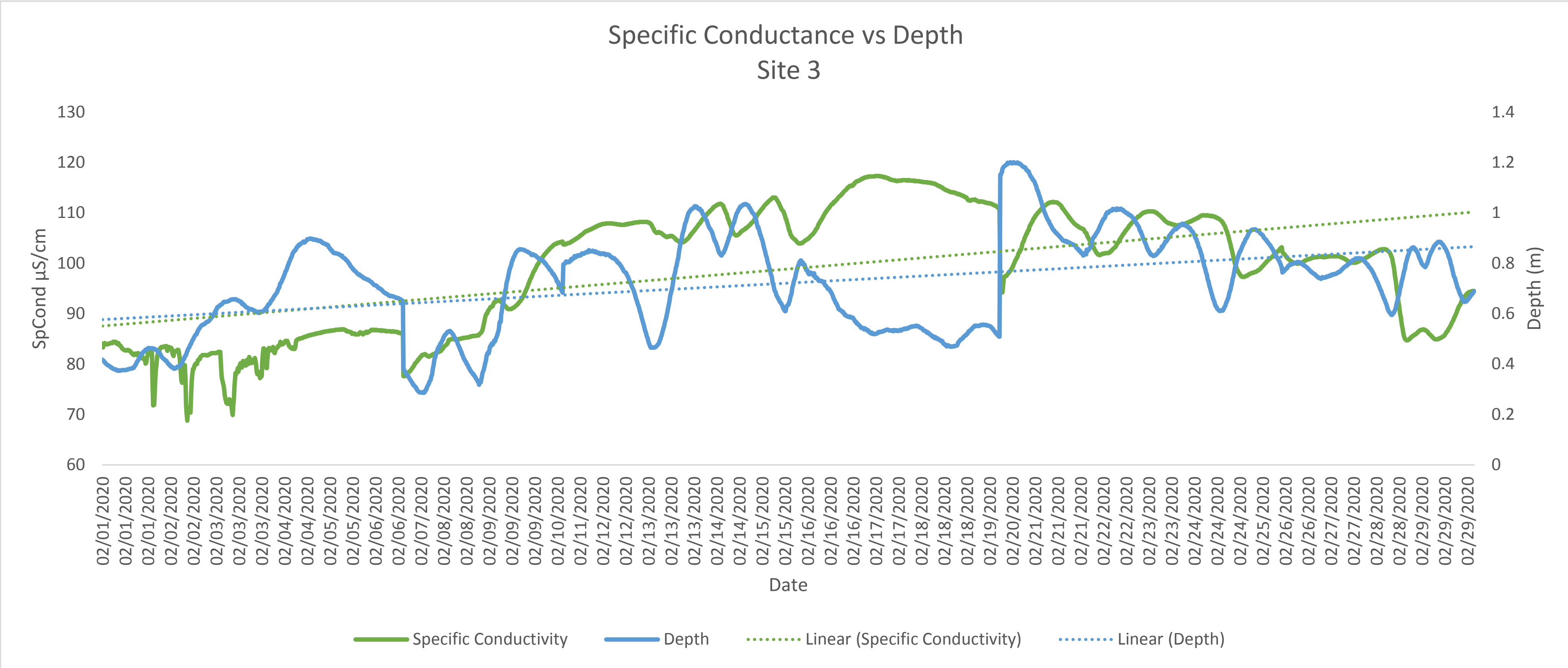

Figure 22: Time series graph from constant monitoring of Specific Conductivity (at 25°C) (green line) and Depth (blue line) between 01/02/2019 and 29/02/2020 on the Dargoal Burn at Site 3, Grid Ref: 227655 571132. Site 3 is located ***below*** *the drain flowing from the restoration site. Data was recorded by an EXO 1 Sonde and readings were taken every 15 minutes.*

6.2 Water sampling

6.2.1 Bladnoch catchment

Water samples were collected from 20 sites around the Upper Bladnoch to gather spatial data on pH within the catchment. Seven sampling days were completed between 22nd January 2020 and 17th March 2020. The results from the data collected can be seen in *Table 2*. This data collection followed on from a previous project where water samples were collected in the same locations in December 2017 and March 2018. The results from these sampling events are also presented in *Table 2*. Maps of the site locations and their pH can be found in *Figures 23, 24* and *25.*

The historical pH data collected in December 2017 and March 2018 was not collected at the most acidic period as hoped, during high floods, as logistical issues impacted site access. Samples were collected as water levels were decreasing.

During December 2017, pH ranged from 4.09 - 7.3, with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment. The majority of sampling locations had pH **above** 5.5 which is above the critical threshold for salmonids. However, eight sampling locations had a pH less than 5.5, with four sampling locations (Site 2 (Polbae Burn), Site 4 (Polbae Burn outflow), Site 3 (Dargoal Burn) and Site 15 (Mulniegarroch of Purgatory Burn)) having a pH less than 5.

During March 2018, pH ranged from 4.74 - 6.53, again with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Figure 22; Table 2). The majority of sampling locations had a pH **above** 5.5. However, seven sampling locations had a pH below 5.5, with two sampling locations (Site 3 (Dargoal Burn) and Site 4 (Polbae Burn outflow)) recording a pH below 5.

Data collected during the 2020 study period was collected at random periods and not aimed at flood events each time. This was to give an insight into the ranges of pH seen within the catchment in response to varying water levels.

During January 2020, pH ranged from 4.06 - 6.67, again with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Figure 24; Table 2). The majority of sampling locations had a pH **above** 5.5. However, five sampling locations had a pH below 5.5, with two sampling locations (Site 3 (Dargoal Burn) and Site 4 (Polbae Burn outflow)) recording a pH below 5.

During February 2020, pH ranged from 3.85 - 6.61, again with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Figure 25; Table 2). The majority of sampling locations had a pH **below** 5.5 at some point during February (17/21 sites sampled). Eleven of these seventeen sites sampled recorded pH below 5. Only four sites never went below pH 5.5 during February (Site 7 (Beoch Burn), Site 11 (Black Burn), Site 20 (Tarf Water) and Site 21 (River Bladnoch)).

During March 2020, pH ranged from 3.96 – 6.69, again with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Table 2). The majority of sampling locations had a pH **below** 5.5 at some point during March (17/20 sites sampled). Eleven of these seventeen sites sampled recorded pH below 5. Only three sites never went below pH 5.5 during February (Site 11 (Black Burn), Site 20 (Tarf Water) and Site 21 (River Bladnoch)). Water levels at this site ranged from 4.5 m in flood on the 10th March to 1.92 during normal conditions on the 17th March.

The lowest pH was consistently read at Dargoal Burn (Site 3) and the maximum on Tarf Water (Site 20).

Four sites never dropped below pH 5.5 during the study period (Sites 7,11, 20 and 21). Seven sites never dropped below pH 5 during the study period (Sites 7,10,11,12,14, 20 and 21). The fluctuations in pH at each site on each sample day can be seen in *Figure 26*.

Table 2: pH readings of water samples collected at 21 sampling locations from 22/01/2020 and 17/03/2020. Table includes historical data collected December 2017 and March 2018. Note sampling location 3A was only sampled on two occasions. Access was very limited to this site due to forestry activity.

Sample Site No.	River	Grid Reference	pH 13/14 Dec 2017	pH March 2018	pH 22nd Jan 2020	pH 6th Feb 2020	10th Feb 2020 Flood	19th Feb 2020 Rising	25th Feb 2020 Flood	10th March Flood	17th March	Minimum	Maximum	Average
1	River Bladnoch; outflow of Loch Maberry	228947 573681	5.7	5.94	5.54	5.74	5.68	5.05	5.19	4.96	5.49	**4.96**	**5.94**	**5.48**
2	Polbae Burn	226714 772779	4.9	5.13	5.94	5.83	5.16	5.55	4.94	5.01	5.86	**4.9**	**5.94**	**5.37**
3	Dargoal Burn	227631 571154	4.1	4.3	4.06	3.99	3.94	3.96	3.94	3.96	4.04	**3.94**	**4.06**	**3.96**
3A	Top of Dargoal Burn	227800 570016	-	-	-	-	3.85	-	3.88	-	-	**3.85**	**3.88**	**3.8**
4	River Bladnoch	228358 572764	4.8	4.74	4.73	4.58	4.22	4.45	4.32	4.32	4.56	**4.22**	**4.8**	**4.52**
5	River Bladnoch	228993 572210	5.1	5.01	5.26	5.27	4.97	5.18	4.74	4.78	5.29	**4.74**	**5.29**	**5.06**
6	River Bladnoch	230197 570798	5.4	5.29	5.28	5.29	4.93	5.03	4.70	4.71	5.19	**4.7**	**5.29**	**5.17**
7	Beoch Burn	231415 571348	6.1	5.51	5.84	5.83	5.63	5.69	5.52	5.43	5.79	**5.43**	**6.1**	**5.7**
8	River Bladnoch	231629 570561	5.73	6.03	5.58	5.5	5.02	5.30	4.86	4.83	5.45	**4.83**	**6.03**	**5.36**
9	River Bladnoch (Glassoch Bridge)	233347 569513	5.7	5.69	5.51	5.5	4.96	5.31	4.84	4.82	5.45	**4.82**	**5.69**	**5.27**
10	Black Burn	228505 566547	6.0	5.66	6.42	6.38	5.57	6.14	5.34	5.27	6.29	**5.27**	**6.42**	**5.89**
11	Black Burn	232145 567165	6.5	5.85	6.3	6.23	5.69	6.23	5.70	5.54	6.33	**5.54**	**6.5**	**6.04**

12	River Bladnoch	234134 565041	6.3	6.23	6.07	5.95	5.35	5.91	5.52	5.44	6.01	**5.35**	**6.3**	**5.9**
14	Upper Tarf	222717 568895	5.5	5.49	6.19	6.08	5.46	6.08	5.51	5.10	6.04	**5.1**	**6.19**	**5.7**
15	Mulniegarroch of Purgatory Burn	222702 569314	4.9	5.48	5.72	5.56	4.85	5.45	4.65	4.71	5.59	**4.65**	**5.72**	**5.2**
16	Tarf Water	223848 568434	5.1	5.99	5.8	5.78	4.87	5.68	4.86	4.86	5.76	**4.86**	**5.99**	**5.4**
17	Tarf Water	224689 567319	5.3	5.86	5.96	5.94	5.02	5.7	4.89	4.92	5.81	**4.89**	**5.96**	**5.5**
18	Tarf Water	225528 565797	5.7	5.89	6.26	6.10	5.18	5.9	4.99	5.04	6.05	**5.18**	**6.26**	**5.7**
19	Tarf Water	225500 564770	5.5	5.62	6.23	6.16	5.29	5.89	5.04	4.87	6.10	**4.87**	**6.23**	**5.6**
20	Tarf Water	233768 560372	6.6	6.45	6.67	6.61	6.15	6.48	5.99	6	6.69	**5.99**	**6.67**	**6.4**
21	River Bladnoch	234810 559766	6.3	6.53	6.48	6.48	6.06	6.46	6.05	6	6.58	**6.05**	**6.58**	**6.3**

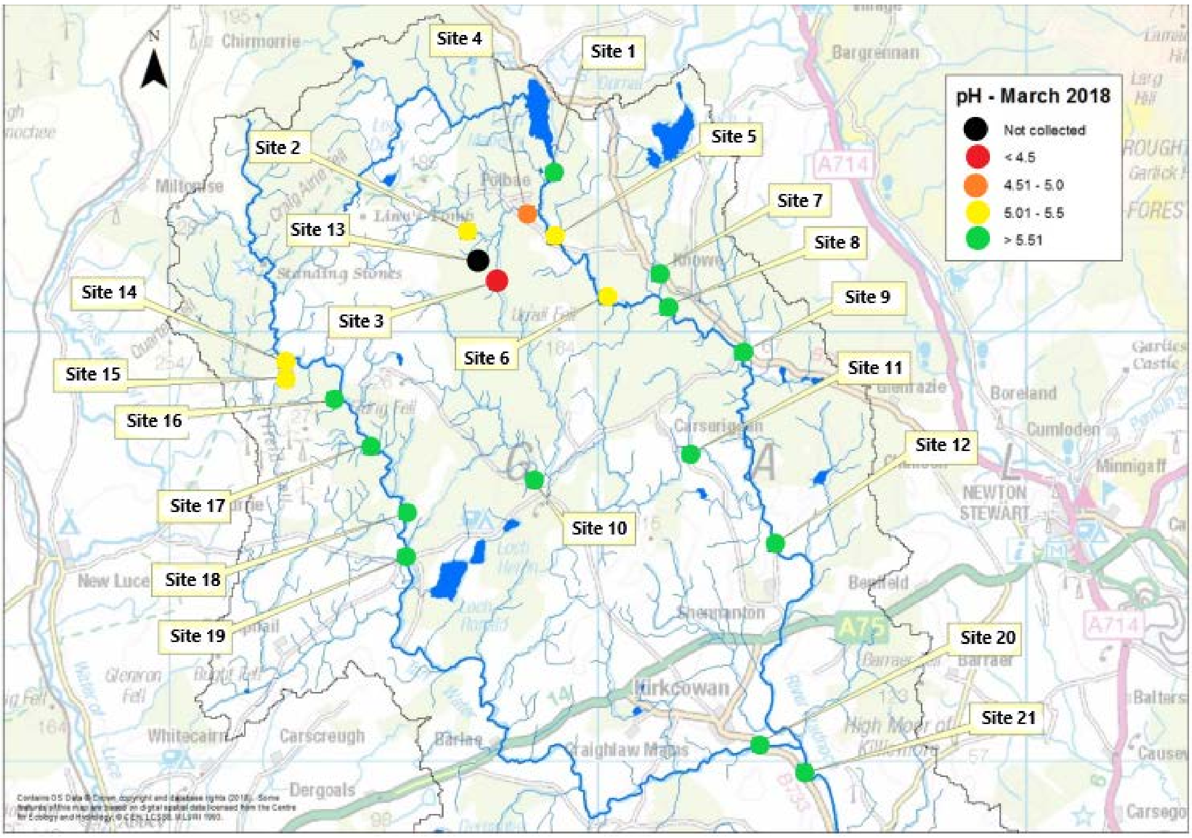

Figure 23: Spot sampling at 20 locations throughout the Bladnoch catchment. Samples were collected in March 2018 when water levels were normal. The pH at each site is represented by a colour code detailed in the legend.

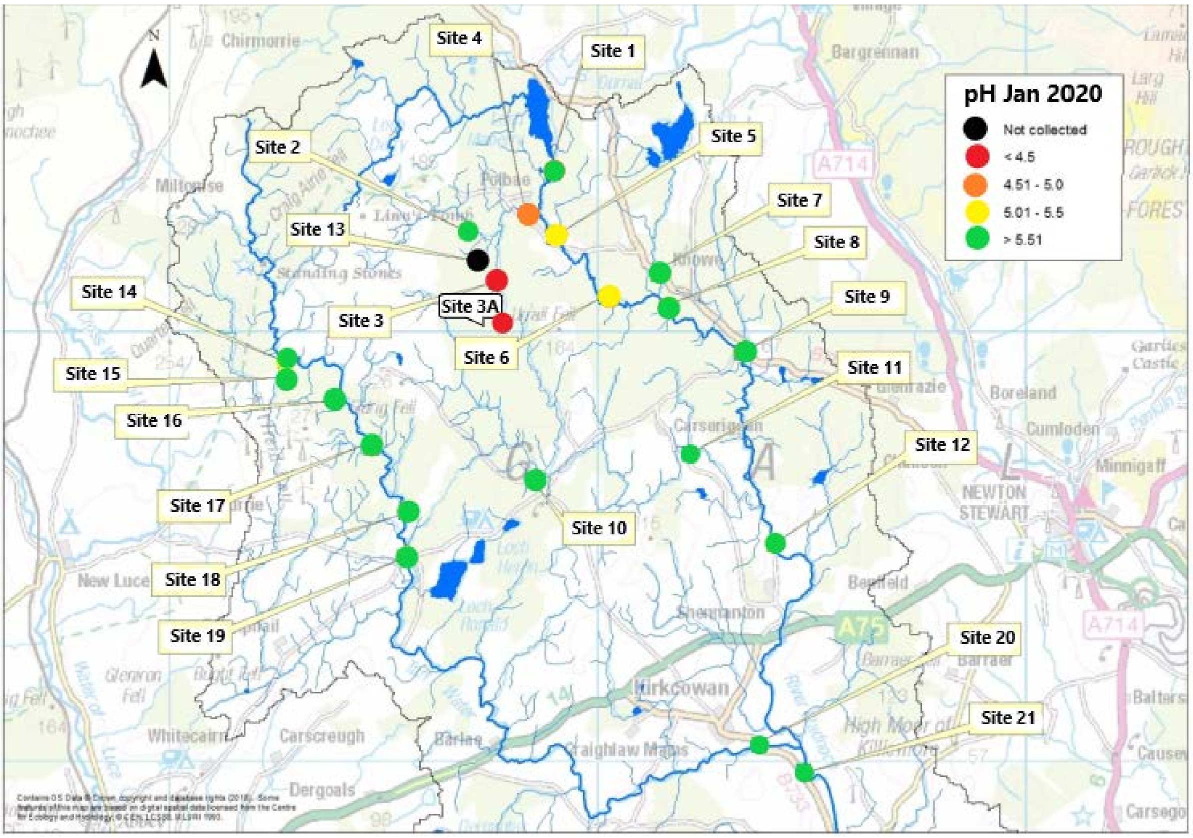

Figure 24: Spot sampling at 21 locations throughout the Upper Bladnoch catchment. Samples were collected on 22nd January 2020 during a period of normal water levels. The pH at each site is represented by a colour code detailed in the legend.

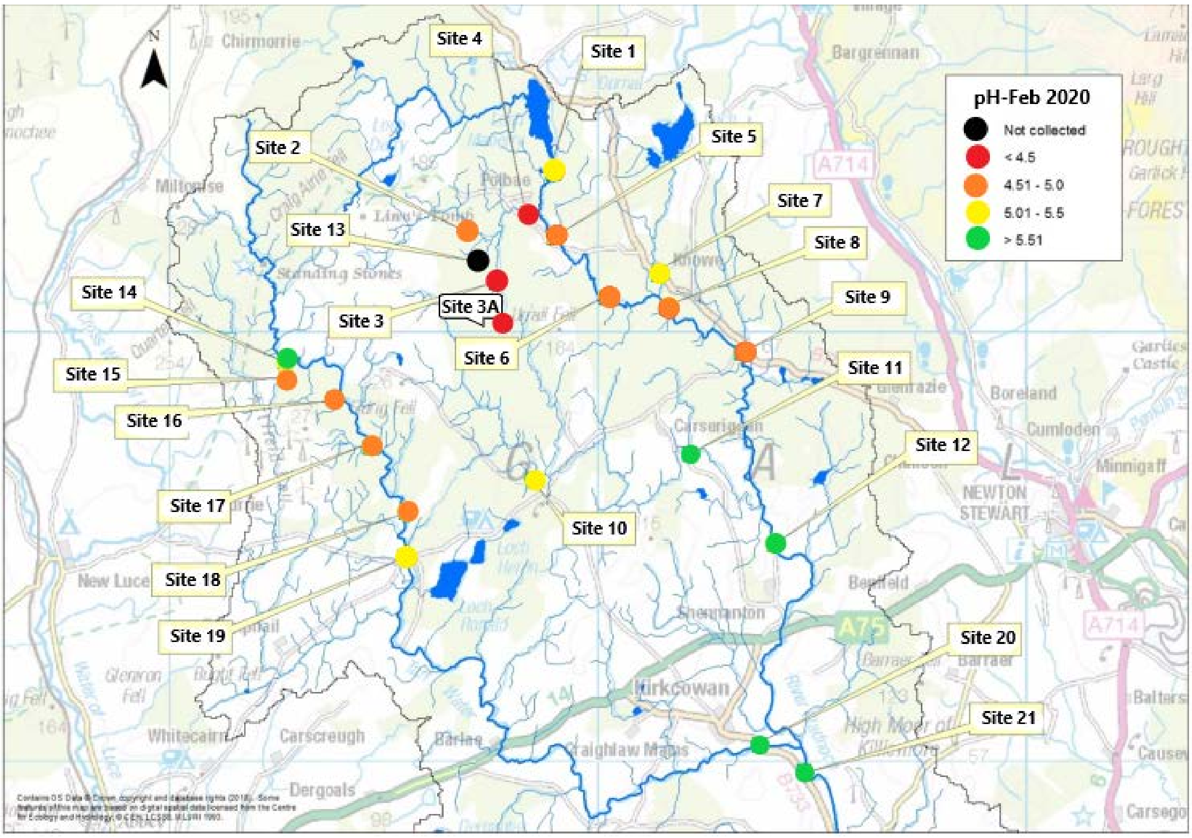

Figure 25: Spot sampling at 21 locations throughout the Bladnoch catchment. Samples were collected on 25th February 2020 during a flood event. The pH at each site is represented by a colour code detailed in the legend.

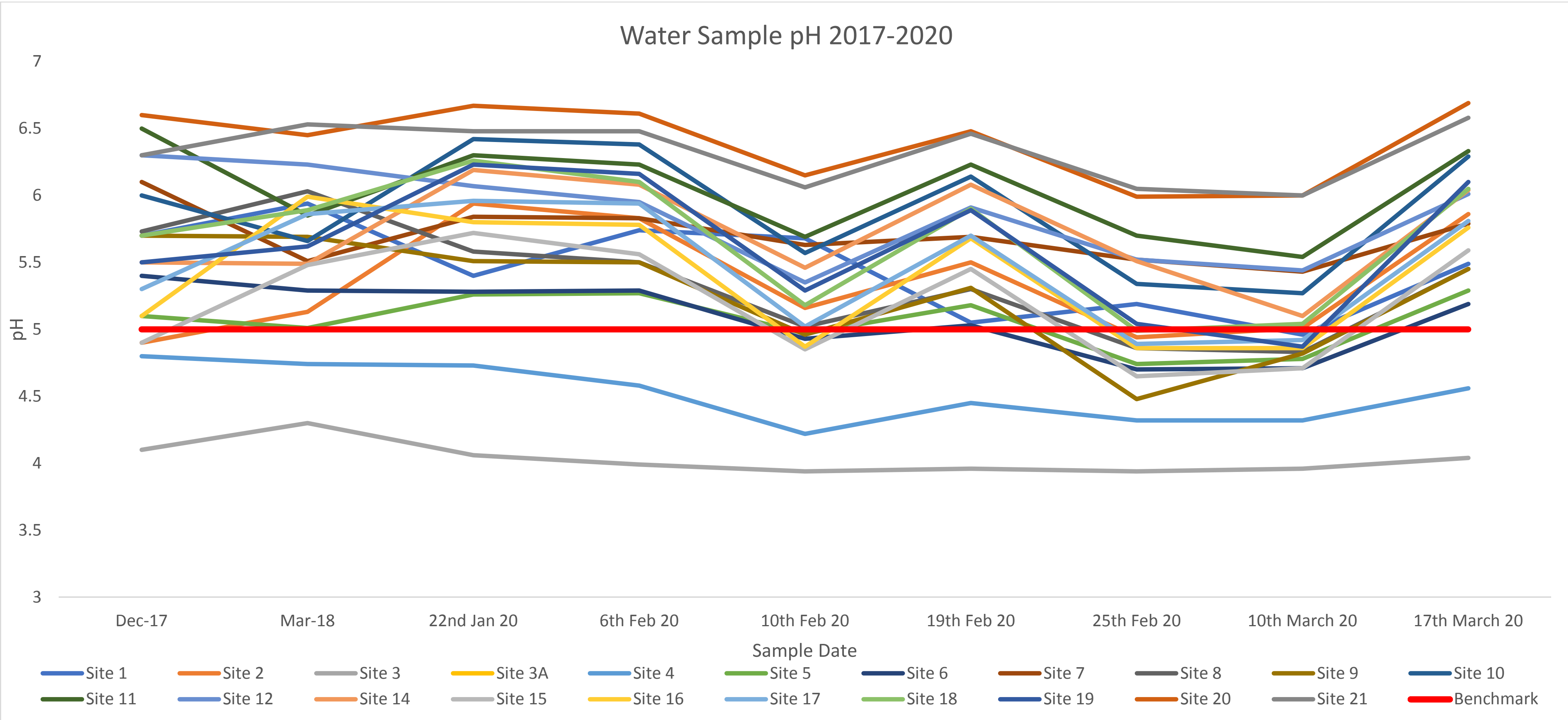

Figure 26: Graph plotting pH data recorded from each sample site throughout the study (including historical data). The red line is the critical pH below which is detrimental to juvenile salmonids.

6.2.2 Cree catchment

Water samples were collected from around the Upper Cree and Upper Minnoch to gauge pH ranges in areas known to have dense forestry planted over areas of deep peat (*Figure 28*). Data was collected on one occasion on the 11th March using spot sampling with an EXO 1 Sonde. River levels were not exceptionally high however there was a slight elevation in water level at that time. The pH at these sites ranged from 6 (Site 1, Pilnyark Burn) - 4.55 (Site 6, Loch Moan outflow). Three out of the 11 sites sampled had pH which was below the critical pH of 5 for juvenile salmonids. Results can be seen in *Table 3* and data is presented in *Figure 27* as a histogram against the benchmark of pH 5.

Table 3: pH readings of water samples collected at 11 sampling locations in March 2020. Data was collected using an EXO 1 Sonde

Sample Site No.	River	Grid Reference	pH 11th March
1	Pilnyark Burn	236911 591737	6
2	Eldrick Hill Burn	235838 591457	5.45
3	Rowantree Burn	235760 590283	5.21
4	Water of Minnoch	235927 590069	5.41
5	Water of Minnoch	235891 586636	5.27
6	Loch Moan outflow	233439 586138	4.55
7	Water of Trool	239706 579044	5.26
8	Water of Trool	237951 578227	5.35
9	River Cree	230238 580469	4.58
10	River Cree	232410 579374	4.89
11	Fardin Burn	232318 587041	5.36

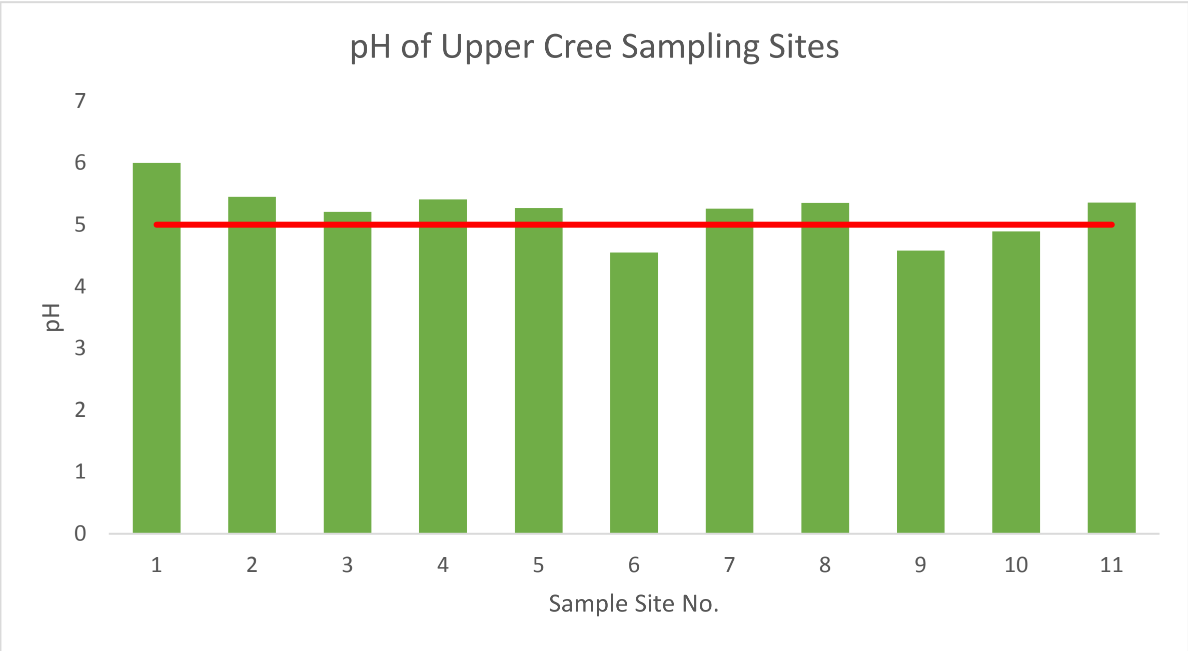

Figure 27: Histogram of pH data collected at 11 sites throughout the Upper Cree catchment on the 11th March 2020. Data was collected using an EXO 1 Sonde. The red line represents the lower critical point for survival of salmonids.

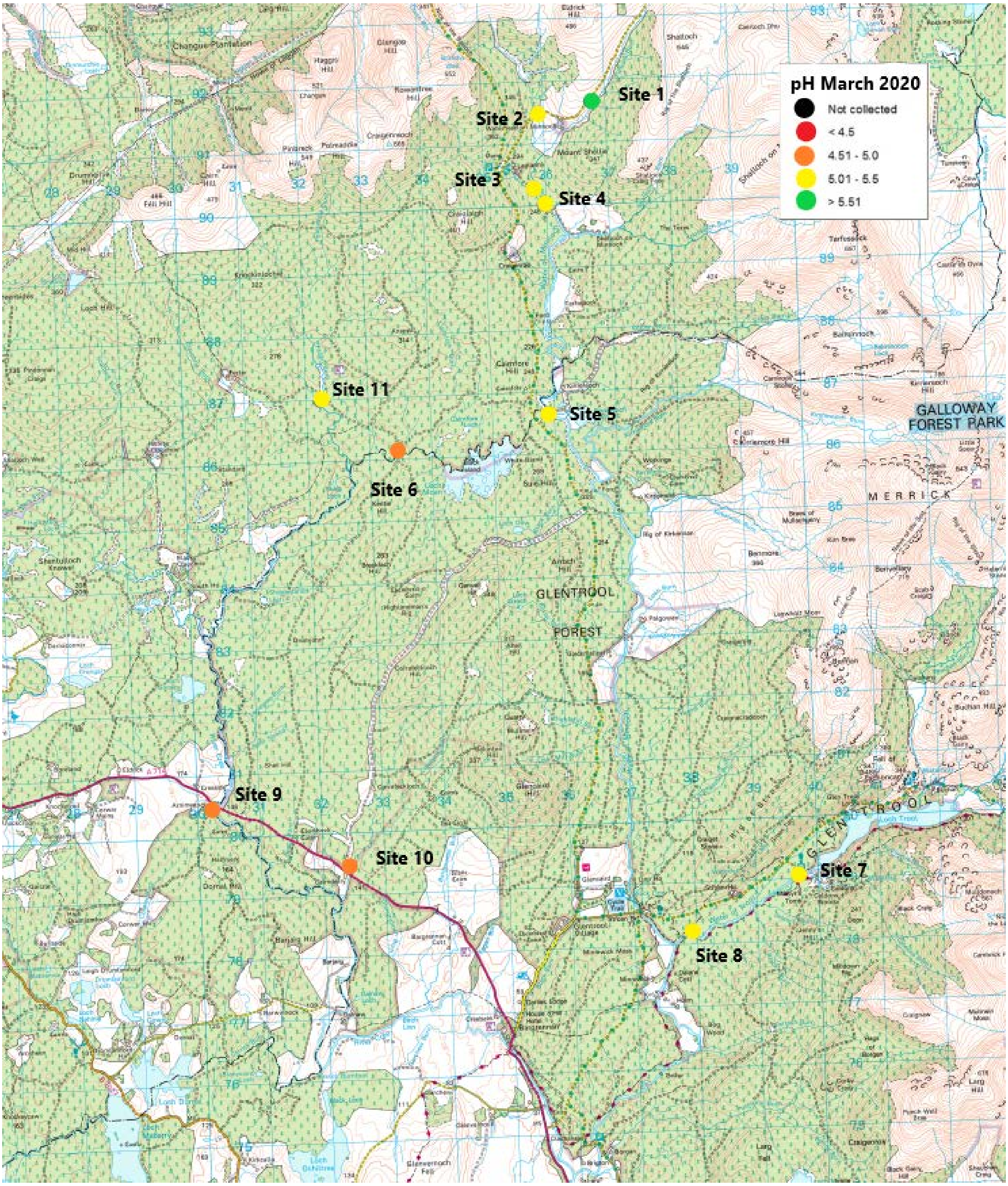

Figure 28: Locations of water sampling sites within the Cree catchment. Samples were collected on 11/03/2020. The pH at each site is represented by a colour code detailed in the legend

7 DISCUSSION

GFT has been working closely with the local Peatland Action officer Emily Taylor over the last few years and recognise that water quality monitoring is a fundamentally important aspect of peatland restoration.

WQM can be utilised at each phase of the restoration process. Before restoration begins monitoring can be utilised as part of a feasibility study to determine the most sensitive areas as this can help prioritise target areas for restoration. It can also be used to monitor the restoration process for any sudden changes throughout times of high disturbance. After the restoration is complete, future monitoring can be used to quantify any improvements as a result of the restoration.

Since 2015, GFT have been managing three sondes. These sondes have been tried and tested and have been gathering data across our local catchments which has provided an insight into area specific water quality. This period of data collection has also flagged up limitations and factors to consider when carrying out a water quality monitoring program which has improved GFT's understanding of the sondes and their use in peatland restoration projects.

The aim of this study was to provide Peatland Action with pre-restoration, baseline water quality data from the watercourse surrounding the restoration area. Without such data it would be impossible to quantify impacts or benefits of the process. Without understanding what the normal ranges of key parameters are before restoration, it would not be possible to determine if any improvements or impacts had occurred as a result. Baseline data allows for the impacts, either positive or negative to be quantified.

As discussed in section 3.1.1 it would be useful to have a full year's worth of data, if not two, to allow for as many natural fluctuations and temporal changes to be acknowledged and considered when analysing post-restoration data. This would account for annual differences seen within the site, as well as seasonal.

As detailed in section 4 this proposed restoration site is Tannylaggie is an area of forestry located within the River Bladnoch catchment, which is the site of a three-year, forest-to-bog restoration project, led by FLMS. This project aims to restore up to 300 Ha of deep peat through felling trees, stump flipping and ground smoothing.

The funding provided for this study allowed GFT to monitor the restoration site for two and a half months. The fund was agreed the end of November 2019 and the sondes were sent away for their annual service before the monitoring period began. Sondes were deployed on the 30th December 2019. During December whilst the sondes were being serviced, GFT met with Emily Taylor to discuss what monitoring would be most useful within the available time. WQM is best carried out between November and March as this is the most sensitive time period for juvenile salmonids whilst eggs are in the gravel. It is also the most susceptible period for acid pulses as a result of heavy precipitation, snow melt and flood events.

It was agreed that collecting baseline data for Tannylaggie pre-restoration would be useful and sites for sonde deployment were set. This study was split into two key parts, constant monitoring, and water sampling. Constant monitoring was carried out at three sites within Dargoal Burn to gather temporal data and capture natural fluctuations within the site. Water samples were collected to gather spatial data around the catchment to record variations in pH throughout the system under different conditions.

7.1 Constant monitoring

Three sondes were deployed in sites surrounding the restoration area. The restoration site has one primary forest drain which is useful as any impacts of restoration should be picked up in a relatively localised and precise area. Due to the walking conditions at the site, it was considered a health and safety risk to allow lone working so two members of staff were required for each site visit.

Walking conditions also limited the locations of the sondes. It would have been preferable for the sondes to be more spaced out however due to conditions and the requirement for regular site visits the risk would have been too high to place them much further apart.

All three sites had extremely dark, humic water. Sites 1 and 3 (both Dargoal Burn) were characterised by deep glide and the burn had a strong meander. Dargoal Burn is highly eroded with banksides of bare peat visible (*Figure 29*). In most conditions, the burn substrate or contents are not visible however in extremely low water it was possible to get a glimpse. There is very little in the way of solid substrates however in shallower areas, patches of cobbles and boulders were visible the base of the burn was primarily made up of high organic matter, primarily peat. Under flood events the burn burst its banks significantly however there appeared to be no visible change in flow speed (*Figure 35*). Site 2 was much shallower and narrower however was still a deep channel surrounded by dense overhanging vegetation.

Figure 29: Dargoal burn on 22/04/2020. Bare peat eroding from bankside and entering the water system.

The sonde at Site 1 was in a corner pool above the forest drain (Grid reference: 227694 570938) (*Figure 30*). The water depth at this site ranged between 0.5 and 1.5 m with an average of 0.96 m during the monitoring period. Throughout this study, there has been significant differences in parameter responses and ranges between Site 1 and Sites 2 and 3. There are a few hypothesise as to why this might be happening. The first hypothesis is that due to the nature of the burn's substrate, that silt and peat in this area has built up around the base of the sonde housing, influencing the readings. The second hypothesis is that this could be as a result of the location of this sonde being in a corner pool, as opposed to the main channel were Sites 2 and 3 are located. These areas could be considered to be Transient Storage Zones (TSZ), which can lead to increases in capacity of the water in that area to remove or transform nutrients through biological or physical processes (Mulholland & De Angelis, 2000). Transient storage is the temporary hydrologic retention of water that moves downstream more slowly than water in the main channel (Bencala & Walters, 1983). Transient storage zones can occur in surface (e.g., backwaters and eddies) or subsurface (hyporheic) areas (Harvey *et al*., 1996). Backwaters and eddies can facilitate the deposition and retention of dissolved, fine particulate, and coarse particulate organic matter (DOM, FPOM, and CPOM, respectively) in burns (Bilby & Bison, 1998). They are often caused by coarse woody debris or other large objects in the water. In low water, large mounds were visible, which are likely remaining sections of eroded bankside, (*Figure 32*) and large pieces of coarse woody debris was apparent throughout the burn (*Figure 31*).

Figure 30: Site 1 sonde placement in a corner pool on the Dargoal burn. Picture taken at low water on the 22/04/2020

Figure 31: Woody debris visible at low flows. Picture taken on 22/04/2020

Figure 32: Large tufts of eroded bankside still standing in the channel, visible in low flows. Picture taken on the 22/04/2020

Site 2 was in the forest drain (Grid reference: 227602 570976) (*Figure 33*). Water depth within the burn ranged between -0.09 and 0.6 m and the width of the burn was <1 m. The average depth was recorded at 0.5 m. Negative figures in the depth readings were recorded likely as a result of changes in barometric pressures since calibration. Flow was faster in some areas of the burn however most of the burn was characterised by shallow, smooth glide.

Figure 33: Sonde at Site 2 situated in the forest drain.

Site 3 was located downstream of the drain (Grid reference: 227655 571132). Water depth within this site ranged between 0.2 and 1.2 m deep with an average depth of 0.6 m. The width was approximately between 1.5 and 2 m wide. Flow type smooth glide and the site hosted some instream vegetation primarily tall reeds and lily pads.

Figure 34: Site 3 under low flow conditions on the 22/04/2020

Figure 35: Site 3 under flood conditions on the 19/02/2020

For GFT the primary focus of any upland WQM project is pH. Acidification is one of the key impacts of degrading peatlands however it needs to be recognised that lowering pH is as a result of many other changes in water chemistry. It is therefore important to consider other parameters that may impact pH as are just as important to the overall health of the waterbody. This baseline data report is looking into pH, fDOM, Dissolved Oxygen, temperature and Specific Conductivity. As not every relationship between parameters for each time period at each site could be displayed in graphical form, graphs presented throughout the results were chosen to display results from the periods which had the widest range of variables, or periods of maximum or minimum values. Graphs were primarily displayed for Site 3 as this is the site which could potentially highlight any changes as a result of the restoration.

7.1.1 pH

The pH results from this monitoring period are being compared against the known critical point of juvenile salmonid survival, pH 5. At or below this pH, salmonid eggs will have extremely low hatching success, if any. Previous egg box experiments carried out by GFT, (2008), demonstrated egg survival varied significantly between locations separated by small geographic distances (*Figure 36*). The results from these egg box experiments were further supported by electrofishing surveys, which demonstrated little recruitment of juvenile Atlantic salmon in the upper River Bladnoch catchment.

As water quality has been shown to be a factor which affects juvenile Atlantic salmon survival, this study used constant water quality monitoring and spot sampling during winter/early spring to investigate acidification during the most vulnerable months for juvenile

Atlantic salmon. During constant water quality monitoring, pH was found to fluctuate both daily and monthly, with pH falling below pH 5 during acid pulses.

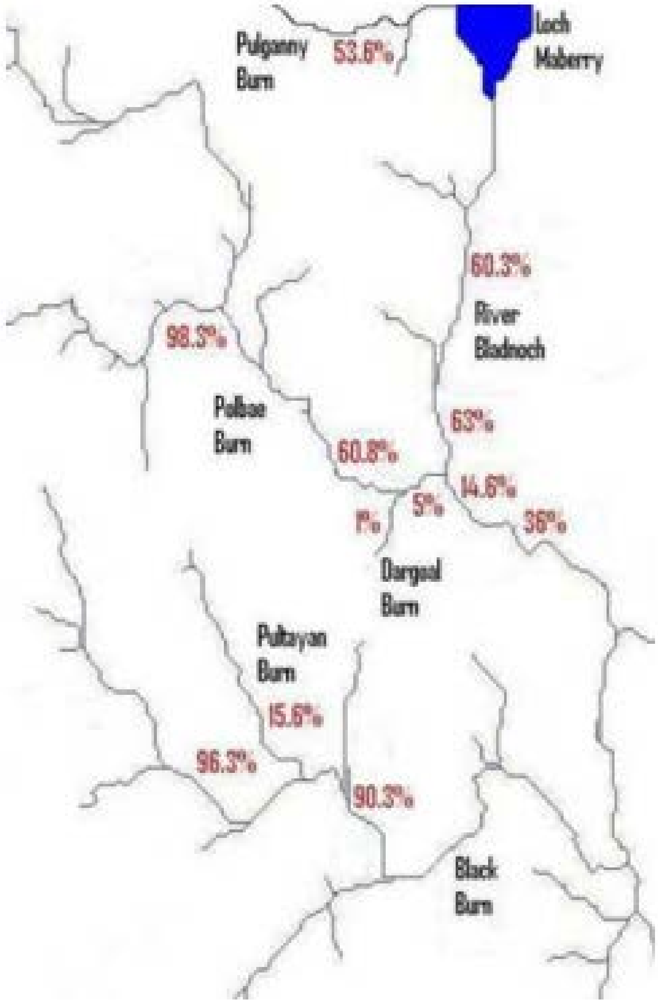

Figure 36: Survival of Atlantic salmon alevins from egg box experiments, with survival rates ranging from 1 - 98.3%. Thus, highlighting areas where Atlantic salmon survival is poor and most likely the result of acidification (GFT, 2008)

There was a considerable difference in pH between Site 1 (*Figure 10*) and Sites 2 and 3 (*Figures 11 and 12; Appendix 1*). Site 1 had an average pH of between 6 and 6.07, whereas Sites 2 and 3 had average pH readings between 4.02 and 4.05. The pH seen at Site 1 was unexpected as these values are much higher than the lower two sites. It is possible, that this high pH is as a result of sediment deposition on the sondes housing or the location of the sonde being in an TSZ as described in section 7.1. It could also be that there are some areas of Dargoal with higher pH if there are greater buffer zones or less drainage entering the watercourse. The temporal fluctuation of pH at Sites 1 and 2 was 0.6 and Site 3 fluctuated by 0.43. This indicates that Site 1 is responding in a similar way to the lower two sites, which supports the theory that there may be varying levels of pH within the Dargoal Burn. During the monitoring period, to determine whether pH improved dramatically above the forestry drain consistently, which would indicate that the drain was having a severe impact on the burn, water samples were collected from the top of the Dargoal Burn in its headwaters. Samples were only collected at this location (Site 3A) on two occasions due to access limitations resulting from forestry activity. The pH of the samples collected here ranged between 3.85 and 3.88 which indicates there is severe issues with pH throughout the Dargoal and it is not limited to the forestry drain alone. It was noted that this burn was flowing from an area of dense forestry and through an area of felled forestry. It would be recommended that further samples along the length of the Dargoal Burn are collected.

7.1.2 Dissolved oxygen

Dissolved oxygen (DO) is an important indicator of the biological health of rivers and is primarily dependent upon water temperature; however, this dependence can differ in response to due to the intensity of biological processes such as photosynthesis, respiration and decomposition of organic matter (Rajwa-Kuligiewicz *et al.,* 2015). Levels of DO vary depending on factors including water temperature, time of day, season, depth, altitude, and rate of flow. Water at higher temperatures and altitudes will have less dissolved oxygen (Fondriest Environmental, 2014a). Dissolved oxygen reaches its peak during the day. At night, it decreases as photosynthesis has stopped while oxygen consuming processes such as respiration and oxidation continue, until shortly before dawn (Behar, 1996).

As detailed in *Figure 37*, there are ranges of DO concentrations which are considered stressful for juvenile salmonids at different stages of development. In acidified waters, the most sensitive stage of development is when eggs are in the gravel, and although these particular watercourses will not host fish or contain spawning grounds, they are impacting Polbae Burn and the River Bladnoch downstream.

At this level of monitoring and considering the complexity of the biological processes which can alter DO concentrations within a watercourse, DO measurements should only be used as an indicator of change within the system. Significant drops or increases in DO could suggest an impact or improvement in the health of the waterbody in response to changes in land use.

A study by Driscoll *et al.,* 2016 studied the impact of forestry clear-felling on DO concentrations and found a reduction in DO concentration which could be attributed to changes in respiration owing to increases in stream temperature and higher concentrations of organic suspended sediment following clear-felling. Forest clear-felling can cause inputs of fresh brash into receiving waters (Lockaby *et al*., 1997), stimulating heterotrophic processes (Clapcottt and Barmuta, 2010), and Drinan *et al., (*2013) reported elevated BOD following clear-felling supporting this theory. Ponce (1974) reported on the high demand for oxygen exerted by microbes associated with fresh brash and mentioned it can rapidly deplete DO concentrations in receiving water.

The results from Driscoll *et al*., 2016 indicated that the highest oxygen concentrations, which are observed in early spring, result from low water temperatures, high discharge from snowmelt and flooding of the area that washes out from the system the ‘old’ water heavily loaded in organic matter. This monitoring period also indicated that high DO was linked to lower water temperatures. *Figure 16* shows the diurnal fluctuations and the correlation between increasing temperatures and decreasing DO in response during January at Site 3. This response was also found at Site 2.

DO at both Site 2 and 3 increased in response to increased water levels which could also be linked to floods washing out heavily loaded organic matter. There was little difference in DO levels between the sites.

DO at Site 2 had slightly lower minimum levels, which were recorded within the range classified as “stressful to trout eggs” in *Figure 31* approximately 11% of the time and were below optimal ranges 97% of the time. Site 3 was in the stressful range for only 4.4% of the time and below optimum levels 95% of the time indicating better DO concentrations in the main burn as opposed to the drain which is not unexpected. DO concentrations were considered optimal for juvenile and adult salmonids 100% of the time at both sites.

Unfortunately, the DO sensor sonde Site 1 was not working during the study. This was noticed when the first calibration took place in January however given the time required to send away and repair, it was decided to sacrifice the parameter as opposed to delaying the study.

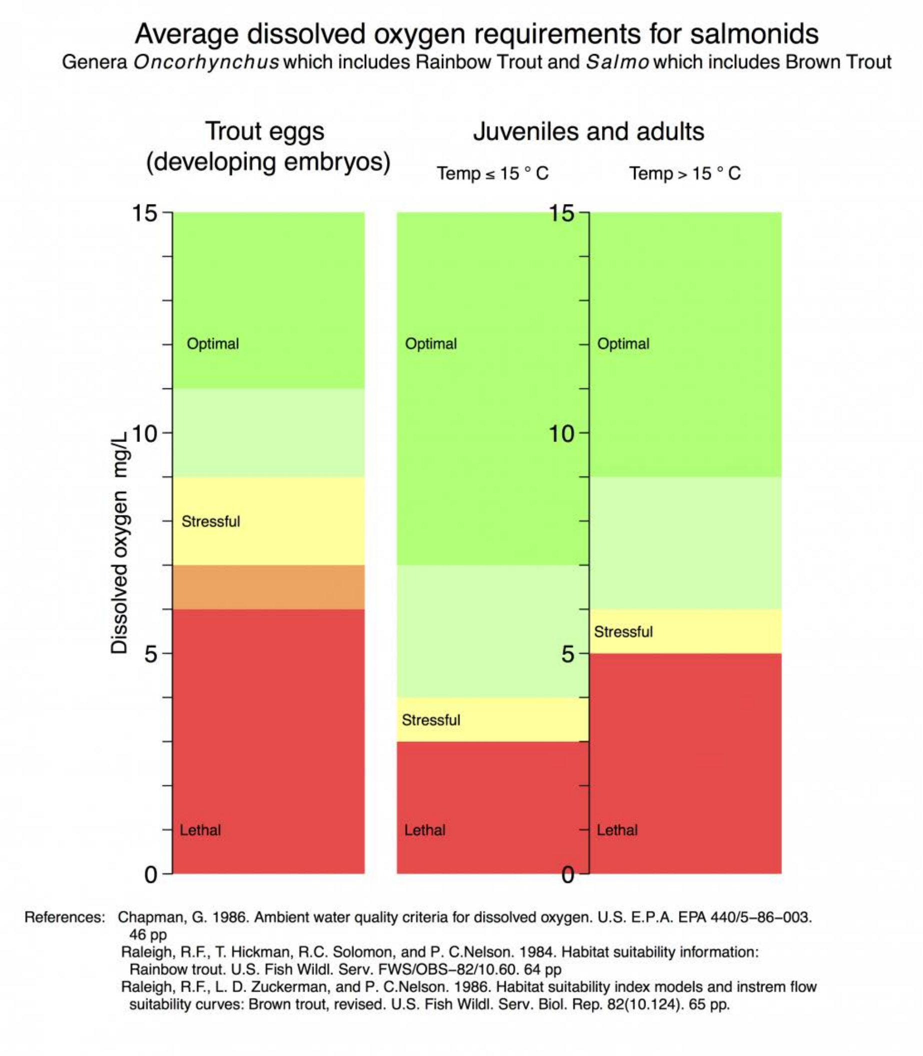

Figure 37: Average Dissolved Oxygen requirements for salmonids

7.1.3 fDOM

In most river headwaters, inputs of terrestrially derived dissolved organic matter from microbially modified plant litter and soil organic matter are important carbon sources fuelling heterotrophic respiration (Kaplan *et al.,* 2008).

Organic matter in water is composed of two major fractions: dissolved and non-dissolved, defined on the basis of the isolation technique using filters (0.1–0.7 μm). Dissolved organic matter (DOM) is the fraction of organic substances that passes the filter, while particulate organic matter (POM) remains on the filter (Mostofa *et al.,* 2013).

Coloured DOM (CDOM) / FDOM is used to measure the relative amount of dissolved organic material (DOM) in the water that absorbs UV light. Although it is naturally occurring, human influence through aspects such as forestry, agriculture, effluent discharge, and wetland drainage can affect the levels of DOM in freshwater systems. It is usually made up of tannins that are released from the breakdown of plant material. A fraction of CDOM fluoresces when it absorbs light of a certain spectrum, and is called fluorescent dissolved organic matter, or fDOM. FDOM fluorescence corresponds to total organic carbon (TOC), which is an indicator of discharge water quality (Aquaread, 2008).

It is vital to measure the levels of CDOM/FDOM and understand their trends because they can have a significant effect on aquatic ecosystems. Raised levels of CDOM/FDOM can inhibit the growth of phytoplankton and limit photosynthesis, damaging the food chain and limiting the production of oxygen in water bodies.

As with pH, Site 1 had much higher readings than Sites 2 and 3. Site 1 presented fDOM concentrations averaging 69% higher than site 2 and 56% higher than site 3. This could be in response to the TSZ and a buildup of DOM which does not get flushed away as readily as main channel areas. This corresponds to the relationship between depth and fDOM, as depth increases (floods), fDOM readings decrease, and as water levels drop, fDOM concentrations increase. This relationship has been presented in *Figure 17* using data collected at Site 3 during February where the greatest range in variables was recorded. This relationship is apparent at all three sites. *Figure 19* is a temporal graph using data collected during February at Site 3 which highlights the relationship between fDOM and temperature. *Figure 18* displays four days' worth of data to show the fluctuations in greater detail. *Figure 20* highlights a period of spiked fDOM readings within Site 2 which appear to be related to temperature changes however, they stand out from normal readings so may be as a result of DOM entering the system from an unknown source.

7.1.4 Temperature

Water temperature is influenced by numerous natural variables, including solar radiation, air temperature, ground temperature, precipitation, surface water inflows, groundwater exchanges and canopy cover (Sinokrat & Stefan, 1993). Water temperature is known to have a clear impact on the bio-physio-chemical integrity of burns (Stott & Marks, 2000). Most freshwater parameters are linked to temperature in one way or another. River temperature is important for cold water adapted fish species, such as salmonids, affecting their growth, survival, and demographic characteristics (Elliott & Elliott, 2010). Climate change is expected to increase potentially altering the thermal suitability of rivers (Comte *et al.*, 2013; Jackson *et al.*, 2018).

In a study by Driscoll *et al*., (2016), clear-felling was shown to influence the thermal regime of a burn with temperatures increasing significantly post-felling. Canopy removal eliminated the shading effect of the trees naturally implying a change in lighting conditions in the open stretches of the impacted burn following clear-felling. Solar radiation is the predominant contributor of energy for summer warming in burns with no canopy (Bowler, 2012). Gomi *et al.,* (2006) suggest riparian areas along streams protect the stream from increased thermal variability, with effects varying to some degree with buffer width.

It has been previously reported that it takes several years for upland blanket peat sites to revegetate following clear-felling (O'Driscoll *et al*., 2011); however, it is not clear how the thermal regime recovers with recovering growth in vegetation in the ensuing years.

In addition to canopy removal, alteration of stream discharge could also impact on the stream thermal regime (Gomi *et al*., 2006). Headwater streams can be shallow and experience low discharge enhancing the opportunity for warming. This finding is similar to previous studies which attributed the increase to a reduction in evapotranspiration following tree removal (Robinson *et al*., 2003).

Site 1 had significantly higher temperatures compared to Sites 2 and 3. Temperatures at Site 1 averaged between 6.1 and 6.4°C. Site 2 had an average temperature between 4.3 and 5°C and Site 1 had average temperatures between 4.5 and 5°C. Site 2 recorded the lowest (2.1) and highest (7.3) temperatures out of the three sites. This was to be expected as this forestry drain is much shallower therefore it is more prone to fluctuating temperatures. Site 1 also showed to have much more temperature stability, with a maximum fluctuation of only 1.2°C in comparison to a fluctuation of 5.2°C at Site 2 and 5.1°C at Site 3. The differences seen in Site 1 are likely to be as a result of the TSZ holding water for longer and allowing temperatures to increase. Reduced flow in the site would reduce the fluctuations in temperatures in that area.

Although clear-felling is noted to increase water temperature, the benefits of Peatland Restoration overall, outweigh the impact potential water temperature increases may have. The monitoring sites within this site are currently not under dense tree cover however other areas that are due to be restored may be. It is a parameter that should be monitored closely during and post restoration.

7.1.5 Specific conductivity

The basic unit of measurement for conductivity is microsiemens per centimeter (µS/cm). Distilled water has a conductivity ranging from 0.5 to 3 µS/cm, while most rivers and burns range between 50 to 1500 µS/cm. Freshwater burns ideally should have a conductivity between 150 to 500 µS/cm to support diverse aquatic life. Significant increases in conductivity may be an indicator that polluting discharges have entered the water (Behar, 1996).

Specific conductance is a conductivity measurement made at or corrected to 25° C. This is the standardized method of reporting conductivity. As the temperature of water will affect conductivity readings, reporting conductivity at 25°C allows data to be easily compared (Fondriest Environmental, 2014b). When water temperature increases, so will conductivity. For every 1°C increase, conductivity values can increase 2 - 4% (Miller *et al.*, 1988). Temperature affects conductivity by increasing ionic mobility as well as the solubility of many salts and minerals (University of Virginia Physics Department, 2003). This can be seen in diurnal variations as a body of water warms up due to sunlight, (and conductivity increases) and then cools down at night (decreasing conductivity), therefore conductivity is re-calibrated against a set temperature.

Factors that affect water volume (like heavy rain or evaporation) affect conductivity. Runoff or flooding over soils that are high in salts or minerals can cause a spike in conductivity despite the increase in water flow.

Water temperature can cause conductivity levels to fluctuate daily. In addition to its direct effect on conductivity, temperature also influences water density, which leads to stratification. Stratified water can have different conductivity values at different depths.

Conductivity is an early indicator of change in a water system. Most bodies of water maintain a fairly constant conductivity that can be used as a baseline of comparison to future measurements (EPA, 2012). Significant change, whether it is due to natural flooding, evaporation or man-made pollution can be very detrimental to water quality. A sudden increase or decrease in conductivity in a body of water can indicate pollution (*Figure 38*).

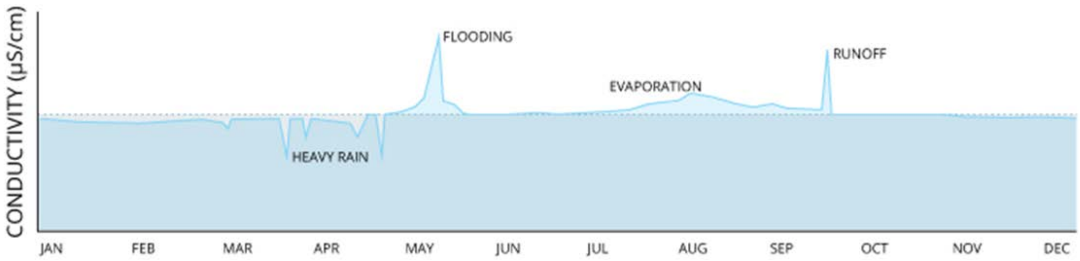

Figure 38: Factors that affect water volume (like heavy rain or evaporation) affect conductivity. Runoff or flooding over soils that are high in salts or minerals can cause a spike in conductivity despite the increase in water flow (Fondriest Environmental, 2014b).

Finnegan *et al., (*2014) suggest that conductivity is not a parameter that is significantly impacted by clear-felling alone however peatland restoration activities may produce significant run off which may affect the conductivity of the watercourse.

As with other parameters recorded within this study, Specific conductivity was higher at Site 1 with averages between 178 and 291 µS/cm, fluctuating in response to water depth. Sites 2 and 3 had relatively similar conductivity readings, with averages at Site 2 ranging between 73.6 and 89.1 µS/cm, and between 81 and 98.8 µS/cm at Site 3. Site 2 displayed the minimum conductivity of all sites reading 55.4 µS/cm.

7.2 Water sampling

7.2.1 Bladnoch catchment

In 2017 and 2018, pH readings were taken throughout the Bladnoch catchment. This was as part of a Bladnoch restoration feasibility study, and the aim of this sampling was to highlight where juvenile Atlantic salmon are unlikely to survive within the catchment due to low pH.

Spot sampling was conducted at 20 sampling locations in December 2017 and March 2018 to investigate spatial variability of pH. This data highlighted that Polbae outflow was having a significant impact on the River Bladnoch, lowering pH readings from >5.5 to between 5.01 and 5.5. This lower pH was recorded for a distance downstream and then appeared to recover by Site 7 (*Figure 23*).

This spatial data allows an understanding of the differences in pH throughout the system and can highlight specifically sensitive areas. As a true flood event was not sampled in 2017/2018, it was decided to continue this work and collect samples over the study period at Tannylaggie, as restoration work may improve the impacts of Polbae outflow. Seven sample events were completed between 22nd January until the 17th of March. Samples were collected regardless of water levels to allow for the varying ranges of pH over time to be identified. Data has been presented in *Table 2* and *Figures 24* and *25* visualise the varying pH recorded throughout the system at periods of low and high flow using colour code.

All sites remained the same as were recorded in 2017/2018, except for the addition of site 3A which was the headwater of Dargoal Burn. Due to limited access as a result of forestry activity, this site was only sampled twice, both reading pH 3.8. This site was situated in an area of felled forestry, downstream of a patch of dense forestry and this may have attributed to its significantly low pH.

Only seven out of the twenty-one sites sampled recorded pH levels consistently above the critical point, pH 5. Every other site, at one point within the study period produced readings below the critical point. Average pH in the catchment ranged from 3.8 – 6.4. Dargoal Burn was the site where the lowest pH readings were recorded across the study period, and the maximum pH was recorded on the Tarf Water near Kirkcowan. The further down the catchment samples were taken, the higher the pH readings were. This is as a result of the dilution of the acidic water draining from the headwaters.

There is a significant difference in pH readings taken under differing flow conditions as can be seen when comparing *Figures 24* and *25*. *Figure 24* is detailing pH readings collected during a period of normal flow on the 22nd January 2020. The pH of 90% of the samples was recorded above the critical point (pH 5), and 80% of the samples were recorded above pH 5.5. This data would suggest a relatively healthy watercourse. However, as presented in *Figure 25*, under periods of high flow conditions, pH was recorded above the critical point only 42% of the time. Under both low and high flows, it is clear that areas of significantly low pH can be identified. The effects of the Dargoal Burn are obvious regardless of flood events, however other areas of the catchment are able to recover well and may not present acidic conditions out with high flows.

A recent report by GFT (2018), compared electrofishing results from 2017 against known water quality data from the headwaters of the River Bladnoch and Tarf Water. The results demonstrated there was no recruitment of juvenile Atlantic salmon in either areas in 2017. It was apparent that although salmonids could inhabit the areas which were prone to acid pulses during flood events, it was severely impacting the recruitment potential of the upper reaches. Electrofishing results from the mid reaches of the catchment also showed moderate to low juvenile Atlantic salmon densities. Water quality spot sampling results demonstrated these areas also had a higher pH, which pH ranging from 5.66 - 6.07.

This data highlights the importance of the restoration work that is being carried out at Tannylaggie. By producing pH data for the catchment, it indicates areas that may be suitable or could benefit from further peatland restoration. It also provides opportunities for comparison studies in years following the restoration. It could be said that any improvements seen in the future within this area support the claim that peatland restoration is a crucial step in the battle against acidification, and that water quality is a key driver in the restoration process.

7.2.2 Upper Cree catchment

The upper Cree catchment is mostly publicly owned and managed by FLMS and used for forestry. It suffers from acidification and it is known there are areas of peatland planted over with trees. Some limited peatland restoration has been undertaken in the past but quite random, not prioritised and based on just peat depth surveys. There is an opportunity through FLMS to consider forest to peatland restoration and has been mentioned previously for around Upper High Cree. A recent proposed wind farm application (Clauchrie) stated it was interested to undertake peatland restoration as an amelioration measure. There is interest and future opportunities for peatland restoration in Cree catchment, so baseline data was collected to start feeding into the process.

Only one sampling day was completed on the 11th March 2020 under falling water levels. It was hoped that more sampling days could be carried out under higher water flows to pick up on acid pulses however due to unforeseen circumstances, no more sampling was possible.

The pH of the watercourses sampled ranged from 4.55 to 6 (*Table 3*). Three out of the eleven sites sampled recorded pH levels below the critical period as displayed in the histogram presented in *Figure 27*. *Figure 28* is a map of the catchment, displaying the ranges of pH recorded throughout the catchment using colour code.

8 SUMMARY

The River Bladnoch is a designated Special Area of Conservation (SAC) under the European Commission's Habitats Directive for Atlantic salmon (GFT, 2018). It is also a catchment which is heavily afforested over deep peat and there is evidence that this is contributing to poor water quality in the upper reaches. This poor water quality is affecting the survival of Atlantic salmon within large areas of the river, particularly in its headwaters. In response to these concerns, FLMS have agreed a three-year forest-to-bog restoration which aims to restore key areas of deep peat. As well as improving the carbon storage potential of the area, raising the water table which could reduce flooding, it could also improve water quality in the worst affected areas.

Before restoration begins, it is crucial to collect baseline data which documents the current condition of the watercourses which are likely to benefit from the restoration, but which also will be most heavily impacted during the process. This data will allow for comparisons in future years which could provide evidence to support the benefits and risks of peatland restoration.

Data collected throughout the duration of this study has highlighted and documented ranges of key parameters which can be used to monitor the health of significant watercourses linked to the peatland restoration within Tannylaggie. Monitoring has captured fluctuations and responses to varying water flows and flood events throughout the most sensitive time of year for salmonids and when acid pulses will be at their worst.

9 NEXT STEPS

This project was agreed to be part of a rolling WQM fund, which allows GFT to gather valuable data on an annual basis over the peak flow months. This project has a flexibility which allows it to be shaped and designed to suit ever evolving peatland restoration projects and can be altered and designed to suit all needs.

9.1 Tannylaggie

Having collected baseline data, the next step would be support ongoing restoration works. Monitoring high activity areas will pick up any unacceptable fluctuations to be addressed and to allow for mitigation to be put in place when required. Site selection can be determined in conjunction with restoration plans and timescales to ensure the sondes are downstream of ongoing works.

Returning the sondes to the sites monitored this year is recommended to continue gathering data which will allow for comparisons to be made and this should be continued on an annual basis for at least five years post restoration. One or two months in peak flow season would be enough to highlight issues or improvements.

Collecting water samples from around the catchment is key for monitoring improvements. It is important to consider water heights when taking samples to pick up on flood events and low water to gauge changes. Repeated electrofishing surveys in the upper reaches of the Bladnoch and Tarf Water would be useful in quantifying improvements in future years.

9.2 Upper Cree

It would be prominent to continue sampling at these sites to help determine the worst affected areas which could be restored in the future. Comparative electrofishing studies would be key in supporting this water quality data in the future.

9.3 Water of Fleet

Currently there are discussions regarding potential restoration of forestry which has notoriously impactful drains which feed into Cardoon Burn. There is a site visit planned in May 2020 which consider the next steps of this project. If restoration does go ahead, sondes need to be put in place to gather further data pre-restoration.

10 APPENDIX 1

Table 4: Minimum, maximum, and average data from the EXO 1 Sonde recording ***above*** *the restoration drain. Data was recorded every 15 minutes and grouped into months to calculate results. Data was recorded from the 30th December 2019 to the 17th March 2020. Temperature, pH, fluorescent Dissolved Organic Matter, Total Dissolved Solids, Depth, Specific Conductivity (at 25°) and Optical Dissolved Oxygen were all recorded. All results have been rounded to the nearest one decimal point except for pH due to its logarithmic scale.*

Factor	**pH**			**Temp (°C)**			**fDOM (QSU)**			**Depth (m)**			**SpCond (µS/cm)**			**ODO (mg/L)**		
Month	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*
January	5.59	6.18	6	5.7	6.8	6.5	82.9	302.2	231.5	0.5	1.4	0.9	121.5	220.3	178	-	-	-
February	5.93	6.19	6	5.6	6.3	6.1	279	302.67	293.5	0.6	1.5	1.1	189.2	245.8	219.6	-	-	-
March	5.9	6.18	6.07	5.8	6.7	6.4	224.65	305.71	278	0.6	1.3	0.9	165.1	240.3	197	-	-	-

Table 5: Minimum, maximum, and average data from the EXO 1 Sonde recording ***in*** *the restoration drain. Data was recorded every 15 minutes and grouped into months to calculate results. Data was recorded from the 30th December 2019 to the 17th March 2020. Temperature, pH, fluorescent Dissolved Organic Matter, Total Dissolved Solids, Depth, Specific Conductivity (at 25°) and Optical Dissolved Oxygen were all recorded. All results have been rounded to the nearest one decimal point except for pH due to its logarithmic scale.*

Factor	**pH**			**Temp (°C)**			**fDOM (QSU)**			**Depth (m)**			**SpCond (µS/cm)**			**ODO (mg/L)**		
Month	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*
January	3.97	4.56	4.20	2.9	7.3	5.0	111.1	168.9	124	-0.09	0.6	0.3	55.4	83.8	73.6	8.3	11.6	9.6
February	3.95	4.29	4.02	2.2	6.7	4.2	18	159.3	46.8	-0.01	0.6	0.3	70.7	102.2	89.1	8.5	11.6	10
March	4	4.3	4.1	2.2	6.7	4.5	45.1	101.84	81.1	-0.01	0.5	0.9	71.5	111.9	78.8	8.5	11.6	10

Table 6:Minimum, maximum, and average data from the EXO 1 Sonde recording below the restoration drain. Data was recorded every 15 minutes and grouped into months to calculate results. Data was recorded from the 30th December 2019 to the 17th March 2020. Temperature, pH, fluorescent Dissolved Organic Matter, Total Dissolved Solids, Depth, Specific Conductivity (at 25°) and Optical Dissolved Oxygen were all recorded. All results have been rounded to the nearest one decimal point except for pH due to its logarithmic scale.

Factor	**pH**			**Temp (°C)**			**fDOM (QSU)**			**Depth (m)**			**SpCond (µS/cm)**			**ODO (mg/L)**		
Month	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*
January	3.91	4.21	4.04	2.6	7.1	5	110.7	131.7	122.6	0.2	1	0.6	65.6	90.8	81	8.5	11.4	9.8
February	3.82	4.19	4.02	2.5	6.6	4.4	103.9	133.2	116.4	0.3	1.2	0.7	68.8	117.3	98.8	9	11.6	10.4
March	3.78	4.15	4.05	2.2	6.4	4.4	105.2	123.8	113.6	0.3	0.94	0.5	75.8	102.6	91	9.47	11.3	10.3

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