A Scottish Registered Charity No. SC 020751

The River Bladnoch Scallop Shell Project Baseline Report

For further information on this report please contact:

Galloway Fisheries Trust
Fisheries House
Station Industrial Estate
Newton Stewart
DG8 6ND
01671 403011
kacie@gallowayfisheriestrust.org

This report should be quoted as:

Galloway Fisheries Trust. December 2025. The River Bladnoch Scallop Shell Project Baseline Report.

Table of Contents

1 Introduction

1.1 Project Background

Galloway Fisheries Trust (GFT) began developing the Scallop Shell Project in June 2024 following a request from the River Bladnoch District Salmon Fishery Board (RBDFSB) to investigate the potential impacts of adding scallop shells to acidified watercourses. Baseline monitoring began in September 2024 prior to the project works commencing in March 2025. The project involves partnerships with GFT, RBDSFB, Forestry and Land Scotland (FLS), Scottish Woodlands and private landowners, with additional input from NatureScot and SEPA. The project is funded by the Salmon Scotland Wild Fisheries Fund and GFT. This report outlines the baseline results collected during 2024 and 2025 prior to the project works commencing.

1.2 Acidification Within the River Bladnoch

The River Bladnoch originates from the outflow of Loch Maberry and is located in Galloway, South West Scotland. It is approximately 56 km long and has a catchment area of roughly 340 km^2. The River Bladnoch was designated a Special Area of Conservation (SAC) for Atlantic salmon in March 2005, which aims to ensure that its Atlantic salmon population remains in a favourable condition. However, certain areas of the catchment are acidified which prevents them supporting an Atlantic salmon population due to recruitment failure as their eggs cannot hatch successfully. A pH of below 4.5 blocks the hatching enzyme chorionase from being released leading to mortality of Atlantic salmon eggs (Waiwood and Haya, 1983).

The acidification within these areas is due to a combination of causes; acid rain, poorly buffered underlying geology, scavenging of pollutants by conifers, and surrounding land use practices digging into and draining surrounding peatlands. When areas of peat – particularly deep peat – are drained or dug up and exposed, this can result in acidification of downstream watercourses. Draining peatlands lowers the water table which exposes the peat to aerobic decomposition, leading to the carbon previously stored in the peat being released into the environment (Martin-Ortega *et al.,* 2014).

GFT undertook a large scale water quality monitoring project within the River Bladnoch catchment between 2023 and 2024 which was funded by Peatland Action and which highlighted the key areas that are most impacted by acidification. The report can be found on the GFT website at: https://www.nathonjones.com/files/GFT_2024_Bladnoch_WQM_Report_Final.pdf. The results from the water quality monitoring project were used to guide the site selection for the scallop shell project.

1.3 Scallop Shells

Scallops are a popular delicacy across Scotland with thousands of tonnes of scallops harvested by Scottish vessels for the food industry every year. This leads to large amounts of waste shells building up which are difficult to dispose of. One way that the RBDSFB and GFT thought to investigate was to experiment with using waste shells to mitigate acidification in watercourses.

Scallop shells, like all marine mollusc shells, consist of calcium carbonate which can be used as an effective acid neutraliser. Calcium carbonate is the main component of limestone, which has been historically used to treat acidification issues in various freshwater systems with generally positive but varied results, which were largely dependent on the watercourse (Mant *et al.,* 2013).

However, limestone is an important raw material for several industries and the high demand for the mining of limestone has had a severe environmental impact (Ganapathi and Phukan, 2020). While liming had general success for reducing acidification across watercourses, it is not feasible to carry out long term due to the environmental concerns of mining, cost and the lack of supply due to high demand. In Scotland, with scallops being consistently harvested for the food industry, it is reasonable to assume waste shells will continually be readily available and may be a possible mitigator of acidification and a suitable replacement for liming in watercourses. Liming should always be considered a short term mitigation while long term solutions to the cause of acidification are delivered.

The scallop shells used in this project were sourced locally from West Coast Sea Products in Kirkcudbright, South West Scotland.

1.4 Supporting Literature

Studies in other areas of the world have shown promising results from using discarded seashells to improve water quality, including reducing the impact of acidification. One study in particular, which heavily guided this project, was conducted in Maine, USA between the years of 2010 – 2014 (Whiting, 2014). The study looked at the use of clam shells for mitigating acidification in streams and for enhancing the populations of fish, particularly Brook trout and Atlantic salmon. The study included six sites and added 2 – 6 tonnes of whole clam shells into each site annually from 2010 until the project was terminated in 2014.

In the first three years of the study, two sites had an increase of 1 pH unit and doubled the number of fish. Another site saw an increase of 0.71 pH units and a sixfold increase in the density of Brook trout. One site was fishless in the baseline surveys but had Creek chub present in the 2014 monitoring. Invertebrate populations and diversity increased at all sites with acid sensitive families showing up later in the project. This provided an increase in food availability and, combined with the increase in pH, made conditions more favourable for fish.

Both soft and hard clam shells were used in this study and it was found that the soft shells would dissolve within 6 – 8 months, with the hard shells taking up to two years to fully dissolve. It was suggested that applying shells 1 - 2 times per year would keep up the treatment. It was found that shell treatments did not neutralise water effectively during periods of high flows due to a reduced contact time between the water and the shells, and that they only had a positive effect on pH during long periods of low – normal flows. The study suggested that shells can improve pH in streams but it may not be enough to fully recover watercourses affected by acidity. It was then suggested that using terrestrial applications alongside instream applications may potentially improve treatment during high flows and allow for more consistent acidity regulation. Terrestrial applications of scallop shells onto forestry roads (owned by FLS) were carried out in Galloway a number of years ago. However, the water quality benefits were not monitored at the time as it was only trialling the practical application of the shells and the process stopped shortly after. There were also concerns regarding pollution as the shells still contained a lot of waste flesh, which is not the case now due to improved methods of factory processing.

1.5 Project Outline

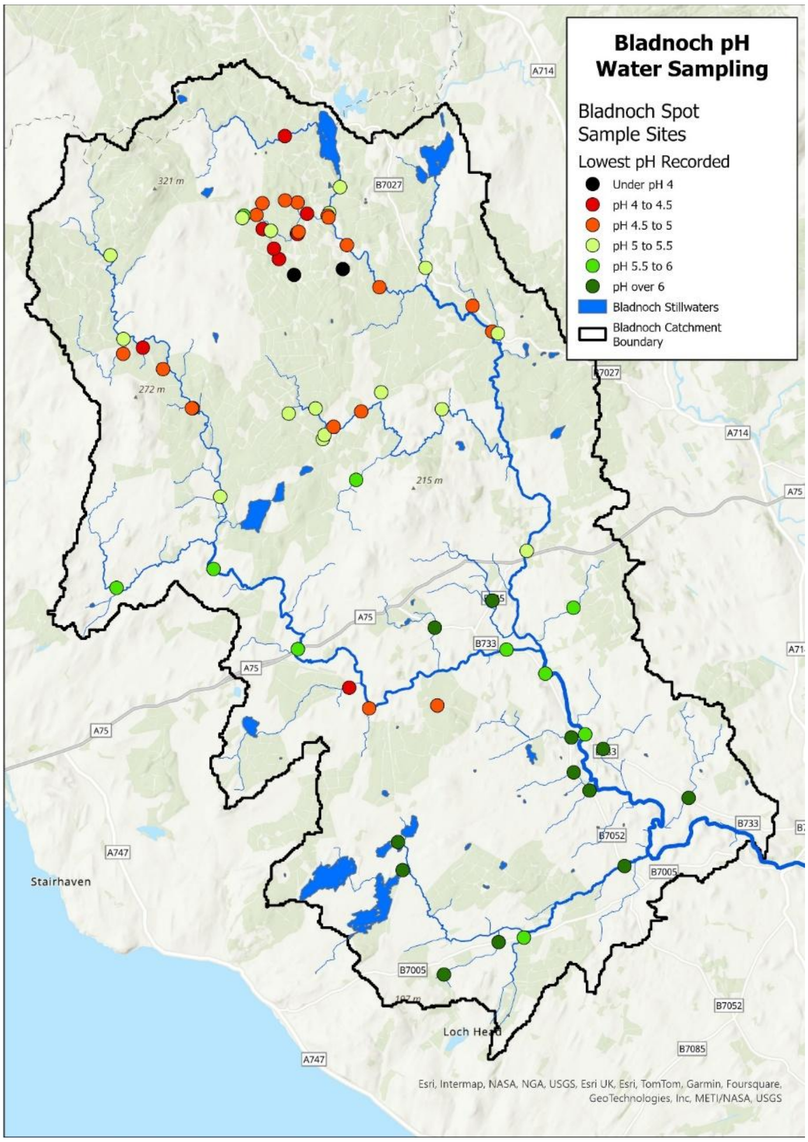
This project involves both terrestrial applications of scallop shells onto old style forest tracks which drain into nearby watercourses, and instream applications of scallop shells hand placed directly into watercourses. This is an experimental project and the works carried out between March and May 2025 were treated as a trial only with no current plans to reapply shells.

Monitoring of the project will continue for five years with an annual report produced. Should the project prove to be effective in the mitigation of acidification, it can be used to guide and support future projects.

2. Site Selection and Methodologies

2.1 Site Selection

Sites were selected by GFT and were prioritised based on the results from the Bladnoch Water Quality Monitoring Project, access to the sites, landowner permissions, and avoidance of external ongoing restoration projects and drinking water sources. Map 1 details the lowest pH results recorded during the Bladnoch Water Quality Monitoring Project which were used to guide site selection.



Map 1: The lowest pH recorded from spot sampling at each site during the 2023-2024 Bladnoch Water Quality Monitoring Project. Spot samples were collected following heavy rainfall to target the acid flushes which occur during periods of high flows.

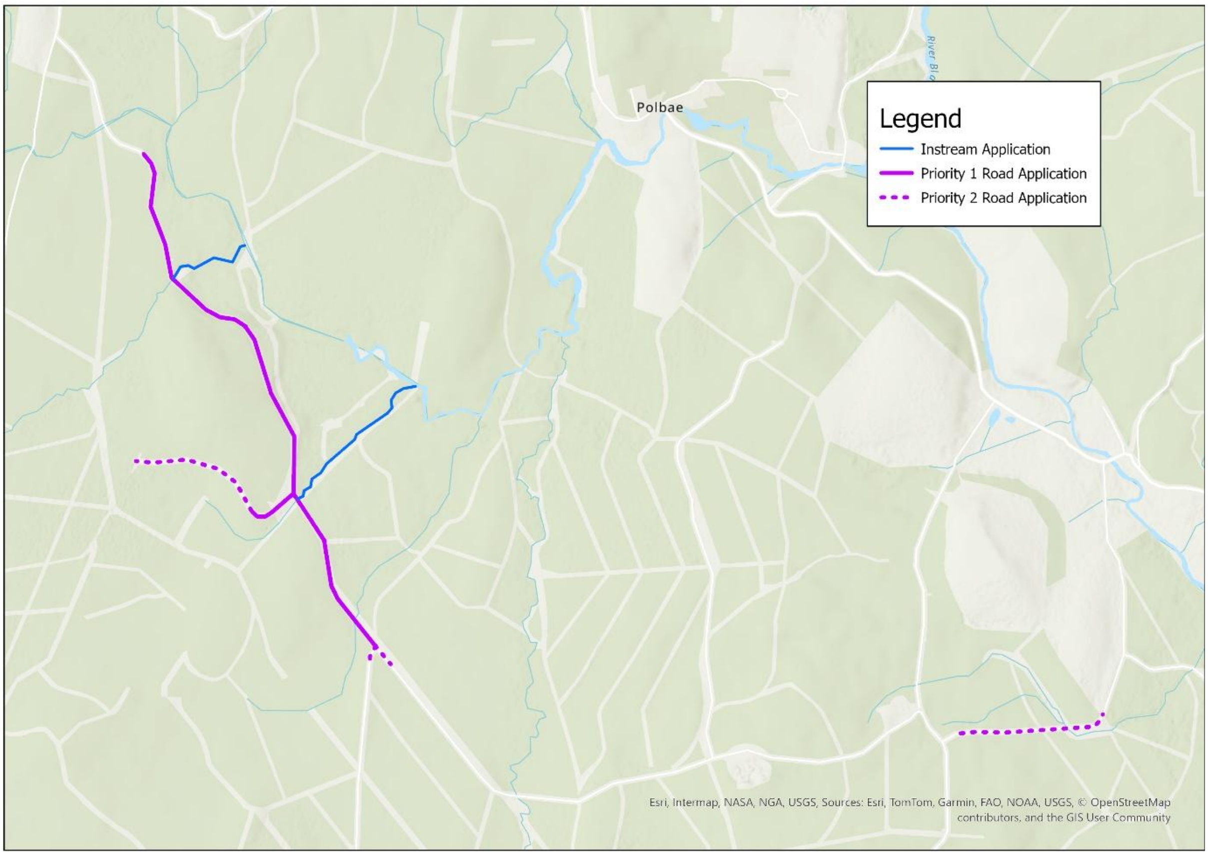
Two areas within the Bladnoch catchment were highlighted as potentially suitable for scallop shell applications, the Polbae Burn catchment and the Pultayan Burn (a tributary of the Black Burn). The terrestrial application sections were selected based on the drainage surrounding forest tracks. The instream application sites were selected based on the accessibility and characteristics of the watercourses.

Walk-over surveys were carried out of all sites and the drainage ditches within the Polbae Burn catchment were identified as being unsuitable to support fish. Electrofishing surveys were then carried out on the drainage ditches within the Polbae Burn to confirm that they were fishless. A walk-over survey of the Pultayan Burn was also carried out and it was deemed unsuitable for spawning due to the low pH: but suitable habitat did exist to support fish. The burn was then electrofished to confirm that no fry-aged Atlantic salmon or Brown trout were present.

The scallop shell project locations were categorised into terrestrial only applications, instream only applications, and both terrestrial and instream applications. This will allow direct comparisons on how the water chemistry responds to each application type, both separately and as a combination.

2.1.1 Polbae Burn Catchment

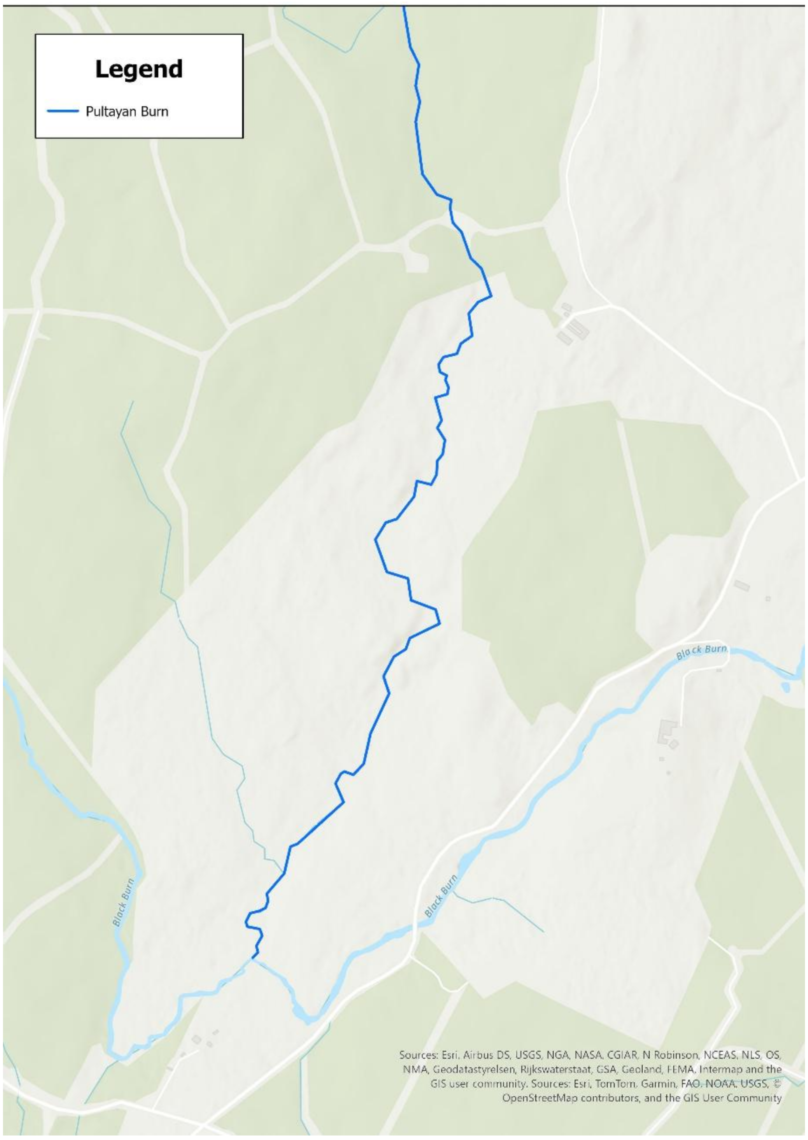
The Polbae Burn flows into the upper River Bladnoch and is an acidified catchment with several accessible locations for both terrestrial and instream scallop shell applications. There is an ongoing peatland restoration project being carried out by FLS around the Dargoal Burn, which flows into the Polbae Burn. This area has been avoided completely during the scallop shell project so that there is no interference with the peatland restoration monitoring that is being undertaken by Forest Research. There were several drainage ditches and stretches of road out with the Dargoal Burn catchment which were highlighted as having the potential to benefit from scallop shell applications. Map 2 details the roads and drainage ditches selected for shell applications within the Polbae Burn Catchment. The road sections were split into two categories: Priority 1 and Priority 2 sections.



Map 2: Priority 1 and 2 areas within the Polbae Burn catchment selected for terrestrial and instream applications of scallop shells

2.1.2 Pultayan Burn

The Pultayan Burn is a highly acidified tributary of the Black Burn which causes a localised issue with pH downstream of its confluence. The Black Burn appears otherwise unimpacted by acidification so the Pultayan Burn was highlighted as an area of high concern. The Pultayan Burn was selected as an instream only application site due to having no nearby roads to drain into the catchment. Map 3 details the Pultayan Burn.



Map 3: The Pultayan Burn

2.2 Terrestrial Applications of Scallop Shells

King scallop shells were used for all terrestrial road applications. Shells were crushed at West Coast Sea Products in Kirkcudbright before being delivered to the Polbae Burn catchment in 26 tonne lorry loads. The crushed shells were deposited on site where an excavator transferred them to a 9 tonne dumper modified for spreading. Forest tracks were laid with crushed shells at depths between 50 – 75 mm. Figures 1 – 5 detail this process.

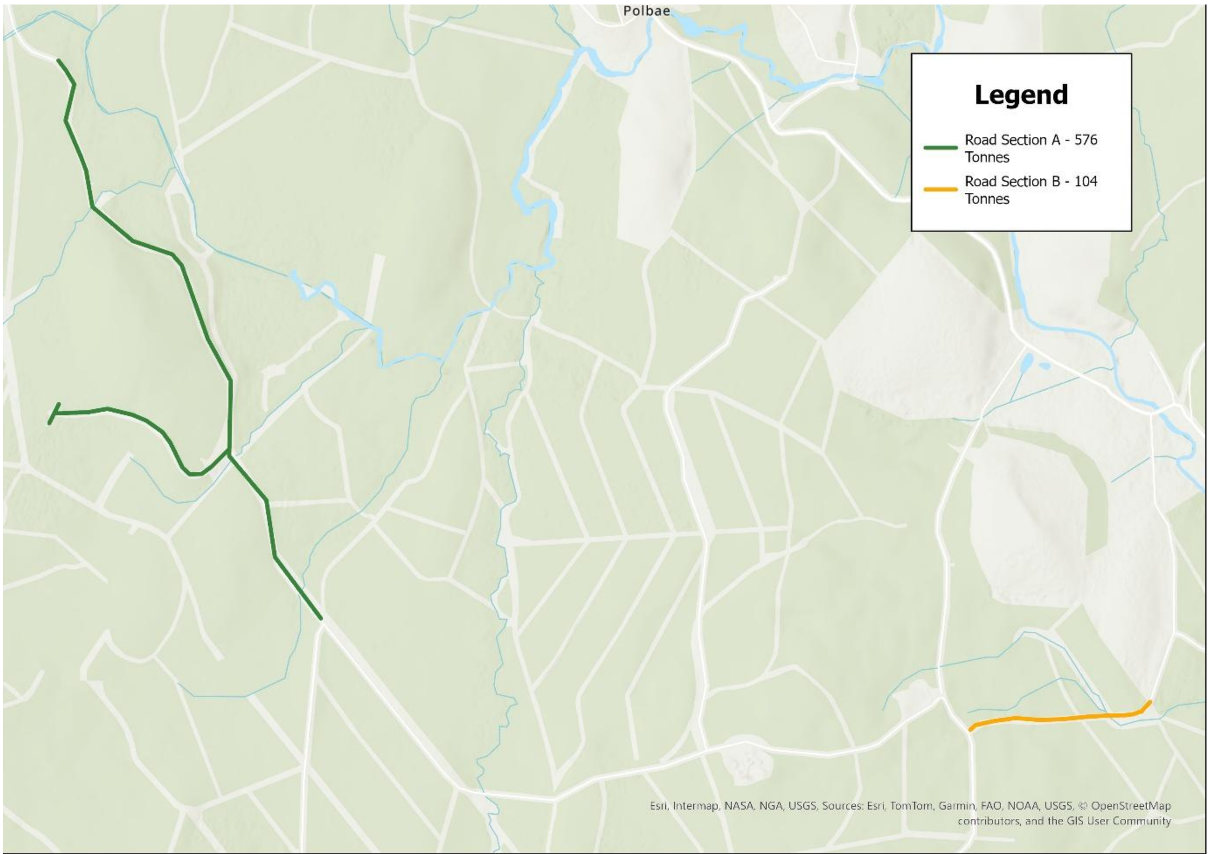
Figure 1: King scallop shells being crushed at the seafood processing company

Figure 2: Crushed king scallop shells being stockpiled on site

Figure 3: Shells being transferred to the dumper spreader


Figures 4 and 5: Crushed king scallop shells being laid along the forest tracks via a spreader

A total of 680 tonnes of crushed king scallop shells were laid along forest tracks between 17th and 28th March 2025. Map 4 presents the two sections of road applied with crushed king scallop shells with the tonnage of shells applied to each. Road section A received 576 tonnes of crushed shells and section B received 104 tonnes of crushed shells.



Map 4: Both road sections with the tonnage of crushed king scallop shells applied to each

2.3 Instream Applications of Scallop Shells

Queen scallop shells were used for all instream road applications. Whole queen scallop shells were transported to both the Polbae Burn catchment and the Pultayan Burn and stockpiled prior to use.

In the Polbae Burn catchment, 20 kg loads of queen scallop shells were placed into large garden sacks and carried along previously created pathways to the water's edge where they were placed instream by hand. Two drainage ditches were applied with instream shells, with mesh screens placed upstream of their confluences to the Polbae Burn which will allow for any build-up of shells to be monitored and removed if necessary. The mesh frames can also provide insight into if shells move downstream in large quantities. The two drainage ditches were named "Middle Burn" and "Upper Burn". A total of 6.2 tonnes of whole queen scallop shells were placed into two drainage ditches within the Polbae Burn catchment, with 3.7 tonnes placed into Middle Burn and 2.5 tonnes placed into Upper Burn. Shells were applied in April and May 2025 following the road application works.

At the Pultayan Burn, 30 kg loads of queen scallop shells were placed into large garden sacks and transported to the water's edge using a quad bike and trailer. Shells were then placed instream by hand ensuring that the original substrate was not completely covered (Figure 6). No mesh screen was placed in the burn as it is accessed by fish, however the bottom of the Pultayan Burn is a large pool area which was not applied with shells and any potential build ups from shells moving downstream would be deposited here. A total of 6.1 tonnes of whole queen scallop shells were placed into the Pultayan Burn during March and April 2025.

Figure 6: Whole queen scallop shells placed into the Pultayan Burn in March 2025

Table 1 presents the details of each watercourse applied with whole queen scallop shells, with the upper and lower limits and the tonnage of shells applied to each.

Table 1: The start and end grid references for each watercourse applied with whole queen scallop shells and the tonnage of shells applied to each

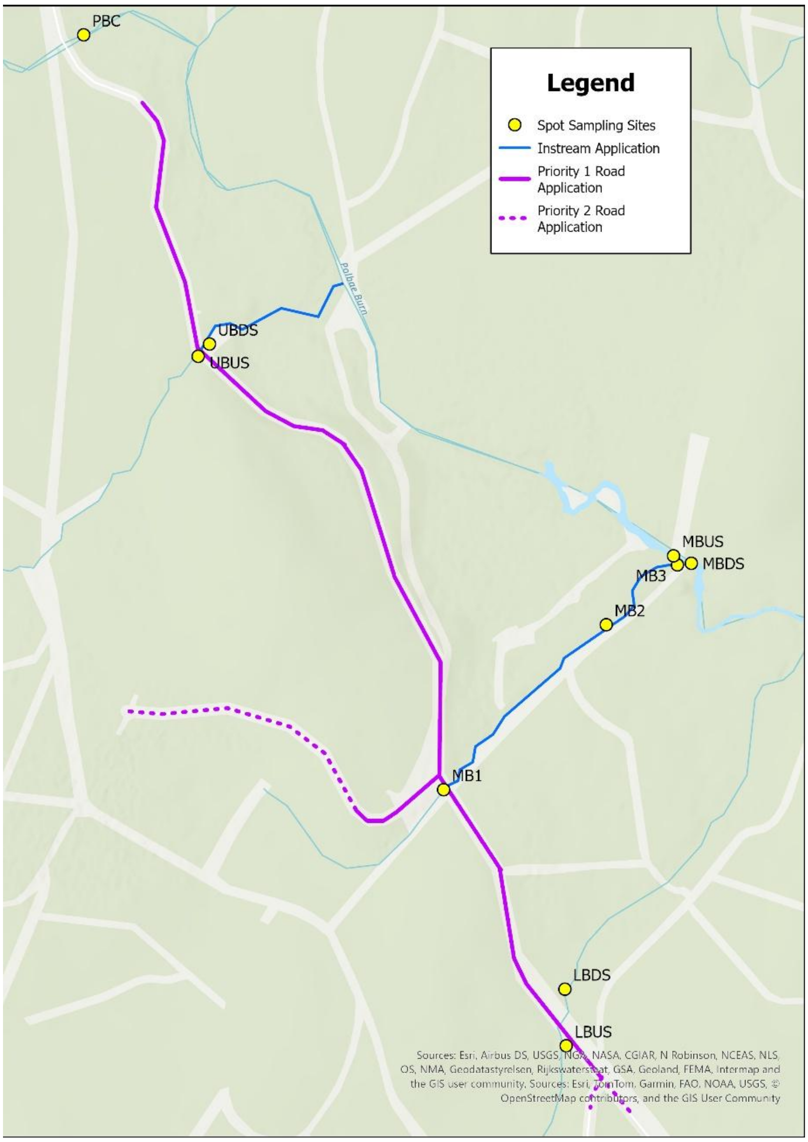
Watercourse	Upper Limit Grid Reference	Lower Limit Grid Reference	Tonnes of Shells Added
Middle Burn, Ditch Draining into the Polbae Burn	227052 571939	227326 572222	3.7
Upper Burn, Ditch Draining into the Polbae Burn	226727 572510	226895 572583	2.5
Pultayan Burn, Tributary of Black Burn	229150 567823	228785 566818	6.1

2.4 Monitoring Methodologies

2.4.1 Spot Sampling

Fifteen locations were selected for regular spot sampling monitoring and this includes five control sites. Baseline spot sampling began in November 2024 and was undertaken at least three times each month on a random basis to allow for all levels of flow to be targeted. One litre bottles were used for each spot sample and were rinsed three times within the site prior to being filled completely, ensuring no air bubbles were present where possible. The time of day, depth of the site and the temperature were recorded each time. The samples were returned to the GFT office to be analysed using a high precision EXO water quality monitoring sonde which was calibrated each time. The pH, conductivity, and dissolved oxygen were recorded.

The spot samples are being used to monitor the different application types to highlight whether the terrestrial and instream applications have different impacts, and if both application types combined is more effective. Maps 5 and 6 present the spot sampling locations and Tables 2 and 3 detail each spot sampling location, with a site description and the type of application being monitored.

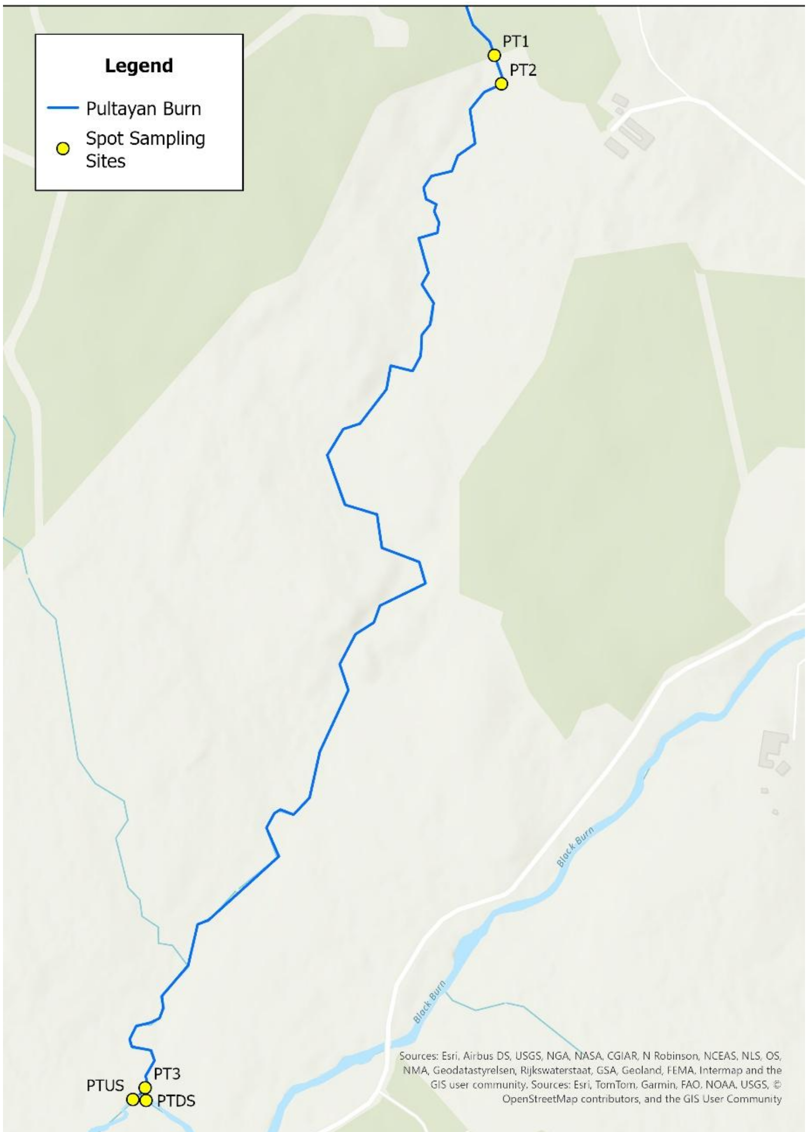


Map 5: The spot sampling locations within the Polbae Burn catchment area, overlaying the instream and terrestrial application sites

Table 2: Spot sampling sites within the Polbae Burn catchment area with the site locations, site descriptions, and method of application monitoring

Site	Grid Reference	Site Description	Monitoring Method
PBC	226572 572915	Downstream of the bridge	Control Site
UBDS	226736 572512	Within the drainage ditch receiving an instream shell application	Terrestrial and Instream Application
UBUS	226721 572496	Upstream of the road	Control Site
MB1	227401 571931	Upstream of the culvert	Terrestrial Application
MB2	227253 572146	Within the drainage ditch receiving instream shell application	Terrestrial and Instream Application
MB3	227346 572224	Lower area of the drainage ditch receiving an instream shell application, downstream of the treatment	Terrestrial and Instream Application

MBDS	227364 572226	Polbae Burn, downstream of the drainage ditch receiving an instream application	Terrestrial and Instream Application
MBUS	227341 572236	Polbae Burn, upstream of the drainage ditch receiving an instream application	Control Site
LBDS	227199 571671	Downstream of the road	Terrestrial Application
LBUS	227201 571597	Upstream of the road	Control Site



Map 6: The spot sampling locations within the Pultayan Burn catchment area

Table 3: Spot sampling sites within the Pultayan Burn catchment area with the site locations, site descriptions, and method of application monitoring

Site	Grid Reference	Site Description	Monitoring Method
PT1	229157 567836	Upstream of the instream shell application area	Control Site
PT2	229058 567653	Within the area of the instream shell application	Instream Application

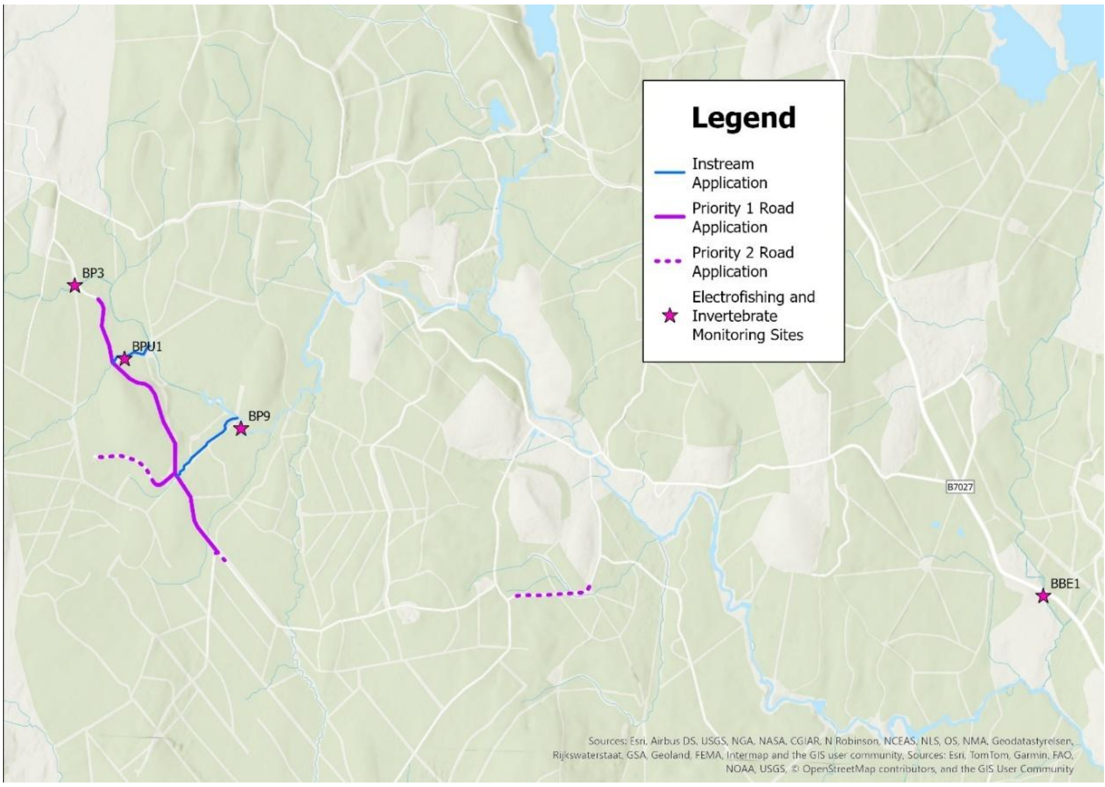
PT3	228756 566704	Downstream of the shell application area	Instream Application
PTDS	228738 566681	Black Burn, immediately downstream of the Pultayan Burn inflow	Instream Application
PTUS	228758 566681	Black Burn, upstream of the Pultayan Burn inflow	Control Site

2.4.2 EXO Water Quality Monitoring Sonde

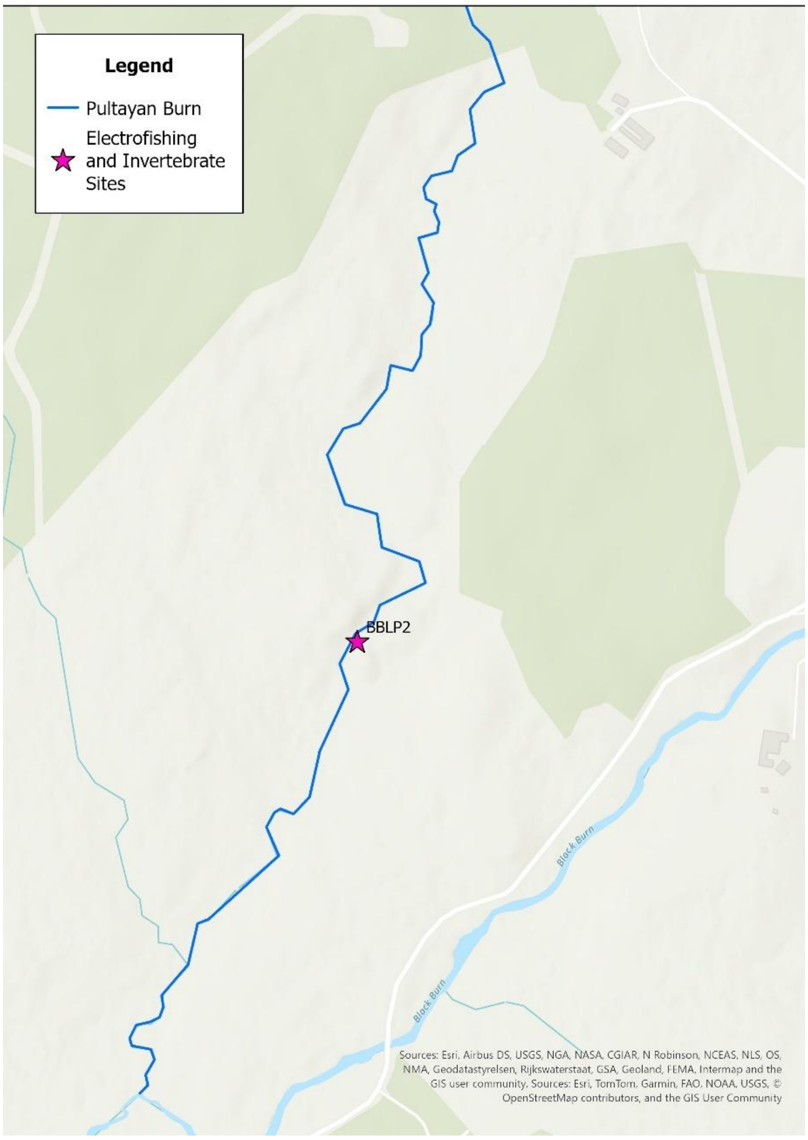
In February 2025, a high precision EXO water quality monitoring sonde was deployed in the lower section of the Pultayan Burn to collect baseline data prior to the instream shell application. The sonde recorded data every 15 minutes and was removed to download the data immediately prior to the shell application on the Pultayan Burn. The sonde was then re-deployed, again prior to the instream application works to monitor the water chemistry post-application. The sonde collects constant data on pH, conductivity, depth, temperature, and dissolved oxygen. The main focus for this project however is pH and depth, as water depth directly impacts the pH during periods of varying flows.

2.4.3 Electrofishing and Invertebrate Surveys

Five sites were selected as fish and invertebrate monitoring locations to monitor and highlight any changes in the aquatic fauna throughout the course of the project. Two sites were included within instream application watercourses, with one site downstream of an instream application watercourse, and two external control sites. Baseline surveys were undertaken in September 2024 and will be repeated annually throughout the five year project monitoring. Maps 7 and 8 present each electrofishing and invertebrate monitoring site.



Map 7: Three electrofishing and invertebrate monitoring locations within the Polbae Burn catchment and one external control site on the Beoch Burn



Map 8: The electrofishing and invertebrate monitoring site within the Pultayan Burn

Electrofishing Surveys

To assess the fish populations present within a section of river, various techniques have been developed in the recent decades. The main method of determining the status of a juvenile salmonid population is through employing the use of electrofishing equipment. The equipment used is a mobile backpack electrofishing kit. The battery powered E-Fish backpack consists of an electronic controller unit with a linked cathode of braided copper (placed instream) and a linked, mobile, single anode consisting of a pole-mounted stainless steel ring and trigger switch which is used instream to capture fish. Smooth direct current was used at all survey sites.

This technique of electrofishing involves the 'stunning' of fish using an electric current which overpowers the nervous system of the fish and enables the operator to remove them from the water. Once captured, the fish recover in a holding container. They are then anaesthetised using a specific fish anaesthetic, identified to species, measured, and recorded, and once recovered, returned unharmed to the area from which they were captured.

The method of fishing involves the anode operator drawing stunned fish downstream to a net held against the current by an assistant. A hand net operator completes the three-man team.

Captured fish are then transferred to a water-filled recovery container. The fishing team works its way across the survey section and upstream, thereby thoroughly fishing all the water in the chosen survey area.

A minimum estimate of fish per 100 m^2 of water is calculated for that section of river. After the electrofishing exercise has been completed, a targeted and detailed Scottish Fisheries Coordination Centre (SFCC) habitat survey is completed of the actual fishing site.

For this study, electrofishing was undertaken by three experienced GFT staff at all survey sites.

Limitations of electrofishing surveys

The SFCC method of electrofishing was primarily developed to survey juvenile salmonids in relatively shallow running water. Non-salmonid fish species may be present and caught during these surveys, but their populations may not be properly determined using this method of electrofishing. Any non-salmonid fish species are therefore counted but no population estimate is made (see Table 9 in section 3.3 for results).

Electrofishing rarely captures all of the fish in a survey site, so densities presented in this report are as a minimum estimate of the density of salmonids within each watercourse.

A low density of fish can be assessed with electrofishing techniques; however, it is harder to fully assess the actual population density of the watercourse or the representative site. If there is a low and patchy distribution of fish it may be harder to draw conclusions from the data.

Age Determination

For this study the electrofishing surveys concentrated on assessing the status of juvenile salmonid species. In the majority of cases age determination can be made by assessment of the length of fish present. However, with older fish it is often more difficult to clarify age classes. In these cases, a small number of scale samples can be taken from fish, in addition to taking length assessments, to verify the ages of fish whose age cannot be determined with certainty from the length.

For this project, juvenile salmonids are differentiated into fry (age 0+) and parr (age 1++) age groups (see Table 4).

Table 4: Salmonid age classifications referred to in this report

Atlantic salmon fry (0+)	Young fish less than one year old resulting from spawning at the end of 2023
Brown trout fry (0+)	Young fish less than one year old resulting from spawning at the end of 2023
Atlantic salmon parr (1+ and older)	Young fish of greater than one year from spawning in 2022 or previously
Brown trout parr (1+ and older)	Young fish of greater than one year from spawning in 2022 or previously

Along with classifying salmonids into age brackets within the electrofishing results, juvenile salmonid numbers recorded have also been classified into several ‘density’ categories. A classification scheme for densities of salmonids was previously generated by the SFCC using data collected from 1,638 Scottish electrofishing survey sites covering the period 1997 to 2002 (SFCC, 2006). From this, regional figures were created to allow more accurate local ‘density ranges'. The categories referred to in this report are based on quintile ranges for one-run electrofishing events in the Solway region (Solway Salmon Fishery Statistical Region).

The juvenile salmonid density classification scheme (SFCC, 2006) is based solely on data from surveyed sites containing fish in 1997 to 2002 and refers to regional conditions at that time; it must only be used as a very relative guide and not be used to draw conclusions. Moreover, the figures for juvenile trout are less reliable for various reasons (e.g., some surveyed populations of trout are isolated; sea trout contributing to stock in some areas etc.) and so can only be used as a relative indication of numbers. Table 5 shows these quintile ranges for the Solway region, within which the River Bladnoch catchment lies.

Table 5: Quintile ranges for juvenile salmonids (per 100 m^2 of water) based on one-run electrofishing events, calculated on densities >0 over 291 sites in the Solway Statistical Region

	Salmon 0+	Salmon 1+	Trout 0+	Trout 1+
Very Low	0.22	0.38	0.38	0.35
Low	5.21	2.86	4.14	2.27
Moderate	12.68	5.87	12.09	4.71
High	25.28	9.12	26.63	8.25
Very High	46.53	15.03	56.49	16.28

SFCC Habitat Survey

At each survey site a total site length was recorded, and average wet and channel widths calculated. The average wet width was calculated from three or more individual widths recorded at equidistant intervals from the bottom of the site (0 m) to the top. At each site the final width was noted at the upper limit of the surveyed water. From these site measurements the total area fished can be calculated.

At each electrofishing site a detailed habitat assessment using SFCC protocol is made of the instream habitat available for older (parr (1++) aged) fish. This assessment grades the instream 'cover' available to salmonids as none, poor, moderate, good or excellent. This grading provides an index of instream cover where diverse substrate compositions will score more favourably than areas of uniform substrate which provides lower levels of cover for individuals. In accordance with SFCC protocols, percentage estimates of depths, substrate type and flow type are made at each electrofishing site. Additionally, percentage estimates of the quantity of the bankside cover features such as undercut banks, draped vegetation, bare banks and marginal vegetation are made. When any reference to left or right bank is made, it is always classed as left and right bank when facing downstream.

Invertebrate Sampling

Invertebrate samples were collected upstream of each electrofishing site using a standard 25 cm frame kick sampling net with 1 mm mesh. The sampling methodology used was the standard macroinvertebrate sampling of three minutes of kick sampling followed by one minute of manual searching. As with the standard procedures, the kick sampling was split proportionally based on the invertebrate habitats present within the sample sites. The manual search focused on the surface layer, bankside vegetation/undercuts and stone washing. The resultant material collected during the kick sample and manual search was placed into a labelled container and preserved in 70% isopropanol.

Samples were sorted at the GFT office with all individuals being counted and identified to family level in accordance with sampling for biotic assessment. Identification was completed using a low powered microscope with x10 to x40 variable magnification and using the Freshwater Biological Association Guide to British Freshwater Macroinvertebrates for Biotic Assessment identification guide.

Samples were scored using the WHTP scoring system, which scores different invertebrate families based on their general water quality requirements and analysed using the River Invertebrate Classification Tool (RICT). Based on environmental variables recorded at sample sites and predicted by DEFRA Input Variable software, the RICT software predicts the invertebrate communities that should be found and compares the predicted values with those recorded during invertebrate sampling. This gives a score which can be used to assess general water quality based on the scoring shown in Table 6.

Table 6: RICT Overall Score and Average Score per Taxon (ASPT) and NTAXA Ratings

ASPT	NTAXA	Water Quality Rating
0.97+	0.80+	High
0.86 – 0.96	0.68 – 0.79	Good
0.72 – 0.85	0.56 – 0.67	Moderate
0.59 – 0.71	0.47 – 0.55	Poor
<0.59	<0.47	Bad

ASPT (Average Score per Taxon) represents the average WHPT water quality score for the invertebrate families recorded within a sample. NTAXA is the number of different invertebrate families recorded within a sample. Two additional Biotic Indices have been used to analyse the results and give an indication of the condition of the invertebrate communities at each sample site at the time of sampling (both of which can also be calculated by the RICT software). The two indices used are The Proportion of Sediment-sensitive Invertebrate Index (PSI) and the Acid Water Indicator Community (AWIC) Index. Whilst the RICT software gives an overall indication of water quality/invertebrate community health, the PSI Index assesses the levels of sedimentation within watercourses by looking at the proportion of sediment sensitive invertebrate families within an invertebrate sample. Drainage and land erosion can result in high levels of sediment input from the surrounding land, which can "smother" riverbeds resulting in the death of buried fish eggs and some sediment intolerant invertebrate species. PSI has been included in this monitoring to highlight the current state of siltation within the watercourses as this has the potential to impact on some of the other indices if severe. In a similar manner to the RICT and PSI indices, the AWIC Index uses the pH tolerance of different families of invertebrates to estimate the mean pH within a watercourse based on the invertebrates recorded. The scoring systems for both indices are shown in Tables 7 and 8.

Table 7: PSI Score Ratings

PSI Score	Level of Sedimentation on River Bed
81 – 100	Minimally / Not Sedimented
61 – 80	Slightly Sedimented
41 – 60	Moderately Sedimented
21 – 40	Sedimented
0 - 20	Heavily Sedimented

Table 8: AWIC Score Ratings

AWIC Score	Mean pH	Lower 95 Percentile	Upper 95 Percentile
2	5.46	4.55	6.37
2.5	5.84	4.93	6.75
3	6.22	5.31	7.12
3.5	6.6	5.69	7.5
4	6.98	6.07	7.88
4.5	7.36	6.45	8.27
5	7.74	6.83	8.65
5.5	8.12	7.21	9.03
6	8.5	7.59	9.41

Limitations of Invertebrate Analysis

Family level invertebrate analysis may not always provide accurate assessments of environmental impacts due to the oversimplification of taxa diversity. Family level identification may mask variations in species sensitivities to acidification and sedimentation. Some families may include species that are highly tolerant to changes in water chemistry or sediment load, while others within the same family may be more sensitive, leading to misleading conclusions about the overall health of aquatic ecosystems. However, family level analysis can still be used for monitoring drastic changes to water quality as any significant impacts on the aquatic ecosystem is still likely to be picked up as significant changes in the families present, and as a result, changes in the biotic index ratings over time.

2.5 Hatchery Experiments

GFT have access to a hatchery in which four separate tanks were set up to monitor the effects that scallop shells have on freshwater pH in a controlled environment. The experiments are being included as interest only and will run alongside the scallop shell project works in the field rather than being carried prior to the projects works to be used as guidance.

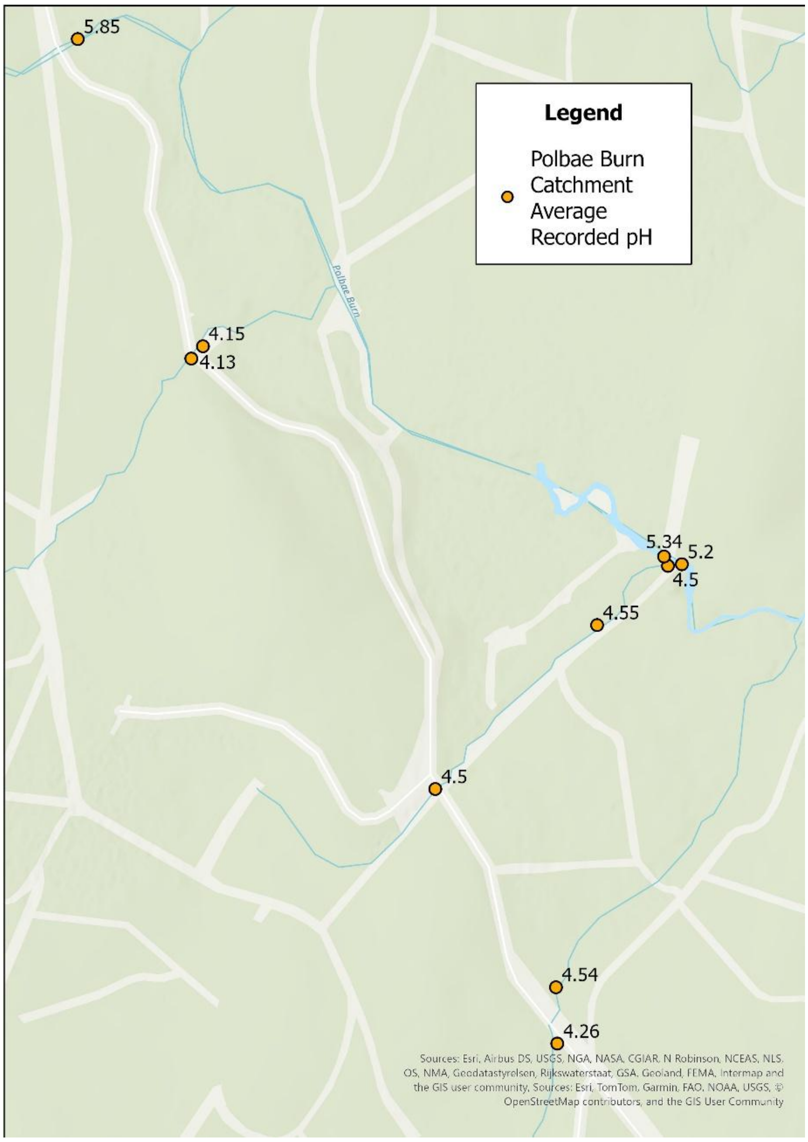
Four separate tanks have been filled with 20 kg each of whole king shells, crushed king shells, whole queen shells, and crushed queen shells. Each tank will have water running through them and the pH of each tank will be intermittently tested by collecting a water sample and analysing the results with an EXO water quality monitoring sonde. During each survey, the results will be compared against a sample of the inflow water to monitor how effective each type of shell is at increasing the pH. It is important to note that the inflowing water at the hatchery is more buffered (higher pH) than the experimental field sites.

3. Results

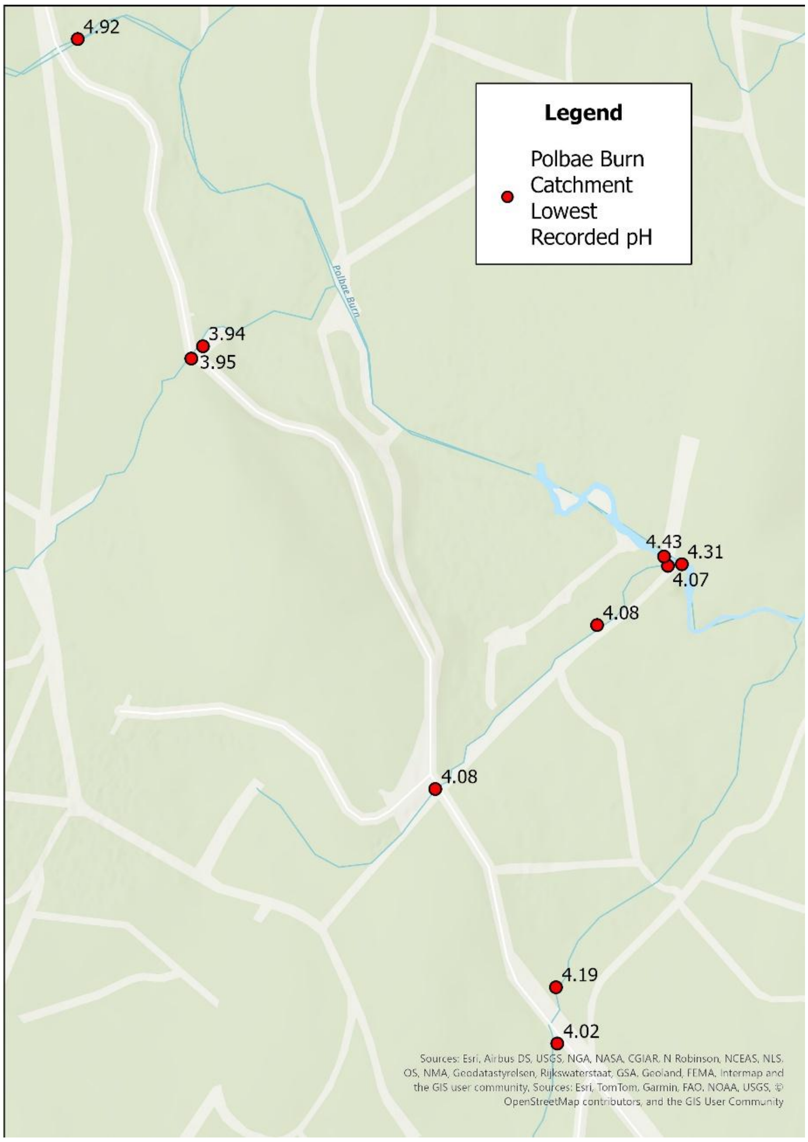
3.1 Spot Sampling

3.1.1 Polbae Burn Catchment

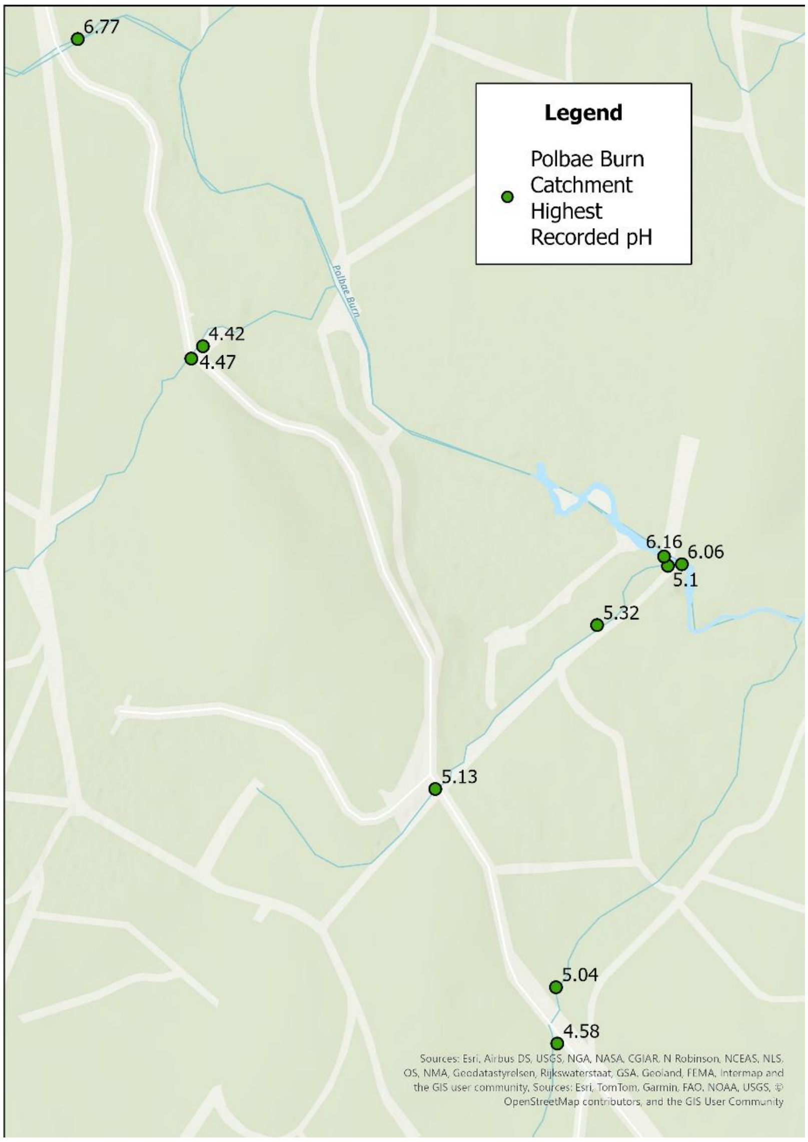
This section outlines the pH results from the baseline spot sampling monitoring carried out within the Polbae Burn catchment. Maps 9 – 11 present the average, lowest, and highest recorded pH collected during baseline spot sampling surveys at all ten sites. Graphs 1 – 13 present the pH and depth results recorded during each sample date at the Polbae Burn catchment monitoring locations, with comparison graphs showing the pH between monitoring locations that fall within the same watercourse. The pH results are graphed alongside the depths recorded during each sample collection to allow observations of how the pH responded to various levels of flow. Appendix 1, section 6.1.1, details the full data collected during each survey and analysis.



Map 9: The average pH recorded during the baseline spot sampling surveys within the Polbae Burn catchment between November 2024 and March 2025



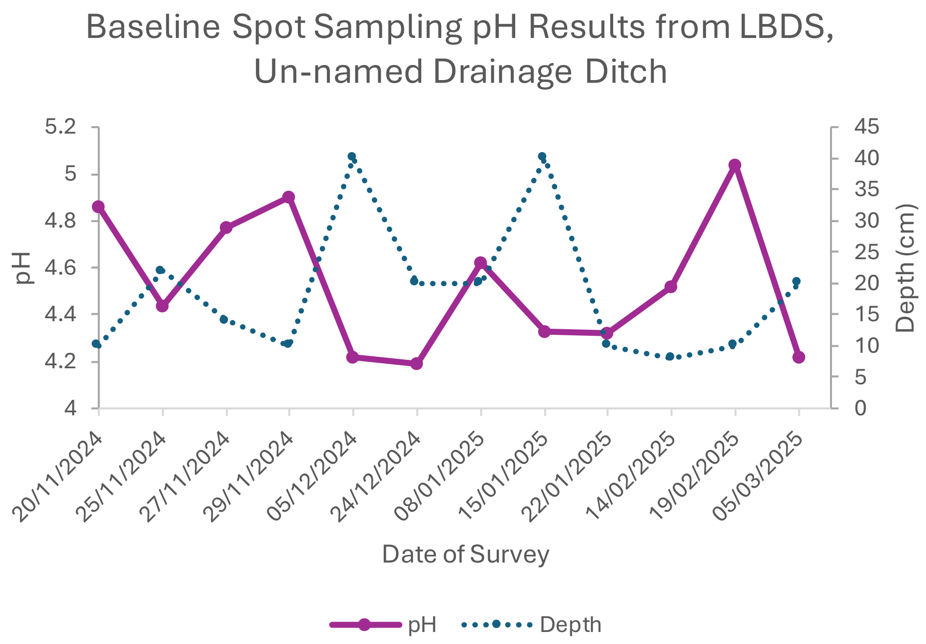
Map 10: The lowest pH recorded during the baseline spot sampling surveys within the Polbae Burn catchment between November 2024 and March 2025



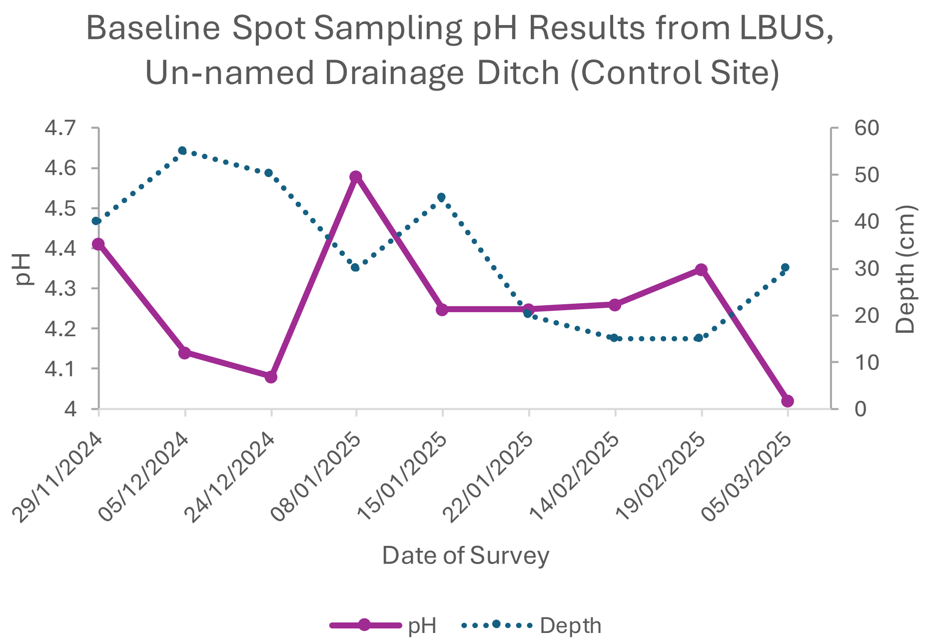
Map 11: The highest pH recorded during the baseline spot sampling surveys within the Polbae Burn catchment between November 2024 and March 2025

Lower Drainage Ditch

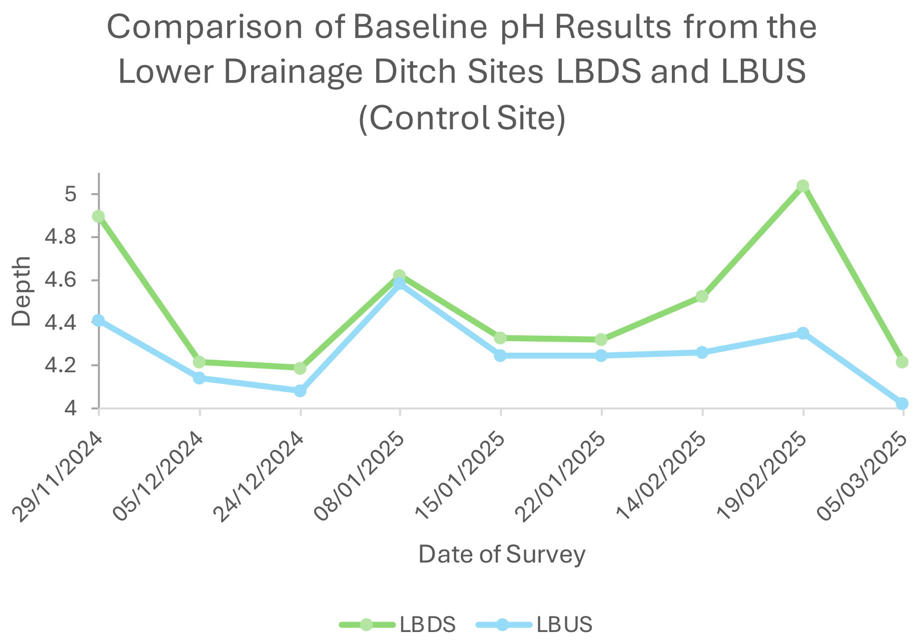
The lower drainage ditch is being monitored as a road only application site with site LBDS falling downstream of the road application area, and control site LBUS upstream of the application area. The ditch drains into the Polbae Burn.



Graph 1: Baseline pH and depth results collected during spot sampling at site LBDS between November 2024 and March 2025. This location is monitoring road only applications



Graph 2: Baseline pH and depth results collected during spot sampling at control site LBUS between November 2024 and March 2025

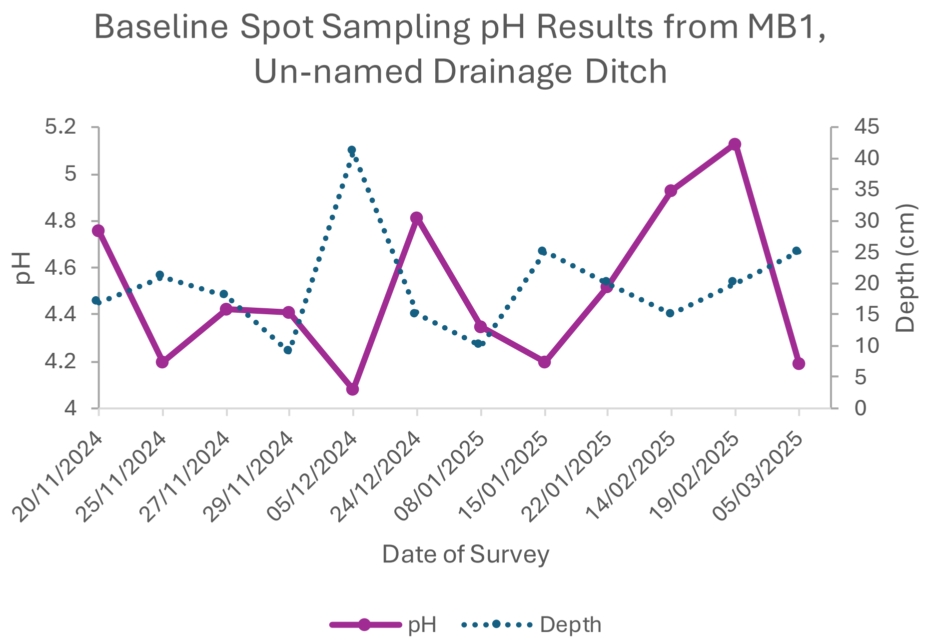


Graph 3: A comparison of the baseline pH results collected from spot sampling on the lower drainage ditch at sites LBDS (downstream of the road applied with shells) and LBUS (control site upstream of the road applied with shells)

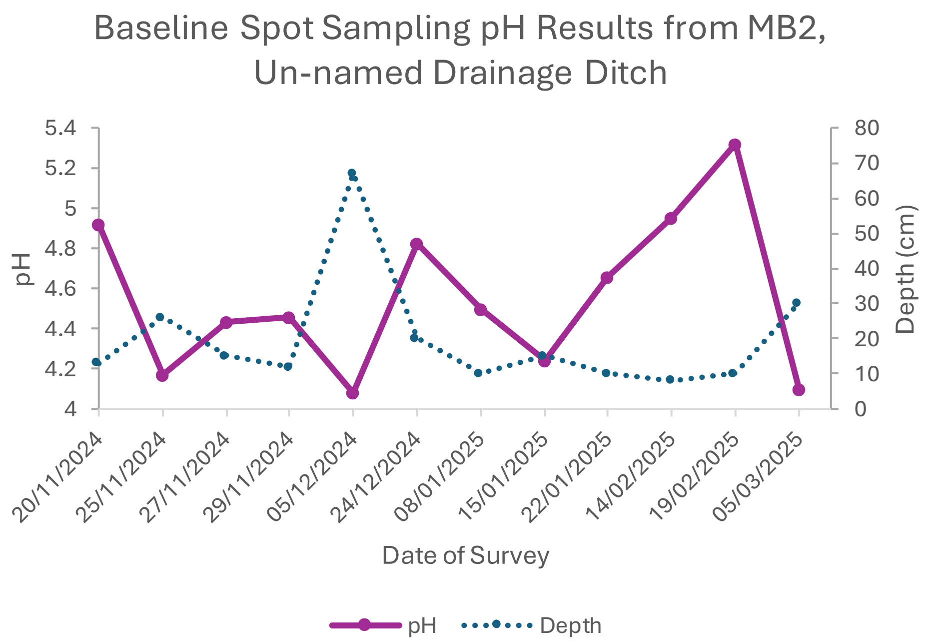
Sites LBDS and LBUS (control) both fluctuated during the baseline spot sampling surveys. Site LBDS fluctuated slightly more with a lowest pH of 4.19 and a highest pH of 5.04 while control site LBUS had a low of 4.02 and a high of 4.58.

Middle Drainage Ditch

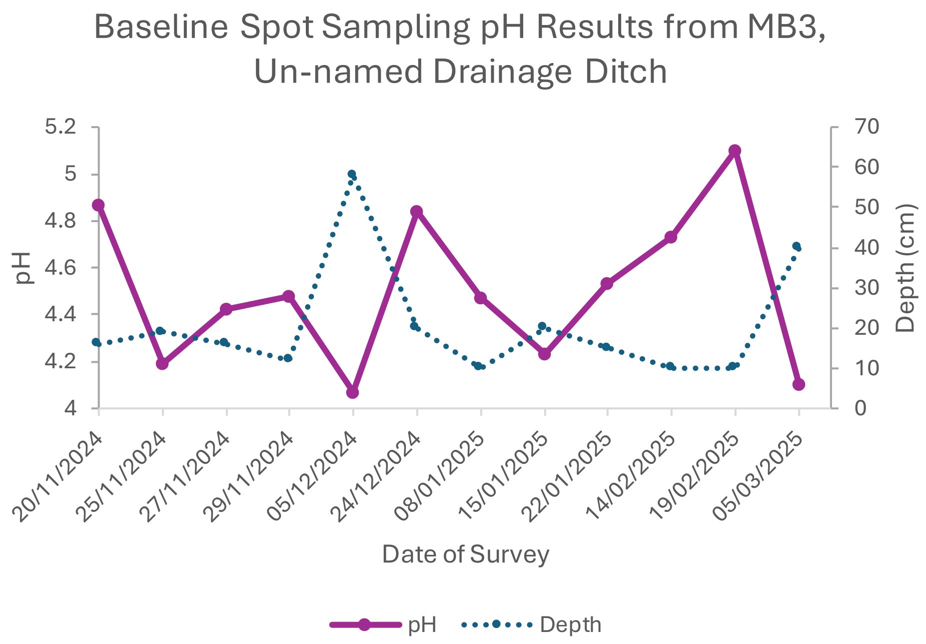
The middle drainage ditch is being monitored as both a road only application site, and a road and instream application site. Site MB1 falls upstream of the culvert and is a road only monitoring site. Downstream of the culvert was treated with instream shell application and includes sites MB2 and MB3. The ditch drains into the Polbae Burn, which includes monitoring site MBDS falling downstream of the ditch inflow and site MBUS which is above the ditch inflow and used as a control site.



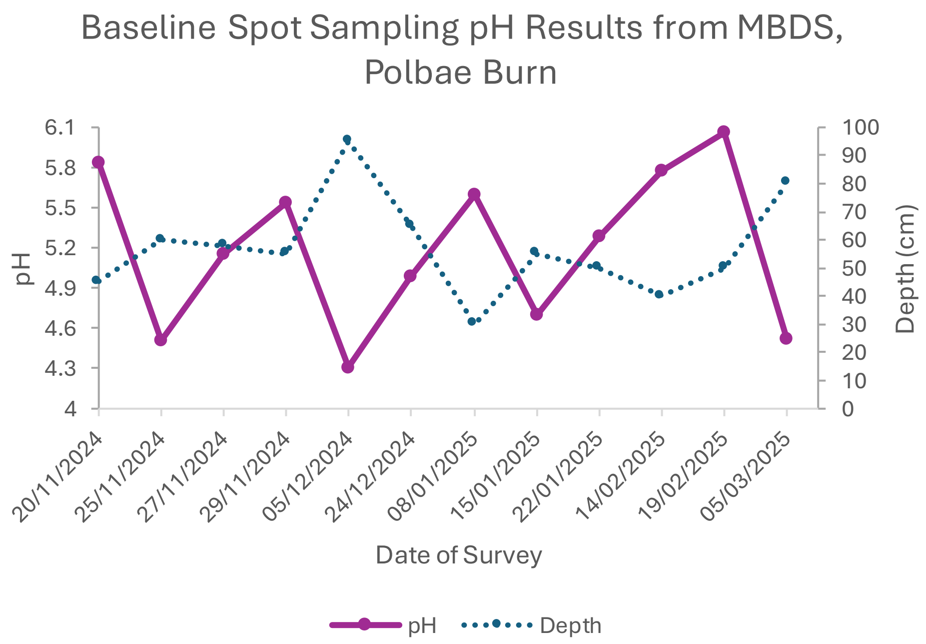
Graph 4: Baseline pH and depth results collected during spot sampling at site MB1 between November 2024 and March 2025. This location is monitoring road only applications



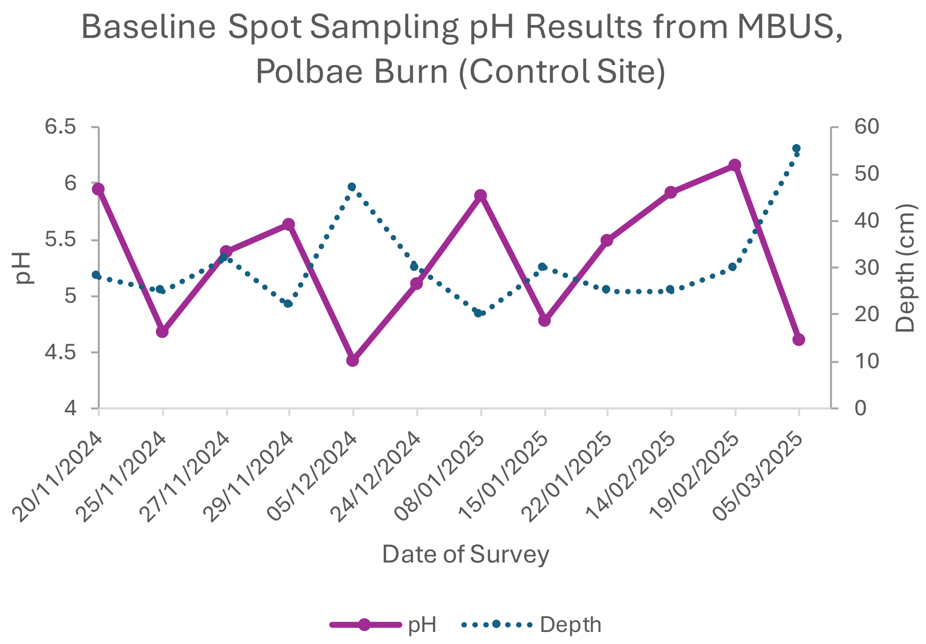
Graph 5: Baseline pH and depth results collected during spot sampling at site MB2 between November 2024 and March 2025. This location is monitoring both road and instream applications



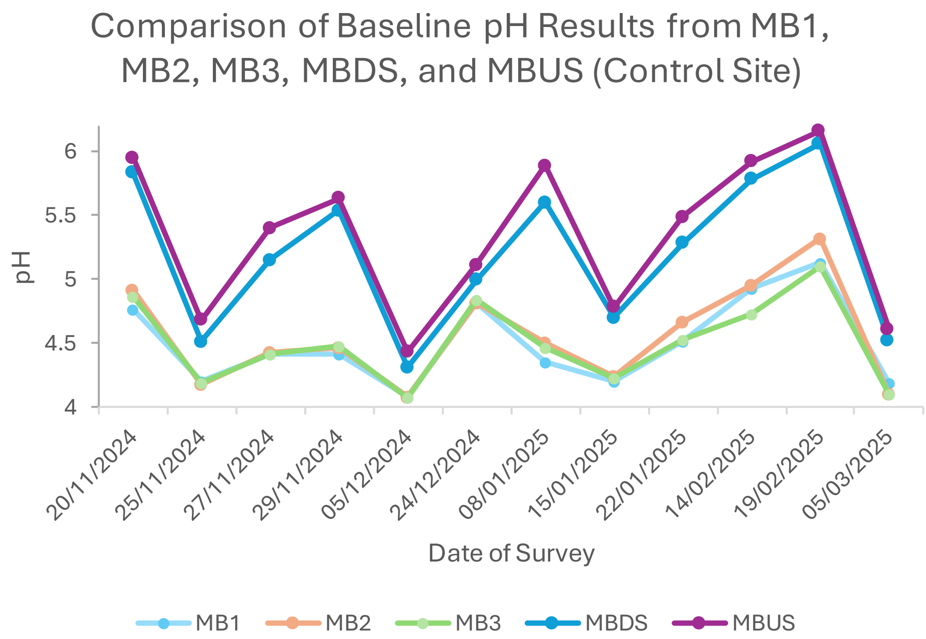
Graph 6: Baseline pH and depth results collected during spot sampling at site MB3 between November 2024 and March 2025. This location is monitoring both road and instream applications



Graph 7: Baseline pH and depth results collected during spot sampling at site MBDS between November 2024 and March 2025. This location is downstream of the middle drainage ditch which was treated with both road and instream applications



Graph 8: Baseline pH and depth results collected during spot sampling at control site MBUS between November 2024 and March 2025. This location is upstream of the middle drainage ditch which was treated with both road and instream applications

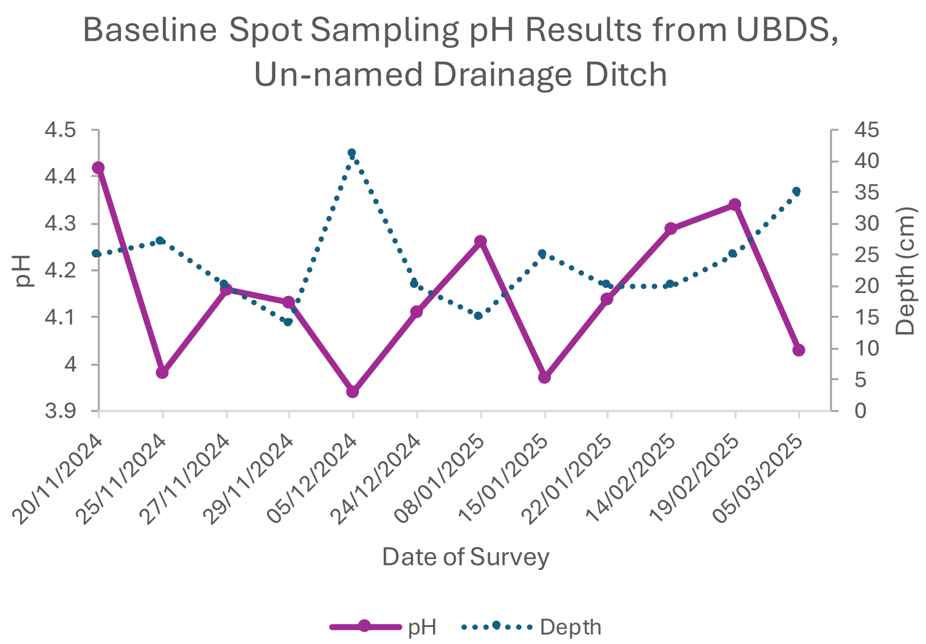


Graph 9: A comparison of the baseline pH results collected from spot sampling on the middle drainage ditch at sites MB1 (road only monitoring site), MB2 (road and instream monitoring site), MB3 (road and instream monitoring site), MBDS (Polbae Burn downstream of the shell treated ditch), and control site MBUS (Polbae Burn upstream of the shell treated ditch)

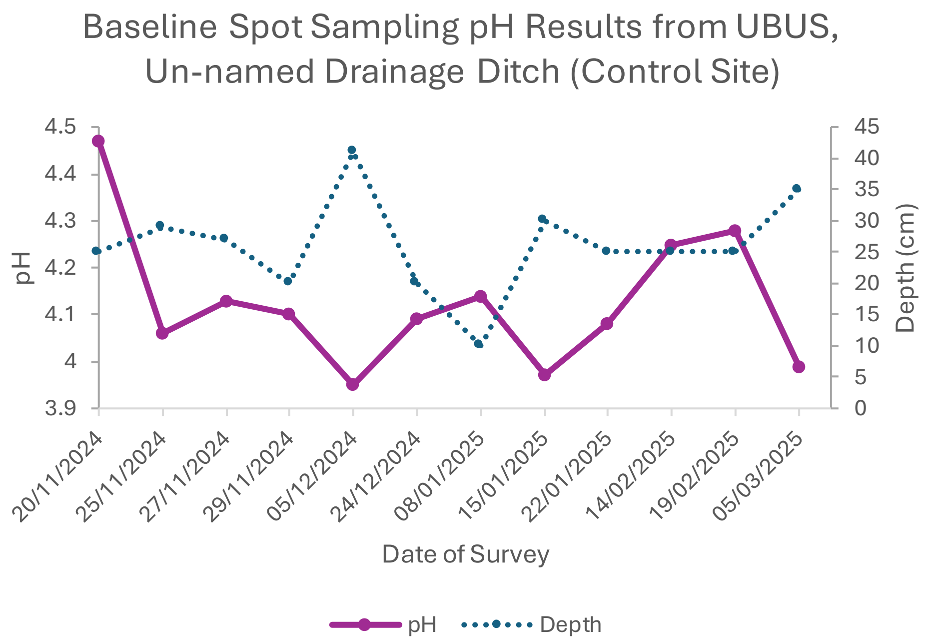
The three sites within the middle drainage ditch (MB1, MB2, and MB3) returned similar pH results during all spot sampling surveys, with a lowest recorded pH of 4.08, 4.08, and 4.07 respectively, and a highest recorded pH of 5.13, 5.32, and 5.1 respectively. Site MBDS (downstream of middle drainage ditch) on the Polbae Burn was slightly more acidic than the control site MBUS (upstream of middle drainage ditch) during all spot sampling surveys. Site MBDS had a lowest recorded pH of 4.31 and a highest recorded pH of 6.06. Site MBUS had a lowest recorded pH of 4.43 and a highest recorded pH of 6.16. The results indicate that the middle drainage ditch reduces the pH immediately downstream in the Polbae Burn by around 0.1 units.

Upper Drainage Ditch

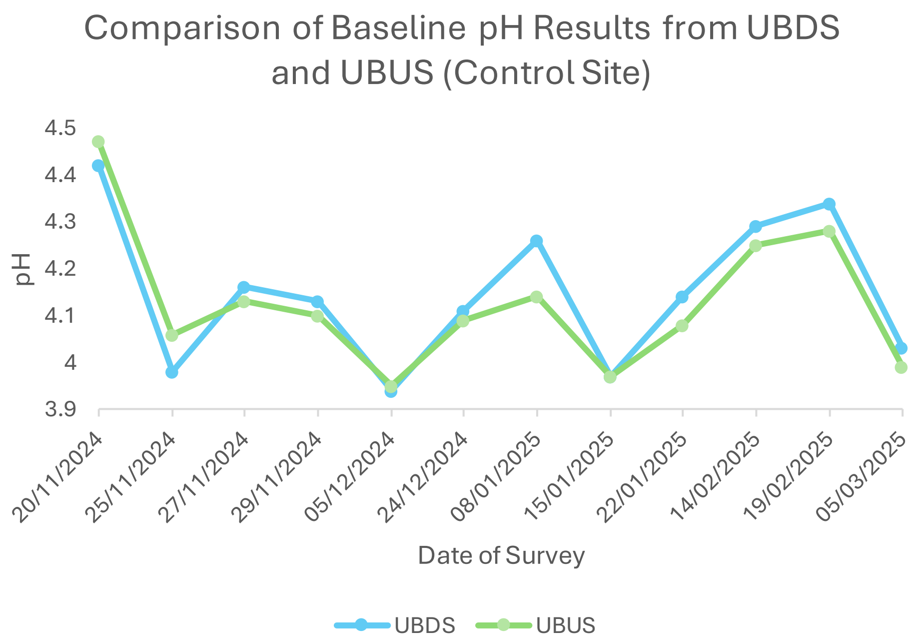
The upper drainage ditch is being monitored as both road and instream application sites. Site UBDS was treated with shells and falls downstream of the road laid with shells. Control site UBUS falls upstream of the road laid with shells. The ditch drains into the Polbae Burn.



Graph 10: Baseline pH and depth results collected during spot sampling at site UBDS between November 2024 and March 2025. This location is monitoring both road and instream applications



Graph 11: Baseline pH and depth results collected during spot sampling at control site UBUS between November 2024 and March 2025

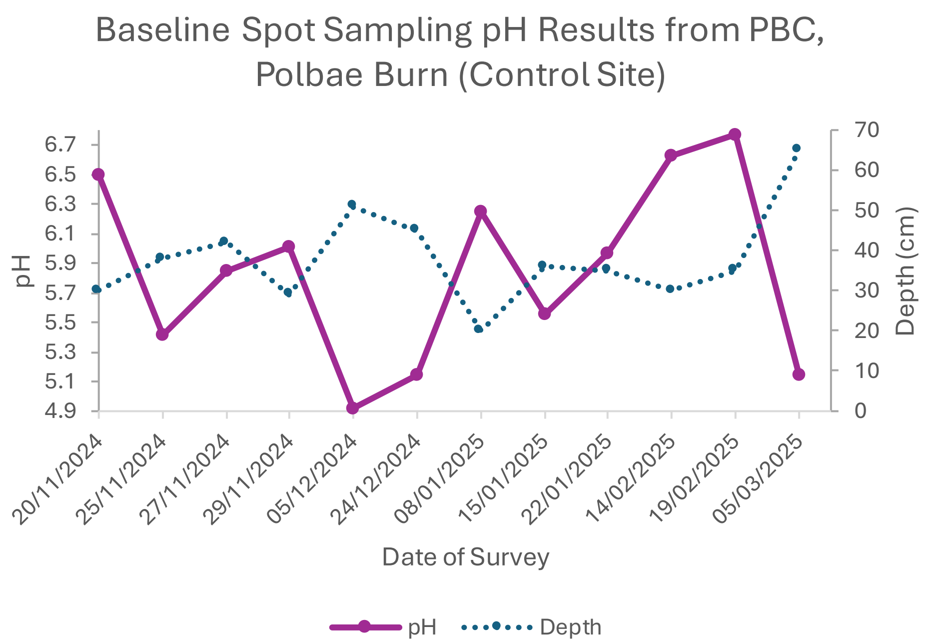


Graph 12: A comparison of the baseline pH results collected from spot sampling on the lower drainage ditch at sites UBDS (watercourse treated with instream shells which is situated downstream of the road applied with shells) and UBUS (control site upstream of the road applied with shells)

The upper drainage ditch sites remained acidified during all spot sampling surveys and returned relatively similar pH results. Site UBDS had a lowest recorded pH of 3.94 and a highest recorded pH of 4.42 while control site UBUS had a lowest recorded pH of 3.95 and a highest recorded pH of 4.47.

Polbae Burn (Control Site)

The Polbae Burn control site (PBC) falls upstream of all shell applications.

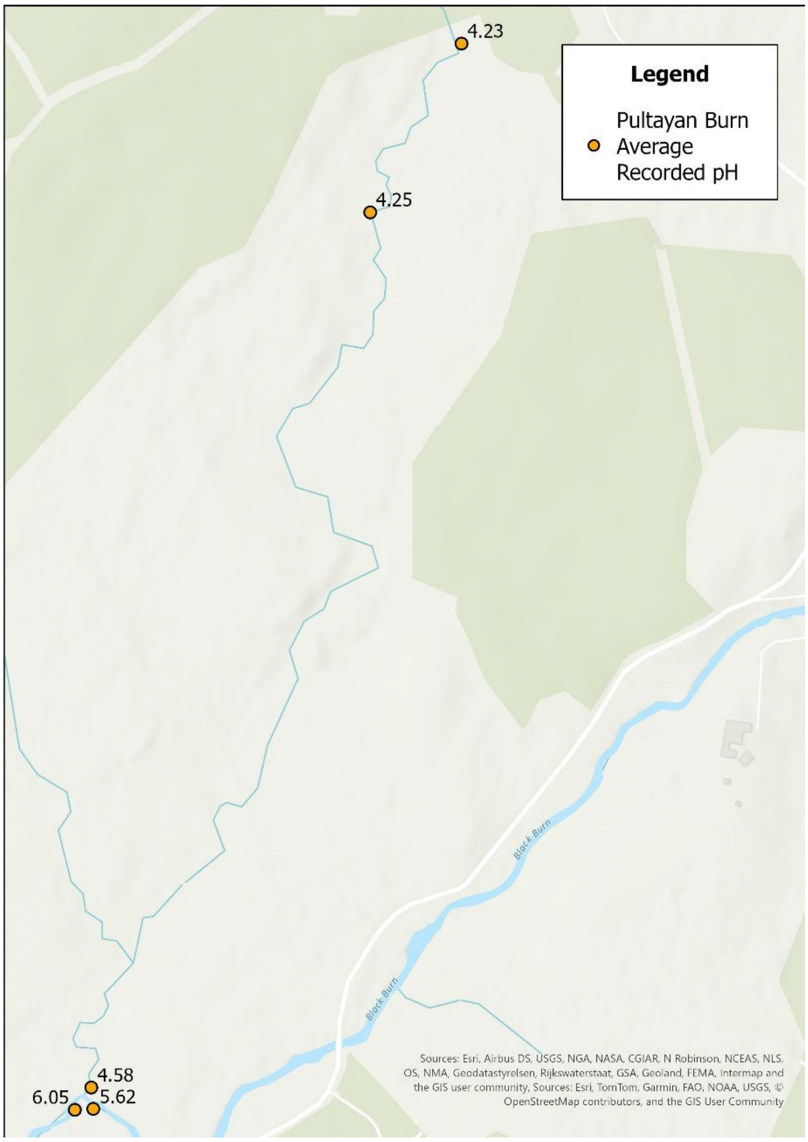


Graph 13: Baseline pH and depth results collected during spot sampling at control site PBC between November 2024 and March 2025. This site is out with all areas of shell applications

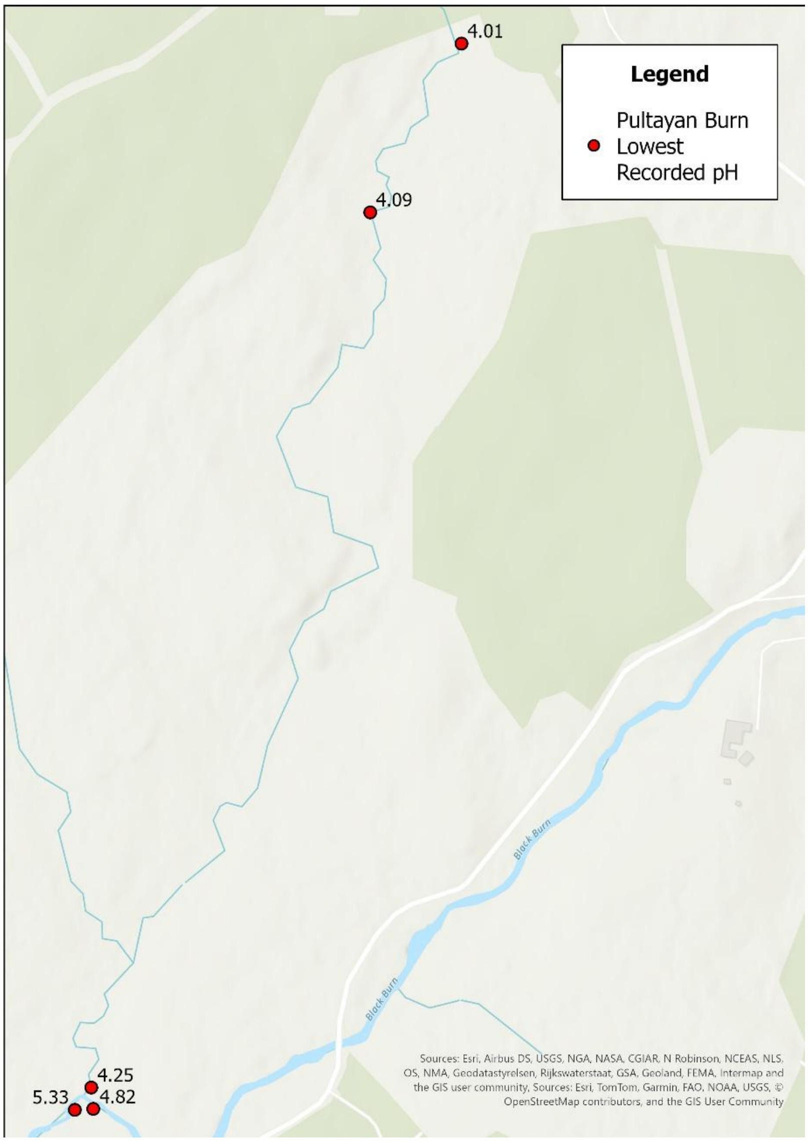
The Polbae Burn control site (PBC) fluctuated during the spot sampling surveys relative to variations in water level, and had a lowest recorded pH of 4.92 and a highest recorded pH of 6.77.

3.1.2 Pultayan Burn

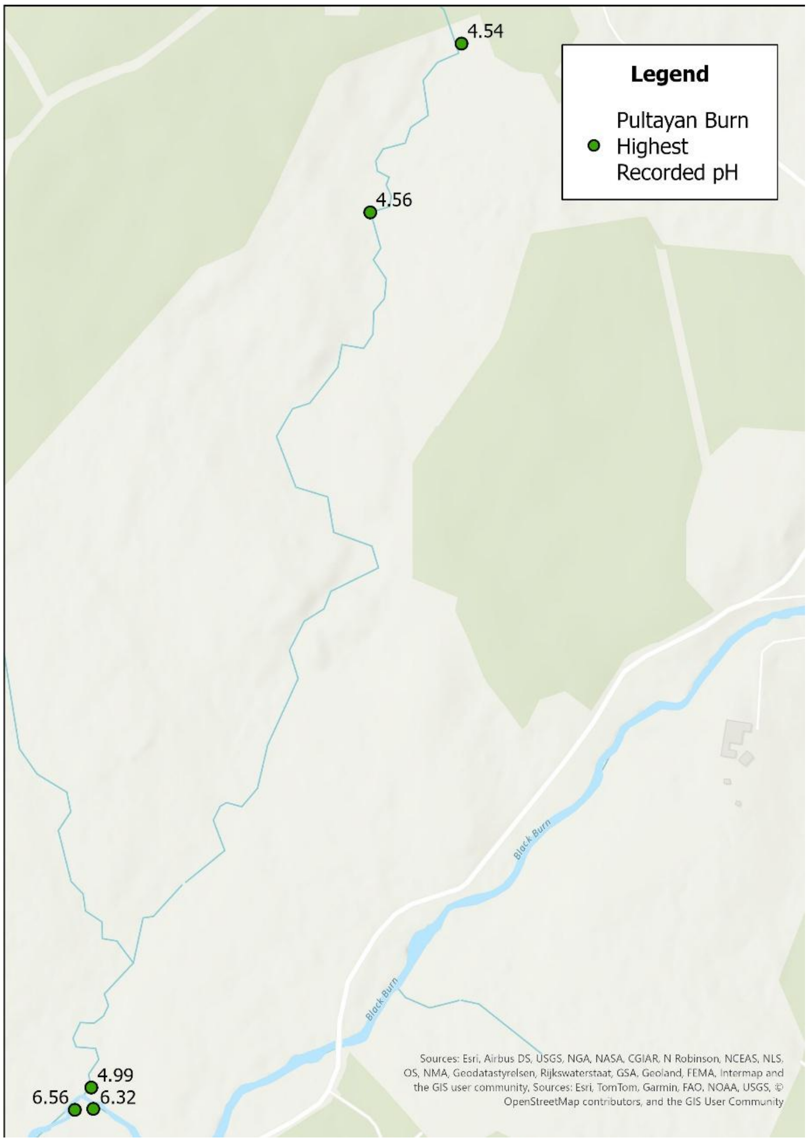
This section outlines the pH results from the baseline spot sampling monitoring carried out within the Pultayan Burn and the Black Burn. Maps 12 – 14 present the average, lowest, and highest pH results recorded during baseline spot sampling surveys at all sites. Graphs 14 - 20 present the pH and depth results recorded during each sample date at the five Pultayan Burn monitoring locations. The pH results are graphed alongside the depths recorded during each sample collection to allow observations of how the pH responds to various levels of flow. All Pultayan Burn sites were surveyed as instream only shell application monitoring locations with no road applications within the catchment. Appendix 1, section 6.1.2, details the full data collected during each survey and analysis.



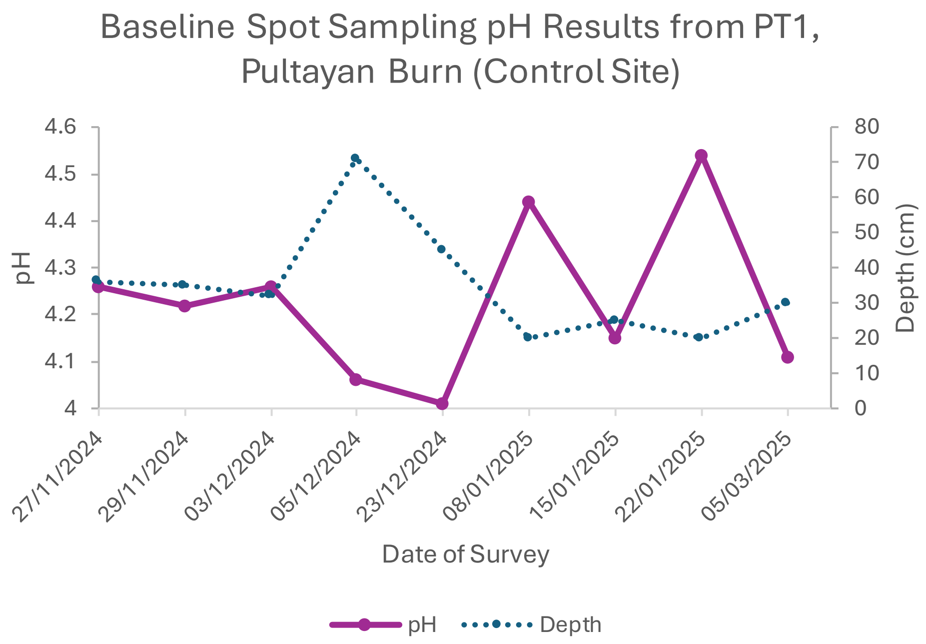
Map 12: The average pH recorded during the baseline spot sampling surveys on the Pultayan Burn and Black Burn between November 2024 and March 2025



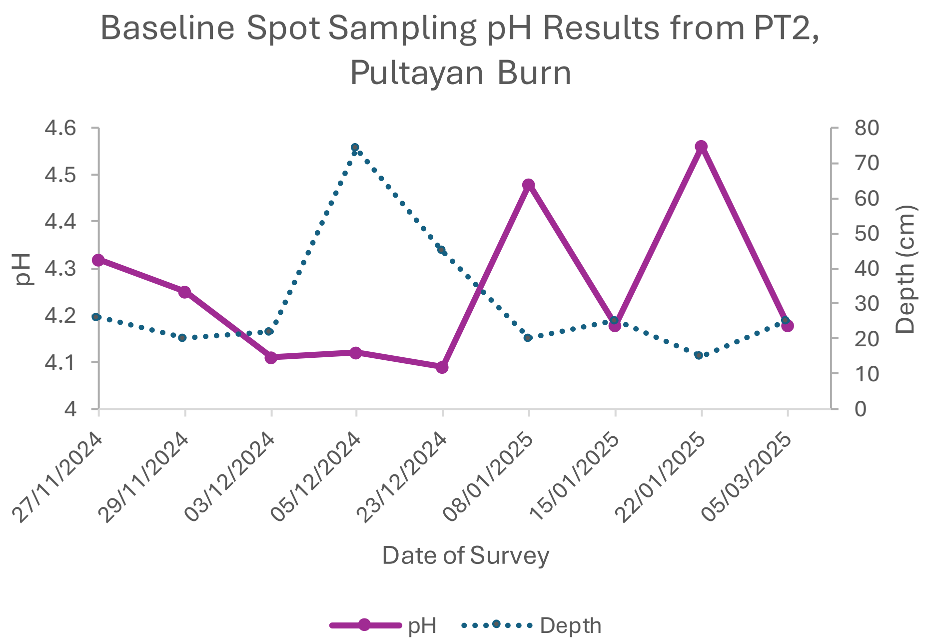
Map 13: The lowest pH recorded during the baseline spot sampling surveys on the Pultayan Burn and Black Burn between November 2024 and March 2025



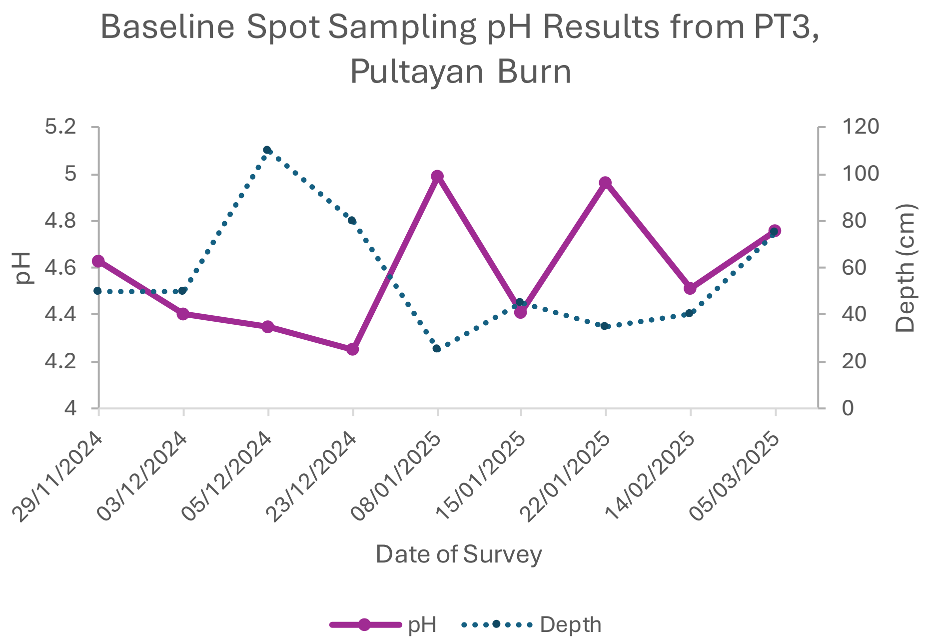
Map 14: The highest pH recorded during the baseline spot sampling surveys on the Pultayan Burn and Black Burn between November 2024 and March 2025



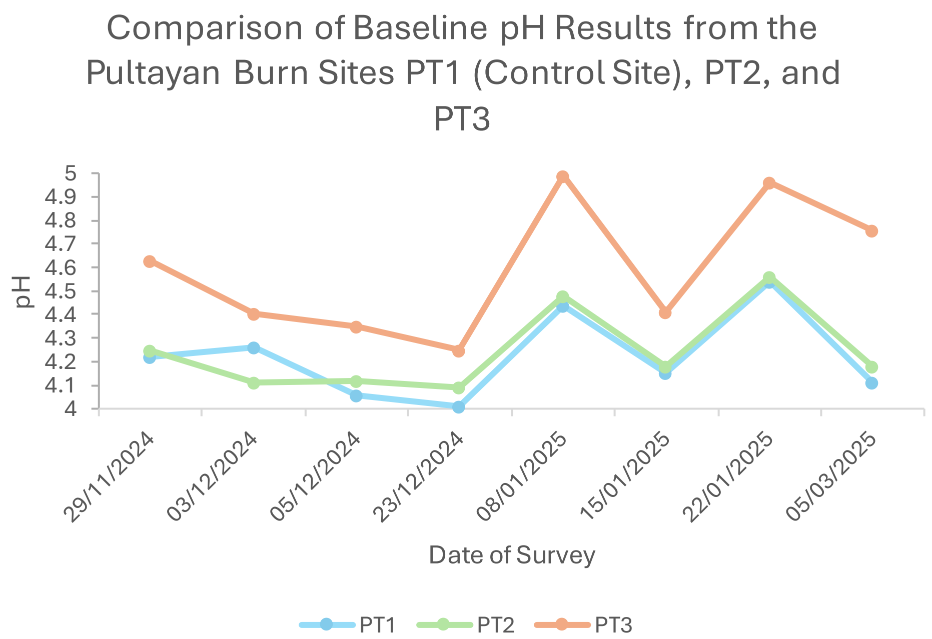
Graph 14: Baseline pH and depth results collected during spot sampling at control site PT1 between November 2024 and March 2025



Graph 15: Baseline pH and depth results collected during spot sampling at site PT2 between November 2024 and March 2025

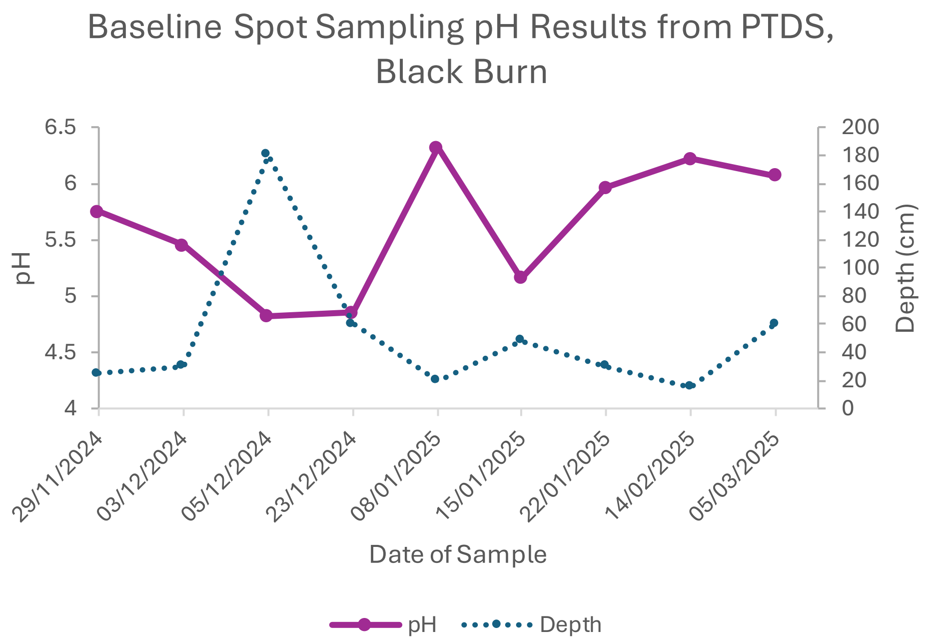


Graph 16: Baseline pH and depth results collected during spot sampling at site PT2 between November 2024 and March 2025

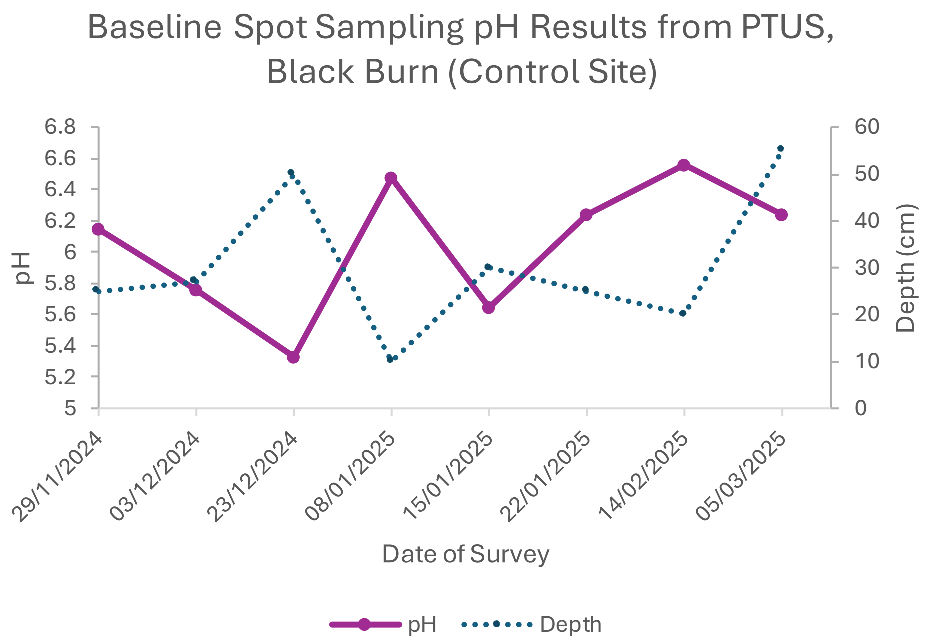


Graph 17: A comparison of the baseline pH results collected from spot sampling on the Pultayan Burn at sites PT1 (control site upstream of shell applications), PT2 (monitoring site within the area of shell applications), and PT3 (monitoring site immediately downstream of shell applications)

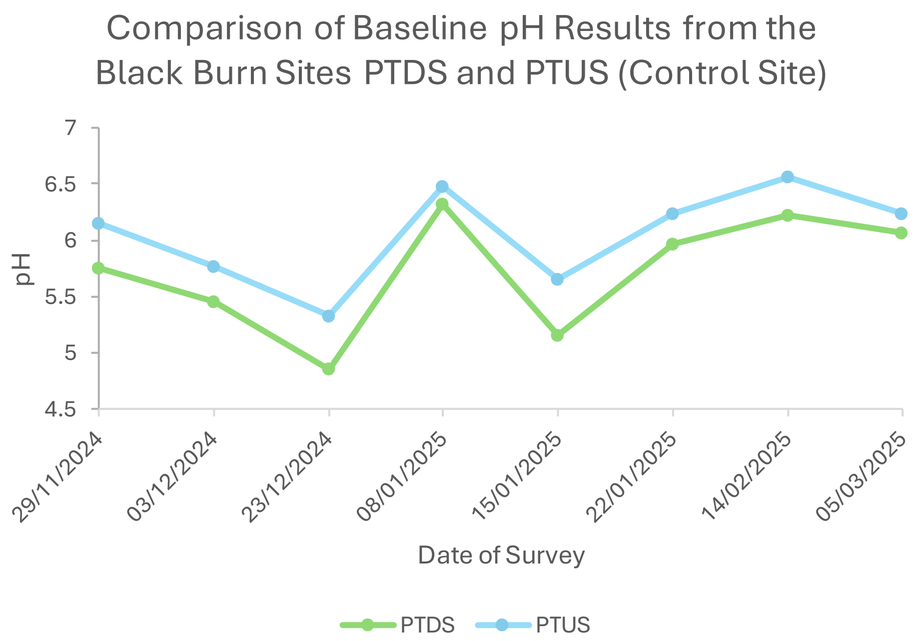
The Pultayan Burn sites remained acidified throughout the baseline spot sampling surveys. Sites PT1 (control) and PT2 returned very similar pH results while PT3 was consistently slightly higher. Sites 1 and 2 had a lowest recorded pH of 4.01 and 4.09 respectively, and a highest pH of 4.54 and 4.56 respectively. Site PT3 had a lowest recorded pH of 4.25 and a highest recorded pH of 4.99.



Graph 18: Baseline pH and depth results collected during spot sampling at site PTDS between November 2024 and March 2025. This site is downstream of the Pultayan Burn which was treated with instream shell applications



Graph 19: Baseline pH and depth results collected during spot sampling at control site PTUS between November 2024 and March 2025. This site is upstream of the Pultayan Burn and out with the area of instream shell applications

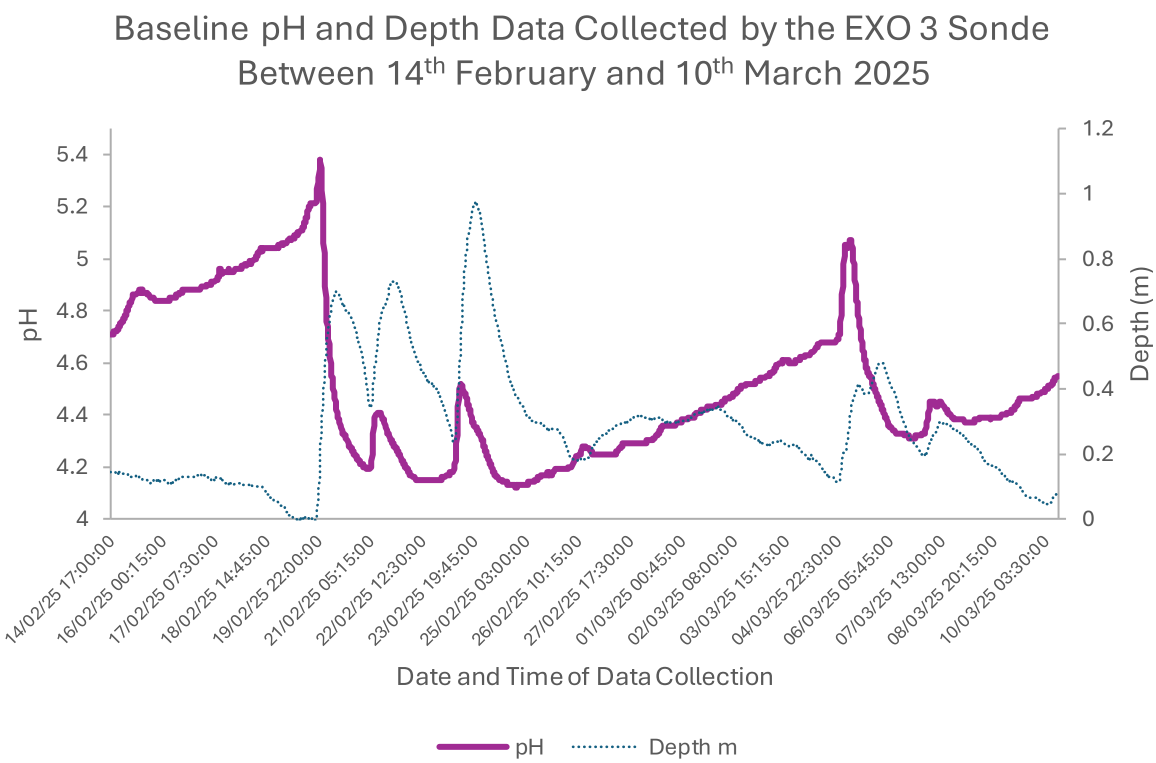


Graph 20: A comparison of baseline pH results collected from spot sampling on the Black Burn at sites PTDS (monitoring site downstream of the Pultayan Burn inflow) and PTUS (control site upstream of the Pultayan Burn inflow)

Sites PTDS and PTUS (control) both fell within the Black Burn. Site PTDS (downstream of the Pultayan Burn) was consistently lower in pH than control site PTUS (upstream of the Pultayan Burn). Site PTDS had a lowest recorded pH of 4.82 and a highest recorded pH of 6.32 while control site PTUS had a lowest recorded pH of 5.33 and a highest recorded pH of 6.56. During periods of high flows, site PTDS was more significantly lower in pH than site PTUS.

3.2 EXO Water Quality Monitoring Sonde

This section presents the baseline pH and depth data collected by the EXO 3 water quality monitoring sonde which was situated within the Pultayan Burn between 14th February and 10th March 2025. The sonde is in place in the lower end of the Pultayan Burn, downstream of the area applied with scallop shells. Data was collected every 15 minutes and Graph 21 details the pH and depth results recorded during the baseline period.



Graph 21: Baseline pH and depth data recorded by the EXO 3 water quality monitoring sonde from the Pultayan Burn between February and March 2025

The EXO 3 water quality monitoring sonde recorded data every 15 minutes from the lower section of the Pultayan Burn. The sonde recorded the lowest pH as 4.13 and the highest pH as 5.38, with an average of 4.51. The fluctuation in pH correlated to fluctuations in depth, with lower water resulting in a higher pH and vice versa. The data suggests that once water levels begins to drop following a period of flooding, the pH recovers slowly.

3.3 Electrofishing Surveys

Baseline electrofishing surveys were carried out in September 2024 at five locations which includes 2 control sites. The data from these surveys can be used as comparisons during future monitoring survey years. This section outlines each site in detail with photographs and habitat survey reports. Table 9 presents the results from each site during the 2024 surveys.

- BP9, Polbae Burn

This site was situated around 30 m downstream of the scallop shell treated drainage ditch (Figure 7).

Instream cover was classed as moderate at this site and depths ranged from <10 – 30 cm. Substrates were primarily large and consisted of boulders (40%) and cobbles (40%), with some pebbles (15%) and gravel (5%). It was noted that the substrates at this site were largely covered in algae and moss, with the river bed having a vegetation cover of 80%. Flows were largely slow moving at this site and consisted primarily of shallow pools (50%), with areas of riffle (30%), and small percentages of run (10%) and shallow glide (10%). Both bankings were 100% bare with no fish cover provided. The surrounding landscape was classed as conifer plantations on moorland heath, with some regen noted to be present on the bankings.

Brown trout fry were present in a very low density (3.78 fish per 100 m^2 of water) and trout parr were present in a low density (2.52 fish per 100 m^2 of water) (Figure 8). Two European eels (145 and 350 mm) and one Northern pike (215 mm) were also present.

Figure 7: Site BP9 on the Polbae Burn, looking upstream

Figure 8: Brown trout adult (top fish) and trout fry (bottom two fish) caught in BP9

- BPU1, Un-named Drainage Ditch

This site was located within the upper drainage ditch which was applied with scallop shells (Figure 9).

Instream cover was moderate at this site and depths ranged from 11 – 50 cm. Substrates were mixed at this site and consisted of pebbles (35%), cobbles (30%), gravel (25%), and boulders (10%). Flows consisted primarily of run (40%) and riffle (40%) with some deep pools (10%), shallow pools (5%), and shallow glide (5%). Both banks were 100% bare with no fish cover provided. The surrounding landscape was classed as conifer plantations on moorland heath and it was noted that there was conifer regen growing on the upper half of the left bankside. This site was noted as being unsuitable to support fish but was surveyed as a fully quantitative site to confirm the absence of fish and to include as an invertebrate monitoring site. Downstream of this site has several blockages caused by felled conifers left over the water which prevent fish access to this watercourse. It was also noted that this was the only section of this watercourse to have any substrates present, with the river bed in the downstream section consisting entirely of peat.

Fish were absent from this site.

Figure 9: Site BPU1 on the un-named drainage ditch, looking upstream

- BBLP2, Pultayan Burn

This site was situated upstream of the fence, within the area of the Pultayan Burn being treated with scallop shells (Figure 10).

Instream cover was classed as moderate at this site and depths ranged from <10 – 30 cm. Substrates were primarily large at this site and consisted of cobbles (40%) and boulders (35%) with some pebbles (15%) and gravel (10%). It was noted that there was a lack of spawning substrates available at this site. Flows consisted of shallow glide (50%) and run (40%) with some riffle (10%). Both banks had 20% of fish cover provided by areas of undercut and draped vegetation. The surrounding landscape was classed as improved grassland and it was noted that the right bankside had dead ash trees along it.

Brown trout parr were present in a low density (4.57 fish per 100 m^2 of water) (Figure 11). One European eel (300 mm) and one Northern pike (99 mm) were also present.

Figure 10: BBLP2 on the Pultayan Burn, looking upstream

Figure 11: Brown trout parr caught in BBLP2

- BP3, Polbae Burn (Control Site)

This site was located upstream of the culvert (Figure 12).

Instream cover was classed as good at this site and depths ranged from <10 – 40 cm. Substrates consisted primarily of boulders (45%) and cobbles (40%) with some pebbles (10%) and gravel (5%). Flows consisted almost entirely of run (70%) with some riffle (30%). The left bank had 15% of fish cover, and the right bank had 20% of fish cover, both provided from areas of undercuts and rocks embedded in the bankings. The banks were noted as being densely covered in ferns. The surrounding landscape was classed as improved grassland and conifer plantations, with the plantations being noted as being well back with a good buffer zone.

Brown trout fry were present in a high density (26.83 fish per 100 m^2 of water) and trout parr were present in a low density (2.98 fish per 100 m^2 of water) (Figure 13).

Figure 12: Control site BP3 on the Polbae Burn, looking upstream

Figure 13: Brown trout parr (top fish) and trout fry (bottom five fish) caught in BP3

- BBE1, Beoch Burn (Control Site)

This site was located upstream of the bridge at Knowe Village (Figure 14).

Instream cover was classed as good at this site and depths ranged from <10 – 50 cm. Substrates were mixed and consisted of cobbles (40%), boulders (20%), pebbles (20%), gravel (15%), and sand (5%). Flows consisted primarily of run (70%) with some riffle (20%) and shallow glide (10%). The left bank had 5% of fish cover provided by rocks embedded in the banking, and the right bank had 20% of fish cover provided by marginal vegetation. The surrounding landscape was classed as a broadleaf woodland which was noted as providing a good amount of shade to the watercourse.

Atlantic salmon were present in a high density (27.91 fish per 100 m^2 of water) and salmon parr were present in a very low density (1.99 fish per 100 m^2 of water). Brown trout fry were present in a low density (11.96 fish per 100 m^2 of water) and trout parr were present in a very low density (1.99 fish per 100 m^2 of water) (Figure 15). One European eel (350 mm) was also present at this site.

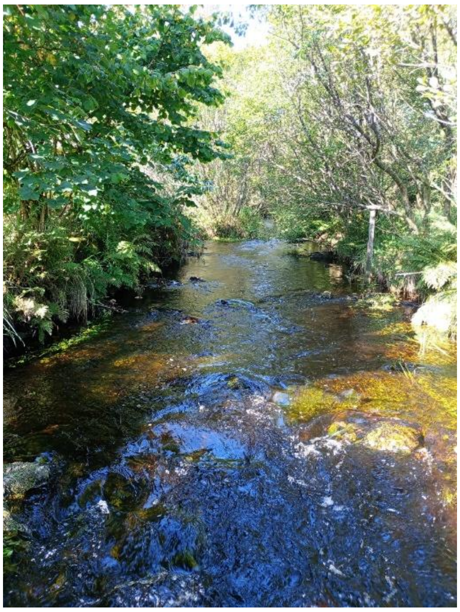


Figure 14: Control Site BBE1 on the Beoch Burn, looking upstream

Figure 15: Atlantic salmon parr (top fish), Brown trout fry (2nd and 3rd fish from the top), and Atlantic salmon fry (bottom four fish) caught in BBE1

Table 9: Electrofishing Results from the 2024 Baseline Surveys (Results are Presented as a Minimum Density Estimate of the Number of Fish per 100 m^2 of Water)

Site	Grid Reference	Date Surveyed	Atlantic salmon Fry	Atlantic salmon Parr	Brown trout Fry	Brown trout Parr	Other Fish Species Present
BP9, Polbae Burn	227369 572176	27/09/2024	0	0	3.78	2.52	Eel (2), Pike (1)
BPU1, Un-named Ditch	226782 572528	29/10/2024	0	0	0	0	0

BBLP2, Pultayan Burn	228990 567202	01/10/2024	0	0	0	4.57	Eel (1), Pike (1)
BP3, Polbae Burn (Control)	226531 572898	10/09/2024	0	0	26.83	2.98	0
BBE1, Beoch Burn (Control)	231413 571332	06/09/2024	27.91	1.99	11.96	1.99	Eel (1)

3.4 Invertebrate Sampling

Invertebrate samples were collected immediately upstream of the five electrofishing sites, therefore the site descriptions, photographs, and habitat surveys presented within the electrofishing results section (section 3.3) remain the same. This section details the results of the invertebrate sample analysis and presents the RICT and biotic index ratings for each site. Table 10 presents the analysis results and Table 11 presents the water quality ratings for the results. Appendix 3 details the full invertebrate results from each sample collected in 2024.

Table 10: Results from the RICT and Biotic Index Analysis on the 2024 Invertebrate Samples

Site	RICT ASPT	RICT NTAXA	AWIC	PSI
BP9	0.94	1.01	3.9	75
BPU1	0.9	0.84	3.3	69.6
BBLP2	1.01	0.67	3.3	75
BP3 (Control)	0.92	0.91	4.1	87.5
BBE1 (Control)	1.08	0.76	4.1	80

Table 11: Water Quality Ratings for the RICT and Biotic Index results from Table 10

Site	RICT ASPT (Water Quality Rating)	RICT NTAXA (Water Quality Rating)	AWIC (Mean pH)	PSI (Level of Sedimentation)
BP9	Good	High	6.6	Slight
BPU1	Good	High	6.22	Slight
BBLP2	High	Poor	6.4	Slight
BP3 (Control)	Good	High	6.98	Minimal/None
BBE1 (Control)	High	Good	6.98	Slight

4. Discussion

The scallop shell monitoring surveys will be repeated for a minimum of five years post-application works and compared to the baseline results outlined in this report. This will allow for any potential changes to water quality and/or fish and invertebrate communities post-application to be highlighted. Monitoring results can then be compared to the control sites to determine whether any changes are a result of the scallop shell applications or due to external causes. The use of control sites will allow for year to year comparisons to be more accurate, as differences in yearly weather have a great impact on the variation of pH within watercourses i.e. wetter years cause longer depressions of pH than drier years. The control sites will remove this bias by providing insight into how the watercourses would have responded during each year without the shell applications.

The American study which guided this project showed the potential for clam shells to effectively mitigate acidification under base flow conditions. The study suggested that the shells are less effective during periods of higher flow due to the reduced contact time of the shells with the water, but that the pH in the treated watercourses recovered faster than prior to the shell applications. It was suggested that, while instream applications of seashells can have a positive impact on pH, that terrestrial applications may further support the instream applications to have a longer term impact (Whiting, 2014).

The American study was limited by testing instream only applications and it lacked control sites, meaning the results may have been impacted by different weather conditions between the post-application years. The River Bladnoch Scallop Shell Project is testing the efficiency of instream only applications, road only (terrestrial) applications, and both instream and road applications with the use of control sites included. This will give insight into if each application type impacts the surrounding water quality, and if a combination of both application methods is more impactful on the water quality. If the results are positive they may be used to guide future projects. This project uses various monitoring methodologies to accurately identify any potential changes to water quality that may arise during the post-application surveys.

4.1 Terrestrial and Instream Applications

Terrestrial and instream applications of scallop shells were undertaken in March, April, and May 2025 around the Polbae Burn catchment (road and instream) and the Pultayan Burn (instream only). A total of 692.3 tonnes of shells were used for this project.

4.1.1 Terrestrial Applications

In total, 680 tonnes of crushed king scallop shells were laid along forest tracks at 50 – 75 mm deep.

During the road application works, it was observed that the finer the crushing of the shell, the more shells could be laid along the tracks. It was originally thought that the roads would only need one coating of shells from the spreader, however following vehicle access to the site, the roads actually required several layers of crushed shells.

Visual surveys will be undertaken during visits to the site for other monitoring purposes, with depths taken from selected spots to assess whether the depth of shells decreases over time following vehicle access to the area and heavy rainfall. It is unclear whether shells will dissolve on the roads as, unlike the instream applicated shells, they will not have constant contact with water. The only time the roads applied shells would be in contact with water would be during precipitation (rain). It is assumed that the shells would dissolve, albeit very slowly and likely over several years or even decades. This would possibly be quickened due to the shells being crushed and therefore having more surface area to be impacted by the acid rain. Future visual surveys will give insight into how the road applied shells react to the environment and weather conditions.

The Tannylaggie Forest, in which the crushed king scallop shells are applied, is set to be harvested during 2025 and 2026. This means that the roads applied with shells will be regularly driven over by both regular vehicles and heavy machinery which will further crush and compact the shells. Road section B, which received 104 tonnes of crushed king scallop shells, is near the main entrance to the forest and is the main access route into this area and therefore will be driven over at a much higher rate than section A. One part of road section A is a dead end T junction which is likely to remain unused by machinery which will allow a comparison on how the shells crush and compact between unused, lightly used, and regularly used tracks. The depths of the three road sections can be compared periodically to give insight into how much, if any, depth is lost due to regular vehicle access.

4.1.2 Instream Applications

In total, 12.3 tonnes of shells were placed by hand into watercourses between March, April, and May 2025. The shells will be visually monitored during spot sampling surveys to assess dissolution and potential downstream migration.

In the forest drainage ditches, mesh screens were placed which block shells from leaving the watercourses. This will give insight into whether shells move downstream and potentially would have left the watercourse, as shells will build up behind the screens if they move downstream in large quantities. In the event of the shells being observed significantly build up behind the screens, mitigation efforts will take place to remove the shells. The Pultayan Burn is unable to be blocked off due to this being a watercourse that fish access. However, the bottom section of the Pultayan Burn is a deep, non-moving pool which would show shell accumulation. The shells were not placed into this section of the Pultayan Burn so if several shells are observed in the bottom section then mitigation efforts will take place to remove the shells.

4.2 Spot Sampling

Baseline spot sampling began in November 2024 and surveys were conducted 3-4 times per month until March 2025 when the scallop shell application works began. Spot samples, which are usually collected following periods of high flows to target acid flushes, were undertaken randomly and during all levels of flow to remove the bias of only targeting known periods of lower pH. This gave insight into the water quality of each watercourse during all possible weather conditions and flow levels. The results showed that, overall, the watercourses selected for monitoring remained acidified even during long periods of winter low flows. During high flows following periods of heavy rainfall, the results dropped to pH levels that pose serious risks to fish health.

4.2.1 Polbae Burn Catchment

The Polbae Burn catchment includes ten spot sampling locations, four of which are control sites. The spot sampling locations include two road application only monitoring sites and four instream and road application monitoring sites. Post-monitoring surveys can be used to compare each application type against each other and test the efficiency of each technique separately i.e. road only applications against instream only applications (Pultayan Burn). The efficiency of both techniques separately can also be compared with both techniques used together to assess whether a combination of the techniques has a greater impact.

The baseline spot sampling within the Polbae Burn catchment indicates that the drainage ditches are persistently acidified even during periods of low flow. This is having an impact on the Polbae

Burn where the ditches drain into, often lowering the pH to dangerous levels for fish and invertebrate health. The drainage ditches that have been tested during the spot sampling are unsuitable for supporting fish and therefore the low pH within the ditches are not impacting on any fish communities, however the concern lies downstream of the ditches where the acidification is impacting the Polbae Burn.

The spot sampling locations within the Polbae Burn catchment were selected to monitor both road only shell applications (the lower burn sites and site MB1 on the middle burn) and a combination of road and instream shell applications (the remaining middle burn sites and the upper burn sites).

4.2.2 Pultayan Burn

The spot sampling locations on the Pultayan Burn are monitoring instream only shell applications. The baseline spot sampling results collected from sites PT1 (control), PT2, and PT3 indicate that the Pultayan Burn is impacted by persistent acidification during the winter season. Sites PT1 (control) and PT2 are located within the upper accessible section of the Pultayan Burn, and directly downstream of where it flows through a heavily drained and degraded peatland with a mature old style conifer plantation on it. Site PT1 (control) and PT2 have a consistently lower pH than site PT3, which is located at the bottom of the Pultayan Burn, where it has flown through healthier, unacidified grassland for a significant distance meaning the acidification gets slightly diluted. However, site PT3 was still very acidified and unsuitable for spawning due to the consistently low pH. Control site PT1 is immediately upstream of the instream shell application area and can be used as a direct comparison to sites PT2 and PT3. If the pH changes at sites PT2 and PT3 but is significantly lower at control site PT1, it can be assumed that the change in pH is a result of the instream shell application. Site PT2 falls within the area being treated with scallop shells, and site PT3 falls downstream of the area being treated with scallop shells. This will give insight into how any changes to pH affect areas directly treated and if the impacts also affect downstream.

Sites PTDS and PTUS (control) fall within the Black Burn and can be used to monitor whether any changes in pH within the Pultayan Burn may affect the Black Burn. Site PTDS is immediately downstream of the Pultayan Burn confluence and site PTUS (control) is immediately upstream the confluence. Site PTDS is consistently lower than control site PTUS (control) which indicates that the Pultayan Burn is having a localised acidification impact on the Black Burn. Sites PTDS and PTUS (control) can be directly compared to observe if any changes in pH may arise to the Black Burn downstream of the Pultayan Burn confluence following the scallop shell treatment.

4.3 EXO Water Quality Monitoring Sonde

The EXO 3 water quality monitoring sonde is in place immediately downstream of where shells were placed into the Pultayan Burn. The baseline data collected between 14th February and 10th March 2025 recorded the lowest pH as 4.13 and the highest pH as 5.38, with an overall average pH of 4.51. Atlantic salmon eggs begin to undergo delayed hatching at a pH of 5.5 or less. A Canadian study (Farmer, 2000) estimated that at a pH of 4.7, Atlantic salmon eggs face the LL50 (the lethal limit at which 50% of eggs fail to hatch), with total prevention of egg hatching often occurring between pH 4 and 4.2. Furthermore, the low pH in watercourses increases the toxicity of toxic metals, particularly labile aluminium, with the same study observing a 70.8% mortality rate of Atlantic salmon fry over a 53 day period within a watercourse of pH 4.96 (Farmer, 2000). For parr aged Atlantic salmon, the pH at which mortality rates are high is estimated to be 4.7, with a study showing a 100% mortality rate when Atlantic salmon parr were exposed to pH 4.7 for 54 days (Lacroix and Townsend, 1987).

The Pultayan Burn sonde recorded data a total of 2,282 times during the baseline period, with all recordings being below a pH of 5.5, which is the pH at which eggs begin to experience delayed hatching. Of the 2,282 recordings, only 193 were at or above a pH of 5, with 2,089 of the recordings below a pH of 5. 1,703 recordings were at or below a pH of 4.7, which is the estimated pH of the LL50, and 334 were below pH 4.2, which is the estimated pH at which eggs undergo total recruitment failure. During the baseline period, the Pultayan Burn was at a pH within the 50% lethal limit for salmon eggs 59.99% of the time, and at a pH that induces total egg loss 14.64% of the time. Combined with the spot sampling results, it can be assumed that these limits persist during all winter months and throughout the salmonid spawning season. Within the River Bladnoch catchment, Atlantic salmon eggs hatch between January and February meaning that the Pultayan Burn remains at a toxic pH level during the most crucial months for juvenile salmonids.

The persistent low pH of the Pultayan Burn means that labile aluminium will also be a huge risk to fish health. The sonde recorded a pH at or below 4.96 a total of 2,055 times during the baseline period, which is the estimated pH at which Atlantic salmon fry begin to face high mortality rates when exposed for long periods of time. This means that the Pultayan Burn was at or below this limit 90.05% of the time during the baseline period and with the spot sample results it can be assumed that labile aluminium poses a risk during all of winter. However, the 4.96 pH limit for labile aluminium was estimated for Atlantic salmon fry, which do not presently exist within the Pultayan Burn. Post-application monitoring will inform on whether the pH remains a concern for Atlantic salmon fry in the Pultayan Burn if future spawning becomes possible. The electrofishing surveys in September 2024 showed no indication of fry aged salmonids being present within the Pultayan Burn. It is unclear whether the burn is acidified year round and preventing the upwards migration and survival of fry aged fish from the Black Burn. Post-monitoring surveys will provide insight into this.

Only Brown trout parr were present during the electrofishing surveys, with Brown trout generally facing the same stressors and pH limits as Atlantic salmon. The pH level of the Pultayan Burn remained highly toxic over winter for parr aged fish, with 74.62% of the baseline period falling at a pH of 4.7 or below, which is the estimated pH at which parr aged Atlantic salmon begin to experience high mortality rates during long-term exposure. Due to the movement that parr-aged salmonids undergo, it is difficult to say whether the Pultayan Burn induces mortality within the Brown trout parr population residing in the burn. Parr are likely to move around a watercourse and into the surrounding watercourses, therefore they may not reside within the Pultayan Burn long enough to experience mortality due to aluminium toxicity arising from the persistent low pH. However, the low pH remains a concern and future electrofishing surveys can determine whether an improved pH in turn improves the fish population within the Pultayan Burn.

Overall, the EXO 3 water quality monitoring sonde data shows that the winter pH within the Pultayan Burn poses a persistent and severe risk to the health of salmonids during all life stages, both directly due to acidification and indirectly due to increased toxicity of labile aluminium. The sonde and the spot sampling results (when compared to the control sites) will show any changes to the pH during the post-application monitoring. This will give insight into whether the instream application of scallop shells can improve a low pH and in turn improve salmonid survivability within a watercourse.

4.4 Electrofishing Results

4.4.1 Polbae Burn Catchment

The number of electrofishing sites for this project is low and within the Polbae Burn catchment are only being included for interest as any significant changes to the pH of the drainage ditches within this study would be very localised and unlikely to impact on the wider catchment. Presence/Absence electrofishing was primarily used within the Polbae Burn catchment to confirm that all drainage ditches within the project area were fishless. Two quantitative monitoring sites were included within the Polbae Burn area in the 2024 baseline surveys (BP9 and BPU1) with control site PBC also included as a quantitative site. Site BPU1 falls within the upper drainage ditch and is unsuitable to support fish. In 2024, BPU1 was electrofished as a fully quantitative site to include invertebrate monitoring. This site is only included in the monitoring programme to provide the habitat survey to support the invertebrate monitoring. This site would be expected to remain fishless during all survey years and therefore will not be discussed as a fish monitoring location.

Site BP9 is located around 30 m downstream of the middle drainage ditch, which was the location of both terrestrial and instream shell applications. An increase in pH within the middle may not impact so far downstream to site BP9 or improve the conditions for fish. Furthermore, the locations of shell applications within the Polbae Burn catchment are far upstream of where the acidification issues persist within this catchment. This means that even if the pH increased within the study area, salmonids are unlikely to re-establish due to the persistent acidification barrier downstream of the project area. However, it is important to monitor the fish population within the project area to ensure that no negative impacts to fish health arise as a result of the scallop shell applications and to pick up any changes in the event of positive impacts occurring locally.

4.4.2 Pultayan Burn

Within the Pultayan Burn, only Brown trout parr are currently present. The Pultayan Burn under natural conditions would be an ideal spawning burn for trout due to its size and habitat availability. However, spawning is currently not viable in the Pultayan Burn due to the persistent low pH over the winter spawning season. While this burn may reach a more desirable pH during long periods of low flows, the winter climate of persistent precipitation means that the water level is consistently higher leading to a pH that is a risk to fish health during spawning season. If the instream scallop shell applications are successful within the Pultayan Burn and significantly increase the pH over spawning season, trout fry may be present during future electrofishing surveys. Therefore, it is important to monitor the fish population within the Pultayan Burn.

4.4.3 Control Sites

The two external control sites can be compared to during future surveys to highlight whether any fluctuations in fish numbers are due to the project or to external causes. The control sites will be difficult to draw strong comparisons from without significant changes to fish populations within the monitoring sites. The main potential change to fish densities as a result of the scallop shell applications would be the presence of trout fry within the Pultayan Burn if an increase in pH allows for spawning to become suitable. If trout fry were to appear within the Pultayan Burn, the control sites would be used to compare fry densities to and indicate whether spawning was as successful as in an unimpacted site, or if there may still have been a level of recruitment failure within the Pultayan Burn.

The Polbae Burn control site (BP3) falls within the upper section of the Polbae Burn which is less acidified. This site can provide an important insight into how Brown trout are faring where water quality is better and trout densities at site BP3 can be directly compared to site BP9.

Control site BBE1 is out with both catchments involved in this project and is a good example of a healthier, unimpacted watercourse which supports both Atlantic salmon and Brown trout. Both control sites can be compared to BP9 and BBLP2 to highlight whether any changes to the fish densities at these locations are correlating with watercourses unimpacted by the project, or if there have been significant changes which may be due to the scallop shell applications.

4.5 Invertebrate Sampling

All sites received a “Good” to “High” water quality rating from the RICT scores with the exception of site BBLP2 which received a “Poor” rating for the NTAXA, however the ASPT rating was “High” at this site. This suggests that there was a very small number of highly pollution sensitive families within this location. All other sites showed no concern in regards to overall water quality.

The PSI results indicate that site BP3 had minimal to no sedimentation, while all other sites produced a slightly sedimented result. Slight sedimentation is of no concern to fish health and does not indicate bad water quality. Sedimentation is less likely to be a concern during periods of low flows over summer and autumn, but may cause concern during the winter months when persistent high flows cause an influx of sediment. The PSI scores were included to ensure that the addition of scallop shells does not cause a negative response in the abundance of sediment sensitive invertebrate families.

The baseline invertebrate results produced a mean pH of 6.4 – 6.98 at all sites, which does not correlate with the data collected during spot sampling or the water quality monitoring sonde. This is likely due to the inconsistencies within invertebrate families. While some invertebrate families are marked as acid sensitive, they may contain individual species which are acid tolerant but which do not impact on the score due to being within a family that is marked as sensitive. This is particularly an issue with acidification biotic indices, which are much more accurate at a species level. Furthermore, the AWIC scores may be rated as higher mean pH during summer and autumn, where persistent low flows have allowed for acid sensitive invertebrate populations to establish. Invertebrate monitoring is unsuitable during the winter months where acidification is having its greatest impact on organisms living within the watercourses, meaning monitoring must be carried out during the months in which acidification is at its lowest. However, it is important to include the family level AWIC score in the monitoring programme as it can still be used to highlight significant changes in acid sensitive invertebrate families.

4.6 Hatchery Experiments

The hatchery experiments aim to support the field study by providing information on how the pH of freshwater responds to both shell types as well as whole shells and crushed shells. A potential limitation to the experiments is that the inflow water to the hatchery is not acidified and therefore any potential results may be very minor, or it may be difficult to observe any changes to the pH at all. The total pH limit for calcium carbonate solubility in water is around a pH of 12, meaning that calcium carbonate has the potential to increase the pH of water to this point (Hart *et. al.,* 2011). However, this limit applies to distilled water and calcium carbonate is highly unlikely to have as significant of an effect within a natural freshwater system. Solubility decreases significantly as the pH becomes higher and therefore the shells will be unable to significantly increase the pH of unacidified water, but there is still the potential for the hatchery experiments to show slight changes. The experiments may provide interesting comparisons between the effectiveness of king scallop shells against queen scallop shells, and whole shells against crushed shells on the pH of freshwater systems.

6. Appendices

6.1 Appendix 1 – Spot Sampling Results

6.1.1 – Polbae Burn Catchment

Site	Easting	Northing	Date	Time	Depth (cm)	Temperature (°C)	pH	DO (% Saturation)	Conductivity (μms^{-1})

LBDS	227199	571671	20/11/2024	08:47	10	4.8	4.86	100.4	63.6
LBDS	227199	571671	25/11/2024	10:00	22	6.4	4.44	92.9	60.9
LBDS	227199	571671	27/11/2024	10:54	14	4.6	4.77	93.5	59.8
LBDS	227199	571671	29/11/2024	11:35	10	5.2	4.9	97.7	59.7
LBDS	227199	571671	05/12/2024	09:40	40	7	4.22	92.4	66.9
LBDS	227199	571671	24/12/2024	11:44	20	4.8	4.19		64.4
LBDS	227199	571671	08/01/2025	15:30	20	2.6	4.62		72.3
LBDS	227199	571671	15/01/2025	11:45	40	5.5	4.33	97	92
LBDS	227199	571671	22/01/2025	10:42	10	5.5	4.32	94.7	53.6
LBDS	227199	571671	14/02/2025	11:02	8	4	4.52		64.2
LBDS	227199	571671	19/02/2025	14:34	10	4.4	5.04		61.3
LBDS	227199	571671	05/03/2025	11:28	20	6.1	4.22	95	65
LBUS	227201	571597	29/11/2024	11:32	40	5.2	4.41	98.6	61.2
LBUS	227201	571597	05/12/2024	09:42	55	7	4.14	91.2	68.6
LBUS	227201	571597	24/12/2024	11:46	50	4.8	4.08		66.7
LBUS	227201	571597	08/01/2025	15:30	30	2.6	4.58		74.2
LBUS	227201	571597	15/01/2025	11:55	45	5.5	4.25	96.8	96
LBUS	227201	571597	22/01/2025	10:43	20	5.4	4.25	56.3	53.7
LBUS	227201	571597	14/02/2025	11:06	15	4.1	4.26		65.4
LBUS	227201	571597	19/02/2025	14:36	15	4.2	4.35		63.6
LBUS	227201	571597	05/03/2025	11:29	30	6.1	4.02	91.7	68.1
MB1	227041	571931	20/11/2024	08:58	17	5.6	4.76	105.7	54.6
MB1	227041	571931	25/11/2024	10:05	21	6.2	4.2	93.6	58.6
MB1	227041	571931	27/11/2024	11:36	18	5.3	4.42	98.4	55.5
MB1	227041	571931	29/11/2024	12:04	9	4.7	4.41	99.6	53.8
MB1	227041	571931	05/12/2024	10:19	41	6.8	4.08	92.5	62.5
MB1	227041	571931	24/12/2024	12:29	15	4.7	4.81		59.7
MB1	227041	571931	08/01/2025	16:05	10	3.2	4.35		66.5
MB1	227041	571931	15/01/2025	11:30	25	4.6	4.2	98.5	89
MB1	227041	571931	22/01/2025	11:16	20	5.2	4.52	93.5	46.2
MB1	227041	571931	14/02/2025	11:34	15	4.1	4.93		50.5
MB1	227041	571931	19/02/2025	15:15	20	4.5	5.13		50
MB1	227041	571931	05/03/2025	11:40	25	6.2	4.19	96.9	57.3
MB2	227253	572146	20/11/2024	09:48	13	5.2	4.92	114.9	53.6
MB2	227253	572146	25/11/2024	10:33	26	6.3	4.17	99.2	57.8
MB2	227253	572146	27/11/2024	11:27	15	5.2	4.43	105.4	54.5
MB2	227253	572146	29/11/2024	11:57	12	5	4.46	103.2	52.9
MB2	227253	572146	05/12/2024	10:11	67	6.8	4.08	93.7	61.9
MB2	227253	572146	24/12/2024	12:22	20	4.6	4.82		59.9
MB2	227253	572146	08/01/2025	15:50	10	2.9	4.5		65.3
MB2	227253	572146	15/01/2025	11:21	15	4.7	4.24	101.8	88
MB2	227253	572146	22/01/2025	11:09	10	5.3	4.66	99.9	45.1
MB2	227253	572146	14/02/2025	11:27	8	3.9	4.95		48.9
MB2	227253	572146	19/02/2025	15:07	10	4.4	5.32		48.3
MB2	227253	572146	05/03/2025	12:16	30	5.9	4.1	100.7	57
MB3	227346	572224	20/11/2024	09:31	16	4.8	4.87	110.6	53.7
MB3	227346	572224	25/11/2024	10:24	19	6.3	4.19	99.5	57.8
MB3	227346	572224	27/11/2024	11:17	16	5	4.42	107	54.6

MB3	227346	572224	29/11/2024	11:49	12	5.1	4.48	100.8	53
MB3	227346	572224	05/12/2024	10:03	58	6.8	4.07	93.6	61.3
MB3	227346	572224	24/12/2024	12:13	20	4.6	4.84		60.1
MB3	227346	572224	08/01/2025	15:48	10	2.8	4.47		65.9
MB3	227346	572224	15/01/2025	11:13	20	4.8	4.23	100.8	88
MB3	227346	572224	22/01/2025	11:00	15	5.4	4.53	99.1	45.5
MB3	227346	572224	14/02/2025	11:21	10	3.6	4.73		48.9
MB3	227346	572224	19/02/2025	14:59	10	4.2	5.1		48
MB3	227346	572224	05/03/2025	12:10	40	6	4.1	98.2	54.8
MBDS	227364	572226	20/11/2024	09:21	45	2.9	5.83	115.3	49.9
MBDS	227364	572226	25/11/2024	10:19	60	6.2	4.51	99	50.2
MBDS	227364	572226	27/11/2024	11:15	58	4.1	5.15	106.7	46.4
MBDS	227364	572226	29/11/2024	11:48	55	4.9	5.54	101	47.2
MBDS	227364	572226	05/12/2024	10:00	95	7	4.31	95.8	53.6
MBDS	227364	572226	24/12/2024	12:09	65	4.4	4.99		50.4
MBDS	227364	572226	08/01/2025	15:42	30	1.3	5.6		62.4
MBDS	227364	572226	15/01/2025	11:10	55	5.9	4.7	101.3	77
MBDS	227364	572226	22/01/2025	10:58	50	5.2	5.28	96.7	42.9
MBDS	227364	572226	14/02/2025	11:18	40	3.2	5.78		49.2
MBDS	227364	572226	19/02/2025	14:57	50	3.3	6.06		49.3
MBDS	227364	572226	05/03/2025	12:09	80	6.2	4.52	101.8	45
MBUS	227341	572236	20/11/2024	09:26	28	2.7	5.95	112.8	49.5
MBUS	227341	572236	25/11/2024	10:22	25	6.2	4.68	99.5	47.6
MBUS	227341	572236	27/11/2024	11:21	32	4	5.4	108.4	45.4
MBUS	227341	572236	29/11/2024	11:51	22	4.7	5.63	102.1	46.8
MBUS	227341	572236	05/12/2024	10:05	47	7	4.43	106.5	51
MBUS	227341	572236	24/12/2024	12:15	30	4.3	5.11		50
MBUS	227341	572236	08/01/2025	15:40	20	1.2	5.89		62.9
MBUS	227341	572236	15/01/2025	11:15	30	5.9	4.78	101.9	75
MBUS	227341	572236	22/01/2025	11:01	25	5.3	5.49	96.4	42.5
MBUS	227341	572236	14/02/2025	11:22	25	3.1	5.92		48.5
MBUS	227341	572236	19/02/2025	15:00	30	3	6.16		50.2
MBUS	227341	572236	05/03/2025	12:12	55	6.3	4.61	102.7	44.1
PBC	226572	572915	20/11/2024	10:26	30	2.7	6.5	121.3	50.3
PBC	226572	572915	25/11/2024	10:57	38	6.2	5.41	111.5	44.3
PBC	226572	572915	27/11/2024	11:50	42	3.1	5.85	115.8	44.7
PBC	226572	572915	29/11/2024	12:24	29	5.2	6.01	113.4	46.1
PBC	226572	572915	05/12/2024	10:30	51	7.2	4.92	108.7	43.5
PBC	226572	572915	24/12/2024	12:42	45	4.6	5.14		42.7
PBC	226572	572915	08/01/2025	14:55	20	1.1	6.25		62.8
PBC	226572	572915	15/01/2025	10:44	36	6.4	5.55	103.6	68
PBC	226572	572915	22/01/2025	11:28	35	5.1	5.97	111.1	46.1
PBC	226572	572915	14/02/2025	11:49	30	2.9	6.63		49.4
PBC	226572	572915	19/02/2025	15:30	35	3.3	6.77		52.8
PBC	226572	572915	05/03/2025	12:14	65	6.3	5.14	107.9	43.1
UBDS	226736	572512	20/11/2024	10:14	25	3.6	4.42	115.7	44.7
UBDS	226736	572512	25/11/2024	10:47	27	6.3	3.98	106.9	63.1
UBDS	226736	572512	27/11/2024	11:43	20	4.1	4.16	110.5	57.2

UBDS	226736	572512	29/11/2024	12:15	14	5.3	4.13	106.2	54.2
UBDS	226736	572512	05/12/2024	10:22	41	7	3.94	105.5	69.4
UBDS	226736	572512	24/12/2024	12:33	20	4.4	4.11		66.3
UBDS	226736	572512	08/01/2025	15:05	15	1.8	4.26		79.2
UBDS	226736	572512	15/01/2025	10:50	25	5.7	3.97	102.1	109
UBDS	226736	572512	22/01/2025	11:21	20	5.1	4.14	107.8	62.4
UBDS	226736	572512	14/02/2025	11:41	20	3.2	4.29		65.9
UBDS	226736	572512	19/02/2025	15:22	25	3.8	4.34		62
UBDS	226736	572512	05/03/2025	11:33	35	5.9	4.03	103.9	63.9
UBUS	226721	572496	20/11/2024	10:18	25	3.5	4.47	114.9	53.6
UBUS	226721	572496	25/11/2024	10:50	29	6.2	4.06	104.6	63.5
UBUS	226721	572496	27/11/2024	11:45	27	4.1	4.13	110.3	57.5
UBUS	226721	572496	29/11/2024	12:17	20	5.2	4.1	105.8	54.6
UBUS	226721	572496	05/12/2024	10:24	41	7	3.95	102.9	69.8
UBUS	226721	572496	24/12/2024	12:35	20	4.4	4.09		66.9
UBUS	226721	572496	08/01/2025	15:05	10	1.8	4.14		80.1
UBUS	226721	572496	15/01/2025	10:55	30	5.6	3.97	103.3	109
UBUS	226721	572496	22/01/2025	11:22	25	5.1	4.08	107.8	62.1
UBUS	226721	572496	14/02/2025	11:44	25	3.3	4.25		67.5
UBUS	226721	572496	19/02/2025	15:23	25	3.8	4.28		63.6
UBUS	226721	572496	05/03/2025	11:35	35	6	3.99	104.2	63.9

6.1.2 – Pultayan Burn

Site	Easting	Northing	Date	Time	Depth (cm)	Temperature (°C)	pH	DO (% Saturation)	Conductivity (μms^{-1})
PT1	229157	567836	27/11/2024	09:59	36	4.3	4.26	113.2	77.3
PT1	229157	567836	29/11/2024	10:23	35	4.9	4.22	115.8	75.5
PT1	229157	567836	03/12/2024	13:12	32	5.6	4.26	102.2	77.5
PT1	229157	567836	05/12/2024	11:01	71	7	4.06	100.3	82.4
PT1	229157	567836	23/12/2024	10:44	45	4.4	4.01		57.2
PT1	229157	567836	08/01/2025	12:59	20	1.2	4.44		85
PT1	229157	567836	15/01/2025	10:15	25	5.3	4.15	106.7	111
PT1	229157	567836	22/01/2025	10:19	20	5.4	4.54	101.8	69.2
PT1	229157	567836	05/03/2025	10:44	30	6.3	4.11	104.6	80.7
PT2	229058	567653	27/11/2024	10:06	26	4.3	4.32	111.4	76.3
PT2	229058	567653	29/11/2024	10:18	20	4.9	4.25	117.3	74.6
PT2	229058	567653	03/12/2024	13:06	22	5.6	4.11	103	75.8
PT2	229058	567653	05/12/2024	11:06	74	7	4.12	100.7	81
PT2	229058	567653	23/12/2024	10:39	45	4.4	4.09		56.2
PT2	229058	567653	08/01/2025	12:55	20	1.3	4.48		84.5
PT2	229058	567653	15/01/2025	10:10	25	5.4	4.18	105.3	109
PT2	229058	567653	22/01/2025	10:14	15	5.4	4.56	101.6	68.6
PT2	229058	567653	05/03/2025	10:39	25	6.3	4.18	104.4	79.1
PT3	228756	566704	29/11/2024	09:51	50	5.1	4.63	114.2	66.3
PT3	228756	566704	03/12/2024	12:50	50	5.4	4.4	103.9	68.2
PT3	228756	566704	05/12/2024	11:24	110	7	4.35	100.3	73.7
PT3	228756	566704	23/12/2024	10:07	80	4.3	4.25		52.4

PT3	228756	566704	08/01/2025	13:19	25	0.9	4.99		76.9
PT3	228756	566704	15/01/2025	09:45	45	5.5	4.41	104.5	99
PT3	228756	566704	22/01/2025	09:54	35	5.4	4.96	107.9	60.3
PT3	228756	566704	14/02/2025	10:24	40	2.7	4.51		72.6
PT3	228756	566704	05/03/2025	10:19	75	6.4	4.76	106.4	67.3
PTDS	228758	566681	29/11/2024	09:56	25	5.1	5.75	112.2	65.3
PTDS	228758	566681	03/12/2024	12:45	30	5.3	5.45	106.3	61.6
PTDS	228758	566681	05/12/2024	11:21	180	7	4.82	104	61.1
PTDS	228758	566681	23/12/2024	09:57	60	4.4	4.85		46.7
PTDS	228758	566681	08/01/2025	13:22	20	1.2	6.32		78.4
PTDS	228758	566681	15/01/2025	09:50	48	5.7	5.16	105.3	89
PTDS	228758	566681	22/01/2025	09:50	30	5.3	5.96	111.1	62.3
PTDS	228758	566681	14/02/2025	10:19	15	2.8	6.22		69
PTDS	228758	566681	05/03/2025	10:15	60	6.5	6.07	106.5	61.6
PTUS	228738	566680	29/11/2024	09:59	25	5.1	6.15	115.4	67
PTUS	228738	566680	03/12/2024	12:47	27	5.2	5.76	105.3	61.3
PTUS	228738	566680	23/12/2024	10:01	50	4.5	5.33		44.3
PTUS	228738	566680	08/01/2025	13:25	10	1.2	6.48		79.8
PTUS	228738	566680	15/01/2025	09:55	30	5.8	5.65	104.8	88
PTUS	228738	566680	22/01/2025	09:52	25	5.2	6.24	111.4	63.4
PTUS	228738	566680	14/02/2025	10:22	20	2.8	6.56		68.1
PTUS	228738	566680	05/03/2025	10:17	55	6.6	6.24	105.3	58.8

6.2 Appendix 2 – Invertebrate Sample Results

	BP9	BPU1	BBLP2	BP3 (Control)	BBE1 (Control)
Mayflies					
Baetidae	2	2		7	
Heptageniidae				63	10
Leptophlebiidae	2				9
Stoneflies					
Leuctridae	195	211	83	9	10
Nemouridae	199	164	315	155	49
Perlodidae	6				
Chloroperlidae		1			
Caddisflies					
Rhyacophilidae	3		11	7	1
Hydropsychidae				2	8
Polycentropodidae	236	50	52	6	11
Philopotamidae					
Limnephellidae	4	63	6	1	1
Sericostomatidae				1	
Beetles					
Elmidae	120		25	167	43
Gyrinidae	1				
Worms/Leeches					
Oligochaeta	3			15	16
True Flies					
Simuliidae	42	2	26	14	

Chironomidae	207	4	37	52	
Tipulidae					
Pediciidae	2	16	3		
Athericidae					2
Dragonflies					
Cordulegastridae	23	1	3		2
Damselflies					
Coenagrionidae		4			
Molluscs					
Sphaeriidae	4				
True Bugs					
Veliidae		1			
Corixidae					

7. References

B A Waiwood, K. (1983). Levels of chorionase activity during embryonic developement of Salmon sala under acid conditions. *Bulletin of Environmental Contamination and Toxicology*, 511.

Farmer, G. (2000). *Effects of low environmental pH on Atlantic salmon (Salmo salar L.) in Novia Scotia*. Dartmouth: Department of Fisheries and Oceans.

Harsh Ganapathi, M. (2020). Environmental hazards of limestone mining and adaptive practices for enviroment management plan. *Environmental Processes and Management*, 121-134.

J Martin-Ortega, T. (2014). Valuing water quality improvements from peatland restoration: evidence and challenges. *Ecosystem Services*, 34-43.

Mant, R. C. (2013). A systematic review of the effectiveness of liming to mitigate impacts of river acidification on fish and macro-invertebrates. *Environmental Pollution*, 285-293.

Peter W. Hart, G. W. (2011). Application of Carbon Dioxide to Reduce Water-Side Lime Scale in Heat Exchangers . *Journal of Science & Technology for Forest Products and Processes*, 67-70.

Townsend, G. L. (1987). Responses of juvenile Atlantic salmon (Salmon salar) to episodic increases in acidity of Novia Scotia rivers. *Canadian Journal of Fisheries and Aquatic Sciences*, 1475-1484.

Whiting, M. (2014). *Final Report for Project SHARE's Clam Shell Pilot Project, An Experimental Acid Rain Mitigation Plan for the Downeast Salmon Rivers, The 2014 Field Season And a Completion Report for Maine Pollutant Discharge Elimination System (MEPDES) Permit #ME00027*. Maine: Maine Department of Environmental Protection.