Allis Shad Fish Passage Options Appraisal – Gunnislake Weir

Plymouth Sound and Estuaries Special Area of Conservation (SAC)

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Foreword

The **Improvement Programme for England's Natura 2000 sites (IPENS)**, supported by European Union LIFE+ funding, is a new strategic approach to managing England's Natura 2000 sites. It is enabling Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

As part of the IPENS programme, we are identifying gaps in our knowledge, and where possible, we are addressing these through a range of evidence projects. Results from these projects will feed into Theme Plans and Site Improvement Plans. This project forms one of these studies.

This project was commissioned to appraise the options to improve the passage of Allis shad over Gunnislake Weir on the Tamar Estuary. Allis shad are a designated feature of the Plymouth Sound and Estuaries Special Area of Conservation (SAC) and this site is the only known breeding site for this species in the UK. Currently the vast majority of adults in the site spawn just below the weir in a brackish area, which is highly unusual as this species normally spawns in freshwater, sometimes hundreds of kilometres upstream. It is believed that the nature of the weir and the existing fish pass prevent most adults migrating into the freshwater zone as shad are known to struggle to swim over blockages, with very limited numbers recorded in the fish counter above the fish pass. This currently limits spawning to a small area making the population very vulnerable to events in that area.

This report reviews the different options to improve passage over the weir; make recommendations on practicality and likely success of these options; and providing costings and steps to progress the preferred option. The issues covered by this study are recorded in the Plymouth Sound and Tamar Estuary Site Improvement Plan.

The key audience for this work is the staff within Natural England as well as partners including the Environment Agency, South West Rivers Trust, and the owners of the site.

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Executive Summary

Natural England commissioned Fishtek Consulting to undertake an options appraisal to assess methods for improving allis shad passage at Gunnislake Weir on the River Tamar.

Allis shad is an anadromous species; maturing in the sea and migrating into freshwater to spawn. The River Tamar currently supports the only recorded breeding population of allis shad in the UK, with the species listed as an Annex II species on the Plymouth Sound Special Area of Conservation. Allis shad populations have declined significantly across the UK in recent decades and the River Tamar is therefore of national importance to the species.

At present there are two pool and traverse fish passes on Gunnislake Weir. This type of pass is typically unsuitable for allis shad due to highly turbulent flows and consequently only a small number of shad are recorded progressing upstream of the weir each year.

An outline survey of the channel upstream of the weir indicated the presence of areas of high quality shad spawning habitat, suggesting that there are considerable benefits to improving the rate of upstream shad migration.

A number of fish passage options were considered for the site, including baffle passes, a natural bypass channel, fish lift and a vertical slot pass. The vertical slot pass was identified as the most appropriate option for the site due to a proven effectiveness for passing shad species, in addition to moderate build costs and a high feasibility with regards to construction.

The head drop across the weir during high flow was measured at approximately 1.60 m; therefore a vertical slot pass would need to be approximately 35 m long, based on an average gradient of 4.5 % and head drops of 0.2 m between pools. To function effectively the slot widths would need to be > 0.45 m, with resting pools of approximately 4.5 x 3.6 x 1.2 m (L x W x D). A pass of these dimensions would discharge in the range of 0.75 – 0.9 m^3/s.

Having identified the preferred option, a number of potential locations to install a vertical slot pass at the site were considered, with input on the extent and cost of anticipated engineering works provided by Castleford Engineering. The option of building the vertical slot pass in the existing sluice channel structure was identified as the preferred option due to easier site access and lower total build costs.

It is expected that a vertical slot pass constructed in the sluice channel would cost in the region of £250,000 – £300,000. This figure assumes a best case scenario with good ground conditions – subsequent ground investigations would be necessary to provide more detailed costings. The provision of monitoring equipment for the pass, including a VAKI fish counter or camera monitoring facilities, is expected to cost in the range of £20,000 – £40,000.

Phase II of the project, which would include obtaining all the necessary consents and approval, in addition to detailed ground investigation surveys, would cost a further £17,000 - £18,000.

Frequent on-going communication with primary stakeholders, namely South West Water and Gunnislake Fisheries Limited, will be essential for the successful advancement of the project.

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Appendix 1. The utilities search result provided by BT, showing the underground plant cable (black line) within the proposed development site (red outline)

Appendix 2. The utilities search result provided by Western Power Distribution, showing the low voltage underground cable (blue dashed line) within the proposed development site (red outline)

Appendix 3. A summary of the two listed structures (red dots) in close proximity to the proposed development site (red outline)

Appendix 4. A map showing the land owned by South West Water at Gunnislake Weir (blue hatching), in addition to access rights (light yellow)

1. Introduction

Fishtek Consulting were commissioned by Natural England to undertake an options appraisal for improving fish passage for allis shad, *Alosa alosa*, at a site located on the lower River Tamar, Cornwall.

1.1 Site details

The site discussed in this report is located at Gunnislake Weir (NGR SX 43688 71135) approximately 20 km inland at the tidal limit of the River Tamar, Cornwall. The Tamar arises in North Cornwall and flows in a broad southerly direction for approximately 90 km before discharging into Plymouth Sound. The river is known to support a population of allis shad (*Alosa alosa*), in addition to migratory salmonids – Atlantic salmon (*Salmo salar*) and sea/brown trout (*Salmo trutta*), a range of coarse fish species, European eels (*Anguilla anguilla*) and lamprey (*Lampetra* spp.)

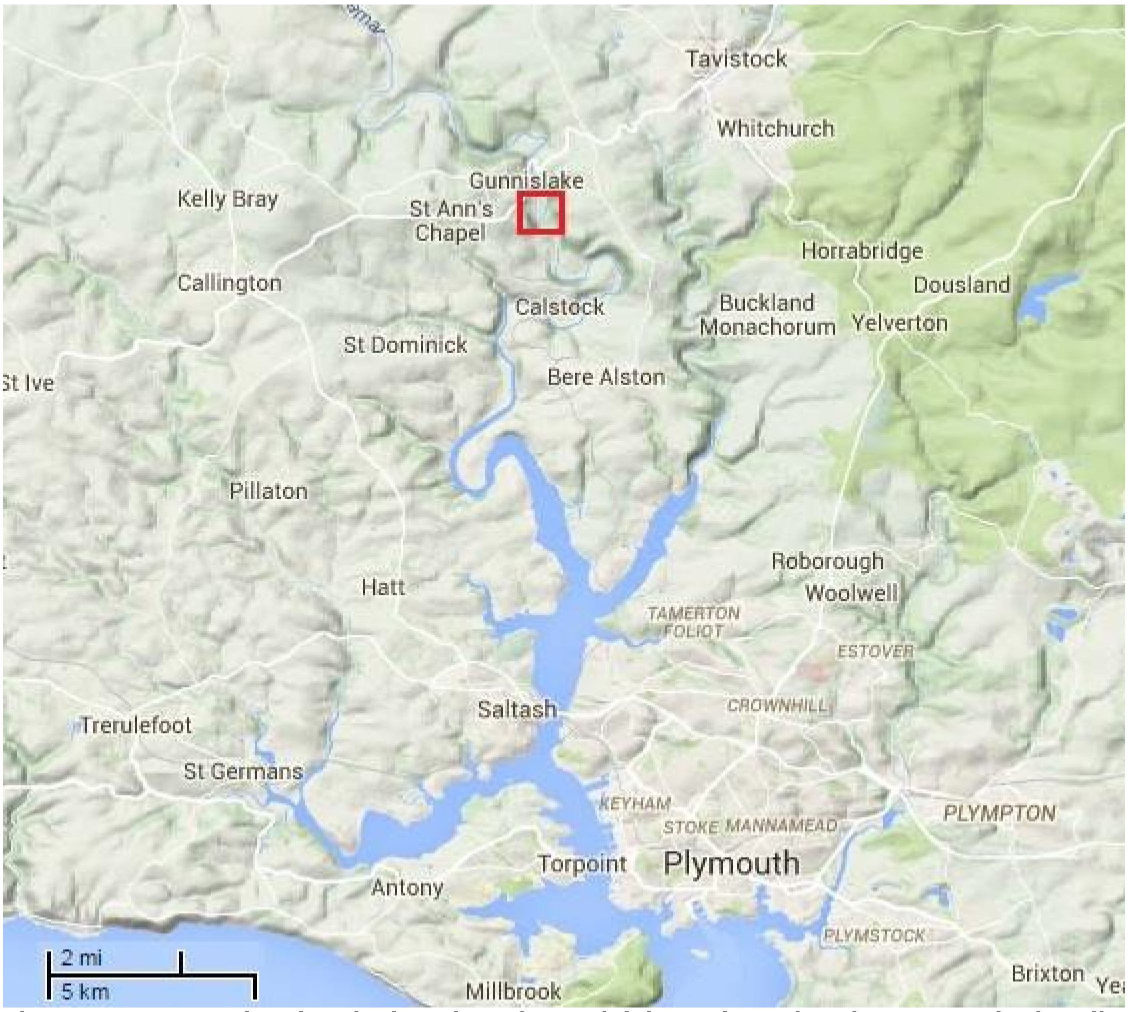

Figure 1.1. A map showing the location of Gunnislake Weir on the River Tamar (red outline).

A flow duration curve for the River Tamar at Gunnislake gauging station, 3 km upstream of Gunnislake Weir, based upon long term gauging data (1956 – 1990) is given in figure 1.2. The Tamar is a moderately large river, with a Q95, Qmean and Q10 of 1.83, 22.52 and 55.19 m^3/s. This equates to a Q95:Qmean ratio of 0.08:1 – a low base flow indicative of a flashy river.

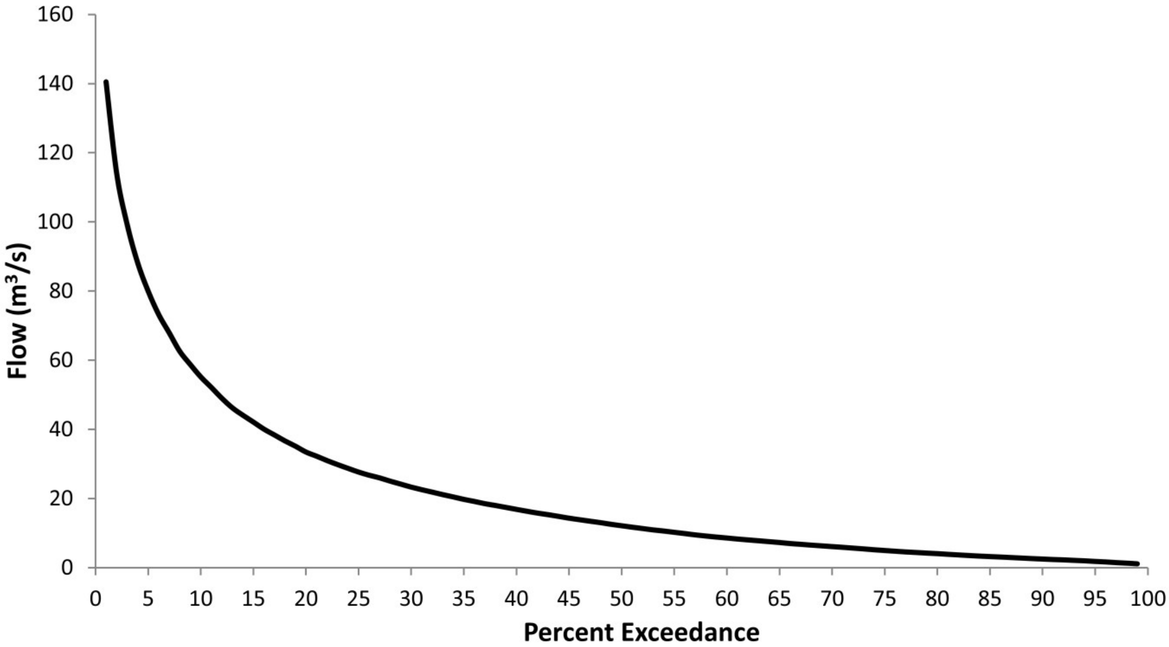

Figure 1.2. A flow duration curve for the River Tamar at Gunnislake gauging station (station number 47001) based upon long-term gauging data (1956 – 1990).

1.2 Project aims

The aims of this report are as follows:

1) Conduct an outline assessment of spawning habitat quality for allis shad and possible barriers to migration upstream of Gunnislake Weir on the Tamar to gauge the potential benefits of improving shad passage at Gunnislake.

2) Undertake an options appraisal to identify the preferred option(s) and location(s) for a fish pass to improve allis shad passage upstream of Gunnislake Weir.

3) Provide outline specifications and costings for the preferred option(s).

1.3 Site visit

A meeting was held on Tuesday 21 October 2014 at the Environment Agency Bodmin Office, where Paul Gratton and Pete Kibel (Fishtek Consulting) met with Trudy Russell (Natural England), Simon Toms (Environment Agency), Kelvin Broad (Environment Agency), and Glenis Pewsey (South West Water).

A subsequent site visit was conducted following the meeting, where Paul Gratton and Pete Kibel from Fishtek Consulting met with William May Somerville (Chairman of River Tamar and Tributaries Fishing Association) in addition to Trudy Russell, Kelvin Broad and Glenis Pewsey.

1.4 Utilities search

A utilities search of Gunnislake Weir and the immediate surrounding area was commissioned, encompassing a total area of approximately 0.2 km^2. A total of 25 companies were contacted to establish whether they own assets within the proposed development site that may be impacted, all of which replied. The majority of companies replied to state that the proposed development would have no impact. However, British Telecommunications (BT) stated that they have an underground plant in the immediate vicinity of the site (appendix 1), while Western Power Distribution have a low voltage underground cable running through the proposed site (appendix 2).

1.5 Ecology of allis shad

Allis shad belongs to the Clupeidae family – commonly known as herrings. It is an anadromous species; maturing in the sea and migrating into freshwater to spawn. Despite a widespread distribution covering much of West Europe and North Africa, populations have reduced significantly in recent decades due to a range of factors, including loss of spawning habitat, overexploitation and the presence of barriers that hinder access to upstream spawning habitat. While previously widespread throughout the United Kingdom, the River Tamar is now thought to support the only known breeding population and is therefore of national importance (Hillman, 2003).

The migration of allis shad into freshwater systems appears to be triggered by a combination of temperature and river discharge. Hillman (2003) observed allis shad migrating into the River Tamar at mean water temperatures of 16.7 °C and at flows of 5.8 – 6.3 m^3/s (approximately Q70).

Allis shad are capable of undertaking long distance migrations into freshwater systems. Prior to the construction of dams on the Rhone, Quignard and Douchement (1991) estimated that allis shad undertook upstream migrations of up to 600 km. Similarly, the construction of the Donzère-Mondragon Dam in South France restricted allis shad to the lower 30 % of their natural range, despite being some 150 km upstream of the river mouth (Keith and Allardi, 1996). Allis shad typically show a preference for spawning in freshwater above the tidal limit (Hillman, 2003) and therefore, although a population of shad have been witnessed spawning downstream of Gunnislake Weir, this may be as a response to an inability to migrate beyond the weir into more optimal spawning habitat upstream of the tidal limit. It is possible that this may restrict the overall population size, as juvenile mortality of allis shad is likely to be higher when spawning occurs in sub-optimal habitat.

Allis shad is listed on Appendix II of the Bern Convention and Annexes II and IV of the Habitats Directive. Additionally, it is protected under Schedule 5 of the Wildlife and Countryside Act 1981 (WCA). Allis shad is also listed as an Annex II qualifying feature of the Plymouth Sound and Estuaries Special Area of Conservation (SAC), which extends as far upstream as Gunnislake Weir.

1.6 Benefits of improving shad passage

In order to assess the extent and quality of habitat that would be opened up by improving shad passage at Gunnislake, an outline assessment of the river and obstructions upstream of Gunnislake was conducted on 5th November 2014, when discharge was estimated at approximately Qmean.

A map showing the quality of allis shad spawning habitat is shown in figure 1.3.

Immediately upstream of Gunnislake Weir and extending for approximately 2 km the Tamar is characterised by a wide, deep slow flowing channel (> 2 m depth, < 0.2 m/s velocity; figure 1.4).

This stretch therefore offers minimal potential for shad spawning habitat, which display a preference for areas of shallow, faster flowing riffle sections.

A further 500 m upstream the depth of the channel decreases and velocities increase (< 0.4 m depth, > 1.0 m/s velocity; figure 1.5), with substrate dominated by cobble and gravel. This area was highlighted as offering a good potential for shad spawning habitat and extends for approximately 1 – 1.5 km upstream. There is an additional area of riffle habitat evident approximately 3 km further upstream, interspersed by a deeper section of slow flowing water where spawning potential is limited.

There are several small weirs on the Tamar upstream of Gunnislake Weir. It was not possible to assess the majority of these due to access constraints. One of the weirs identified – adjacent to Lamahooe Wood (figure 1.6) may present a partial barrier to allis shad depending upon flow levels, as the head drop on the day of the survey appeared to be in excess of 0.3 m. However, this weir is located approximately 9 km upstream of Gunnislake, and therefore improvement to shad passage at Gunnislake Weir has the potential to open up significant areas of high quality spawning habitat.

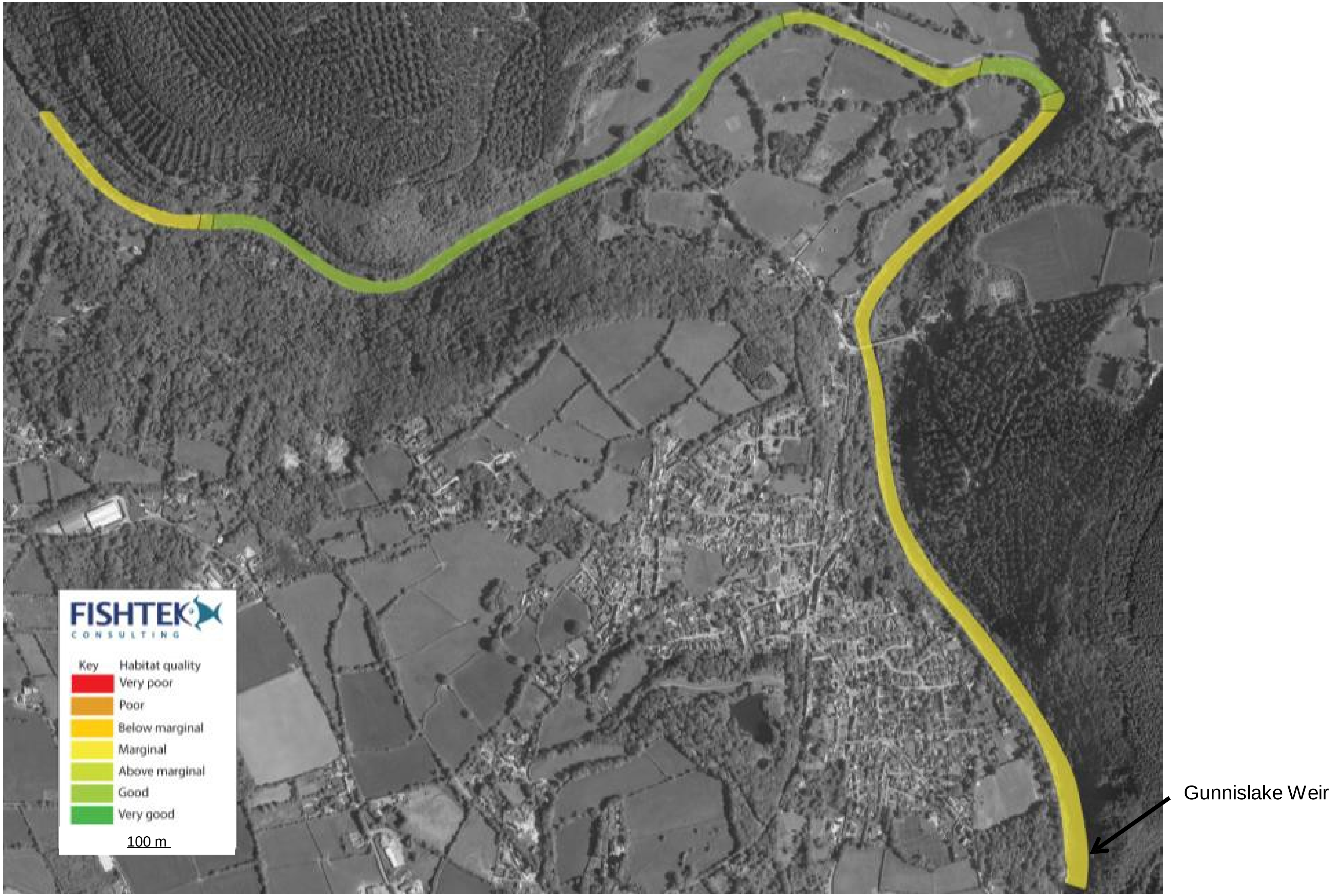

Figure 1.3. The allis shad spawning habitat quality identified upstream of Gunnislake Weir.

Figure 1.4. The River Tamar approximately 0.5 km north of Gunnislake Weir, facing downstream. The channel is deep and slow flowing, offering limited potential for allis shad spawning habitat.

Figure 1.5. The area of riffle habitat approximately 2.5 km upstream of Gunnislake Weir identified as offering high potential for allis shad spawning habitat.

Figure 1.6. The weir adjacent to Lamahooe Wood, approximately 9 km upstream of Gunnislake that may present a partial barrier or delay to shad migration depending upon flows.

Figure 1.7. A map showing the location of Lamahooe Weir in relation to Gunnislake Weir.

1.7 Current site status

The weir at Gunnislake is understood to have been constructed during the 1860s – 1880s (Michael Symons, Gunnislake Fisheries Limited, personal communication), with the fish passage facilities at the site constructed in the decades following. At present there are two fish passes at Gunnislake Weir – a large pool and traverse pass on the Cornish side of the channel (true right) and a smaller pool and traverse pass towards the Devon bank (true left). A photograph of the two passes is given in figure 1.8. The larger pass on the Cornish bank was initially constructed at the turn of the 20th century, although it was adapted to its current form in 1990, with further alterations in the following years to enable the trapping and monitoring facilities to operate (Toms, personal communication).

A search of the English Heritage database revealed no listed buildings or structures in close proximity to Gunnislake Weir. A map of the nearby listed structures is given in appendix 3.

Figure 1.8. A photograph of Gunnislake Weir facing upstream, showing the Cornish fish pass (left) and the Devon fish pass (right).

The River Tamar is one of a number of Environment Agency 'index sites' in the United Kingdom that are monitored to provide detailed long-term data on the biology and population structure of migratory salmonids – Atlantic salmon and sea trout.

Results from trapping performed at the fish pass at Gunnislake indicates that a number of allis shad ascend upstream of the weir each year (figure 1.9).

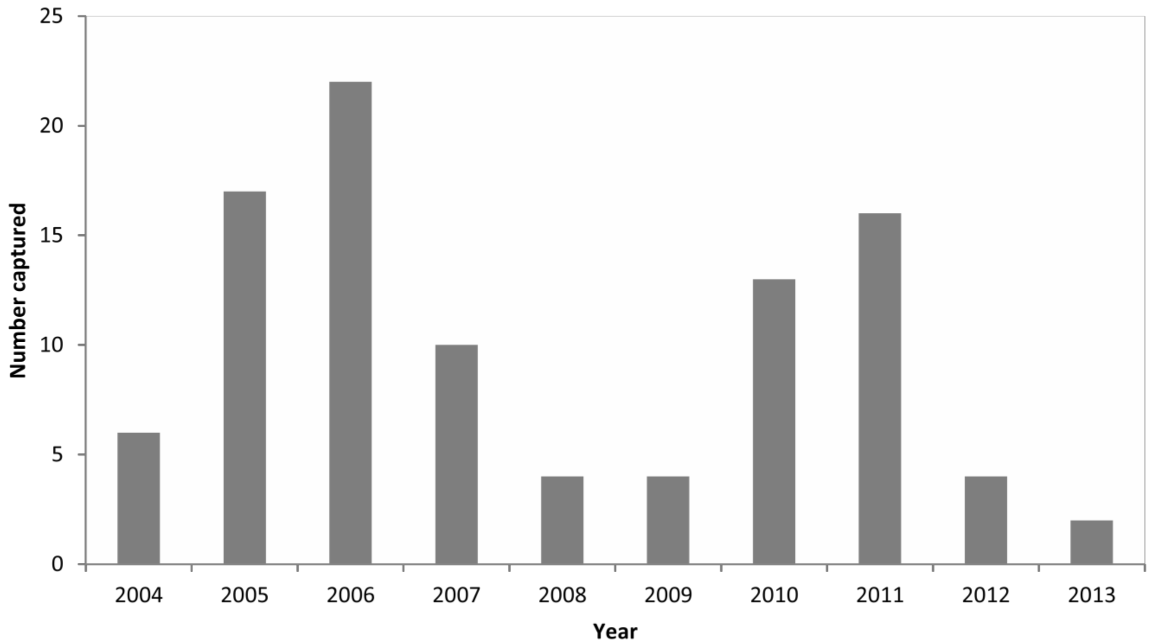

Figure 1.9. The number of allis shad captured in the fish trap at the upstream end of the Cornish pool and traverse fish pass at Gunnislake Weir between 2004 and 2013.

Trapping at the fish pass was, on average, conducted for 30 % of the migration period each year (Rob Hillman, Environment Agency, personal communication). By making the assumption that allis shad passage only occurs via the Cornish fish pass, it is possible to form a simple estimate of the number of shad migrating upstream of Gunnislake Weir each year (table 1.1). The number of migrating allis shad showed a high level of annual variability, although in the last two years of monitoring only a limited number of individuals were recorded.

Table 1.1. The number of allis shad trapped at Gunnislake Weir each year and the estimated total migrating upstream.

Year	Number trapped	Estimated total
2004	6	20
2005	17	57
2006	22	73
2007	10	33
2008	4	13
2009	4	13
2010	13	43
2011	16	53
2012	4	13
2013	2	7

2. Fish passage options

A range of fish passage options have been considered in relation to the behaviour of allis shad and site constraints. These are discussed below and an overall rating for each solution is given in table 3.1.

Any preferred options identified must meet the following criteria:

- Provide upstream passage for allis shad across the required operating range (Q95 – Q20).
- Produce a suitable attraction flow to allow allis shad to locate the entrance to the fish pass without undue delay.
- Have a low risk of blocking with minimal ongoing maintenance required.
- Offer the potential for detailed monitoring to be conducted with regards the biological performance of the fish pass.
- Not increase the flood risk at the site.
- Remain in-keeping with the surrounding aesthetics of the site.
- Be feasible with regards to buildability and economics.
- Not impact upon the effectiveness of the existing pool and traverse pass, the overall upstream passage rate of salmonids, nor the ability to monitor salmonid populations at the site.

2.1 Baffle passes

Alaskan/Denil pass

Alaskan 'A' fish passes were originally designed to provide passage to migratory salmonids in remote locations and are popular at sites where there is a large change in upstream head. The box-like structure has a fixed dimension of 0.56 m width (0.35 m of internal free passage), with baffles arranged along the sides and the base of the pass. This type of pass has a maximum recommended slope of 25 % for migratory salmonids (20 % for other species and non-migratory fish) and a target operating depth of 0.325 m, achievable at a flow of 0.1 m^3/s. A photograph of an Alaskan fish pass is given in figure 2.1.

Due to the steep angle at which Alaskan passes can be run, they can be used to span significant head drops (up to 3 m) with a single flight and can also accommodate considerable changes in the upstream water depth. They are particularly suitable for passing salmonids, including brown trout.

However, the action of water passing the baffles creates turbulent conditions inside the fish pass. This is largely unsuitable for the passage of allis shad which display a preference for streaming, laminar flows. Furthermore, the narrow free width inside the pass (0.35 m) is below the recommended 0.45 m for allis shad to allow passage of entire shoals (EA Fish Pass Manual, 2010). Consequently, the efficiency of this type of pass is typically low. For example, Larinier & Travade (2002) estimated the mean efficiency of the Bazacle Denil pass, France, to be 18.5 % for shad, while at Beaucaire on the Rhône efficiency is described as being very low for allis shad due to the hydraulic conditions within the pass (Aphrahamian et al.,2003).

Figure 2.1. A free-standing Alaskan fish pass, showing the metal baffles extending up each side of the pass.

Larinier

The Larinier fish pass was developed in France in the 1980s (Larinier & Miralles, 1981). It is a popular technical fish passage solution given its suitability for a wide range of species and its relatively low maintenance needs. Larinier passes are typically constructed in a concrete channel with various baffle height configurations. Baffles are organised along the base of the pass and help to generate a heterogeneity in flows that is exploitable by a range of fish species. The maximum recommended slope of a Larinier pass is 15 %. A photograph of a Larinier pass is shown in figure 2.2.

However, due to the turbulent flow created by baffle passes, they are typically unsuitable for allis shad, which display a preference for laminar, streaming flows.

Figure 2.2. A Larinier super-active baffle pass showing the turbulent flow through the pass.

2.2 Fish lift

Fish lifts operate in a similar fashion to an elevator. Water is drawn into a holding pool on the downstream end, with guiding screens or other devices often used to maximise the attraction of fish into the holding pool. Once fish are attracted into the holding tank it ascends on guided rails to the top of the weir or obstruction. Thereafter, the tank is tipped to release fish upstream – either back into the river or into a specially constructed channel to prevent fish being drawn back downstream. Fish lifts have been shown to function relatively effectively for shad species, with Moser et al. (2000) noting passage efficiency of 18 % (1997) to 61 % (1998) for American shad, *Alosa sapidissima*. Fish lifts have also been installed in France at Tuilières on the River Dordogn and at Golfech on the River Garonne. From 1995 to 1996 these passed 90,000 and 75,000 shad, respectively (Larinier, 1998), although the exact efficiency of either is not known. Elsewhere, Barry and Kynard (1986) reported an efficiency of 42 % for a fish lift at the Holyoke Dam on the Connecticut River, United States, following a radio tracking study.

Figure 2.3. An example of a fish lift used to transfer American shad upstream of Holtwood Dam on the Susquehanna River, USA.

2.3 Plunging pool and traverse pass

Pool and traverse passes are one of the oldest types of fish pass and function by splitting a single large head drop over a weir or other similar structure into several smaller head drops. Below each head drop there is a pool, which dissipates the energy of the falling water. Depending upon the characteristics of the pools, a pass can either produce plunging flow or streaming flow. A plunging flow occurs when the lower water level is below the level of the notch between two pools. This produces a hydraulic jump at the bottom of the fall and turbulent mixing in the pool below. The gradient of pool passes is typically below 10 %, although the exact gradient is dependent upon pool dimensions and the head drop between each pool. A photograph of the plunging pool pass at Gunnislake Weir is given in figure 1.8.

Past research has shown the efficiency of plunging pool passes to be very low for allis shad, due to a combination of the turbulent flow and often large (> 0.25 m) head drops between pools. Monitoring of the existing pool and traverse pass at Gunnislake, for example, has shown a very low efficiency, typically passing only 5 – 15 allis shad per year (figure 1.9). Consequently, only a small number of allis shad are observed upstream of Gunnislake Weir during the migration season (Michael Symons, Gunnislake Fisheries Ltd, personal communication).

2.4 Vertical slot pass

A vertical slot pass is a type of modified pool pass, typically formed within a rectangular concrete channel. There are a series of pools interspersed with concrete dividing walls, each of which contains a vertical slot that extends the entire depth of the channel. Due to the unique behavioural characteristics of shad species, there are certain adaptations that are necessary to ensure that vertical slot passes function effectively. Firstly, allis shad typically migrate in shoals and if an opening in a fish pass is not sufficiently wide it will often break up a group, causing the shoal to fall back downstream into the river channel (Larinier and Travade, 2002). Secondly, the head drop between each pool should ideally be < 0.2 m to allow shad to progress between pools without the need to jump (Larinier and Travade, 2002). Providing these criteria are met, vertical slot passes can deliver high efficiencies for shad passage. A vertical slot at the Bazacle Dam on the River Garonne, Toulouse, delivered efficiencies in excess of 70 % (Dartiguelongue, 1990), while a vertical slot at the Mauzac Dam on the Dordogne River was found to be up to 56 % efficient (Larinier, 2002).

Figure 2.4. An example of a large vertical slot fish pass on the River Rhine that facilitates the passage of allis shad upstream of the 10 metre high Iffezheim Dam.

2.5 Weir removal

Removing the weir and undertaking re-grading of the channel would completely remove the barrier to migration, providing clear improvements to fish passage on the Tamar for a range of migratory species. However, this is not a feasible option for a number of reasons. Firstly, as Gunnislake Weir is an index site for the Environment Agency, extensive monitoring is undertaken on passage of fish through the existing pool and traverse pass on the weir. The removal of the weir would therefore prevent the collection of important data pertaining to passage efficiency and salmonid population composition in the Tamar. Secondly, South West Water, the owner of the weir, rely on it to maintain an appropriate upstream water level for abstraction purposes. The removal of the weir would produce a sizable reduction in the upstream water level, impacting upon the ability of South West Water to meet their abstraction requirements.

2.6 Bypass channel

Bypass channels provide a naturalised passage solution suitable for a wide range of species. A separate channel is excavated around the obstruction, typically at a low gradient of < 5 %, although ideally in the region of 1 – 3 %. Boulders and vegetation are often added to the channel to reduce the mean velocity and provide a more heterogeneous flow regime. A formal flow control structure at the upstream end would regulate flow through the channel, perhaps within a range of 0.3 – 0.6 m^3/s at Gunnislake. A photograph of a bypass channel is given in figure 2.5.

Figure 2.5. An example of a bypass channel set at a slope of 5 %. Boulders have been added to the channel to reduce mean water velocities.

3. Preferred option(s)

3.1 Option assessment

The suitability of each option identified in section 2 was considered against the aims presented in section 1.6 and the criteria presented below. Each criterion has been assigned a multiplication weighting between 1 and 4, indicated by the number given in brackets after each criterion. A criterion assigned a weighting of 3, for example, contributes a score triple that of a criterion assigned a weighting of 1. This ensures that the most important factors such as the biological effectiveness of the fish pass have the greatest bearing on the overall score assigned to each option.

- **Maintenance** (*weighting 1*) – A low on-going maintenance requirement, including consideration of the lifespan of materials likely to be used for construction and likely frequency of debris blockage in the pass.

- **Compatibility** (*weighting 2*) – The ability for the proposed pass to work in conjunction with other structures at the site. This includes consideration of the minimum flow requirements for effective operation of the proposed pass and the potential impact that an additional fish pass may have upon the functioning and monitoring of the existing passes located on the weir, including potential alterations to the existing passage rate of salmonids at Gunnislake Weir.

- **Cost** *(weighting 2)* – The overall construction cost – both of the structure itself and any remedial works to the bank, channel or existing structures that are deemed necessary.

- **Construction feasibility** *(weighting 3)* – The feasibility of installing the pass on site, including considerations of site access, space constraints, health and safety, time scales and overall effort of pass construction and any additional remedial works.

- **Function** *(weighting 4)* – The ability of the pass to function effectively for allis shad based upon evidence from peer-reviewed literature and the main behavioural considerations of allis shad that need to be met.

Each fish passage option was scored from 1 to 10 against each of the five criteria, with a score of 1 representing an optimum solution that meets the criteria, while a score of 10 means that it fails to meet the criteria altogether. An overall score was then obtained for each solution by multiplying the score by the weighting assigned to each criterion, with the scores then totalled to produce an overall rating. A lower overall score is indicative of a design that more fully meets the aims given in section 1.6. These scores are presented in table 3.1.

3.2 Results

The turbulent or plunging flow-type passes – plunging pool and traverse, Larinier/Denil and Alaskan passes received the highest ratings (lowest suitability) and were therefore discounted as potential options. This is due to the poor functioning of these pass types in relation to the behavioural characteristics of shad, which is an essential criteria for an effective passage solution at the site. In addition, moderately high scores were assigned for compatibility, as these passes produce a strong, plunging attraction flow which is more suited to migratory salmonids. The installation of one of these passes is therefore likely to produce notable changes to the rate of salmonid migration at the weir.

The fish lift device received a moderate score as past studies have demonstrated the potential for effective passage of shad species in France and the USA using a similar approach. However, there are significant issues regarding a high construction cost and feasibility of installing such a pass at the site, so this option was therefore discounted.

The by-pass channel receives a moderate rating owing to a somewhat cheaper construction cost and limited evidence that such passes can be used to improve shad passage. However, a high score is assigned for construction feasibility due to space constraints on site that may hinder the construction of a 50 – 75 m long channel.

The removal of the weir receives a similar overall rating. This option scores highly in function as it would completely remove the barrier to migration. However, the removal of the weir would lead to significant issues for stakeholders at the site (see section 2.5) and this option has therefore been dismissed.

The highest rating was gained by the vertical-slot type pass, owing largely to the proven effectiveness of these passes for improving shad migration, in addition to a moderate construction cost and a feasible build process. Furthermore, a low score was assigned for compatibility. These passes produce a less turbulent attracting flow and therefore, if the pass was located adjacent to the existing Cornish pool and traverse pass, then the vast majority of migratory salmonids would be expected to opt for the existing route upstream due to the turbulent, higher velocity flow produced by the Cornish pass. The vertical slot fish pass option was therefore identified as the preferred option for the site and assessed in greater detail with regards to the preferred location.

Table 3.1. A summary of the advantages, disadvantages and ranking of each option for improving allis shad passage at Gunnislake Weir.

Option	Main advantages	Main disadvantages	Construction feasibility (3)	Cost (2)	Compatibility (2)	Function (4)	Maintenance (1)	Total
Larinier pass	• Will function across a wide range of flows • Typically low maintenance	• High construction cost • Large scale construction works • Poor efficiency for allis shad due to high turbulence	5	7	6	10	6	**87**
Bypass channel	• Naturalised, therefore would allow shad to pass whilst remaining in-keeping with surroundings	• Requires significant excavation due to low gradient • Poor attraction flow	7	5	4	6	3	**66**
Plunging pool and traverse pass	• Will function across a wide range of flows • Low maintenance	• Already present on site • Very few shad use existing pass	6	6	5	9	4	**80**
Alaskan/Denil Pass	• Will function across a wide range of flows • Moderate construction cost	• Likely to block • Poor efficiency for allis shad due to high turbulence	5	4	6	10	7	**82**
Fish lift	• High effectiveness proven for allis shad	• High construction cost • High ongoing maintenance cost	8	9	2	4	8	**70**
Vertical slot pass	• High effectiveness proven for allis shad	• High construction cost	6	7	2	2	5	**49**
Weir removal	• Completely removes migration barrier	• Impacts upon biological monitoring at the site • Affects abstraction licences upstream	8	6	10	1	2	**62**

3.3 Impacts of preferred option upon existing regime

Various concerns have been raised regarding the impact of the proposed vertical slot pass on the existing flow regime at the site; specifically with regards to alterations to the rate of upstream salmonid migration and the ability of South West Water to meet their abstraction requirements upstream of the weir.

As outlined in section 3, the addition of a vertical slot pass is unlikely to significantly change the rate of upstream salmonid migration at the site. Atlantic salmon and sea trout typically display a preference for high velocity, plunging attraction flows – the type produced by the existing pool and traverse pass. In comparison, the vertical slot pass would produce a more streaming flow of lower velocity that is less attractive to salmonids. It is therefore expected that the majority of salmon migrating upstream would continue to use the existing pass facilities. If on-going concerns remain then it may be feasible to operate the shad fish pass seasonally through the use of stop logs so that the pass only functions during the key shad migration window.

The addition of a vertical slot pass in the preferred location would result in a slight change to the hydrology within the weir pool, with a small increase in discharge on the true right of the weir pool and a concomitant reduction over the central and true left part of the weir. This change in hydrology has the potential to alter the extent and position of areas where salmon hold up prior to migrating upstream of the weir and may therefore impact somewhat upon Gunnislake Fisheries Ltd's use of the area. At present salmon tend to accumulate downstream of the two fish passes where the majority of attraction flow is produced, with slightly more fish thought to group downstream of the Cornish pass due to the higher discharge/attraction flow relative to the Devon pass (Robert Cumming, Gunnislake Fisheries Ltd, personal communication). The addition of a vertical slot pass in the preferred location may therefore result in marginally more salmon holding up on the true right of the weir pool as a result of the increased discharge in this area. However, this change would be relatively confined as there is already a strong attraction flow in this area from the Cornish pass and any additional discharge from a vertical slot pass would be a streaming-type flow of lower velocity and therefore less attractive to salmonids.

During periods of low river discharge the addition of a vertical slot fish pass would lead to a small reduction in discharge through the Cornish pool and traverse pass, potentially impacting upon the performance of the fish pass if fish are attempting to migrate during low flow events.

Solomon et al. (1999) found that flows in excess of Q95 triggered upstream salmonid migration in the lower reaches of riverine systems. Analysis of 11 years of fish counter data from Gunnislake Weir (1998 – 2003 and 2009 – 2013) across the key migration window (April – October) further support this theory. During this 11-year period there were a total of 27 days when river discharge was < 1.8 m^3/s (approximately < Q95), with a total of 102 salmon and 44 sea trout recorded passing upstream. At least one salmon passed upstream during 18 of the 27 days (67 %), while at least one sea trout passed upstream during 17 of the 27 days (63 %). Over the same 11-year period there were a total of 241 days of moderately low flow (1.8 – 3 m^3/s; equivalent to approximately Q95 – Q85). During this period 2973 salmon and 7689 sea trout were recorded passing upstream, with at least one salmon migrating upstream on a much higher proportion of the days (225; 93 %), while at least one sea trout migrated upstream on 182 of the days (76 %).

An unpaired t-test conducted on the passage rates of the two species during low (< Q95) and moderately low (Q95 - Q85) discharge levels shows that significantly fewer fish per day attempted to migrate upstream at flows below Q95 (table 3.2). It therefore appears that discharges in excess of Q95 (1.8 m^3/s) act as trigger to upstream salmonid migration on the Tamar.

This discharge level is in excess of what would be required for the existing pool and traverse pass to function effectively. The majority of upstream salmonid migration would therefore be expected to cease before the point at which the Cornish fish pass stops functioning effectively from a hydraulic perspective and hence the addition of a vertical slot fish pass at the site would not be expected to impact upon the total upstream salmonid migration rate during low flow periods. It would, however, be prudent to undertake a topographic survey of the existing fish pass in the following phase of works to confirm the exact notch dimensions and flow requirements of the Cornish pass.

Table 3.2. A summary of the total number of Atlantic salmon and sea trout recorded passing upstream of Gunnislake Weir between 1998 – 2003 and 2009 – 2013 at low (< Q95) and moderate (Q95 – Q85) flows and the output of an unpaired t-test assessing the difference in the number of each species migrating at the two respective flow levels.

Species	**Fish migrating on low flow days (< Q95, n = 27)**	**Fish migrating on moderate flows days (Q95 – Q85, n = 241)**	**Unpaired t-test**
Atlantic salmon	102 *Daily mean: 3.8*	2973 *Daily mean: 12.3*	$p < 0.001$
Sea trout	44 *Daily mean: 1.6*	7689 *Daily mean: 31.9*	$p < 0.001$

Depending upon the exact configuration and design of the fish pass it is possible that there may be a very small reduction in the water level upstream of the weir due to the diversion of a proportion of the discharge through the proposed fish pass. However, with an approximate fish pass discharge of 0.75 – 0.9 m^3/s (section 4.4), the reduction in the upstream water level would be in the range of 5 – 20 mm. Such a reduction is not likely to have any impact upon the ability of South West Water to abstract water upstream.

4. Details of preferred option

4.1 Preferred location

An additional assessment matrix was conducted to determine an optimum location for the proposed vertical slot pass. A total of three options were considered – these are outlined in figure 4.1 and summarised below:

Option 1) Adapting the existing ‘Devon’ pool and traverse pass structure on the true left of the weir. The pass would discharge fish approximately 10 – 15 metres upstream of the weir crest adjacent to the true left river bank.

Option 2) Excavating ground on the eastern side of the island and installing the vertical slot pass on the true right of the existing ‘Cornish’ pool and traverse pass. The pass would discharge fish approximately 10 metres upstream of the weir crest on the true right of the channel.

Option 3) Adapting the existing canal channel/true left sluice gate structure and installing the vertical slot pass into the channel downstream of the existing sluice gates. This option would make use of the existing true left wall of the disused canal and discharge fish at the downstream end of the canal channel, which connects directly to the main river channel approximately 80 m upstream. Depending upon the exact length of the fish pass it may be necessary to extend the pass several metres upstream of the existing sluice gates.

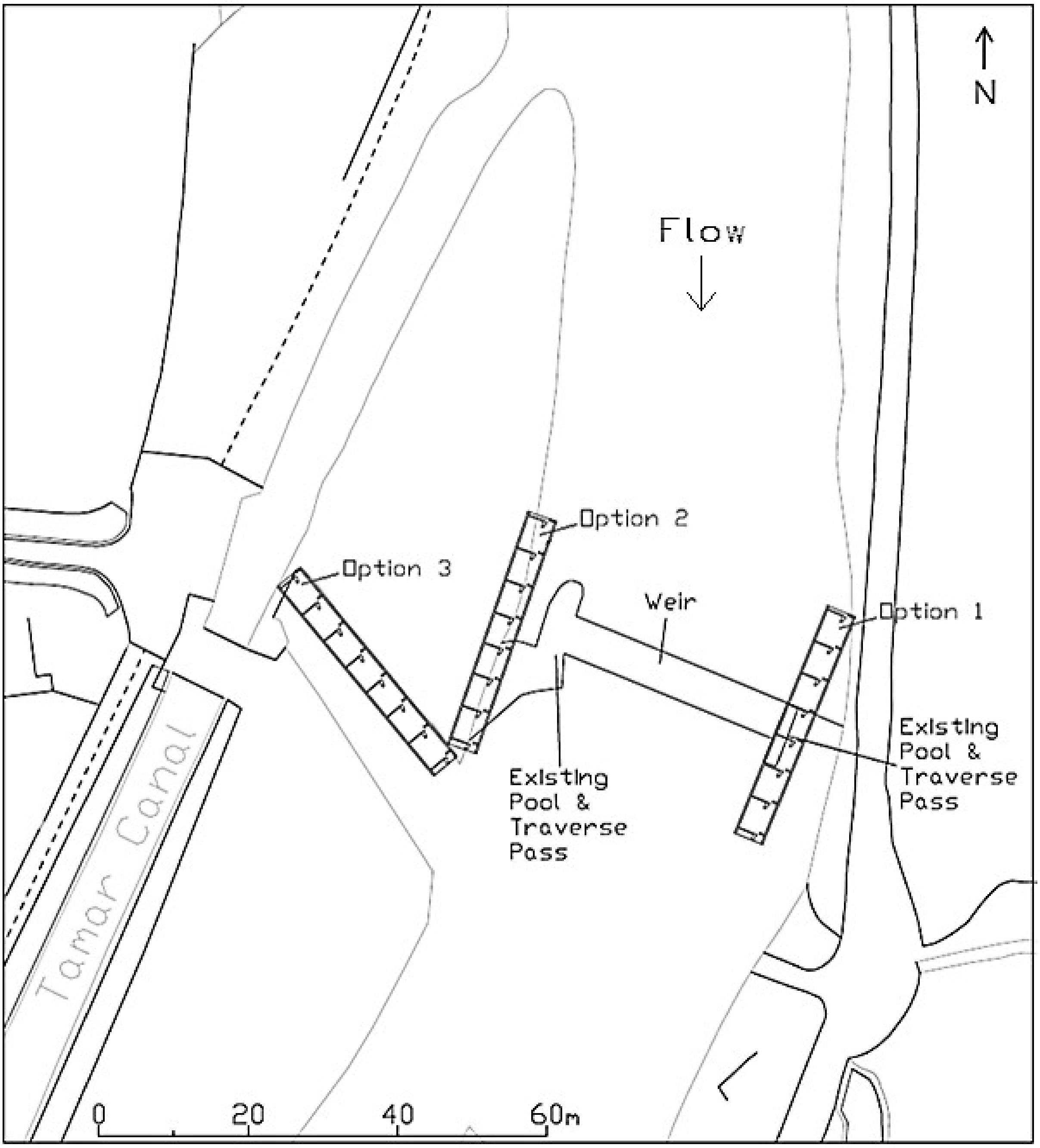

Figure 4.1. The three possible locations considered for the vertical slot fish pass on Gunnislake Weir during the second site visit.

To assess each of the three possible locations, a second site visit was conducted on Wednesday 5 November 2014. Steve Rule from Castleford Engineering was present on site to provide outline estimates of the necessary engineering works, budgetary costs, site access constraints and ongoing maintenance of the structure for each of the locations identified in figure 4.1.

All outline budgetary costs given below are based upon a best-case scenario on the assumption of good ground conditions. Results from subsequent ground survey investigations may lead to an increase in costs if further measures such as bearing piles are deemed necessary. Furthermore, none of the costs provided include facilities for monitoring the performance of the fish pass, which is discussed further in section 4.6.

Each of the three options was rated against the following criteria (bracketed numbers indicate weighting assigned to each criterion):

- Construction feasibility (3)
- Cost (3)
- Access to fish pass for ongoing maintenance and monitoring (1)

4.2 Results

Option 1 (adapting the existing Devon pass) received the highest score and is therefore considered the least feasible of the three locations. Site access is more difficult than the alternative two locations, while it would also be necessary to cut into the weir crest and cofferdam off part of the main river channel. Each of these factors lead to an increase in the overall construction cost. Furthermore, the on-weir location also makes access for long term maintenance and monitoring of the pass more difficult and would necessitate the construction of a boardwalk type structure to provide ongoing access.

Outline budgetary costs: £350,000 – £400,000 +

Option 2 (building through the eastern bank of the island) received a moderate score, owing to easier access and a high existing ground level that would provide sufficient material to excavate the pass into. However, this location would require the construction of a temporary or permanent access bridge and carries a higher risk during construction as the location is potentially more prone to flooding.

Outline budgetary costs: £300,000 – £350,000

Option 3 (building within the existing sluice/canal channel structure) receives the lowest score and is therefore considered the most feasible location. This is due to site access already being present via the existing canal bridge and an easier construction process, both of which reduce total costs. Additionally, the pass could share the existing wall downstream of the sluice gates on the true left of the channel, maintenance to which could be performed during the construction phase.

Outline budgetary costs: £250,000 – £300,000

Table 4.1. A summary of the advantages, disadvantages and criteria ranking for a vertical slot pass at each of the locations identified in figure 4.1.

Location	Advantages	Disadvantages	Construction Feasibility	Cost	On-going access	Total
Option 1	• Could utilise existing flow allocated to the Devon fish pass	• Access difficult for construction and ongoing monitoring • May alter rate of upstream salmonid migration by removing one of the existing fish passes • High construction cost • Requires cutting into weir	9	9	8	62
Option 2	• May be reasonable ground to build pass into	• Would require construction of a substantial bridge across to the island for construction access • Higher construction risk due to potential for flooding at high flows	6	7	3	42
Option 3	• Good access via existing bridge • Comparatively low construction cost • Can share existing wall of sluice gate structure – maintenance of which could be undertaken in conjunction with pass construction	• Low ground level, so little existing earth to build pass into	4	5	2	29

4.3 Outline specification

As detailed previously, the slot width for a vertical slot pass catering for allis shad needs to be a minimum of 0.45 m to function effectively. Based upon the pass configurations presented by Rajaratnam, Van der Vinne and Katopodis (1986), this would equate to a pass 3.6 metres wide with pool lengths of 4.5 metres, although somewhat smaller dimensions may be possible. For example, despite having a slot width of 0.50 m, the vertical slot design at Ramier on the Garonne River has a smaller internal width of 2.50 m, while the length of each pool is 4.50 m (Larinier and Travade, 2002).

Based upon head drops of 0.20 m between slots and 4.50 m long resting pools the overall length of the proposed fish pass would be approximately 35 m (figure 4.2).

4.4 Pass discharge

The discharge (m^3/s) through a vertical slot pass is calculated as follows:

$$Q = Cd * b * H_1 * (2gDH)^{\wedge 0.5}$$

Where:

Cd = coefficient of discharge (0.85)

b = slot width (0.45 m)

H_1 = pool depth (1.20 m)

g = gravitational constant (9.81 ms^{-1})

DH = head drop between pools (0.20 m)

Hence:

$$Q = 0.90\ m^3/s$$

Due to the depth of the resting pools it is recommended that small sills (approximately 200 mm high) are installed at the base of each notch. This helps to stabilise the flow through the pass and prevent water from flowing directly from slot to slot and bypassing the pools (EA Fish Pass Manual, 2010). The addition of sills results in a small reduction in discharge through the pass – for example a 200 mm sill would reduce the discharge from 0.90 m^3/s to approximately 0.76 m^3/s.

4.5 Pass velocity

The maximum water velocity through the fish pass is a function of the head drop across each pool and is calculated as follows:

$$V = 2gh^{\wedge 0.5}$$

Where:

g = gravitational constant (9.81 ms^{-1}) h = head drop between pools (0.20 m)

Hence:

$$V = 1.98\ ms^{-1}$$

Such velocities are well within the swimming ability of shad, which are capable of maintaining speeds of 2.75 – 3.30 ms^{-1} for 15 – 60 seconds (Larinier, 1996), with absolute maximum speeds estimated at 4.1 – 6.1 ms^{-1} (Litaudon, 1985). Furthermore, there will be areas of lower velocity within each resting pool.

Assuming pool dimensions of 4.5 x 3.6 x 1.2 m (L x W x D), energy densities would be approximately 81 W/m^3 at Q95 - well below the maximum threshold of 100 - 150 W/m^3 recommended for shad passage (EA Fish Pass Manual, 2010).

4.6 Monitoring facilities

The inclusion of monitoring facilities with the proposed fish pass would allow the collection of important data, including the range of species using the pass and the respective efficiency for each species. Typical monitoring approaches utilise technology such as automatic fish counters or underwater camera facilities. A fish counter such as the Vaki ‘Riverwatcher Fish Counter’ uses infrared light and cameras to capture and process the silhouette of each fish at the upstream end of the fish pass, with identification accuracy typically in excess of 99 % (Orell *et al*. 2012). Such a counter would also provide valuable data on the annual temporal variation of upstream allis shad migration in the Tamar, allowing the fish pass to be operated only during the key shad migration season, if required. The cost of purchasing and installing an automatic counter such as the Vaki Riverwatcher is likely to range from £30,000 – £40,000 depending upon the exact configuration.

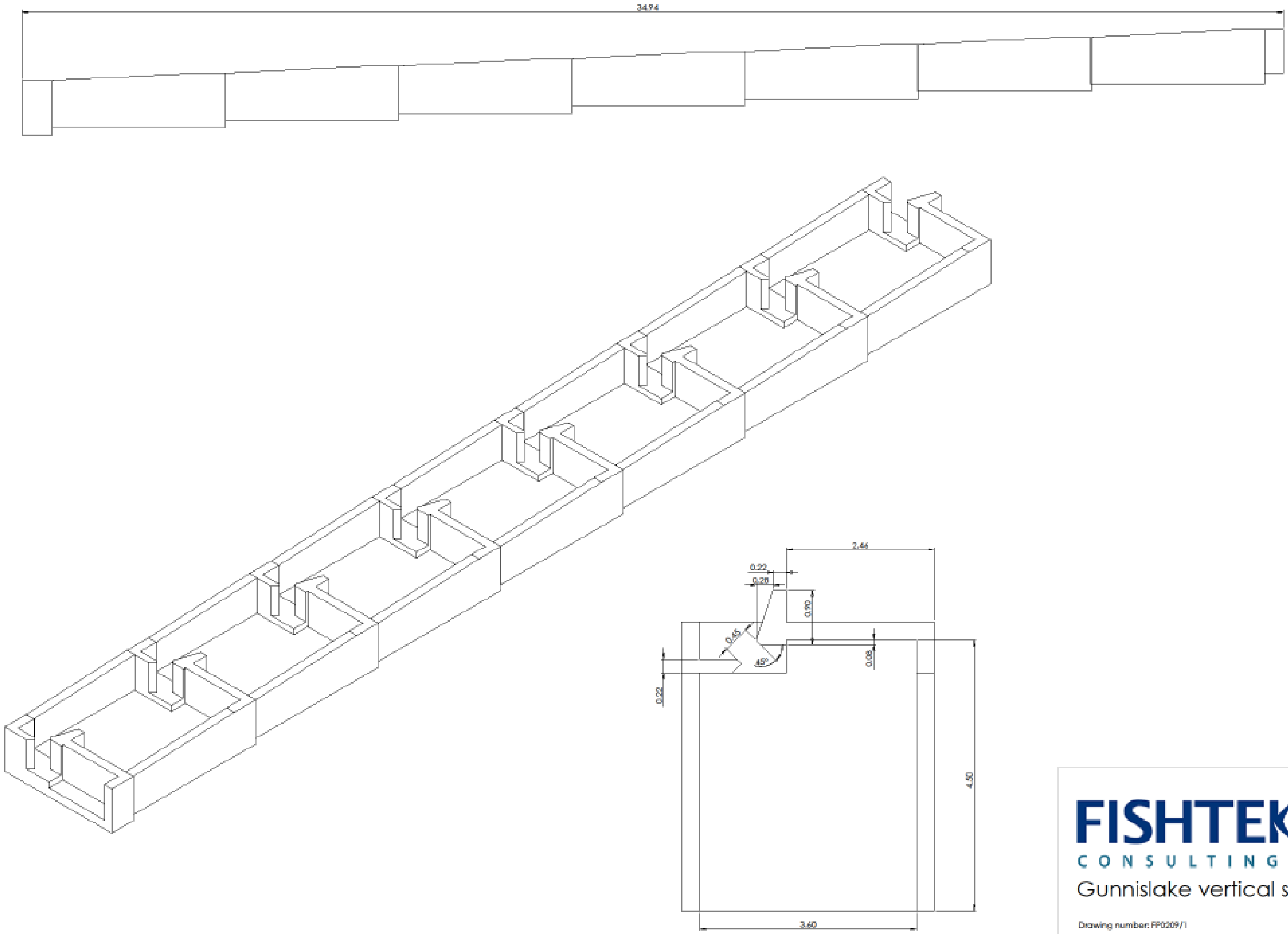

Figure 4.2. The proposed outline vertical slot fish pass configuration for Gunnislake Weir.

4.7 Land ownership in preferred location

The entirety of Gunnislake Weir was previously under the ownership of Gunnislake Fisheries Ltd, although in 1989 ownership of the weir and the fish passes located on the weir was passed to South West Water (Glenis Pewsey, South West Water, personal communication).. Under the covenant that passed ownership of the weir to South West Water, any additions or alterations to the weir and/or sluice gates cannot be made without the prior consent of Gunnislake Fisheries Ltd (or successor) (Glenis Pewsey, South West Water, personal communication).

A map is given in appendix 4 that shows the extent of South West Water's land ownership at the site, which also includes the sluice structure located between the Tamar Canal and the main river channel.

The island located between the Tamar Canal and the main river channel is owned by the owner of Lock Cottage, located 300 m downstream on the true right bank at NGR SX 43516 70850 (Robert Cumming, Gunnislake Fisheries Ltd, personal communication). This includes the southern bank of the island, where the preferred option (option 3) would be located.

5. Recommended further works and costings

The following additional works would be required during Phase II of the project:

- Topographic survey – including levels above ordnance datum for the weir crest, upstream and downstream water levels, relative invert levels of each fish pass and head drops between pools in the Cornish fish pass.

  Estimated cost: £1000 – £1500

- Ground investigations – a survey of the grounds surrounding the preferred location to provide information on the physical properties of the rock or soil present, allowing more detailed design and costings for any necessary foundations for the fish pass.

  Estimated cost: £1500 – £2000

- Installation of pressure sensors downstream of the weir to provide accurate downstream water levels. This information would be used to refine the exact length and invert levels of the fish pass.

  Estimated cost: £1000

- Full civil/construction drawings.

  Estimated cost: £5000

- Detailed fish pass design, National Fish Pass Panel (NFPP) submission and approval.

  Estimated cost: £3000

- Phase 1 habitat survey.

  Estimated cost: £800

- Planning/approval processes – obtaining local council planning permission, Flood Defence Consent, a transfer licence and inputting information (including risk analyses) into the tender pack.

  Estimated cost: £5000

  Total: £17,300 - £18,300

Estimated time required for final design/NFPP approval, all consents and preparation of tender pack: 6 - 8 months.

6. Conclusions and recommendations

Gunnislake Weir likely forms a significant obstacle to allis shad attempting to migrate upstream on the Tamar, with only a limited number of individuals recorded ascending the existing fish pass each year.

An outline survey of the river channel upstream of Gunnislake Weir indicated the presence of extensive areas of good quality spawning habitat for allis shad. Furthermore, there is a length of up to 9 km before the next barrier upstream and therefore appears to be measurable benefit to be gained from improving passage upstream of Gunnislake Weir.

A vertical slot fish pass would offer the most effective solution for improving allis shad passage at the weir. A location downstream of the sluice gates between the Tamar Canal and the main river channel was identified as the preferred location.

Assuming a best case scenario with good ground conditions, it is anticipated that a vertical slot pass in the preferred location would cost a minimum of £250,000 - £300,000 to install, with monitoring equipment such as a Vaki fish counter expected to cost an additional £30,000 - £40,000. It would be wise to include a contingency of 20 – 30 % to allow for cost over runs due to difficult site conditions, adverse weather and project management overheads.

Any technical fish pass design would need to be submitted to the Environment Agency NFPP to gain full approval prior to construction. Additionally, any proposed works would need full planning permission granted by the local council and, depending upon the impact on water levels, may also require flood defence consent.

If the project progresses to Phase II then it is recommended that ground investigations are undertaken at the site to obtain a more accurate indication of the engineering works required and the associated construction costs.

The covenant that passed ownership of the weir and sluice gates to South West Water requires the consent of Gunnislake Fisheries Ltd prior to any alterations or additions to the structures. Hence, frequent on-going communication with primary stakeholders, namely South West Water and Gunnislake Fishing Ltd, will be essential for the successful advancement of the project.

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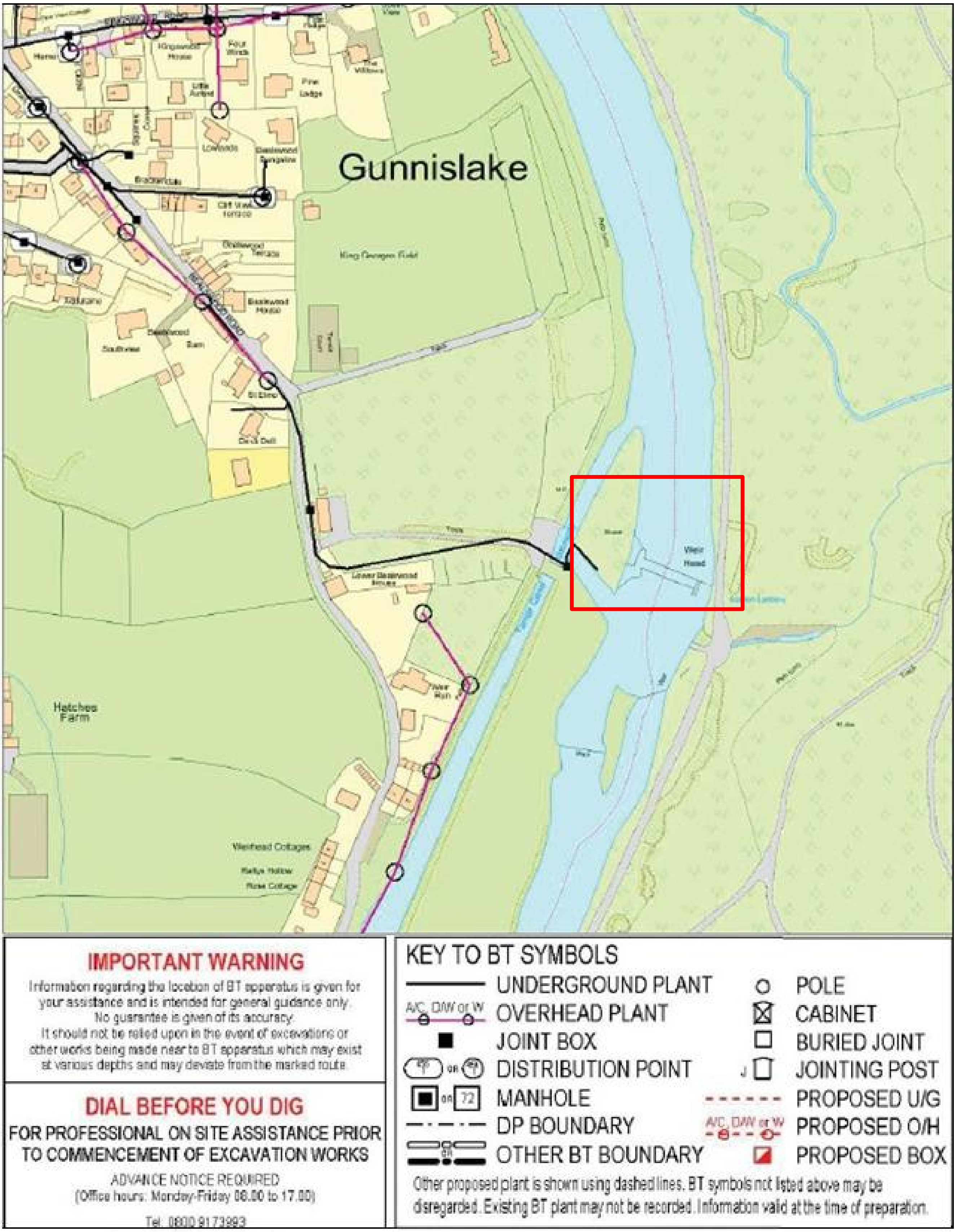
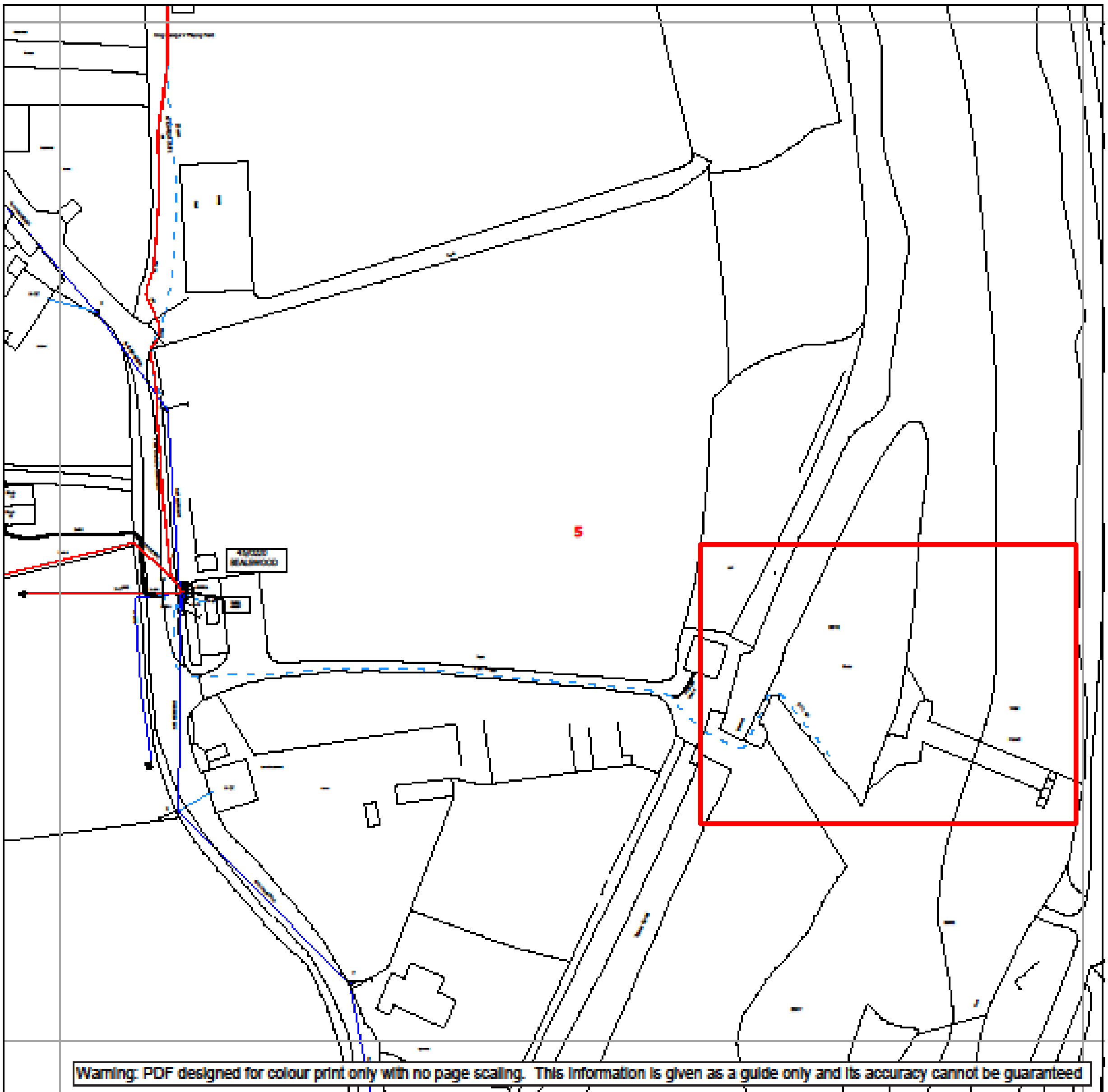
Appendix 1. The utilities search result provided by BT, showing the underground plant cable (black line) within the proposed development site (red outline).



Appendix 2. The utilities search result provided by Western Power Distribution, showing the low voltage underground cable (blue dashed line) within the proposed development site (red outline).



Link Box

Site Location Line/Area

Overhead Line: PL, Service, LV, HV (11kV), HV (33kV), HV (66kV), HV (132kV)

Underground Cable

SURF Telecoms

Pilot Cables

PME Earth

Underground Earth

Pole Mounted Transformer

Ground Mounted Transformer

* Advice should be sought from the Western Power Distribution General Enquiries team for any work that is to take place in proximity to 132kV underground cables and 132kV overhead lines

Contact Us

Mapping Enquiries:

All areas 0121 623 9780

General Enquiries:

Midlands 0845 724 0240

South Wales 0845 601 3341

South West 0845 601 2989

Date Requested: 28/10/2014

Job Reference: 2907452

Site Location: 243601 71186

Requested by:

Miss Chrissy Elliott

Your Scheme/Reference:

34049/SA

Approx. Scales:

1:1250 Area or Circle dig site

1:500 Line dig site

IMPORTANT NOTICES

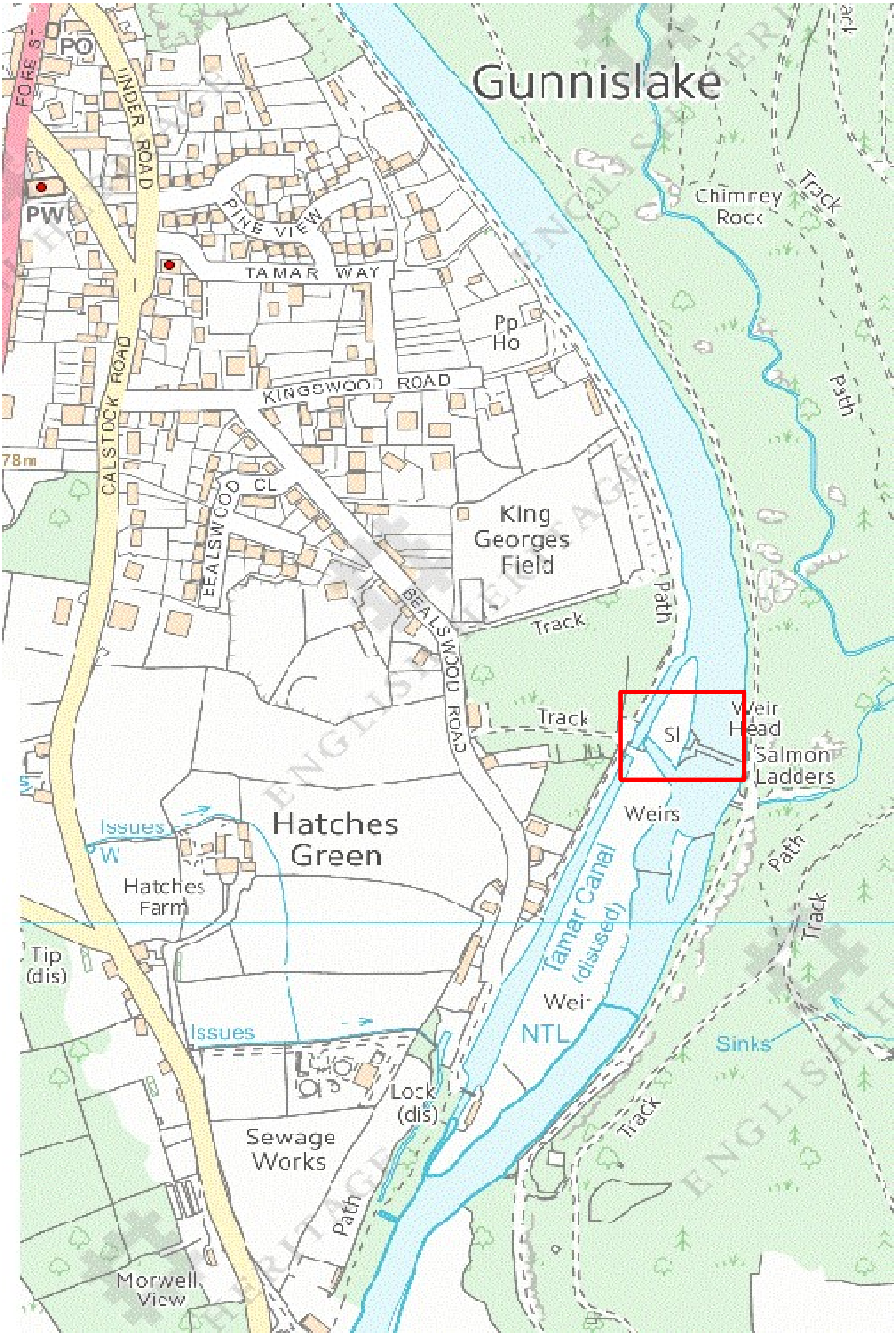
- These plans are provided as a general guide only. Services or recent additions to the network may not be shown.
- Cables, overhead lines & substations owned by other electricity network owners or private companies may be present but will not be shown.
- You should always verify exact locations of cables using a cable locator and by careful use of hand tools in accordance with HSE guidance note HSG47.
- When working within 10m of any overhead electric line you should follow the requirements of HSE Guidance Note GS6.
- For further advice on working near our electricity cables or lines, call our General Enquiries number.

Report damage Immediately – KEEP EVERYONE AWAY FROM THE AREA

0800 6783 105

Plans generated by DigSAFE Pro (tm) software provided by PelicanCorp

Appendix 3. A summary of the two listed structures (red dots) in close proximity to the proposed development site (red outline).



Appendix 4. A map showing the land owned by South West Water at Gunnislake Weir (blue hatching), in addition to access rights (light yellow).