Queen's Marsh Feasibility Study

Dartington Hall Trust

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1 Introduction

Queen's Marsh forms the southern boundary of the Dartington Hall estate between the town of Totnes and the village of Dartington. The site is a former tidal creek where the Bidwell Brook joins the main River Dart. The tidal connection between the brook and the marsh was lost after the installation of Totnes Weir, thought to be during the 16th century. The brook now runs in a perched position along the edge of the study area; interaction with the River Dart leads to regular, widespread flooding of Queen's Marsh via breaches in the left bank and backwater extending up the brook channel from high levels on the larger river.

Queen's Marsh was designated as County Wildlife Site in the 1970's, however the biodiversity value of the site has reduced significantly since this time. Dartington Hall Trust has formed a collaborative partnership with the Environment Agency and Natural England to assess options to enhance the biodiversity of the site through better connection between the brook and the floodplain, and the creation of wetland habitats, including grazing marsh, ponds, reed bed and wet woodland. This mosaic of different habitats has the potential to benefit multiple species including birds, otters, fish, amphibians, invertebrates and bats. Opportunities to further enhance public enjoyment of the site, which is already bordered by well-trodden public footpaths, are also presented.

This feasibility study draws together all the available data, including previous reports and historical accounts from the Dartington Hall Trust archive. This information together with additional site survey work and hydraulic model of the brook and floodplain, provides a clear illustration of the opportunities and constraints associated with potential restoration options. Viable options are presented together with the associated biodiversity benefits in order to facilitate discussion with and between the partners. An outline design of the preferred option is then presented to inform the detailed design stage and ultimately help secure funding for the restoration work itself.

This feasibility study was conducted by Westcountry Rivers Ltd., the trading subsidiary of one of the leading southwest based conservation charities, the Westcountry Rivers Trust, and supported by specialist hydrology consultancy Thomas Mackay Ltd.

2 Site Description

The site comprises cattle grazed pasture of approximately 6.8ha, with a fenced section dominated by scrub at the eastern end of approximately 0.3ha. Within the wider area, the Dartington Estate extends to the north-west, with areas of woodland (including Dartington Hill Plantation and Buckham Park Copse) and managed farmland. A number of residential properties and gardens lie to the south of the site beyond Bidwell Brook, including a current construction site for Bloor Homes.

Queen's Marsh has been agriculturally improved (drained and fertilised) and until recently, has been grazed relatively intensively with occasional silage cuts. However, it is understood that fertilisers have not been applied for at least seven years and the site is now wet improved grass of relatively low conservation value. The site is designated a County Wildlife Site based on a survey from the 1970s, although recent surveys accept that the biodiversity interest has now diminished possibly due to agricultural improvement. A popular cycle and foot path runs along the northern boundary of Queen's Marsh, connecting Totnes and Dartington. Another footpath runs along the southern edge of Queen's Marsh from the Tweed Mill and leaving the main cycle path to run along the brook, crossing it with a wooden footbridge to the A385 main road. A wooden fence separates the footpath as it runs along Queen's Marsh for 50m.

In a wider context, Queen's Marsh lies adjacent to the A385 main road. The site, previously known as Buckham's Bay, was historically an old tidal creek linked to the River Dart (this was before a weir was first installed 150m downstream on the Dart in 1584 to prevent tidal flooding of the creek, which created the Queen's Marsh wetland). Etymology suggests that the brook's name pays tribute to the sailor's wives or sweethearts who would wave and "Bide well" to loved ones as they set off on their voyage out to the open sea when the brook was a tidal creek with free navigation to sea.

Figure 1 Upper (south west) area of Queen's Marsh to the left bank of the Bidwell Brook.

The Bidwell Brook drains a largely rural catchment of 12.14km^2 to the upstream extent Queen's Marsh. At this location, the brook emerges from a steep-sided narrow valley to follow the southern boundary of the Dartington Hall estate bordering the relatively flat marsh area to its left bank (Figure 1). The brook is conveyed under Dartington Lane, an access road to the estate, by a small stone bridge (Figure 2). In-channel vegetation is largely absent from the brook, though, as shown in Figure 2, there is substantial colonisation of sediment deposited in the lower, slower reaches. After the bridge, the watercourse runs through an area known as Berryman's Marsh, which contains densely vegetated wet woodland with ponds, primarily managed for wildlife (Figure 3). The wet woodland areas encroach into and across the lower reaches. The brook discharges to the River Dart a short distance upstream from Totnes Weir.

Figure 2 Stone bridge over the Bidwell Brook at Dartington Lane.

Figure 3 Densely vegetated wet woodland area encroaching on Bidwell Brook from Berryman's Marsh close to the Dart confluence.

The margins of the brook in Queen's Marsh are highly vegetated – trees line the greater proportion of both banks and there is high potential for blockages to form around fallen debris lying close to or across the channel leading to flooding. Site inspection during this study confirmed the presence of two main areas at which the left bank of the brook is breached as previously identified by Environment Agency geomorphological staff (see Appendix 1). Figure 4 shows the larger of these two features; a tree trunk is visible a short distance downstream from the lowered bank which is likely to promote the formation of debris dams in high flows in addition to reducing the cross section area of the brook at this location. A similar mechanism is likely to operate at the existing South West Water sewer pipe crossing (described in 3.3 Utilities).

Figure 4 Lower breach to the left bank of the Bidwell Brook looking downstream.

The right floodplain of the brook is relatively constrained by the presence of a steep bank in the upper reaches of the Queen's Marsh area. A steep hillside to the south of the marsh confines flood water to isolated areas around two small lateral inflows, the garden of a property beneath the Clay Lane-A385 road junction (Puddavine Cottage) and the land surrounding the lodge at Dartington Lane. Queen's Marsh forms the entire left floodplain of the brook upstream from the road. A sluice and weir structure comprised of three culverts which merge to a form a single outfall to the Bidwell Brook a short distance downstream from the bridge carries water from the marsh under Dartington Lane.

Several linear artificial drainage channels (Figure 5) have been cut into the marsh surface to convey attenuated water from the marsh via culverts and the sluice, weir and culvert structure at Dartington Lane. A large area of standing water is routinely observed in the north eastern area of the marsh. This area readily forms from collection of rainfall and any floodwater from the brook. It is also conceivable that any groundwater that reaches the marsh may collect at this point

Figure 5 Linear drainage channels photographed from north east corner of Queen's Marsh.

3 Current Condition

3.1 Biodiversity & Ecology

Desk Study

A desk-based study was undertaken to assess existing data, including historical biodiversity records, the HLS farm environment plan, Environment Agency fisheries and biodiversity data, soil analysis and Devon Biodiversity Records Centre (DBRC) records. In addition, web-based resources were utilised, including NBN Gateway, aerial photographs and MAGIC in order to assess the presence of any adjacent protected sites and species, and to put the site into context with its surroundings.

Designated Sites

There are no statutory site designations within 2km of the site. The Queen's Marsh site is included within the non-statutory site designation for Queen's Marsh and Meadowsweet Marsh County Wildlife Site (CWS). The site was designated for unimproved swamp and fen (National Vegetation Classification M27 and a larger area of relatively species-poor floodplain with ditches).

Habitats

The Dartington Hall Trust holds a significant amount of ecological data for the estate, including data from a number of surveys of the Queen's Marsh site. These include a survey undertaken of the estate by the Dartington Amenity Research Trust in 1975 and one undertaken by Devon Wildlife Trust in 2004. The 1975 survey recorded a diverse sward at the site, with 34 plant species recorded, including creeping bent, marsh foxtail and floating sweet-grass. It is likely that significant agricultural improvement took place following the 1975 survey, as the 2004 survey of the site showed a much impoverished and species poor sward.

The site is understood to have been regularly grazed by livestock, and is currently tenanted and grazed on a rotational basis. The site has been managed organically for the last seven years and is

covered by an HLS agreement with Natural England. Conversations with the Conservation Warden for the estate indicate that the site regularly floods and generally holds standing water over the winter, especially at the eastern end of the site.

Species

There are limited species records directly attributable to the site itself, however a large number of records exist for the wider Dartington Hall estate. There are records of eight bat species using the estate, comprising soprano pipistrelle, common pipistrelle, barbastelle, brown long-eared, greater horseshoe, lesser horseshoe, noctule and serotine. Bat roosts have been recorded within a number of estate buildings, including evidence of greater and lesser horseshoe roosting within a building close to the site along Dartington Lane (the Old Pumphouse). Other mammals recorded on the estate include water shrew, otter, mink and dormouse. There are a significant number of invertebrate records, including records for brown hairstreak and wall butterfly on the Queen's Marsh site, although these records date from 1993. Bird records on the estate include gadwall, little egret and lapwing. WeBS data from the adjacent River Dart, approximately 1km north-east of the site include mute swan, Canada goose, wigeon, teal, mallard, little grebe, grey heron, moorhen, little egret and kingfisher. Recent records from the Devon Birds website for the Queen's Marsh site include sightings on 8th November 2015 of 8 wigeon, 60+ mallard and 400+ Canada geese, and sightings on 9th November 2015 of 14 wigeon and up to 90 mallard.

Field Survey

A walkover of the site was undertaken by an ecologist on 28th September 2015. The aim of the walkover was to identify the broad habitats within the site and the presence or potential presence of protected and notable species, to allow assessment of any on-site ecological constraints, and the most effective areas for targeted habitat creation and enhancement measures.

Habitats

The site was very wet underfoot at the time of survey, generally drier towards the north-western end at the head of the marsh, with standing water within a series of drainage ditches at the eastern end. The sward is species poor and dominated by grasses including perennial rye-grass, cock's-foot and timothy, with frequent creeping buttercup and docks. Other species present occasionally in the sward include lesser stitchwort, common sorrel, redshank, meadow foxtail, silverweed, jointed rush and hairy sedge. Soft rush is locally frequent, especially within wetter areas. The non-native invasive species Himalayan balsam is present occasionally through the site.

The boundary fence line along the footpath is overgrown in areas with scrub including thistle, bramble and nettle. Mature standard trees are present beyond the footpath forming a sheltered lane, with woodland beyond. The stream is heavily over-shaded along large sections, primarily from mature standard trees along the opposite bank, including oak, ash, sycamore and hazel. The banks are earth for the most part, with some reinforcement along the roadside. Generally the banks are higher at the head of the marsh, up to approximately 2m, however generally the banks are around 1.5m high and steep, with minimal vegetation on the bank top dominated by thistles, nettle and bramble, with occasional dock, angelica, meadowsweet, ivy and Himalayan balsam. Some sections of the stream comprise gravel substrate, with a siltier substrate present in sections of slower flows.

The small overgrown section adjacent to the north-western end is occasionally managed through selective coppicing and vegetation clearance, primarily to encourage butterflies. It has not been managed for a number of years and currently comprises dense scrub and self-seeded saplings, with species including alder, buddleia, hazel, bramble, ash, meadowsweet, dogwood, spindle, willow, pond sedge and thistles. Significant stands of Himalayan balsam are present throughout. The site is dry underfoot, with some central areas of hard-standing (left over remains of an old sewage treatment works), which is becoming colonised by mosses. There is very little mature vegetation/trees.

Species

Mammals

Evidence of badger was recorded on site in the form of foraging signs along the northern boundary of the site. No setts were recorded on site, but they are likely to be present within the wider estate and the site forms suitable foraging habitat for badger. There is anecdotal evidence within some of the archive documents provided by Dartington Hall Trust of badger setts located within the woodland strip to the north of the site, but it is not known if these are still present or active.

The site is known to provide foraging and commuting habitat for a range of bat species, particularly greater and lesser horseshoe, along with wider habitats, especially along sheltered path to north of the site and along the brook corridor. The site has good links to adjacent habitats and is located close to a number of known bat roosts within the estate. Organic sites grazed by cattle are known to provide good foraging habitat for greater horseshoe bats. The site is likely to support a good abundance of invertebrates, however the species poor sward is likely to limit invertebrate diversity, which may restrict the species of bats present and their use of the site across the year.

No evidence of otter was recorded during the site visit, however the brook provides suitable habitat for otter for commuting and foraging. The bankside habitats are limited within the site and no obvious suitable sites for holts or lay-ups were noted. There are numerous records of otter on the wider Dartington Estate, as well as historic records of mink, although mink are often thought to be outcompeted by strong otter populations, and frequent recent records of otter may indicate a lowered likelihood of the presence of this species.

Water voles are rare across Devon, thought to have gone extinct from the county, and now subject to a number of reintroduction projects. This species is not currently known to be present on the River Dart or tributaries (although is likely to have been present historically) and no evidence was noted during the site visit. The brook provides some potential habitat, with the presence of earth banks, however the limited marginal and aquatic vegetation means that the site lacks good habitat for foraging and cover, and the potential presence of predatory mink makes the current site sub-optimal.

Records of dormice are present for the wider estate but no suitable habitat is present on site, with the possible exception of some areas of scrub within the western end of the site. The site is likely to support a range of small mammals, potentially including water shrew.

Birds

A kingfisher was sighted during the site visit, flying upstream along the brook. No suitable nest sites are present on site for kingfisher, but the sighting indicates that it forms part of a foraging

area/territory. Bankside trees and the area of scrub area at the western end of site form suitable nesting habitat for an assemblage of common bird species. The site provides some suitable habitat for wintering birds, especially for waterfowl when partially flooded (Figure 6), but relatively enclosed nature of the site may reduce its suitability for some species of wildfowl or waders.

Figure 6 Showing Canada Geese on the Queen's Marsh site during flood in November 2015 (Photo courtesy of Stephanie Bailey)

Reptiles and Amphibians

Small numbers of widespread reptile species are likely to use the site such as slow worm and grass snake, however management of the site means that there is unlikely to be a significant population. Flooding of the site provides temporary pools which could occasionally be used by breeding amphibians, but breeding potential is limited on the site, although grassland areas provide some suitable terrestrial habitat for common amphibians.

Terrestrial Invertebrates

A small copper butterfly was noted during the site visit. The site is likely to support a good abundance of common invertebrate species, however the limited plant species and structural diversity on site, coupled with historic management and agricultural improvement is likely to limit invertebrate species diversity and the presence of notable species. The scrubby area at the north-western end of the site has been coppiced in previous years to encourage butterfly species.

Freshwater Invertebrates

Freshwater invertebrate sampling was outside of the scope of the feasibility study, however Environment Agency sample data is available for sample points along the Bidwell Brook between

2005 and 2014, including the biological monitoring working party (BMWP) scores. The BMWP is a procedure for measuring water quality using families of macroinvertebrates as biological indicators (Table 1). The method is based on the principle that different aquatic invertebrates have different tolerances to pollutants. Species are allotted points to rank their importance in the ecosystem, the less tolerant a group of invertebrates is to pollution the higher the points they are allotted. A higher BMWP score is considered to reflect a better water quality.

Table 1 BWMP score classification

BMWP score	Category	Interpretation
0-10	Very poor	Heavily polluted
11-40	Poor	Polluted or impacted
41-70	Moderate	Moderately impacted
71-100	Good	Clean but slightly impacted
>100	Very good	Unpolluted, unaffected

Based on the BMWP score from Environment Agency sample data (Table 2), the Bidwell Brook consistently scores more than 100, suggesting the brook is largely unpolluted or unaffected.

Table 2 Freshwater invertebrate Environment Agency data

Water Body	BIDWELL BROOK	BIDWELL BROOK	BIDWELL BROOK	BIDWELL BROOK	BIDWELL BROOK	BIDWELL BROOK	BIDWELL BROOK
Site Name	10M U/S RD BR TIGLEY	10M U/S RD BR TIGLEY	10M U/S RD BR TIGLEY	D/S LOUNARD MILL, 30M U/S BR. WEEK	D/S LOUNARD MILL, 30M U/S BR. WEEK	D/S LOUNARD MILL, 30M U/S BR. WEEK	D/S LOUNARD MILL, 30M U/S BR. WEEK
Site Location	SX-75720-60870	SX-75720-60870	SX-75720-60870	SX-78010-62297	SX-78010-62297	SX-78010-62297	SX-78010-62297
Sample Date	08-Mar-05	13-Sep-05	24-May-06	04-Mar-13	02-Oct-13	28-Apr-14	10-Sep-14
BWMP Score	202	176	215	176	129	184	149
ASPT	6.73	6.07	6.72	6.52	6.14	6.81	6.21
No Of Taxa	30	29	32	27	21	27	24
CCI						10.5	7.37
FAMILY LIFE	7.9	7.52	7.84	7.77	7.81	8	8
SPECIES LIFE						8.96	9.13

Fish

Analysis of historic fish surveys on the Bidwell Brook suggests salmon are present in the lower Bidwell Brook as shown in fish surveys at the EA Dartington Sewage Treatment Works (STW) site. The Dartington STW site is at the top of Queen's Marsh. Unfortunately, EA ceased sampling at the Dartington STW site in 1999, with Brooking (upstream) the only site on Bidwell Brook now surveyed periodically (every 6 years) since 2002. The first EA fish survey record on the Bidwell Brook is 1987.

Salmon have only ever been recorded on the Bidwell Brook at the Dartington STW site at the top of Queen's Marsh, this would suggest that salmon are not penetrating the upper reaches of the Bidwell Brook, possibly due to the impassibility of the waterwheel structure (until 2012 when notches were

created to improve fish migration). Surveys have also regularly recorded eels and bullheads, with occasional records of minnow and stoneloach. This suggests a good diversity of fish and therefore a range of habitats required to continue to support this diversity. WRT surveyed the Bidwell Brook at Brooking in 2013, salmon were absent from the survey, trout were recorded in poor fry numbers, but good parr numbers.

Although EA surveys have now ceased at Dartington STW, we should assume that the lower section of the Bidwell Brook is used by salmon (parr and older) and any in channel modifications should consider salmon habitat benefits. This is particularly important considering the upcoming improved fish pass installation at Totnes Weir in association with the hydropower scheme. The Tweed Mill sluice structure poses quite a barrier to migratory fish species including eels, however in 2012 and 2014, improvements were made to improve migration over the structures via a number of eel tile passes and notches in the weirs.

Anecdotal evidence and comments from current and previous Dartington residents recall fond memories of fishing for brown trout, eel and sticklebacks in the Bidwell Brook along Queen's Marsh.

Aquatic Macrophytes

Mean Trophic Rank (MTR) is a biotic index based on the presence and absence of aquatic macrophytes and uses a simple scoring system to derive a single index describing the trophic status of a site. Species present are assigned a score (species trophic rank STR) according to their tolerance to eutrophication (the higher the score the lower the tolerance) and a mean score (MTR) for the site is then calculated, weighted according to the relative percentage cover of the individual species. MTR scores range from 1 to 100 and increase with decreasing eutrophy (100 equal to pristine). Based on this, the EA macrophyte data (Table 3) and MTR scores for the Bidwell Brook in 2012 and 2014 suggests a moderately impacted system.

Table 3 Environment Agency macrophyte data from the Bidwell Brook

Water Body	**BIDWELL BROOK**	**BIDWELL BROOK**
Site/Station Name	D/S LOUNARD MILL, 30M U/S BR. WEEK	D/S LOUNARD MILL, 30M U/S BR. WEEK
Sample Date	07-Sep-12	09-Sep-14
MTR Score	38.7	43.2

Little aquatic/emergent plant species were noted within the brook at the time of the survey. However, a small patch of *Ranunculus* was observed in the lower section of the reach.

Figure 7 *Ranunculus* growing in lower reach of Bidwell Brook

Diatoms

The Trophic Diatom Index (TDI) provides a useful indicator of the nutrient enrichment of freshwaters (phosphorus (P) is presumed to be the limiting nutrient), particularly in judging the impact of a point source such as a Sewage Treatment Works outflow. Increased TDI values would suggest increased eutrophication. In rural areas, watercourses are often subject to both point and diffuse input of nutrients from agricultural sources within the catchment. The percentage of motile valves for each sample is also calculated to aid the interpretation of changes in the TDI. Percentage of Motile Valves provides a siltation index, with higher percentages of motile valves suggesting increased organic pollution. Therefore, samples with high concentrations of suspended solids will have a high percentage motile diatom valves.

Without multiple survey sites on the brook and with no other site specific data presented in EA results (Table 4), it can be difficult to put into context and draw a confident conclusion. But the difference between the two samples in the year suggests changes due to (increased) nutrients from a TDI of 49 to 74 (TDI = 74 indicates a fairly eutrophic site, Sept 2014 sample).

Table 4 Environment Agency diatom data from the Bidwell Brook

Water Body	BIDWELL BROOK	BIDWELL BROOK
Site/Station Name	D/S LOUNARD MILL, 30M U/S BR. WEEK	D/S LOUNARD MILL, 30M U/S BR. WEEK
Sample Date	28-Apr-14	10-Sep-14
Total TDI Cells	384	310
PTV%	24	7

River TDI3	49.15	74.03
River TDI4	46.52	-
Motile%	28	21

Soil Samples

In addition to a biological survey, soil samples were taken from three locations within the site during October 2015. These were analysed for soil nutrient levels, and the north-western-most sample also included analysis for heavy metals to assess any likely historical contamination associated with the historic tweed mill. Analytical results (Appendix 2) suggest relatively low levels of Phosphorous in all samples (11-12ppm), which is equivalent to Index 1 on the Olsen P range (Table 5) and the upper marsh sample was fairly low in heavy metals. The soil analysis therefore does not indicate that high phosphate or heavy metal loads are the cause of the poor sward. The soil samples show pH levels of 5.5 – 5.6 indicating an acid-neutral soil.

Plymouth University are in the process of undertaking research into heavy metal contamination within sediments in the Bidwell brook catchment, early data indicates that the channel bank from the stream at the marsh is elevated in Zinc and other metals. Further consideration into metal contamination of the soils may need to be undertaken prior to any significant soil excavation.

Table 5 Soil nutrient data – Olsen P range (Floodplain Meadows Partnership)

Index	OP range mg/l	Comments
0	0-9	5-15 is the range in which many species rich floodplain meadow species are found
1	10-15	This is the perfect range for floodplain meadow plant community
2	16-25	Species richness declines over 20mg/kg
3	26-45	Restoration difficult without trying to reduce the P level
4	46-70	Values above 50 are too high to try restoration without drastic measures e.g. soil stripping, deep ploughing or chemical amendment

Assessment

The site is dominated by species poor cattle grazed pasture. Whilst the site is covered by a CWS designation, it is considered that the habitats present would not meet the current requirements for designation. It is considered likely that the decrease in sward diversity on site is due to a combination of historical agricultural inputs, possible inputs from frequent inundation by flood water and management regimes. Whilst the soil analysis indicates that phosphate levels are not at a level likely to significantly impact the sward diversity, other inputs may be a factor, such as from sediments. Both under-grazing and over-grazing can also impact species diversity, and differing management regimes over the years may have contributed to the domination of the site by coarse grasses and tall herbs which out-compete less vigorous herbs and fine-leaved grasses. It is considered that there is significant scope to increase biodiversity on the site through increasing species and structural diversity across the site and implementing an appropriate management regime.

3.2 Historical Features

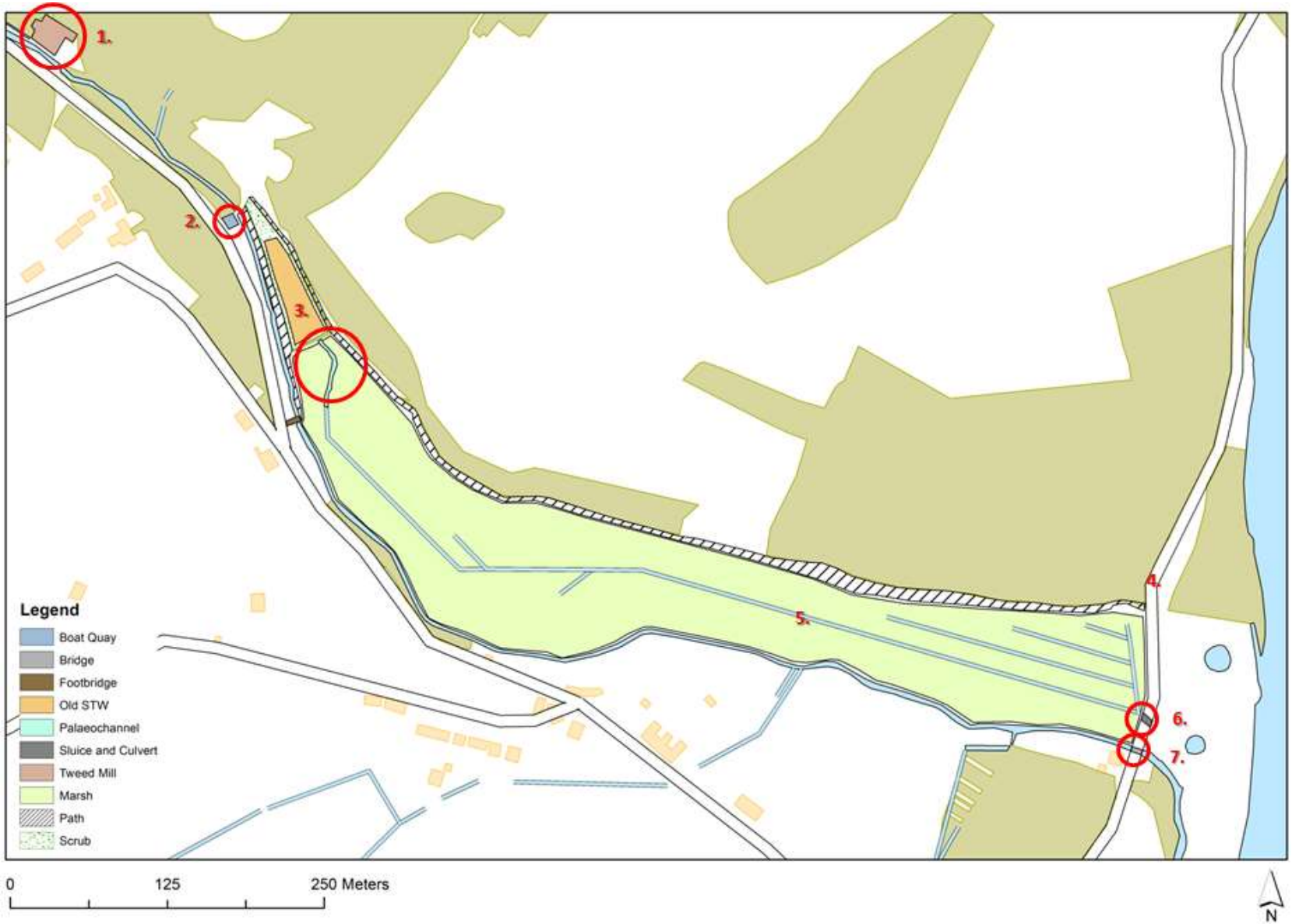


Figure 8 Location of historic features. 1. Tweed Mill, 2. Boat Quay, 3. Sewage Treatment Works, 4. Access, 5. Drainage channels, 6. Sluice and Culverts, 7. Bridge.

Tweed Mill

When Irish Weaver Toby Fitzpatrick came to Dartington Hall in 1927, he successfully advocated machine weaving to the Elmhirsts. The purpose-built tweed mill was designed by Oswald P. Milne in 1930. The site of the mill was chosen specifically for the purpose of harnessing the Bidwell Brook to drive the water-wheel, the main source of power to directly drive a number of machines.

Boat Quay

There are remnants of a boat quay and associated features upstream of Queen's Marsh, near the Queen's Arms public house. Accounts from current and previous Dartington residents recall remnants of a wooden boat emerging from the marsh in dry years.

"As a child in the early forties we used to see an old wooden hull of a large boat sticking up in the marsh roughly opposite the old Queen's Arms. The continual rubbing by the bullocks finally made it disappear altogether." Pamela Sandry Gorman, local resident.

"In the 1950's I observed the skeletons of two wooden vessels in the marsh, Buckham's Marsh, (near the former Queen's Arms). Whilst I remember them, as a schoolboy, others do as well (personal communication). It is possible to speculate that they were barges to carry limestone, from the nearby quarry, to build the town bridge, (Charles Fowler 1827/28)" James Bellchambers, local resident and volunteer at Totnes Museum.

"During one dry year the skeleton of a boat/barge emerged from the turf. We were told that before the weir was constructed barges/boats would moor up at the bottom of Vineyard Hill to load wool" Richard Orr, resident of Bidwell Cottage, 1973-1985.

Further investigation may be required before excavations are made on site as to the approximate location of the boat and its archaeological significance.

Sewage Treatment Works

A now redundant Sewage Treatment Works was located at the head of Queens Marsh. Little information of the operation of the site was found during this study; however the works is thought to have closed around 1992. Much of the associated buildings and infrastructure has since been removed. A significant area of hardstanding is still present immediately adjacent to the head of the marsh. The exact dimensions and depth of the hardstanding is unclear.

At the head of the marsh, there is an apparent channel shaped depression, separate to the drainage ditches. The origin of this depression is unknown. There has been some speculation that it could represent the remnants of a palaeochannel, though there are no records or evidence to support this. The orientation and location of the depression suggest a potential association with the redundant sewage treatment works.

The Causeway

No records of the date of the construction of the causeway have been found though it is between 1584 and 1889, as it is included in the first OS map (Appendix 3). Runoff from the causeway itself drains directly into the Brook.

Land use and Drainage

By studying historic Ordnance Survey maps it is possible to assess some of the changes to the marsh and surrounding area in the last 120 years. Before 1889, Queen's Marsh was divided into four fields, with the first OS maps indicating the path of the brook in its current situation.

Between this date and the early 1930s Queen's Marsh was agriculturally improved (drained and fertilised) to enable cattle grazing during drier periods. At present, the drainage ditches remain wet through the year. These appear to have been instated in two main stages;

- In the early 1930s, an initial ditch parallel with the causeway was installed along with the sluice and culvert under the causeway, after which it joins the brook. The culvert and sluice allow floodwater out of the marsh back into the Bidwell Brook on the other side of the road. The sluice structure also restricts floodwaters from the main River Dart inundating the marsh.

- The remaining ditches were installed on Queen's Marsh 1938 and 1954 together with water features (historic water cress beds) in the King Edward Stream, near the Lodge House.

Over this period the course of the Bidwell Brook appears relatively unchanged.

Devon County Council altered the line of the Bidwell Brook in 1970 ahead of planned roadworks to the A385 (referred to as A384 in letter), as referenced in a letter to the Estate Steward, from E.J Harding the Divisional Surveyor at the time (letter dated 5th January 1970 provided by Dartington Estate Archives). Necessary works suggested by the Estate Steward included widening of the brook and increased bank height and bank protection to reduce flooding in the marsh (letter dated 2nd January 1970 from the Estate Steward to E.J Harding, provided by Dartington Estate Records), however it is uncertain whether these works were carried out in full.

Letters and accounts from local residents about Queen's Marsh were sent to Dartington Hall Estate in response to a press release issued during this study. Many were invaluable for furthering our knowledge on the recent history of the site and an extract from one of these is provided below.

"As a child brought up on the estate and my step father, Bill Parnell, being the foreman of Barton Farm. I remember when he set to making drainage dykes in the Queen's Marsh to try and stop the lower drive from being flooded in the winter plus the lodge and thatched cottage. They even got a digger into the Bidwell to try and make it deeper and wider, but it still flooded." Pamela Sandry Gorman, local resident (early 1940s).

The following figures provide a series of historic maps dating back to 1805. The 1805 map (Appendix 3) has little detail, but does possibly infer the route of the Bidwell Brook at that time, along the northern edge before crossing the marsh to exit under the bridge to re-join the River Dart. More recent OS maps (Appendix 3) show the brook in or close to its current position.

3.3 Utilities

An initial search for utility information was made using the on-line asset search service 'LinesearchbeforeUdig Limited' (http://www.linesearchbeforeudig.co.uk, Enquiry Reference 7327455, 4th September 2015). Enquiries were also made to Dartington Hall Trust staff and organisations with responsibility for local utility infrastructure to determine whether or not assets are located within the area proposed for restoration.

These enquiries revealed that the following assets are present within Queen's Marsh and Bidwell Brook on Dartington Hall Estate property that may either be affected by, or have a bearing on, the proposed restoration work:

- Sewer Pipes (South West Water)
- Disconnected Underground Cable (Western Power Distribution)

Additional existing assets that may influence option selection include:

- A385 Road Drainage to the Bidwell Brook (Devon County Council)
- Outfall to the Right Bank of the Bidwell Brook (Puddavine Cottage garden).

At the time of preparation of this report, construction of a Bloor Homes housing development was in progress. To service this development, South West Water has proposed a new underground sewer to cross Queen's Marsh. As is the case with the existing sewers, the construction of this new infrastructure will have a bearing the range of restoration options that may be judged viable for implementation. Further information concerning this proposed new asset is included below.

3.3.1 South West Water

South West Water was consulted directly to obtain details of their local infrastructure. The water company maintains two underground existing sewers that traverse and run along Queen's Marsh. A 300mm diameter combined sewer pipe runs roughly parallel with the cycle and footpath located at the northern edge. A line of maintenance manholes is visible on the surface of the marsh along this route. A smaller 150mm diameter sewer which services properties at Puddaven Terrace runs from the southern edge of the marsh to join the main pipe opposite Buckham Park Copse. The approximate locations of these pipes are indicated in Figure 9.

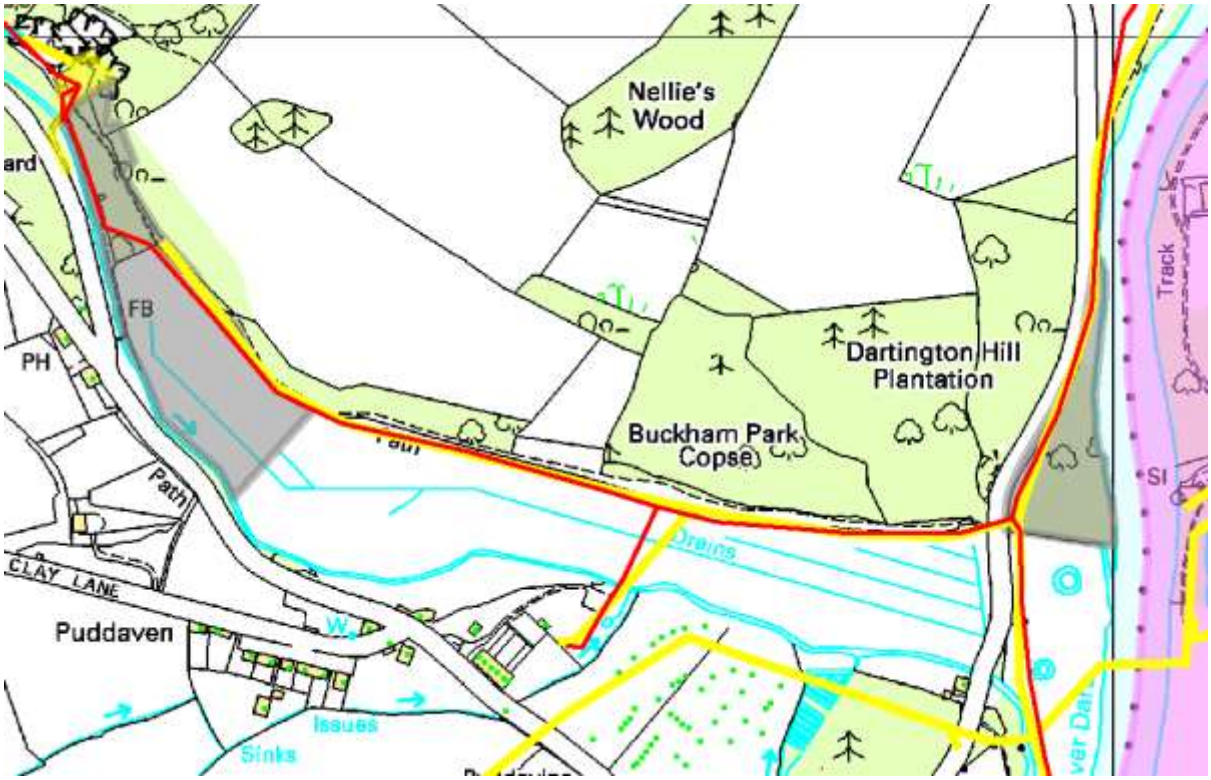


Figure 9 Indicative map of South West Water existing sewer pipe locations (courtesy South West Water 16th September 2015). Red lines indicate existing sewers, yellow lines indicate legal agreements. Note that the yellow line to the south of Queen's Marsh indicates the Roborough to Littlehempston water main, not a sewer.

The 150mm diameter sewer is exposed at a crossing of the Bidwell Brook (Figure 10). At this point, the pipe is constructed from ductile iron and is supported on, and partially defended by, a steel I-beam. The pipe and I-beam run across the brook below bank level: based on a cross section survey undertaken for this study, this structure reduces the cross section area of the brook at this location by approximately 30%.

Details of the invert level of the 150mm pipe at the join with the 300mm sewer at the northern edge of Queen's Marsh are not held by South West Water. The crown level of the 150mm pipe at the Bidwell Brook was surveyed as 4.59mAOD (Metres Above Ordance Survey Datum) (Figure 11). The left bank of the brook at this location was surveyed as 4.90mAOD. From this bank, the land drops towards the centre of the marsh; at a point 9.44m from the left bank, the land surface was surveyed at 4.60mAOD. These data suggest that the pipe is likely to run at a relatively shallow depth for much of its length, particularly near the Bidwell Brook and towards the low-lying land at the centre of the marsh.

Figure 10 Existing sewer pipe crossing the Bidwell Brook (NGR 279617, 61575).

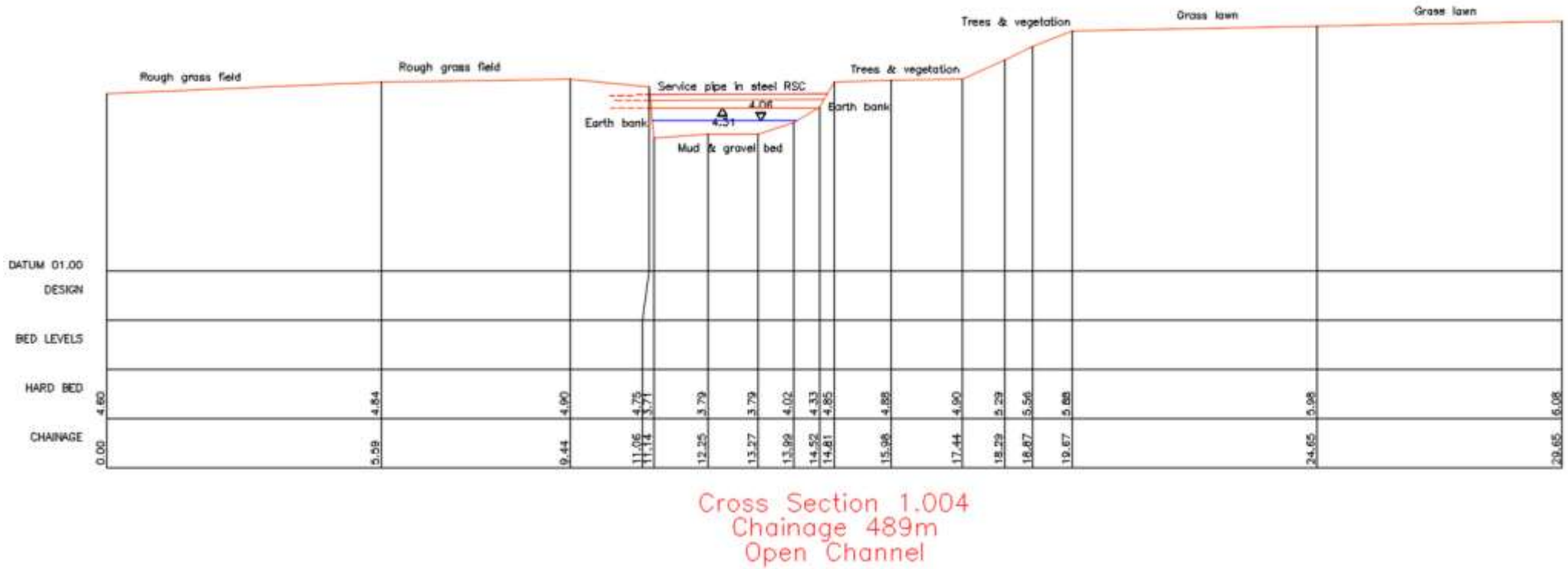


Figure 11 Cross section survey of the existing sewer pipe crossing. AP Land Surveys, September 2015.

3.3.2 Western Power Distribution

The utility enquiry revealed that assets logged as the responsibility of Western Power Distribution are located at Queen's Marsh (Figure 13). Site inspection confirmed the presence of a small electric cable conduit crossing the Bidwell Brook (Figure 12). Direct enquiries about the underground cables as marked in Figure 13 were made to Western Power Distribution (Tony Lewis, Team Planner Plymouth Rural East) and the Dartington Hall Trust site electrician (Ian Price).

Both Western Power Distribution and Dartington Hall Trust confirmed that Dartington Hall Trust, and not Western Power Distribution, is responsible for the two conduits marked on the map and that both lines are disconnected. Tony Lewis provided written confirmation of this including an annotated map via email on 18th September 2015 (Appendix 4).

Figure 12 Western Power Distribution disconnected power cable conduit crossing the Bidwell Brook (NGR 279790, 61526), highlighted with dashed yellow line.

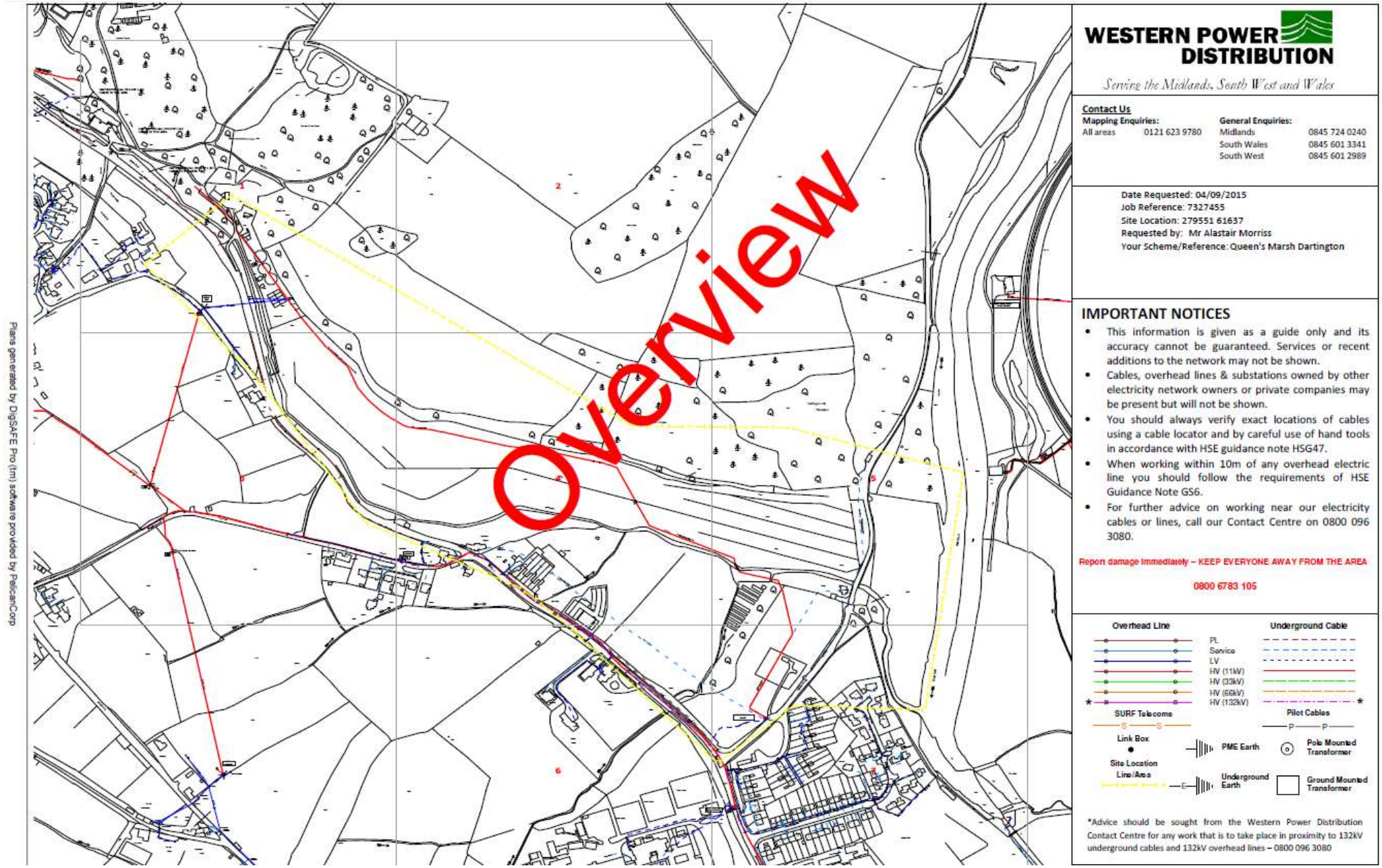


Figure 13 Western Power Distribution asset map as logged on 'LinesearchbeforeUdig'.

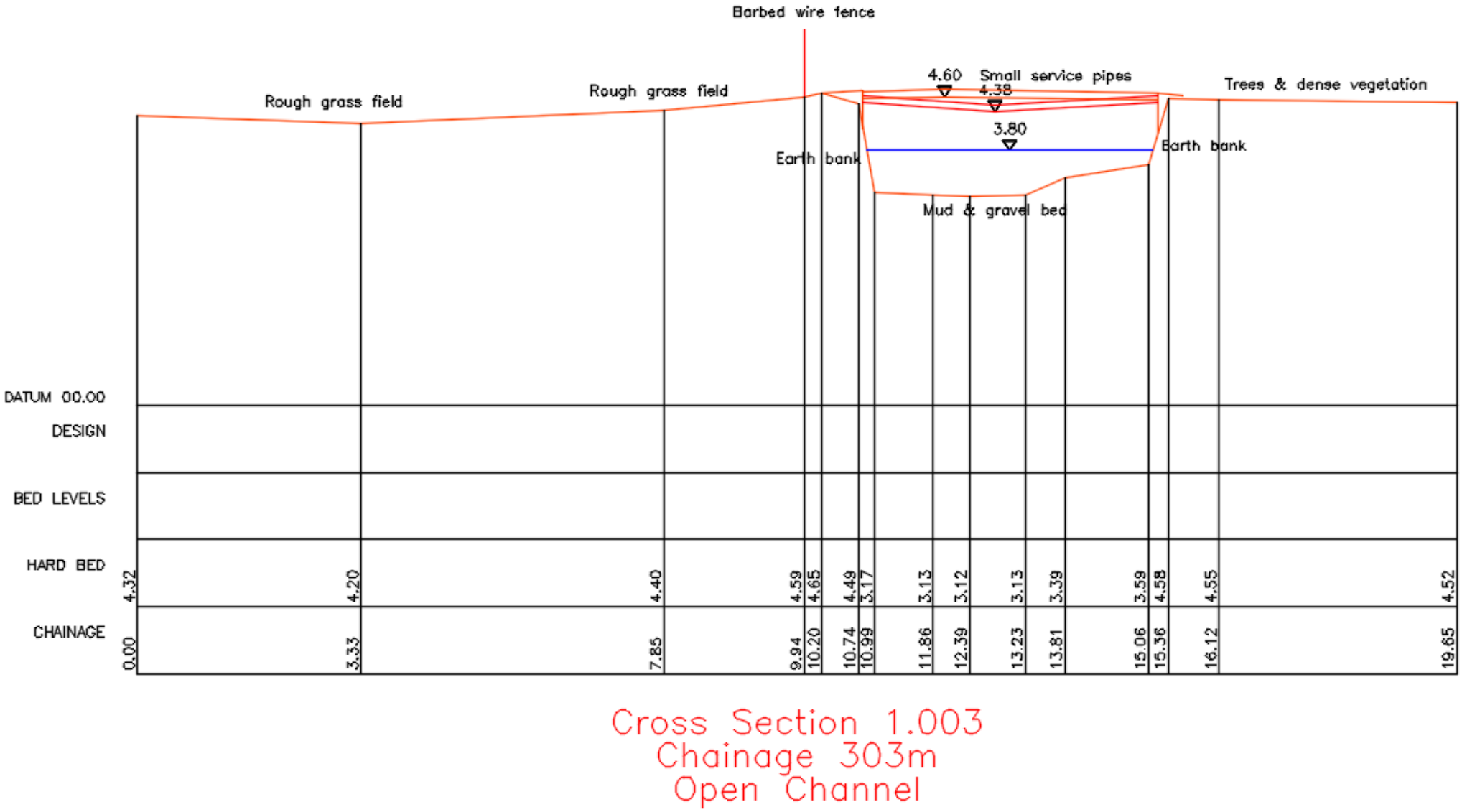


Figure 14 Cross section survey at disconnected electric cable, crossing the Bidwell Brook. AP Land Surveys, September 2015.

3.3.3 Devon County Council

Verbal and written enquiries were made to Devon County Council in an attempt to determine whether or not the Local Authority maintains drainage assets outfall to the Bidwell Brook from the A385 road (Ashburton Road). Enquiries made during the course of this study were inconclusive: Devon County Council is aware of road drainage along the A385, but maintains no records of the locations of these assets or the points to which they discharge (correspondence recorded in Appendix 5).

The Devon County Council Neighbourhood Highway Officer ~~suggested that~~ a camera survey be undertaken to locate any drainage assets and that remedial works be conducted as part of the restoration project if road drainage may be impacted.

3.3.4 Other

Site inspection of the Bidwell Brook revealed an outfall of unknown origin to the watercourse located on the right bank bordering the garden of the thatched cottage at the Clay Lane – A385 junction (approximate NGR 279463, 61552). If this outfall may be impacted by any option taken forward for detailed design, it is recommended that the owners of Puddavine Cottage are approached to attempt to establish whether or not this outfall drains from their property and, if so, the nature of any discharge from it.

3.4 Fluvial Flooding

The flooding aspect of this feasibility study principally considers flooding from fluvial sources from the Bidwell Brook and its connection to the Queen's Marsh floodplain. However, it should be noted that seasonal flooding may be influenced by surface water drainage (for example, from rainfall directly onto the marsh surface) and by groundwater. Examination of the extent of likely contributions to flooding from these sources was beyond the scope of this study. Further work may be necessary to examine probable influx from groundwater (known to affect the lodge at the entrance to the Dartington Hall estate) and the interaction of fluvial and groundwater sources in flood events when considering implementation of the preferred option.

The existing Environment Agency flood map (Figure 16) suggests that few properties are affected by fluvial flooding linked to the Bidwell Brook. A single building is shown to be at risk - the residential lodge at the gate to the Dartington Hall estate. Discussions with Dartington Hall estate staff revealed that the lodge can be affected by fluvial flooding, believed to be caused by a combination of high levels on the Dart and the Bidwell Brook, in addition to reported upwelling from groundwater from beneath the house.

Figure 15 Flooding to lower area of Queen's Marsh on 30th October 2015. Courtesy Harriet Bell, Dartington Hall Trust.

Though no further buildings are at risk from the Bidwell Brook in the Queen's Marsh area, the garden of Puddavine Cottage (approximate NGR 279463, 61552) on the right bank of the watercourse is shown to flood, as is the causeway (Dartington Lane) which is also subject to flooding at relatively low return periods. Several properties to the right bank of the Bidwell Brook downstream from Dartington Lane (the north east margin of Swallowfields) are believed to be at risk of flooding from the Dart. Since backwater from high levels on the Dart increases flooding across the left bank of the brook which prompts storage of floodwater in Queen's Marsh, these properties are judged likely to be relatively unaffected by discharge from the Bidwell Brook.

Outline reach and site-specific hydraulic modelling was conducted as part of this feasibility study. (Further details of the modelling approach adopted for the restoration work are outlined in more detail in Section 6.). Using data provided for and collected during this project, an effort was made to replicate and examine the existing flooding mechanisms from the Bidwell Brook.

Previous Environment Agency modelling work conducted to examine flood risk from the River Dart in Totnes (which included a short reach of the Bidwell Brook in Queen's Marsh) was conducted at a relatively broad scale (Figure 16). The model constructed as part of this restoration feasibility study included finer detail of the terrain of the marsh and a more extensive, though still limited, series of cross sections and survey data to better represent the brook. A key refinement of the latest modelling work was inclusion of the culvert and sluice structures which drain Queen's Marsh at Dartington Lane. These structures were not represented in previous hydraulic analyses.

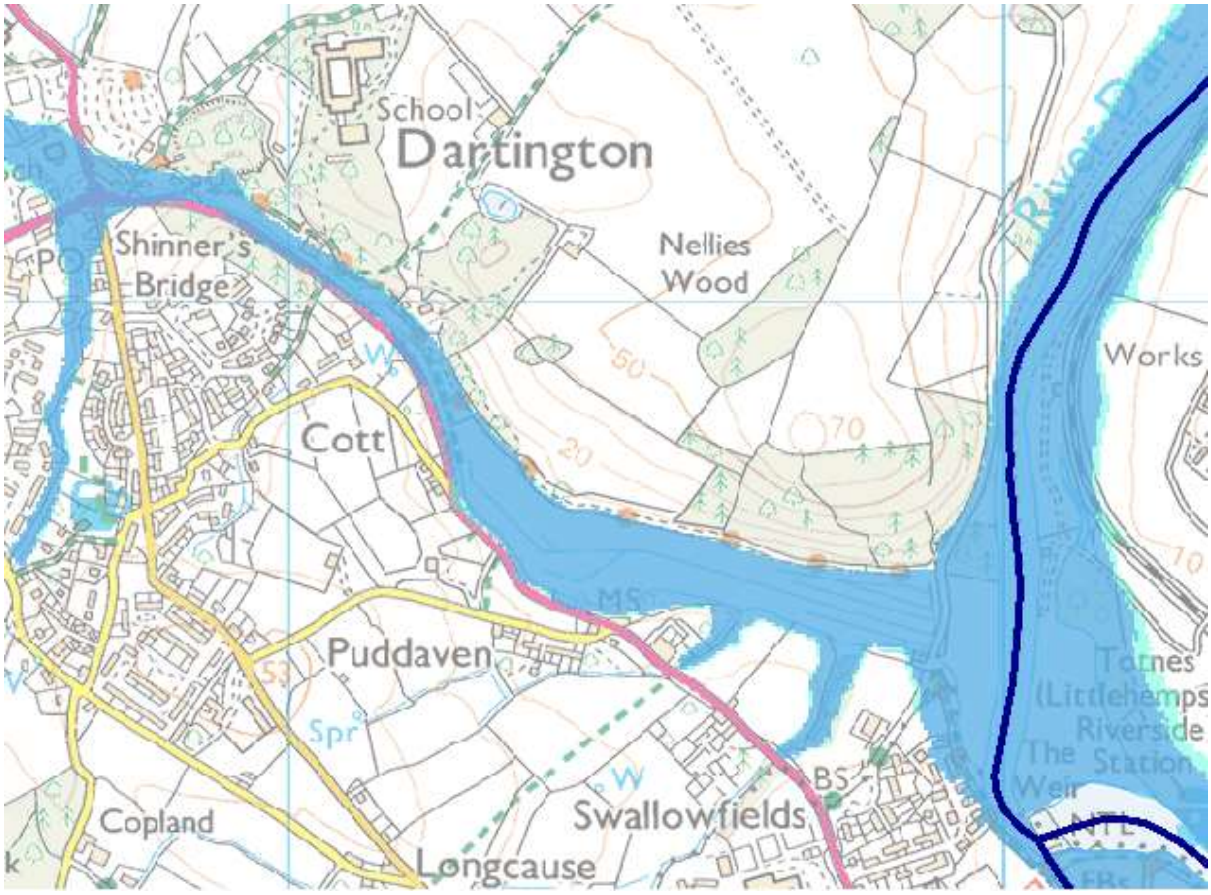


Figure 16 Environment Agency broad-scale flood map for Queen's Marsh.

The non-return gate, culverts and weir structures at Dartington Lane (Figure 17 and Figure 18) play a significant role in controlling both drainage and flooding of the lower marsh area. The gate structure is flapped and set to prevent backwater flooding due to high water levels at the culvert exit extending to the marsh via the right hand barrel (which has a lower invert level than the two adjacent ungated conduits). Spill into and from the two left hand culverts only occurs once the level of the concrete weir at their entrance is exceeded. Dartington Estate staff report that this weir feature was installed to reduce the regularity of flooding from the downstream side of the causeway (rather than to attenuate water in the marsh upstream). As can be seen in Figure 17, the gate to the right culvert is sometimes jammed open by debris.

Model simulations show that backwater can extend from the structure exit to overtop the weir structure at the entrance from high levels on the brook at an early stage in flood events. This can be due to high flow events on the brook catchment as well as due to initiation of flooding driven by the River Dart. These structures also mediate the drainage of water from the marsh as flood levels recede on both watercourses – though this is not the only mechanism and floodwaters also drain directly to the Bidwell Brook as levels on the marsh drop.

Figure 17 Upstream face of the gate, weir and culverts at Dartington Lane.

Figure 18 Single culvert downstream exit of the gate, weir and culverts at Dartington Lane.

The culvert structures, therefore, balance:

- Drainage from the marsh to the brook via the non-return gate when water level conditions at the culvert exit allow
- Drainage from the marsh to the brook via the left hand culverts in tandem with the non-return gate once weir levels are overtopped and conditions at the culvert exit allow
- Floodwater due to, or controlled by, high water levels on the River Dart which may convey water from downstream of Dartington Lane to Queen's Marsh via the left hand culverts once weir levels are overtopped.

The fact that backwater flooding from the structures can take place via overtopping of the weirs at the entrance to the left hand culverts may serve to reduce the probability of the road deck being

inundated when downstream water levels are high by conveying water to the lower marsh area and allowing storage here.

Site-specific modelling confirmed the dominant influence of the River Dart on the amount of water that inundates the study area in theoretical flood events. Flood extents from simulations of the lowest return period examined from a flooding perspective, the 1 in 2 year return period or 50% Annual Exceedance Probability (AEP), are presented in Figure 19, Figure 20 and Figure 21.

Figure 19 shows the maximum flood extent at this return period due to flooding from the Bidwell Brook only. In this simulation, levels on the River Dart have been set to a constant level (the initial condition from a flood model in which both the brook and the Dart have been simulated) in order to isolate and allow examination of the impacts of flooding from the brook. Figure 20 also shows the maximum extent from this event but with the flow on the Bidwell Brook set to a constant condition (the initial starting flow from the 1 in 2 year event) paired with water level results for the right bank of the Dart, including the Bidwell Brook confluence, in order to isolate the impacts of flooding from the River Dart. Figure 21 shows a combined Bidwell Brook and River Dart flood by the maximum flood extent for the same event. This is done by including a time series of water level results for the right bank of the River Dart, which has been extracted from the Totnes flood model.

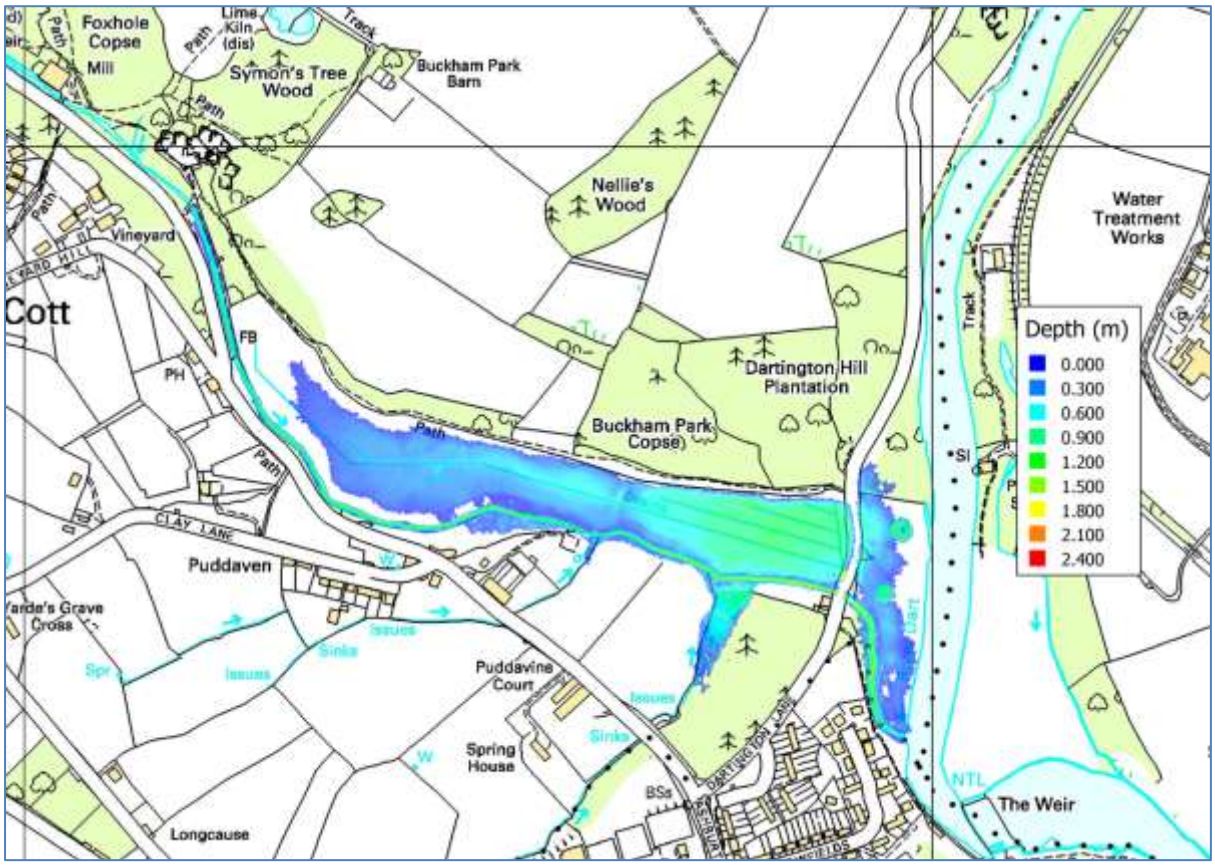


Figure 19 Existing 1:2 year Queen's Marsh fluvial flooding – Bidwell Brook only.

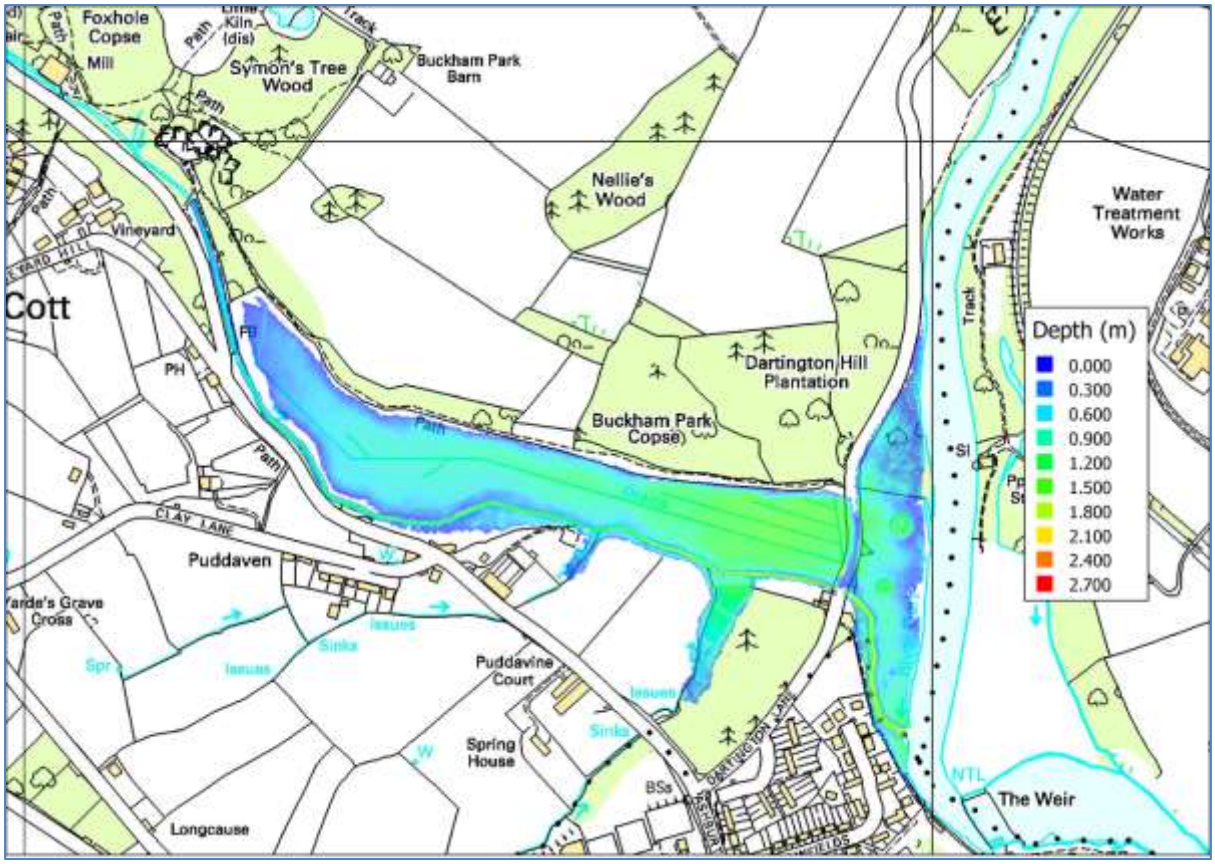


Figure 20 . Existing 1:2 year Queen's Marsh fluvial flooding – River Dart only.

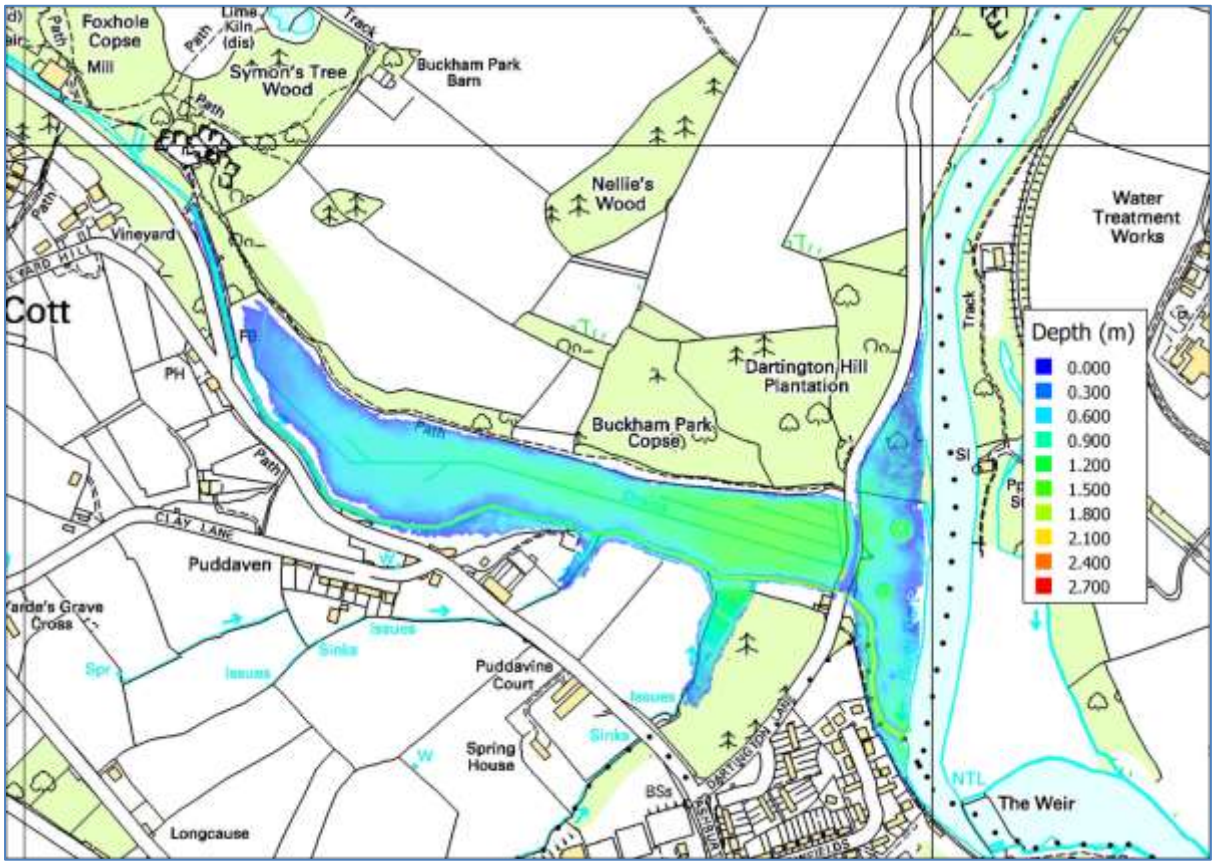


Figure 21 Existing 1:2 year Queen's Marsh fluvial flooding – Bidwell Brook plus River Dart.

Figure 20 highlights the key influence of the Dart on fluvial flooding at Queen's Marsh. Dart-dominated flooding is almost as extensive as the combined Bidwell Brook – River Dart and greatly exceeds that produced by the Bidwell Brook alone. This model (Figure 21) also demonstrates that, even at very low return periods, the flood extent produced by a Bidwell Brook and River Dart flood is very similar to that produced at higher return periods (Figure 16).

As discussed before, the lodge is already affected by flooding and is shown to be at risk from the combined 1 in 2 year flood in this scenario. Irrespective of event-specific anomalies (such as structure blockage for example), high rivers levels and overtopping of the banks of the Dart, as opposed to from the Bidwell Brook, is therefore judged likely to be responsible for initiating fluvial flooding to this property in the majority of events.

The outline modelling suggests that there may be some inundation of Berryman's Marsh from the Bidwell Brook channel in flood events linked to high flows at low return periods on the brook (in addition to backwater from the Dart). Simulations suggest that this water collects along the lower face of the causeway and may reach the two ponds in this area. Flooding to this location can also occur from direct overtopping of the right bank of the River Dart. In addition to these two sources, the two lakes in Berryman's Marsh may be fed by surface and groundwater. Dartington Hall staff report that these two waterbodies stay wet throughout the year and have not been known to dry up.

Though it seems likely that there is a hydraulic link between the Bidwell Brook and Berryman's Marsh, as suggested by model outputs, these results should be regarded with caution. The principal focus of this study is the Queen's Marsh area; cross section and elevation data used to define the course of the brook through Berryman's Marsh are sparse and a large degree of data extrapolation and estimation has been necessary to represent this length of the channel. Furthermore, the bank elevation data which have been derived from LiDAR may be unreliable along this highly vegetated stretch.

For this same reason, it is problematic to assess the influence the woody vegetation that encroaches on the lower reaches of the brook without collection of additional data. Whilst in-stream vegetation may have some impact on the discharge of the brook, it is thought unlikely that this will be the governing factor linked to flooding and/or drainage at Queen's Marsh. Model simulations suggest that it is the backwater effect of the River Dart that exerts the largest influence on flooding and drainage upstream; less so, the condition of the Bidwell Brook channel.

The outline model results also suggest that use of the Queen's Marsh area for additional flood storage of water from the River Dart, in addition to the Bidwell Brook, during flood events would be likely to increase the frequency and severity of flooding to the lodge.

4 Constraints and Opportunities

4.1 Biodiversity & Ecology

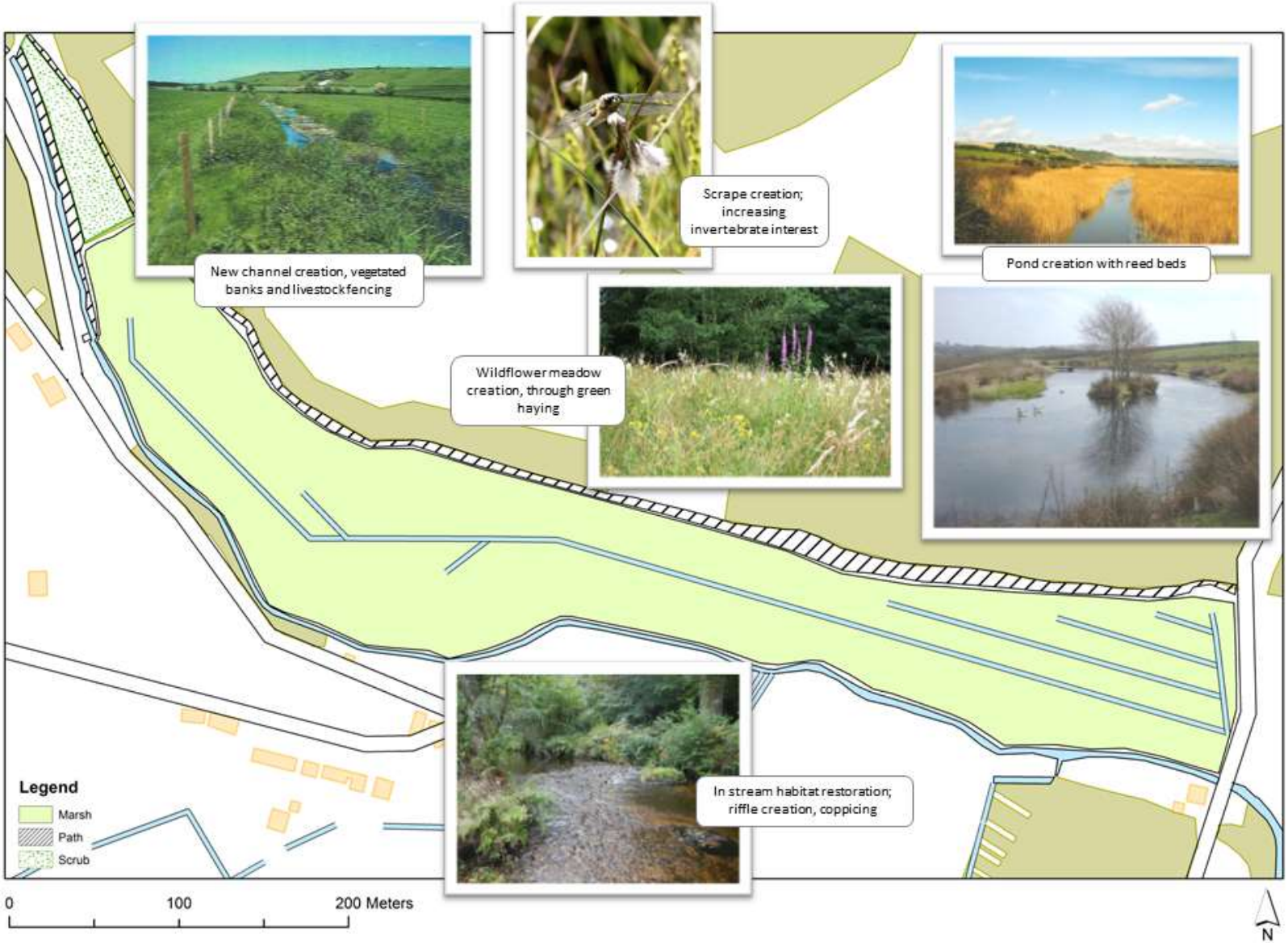


Figure 22 Map to show biodiversity and ecology improvement opportunities within Queen's Marsh.

Regarding biodiversity and ecology, there are limited ecological constraints on site in terms of the location, type or extent of interventions. The main constraints relate to timing, with regards to in-channel works relating to fish (bank works are best undertaken in spring-summer where there are low water levels and to avoid the sensitive spawning and emergence seasons for species such as salmon and trout). Following bank works some bank protection may be required, such as coir matting before bankside vegetation re-establishes. Works should also avoid the clearance of trees and scrub within the main bird nesting season where practical (i.e. outside of March to September); where this is not possible, clearance of vegetation providing potential bird nesting habitat should be undertaken under an Ecological Watching Brief in order to identify any active nests. This relates primarily to trees along the brook corridor, and scrub within the enclosed western area of the site, although other considerations are likely to preclude significant groundworks in this area. In addition the presence of Himalayan balsam, a non-native invasive species, will need consideration within any ground works, to include treatment of affected areas (likely through spraying) and avoidance of moving soils off-site. All works on site will need to conform to good working practices during the creation of any habitat features and channel restoration/creation, such as adherence to the Environment Agency's Pollution Prevention Guidance and consideration to temporary fish rescue if any dry working areas are required. This would be further considered following the finalisation of the design and liaison with appropriate environmental contractors.

There are a wide range of potential ecological enhancements that could be implemented across the site. The final choice of measures is likely to be driven by budget, existing commitments relating to the agricultural management of the site and HLS targets, and the geography and hydrology of the site, including soils, topography, water tables and flooding regime. All of these will affect the floral communities that are likely to establish successfully on the site and the subsequent management requirements of the habitats.

Given the species-poor nature of the sward, which is currently dominated by a low number of competitive grasses, and the current grazing regimes on the site, it is considered impractical to enhance the biodiversity of the entire sward through measures such as wildflower sowing in order to create a wildflower meadow, and therefore it is considered that targeted enhancement would provide the most appropriate means of increasing biodiversity on site in the long-term. A range of different interventions would provide a mosaic of habitats across the site, allowing significantly greater structural and species diversity than currently exists.

Given the hydrological data obtained to date this indicates a habitat with frequent and significant flooding episodes. It is therefore essential that habitat creation include features that are able to tolerate this level of inundation, especially within low-lying areas more prone to standing water, such as the north-east corner of the site. A range of potential habitat features are outlined below, including both in-channel and in-field options.

Habitat Creation

Scrapes

Scrapes are shallow depressions with gently sloping edges, which seasonally hold water. They create obvious in-field wet features that are very attractive to wildlife. They support a wide variety of invertebrates and can provide feeding areas for a range of bird species including waders, as well as other wildlife such as bats and reptiles. It is optimal to create a 'cluster' of scrapes of varying sizes

and topography to provide the greatest benefits for a range of wildlife. The most important parts of scrapes for wildlife are the margins, and edges should always be very gently sloping and with irregular and varied outlines. Scrapes would ideally be a minimum of 20m2 and would have a range of undulating depths. Shallow scrapes can have depths ranging from just above normal water levels to approximately 0.4m below normal water levels, and other scrapes could include areas of deeper water up to 2m deep. The final levels will be dependent on topography, ground water levels and areas available.

Wildflower Meadow Areas

The shallow margins of the scrapes and between the cluster of pools would be a suitable area to target areas of floristic diversity, such as marshy grassland and wildflower areas. It is recommended that the topsoil is stripped from these areas during the creation of the scrapes, to remove existing competitive grasses and lower the existing nutrient content of the soils. The soil tests undertaken at the site indicate that Phosphorus levels are suitable for establishment of a more diverse floodplain plant community, and that pH levels indicate neutral to slightly acidic soils.

There are a range of options for grassland creation, including leaving the areas to establish naturally, seeding or plug planting. Where budgets allow it is recommended that some form of seeding/planting is undertaken as this is likely to encourage a much faster establishment of a more diverse plant community. Plug planting provides immediate results but is expensive, whilst seeding is effective if undertaken correctly and with appropriate follow-on management. The timing of seeding will be crucial on site given the risk of flood water inundation. Given the presence of wet grassland sites within the estate it is considered that green hay could be used to seed these stripped areas at minimal cost, and ensuring the use of local provenance seed. Discussion with the Conservation Warden indicates that Higher Marsh could be a suitable donor site for green hay, but assessment of this area would be required to ensure that suitable species are present within the marsh. A spring cut of hay would be taken from the appropriate donor site and laid over the prepared ground surrounding the scrapes. This can be a very effective technique to import wildflower seed from nearby sites and increase the diversity of plant species within the sward. Consideration may be given to the addition of seed from a commercial mix suitable for the site (such as Emorsgate EP1 Pond Edge Mixture or Emorsgate EM8 – Meadow Mixture For Wetlands). The existing CWS designation indicates some areas of M27 grassland were present in the 1970s – this community is a mire community indicating frequent inundation and significant periods of wet soils. The CWS designation also refers to a wider area of relatively species-poor floodplain, and it is not known exactly where the M27 community was recorded. Given timing and budgetary constraints it has not been possible to model in detail the likely periods and frequency of inundation across different areas of the site, and this may be a consideration prior to the detailed design stage in order to ensure that the most suitable plant communities are targeted for establishment on the site. Floodplain meadow communities such as MG4 can tolerate water levels around 40cm below ground for much of the year, and 20cm in January/February, but will not withstand prolonged inundation. Information to date indicates that the site is likely to support communities more associated with grazing marsh and rush pasture than wildflower meadow communities, however these may be established on drier sections of the site.

Management of the establishing grassland will be key, and establishing vegetation may need initial cuts to reduce annual weed growth. It is anticipated that the site will continue to be grazed, and

where low stocking rates can be achieved the site can be grazed all year round, however it may be prudent to include temporary fencing or gated access, and limit or prevent grazing of the wildflower areas between spring and July/August to allow the flowers to establish and provide more interest to visitors. Winter grazing is likely to be difficult across the wetter parts of the site due to frequent flooding, and could lead to significant poaching. Grazing and poaching of the scrape margins at low levels, however, is beneficial to a number of invertebrate species and will ensure continued diversity of the habitats.

Ponds

An area of deeper permanent water should be considered as this is likely to attract a range of bird species, and form habitat for invertebrates and foraging bats such as Daubenton's and the rare barbastelle. This would also provide a good focal point for visitors and would provide a suitable location for public enjoyment facilities such as a hide. The pond would need to be sited carefully to avoid significant silt inundation where possible. Consideration could be given to the establishment of reed bed to provide some protection against siltation, and also to provide screening and nesting habitat for birds. Ideally the pond would be around 2.5m maximum depth, to ensure permanent open water and prevent colonisation of the whole surface by marginal plants. Consideration may need to be given to plug planting of aquatic and marginal species to provide immediate impact and cover around the pond. Depending on the size and extent of the pond, consideration could also be given to the provision of islands to provide feeding and nesting habitat for birds as well as more open habitat suitable for some marginal wetland plants.

Reed bed

Establishment of reed bed habitats would provide additional structural diversity to the site, and provide valuable cover and breeding habitat for a range of wildlife including birds, invertebrates, otter and water shrew. Reed bed is usually permanently wet and dominated by a monoculture of common reed. This could be established as a screen around the edge of the deeper water on site, such as a large pond, to aid silt filtration. There is also potential to create patches of reed-fen areas on drier ground that is periodically flooded, and this would aim to include a more diverse plant community including a range of tall herbs and marginal species. Reeds prefer to grow in water levels around 5cm – 1m deep, but will also tolerate damp soils with water around 5cm below the surface. There are a range of methods for establishing reed bed, including seeding, rhizome transplantation and planting of pot grown plants. Whilst planting pot grown common reed is more time consuming and expensive that seeding, this offers a much higher rate of success, especially within areas where water inundation cannot be controlled, such as the Queen's Marsh site, and therefore it is recommended that this is a consideration for establishment unless local sites can provide a good source of rhizomes. Planting should ideally take place in late spring after the last of the frosts. Netting is likely to be required whilst the reed bed establishes, to prevent grazing by stock and other species such as geese. Once established grazing is likely to help to control spread of the reed and maintain areas of open water, but occasional cutting on rotation may be required.

Scrub

Areas of scrub planting such as willow, hawthorn, blackthorn, and dog-rose could be considered on site to provide additional cover as well as sustaining a rich invertebrate population and providing over-wintering cover for amphibians and reptiles. This may be restricted to the existing western end of the site where good scrub cover already exists, or consideration could be given to planting

additional areas for screening/cover, such as along the fence adjacent to the footpath and along the roadside. This would need to be managed to prevent encroachment into the field.

Wet Woodland

Willow, alder and birch thrive in poorly drained, seasonally flooded areas/floodplains, growing together to make wet deciduous woodland. Wet woodland provides vital cover and breeding areas for mammals like otters, and also supports numerous bat species including pipistrelle, brown long-eared and noctule bats. Small areas of wet woodland in Queen's Marsh would be beneficial to the biodiversity of the site. Ideally, newly planted wet woodland areas should be fenced to promote natural regeneration and left un-grazed to avoid damage to ground flora from trampling.

There are opportunities to create wet woodland on the Queen's Marsh site; however this may need to be balanced against the retention of sufficient open grassland to maintain viable grazing on site and the need to create open un-shaded areas of channel along the brook. One option may be to create wet woodland on 'island' habitats created by any new meanders or channels within the site, as this would provide a restricted area of planting, or small areas could be planted close to the King Edward stream outfall to connect with existing wet woodland on the adjacent site. Ideally the woodland would be fenced to encourage natural regeneration and the development of ground flora Tree planting may also be beneficial around the large standing water area to provide screening and reduce disturbance to waterfowl. Screening planting is suggested along the footpath and causeway, with gaps left for public viewing at intervals.

In Channel Opportunities

The existing channel is heavily over-shaded for much of its length, with very limited bankside and aquatic vegetation, and limitation variation in channel flows and in-channel features. Soft engineering and creation of optimal pool riffle sequences could significantly improve the existing habitat for a range of wildlife including invertebrates and fish. Selective riparian coppicing along the channel would create a mosaic of light conditions to encourage a more diverse bankside and aquatic flora. The brash from these works could be used to create additional habitats on site. Dead wood associated with water provides a specialised habitat supporting a number of invertebrate species, and consideration could be given to the provision of woody debris habitat within the channel at targeted points. Flow deflectors may also be appropriate where it is unfeasible to significantly alter the existing channel, to assist with altering in-channel flows and the creation of channel variations. Diversity in channel flows and habitat would lead to improved conditions for wildlife including a wide range of invertebrates such as mayfly, midges, stoneflies, worms and caddis, which in turn support a range of fish species.

4.2 Historical Features

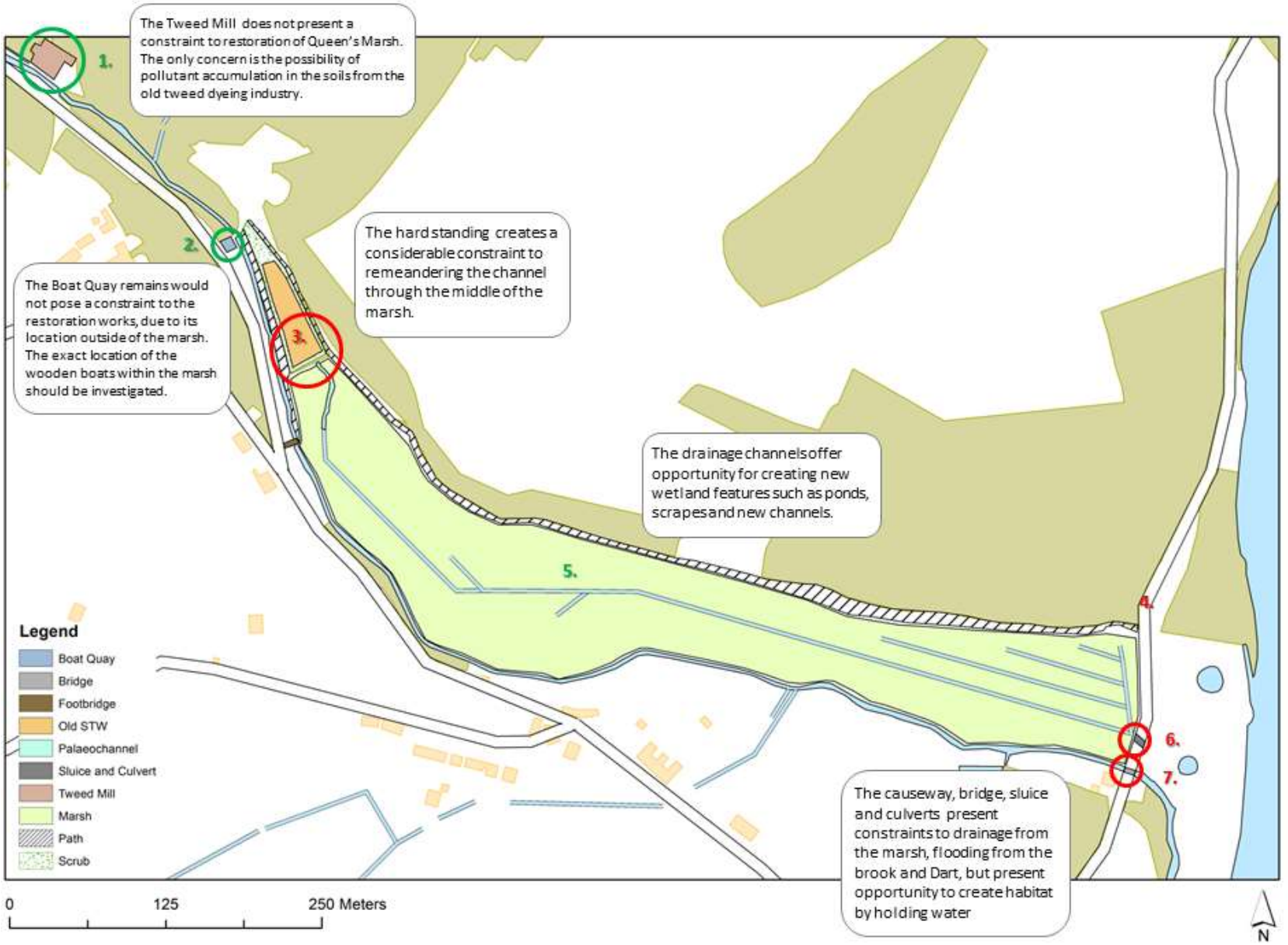


Figure 23 Historical features constraints and opportunities, red circles and numbers indicate those features which present constraints to the project, green circles and numbers indicate those features which present opportunities or no constraint.

Details of the constraints and opportunities of the historical features have been mostly covered in other sections of the reports from a biodiversity or fluvial risk point of view. The hard standing presents the most significant constraint of these features; excavation of this hard standing would add considerable costs to the restoration project, especially with an unknown depth of concrete.

4.3 Infrastructure & Utilities

The existing infrastructure that was identified during the course of this feasibility study have a bearing on the potential for restoration of the Bidwell Brook and Queen's Marsh. Details of some of these items have been previously summarised in Section 3.3 Utilities. Discussion of the potential constraints and opportunities presented and offered by these features is presented below.

4.3.1 South West Water: Existing Sewer

Though the precise depth of the existing sewer pipe below the marsh surface is unknown, it is likely that South West Water's requirement for a minimum depth of fill above a pipe (900mm) will act as a constraint to the amount of material that can be excavated above this structure. The pipe is likely to be buried to a relatively shallow depth, particularly towards the lowest terrain at the centre of the marsh and towards the left bank of the Bidwell Brook where pipe elevations are highest (see Figure 11).

Were the pipe to be exposed during restoration (an option that will have implications for, and would require discussion with, South West Water), it is likely that a replacement section of ductile iron would be required and/or that the pipe be encased in a concrete surround for protection. This may mean creation of a barrier to free passage of water across the marsh or any new channel proposed as part of the restoration. The Bidwell Brook is known to carry a high fine sediment load in times of flood and there is likely to be increased deposition upstream of any discontinuity in gradient. Furthermore, it is considered unlikely that creation of an area of standing water above this pipe would be favourable. Further consultation with South West Water will be essential to establish the extent of this pipe as a constraint and what is viable on selection of a preferred set of options.

Model outputs suggest that the fill above the existing sewer pipe trench is slightly discontinuous with the surrounding gradient of the land. Simulations show that an area of shallow standing water forms above the line of the pipe as the marsh drains from a fluvial flood event (Figure 24). This discontinuity and attenuation of drainage may create more favourable conditions for the introduction of small, seasonally wetted scrapes above the line of the pipe that may hold water from fluvial drainage, rainfall and any groundwater influx.

Since it is unlikely that the existing pipe bridge could be reconfigured or removed without great expense, restoration work is likely to need to accommodate the continued presence of this feature. Given the relatively predictable head loss across the structure, and the consequent flooding of adjoining land from overtopping of the left bank a short distance upstream, if needed, this location may be a suitable point at which to consider stabilising an offtake to feed water into the marsh and any open water / wetland features created as part of the restoration work.

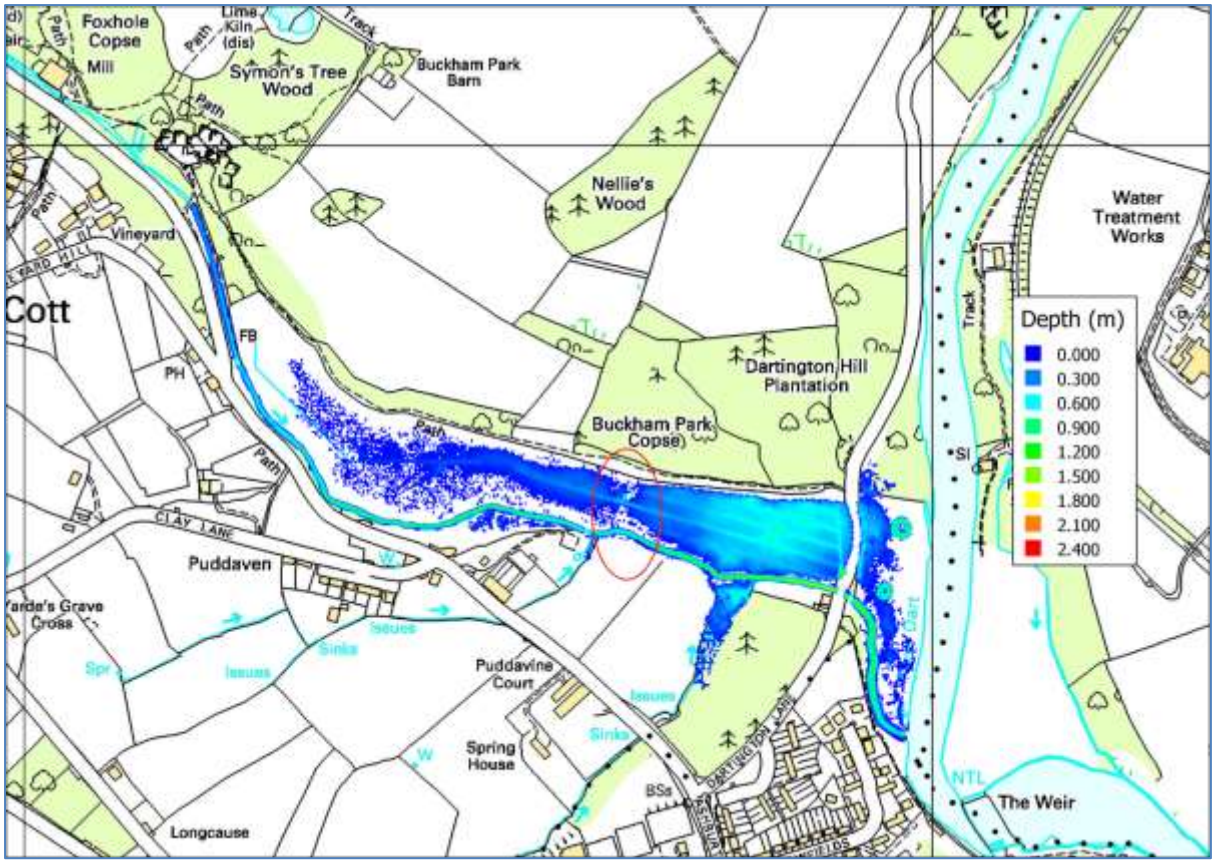


Figure 24 Recession of 1:2 year fluvial flood event. Marsh drainage attenuated by terrain above existing South West Water sewer pipe fill

4.3.2 South West Water & Bloor Homes Development

Consultation took place with South West Water and their contractors, Aqua Tech and Courtier Utility Services Ltd (with whom a meeting was held on site), regarding a proposal to install a new sewer across Queen's Marsh. Designs for the new sewer (Figure 25) show a gravity-fed 150mm diameter pipe running to the pipeline to the north of Queen's Marsh via a separate route from the existing sewer (Figure 20). At the time of preparation of this report a requisition order had been served and it is understood that the new infrastructure may be in place imminently.

While the existing sewer crosses the Bidwell Brook via a bridge, the proposed new sewer plans involve burying the new pipe beneath the brook. This means that the cross section area of the brook at this location should be relatively unaffected by the proposal. The outline plan in Figure 19 shows that the depth of fill above the pipe is fairly shallow, particularly at the inverts of the existing linear drainage features.

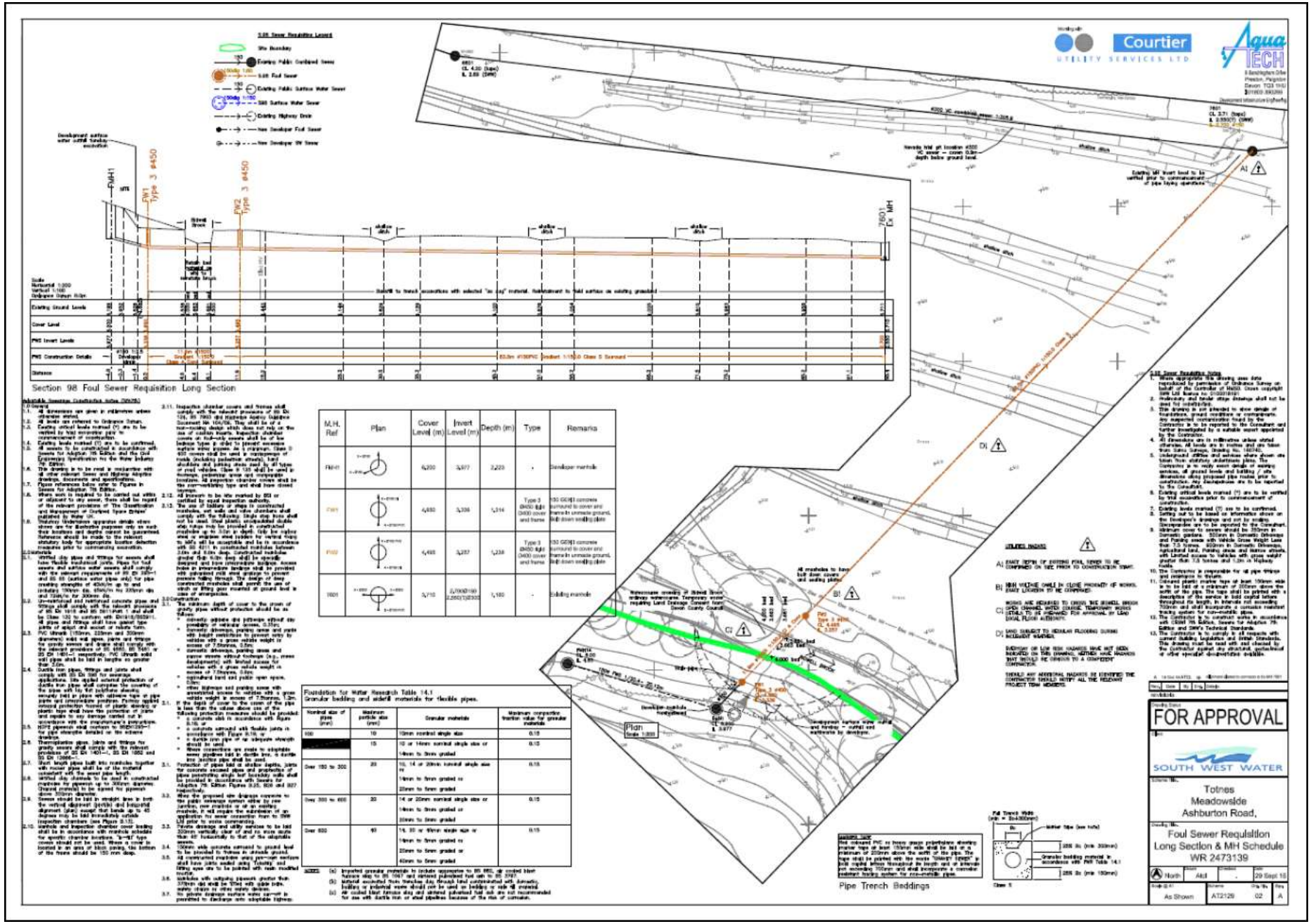


Figure 25 Proposed design for new sewer across Queen's Marsh to service Bloor Homes housing.

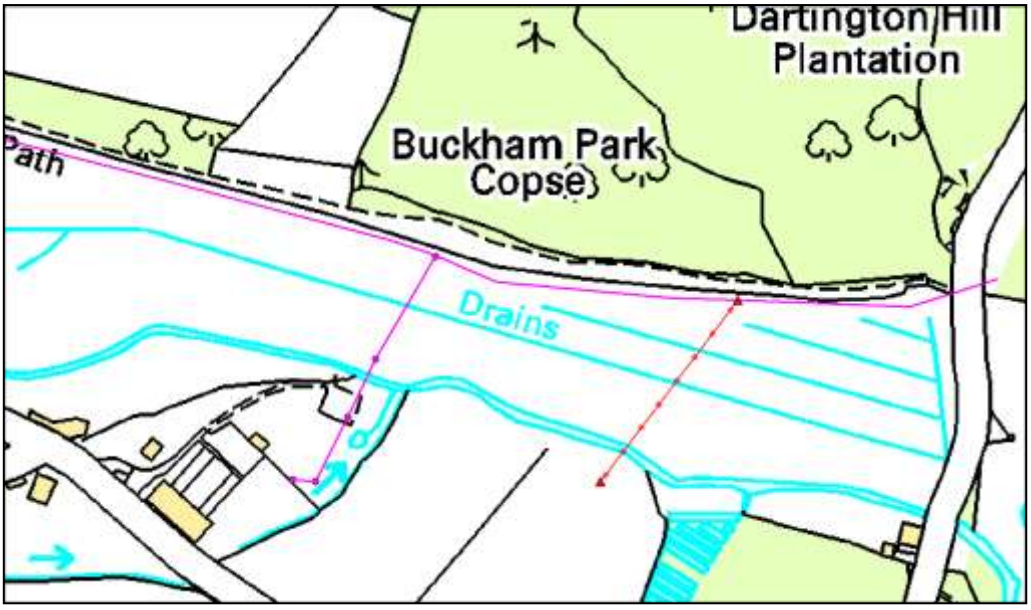


Figure 26 Proposed new sewer approximate route (red line, existing sewers in pink).

The same constraints apply to restoration works as stated in relation to the existing sewer. If an area of standing water is to be created in the north east corner of the marsh, the line of the new pipe may limit the western extent of any new wetland feature.

In addition to the new sewer, it is believed that the Bloor Homes development may have a requirement to discharge attenuated surface water runoff to the Bidwell Brook. If this is the case, any restoration work that has an impact on the channel itself is likely to need to accommodate a new outfall from the housing estate.

4.3.3 Western Power Distribution

Restoration work may provide an opportunity to remove the conduit carrying the cable across the Bidwell Brook (Figure 12). This would remove the constraint to flow that this feature currently presents and remove the possibility of vegetation becoming caught against it in when water levels in the brook are high. This may help to reduce any uncontrolled flooding from this location.

4.3.4 Devon County Council – Possible Road Drainage

As road drainage may exist that discharges from the A384 to the Bidwell Brook, a precautionary approach to proposals for restoration of this reach is recommended when considering options for installation.

4.3.5 Other

As with other outfalls discussed above, further information is required concerning the ownership and function of the outfall from the garden of Puddavine Cottage. Pending further details, as above, a precautionary approach is advocated in which any designs taken forward for implementation accommodate this feature and allow it to continue to function without impediment.

4.4 Fluvial Flooding

As the causeway, weir and culvert structures act as a constraint to drainage from the marsh, the regularity of fluvial flooding from both the Bidwell Brook and the River Dart may present an

opportunity to create additional habitat by withholding water in a large pond area in the north east corner (Figure 27). Potentially, this area could be 'offline' – i.e. fed only by flood events, rainfall and any groundwater influx – or 'online' – i.e. fed by an engineered link from and a return to the Bidwell Brook.

The often jammed gate suggests that there may be local concerns about the volume of water that ponds in this area that may be linked to flood risk or a desire to ensure drainage of the marsh to maximise land availability for livestock grazing. Consequently, rather than alter management of the gate structure to reduce drainage after flood events and to hold water back above existing ground levels, excavation of a pond area to accommodate marginal reed beds and deeper areas of standing water is likely to be preferable from a flood risk perspective.

Potentially, such an area could be fairly extensive, though the new sewer pipe will ultimately constrain the boundaries of a permanent wetland feature. Early consultation with South West Water suggests a pond or permanent standing water should not cover the pipelines. On the basis of this presumption, working with the likely constraints posed by the existing and new sewer pipes, it may be feasible to generate two or more pond areas in between infrastructure linked by a shallow channel (providing that the required minimum depth of fill can be maintained above the sewers).

The routinely wet area that currently forms directly upstream of the causeway may also provide an opportunity for the creation of conditions suitable to generate a variety of additional habitats – such as, for example, wet woodland as found directly downstream of Dartington Lane at the head of Berryman's Marsh. However, there is likely to be a need to balance the generation of new habitat for biodiversity gain with the function of Queen's Marsh as floodplain grazing for the tenant farmer. As outlined in Section 3.4, fluvial flooding, in addition to contributions from groundwater and rainfall, may create an opportunity for periodic wetting up of shallow scrape areas above the line of the existing sewer, an area at which drainage of the marsh is also attenuated.

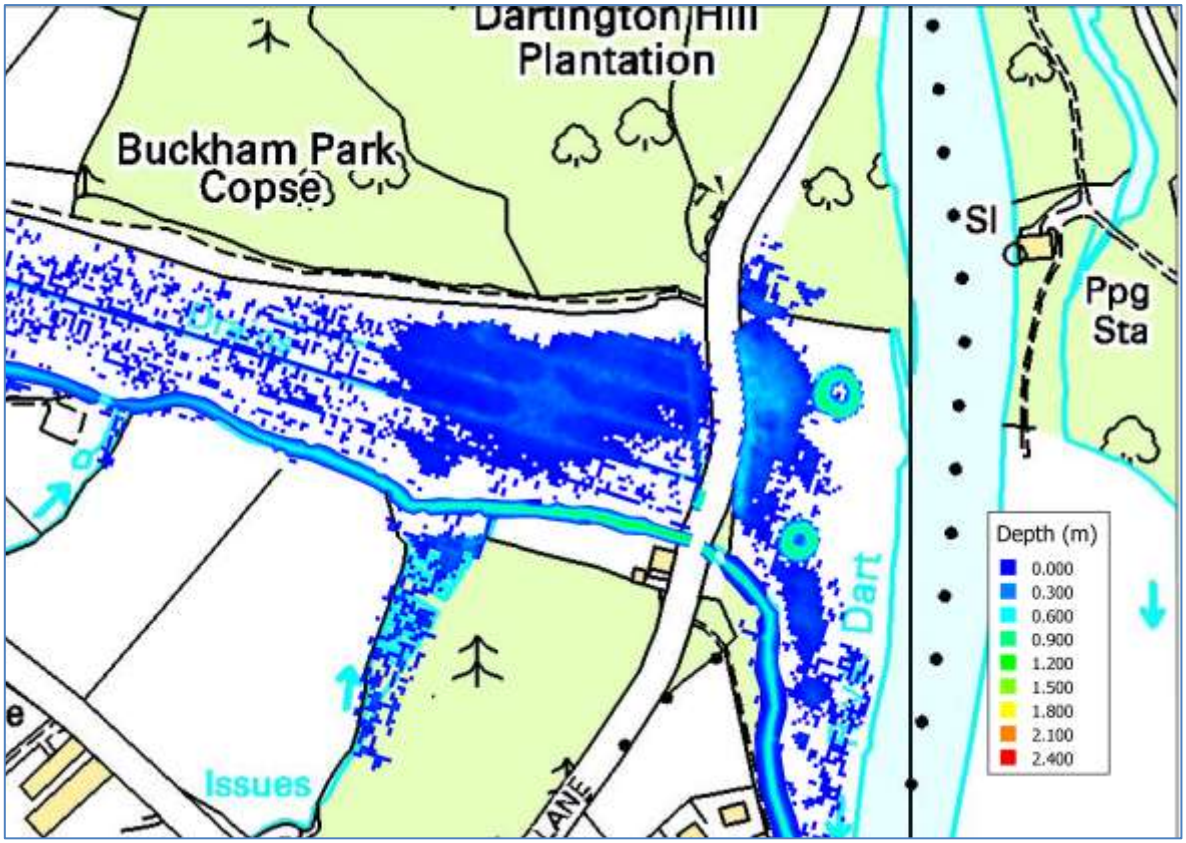


Figure 27 Example of attenuation of drainage of fluvial floodwater in the north east corner of the marsh. Recession of the Bidwell Brook only 1 in 2 year event

Irrespective of flooding from the brook, the large influx of water from the Dart in simulated and observed flood events is both an opportunity and potential constraint to what may be achievable in potential management or diversion of the Bidwell Brook channel. As the marsh is no longer free-draining – the causeway and associated structures hold water back after flood events which would otherwise drain more readily from the floodplain – diversion of the brook from its currently perched position to run at a lower elevation in the marsh centre may mean that any new channel in this location would be prone to sediment deposition, particularly in its lower reaches. Dartington Hall estate staff report that regular removal of sediment from the existing artificial drainage lines was part of routine land maintenance in this area (though it is understood that this has not been the case for the past 9 years).

The brook is known to carry a high fine sediment load (currently the subject of a Plymouth University study) and it is likely that attenuation of discharge from any new lower brook channel due to inundation of the lower marsh will increase local deposition and reduce drainage efficiency. Any attempt to re-engineer the Dartington Lane culvert structures to allow a new brook channel or standing water to drain more freely to reduce the risk of sediment build-up and allow it to be conveyed downstream – e.g. by removal of the existing weir structure - may result in increased regularity of flooding from the Dart. A more dynamic system than that currently in place may be required to balance any new drainage, pond and channel management requirements if this area is re-engineered – i.e. one which reacts to Dart and marsh water levels more actively than the passive arrangement of a weir and one-way gate by allowing unimpeded drainage through all three culverts when conditions on the Dart allow.

While fluvial flooding creates opportunities for habitat creation on the floodplain formed by the marsh, these opportunities must be balanced with other land use and management concerns. A key constraint, as reiterated by the Environment Agency in the course of enquiries made during this study, is that no work will be permitted that increases flood risk to property – particularly the residences at the lodge gate house and Puddavine Cottage, the garden of which, but not the house itself, is readily inundated in all design flood events. These flood risk concerns extend to management of the river channel and banks for biodiversity gain in addition to re-engineering of the floodplain.

Figure 28 Queen's Marsh in dry (a) and flood (b) conditions. (Image credit: Dartington Hall Trust and Gillian Cartwright)

4.5 Enhancing Public Enjoyment

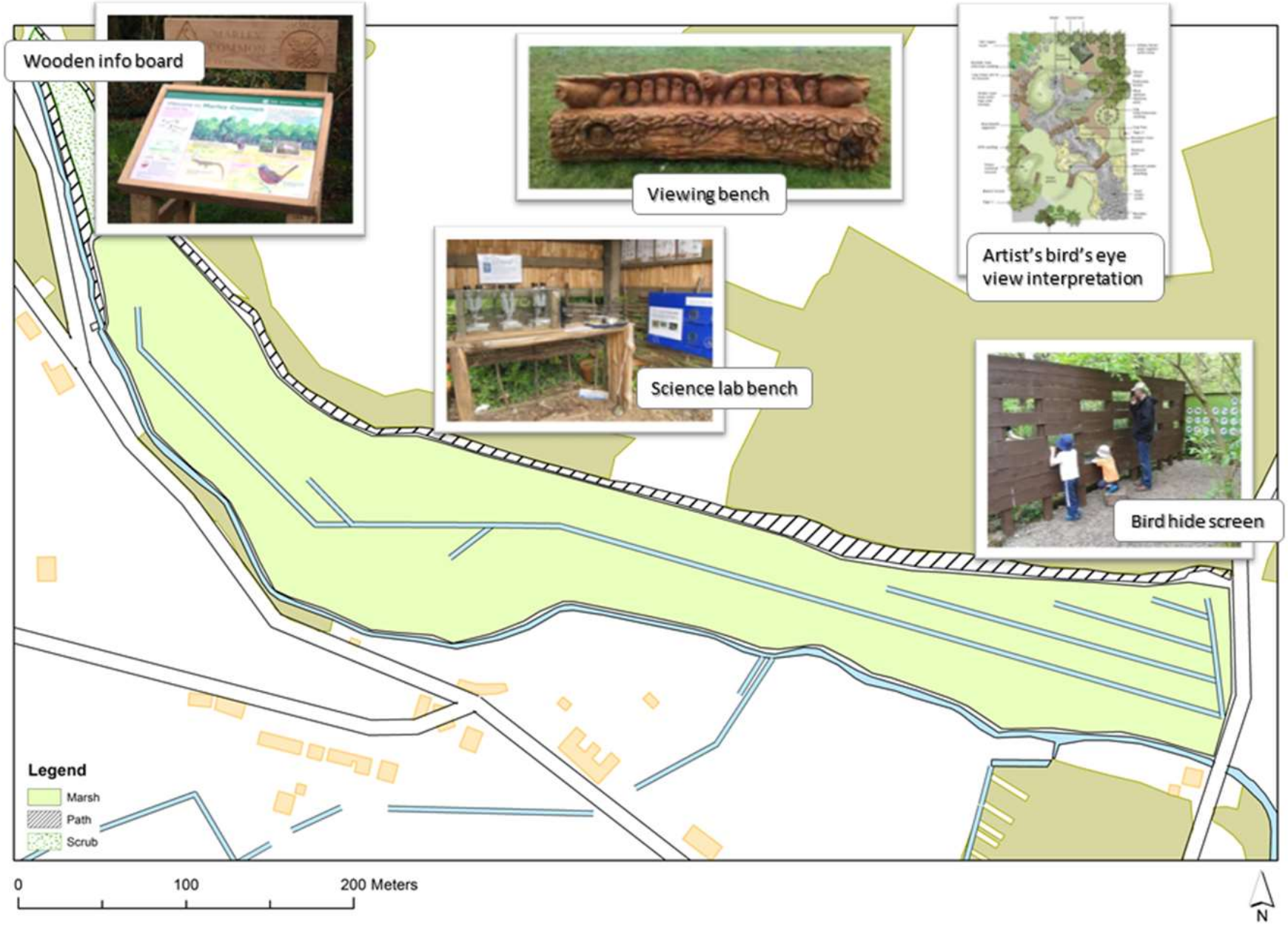


Figure 29 Map with images to show good examples of ways to enhance public enjoyment and enhancement on site.

With Dartington Hall estate open to the public and the Queen's Marsh visual from a very active cycle path; enhancing the local public's enjoyment and understanding of the restoration is vital to the success of this project. Unlike the physical restoration, there are limited constraints to the opportunities for enhancing public enjoyment at Queen's Marsh, other than budget, preference and location.

There are several models and approaches to public enjoyment that would be relevant to the Queen's Marsh restoration project, be it signage boards, benches, or bird hides, some of which are highlighted in Figure 29 above. Whichever method or combination of methods is preferred and most suitable, engagement with local public will be particularly important before and during the restoration project, not just after works are complete. This will enable Dartington Hall Trust to communicate effectively in a clear manner, particularly to explain on site activity and initial disturbance and how the site will change and progress.

Any engagement should be aimed at all age ranges, and be accessible to all. With the cycle and foot path running alongside the northern edge of Queen's Marsh and the other estate paths, creation of wildlife walks could increase visitor interest to the wider Estate. Interpretation panels could be used as a way to relate information to visitors and passers-by and educate them on the history and facts of the places and points of interest.

Signage creation could create links with the wider art community within Dartington and Totnes. Carpenters could be used to carve tactile wooden signage or elaborate viewing benches. Artists could be used to illustrate the wildlife, habitats and site for signage boards. Drawings are much better at illustrating and portraying a message than photos. Willow weavers could create a woven bird hide screen with viewing gaps near the standing water, creating a great opportunity to observe bird life on the pond. A willow screen would be a great alternative to a built bird hide shed.

Feedback from the local community highlight the need and importance for enhanced engagement linked to the restored site. The following quote from a local resident underpins the importance of engagement for enjoyment of the restored Queen's Marsh.

"Myself, I would love to see it turned into a lake with a wild life Island in the middle. Of late I have seen several Egrets and other wild fowl visiting when it is in flood. It is so sheltered that I am sure it would encourage far more wild life and be a birder's paradise. A few hides and more seats it would be a wonderful place to unwind and just sit, look and listen instead of the hustle and bustle of everyday life. Stover Park has done it. Why can't we. It would be amazing." Pamela Sandry Gorman, local resident.

Unfortunately, any signage or structure would need to be robust and vandal proof, with an easy to clean top surface to wipe off graffiti and every day dirt and grime. They also need to be able to withstand constant changes in the weather and the elements.

It is possible that the site could be used for future public engagement events, such education events relating to the habitats and wildlife on site for both school children and adults, and community events that involve local artists or crafts.

5 Preferred Option(s)

Taking into consideration the listed constraints and opportunities, the project team conducted a rapid assessment of suitable habitat enhancements for the Queen's Marsh, in order to quickly discount options that are not deemed viable. The Environment Agency's indicative plan, together with existing site data, models and site visits formed the basis of this assessment. The remaining options are set out in a concise manner below to facilitate ongoing discussion with all the project partners and agree which are taken forward to the develop the detailed implementation plan.

1. **Do Nothing:** This option may be pursued if the cost:benefit ratio of other options on the site does not provide a favourable outcome or are prohibitively expensive. It would however, not fit the project brief or achieve any associated HLS and EA WFD goals, and has therefore not been explored further within this feasibility study. The 'Do Nothing' approach would leave natural processes to achieve 'restoration' of the site and wetland features. This option would not allow maximum potential of the site for habitat and wildlife benefit. Further implication of this option is further outlined within the initial geomorphology notes provided by the Environment Agency (Appendix 1).

2. **Functional re-design:** As detailed in the EA geomorphology and modelling report (Appendix 1), functional re-design would include establishing the Bidwell Brook in a new channel from the supposed palaeochannel and meandering through the middle of the marsh. There several major constraints facing this option;

a. The hardstanding located within the historic sewage treatment works at the western end of the site.
b. The existing sewer pipe and proposed infrastructure additions.
c. The existing comparatively high level of the western end of Queen's Marsh compared to the brook channel.
d. Unknown drainage outfalls into the existing brook, such as from the adjacent A385 and residential properties.
e. Increased risk / vulnerability of sedimentation from the upper Bidwell catchment and River Dart backflow.

3. **Assisted recovery:** This option would include habitat creation across the site in combination with enhancements to the existing brook. This option originally included consideration of a channel bifurcation, although this would need to be explored in more detail to assess hydrological and other constraints. This option could have several iterations, depending on exact requirements of all parties and additional hydrological assessment, and would seek to enhance existing interactions between the Bidwell Brook and Queen's Marsh with a focus on habitat creation and improving biodiversity. Potential features considered within this option include:

a. Cluster of scrapes of differing sizes and depths
b. Large permanent pond
c. Areas of wildflower marsh
d. Reed bed
e. Woody debris and instream habitat
f. Channel creation/bifurcation

g. Livestock fencing

h. Wet woodland creation

i. Riparian corridor restoration

Other options considered included converting Queen's Marsh into a large lake or a managed water meadow, however it is considered that this is unlikely to be conducive to the maintenance of the site as actively managed grazing habitat.

Outline of preferred option.

Following discussions with project partners, it was considered that the assisted recovery option was the most suitable for the site and funding requirements. The channel bifurcation element, however, was discounted during the discussions as it was considered to be unlikely to provide value for money with respect to biodiversity gain compared to wetland enhancements and in channel restoration of the current reach. A proposal to create this secondary channel would need additional detail (off-take control structure, flow split, levels). Impacts upon the main channel (low flows, sediment, fish) would need to be assessed. It was decided that this may not be worthwhile for this length of watercourse and that considerable restoration to the current channel alongside creation of wetland features would provide more value for money and greater biodiversity gain. A description of the proposed features is provided below, with an indicative plan in Figure 30.

a. **Cluster of scrapes** – these would comprise a range of sizes and depths to provide benefit to a maximum range of species. As per the plan below we have suggested in the region of seven scrapes, but this could be altered to suit topography and conditions on the ground. The margins should be very gently sloping and with irregular and varied outlines. The smallest scrape should be no smaller than $20m^2$ and the scrapes should have a range of undulating depths. Shallow scrapes can have depths ranging from just above normal water levels to approximately 0.4m below normal water levels, and other scrapes could include areas of deeper water up to 1.5m deep.
b. **Large permanent pond and semi-permanent pond** – a large pond has been proposed at the eastern end of the site. From ground conditions and observation of features within the adjacent Berryman's Marsh it is expected that this feature would hold water except within years of exceptional drought. No specific modelling has been undertaken for this feature; however it is expected that this would be fed by a combination of groundwater and surface flows from flood events. It is recommended where possible that further investigation (such as installation of dip wells or further modelling) is used to establish any requirement for feeder channels, pond lining etc. The size of the pond will be constrained by the adjacent pipe, and therefore a second pond has been proposed to provide linking habitat and extend the area of standing water. It is likely that this pond will provide an area of semi-permanent water, holding water in most years, but drying more frequently than the larger pond. Where ground conditions allow the ponds should be around 2.5m at their maximum depth, with irregular outlines. The pond margins could be left to colonise naturally, however consideration may be given to plug planting of aquatic and marginal species to provide immediate impact, especially given the prominent location of the feature with respect to visitors. Care will need to be taken to ensure that no invasive species are introduced into the pond, as these are generally extremely difficult to remove once established.

c. **Areas of wildflower marsh** – areas of wildflower creation have been included surrounding the mosaic of scrapes. It is anticipated that this will provide undulating habitat, with wetter areas at the edge of scrapes and more dry sections on higher ground between scrapes and where flooding is less regular, allowing greater species diversity. As outlined earlier in the report the use of green hay may provide a suitable seed source, or should this not be suitable or practicable, use of a commercial seed mix may be required. Species should be suitable for habitats prone to inundation and suitable for frequently wet soils, with a neutral to slightly acidic pH. Use of dip wells would be helpful to assess water-table elevation and target appropriate species mixes. Some examples of species that may be suitable are provided in Appendix 6.

   Seed should be sown in spring or early autumn, and grazing restricted initially to allow the flowers to establish. Frequent cuts are likely to be required in the first year of establishment to control weeds, to a height of around 40-60mm, and ideally the arisings should be removed from site. It is likely that many of the species will be slow to germinate and may not flower in the first growing season, so public expectation may need to be managed until the site begins to develop a more attractive wildflower cover.

   Once the wildflower areas have become more established the areas around the scrapes could be grazed year-round if low stocking rates can be achieved, however consideration may be given to exclusion of stock with temporary fencing between spring and July/August to provide a good display of flowers for visitors. Exclusion is also likely to be required over parts of the winter period to avoid significant poaching. Exact stocking levels are difficult to determine at this stage, especially given the irregular nature of potential inundation, and will need to be assessed on an annual basis as habitats develop and in line with stock breeds and grazing requirements, however a guide to stocking rates as outlined within the Natural England Lowland Grassland Management Handbook is provided in Appendix 7. If the site is not grazed then cutting should be undertaken, ideally a mid-summer cut should be undertaken from July to mid-August, with cuttings removed from the site, although an early autumn cut (in September) could be considered on a three year rotation to allow late flowering species to seed.

d. **Reed bed** – areas of reed bed have been proposed around the fringes of the ponds, with sloping margins providing a gradient of water levels to encourage a good habitat mosaic with drier more herb rich areas towards the outer edges. It is anticipated that the reed beds are likely to be established from pot grown reed or locally sourced rhizomes. Pot grown reed is usually planted at between 1-4 plants per m^2. Netting or cages should protect the establishing reed bed, and once established it is anticipated that management could be undertaken through low level summer grazing (with temporary fencing at other times of year), but occasional cutting may be required over the winter in some years. The reed bed will provide shelter and habitat adjacent to the pond, but planting and management will need to ensure that viewpoints are maintained for visitors, including some views across the pond.

e. **Woody debris and instream habitat** - woody debris plays a vital role in the aquatic ecosystem including supporting invertebrate and fish life. Flow deflectors and machinery could be used to significantly improve the fish habitat within the brook, optimal pool-riffle sequences should be created to increase habitat diversity and connectivity. Site won brash and timber should be used as much as possible to create woody debris habitat, bank

protection and flow deflectors. Introduced woody debris and deflectors would need to be secured through pinning and wiring. The amount and scale of woody debris introduction and habitat creation would need further confirmation through site visits.

f. **Livestock fencing** – sections of temporary fencing are recommended to allow controlled grazing of specific areas of the site, including around the large ponds and the scrapes and wildflower grassland. Exact timings of grazing will be dependent on habitat types and establishment, ground conditions and stock types and numbers, but are outlined within the habitat descriptions. Permanent riparian fencing is recommended along the entire reach of Bidwell Brook on the site. In-stream problems from unfenced reaches include accelerated bank erosion due to trampling and overgrazing, and water quality issues. The Bidwell Brook is prone to flooding and regularly overtops, therefore the following guidelines are recommended:
   - An appropriate buffer margin should be at a minimum of 2m from the bank, which would allow for erosion and grazing through or over the fence.
   - Use treated intermediates of 5'6" length, 3-4" diameter.
   - Use treated strainers of minimum 7'6" length, 7" diameter.
   - Strainer posts should be spaced at a maximum 50-100m.
   - Intermediate posts should be spaced every 4-5m
   - Minimum wire specification of 2 strands of medium tensioned wire. Bottom wire height must be greater than 60 cm from ground.
   - Fence line should align parallel with flood flow to reduce chance of debris catching.
   - Running fit wire to allow extra load of flood debris to be supported. As fencing is on floodplain, it is advised to consult with the EA.
   - A gate could be sited to allow periodic access to bankside grazing.

g. **Wet woodland creation** – small areas of wet woodland and tree planting are proposed to add structural diversity to the site, however the areas have been constrained to ensure that grazing areas are not too restricted. Areas of planting along the stream will need further consideration within flood modelling to ensure that they do not significantly alter flood flows by trapping sediment. Species proposed for planting include alder, willow, rowan and dogwood. It is recommended that ground flora be allowed to establish naturally. Ideally planting should be irregular with clumps of trees, and planted at spacings of around 2.5 – 3m.

h. **Riparian corridor restoration:** Selective coppicing is recommended along the brook corridor in the areas where there is over-shading of the river channel, excessive growth of trees, bank erosion, channel siltation, and poor fish habitat. Coppicing should seek to provide an optimal light:shade mosaic, with 70% light on riffles and 70% shade on pools.

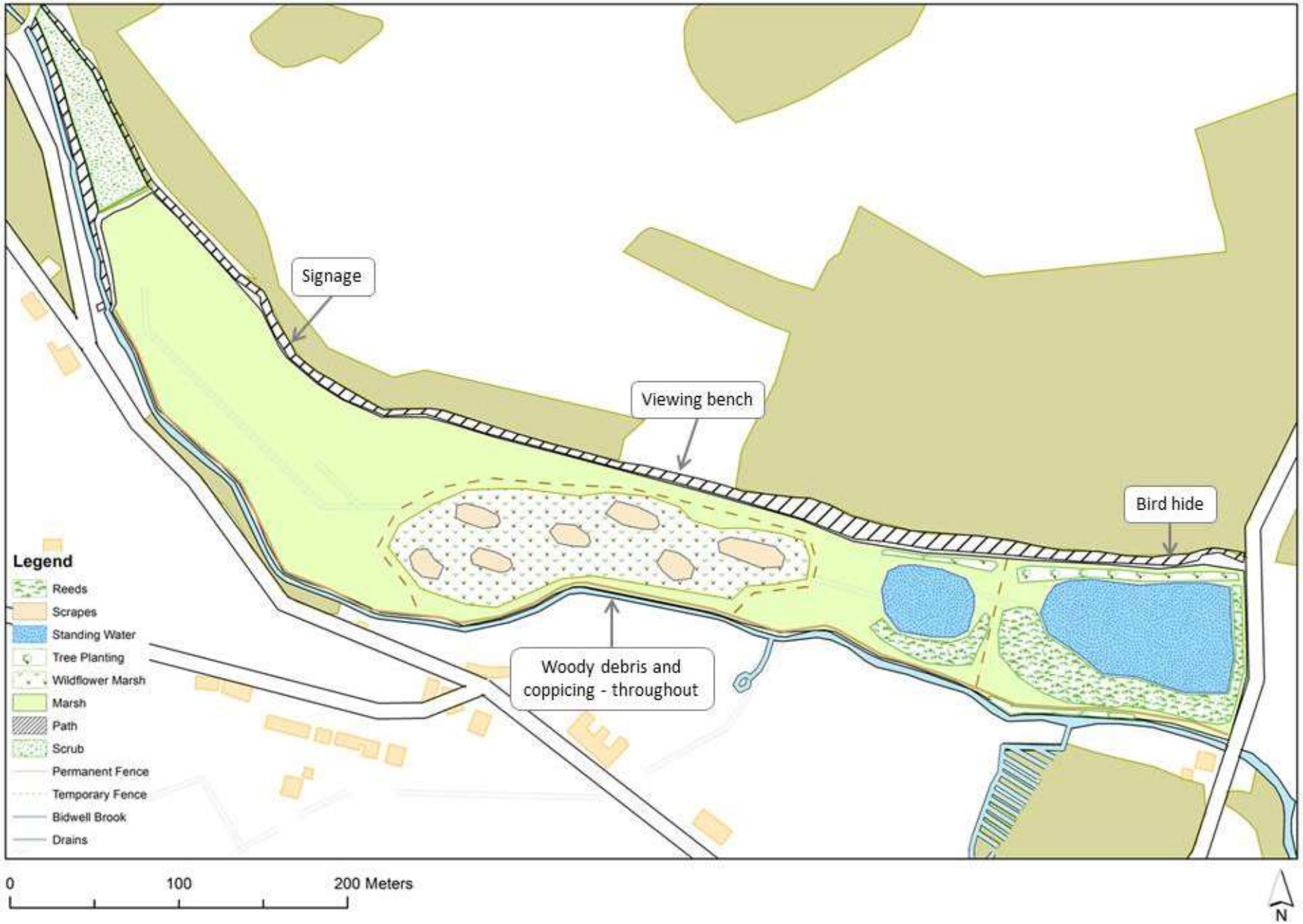


Figure 30 : Map to highlight opportunities within assisted recovery of Queen's Marsh

6 Hydraulic Assessment of Options

A Flood Modeller Pro – TUFLOW 1D-2D hydrodynamic hydraulic model was constructed for use in this feasibility study to examine existing flooding mechanisms and investigate the viability of various options for restoration of the Bidwell Brook and Queen's Marsh. In constructing the model best use has been made of data available within the project time frame which is considered fit for purpose for this feasibility stage. Both the data used for construction and the hydrological and hydraulic approach used may need refinement in a more detailed design phase once preferred options are selected.

The objective of the modelling at this stage was to achieve a more accurate characterisation of existing drainage to and from the marsh than in the SFRM model (Strategic Flood Risk Assessment Model, which does not have a site-specific focus on Queen's Marsh). Model tests based scenarios are used to examine the impacts of varying options for restoration of the brook and adjoining marsh floodplain. The following sections briefly outline the most significant points of interest regarding the hydrological and hydraulic model. A detailed modelling report is beyond the scope of this feasibility study, though recommendations for further work and improvements are made when applicable.

6.1 Design Hydrology Review

Both low and high flow design hydrological estimates were provided by the Environment Agency for use as inflows to the hydraulic model of the Bidwell Brook. A cursory inspection of these data was conducted; a full review and recalculation of all design flow estimates to validate previous work was beyond the scope of this feasibility study. Further detail of the review of the supplied design hydrology is presented in Appendix 8; the key points are summarised below.

Peak Flow Estimates

Flood estimates were calculated as part of the 2013 SFRM contract. A range of methods were used to calculate peak design flood inflows for the ungauged Bidwell Brook in the SFRM study. Given the lack of hydrometric data for validation, the outputs from all methods used showed good consistency. Brief tests of the derived outputs for the brook showed limited sensitivity of outputs to storm duration and the use of the Flood Estimation Handbook (FEH)-derived hydrograph shape was well-reasoned. The design hydrology outputs from the SFRM study were judged to be consistent with good practice and appropriate for use in this study.

Low Flow Analysis

Low flow estimates were derived by Environment Agency staff using LowFlows Enterprise software. Though caution should be applied when comparing low and high flow statistics, in the absence of further information for validation, no serious inconsistency was found in flow duration curve and flood statistics. Consequently, the low flow data were also judged to be appropriate for use in this study.

Conclusion

The following points should be noted:

- In the absence of any hydrometric data for the Bidwell Brook, the design hydrological estimates rely on entirely theoretical approaches for flow derivation.

- Further validation of these estimates may be possible by comparison with local hydrologically-similar catchments for which flow data are held.

- At the time of preparation of this report, Plymouth University has just begun a programme of hydrometric monitoring on the Bidwell Brook. Data generated from this study may be of use in any future hydrological analysis of this catchment.

- It has not been possible to undertake a review of the hydrological and hydraulic elements of the SFRM model of the River Dart which form the lower boundary conditions of the Bidwell Brook model within this feasibility study.

6.2 Hydraulic Model Construction

A previous 'broad scale' SFRM model covered a short reach of the Bidwell Brook and the lower section of Queen's Marsh. The hydrological data generated for the SFRM study for the ungauged Bidwell Brook catchment were reviewed and formed the boundary conditions for all inflows into the brook element of model built for this project. Boundary conditions for the River Dart were derived from SFRM water level outputs: review of the wider Dart elements of the SFRM model and any assumptions underpinning its construction were beyond the scope of this feasibility study.

As specified by the Environment Agency in the scope of work for this project, updates and extensions to the SFRM data were required for this site-specific feasibility contract. In view of this requirement a limited series of new cross sections were surveyed along the brook (AP Land Surveys, September 2015) in order to allow model construction to cover the entire area of Queen's Marsh and to begin to characterise its interaction with the Bidwell Brook and River Dart. The topographic survey also included all structures at Dartington Lane – the bridge, the culvert and gate. These features were not present in the SFRM model.

These data were used to supplement and replace, where necessary, the existing survey (Land and Sea Surveys, 2005) that supported the SFRM work. It was not possible to collect as comprehensive a set of data as would be required to support a restoration scheme design exercise. As a result, a number of areas of the model relied on estimated or sub-optimal topographical data. Despite these limitations, the model is judged fit for the purpose of allowing a more effective assessment of the most viable options for further consideration.

In addition to the use of design hydrological estimates for the ungauged Bidwell Brook catchment, key sources of uncertainty within the feasibility study model are summarised and discussed as follows.

Longitudinal Bank Elevations

Bank elevations along the Bidwell Brook have been derived from LiDAR data and on-site measurements. The highly vegetated nature of the banks means that LiDAR survey may be inaccurate at key points along the modelled reaches. Further longitudinal bank survey - both within Queen's Marsh and downstream to the Dart confluence - using standard topographical survey techniques is recommended in any further study to ensure that these key features are well-represented in future work.

Cross Section Spacing

The model has been constructed from a very limited number of cross sections. This has led to a need to 'transfer' and estimate data collected at one location to represent the hydraulics of similar areas within modelled reaches. Furthermore, though their use has been kept to a minimum, interpolate units have been required when representing the channel and associated structures to ensure mathematical stability of the model framework. More closely-spaced cross sections are recommended to more accurately represent localised reach conveyance in the relatively small Bidwell Brook channel. Additional cross sections should also be collected in areas where it has been necessary to estimate data.

Culvert Structure Losses

The culverts and associated structures at Dartington Lane are a relatively unusual arrangement with an oblique alignment, weir and gate at the entrance and an internal join to form a single outlet from three inlets. Survey of the structures was taken at both the upstream and downstream faces but not internally. Representation of these structures within the feasibility model is appropriate for the level of analysis required at this stage of the restoration initiative. However, collection of further data covering the internal dimensions of the conduits and the point at which they converge may be advisable to allow an improved representation of energy loss through this feature to be attempted.

Vegetation and Debris Dams

The brook channel is highly vegetated along much of its length and, in its current condition, the formation of debris dams which prompt flooding at varying locations is possible in high flow events. The limited number of cross sections available for use in this study has prevented a detailed assessment of the likely impact of debris build-up and partial or total blockage at key 'pinch points' or areas where vegetation is currently most likely to disrupt local conveyance. A more comprehensive survey of channel dimensions and associated features may allow the current impact of local vegetation and encroachment into the brook to be assessed more reliably.

Dart Boundary Conditions

The lower boundary of the feasibility study has been derived from water levels and time series extracted from the Dart SFRM model. While this approach is likely to be reasonably representative of the condition of the larger river in varying design events, a more reliable dynamic boundary condition could be derived to reduce uncertainty. The hydrological boundaries in the SFRM model have been configured to examine flooding from the Dart, as befits the focus of that project. Further work may be advisable at a design stage to assess the combined probability of flood events on the brook and the larger river.

Calibration

At project inception, the Bidwell Brook catchment was ungauged. However, since the start of the feasibility study, Plymouth University has begun a programme of sediment monitoring which has included the installation of hydrometric equipment. Opportunities for calibration of any model framework built upon the work conducted within this study may be possible as this research project progress. Providing a successful calibration is possible, this may allow increased confidence to be invested in model outputs.

6.3 Hydraulic Model Simulations

As outlined in Section 3.4, model simulations conducted to generate a baseline condition – i.e. to replicate the existing situation – revealed that the majority of Queen's Marsh is inundated at the lowest flood return period simulated – the 1 in 2 year. As a result of this finding, it was agreed that there would be no benefit in conducting multiple simulations of higher return periods when assessing the hydraulic link between the brook and Queen's Marsh and examining local flood extents.

The hydraulic modelling approach outlined in the following section was originally proposed with a view to establishing the feasibility of the installation of a new or secondary channel within the centre of Queen's Marsh. Constraints identified during the course of this study – including the existing and proposed sewer pipes – have prevented this option from being taken forward for more detailed consideration. Consequently, the 'Functional Re-Design' outlined in the Environment Agency geomorphological notes has not been simulated. Similarly, no attempt has been made to model the discounted 'Do Nothing' option.

6.3.1 Assisted Recovery

A model of the 'Assisted Recovery' option outlined in Section 5 including channel bifurcation, shallow scrapes and pond area was constructed to examine the viability of this design. Trial simulations were run to examine the impacts of a flood event from the Bidwell Brook (i.e. with the River Dart set to a steady state water level). Terrain modifications were arbitrarily defined for the purposes of illustration only. Scrape depths ranged from 0.1 to 0.4 metres and the pond depth was set to 1.5 metres. The new channel was set to an arbitrary depth of 1.25 metres with a maximum width of 3 metres. Results are presented in Figure 31 and Figure 32.

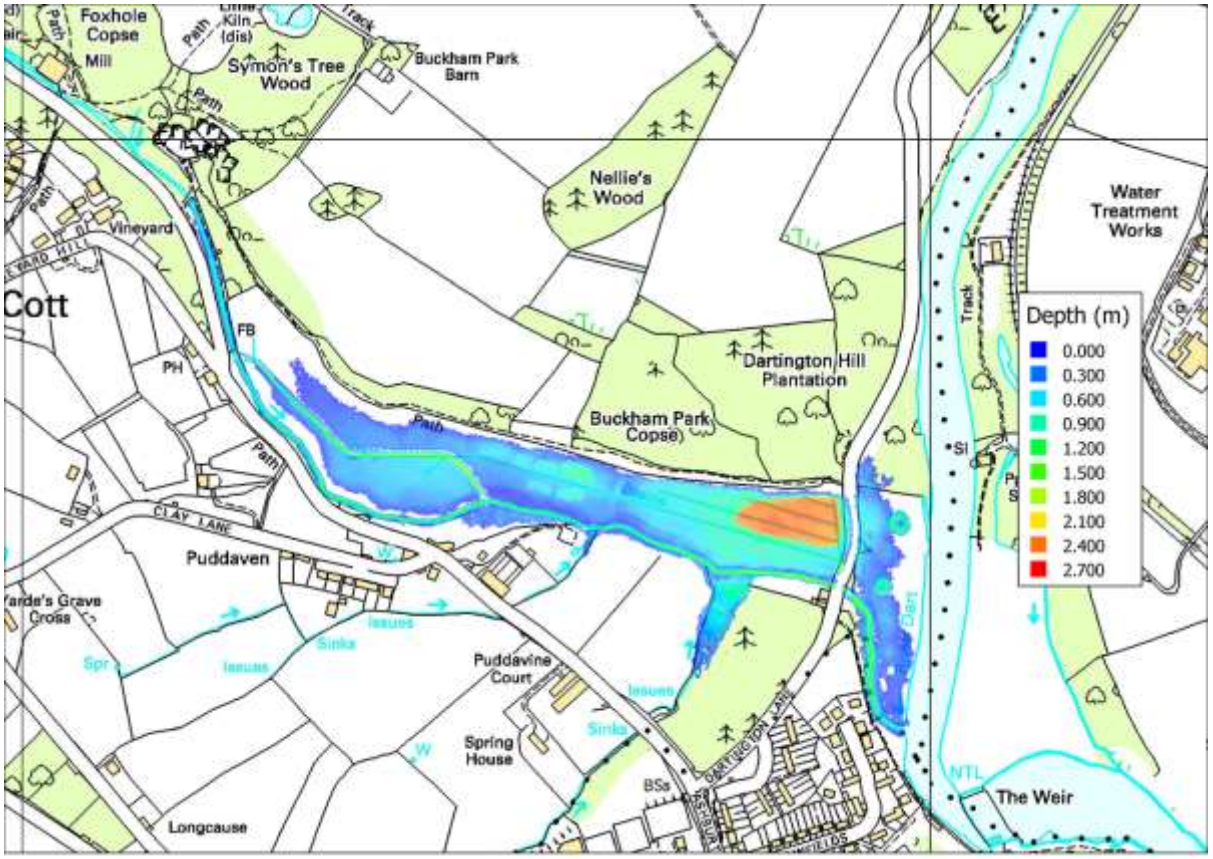


Figure 31 'Assisted Recovery' option model maximum flood extent

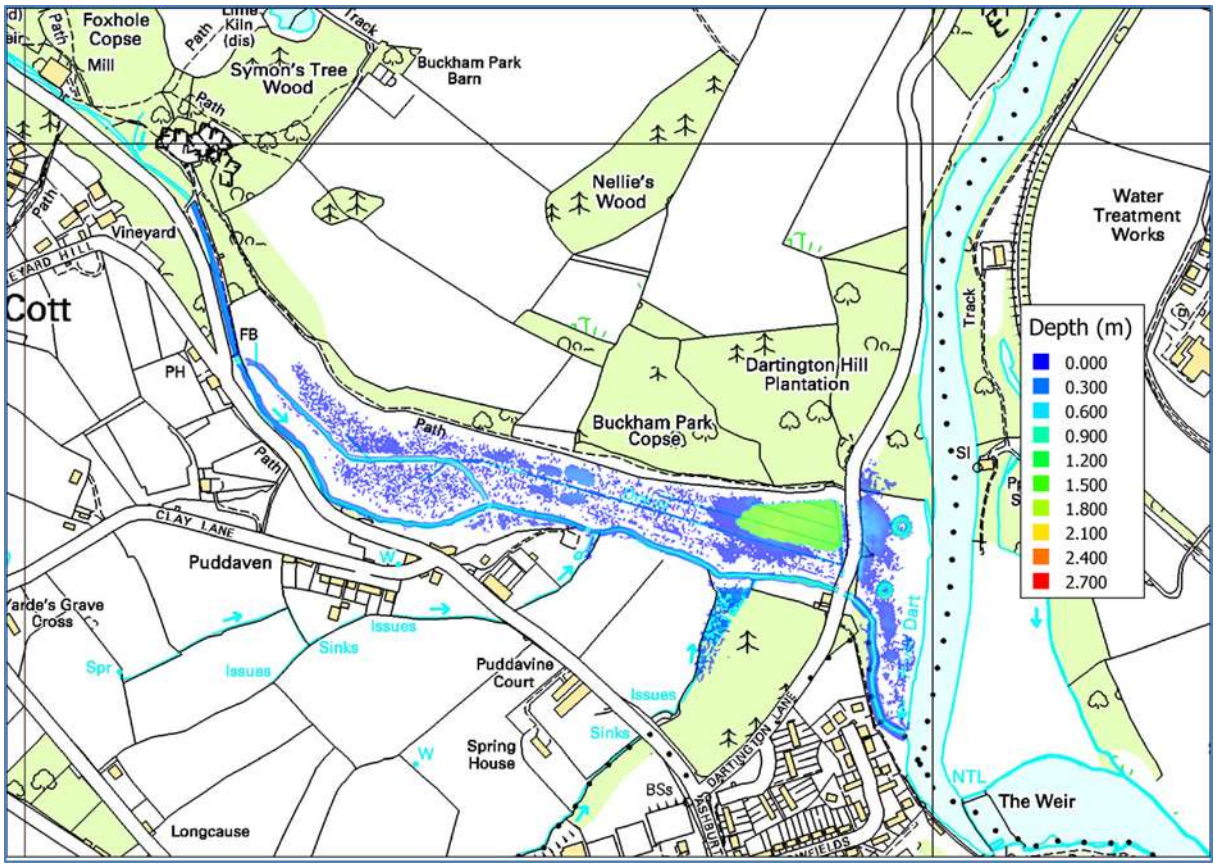


Figure 32 'Assisted Recovery' option model flood recession.

The results indicate no dis-benefit in terms of increased flood risk from this option. As should be expected, simulation of the flood recession (Figure 32) illustrated the potential of the scrapes and pond area to hold water.

The following should be noted:

- The 'Assisted Recovery' option as configured in the model is for illustration of this concept only and is not a final design.
- The secondary channel option has been discounted and has not been considered in more detail due to depth of the existing channel in the upper reaches, the expense of engineering suitable offtake and control structures and the reduction in stock access to a relatively dry area of the marsh
- Scrape and pond dimensions, depths and locations are for illustration only. Scrapes have been sited above the line of the existing sewer where simulations illustrate attenuation of drainage already occurs. The pond has been sited below the line of the proposed new sewer. There may be opportunities to create a larger area of standing water and a second pond in between the two pipes once full details of the latest pipe are available.
- The pond will be entirely inundated in flood events from the Bidwell Brook and/or River Dart. As is believed to be the case with the ponds in Berryman's Marsh, there may be a need for periodic removal of sediment from any new waterbody.
- If necessary, it would be possible to direct flow from the Bidwell Brook to the pond(s) from a newly engineered link from the brook to the pond. It would also be possible to direct the backwater from the Dartington Lane culverts to the pond.
- Both the scrapes and pond may fill from groundwater in addition to rainfall. Assessment of probable groundwater influx is beyond the scope of this feasibility study within the time available for the work.

7 Plan and Costs

As part of the feasibility study, environmental contractors were consulted to obtain indicative costs of the preferred option. With the plan and suggested features, costs are estimated in the region £60k+. At this stage, lack of detail in the proposed plan limit the accuracy of the quotes, and it is considered that a detailed design plan could seek to minimise costs within certain areas. It should be noted that the costings for the ponds alone started at £40k, this is due to the significant amount of excavation of earth and transport of this material off site. As this is such a significant part of the indicative cost, it is recommended that detailed design stages include further consideration for tipping sites, dimension and depths of ponds and water table investigations, in order to minimise the majority of any project budget being spent on this feature alone. Given this is a rough costing, savings could be made on other aspects of the project, i.e length of coppicing, amount of woody debris, number of trees planted. It is suggested that Dartington Hall Trust may consider use of volunteers and local artists to take part in the restoration project, through tree and reed planting and creation of public engagement features. This would help to engage local residents in the scheme at its inception. On top of these costs, a budget would be needed for consents and permissions, further designs and project management.

To obtain indicative costs we stated the following assumptions:

- Utilities and infrastructure search and details will be made available at the tender stage
- Spoil created through the project will be re-used on the site and the wider estate. Specific areas for tipping need to be identified before accurate costs of pond creation can be calculated.
- Consents and permissions will be obtained and in place by the lead organisation, not the contractor.
- A further design process will lead to a more detailed plan, which would enable formation of a method statement by the contractor.
- Flood modelling will be made available to the contractor.
- Costs to include any plants, trees and seeds (if green hay is used, it is assumed that this would be collected and distributed on site by tenant farmer).
- Site won brash and timber will be used as much as possible in woody debris/in channel habitat creation.
- Costs for a bird hide have not been included within the indicative costs, as depending on style and approach costs can vary greatly.

8 Appendices

Appendix 1: Queens Marsh - geomorphology and modelling notes

Introduction

River restoration projects look to restore geomorphic processes to improve range, quality and extent of habitats. The degree of intervention can range from

- do nothing, where natural processes are entirely relied upon to achieve restoration;
- through assisted recovery, where barriers to geomorphic dynamism are removed to allow natural processes to more readily alter the system;
- to designing initial conditions, from which natural processes can then fine tune the resulting habitats;
- and up to a functional design, whereby the restoration looks to deliver the complete form and function of the habitats.

The suitability of approach needs to reflect the available energy of the river system to drive change in form, as well as the scale of impact on the existing habitats and infrastructure and other stakeholder interests.

Description of existing channel and river processes

The existing Bidwell Brook channel is perched to the south of its natural floodplain. Channel gradients are very slack in the lower reaches - immediately upstream of Dartington Lane (the causeway) - resulting in silty bed conditions. Flow variability is only created by vegetation growth in the channel. The embankments on the left banks here are substantial and form a strong disconnection from the floodplain.

At around 250m upstream of Dartington Lane is an eroded low point in the embankment on the left bank. This allows regular high flows to enter the floodplain, providing a discrete connection of the river to the floodplain. The size of this break though should be expected to increase gradually over time, but once it has become sufficiently wide, exit velocities will reduce and further erosion will cease.

The channel at this point retains a slack gradient, with very silty bed conditions but with elements of woody debris introducing some channel variability.

Further upstream, there is increasing sinuosity of the channel, following the valley side profile. There is also an increased presence of woody debris. There is a gradual increase in the size of sediment, with some coarse sands and fine gravels being present.

Some 500m upstream of Dartington Lane, there are various bank works and structures that influence the channel processes. The gradients have increased, enabling the transport of medium to coarse gravels, although the bed material remains dominated by fine sediments. There are more substantial channel profile variations associated with woody dams. Another small break in the embankment on the left bank allows some further reconnection of high flows into the floodplain, but this shows no signs of enlargement.

It is only upstream of Vineyard Hill, in the wooded section of the valley that the gradient increases and the bed load changes to include a gravel, cobble and boulder armour layer. This is where there is a transition of the route of the brook to the natural valley bottom. Woody debris is not present in this reach, but the bed load provides variations in bed features and channel profile.

Restoration options

1) Do nothing

In the longer term, it is likely that the most downstream break in the embankment will widen slightly, which will increase flows entering the floodplain. It appears unlikely that there is sufficient gradient for this breakthrough to erode vertically to such an extent that the channel would naturally divert into the floodplain. This is also made less likely by the damming effect of the causeway, which in larger floods backs up water on the floodplain and reduces the water gradient from the channel into the lower floodplain.

Build up of woody debris will continue to increase channel profile variations, but the lack of gradient will limit the presence of coarser sediments accumulating in

the lower channel. The build up of woody debris has the potential to trigger further breakthroughs of the embankment on the left bank upstream.

Given the size of the channel upstream of Puddavine Terrace, breakthroughs of the embankment are most likely to form downstream of this point, which limits the extent of channel that would be liable to naturally become restored.

Should further breakthroughs of the embankment on the left bank occur, a major constrain on the do nothing approach is the outlet arrangements through the causeway. Should a channel form into the natural valley bottom, this would be disconnected from the road bridge outlet (which would then be prone to blockage from silt and/or vegetation build up). At that point, even in normal flow conditions, waters would pond upstream of the sluice structure. Fish passage to the upper catchment could be affected. Flooding over the causeway would be significantly exacerbated.

2) Assisted recovery

Further breakthroughs in the embankments could be cut, especially between Puddavine Terrace and the upstream woods. The risk with this approach (as in the do nothing) would be that the remaining perched channel would progressively become starved of low flows and sediments. Without changes to the sluice structure at the causeway, this could have the potential to obstruct fish passage from the Dart into the upper catchment in the longer term, as well as increased flooding of the causeway.

Adoption of such an assisted recovery approach would therefore need to include future adjustment of the outlet arrangements through the causeway.

Furthermore, flows in the floodplain will remain affected by the ponding influence of the causeway, and as such there will be limited potential for these increased floodplain flows to erode and effective channel in the valley bottom. Low flows would therefore tend to be concentrated in the existing straight drainage features.

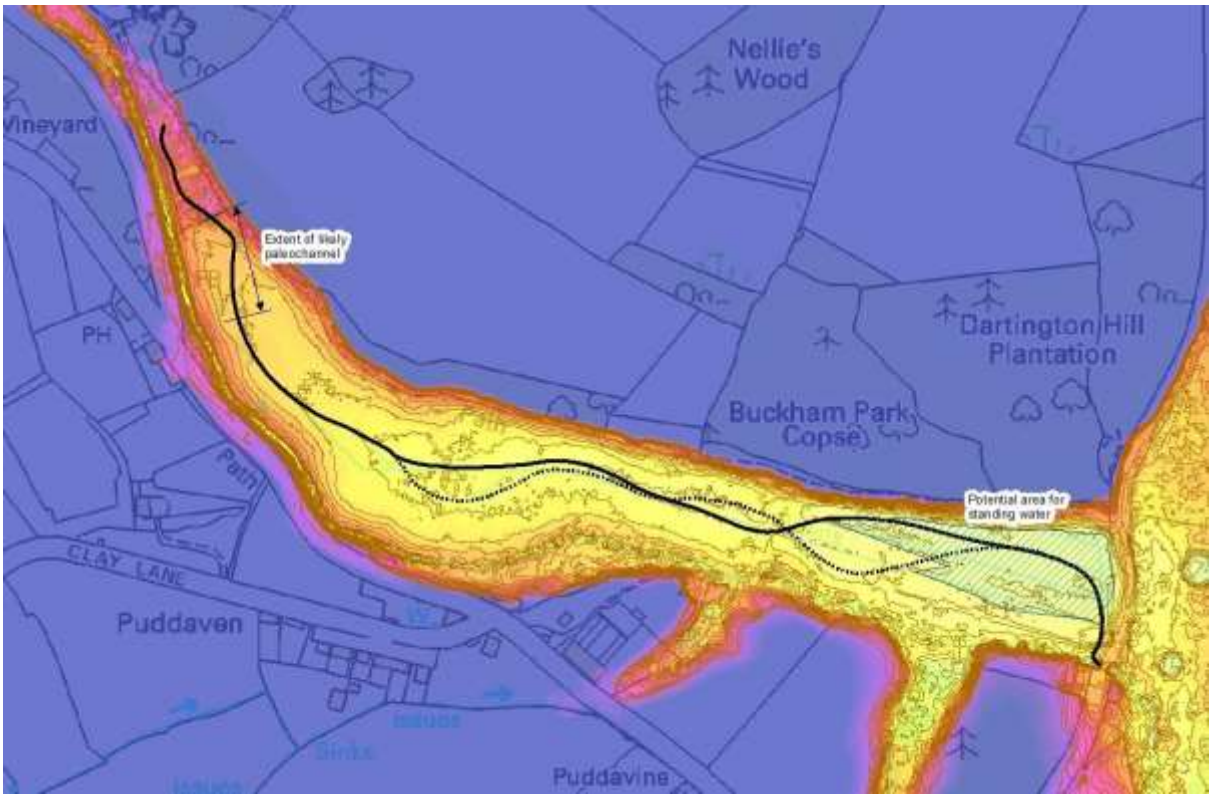
Bed sediment ranges might be improved if any coarse material dredged from any upstream location was returned to the channel in the Queens Marsh reach. However, the scale and frequency of any upstream dredge/desilt operations is not known, and as such it is not clear how significant this measure would be.

3) Designed initial conditions

At the upper end of the marsh is a 50 to 60m depression that appears to be a relict paleochannel. This would provide a useful guide to a suitable route for a restored channel – both in terms of sinuosity, route and dimensions. Since this will have been at least partially in filled with sediment and vegetation, a cross section trench excavation may be worth carrying out to more accurately assess historic channel dimensions, elevation and bed substrate.

As noted in option 2, the presence of the Causeway, and the naturally shallow gradient of the valley (especially to the east of Puddaven Terrace), means that there is limited energy available for river or floodplain flows to erode a new channel. As such, as a minimum an initial shallow channel would need to be excavate along an anticipated final route of the restored channel. An indication of the options for this route are marked in a solid and dotted black line in the plan below (Figure 1).

Figure 1. Potential restoration route options



There would be merits in establishing this channel ahead of diverting the river flows. This would allow vegetation to establish that would then reduce the scale of fine sediments released downstream into the River Dart. Also, future riparian trees and bushes could be planted to either side of the channel, such that these become established and can then stabilise the channel and avoid risks of any

immediate localised lateral erosion. These would also provide some temperature control for the flows once diverted into it.

Upstream of the relict paleochannel, more significant excavation would be required. Some tree clearance or coppicing would be needed.

Excavated material could be stored on site, and later used to infill some of the existing channel - once the diversion is carried out.

At the downstream end of the floodplain, the impounding effect of the causeway is most pronounced. Here there is potential to create a large scrape or permanently wetted areas through further excavation.

However, the nature and extent of these features, and indeed the overall wetting of this lower floodplain will be closely controlled by the out let arrangements. At the time when the cut is made at the upstream end, an outlet channel would also be required from the floodplain connecting to the existing road bridge structure. A combination of this outlet channel, and any alterations to the existing sluice would then control water levels within this lower floodplain.

It is possible that some increase in elevation of the sluice's inlet sill could be made without reducing the overall outlet capacity of the sluice structure and road bridge. However, fish passage would need to be incorporated into any alterations.

Ensuring that capacity is not reduced here will be the principal means of ensuring that flood risks to the Lodge are not increased.

Consideration could be given to introducing sand and gravels into the bed of the channel to effectively 'seed' bed features – otherwise there is the potential for there to be a long period before sufficient material is flushed down from the above the diversion. However, these should be selected on the smaller size to ensure their mobility. Use of material from the existing channel should be considered.

4) Functional Design

A similar approach to option 3 could be used. However, rather than allowing the new watercourse to develop its own channel size, profiles and bed features (including substrates), these would all need to be designed and constructed.

Hydrological data combined with regime theory can be used to determine a likely channel size (which could be informed by a trench excavation across the

paleochannel). Review of upstream reaches and similar local rivers should then inform frequency and extent of riffle and pool sequences.

Appropriately sized sand and gravels should be imported along the length of the channel. This would need to include larger sized material to provide an armouring layer in riffle and/or run locations. To cater for the imported substrate, the channel would need to be overly excavated, with the imported substrate building back up the bed levels to the design elevations.

For this option, either greater time would need to be allowed for riparian trees and bushes to become established, or more mature trees should be planted up. Alternatively soft engineering methods, such as planted coir roles, live hazel of willow faggots, and/or willow spiling could be used to establish the bankline. Any cleared trees, upstream of the paleochannel could also be reused to create in stream large woody dams and constrictions upstream of riffle locations.

Appropriate planting up of the downstream scrapes or permanent ponded areas should be considered. Again, soft engineering approaches may be adopted to establish steeper edges to these features.

Hydraulic and Hydrological Modelling Data

The Environment Agency has had carried out a flood modelling study on the River Dart through Totnes (May 2014), which includes the Bidwell Brook for 400m upstream of the causeway. There was no calibration data available for the Bidwell Brook, and as such the results should be treated with caution.

The magnitude of flood flows for the Bidwell Brook that are used in the model are given in the table below, and represent the entire catchment to the Dart confluence. These are of low confidence, however, as they are based on Regional Growth

curves rather than any direct hydrometric data.

Annual probability	2	10	20	50	75	100	200	500	1000
Peak flow (m^3/s)	7	12	14	17	18	19	22	27	31

In addition to the above caveats, the bridge and sluice structures have been modelled as a single orifice and this is liable to underestimate their capacity.

That having been said, the head difference between upstream and downstream is only 22mm in the 2 year flood, rising to 27mm in the 100 year flood. As such, accuracy of the modelling of this structure is not significant in terms of extreme flood conditions, although it will be crucial for any restoration design.

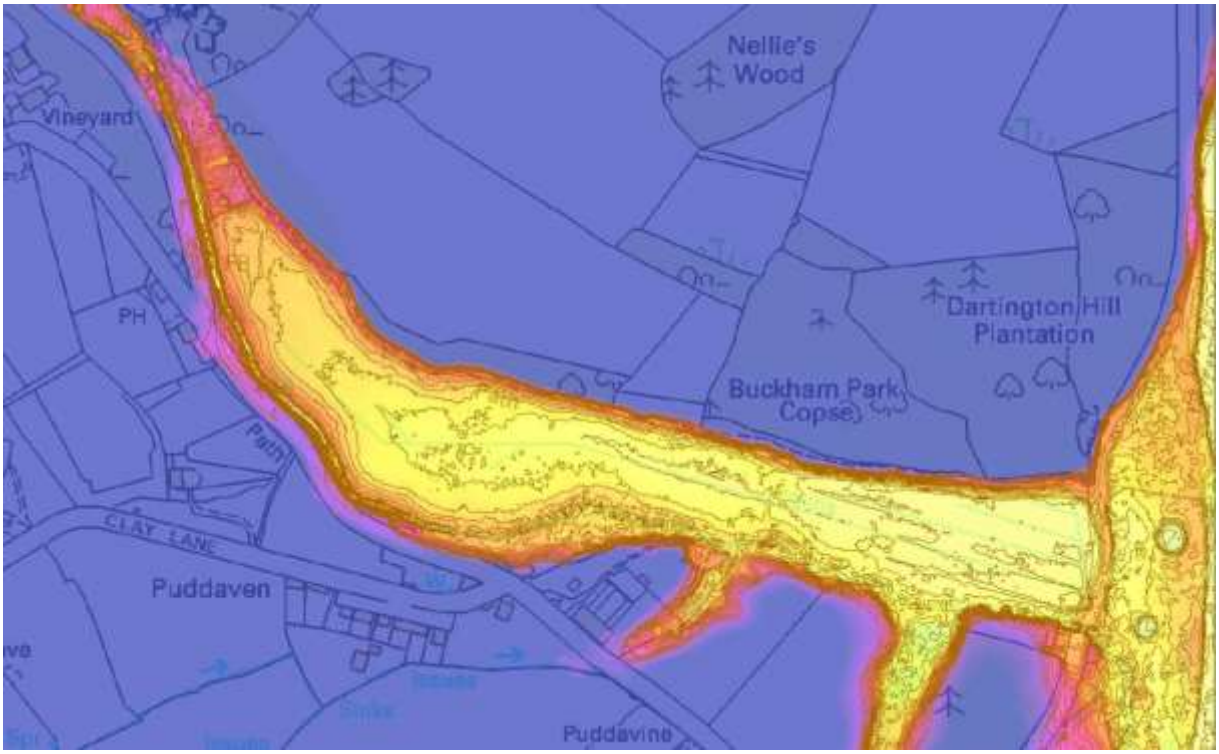
The model shows that the causeway (with minimum crest levels of around 4.95mAOD) would be overtopped in a 2 year return period flood (based on both downstream and upstream levels). This also corresponds to depths of between 300mm and 900mm above the upstream raised river banks, causing the Bidwell Brook to overspill into Queens Marsh during the 2 year return period flood and to back up behind the causeway for at least the 400m of modelled floodplain upstream.

The grounds of the Lodge are protected from flooding by the northern boundary wall and the raised deck of the bridge (at 5.33mAOD). The modelling also shows that the grounds of the Lodge are at risk of flooding from a combined River Dart and Bidwell Brook flood with a return period of approximately 5 years. Flood levels both upstream and downstream of the bridge exceed the level of the bridge deck during these flood conditions.

Tidal flooding is not predicted to extend beyond the causeway for a current 200 year extreme tidal flood, or indeed for the same with climate change in 2113.

Survey Data

The Agency has carried out aerial LiDAR surveys that cover the entire Queen's Marsh to a 1m grid scale. This can be made available for planning the of the works. The data is represented below including 0.25m contours.



As noted above, there is no survey data available for the road bridge or for the sluice under the causeway. Detailed surveying of these structures will be required.

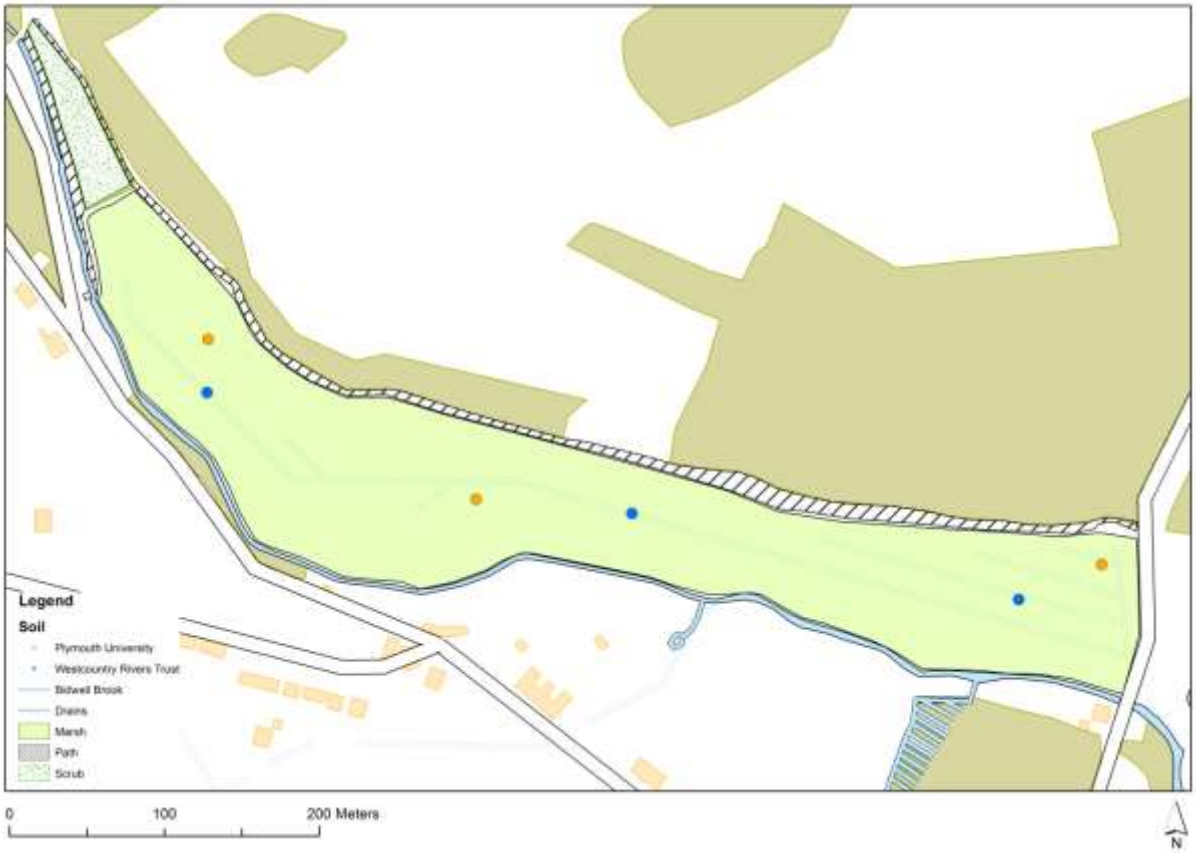
Detailed channel surveys downstream of the bridge to the confluence with the River Dart would also be useful.

If assisted recovery options are to be taken forward, channel surveys at least from Puddaven to upstream of the restoration reach will be required.

If either designed initial condition or full functional design is to be taken forward, channel surveys from Vineyard Hill and upstream will be required.

Appendix 2: Soils WRT and Plymouth University

Soil sample locations by WRL and Plymouth University



YARA Analytical soil results

Analysis Results (SOIL)

Customer DARTINGTON
TOTNES
DEVON

Distributor WESTCOUNTRY RIVERS TRUST
RAIN-CHARM HOUSE
KYL-COBER PARC
STOKE CLIMSLAND
CALLINGTON
CORNWALL
PL17 8PH

Sample Ref QUEENS MARSH LOWER
Sample No E148178/03
Crop GRAZED GRASS (CATTLE)

Date Received 08/10/2015

Analysis	Result	Guideline	Interpretation	Comments
pH	5.5	6.0	Slightly Low	Refer to Lime Requirement.
Phosphorus (ppm)	12	16	Low	**(Index 1.4)** 50 kg/ha P2O5 (40 units/acre).
Potassium (ppm)	72	121	Low	**(Index 1.1)** 30 kg/ha K2O (24 units/acre). Avoid applications in Spring if there is a history of Hypomagnesaemia.
Magnesium (ppm)	61	51	Normal	**(Index 2.2)** PRIORITY FOR LIVESTOCK HEALTH. Apply 25 kg/ha MgO (20 units/acre) every three to four years. Further applications may be required if there is a history of hypomagnesaemia.
Lime Req. (t/ha)	4.0			

Analysis Results (SOIL)

Customer DARTINGTON
TOTNES
DEVON

Distributor WESTCOUNTRY RIVERS TRUST
RAIN-CHARM HOUSE
KYL-COBER PARC
STOKE CLIMSLAND
CALLINGTON
CORNWALL
PL17 8PH

Sample Ref QUEENS MARSH MIDDLE
Sample No E148178/02
Crop GRAZED GRASS (CATTLE)

Date Received 08/10/2015

Analysis	Result	Guideline	Interpretation	Comments
pH	5.6	6.0	Slightly Low	Refer to Lime Requirement.
Phosphorus (ppm)	12	16	Low	**(Index 1.4)** 50 kg/ha P2O5 (40 units/acre).
Potassium (ppm)	60	121	Very Low	**(Index 0.9)** 60 kg/ha K2O (48 units/acre). Avoid applications in Spring if there is a history of Hypomagnesaemia.
Magnesium (ppm)	65	51	Normal	**(Index 2.2)** PRIORITY FOR LIVESTOCK HEALTH. Apply 25 kg/ha MgO (20 units/acre) every three to four years. Further applications may be required if there is a history of hypomagnesaemia.
Lime Req. (t/ha)	3.0			

Analysis Results (SOIL)

Customer DARTINGTON
TOTNES
DEVON

Distributor WESTCOUNTRY RIVERS TRUST
RAIN-CHARM HOUSE
KYL-COBER PARC
STOKE CLIMSLAND
CALLINGTON
CORNWALL
PL17 8PH

Sample Ref QUEENS MARSH UPPER
Sample No E148178/01
Crop GRAZED GRASS (CATTLE)

Date Received 08/10/2015

Analysis	Result	Guideline	Interpretation	Comments
pH	5.6	6.0	Slightly Low	Refer to Lime Requirement.
Phosphorus (ppm)	11	16	Low	**(Index 1.2)** 50 kg/ha P2O5 (40 units/acre).
Potassium (ppm)	71	121	Low	**(Index 1.1)** 30 kg/ha K2O (24 units/acre). Avoid applications in Spring if there is a history of Hypomagnesaemia.
Magnesium (ppm)	56	51	Normal	**(Index 2.1)** PRIORITY FOR LIVESTOCK HEALTH. Apply 25 kg/ha MgO (20 units/acre) every three to four years. Further applications may be required if there is a history of hypomagnesaemia.
Lime Req. (t/ha)	3.0			

Additional Comments
The recommendations should be adjusted if organic manures are used. See RB209 for more information.
Additional technical bulletins are available at www.lancrop.com

Please Note
Whilst every care is taken to ensure that the Results from Analysis are as accurate as possible, it is important to note that the analysis relates to the sample received by the laboratory, and is representative only of that sample. No warranty is given by the laboratory that the Results from Analysis relates to any part of a field or growing area not covered by the sample received. It is important to ensure that any soil, leaf, silage or fruitlet sample sent for analysis is representative of the area requiring analysis and that samples are obtained in accordance with established sampling techniques. A leaflet containing instructions on how to take soil, leaf, herbage, silage and fruit samples for analysis is available from the laboratory on request.

This report has been generated by Yara's Megalab ™ software.

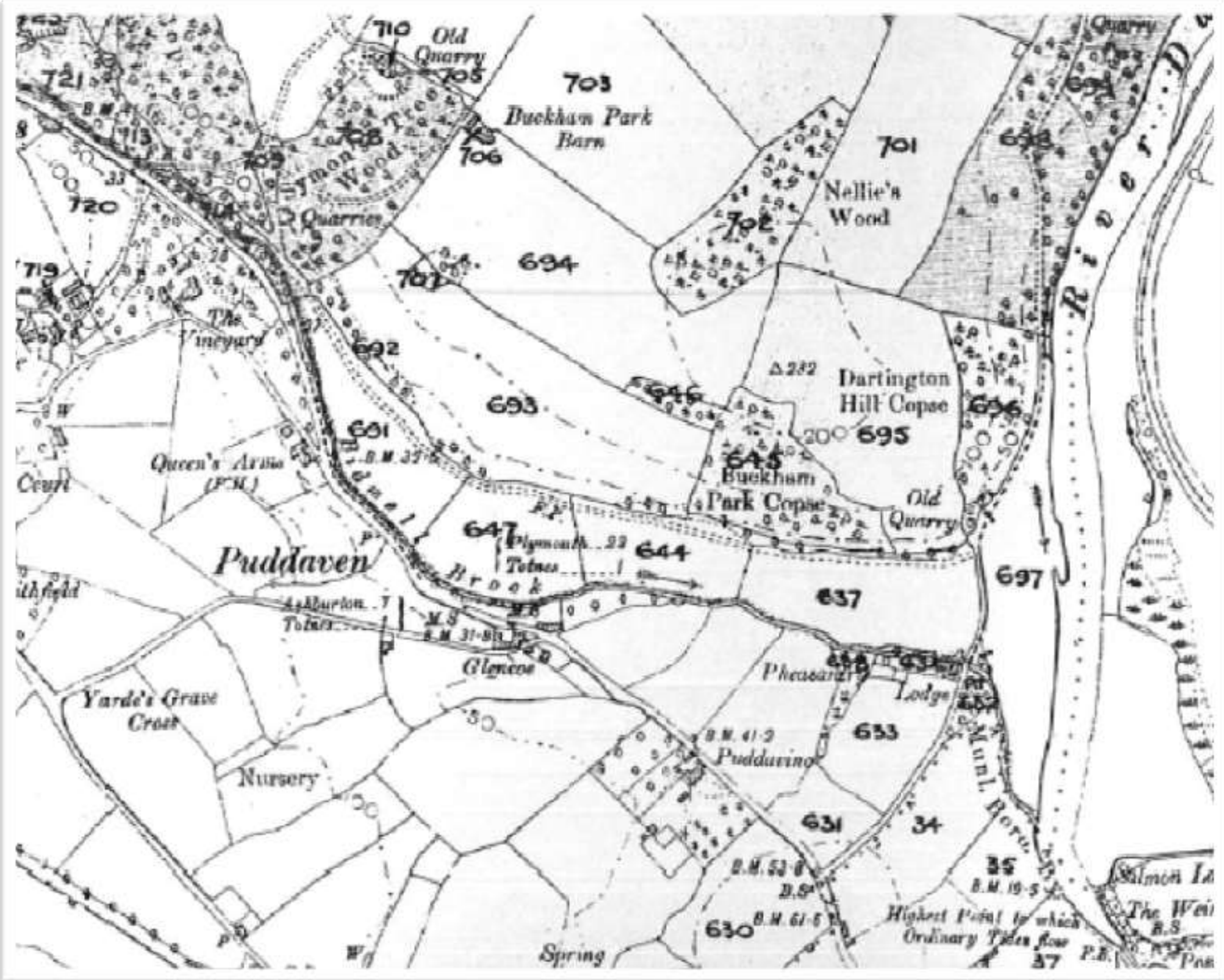
Analysis Results (SOIL)

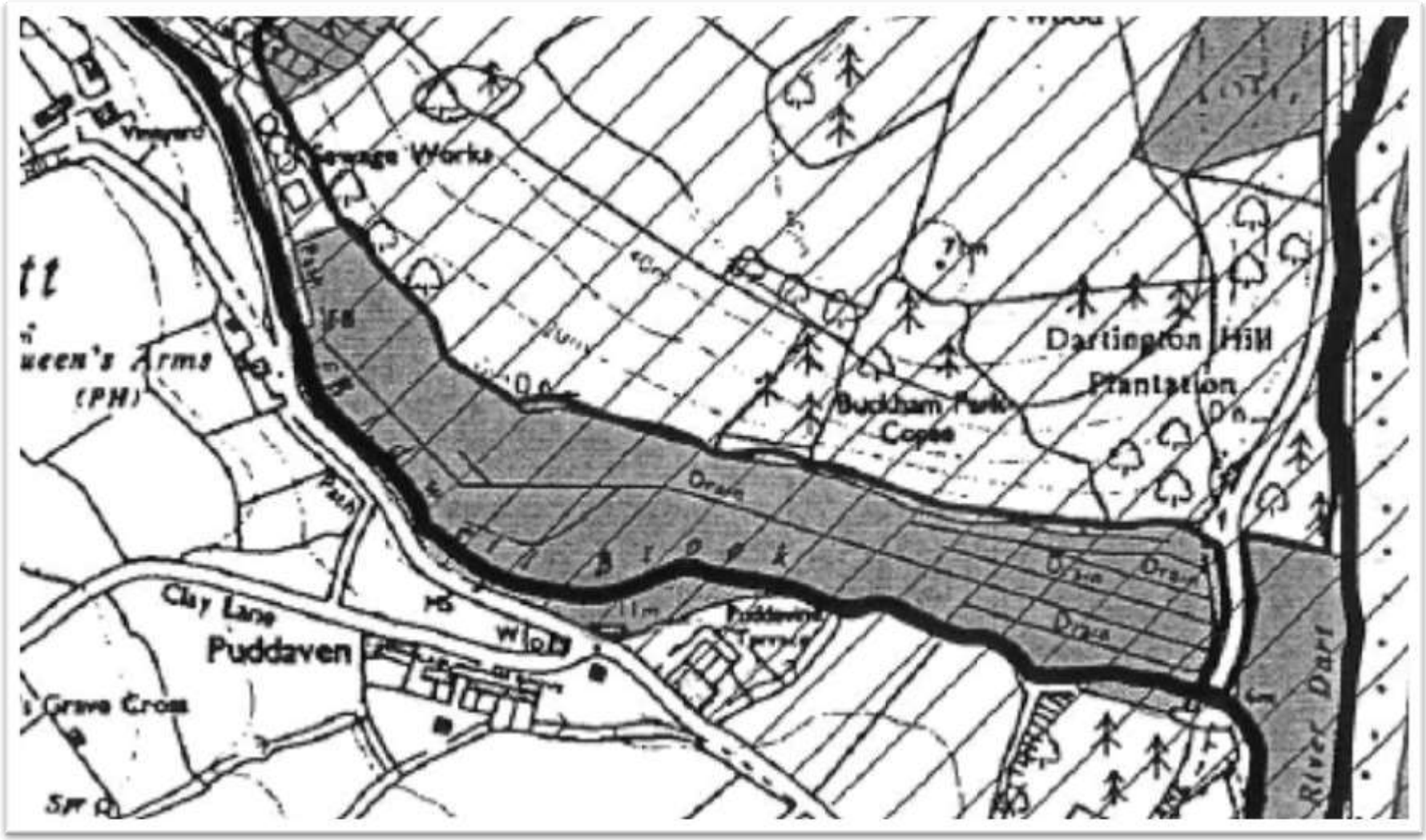
Customer	DARTINGTON TOTNES DEVON	**Distributor**	WESTCOUNTRY RIVERS TRUST RAIN-CHARM HOUSE KYL-COBER PARC STOKE CLIMSLAND CALLINGTON CORNWALL PL17 8PH
Sample Ref	QUEENS MARSH UPPER	**Date Received**	08/10/2015
Sample No	E148178/04		
Crop	GRAZED GRASS (CATTLE)		

Analysis	Result
Lead (mg/kg)	48.95
Nickel (mg/kg)	38.83
Zinc (mg/kg)	164.27
Copper (mg/kg)	38.65
Arsenic (mg/kg)	15.00
Cadmium (mg/kg)	0.52
Mercury (mg/kg)	< 0.01
Chromium (mg/kg)	47.48

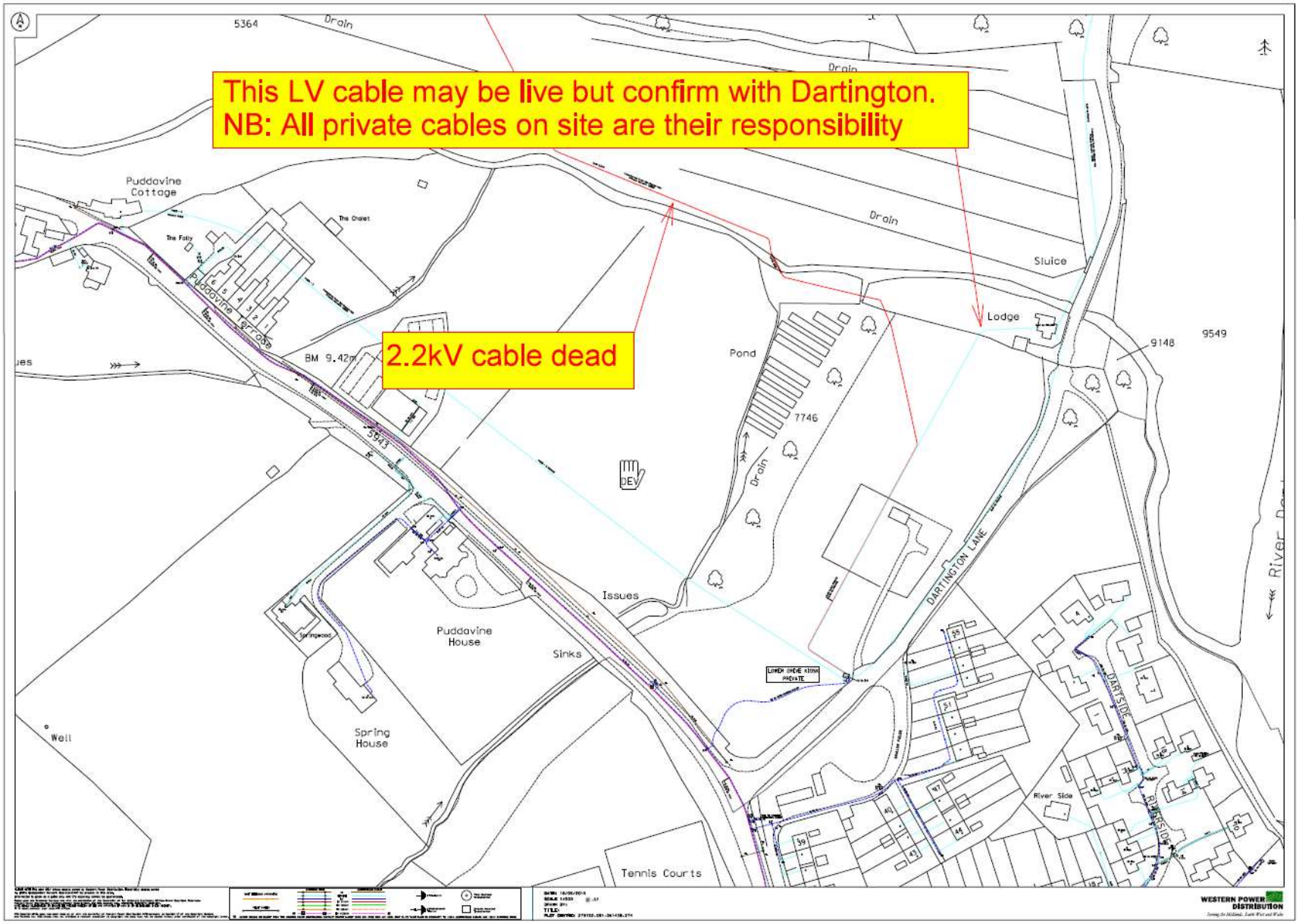
Appendix 3: Historic Ordnance Survey map

1805 b) 1921 c) 2002


Old Quarry
703
Buckham Park Barn
701
Nellie's Wood
702
Quarries
694
The Vineyard
692
693
Dartington Hill Copse
695
696
645
Buckham Park Copse
Old Quarry
Queen's Arms (P.H.)
Court
647
644
Puddaven
Brook
637
697
Glencoe
Pheasantry
Lodge
Yarde's Grave Cross
633
Nursery
631
34
River Dart
35
Highest Point to which Ordinary Tides flow
630
Spring
The Weir
720
721
719
706
707
710
698
699


Sewage Works
Queen's Arms
(PH)
Clay Lane
Puddaven
Grave Cross
Buckham Park
Copse
Dartington Hill
Plantation
River Dart

Appendix 4: Western Power map



Appendix 5: Devon County Council correspondence

From: Customer Service Centre Roads & Transport Team - Mailbox

Sent: 16 October 2015 14:23

Subject: ENQ15833669 - A385 Clay Lane Dartington

Dear Mr Morriss

Thank you for your email dated the 28th September 2015 requesting information on road drainage or assets owned or maintained by Devon County Council at the above location.

Unfortunately we do not keep records of our drainage systems. There are road gullies along this route but I am unaware where they discharge. I would suggest that a camera survey is undertaken by yourselves to establish if diverting the Bidwell Brook will have any impact on any drainage outfall in this location, and for you to undertake any remedial works in the form of extension or redirection to ensure the highway drainage is not affected.

Web Site : http://www.devon.gov.uk/

Disclaimer : http://www.devon.gov.uk/email.shtml

Appendix 6: Wildflower species mix

Possible Species for Drier Areas	
Latin name	**Common name**
Achillea millefolium	Yarrow
Achillea ptarmica	Sneezewort
Betonica officinalis (Stachys officinalis)	Betony
Cardamine pratensis	Cuckoo-flower
Centaurea nigra	Common Knapweed
Filipendula ulmaria	Meadowsweet
Galium verum	Lady's Bedstraw
Leucanthemum vulgare	Oxeye Daisy
Lotus pedunculatus	Greater Bird's-foot Trefoil
Plantago lanceolata	Ribwort Plantain
Primula veris	Cowslip
Prunella vulgaris	Selfheal
Ranunculus acris	Meadow Buttercup
Rhinanthus minor	Yellow Rattle
Rumex acetosa	Common Sorrel
Silene flos-cuculi (Lychnis flos-cuculi)	Ragged Robin
Vicia cracca	Tufted Vetch
Carex flacca	Glaucous sedge
Carex hirta	Hairy sedge
Juncus sp.	Rush
Alopecurus pratensis	Meadow Foxtail
Anthoxanthum odoratum	Sweet Vernal-grass
Briza media	Quaking Grass
Cynosurus cristatus	Crested Dog's-tail
Deschampsia cespitosa	Tufted Hair-grass
Festuca rubra	Red-fescue
Poa trivialis	Rough meadow-grass

Possible Species for Wetter Areas	
Latin name	**Common name**
Achillea ptarmica	Sneezewort
Angelica sylvestris	Wild Angelica
Caltha palustris	Marsh Marigold
Eupatorium cannabinum	Hemp Agrimony
Filipendula ulmaria	Meadowsweet
Geum rivale	Water Avens
Iris pseudacorus	Yellow Iris
Lotus pedunculatus	Greater Bird's-foot Trefoil
Lycopus europaeus	Gypsywort
Lythrum salicaria	Purple Loosestrife
Ranunculus acris	Meadow Buttercup

Scrophularia auriculata	Water Figwort
Silene flos-cuculi - (Lychnis flos-cuculi)	Ragged Robin
Succisa pratensis	Devil's-bit Scabious
Vicia cracca	Tufted Vetch
Agrostis stolonifera	Creeping Bent
Alopecurus geniculatus	Marsh Foxtail
Anthoxanthum odoratum	Sweet Vernal-grass
Briza media	Quaking Grass
Cynosurus cristatus	Crested Dog's-tail
Festuca pratensis	Meadow fescue

Appendix 7: Natural England Lowland Grassland Management handbook

A guide to stocking levels for lowland grassland (number of animals per hectare) (Natural England, 2007).

No. of grazing weeks per year	Neutral grassland		Wet/marshy grassland	
	Sheep	Cattle	Sheep	Cattle
2	100	25	50	12
4	50	12.5	25	6
6	33	8	16	4
8	25	6	12	3
10	20	5	10	2.5
12	17	4	8	2
14	14	3.5	7	2
16	12.5	3	6	1.5
20	10	2.5	5	1
24	8	2	4	
36	5.5	1.5	3	
52	4	0.5	2	

Appendix 8: Design Hydrology Review – Technical Note

This technical note provides commentary from a cursory inspection of the Bidwell Brook design flood inflows as provided in the 2013 SFRM model. LowFlows Enterprise estimates provided by the Environment Agency are also inspected. Other inflows within the 2013 SFRM model have not been reviewed as part of this project. A full review and recalculation of all design flow estimates to validate previous work was beyond the scope of this feasibility study.

Schematisation

A design flood estimate was derived in the SFRM project for the Bidwell Brook to the confluence with the Dart (NGR 279950, 061400) - a catchment area of 13.22km^2. This estimate has been applied to the upstream extent of the model as configured for the SFRM study. The approximate NGR of the upstream inflow to the SFRM model is 279200 61900 - a catchment area of 12.5km^2. Given the relatively small contribution of lateral inflows from the Dart confluence to the model boundary, this simplification was judged to be appropriate.

Peak Flow Estimates

Peak flow estimates have been made for the SFRM study using statistical analysis (with donor) and Revitalised Flood Hydrograph (ReFH) analysis. For the Bidwell Brook, the ReFH analysis used a 5.5 hour winter storm. These figures were also compared to the Devon Hydrology Strategy (DHS) 2012 estimates. A summary of these is given in Table 6.

Table 6 Comparison of design flood estimate outputs from the SFRM study.

	Statistical Ungauged	With donor	ReFH 5.5hrWinter	DHS (2012)	IED 1.007C_EST
Q2	5.6	6.8	6	=0.92*6.8 = 6.3	6.9
Q100	NA	23	16	=0.86*23 =19.8	19.2

From the perspective of design flood estimation for a catchment with no hydrometric data, Table 6 shows a reasonable consistency between all methods for the ungauged approaches. Observed data would be required to increase confidence in estimates further.

The SFRM flood peaks are reported to have been taken from the DHS 2012, (reported within the hydrology study but not verified against the original report). However, it should be noted that the application in the event data files used to input flow to the hydraulic models configured in the SFRM work does not appear consistent with the reported figures, especially at the lower return period of Q2 (the 1 in 2 year return period or 50% AEP) which appears to reflect the statistical estimate. However, these differences are not considered to be significant as they are within the expected range of estimates from alternative techniques.

Hydrograph shapes

The SFRM consultants adopted Flood Estimation Handbook (FEH) hydrograph shapes on the basis that these gave a better match to observed flows to a gauged location on the River Dart at Austins Bridge than the ReFH method (which had a slower rising limb and recession). Use of ReFH would have meant larger volumes when scaled to the statistical peak. This approach appears well reasoned.

Application to Bidwell Brook Focussed Study

The storm duration for the SFRM model is 8.25 hours with a timestep of 0.25. No explanation for the selection of this duration was given in the SFRM report. However it is possible that this was derived from an inspection of observed hydrographs on the River Dart. Alternative durations of 5, 10 and 15 hours were briefly tested in this feasibility study which resulted in peak flows of 6.4, 7.0 and 7.0 cumecs respectively. On this basis, the peak flow for the Bidwell Brook appears relatively insensitive to storm duration. The selected duration of 8 hours seems reasonable in the context of the SFRM study.

It should be noted that the flooding from the Bidwell Brook is likely to be dependent on volumes as well as flow peaks and it is recommended that further work is undertaken at a later stage to check the impact of varying storm durations on the response of this catchment. However, care should be taken to ensure that such an analysis does not result in implausibly long storm durations.

Low Flow Analysis

Low flow estimates have been obtained from the Environment Agency (using LowFlows Enterprise) for three locations along the Bidwell Brook through the site – the top of Queen's Marsh, the Bidwell Brook below the small lateral inflow below Puddaven (Inflow Location 1) and the Bidwell Brook

below the inflow from King Edward Stream (Inflow Location 2). A comparison of calculated discharges for these locations is shown in the table below.

Table 7 Comparison of LowFlows Enterprise estimate outputs provided by the Environment Agency.

NGR	NGR	NGR (near 50m)	LFE Area	FEH Area	Ann Q0.1
Queens Marsh	279199 061954	279200 061950	12.14	12.48	2.919
Inflow Loc 1	279620 061598	279600 061600	12.83	12.83	3.048
Inflow Loc 2	279789 061543	279750 061550	13.14	12.92	3.107

The Q0.1 represents a flow that is exceeded for 0.1% of the time. For the annual flow statistics, this equates to a flow that is exceeded for 0.4 days, or approximately 10 hours. This means that at the site, a flow of approximately 3 cumecs is exceeded for around 10 hours every year. Note that this is not confined to a single event but could be spread over a number of events. An examination of the QMED flood hydrograph (Figure 27) showed that flows exceed 3 cumecs for around 7 hours. Whilst care should be taken when comparing flow duration statistics and flood event hydrographs (different storm severities and durations will influence the duration a threshold flow is exceeded; analysis is also likely to have been applied at different timesteps), this indicates that there is no disagreement between the two assessments.

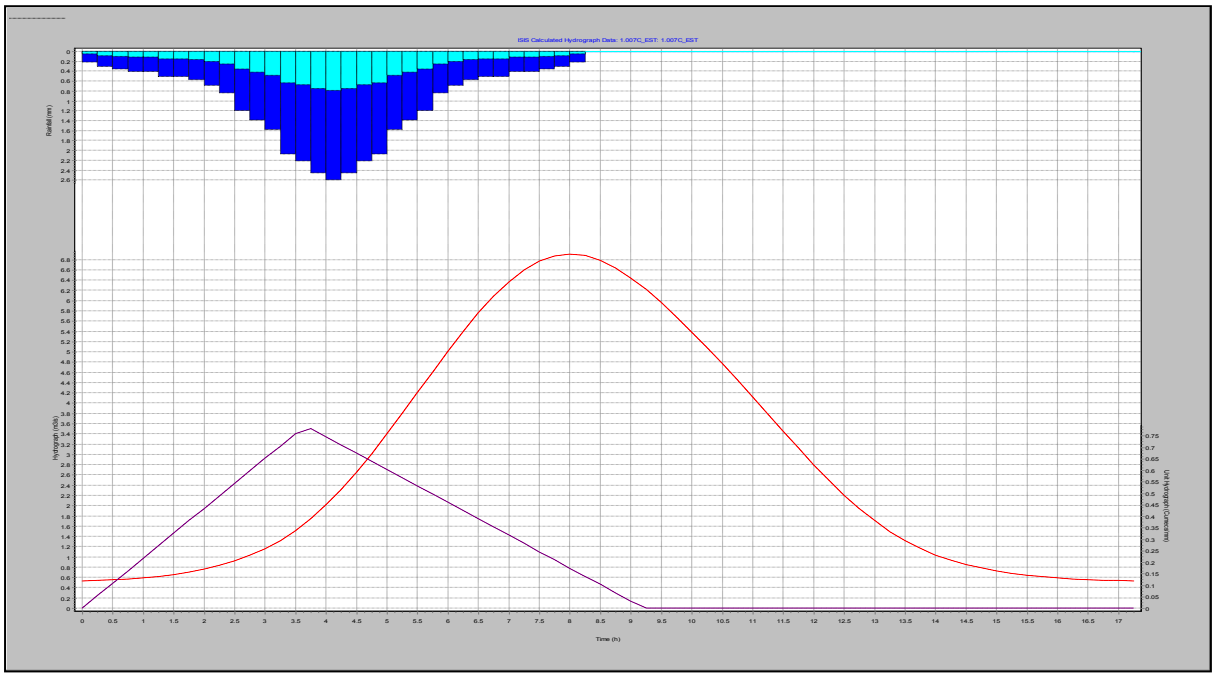


Figure 33 QMED hydrograph as derived from the FEH inflow configured for the SFRM study.

Conclusions and Recommendations

This brief review has identified that the design hydrology adopted in the SFRM study is in line with good practice, and is well documented. The hydrographs for the Bidwell Brook are appropriate for use within this feasibility-level study. The flow duration curve statistics are also compatible with the flood statistics. Should further confidence be required in the hydrology, it is recommended that this

is undertaken through calibration and through comparison with the response of local catchments of similar geographical characteristics (if available).

It is understood that some limited current and future calibration opportunities within the catchment may exist through using hydrometric data currently being collected as part of an academic catchment and sediment management study by Plymouth University. There may be some prospect to transfer hydrometric data collected on the nearby Am Brook catchment as a full or partial surrogate for the response of the Bidwell Brook – though full checks of hydrological similarity are required before doing so.