The Teifi Estuary - A review of the available options for managing its channels

Chris Evans and Tim Wright

April 2015

[October 2015 Revision]

Source: Chris Evans, December 2008

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A report for the Afon Teifi Fairways Limited as part of the

Fishing Vessels to Cardigan - European Fisheries Fund Project

Summary

Accurate charts of the Teifi estuary have existed since 1838, aerial photographs date from 1946 and LIDAR surveys from 2006. Collectively, they reveal limited change in the position of the river channel seaward of Pen yr Ergyd and major change between Pen yr Ergyd and Bryn du. From 1838 to 2014 the meandering channel has repeatedly traversed the whole width of estuary between Pen yr Ergyd and Bryn du. The LIDAR data and visual observations confirm that these processes are continuing. This is indicative of a dynamic sediment regime principally controlled by the tide cycle, but highly modified by high river discharge and individual storm events.

The last accurate bathymetry of the estuary was produced in 2008 by the Afon Teifi Fairways Limited (ATFL). Since that date, significant changes have occurred in the position and flow of the Bryn du and Nant y Ferwig channels. In this report estimates for the channel depth in 2015 are based upon the 2008 data, supplemented by recent observations. Using this data, water depth has been estimated for various tides and applied to key tidal gates between the channel mouth off Gwbert and Cardigan Quay. From this, passage times have been projected for vessels of various drafts.

The following table gives the confining tidal parameters for various vessel drafts based upon a minimum access time of 1hour 30minutes alongside at Cardigan.

Table 1 Tidal threshold values for vessels wishing to access Cardigan Quay

Vessel Draft [m]	2.5	2.0	1.5	1.0
High Water Required [m]	≥4.9	≥4.4	≥3.9	≥3.4

***Local meteorological conditions on the day would engender adjustment.**

Three consultancies have commented on possible approaches to deepen and manage the channels. All stipulate that the initial dredging programme would require annual maintenance dredging. Further, structures such as training walls and/or groynes would be needed to retain sediment and the position of the channel. These would engender additional costs in their own right. In 1998, the cost of the capital work was estimated to be between £2-7million. These historic costs were adjudged to be beyond the economic benefit of the schemes to the community. The maintenance structures and spoil sites also present significant environmental impact within a landscape fringing a National Park. It was considered unlikely that permissions would be granted by those agencies with controlling oversight.

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Navigable Channels in the Teifi Estuary

1.1. Introduction

This report describes the historic and present day physical characteristics of the navigable channels found within the Teifi estuary from Cardigan town to the sea (Figure 1). It provides data and commentary to assist in the evaluation of access potential for vessels wishing to make a passage between the sea and Cardigan Quay. Further, it discusses management approaches, such as dredging, that might be applied to make the town more accessible to vessels.

The town was an important port in the 19th century when vessels up to 140 tons reached the bridge to discharge and load cargo. In the 19th century water depths in the river and especially where it meets the sea off Gwbert (Figure 3), were similar to those existing today. Consequently, the larger vessels could only reach the town on the bigger tides at high water. The trade went into decline in the late 19th century with the coming of the railway. Note that where the channel meets the sea is locally referred to as the bar. However, in this report, the bar is the elevated section of the lower intertidal zone of Poppit Sands. Its position, extent and elevation vary with time. The river crosses this bar to reach the sea and this feature forms the principal navigable channel into the Inner estuary.

Data on the estuary morphology from the mid- 18th century up to 1946 is limited. However, from 1946 aerial photographs have become available and from 2006, Ceredigion County Council has commissioned annual LIDAR surveys. LIDAR provides digital models of the state of the estuary, accurately revealing measurable changes in channel position and sandbank elevation. The LIDAR surveys do not provide information on the depth of water in the channels.

1.2. The Physical Setting of the Estuary

The Teifi is tidal up to Llechryd bridge, some 12.6km (Figure 2) upstream from where the river channel meets the sea. In this report the Outer estuary is defined as that seaward of Pen yr Ergyd and the Poppit Dune system, the Inner estuary extends from Pen yr Ergyd to Cardigan Bridge, and the upper estuary is from there up to Llechryd bridge. Figure 2 shows the Teifi estuary and the main channels from Llechryd bridge to the sea (March, 2014).

1.2.1. The Upper Estuary

The river exits Cilgerran gorge northwards to an open alluvial plain, now dominated by the Rosehill/Pentood marsh (Figure 2). Surface elevation for the marsh runs between 1.8/2.7m OD. This broad valley was the location of the River Teifi prior to the last glacial stage and most of the seaward extent of the valley remains choked with glacial and post-glacial deposits. Part of the town of

Cardigan has also been built over the buried valley. The proto-Teifi river valley is up to 800m wide and notably 'flat-bottomed'. As the present river approaches Cardigan the valley narrows considerably before entering another rock gorge just before the town bridge. The channel in this section is approximately 1.7km in length, lined with thick mud deposits with slate debris locally exposed, and is not prone to migratory change.

Substantial volumes of slate waste were dropped into the river and adjacent marsh around the Cilgerran gorge during the 19th century. Washington (1851) suggested that this dumping led to the shallowing of the estuary. However, downstream of Cardigan bridge there is little evidence to support this. Interestingly, water depths of less than 0.6m at low water were recorded in the channel over the bar before the onset of slate quarrying. (Lewis Morris 1738, Murdoch Mackenzie 1777, Jenkins & Still 1825 & Sherringham 1838)

***Figure 1** Teifi Estuary Location Map*

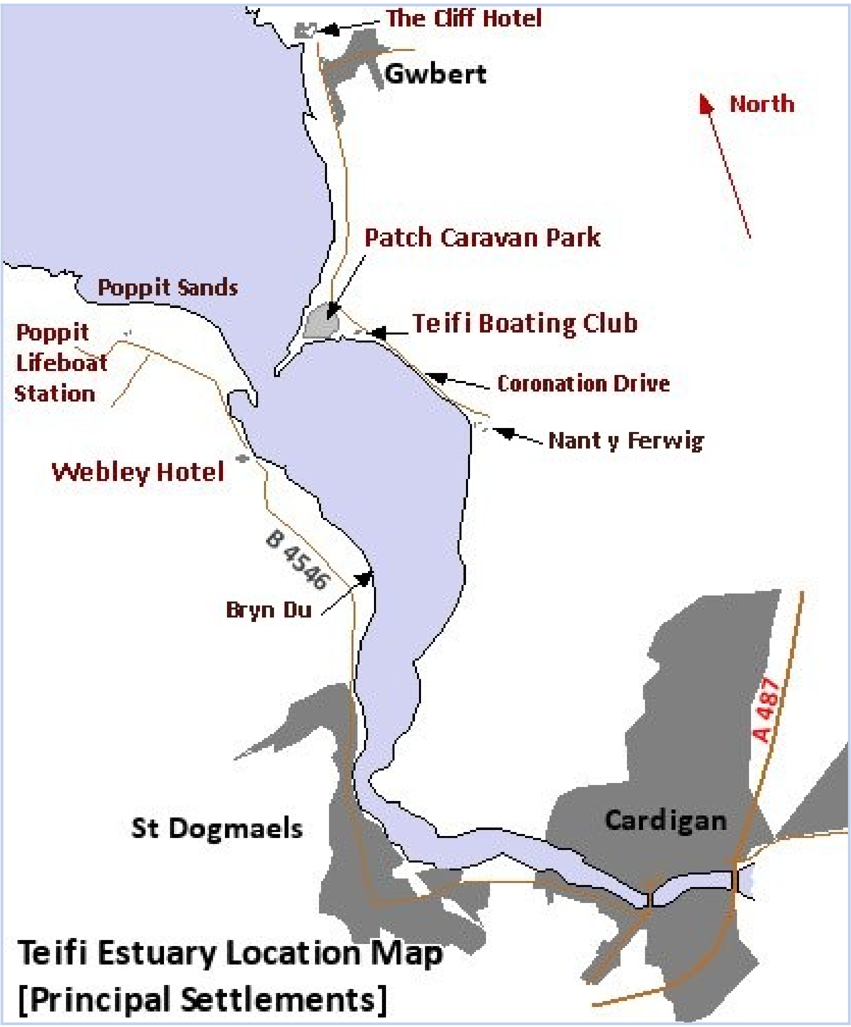
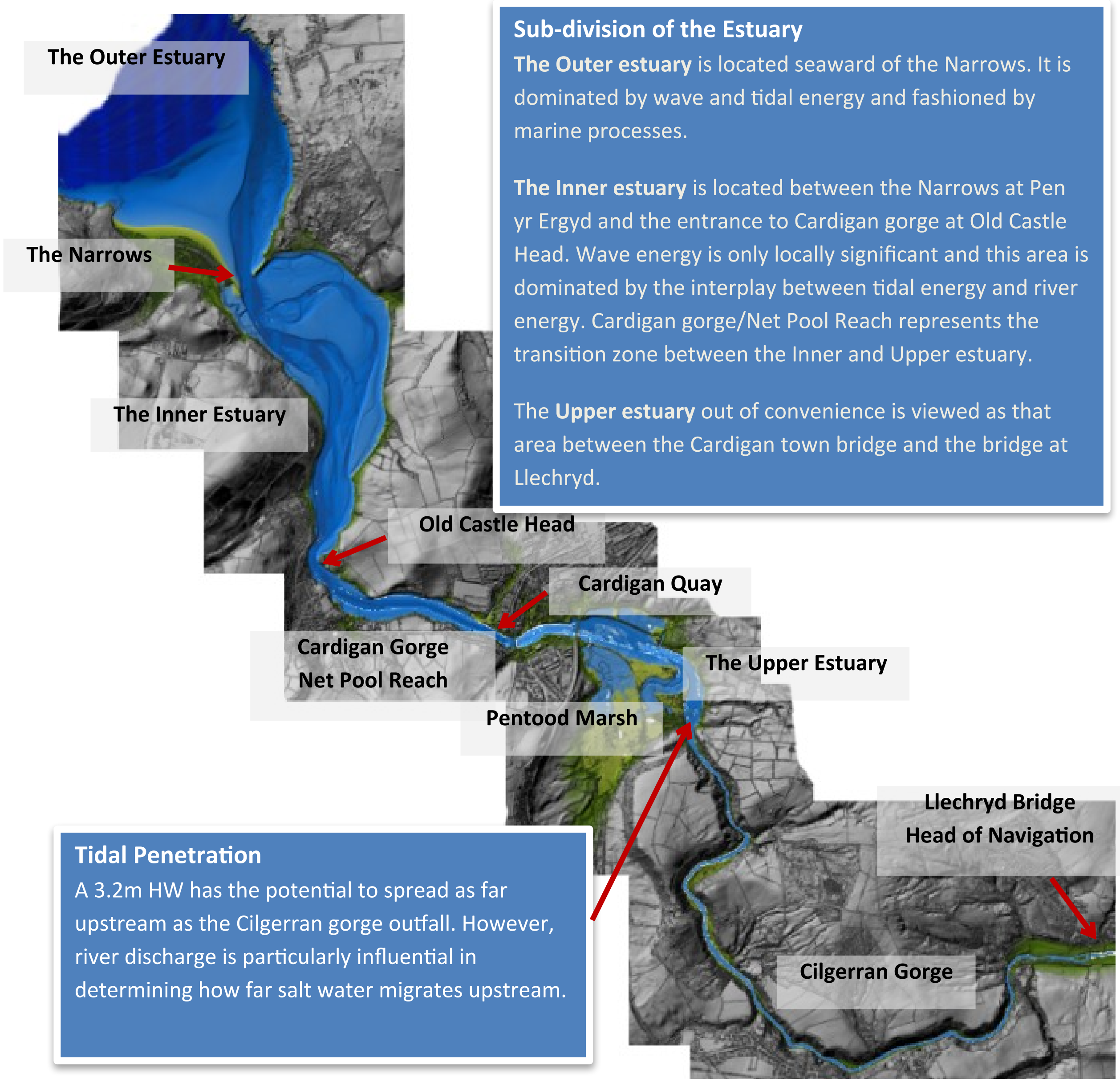


Figure 2 The Teifi estuary 4.7m- Spring Tidal Footprint



1.2.2. The Inner Estuary

From Cardigan Bridge to St Dogmaels, the river occupies a rock gorge, which opens out north of Old Castle Head (Figure 2). This section varies in width between 55m and 150m and is 1.75km long. In places eroded remnants of salt marsh fringe the shore. However, overall, the banks on the southern side are steep and wooded; while to the north the gradients are gentler. From Old Castle Head north past the St Dogmaels landing stage the valley opens out. Although the channel margins are predominantly draped in mud, notable boulders protrude through this mud. It is in mid-channel, approaching St Dogmaels landing that the first sand deposits are encountered. From Old Castle Head to the Bryn du bend is a further 820m. By the Bryn du bend the channel has returned to the broader proto-Teifi river valley, which exceeds 600m in width. The western shore reveals a variety of deposits, from locally exposed Ordovician mudstones, siltstones and sandstones to Quaternary diamicts and estuarine muds. The eastern shore as far north as Nant y Ferwig is draped in extensive mud deposits.[Diamicts are glacial deposits consisting of an unsorted mixture of sand, gravel and cobbles in a stiff muddy matrix.]

The remaining part of the Inner estuary (1.2km in length) to the Narrows at Pen yr Ergyd is dominated by sand banks and migrating channels. The western margin from the Bryn du bend through to the Poppit dune complex is formed from a rapidly eroding salt marsh. The eastern margin fronting Coronation Drive consists of a mobile, thin sand and mud cover underlain by diamict.

1.2.3. The Outer Estuary

Immediately seaward of the Pen yr Ergyd Narrows, the estuary is dominated to the west by the Poppit dune system and an extensive sandy intertidal zone. The lower intertidal part of Poppit Sands effectively forms a bar, which extends north eastwards to Craig y Gwbert and confines the channel to the eastern fringes of the Outer estuary. At present, the sands on the Gwbert shore are a minor component of the Outer Estuary's total volume. From the Narrows to Craig y Gwbert, where the channel meets the sea, is a distance of 1.83km. The bar and the channel crossing it are dynamic features that are constantly changing in elevation, extent, depth and position respectively.

The extensive intertidal sands at Poppit afford the dune system good protection by absorbing wave energy. This is particularly evident from the Narrows north westwards to Trwyn Careg Ddu. At Trwyn Careg Ddu a rock platform is exposed, on top of which rests a variety of glacial and peri-glacial sediments. By Trwyn yr Olchfa the coastline is dominated by steep cliffs of folded Ordovician rocks, which continue northwards to Cemaes Head.

The first 700m of the eastern Gwbert foreshore, north of Pen yr Ergyd is fringed with dunes and diamicts. These have been extensively eroded and have been the subject of a coastal protection scheme, first emplaced in the 1980s. The remaining coastline from Gwbert north to Cardigan Island consists of rock, locally draped by diamicts.

Although, the channel north of the Perch is confined by sand, attention is drawn to the fact that its bed is lodged in diamict. In places, boulders up to a metre across, rest on the surface of the diamict and are strewn across the channel bed and inter tidal zone on the Gwbert shore.

1.3. Bathymetry

Figure 3 shows the bathymetry in the Teifi estuary collected for the ATFL in 2008. The Hydrographic Office's 1969 survey is the only published data for the 20th century and in the Atkins report (2004), a poorly located single line section is included.

The bathymetry of the river from Cardigan Bridge to the northern limits of St Dogmaels has remained almost unchanged over the past two centuries. Most of the change relevant to this project has occurred in the wide sandy reaches from Bryn du (Figure 1) to Pen yr Ergyd, and from Pen yr Ergyd to the sea.

The first map of the estuary published in 1748 [surveyed around 1738] shows a single river channel slightly displaced to the east, with the greater extent of sand on the Poppit shore. The Jenkins and Still map[1] (1825), shows multiple channels occupying a similar position with depths of 0.7m at low water (all depths in this report have been converted to metres) where the channel meets the sea. The Admiralty Hydrographic Office's chart of 1838 is the first accurate chart of the estuary and again shows depths of less than 0.6m at this point and at some other locations upstream. Washington (1851) reports fishermen confirming that depths at the river mouth in the early to mid-19th century were less than 0.5m. However, it must be emphasised that these few charts and maps represent the conditions existing at the time of survey and therefore serve only as a snap-shot. It is probable that the channel in the 19th century migrated across the estuary in a similar manner to that at present, in response to changing physical processes acting upon this environment.

The Ordnance Survey maps for the estuary first appear in 1810/11 with the publication of the 6" series in 1888 improving their resolution. They reveal a change in channel location through time, with the greatest change being seen between Pen yr Ergyd and Bryn du. The 1904 survey, published in 1907, shows the channel crossing the bar still with a small eastward displacement and a significant body of sand on the Gwbert foreshore. Later Ordnance Survey maps (e.g.1938 pub 1948) retain the same location for the channels as new physical surveys had not been undertaken. Therefore, care must be applied when assessing historic changes in the estuary. The 1950 OS map (published in 1953) is the first to indicate the channel crossing the bar distinctly closer to the Gwbert shore.

RAF air photographs from the 1940s confirm that the position of the channel across the bar had already been displaced to the east. It is therefore concluded that this eastward movement was prompted by changes in the physical processes acting upon the estuary between 1905 and 1940.

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[1] Of suspect provenance and may have been invented to influence the 1851 Washington inquiry.

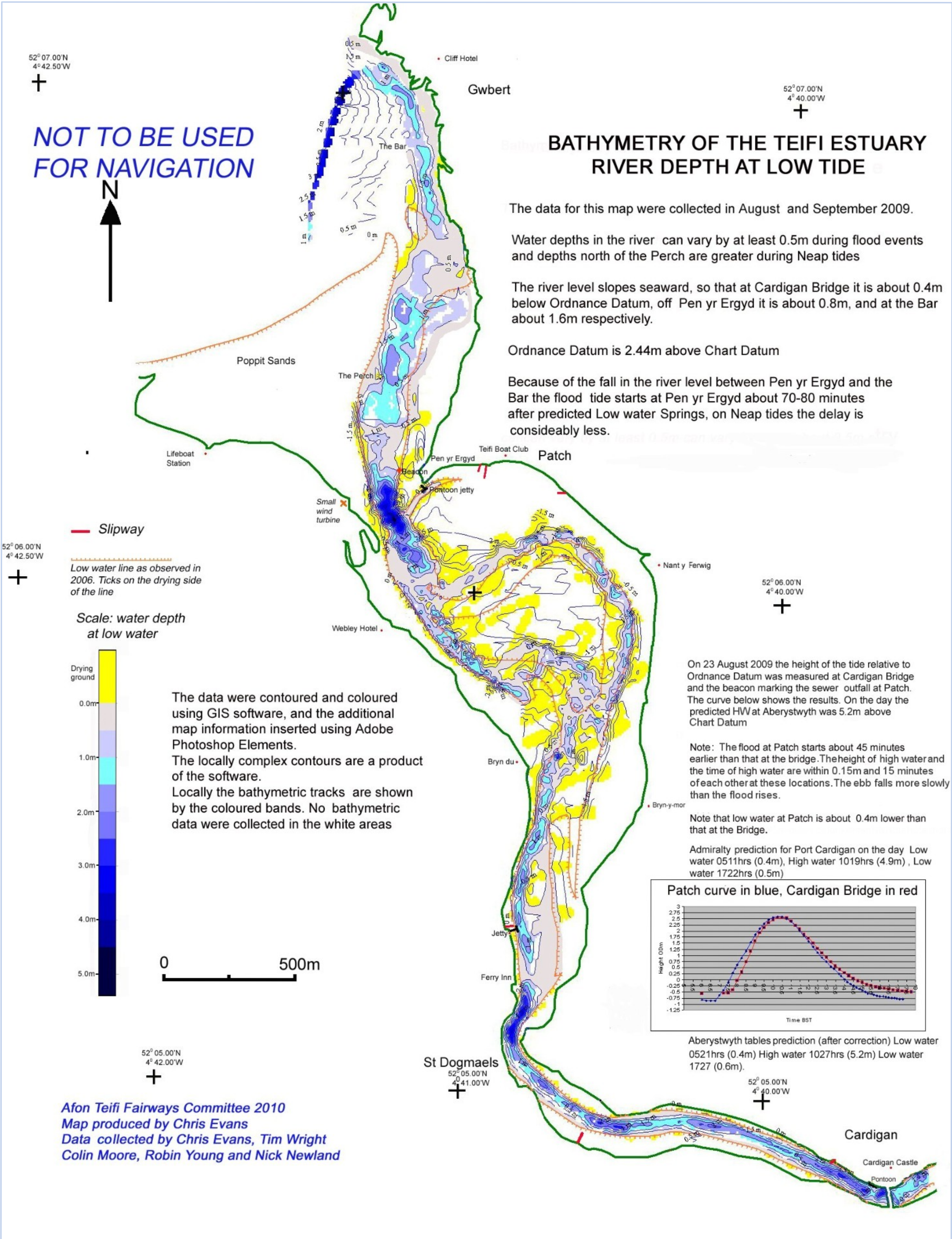


Figure 3 2008 Bathymetry of the Teifi estuary [Afon Teifi Fairways Limited– 2009

Further, the 1946 to present day aerial photographic record indicates that the channel across the bar fluctuates in position from one being close under the Gwbert cliffs, to a second approximately 200m to 250m west of the cliffs. Water depths at the mouth of the river channel remain in the 0.5/0.7m range. Although the position/orientation of the channel mouth has changed during the last two centuries, the depth of the channel at low water has remained less than a metre. There is no evidence that the channel in the Outer estuary over the past two centuries has at any time been substantially deeper than at present.

Processes active within the Teifi Estuary

2.1. Spit Development

Pen yr Ergyd spit and its partner, the Poppit spit, on the western side of the Narrows form the boundary between the Inner and Outer estuary. A linear enclosed deep with a depth of up to 4m occupies the Narrows at low water. Currently, the Poppit spit is a diminishing remnant of the feature that dominated the estuary from the 1930s to 1970s. Although the Pen yr Ergyd spit at about 140m is the larger, it is also a transitory feature.

Up to some 50 years ago Pen yr Ergyd referred to the dune system that formed a broad promontory on the eastern side of the estuary. The Poppit spit achieved a length of 335m in the period between 1945/1950. However, the extensive dune and spit formation at Poppit resulted in a large volume of sand being stripped from the beach. Photographic evidence from the 1940s & 50s reveal that the upper beach was 1.5m/2.0m lower than it is at present. Further, sediment levels in the Inner estuary were also more extensive. The lower beach elevation permitted a greater level of wave attack which led to the erosion of the spit structure. In addition, during the late fifties/early sixties the orientation of the channel began to change as it left the Inner estuary. As it approached and passed through the Narrows it also helped to focus erosion on the upper Poppit shore, contributing to the removal of much of the Poppit spit and saltings. In the area where the channel migrated away from, the lower energy conditions facilitated deposition, which eventually led to the formation of the Pen yr Ergyd spit. These processes continued until the late 1990s when the Pen yr Ergyd spit ceased extending in length. The effectiveness of the coastal protection scheme to the north of the Patch caravan site and the groyne system seaward of the caravan site combined to starve the spit of a supply of sediment. A restriction of supply also impacts the Poppit spit. Here the rock armour placed seaward of the cottages at the eastern end of the dunes appears to arrest sand migration along the upper beach.

This interruption to sediment supply has introduced a period where both the Pen yr Ergyd spit and the Poppit spit are in a state of mass loss. Essentially, the sand component, which forms a significant volume of the spits, is slowly being lost. This leads to deflation and a slow loss in elevation. Inevitably, the spits are now vulnerable to overtopping on big spring tides and more seriously during storm events.

Although there is no evidence for the migration of the Pen yr Ergyd spit into the estuary over time, some material is 'rolled over' onto the landward face of the spit under the influence of storm waves to form debris fans. These debris fans have been mechanically moved from the inshore face and placed back onto the crest after major storms. To date, this process, along with the infilling of the erosional area at the spit's root utilising sediment removed from the recurve at the end of the spit, has successfully maintained the overall integrity of the spit. Fears remain however, that a major storm will breach the spit leading to a significant reduction in the navigability of the channel(s) in the vicinity of the Narrows. Such an event would compromise the investment in the pontoon and the viability of the Teifi Boating Club. It is also important to monitor and record the changes to the spit which relate to the AFTL management processes. Mechanised sediment transfer risks mass wastage of sand and finer sediments from the spit as the cobble surface is removed.

2.2. Channel migration within the Teifi estuary.

Channel migration within the estuary is very dynamic. However, within the confines of the rock gorge between Cardigan Bridge and Old Castle Head, the Net Pool reach, migration is prevented by resistant rock margins. This constraint diminishes northwards to St Dogmaels where the Inner estuary opens out. Figures 4 to 6 illustrate that lateral channel migration is concentrated between the Bryn du bend and the Narrows at Pen yr Ergyd.

Seaward of the Narrows the channel(s) are less sinuous and follow routes to the sea to the east of Poppit Sands. Overtime this has become more accentuated as the channel has been driven to the extreme eastern edge of the estuary, and it now lies at its seaward extent near, or beneath the Gwbert cliffs.

2.2.1. Channel migration with time.

The 1838 Admiralty chart supplies rectifiable data that can be overlain by the 1888, 1907, 1950/3 and 1977 Ordnance Survey sheets. Figures 4 displays the channel change between 1838 and 1977 extracted from the aforementioned sources. However, it would be incorrect to infer that the changes seen here are operating on a twenty to fifty year time scale. This is purely an artefact of the intervals at which survey work was undertaken.

The addition of aerial photographs to the data set (Figure 5) reveals that channel change within the Inner estuary occurs over much shorter time intervals. Figure 6 based on LIDAR data collected between 2006 and 2015 further improves the resolution and facilitates annual comparison.

In summary, the position of the channel(s) is undergoing perpetual modification.

Figure 4 *Position of the channels in the Teifi estuary between 1838 and 1977*

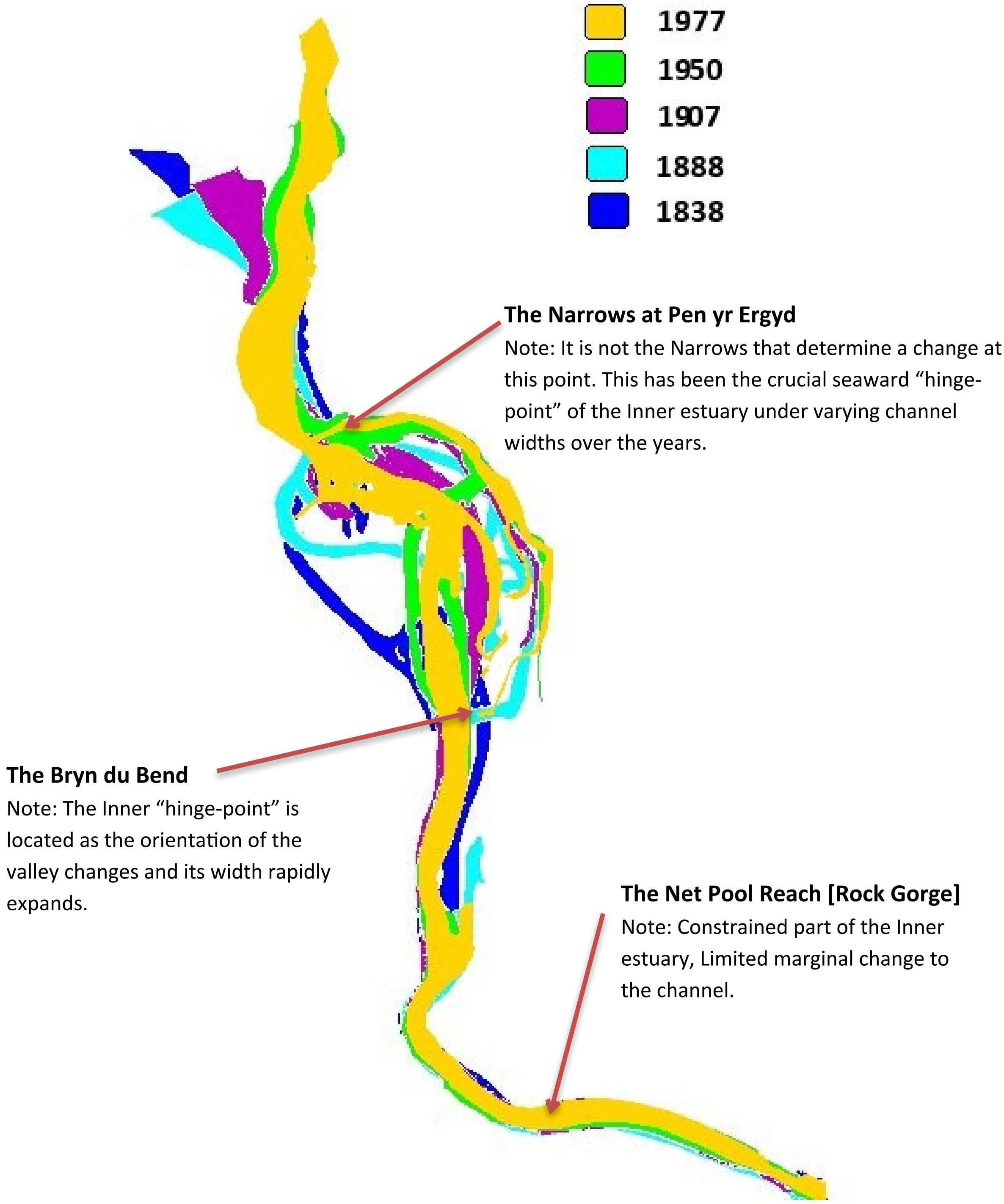


Figure 5 *Positon of the channels in the Teifi estuary between 1946 and 2006*

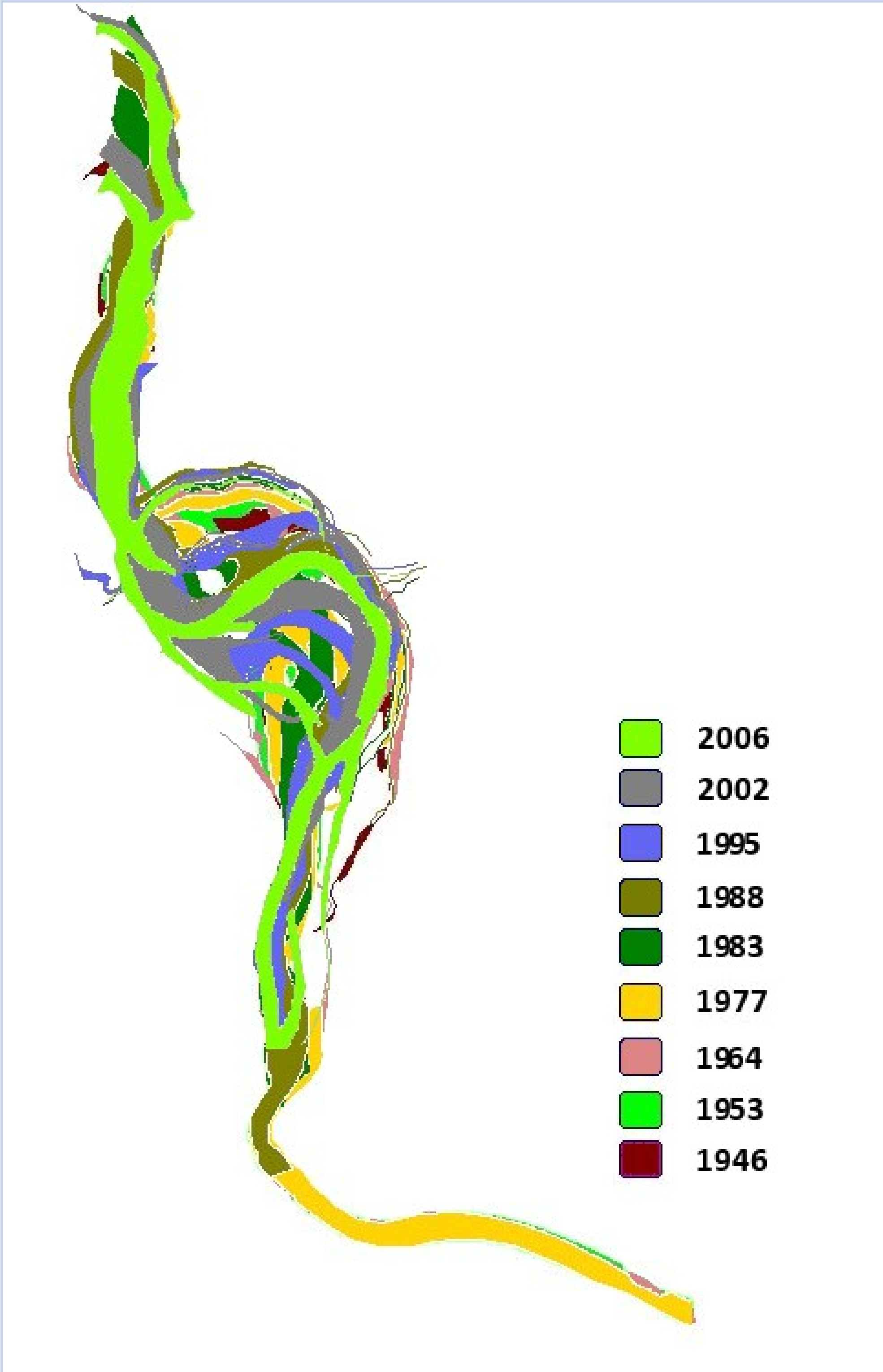
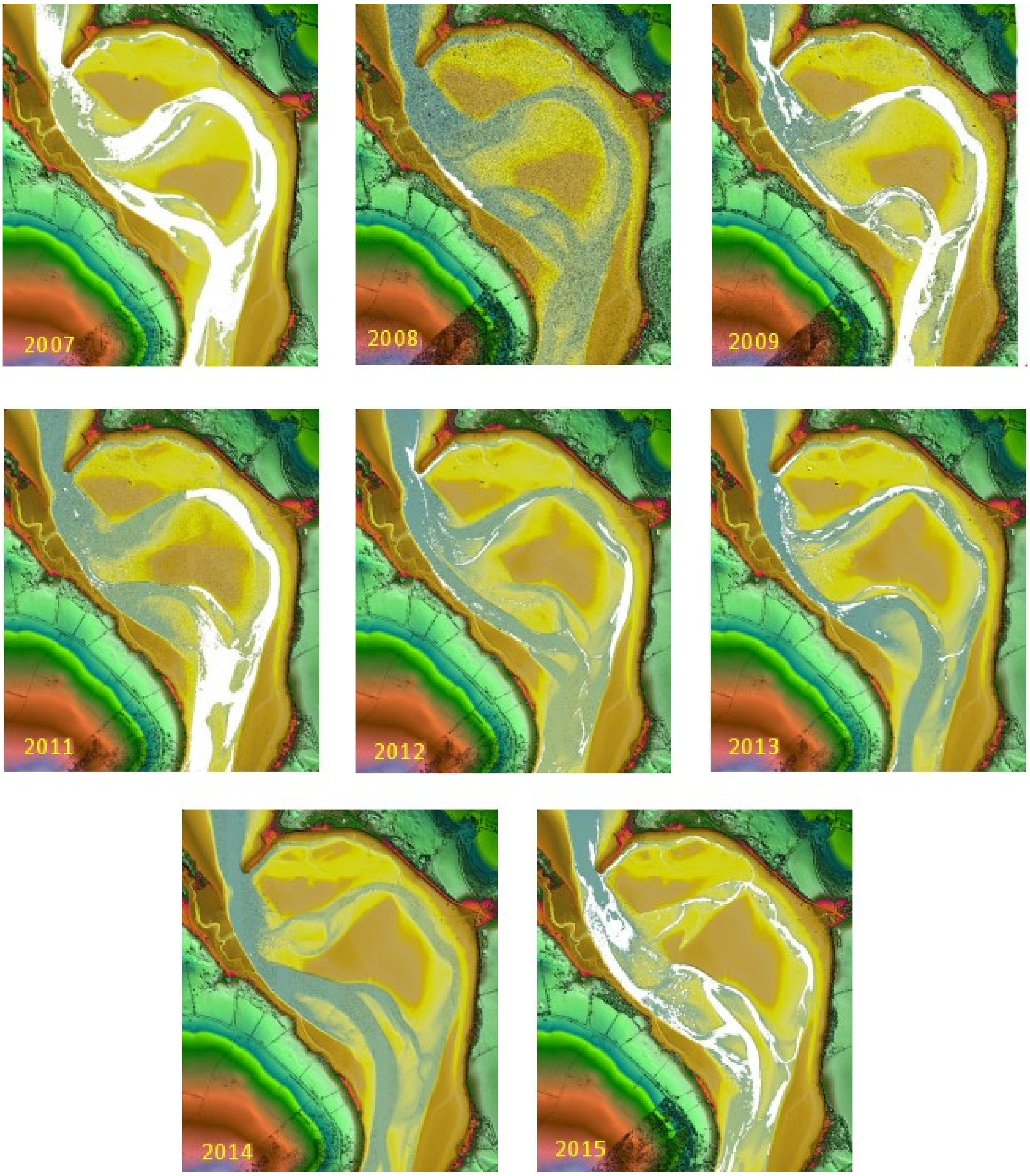


Figure 6 *Position of the channels in the Teifi estuary between 2007 and 2015 – Lidar Extracts*



(In all channel outlines obtained from LIDAR images, minor distortion occurs through the variation in the elevation of the tide and river discharge at the time the data were collected.)

2.2.2. Channel migration by area – Cardigan gorge/Net Pool Reach.

Clearly, within the Net Pool reach the rock gorge limits such changes to the small accumulations of mud on the channel margins.

2.2.3. Channel migration by area – Old Castle Head to the Pen yr Ergyd Narrows.

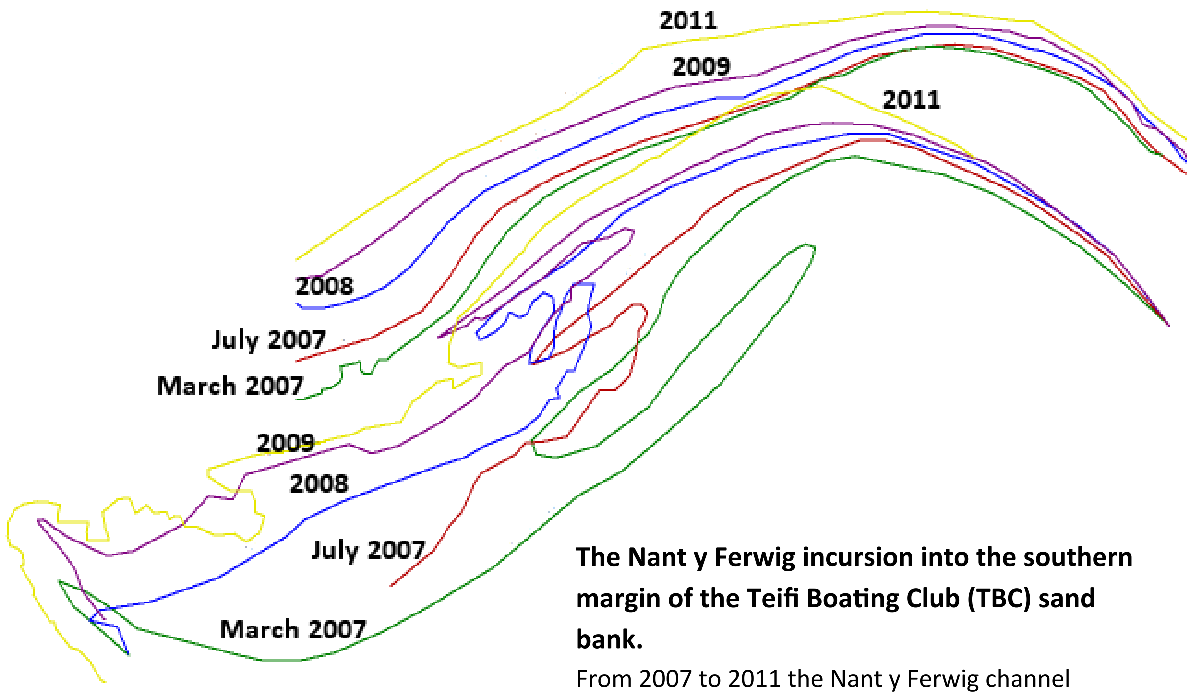
Between Old Castle Head and the Bryn du bend, the channel occupies a position that runs close to the western, St Dogmaels shore. Lateral migration in this section is minimal. Along the eastern shore mud flats predominate and appear to be slowly accreting. A fine clean gravel is occasionally exposed on the channel bed south of the St Dogmaels landing stage. This is most noticeable following high discharges from a flood event. The channel also shallows adjacent to the Ferry Inn from time to time which can impact access upstream for larger vessels. An influx of sand occurs in the central and eastern areas to the north. Since 2009 the north eastern part of this section has seen an increasing accumulation of sand and the formation of north-south orientated banks. The impact of this sedimentation has been to direct water on the ebb away from the Nant y Ferwig channel and into the Bryn du/Webley channel.

Channel migration is at its greatest between the Bryn du bend and the Narrows at Pen yr Ergyd. The morphology of this section also differs from elsewhere in the Inner estuary as its length (1.14km) and breadth (1.03km) are much more similar. An example of the scale of channel migration can be ascertained from the northerly progress of the Nant y Ferwig channel between March 2007 and March 2011 (Figure7). During this period the Nant y Ferwig channel was the principal feature with three times the capacity of its Bryn du/Webley counterpart. By 2015 the position had reversed, with the Bryn du channel being dominant and the Nant y Ferwig channel locally drying out at low water. Recorded observations and LIDAR data analysis (Evans & Wright 2006 – 2013) have revealed between 5m and 17.5m of annual migration along a 500m section of the northern bank of the Nant y Ferwig channel, with the reworking of over 3,000m^3/annum of sediment.

No clear understanding has been obtained of the time it takes for a meander to propagate across this area. The movement is episodic with interruptions and premature cessation during storm events, particularly those linked to high river discharge. It is possible that under optimum conditions a period between 10 and 20 years might occur between major changes in channel meander patterns. [Optimum conditions in this instance are defined as no significant change to the volume of sediment and water entering or leaving this section.]

Currently, the main channel is located along the western side of the Inner estuary, while those areas to the east are registering sediment accumulation. This includes the former Nant y Ferwig channel, which is now virtually extinct at low water. The Bryn du channel is meandering through the southern part of the Nant y Ferwig bank and periodically splits into two braided channels.

Figure 7 *Changes in the position of northern limb of the Nant y Ferwig channel between 2007 and 2011*



*No LIDAR data for 2010

The Nant y Ferwig incursion into the southern margin of the Teifi Boating Club (TBC) sand bank.

From 2007 to 2011 the Nant y Ferwig channel migrated 20m north at its eastern end and 70m+ at its western end. [5m – ~17.5m/year]

For 2007 LIDAR data for March and July indicates the change over a 3.5 month period. [3m – 7m, with some areas recording no change.]

As the Bryn du channel has developed there has been corresponding erosion and retreat along the salt marsh scarp that fringes its western (Webley) shore. This erosion has often been attributed to flood tide flow and to some extent that is correct. However, the rate of erosion increases to the south where the flood tide flow is dissipating. The aggressive meander scrolling on the ebb, particularly linked to those discharges following heavy precipitation in the catchment is a more effective erosional agent. Undercutting occurs at a much lower level on the scarp, which facilitates collapse and subsequent retreat. Just south of the Narrows, retreat of the salt marsh scarp of about 8m has been recorded between 2006 and 2014. This corresponds to a retreat in excess of 20m further to the south during the same period. Of note, the erosion of the salt marsh scarp (900m length) releases around 5,500m^3 of sediment per annum.

Since 2009, accretion of sediment has occurred in the TBC Gut (a narrow shallow channel) as discharge in the Nant y Ferwig channel has deceased. The ATFL policy has been to remove sediment from the access channel to the pontoon and place the spoil on the eroding bank face in front of the TBC. However, this spoil falls and is eroded onto the adjoining foreshore, which exacerbates accretion in the Gut.

2.2.4. Channel migration by area – Pen yr Ergyd Narrows to the sea.

In the Outer estuary marine processes dominate. The main channel is more fixed in its course, although substantial fluctuations in its position can occur where it reaches the sea. Between the Narrows and the Perch the channel surface gradient falls by about 0.3m, while between the Perch and the sea the average fall is 0.5m.

The channel bed is cut into a diamict substrate and locally, particularly to seaward of the Perch, large boulders derived from glacial sediments obstruct the channel. Locally the tops of these boulders are exposed when river discharge is low. At low water, flows in the channel north of the Perch may reach 0.9m/sec

The bar is essentially the lower extent of Poppit Sands extending north eastwards towards the Gwbert cliffs. Its position is of paramount importance to the local fishing and recreational sailing community, as the navigable channel of the river Teifi is forced to cross it at its seaward end. In the Teifi estuary the channel across the bar may occupy two different positions, either tight under the Gwbert cliffs, or some 200m/250m away from the cliffs to the west. No detailed record of the timing of changes has been kept, but it changes position frequently. There have been eight recorded changes between 2006 and 2014. On four occasions a hybrid version has existed whereby both channels have remained open. It is highly likely that other unrecorded events have also taken place. It is not known whether this change is gradual, over a period of a week or two, or is more rapid, occurring over one tide cycle. The processes leading to these changes are not fully understood. Storm events are known to have preceded some changes, as have high river discharges. However, there have been other events where the factors driving the change have not been obvious. It is clear however, that when the channel is trapped close to the Gwbert shore, considerable volumes of sand have moved to the lower part of Poppit Sands. The prevailing wave climate in the bay moves sediment from the west to the east. Over time, this moves sediment into the channel and up to the Gwbert cliff base. As the sand appears to move across the bar in fluxes, a low stand may be created a little to the west, and the river/ebb flow exploits this low area to reach the sea and in so doing forms a new channel.   Of note is the prodigious volume of sand reworked as the channel re-positions itself across the bar. Here up to 15,000m^3 of sand is removed to open the channel and a further 15,000m^3 is reworked to infill the channel once it has been vacated.

2.3. The tidal regime in the Teifi estuary

The Teifi estuary provides a good example of the complex interplay between wave, tide and river energy. The Outer estuary is tide and wave dominated, while in the Inner estuary it is the river and tidal energy that predominates with wave energy being restricted in location and time. The upper estuary usually falls under the influence of river processes interacting upon a flood plain. However, in the Teifi estuary, the entrapment of the river channel within rock gorges at Cilgerran and Cardigan further complicate the tidal dynamics and confine river discharge.

The predicted tidal differences for Port Cardigan, located just seaward of the Bar at Gwbert are shown in Table 2. The Port Cardigan predicted spring range is 4.0m and the neap range is 1.4m. There are no ranges for Cardigan Quay as low water retreats from that part of the estuary. The highest astronomical tide for Cardigan Town is 5.64m over CD. This was exceeded in March 2008 when a 5.2mHWS (High Water Springs) was augmented by an additional 0.57m due to an extremely deep depression arriving at the same tme. November 2014 also recorded an exceptional HW combing with high river discharge [but not a flood event], low atmospheric pressure and an additional component due to the ponding up of water in Cardigan Bay through strong westerly gales persisting for several weeks. The result was extensive flooding in lower Cardigan.

Table 2 Port Cardigan tidal differences based on the Standard Port – Milford Haven

Height Corrections [m]				
	MHWS	MHWN	MLWN	MLWS
Milford	7.0	5.2	2.5	0.7
Corrections	-2.3	-1.8	-0.5	0.0
Port Cardigan	4.7	3.6	2.0	0.7

Source: Read’s Nautical Almanac derived from UK Hydrographic Department, Admiralty Tide Tables.

The figures given in Table 2 are for predicted tides[2]. As the tide wave approaches the estuary from the west, persistent westerly winds enhance the volume and strong easterlies retard it, and this leads to higher or lower tidal levels respectively. Similarly, strong northerly winds pond water up in the Outer estuary to increase the predicted tide level and change the precise time of high and low water. An additional influence is air pressure. The predicted tides are calculated for an air pressure of 1013millibars, and each millibar difference on the day changes the tidal prediction by about a centimetre. Thus lower pressures (<1013mb) lead to an actual high/low tide elevation above the predicted and higher pressure (>1013mb) leads to a lower high/low tide level than the predicted. For example, on Monday 23 Feb 2015 the predicted height of high water at Port Cardigan was 4.9m, but the local air pressure at the time was 984.3mb. Consequently, the predicted 4.9m tide became an actual 5.2m (5.197m to be precise). Of note, although the understanding of the heights of tide impacting upon the estuary is improving, the complexity of the time variable remains a challenge.

The physical constriction of the 'funnel' shape in the Teifi estuary is in part responsible for increasing HW heights as the tide wave passes upstream. For example, on Friday 27 Feb 2015 High Water Port Cardigan was predicted to be 3.4m at 14:40, while the equivalent at Cardigan was 3.6m at 15:20.

The river has the potential to influence the high and low tide levels in the estuary and to modify the morphology of the estuary. The volume of water discharging through the river varies on a day to day basis. The discharge in extreme drought periods has fallen to 0.73m^3/sec, while that of the worst flood event rose to 373.6m^3/sec. Of note, the 2012/2013 winter discharges associated with the unusually high precipitation rates experienced in December and January respectively, averaged 83.71m^3/sec.

Note: The zero (0m) datum on Ordnance Survey maps is termed Ordnance Datum which is close to mean sea level. On Hydrographic Charts, the base plane to which all tidal heights are referred is Chart Datum (CD). Chart Datum is the reference level above which tide heights are predicted and below which charted depths are measured. On UK charts CD is the level of Lowest Astronomical Tide (LAT), which in the Teifi estuary is -2.44m below Ordnance Datum. The estuary has tidal predictions located at Port Cardigan (seaward of the bar) and Cardigan (Net Pool reach).

Fishguard is the nearest port with a tide gauge.

[2] Predicted tides for Port Cardigan and Cardigan Town are based upon secondary port differences from the standard port, Milford Haven. The times for HW produced by this method **are know to be inaccurate**.

All tides are asymmetric within the estuary (Figure 8). Small Neap tides offer the most uniform of relationships between the flood and ebb duration (Neap flood - 6hrs 15mins, Neap ebb - 6hrs 30mins). However, once high water values exceed 4.0m the difference between flood and ebb lengths start to accentuate. Spring floods of 5hrs 15mins or less are common, with corresponding Spring ebbs of up to 7hrs 30mins duration. Tidal asymmetry is complex, but a simple explanation here is…

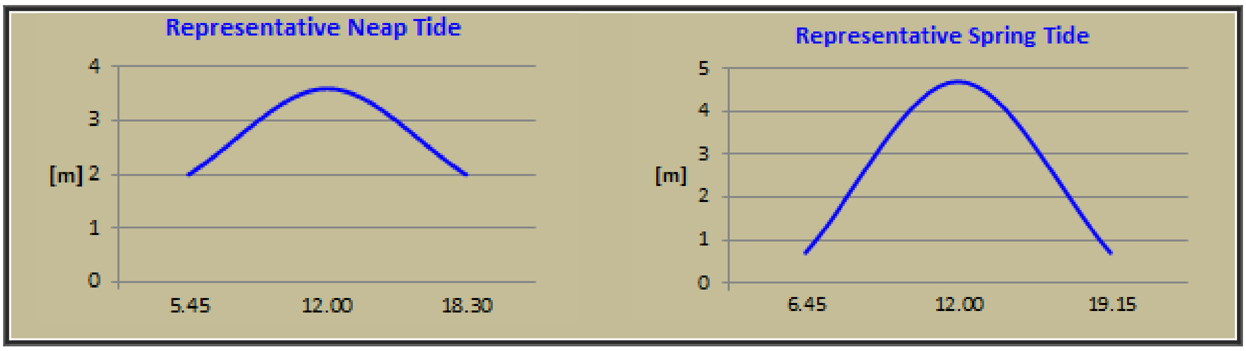
1. Flood tides arrive with high energy levels
2. The flood tide loses energy to bed friction as the water shallows
3. This is further complicated by faster flowing tide water being impeded by slower moving water ahead. In some parts of the estuary the flood also loses energy in overcoming the seaward flow of the river water.

These factors also combine to steepen increase the height of the flood tide limb of the advancing tide wave. However, the ebb tide returns seaward with a reduced energy budget which takes a longer time. A greater complexity occurs in estuaries due to density differences between fresh and salt water along with the volume of the tidal prism increasing due to the river's contribution.

This loss of energy explains why ebb tides take longer as well as the role the tide plays in moving sediment into the estuary in greater volume than it takes out.

Flood and ebb flow seaward of the Perch is typically around 1 - 2knots at Neaps and 1.5 - 3 knots at Springs. At low water when the tidal influence has retreated to seaward of the bar, flows in the channel may reach 0.9m/sec [1.75 knots] depending upon river discharge levels. These flow rates are also not uniform in the channel. With lower speeds being recorded on the more sinuous reaches of the Inner estuary.

Figure 8 *Neap and Spring tide curves for the Teifi estuary*



Flood and ebb flow in the Narrows increases to 3 - 4 knots at Neaps and 3.5 - 5.5 knots at Springs. However, big Spring tides and high river discharge exacerbate flow rates with 7.5 - 8 knots being recorded in the vicinity of the Narrows. Maximum flood rates are found just upstream of the Narrows with corresponding maximum ebb rates just seaward of the Narrows. Note, all of these rates are for flood and ebb flow in the channels.

The tidal regime within the estuary is still under investigation. We have seen a range of time differentials between Port Cardigan HW times and those at Cardigan quay. In addition, there have been double high waters within the estuary some obviously influenced by flood water surges, but others which do not have an identifiable cause so far. On the other hand, on some occasions HWs are subdued or do not occur in the upper estuary. In particular, it has become evident that predicted times and heights for the estuary are not that accurate. This stems from the use of Milford Haven as the standard port which does not share the same tidal regime as Cardigan Bay.

The following tidal description recorded here is based upon the most commonly repeated observations and is used to underpin the work presented here….

1. High water Port Cardigan (HWPC) occurs first seaward of the bar (Port Cardigan, west of Craig y Gwbert).

2. At the Narrows HW occurs a few minutes later in the range HWPC+10mins to HWPC+20mins.

3. At St Dogmaels HW occurs about HWPC+15mins to HWPC+20mins.

4. At Cardigan quay, high water occurs around HWPC+25mins to HWPC+35mins.

Occasionally, in the Inner Estuary between the Narrows and Cardigan quay, a second, usually smaller HW occurs about 15mins to 25 minutes after the first. This can be a short-lived affair of around 5 minutes, or on some occasions may be maintained for up to 30 minutes.

At the Narrows, St Dogmaels and Cardigan quay it has been observed that:

a) The water level starts to rise while the ebb flow is still running and

b) The water level starts to fall while the flood flow is still running.

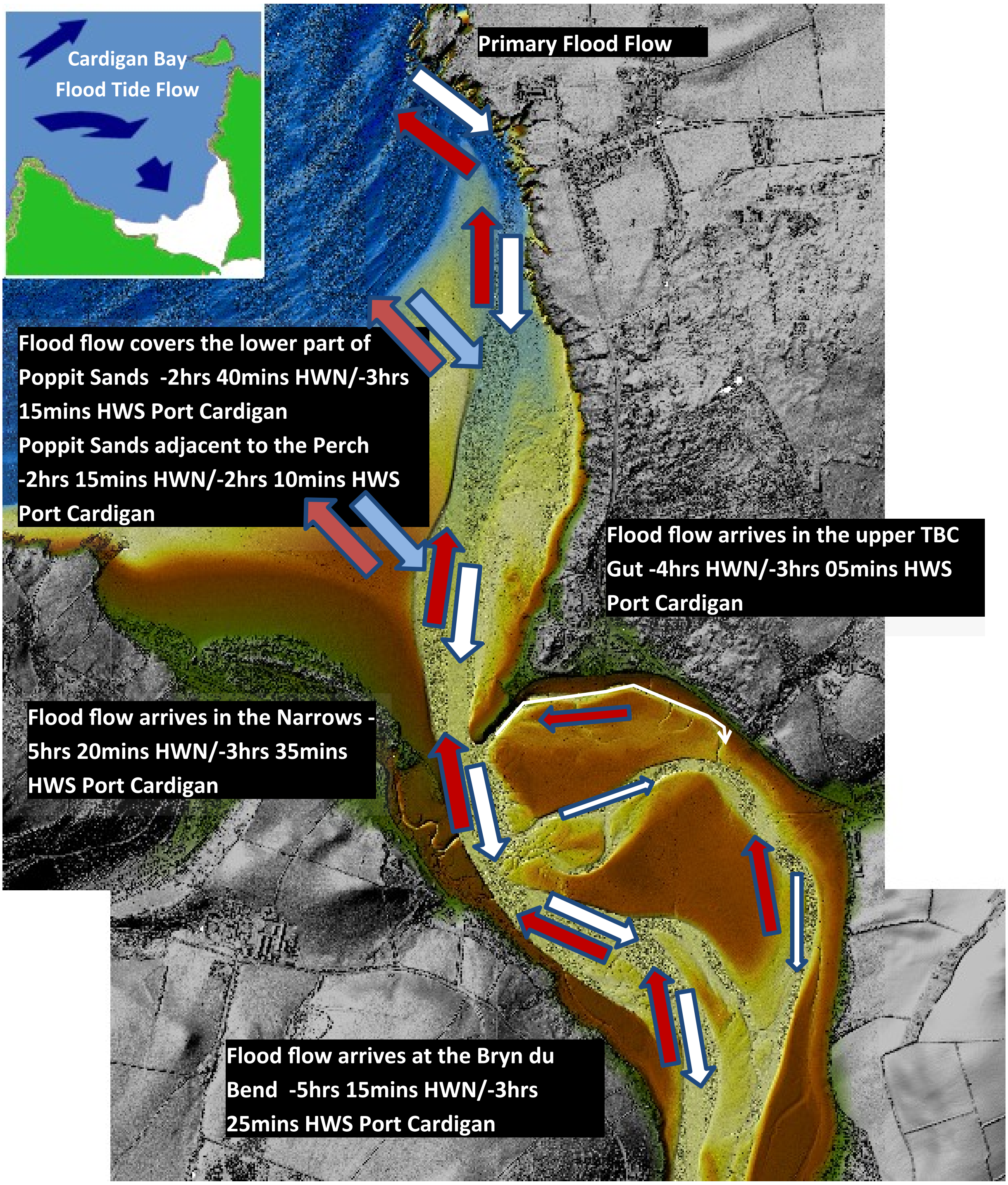
Current velocities within the Inner estuary are complex, changing with the stages of the tide and the covering or exposure of the sandbanks. Water flows within the routes dictated by the main channel throughout the tide cycle on both the flood and the ebb. For a period of up to 5 hours, water also flows across the banks and mud flats (-2hrs HW to +2/+3hrs HW). For the last hour of the flood and the first hour of the ebb the rates across the banks are relatively modest. Relatively higher flows occur at -2hrs HW and again at +2hrs HW and +3hrs HW. The sand bank in front of the Teifi Boating Club just covers at 3.3m HW while the Nant y Ferwig bank just covers at 3.5mHW.

Figure 9 below illustrates the principal tidal pathways in the estuary recorded in 2014.

Note that the dominant flood current flows in along the Bryn du channel and the ebb circulates around the eastern side of the estuary. Interestingly, ebb flow at the surface is not necessarily the same at depth. This is particularly evident where the channel features trend across the estuary [roughly east to west]. Surface water on the ebb will flow northwards, while at depth the water within the channel is travelling westwards.

Of note: Estuaries and coastlines can be classified by their tidal characteristics. The tidal classification for the Teifi estuary sees it straddling the boundary between the mesotidal and macrotidal groups. However, as it experiences spring tides with ranges greater than 4.0m, it is assigned to the macrotidal group. [Dyer, 1973]

Figure 9 Tidal pathways within the Teifi estuary



2.4 Wave Energy

The Teifi estuary is contained within a distinct embayment on the Cardigan Bay coast. Along with its north facing aspect, the embayment provides shelter from the prevailing westerly and south westerly winds.

The Outer estuary is relatively shallow and consequently waves lose a lot of energy to bed friction as they approach the shore. Wave energy augments the flood tide energy in terms of carrying sediment up the beach and counters the ebb flow in its ability to carry sediment seaward. As a result sediment builds within the estuary. It is rare to see high energy waves arriving in the estuary during the late spring, summer and early autumn. [However, climate change is starting to disrupt this historical pattern.] Sediment tends to move up the beach during this period, while being removed from the upper beach over the winter period. At Poppit Sands, the dominant wave direction and beach gradient are slightly misaligned, which tends to wash sediment to the east. This process of longshore drift is responsible for the shape of the Bar and the entrapment of the discharge channel along the eastern foreshore.

More energetic waves attack the eastern foreshore, particularly seaward of Craig y Gwbert. These waves can penetrate further to the south as the flood tide builds. This helps to maintain a rockier foreshore between Gwbert and Patch.

Waves do penetrate the Inner estuary, mainly but not exclusively, on the flood tide, with most erosion occurring along the salt marsh scarp between the Webley and Bryn Du bend. Only under the most severe conditions will waves attack the south eastern shore of the Inner estuary. A more persistent wave train is established in the Inner estuary with strong southerly winds and high water. This has produced significant erosion along the north eastern shore, particularly in front of the TBC.

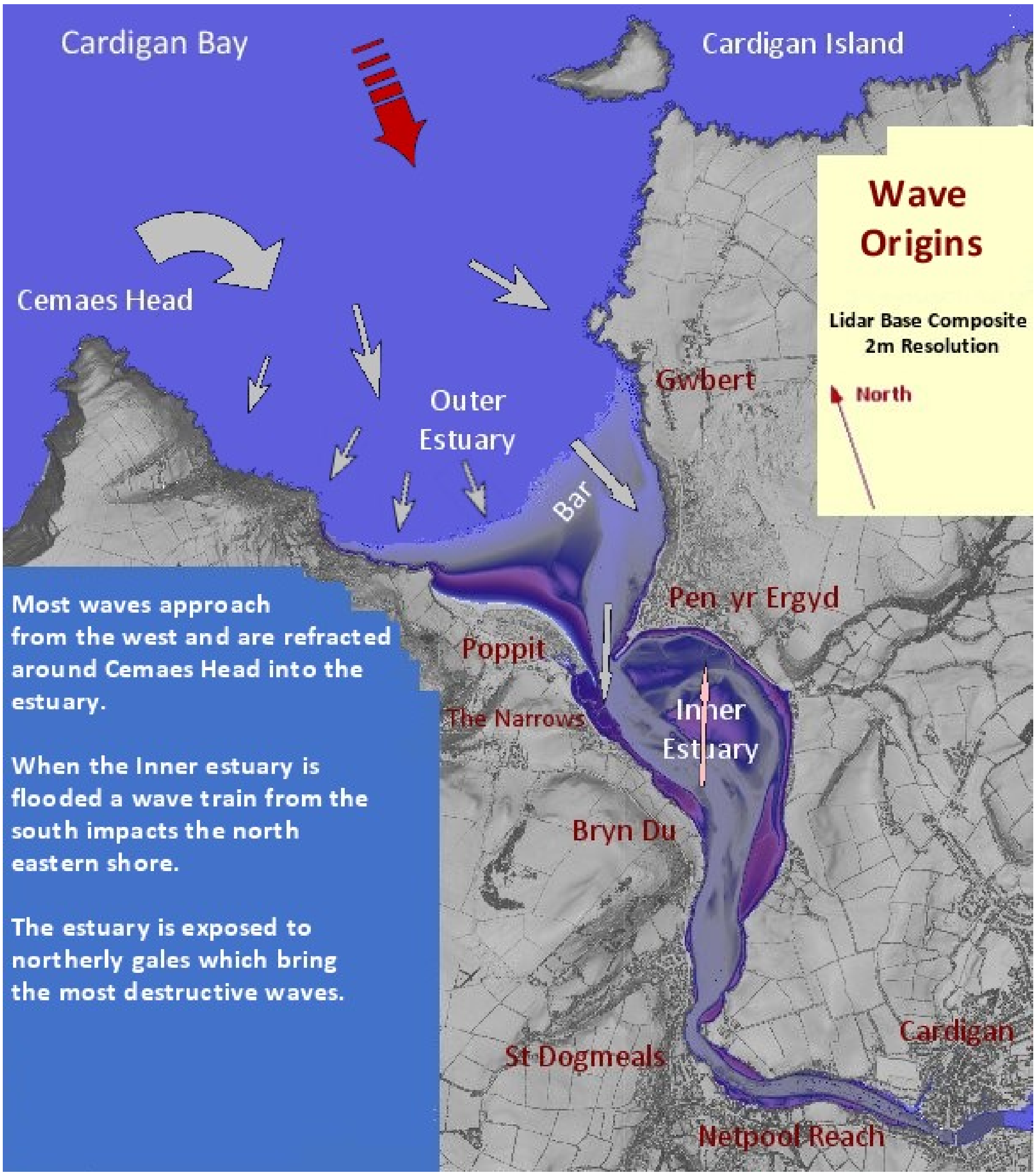
The Outer estuary is open to the north. Consequently, northerly gales can generate high energy, destructive waves.

Of note, are individual violent storm events. In the mid 1980s ex hurricane Charlie eroded the seaward face of the Pen yr Ergyd promontory to such an extent that one row of caravans were lost. On a similar scale during October 1996 the tail-end of hurricane Lily produced waves in the estuary that removed vast quantities of sand from the upper beach at Poppit and dune system. It took over a decade for the dune system to recover.

Of particular interest to commercial and recreational sailors is the behaviour of waves where the channel crosses the Bar. High energy waves generated by northerly gales are hazardous to small vessels trying to find shelter in the Outer estuary, or make an approach into the Inner estuary.

With a moderate sea state and a fresh to strong offshore wind, waves can break in the channel. It is difficult to spot this from a small boat when approaching the channel from seaward. Under certain conditions waves reflect of the Gwbert cliffs causing a confused sea across the bar.

Figure 10 The predominant wave directions in the Teifi estuary



2.5 Wind Energy

The wind is also responsible for moving sand around the estuary. It is very evident on the upper beach at Poppit, where it transfers sand into the dune system from the upper beach. The wind takes over from the tide and wave action once the ebb tide has exposed the sand and it has had sufficient time to dry. Sand is often swept eastwards along the upper beach and returns to the channel just seaward of the Narrows. Sand is also blown into and out of, the Inner estuary, as well as being redistributed once the banks there have dried.

It is beyond this study's ability to accurately account for the substantial volume of sand which is on the move. The process occurs daily as and when sand is exposed and conditions support drying. As might be expected, it is more noticeable during the summer months. Sand is also blow out of the dune system. Consequently, over time, areas will experience sediment gain as well as sediment loss. Using the 2007 Lidar data for March and July it is possible to gain some insight into the sand volumes on the move along the upper beach at Poppit. The area studied was above the HW mark and is usually left undisturbed by wave activity. Interestingly, the area lost a little over 2,990m^3 between March and July. However, the area immediately up beach that fringes the dunes gained a little over 450m^3 of sand. Sand also penetrated further into the dune system, but that is the subject of another study.

2.6. The Sedimentation in the Teifi Estuary

Current thinking asserts that the present day beach and estuary sediments have been moved onshore as sea levels rose since the termination of the last ice cycle.. The effect of processes acting on the Teifi estuary over the past few thousand years has produced west to east trending bars across the entrance and separating the Inner and Outer parts of the estuary (Figures 1 to 3).

Typically, bar-built estuaries are relatively shallow with extensive shallow intertidal basins inside the mouth. The narrow estuary mouths have a restricted cross-sectional area, which produces high local current velocities, as is the case between Poppit sands and Pen yr Ergyd at the Narrows. Inland the inter-tidal basin widens and the current velocities rapidly diminish. The river flow is seasonally variable and large volumes of suspended sediments may be transported during floods.

Coastal erosion of the local shale is minimal and its composition releases little quartz. Off-shore deposits appear to be mainly composed of finer grained material and are often found below 20m, which excludes them from most wave entrainment. Therefore, little sediment is thought to be moved by longshore drift along the coast and into the estuary. Off-shore deposits will however, respond to tidal forcing and move in response to the flood and ebb cycle. As flood tides in Cardigan Bay are more energetic than the ebb tide, sediments capable of entrainment will progressively move in the direction of the flood tide. There is poorly understood in terms of contribution to the sediment in the Teifi estuary.

Consequently, the sources of sediment forming the principal features within the Teifi estuary are thought to be associated with the glacial and post glacial deposits located within the estuary and upon the upland surfaces immediately inland. In this respect the Teifi estuary is an almost closed sediment cell, receiving little sediment from offshore and only significant amounts of suspended sediment from the river during flood discharges. Little sediment appears to be lost offshore, with the bulk of what is, being in the form of suspended sediment.

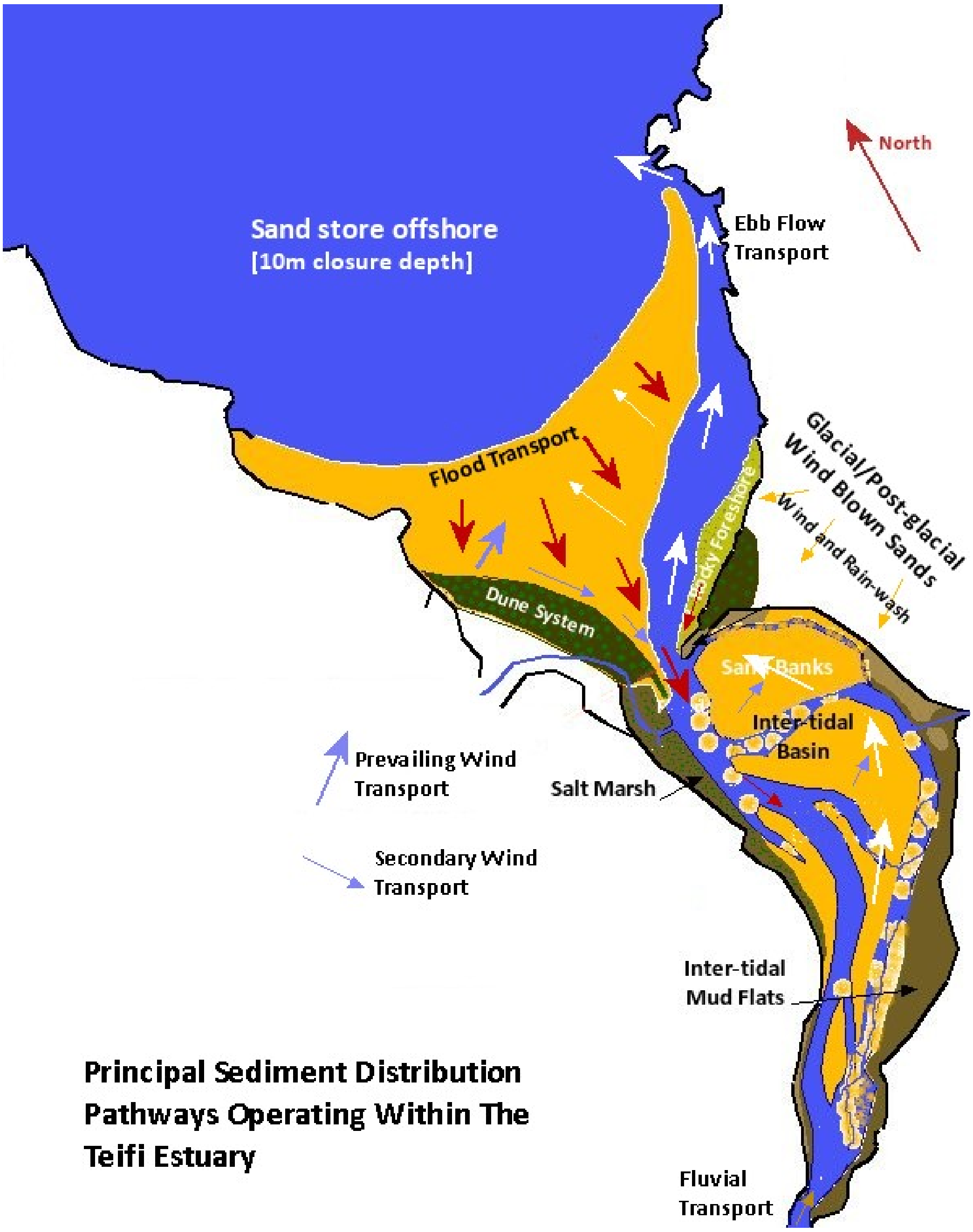
Figure 11 shows the sediment distribution in the Teifi estuary and the main flood and ebb current pathways.

Human intervention has resulted in major changes to the Teifi estuary. The dune systems at Pen yr Ergyd and Poppit have seen an increasing usage for recreational purposes since Edwardian times. Aerial photographs from the 1950s and 1960s reveal an increasing level of erosion amongst the dunes and for Pen yr Ergyd in particular, along the dune front. More significantly, the slippages and subsequent erosion of the diamicts on the slopes immediately north of the Pen yr Ergyd dune system, at least since the 1950s, may have been accelerated by surface water draining from the road above. The combined material released onto the foreshore from the Pen yr Ergyd dunes and the slips were rapidly incorporated into the estuary system. This was facilitated by rising sea level and a wind/wave climate that became more energetic through the latter half of the 1900s.

Although some of the fines will have been lost off shore, much of the sand eroded from the seaward side of the Pen yr Ergyd dunes appears to have been deposited on the Poppit foreshore to extend the intertidal area and bar. It is also suspected that since the 1960s, the accreted sand has helped to offset dune erosion at Poppit, by increasing the supply that feeds the upper part of the beach.

It is very likely that both the Bryn du and the Narrows hinge-points are controlled by underlying features left over from the deglaciation of the lower Teifi valley. There are extensive glacial and post-glacial deposits in the area and the estuary is underlain by about 60m of sediment overlying rock head.

Figure 11 The sediment distribution pathways in the Teifi estuary



Access to Cardigan Quay – the metrics

3.1. Depths in the channels at different stage of the tide

The aim of this report is to evaluate the potential for maintaining a navigable channel from the passage over the bar to Cardigan quay. This requires an understanding of the tide determined channel depths throughout the estuary and an identification of locations that act as tidal "gates". From this it is possible to calculate a range of passage times, for vessels of varying draft, which facilitate access to Cardigan Quay.

Figures 11 to 13 illustrate this data for the Outer estuary, Inner estuary and Cardigan Gorge/ Net Pool Reach respectively.

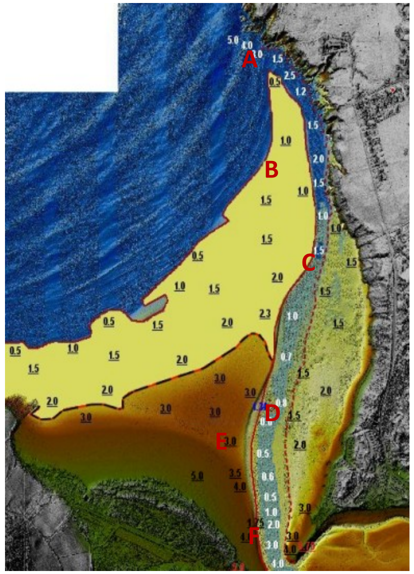


Figure 12 *Tidal controls of water depth in the Teifi estuary- The Outer Estuary*

Key Passage Points - Times Available ± High Water - [3.6m Neap HW & 4.7m Spring HW]																
Draft [m]	1				1.5				2				2.5			
HW [m]	3.6		4.7		3.6		4.7		3.6		4.7		3.6		4.7	
Location	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW
A Seaward of the Bar - 4m Sounding	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15
B The Bar - Dries 1.5m	-3.20	+3.30	-2.50	+4.00	-2.20	+2.25	-2.25	+3.25	-0.45	+0.50	-1.55	+2.45	0.00	0.00	-1.25	+2.00
C Channel Seaward of the Perch - Boulders Dry 1.55m	-3.15	+3.25	-2.50	+3.55	-2.10	+2.20	-2.20	+3.20	-0.25	+0.30	-1.55	+2.45	0.00	0.00	-1.20	+1.55
D Channel - Perch South - 0.6m LW	-5.25	+5.20	-3.35	+4.55	-3.55	+4.00	-3.10	+4.15	-2.50	+3.00	-2.40	+3.40	-1.45	+1.45	-2.10	+3.05
E Channel Edge, Poppit - Dries 1.45m	-3.30	+3.35	-2.55	+4.05	-2.25	+2.35	-2.25	+3.25	-1.00	+1.10	-2.00	+2.50	0.00	0.00	-1.25	+2.05
F Channel - Narrows North 3m Deep	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15

As an example, Figure 12 reveals a 1.5m water depth occurring at the shallows in the Bryn Du channel intake from -1hour 55 minutes HWPC until +1hour 55 minutes HWPC on a 3.6m High Water Neap tide. (HWN).

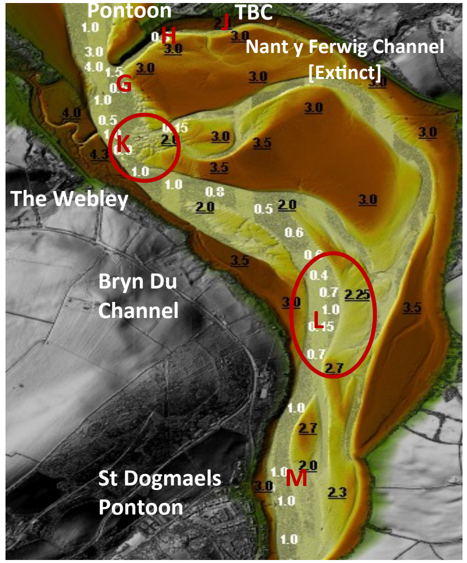
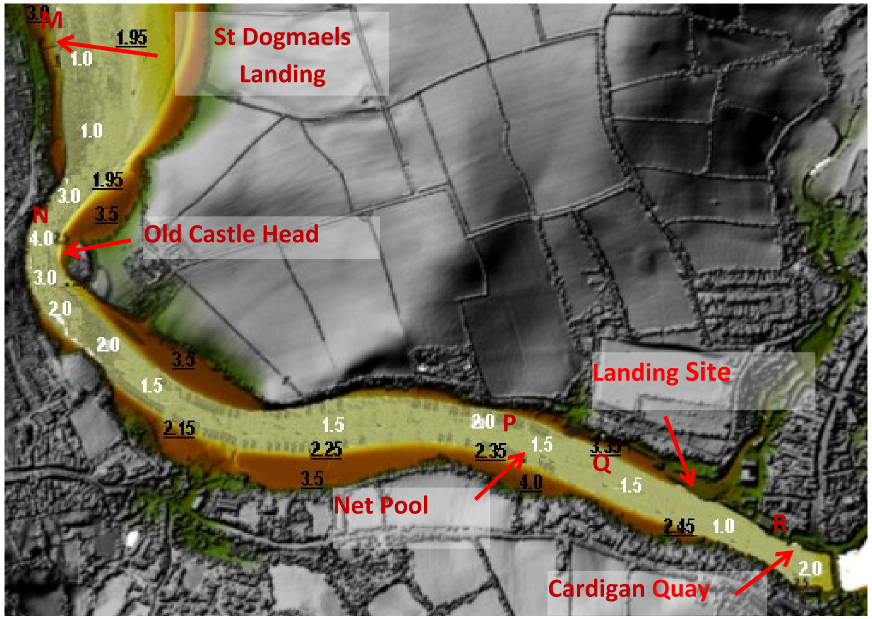


Figure 13 Tidal controls of water depths in the Teifi estuary – the Inner Estuary

Key Passage Points - Times Available ± High Water - [3.6m Neap HW & 4.7m Spring HW]																
Draft [m]	1				1.5				2				2.5			
HW [m]	3.6		4.7		3.6		4.7		3.6		4.7		3.6		4.7	
Location	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW
Fishermen's Moorings - 1.5m to Dries LWS	-5.40	+5.25	-3.35	+4.55	-4.00	+4.05	-3.10	+4.20	-2.55	+3.05	-2.45	+3.45	-1.55	+1.55	-2.15	+3.10
The Pontoon - 0.3m LWS	-3.30	+3.35	-2.55	+4.05	-2.25	+2.35	-2.30	+3.25	-1.10	+1.10	-2.00	+2.50	0.00	0.00	-1.25	+2.05
TBC Slip - Channel Dries 2.14m	-2.00	+2.05	-2.15	+3.15	0.00	0.00	-1.50	+2.35	0.00	0.00	-1.10	+1.45	0.00	0.00	-0.10	0.40
Nant y Ferwig Channel Outfall - Dries 1.95m	-2.25	+2.35	-2.25	+3.25	-1.00	+1.10	-2.00	+2.50	0.00	0.00	-1.25	+2.05	0.00	0.00	-0.40	+1.05
Obstruction Bryn du Chan'l Intake - 0.15m Shallows	-2.55	+3.05	-2.45	+3.45	-1.55	+1.55	-2.15	+3.10	0.00	0.00	-1.45	+2.30	0.00	0.00	-1.05	+1.40
St Dogmaels Landing - 1m in channel	-4.45	+4.40	-3.25	+4.40	-3.45	+3.45	-3.00	+4.10	-2.35	+2.45	-2.35	+3.35	-1.30	+1.30	-2.05	+2.55

Figure 14 Tidal controls of water depths in the Teifi estuary – Cardigan Gorge/Net Pool Reach

Key Passage Points - Times Available ± High Water - [3.6m Neap HW & 4.7m Spring HW]																
Draft [m]	1				1.5				2				2.5			
HW [m]	3.6		4.7		3.6		4.7		3.6		4.7		3.6		4.7	
Location	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW	-HW	+HW
St Dogmaels Landing - 1m in channel	-4.45	+4.40	-3.25	+4.40	-3.45	+3.45	-3.00	+4.10	-2.35	+2.45	-2.35	+3.35	-1.30	1.30	-2.05	+2.55
Old Castle Head Outfall - 4m LW Deep	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-6.15	6.30	-5.15	+7.15
The Net Pool - 1.6m LW Deep	-6.15	+6.30	-5.15	+7.15	-6.15	+6.30	-5.15	+7.15	-3.10	+3.15	-2.45	+3.50	-2.05	2.15	-2.20	+3.15
Fishermen’s Landing - Dries 2.2m	-1.55	+1.55	-2.15	+3.10	0.00	0.00	-1.45	+2.30	0.00	0.00	-1.05	+1.40	0.00	0.00	0.00	0.30
Cardigan Quay -0.3m alongside Pontoon	-1.35	+1.40	-2.10	+3.00	0.00	0.00	-1.40	+2.20	0.00	0.00	-1.00	+1.25	0.00	0.00	0.00	0.00



3.2. Channel sections

Figures 15 to 17 are summary sheets showing the channel characteristics and tidal regime in the Outer estuary, Pen yr Egyd to St Dogmaels and St Dogmaels to Cardigan Quay reaches respectively. The schematic diagrams relate the heights of banks and channel margins relative to chart datum and reference the height of exemplar Spring and Neap tides. [*A3 Page format*]

Figure 15 Summary Tidal Regime – Outer Estuary

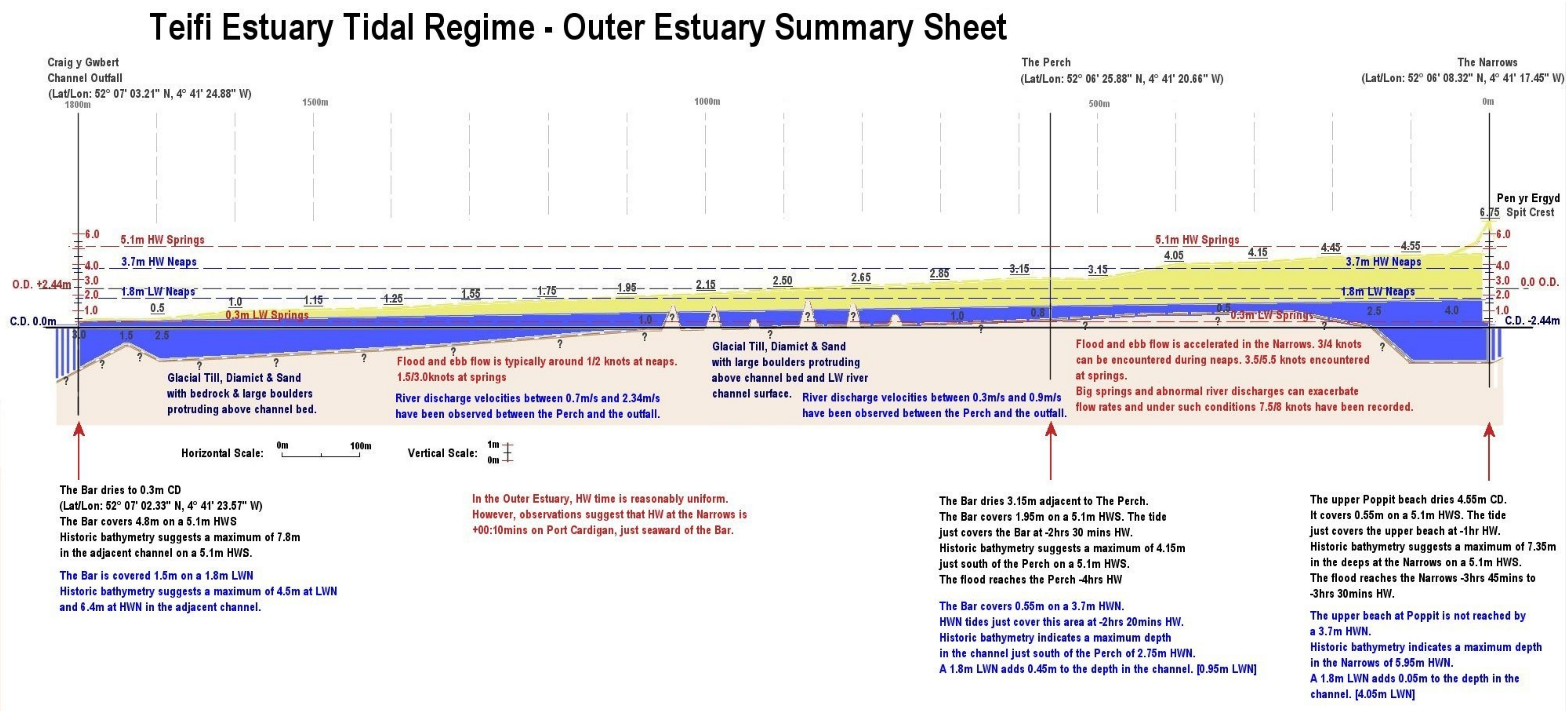


Figure 16 Summary Tidal Regime - Pen yr Ergyd to St Dogmaels

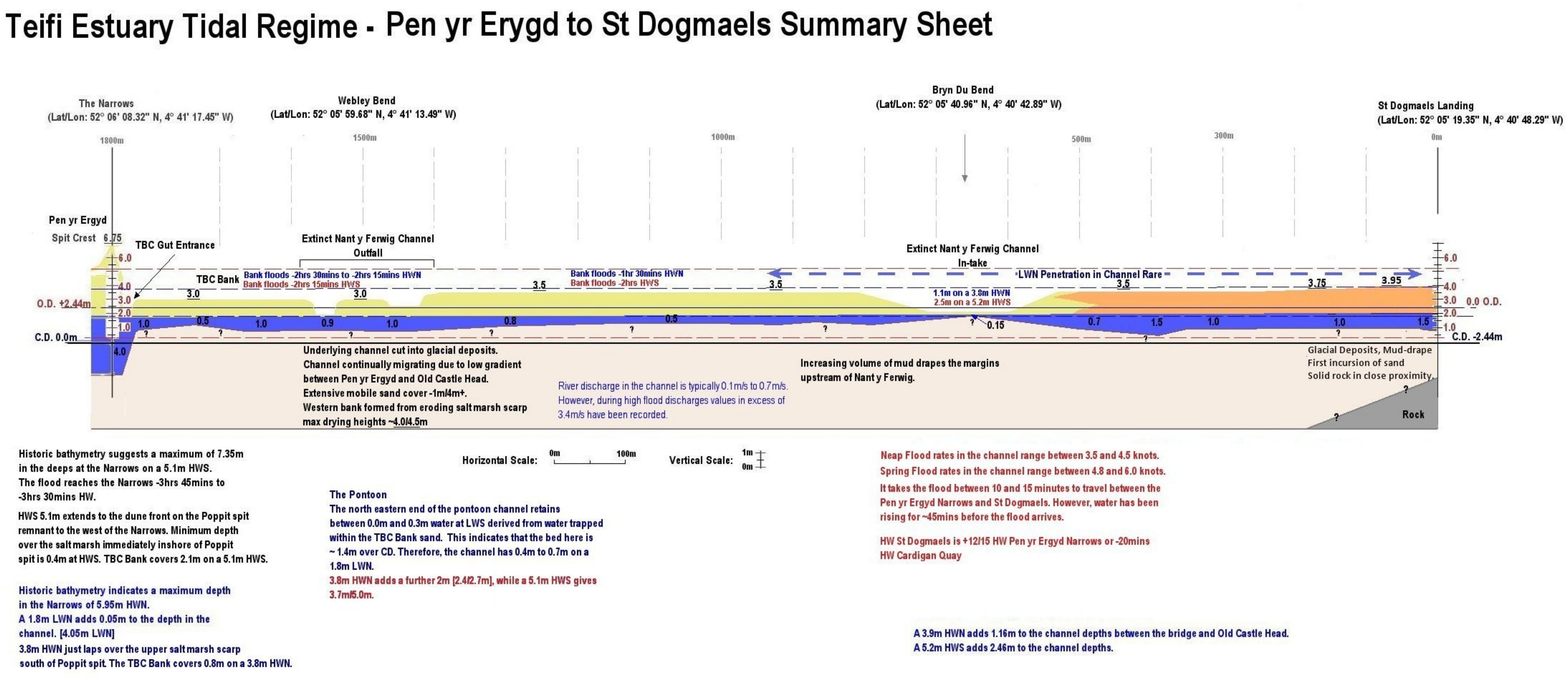
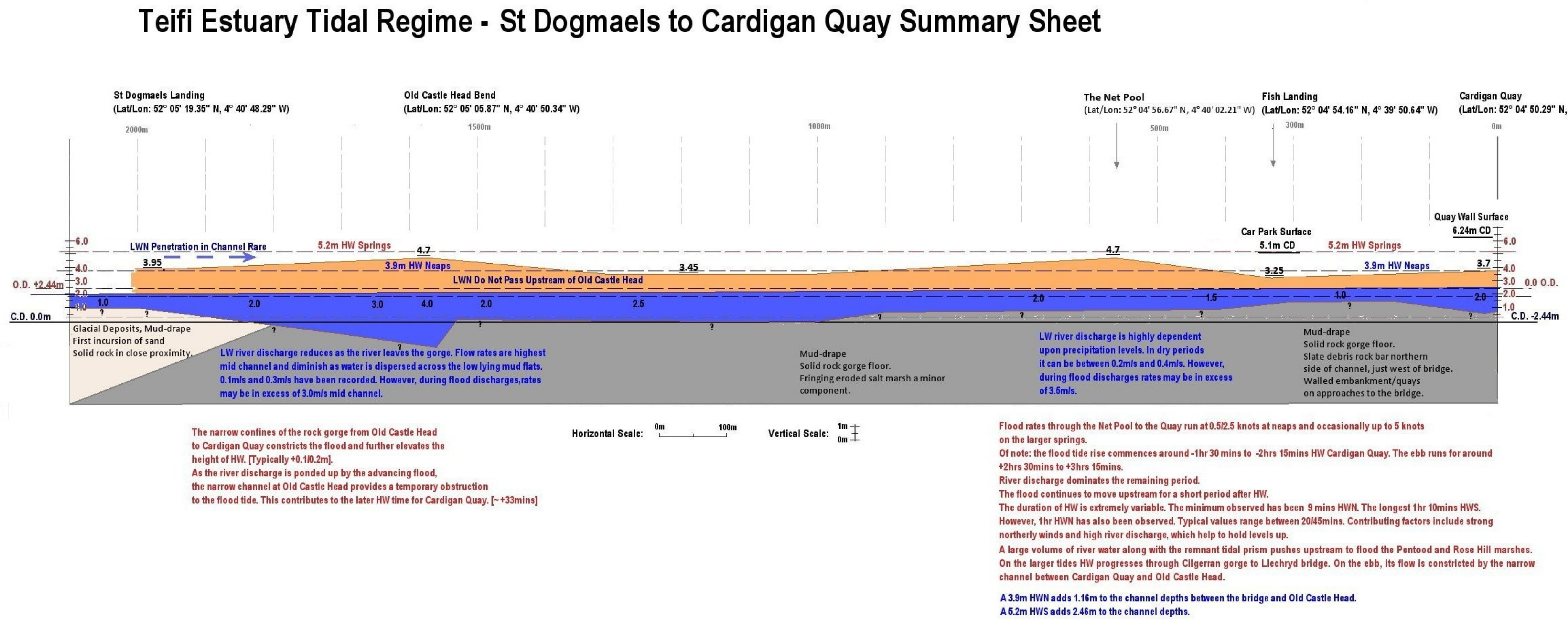


Figure 17 Summary Tidal Regime – St Dogmaels to Cardigan Quay



Creating a navigable channel– a discussion

4.1 Introduction

An analysis of Figures 11 to 13 along with the other data supplied above indicates that the natural channel(s) in the Teifi estuary limit access to Cardigan quay. In particular, the channels between Bryn du and the Narrows have a long history of meandering across the Inner estuary and this process continues today. The data show that shallow sections have always occurred in the channels and the low water depth where the channel meets the sea has always been less than one metre. Further, tidal flows move significant volumes of sand in the estuary, and a quasi-equilibrium exists between the natural channel forms and the hydrodynamic processes. Any attempt to create a navigable channel would have to overcome these processes.

In its simplest form, the creation of a navigable channel involves three major components:

1. Dredging – which entails:
    a. Identifying the route of the dredged channel
    b. Determining the nature of the material to be removed
    c. The production of a working draft specification, relative to chart datum and with a known width of channel, establishing the volume of material to be extracted
2. Engineering structures that:
    a. Prevent channel migration – training walls
    b. Prevent the movement of encroaching sediment – a groyne system
3. Disposal of spoil material

it is also important, when carrying out such a major project that the local community as a whole can support the process.

4.2 Summary of existing Investigation Findings

Over the past 25-30 years, three consultancies have been commissioned to investigate potential dredging programmes of this nature for the Teifi estuary. A summary of their findings follows.

4.2.1. Westminster Dredging Company Ltd - 1987

In 1987, Westminster Dredging Company Ltd supplied budget costs for dredging a channel 40m wide from the entrance of the river in the Outer estuary to Cardigan. The most economical method identified was to utilise a small cutter suction dredger. The estimate assumed that the material from St Dogmaels to Cardigan would be silt and sand, and downstream of St Dogmaels it would be sand. (This is not the case seaward of the Narrows.) The quantities involved were 356,000m^3 in the Inner estuary and 144,000m^3 in the Outer estuary, giving a total of 500,000m^3. No depth of channel was mentioned and no mention was made of the need for maintenance dredging. The costs for such a programme were not published.

4.2.2 HR Wallingford - 1998

In 1998, Ceredigion County Council (CCC) commissioned HR Wallingford (HR Wallingford Report EX 3516) to investigate the feasibility of dredging and maintaining a navigable channel, 2m in depth (below Chart Datum), from Cardigan to within the vicinity of Craig y Gwbert. The report suggested that it would be hydraulically feasible to dredge and maintain an improved navigation channel, but major engineering works would be necessary to guarantee a stable channel.

HR Wallingford concluded that a few severe storms could infill a dredged channel in places, to the pre-dredged levels. Therefore, any improvement to the channel was likely to require some type of structure to prevent sand accumulating within it. This ruled out schemes that were based solely on dredging. They also suggested that some need for dredging would occur from time to time, even if structures, such as training walls were considered a solution. When intermittent maintenance dredging is required the mobilisation of a dredger would add significantly to the ongoing cost of the programme.

A number of options were suggested for the estuary by HR Wallingford. Two options proposed in the Outer estuary were for training walls that would extend above the high water mark, and/or a series of groynes extending 100m offshore along the Pen yr Ergyd to Craig y Gwbert foreshore. The cost would be between £4 and 7million pounds (1998 figures) and would incorporate some dredging. The visual impact of such structures on the landscape at low tide would be significant and potentially detrimental in an area of outstanding natural beauty.

In the Inner estuary the options were similar, a training wall or a series of groynes from Old Castle Head to Pen yr Ergyd. The idea of such a training wall was first suggested in 1880, but the plan was abandoned with the arrival of the railway in Cardigan a few years later. The cost for this part of the scheme was between £2-3million (1998 figures). HR Wallingford (1998) indicated that these schemes although credible solutions to the problem came at a very high cost, and also had a substantial environmental and tourist impact.

The report made no reference to channel depth and its relationship to the proposed dredged channel depth of 2m below Chart Datum. (Chart Datum is -2.44m OD, thus the channel depth would be -4.44m OD). Where the channel meets the sea the water level on the 2014 LIDAR is -1.9m OD and channel bed level is less than -3m OD, thus requiring dredging to a depth of 1.5m . At the confluence of the Nant y Ferwig and Bryn du channels the water level is -0.6m OD and water depth less than a metre. Thus, the proposed dredged channel here would need to be nearly 3m deeper than at present. Of note, no mention is made of the width of the proposed channel, which would be a major consideration in determining the final cost of any dredging.

4.2.3. Atkins - 2004

In 2004, CCC commissioned the Atkins report on “Assessment of works proposed on the Teifi estuary” with a specific remit to examine a scheme “Dredge works to improve vessel access within the Teifi estuary”. They produced a bathymetric section along the estuary to determine the water depths in the channels and based their evaluation on this.

Their brief was to examine the dredging necessary to permit access 4 hours either side of HWPC for vessels with a draught of 1.8m. The volume of sediment to be removed was estimated to be between 200,000m^3 to 250,000m^3 (based on a channel width of 30m). At the time, it was considered that the removal of this volume of sediment was not “cost effective”. Therefore, alternative options were proposed using vessels of shallower draught and/or shorter access time alongside at Cardigan. The least expensive alternative required the removal of 25,000m^3 of sediment, which along with its disposal would cost about £400,000. An additional annual maintenance cost was also acknowledged, which ranged between £20,000 and £80,000.

4.3 An Evaluation of the reports

All three reports emphasised that these were estimates and more ground investigations and numerical modelling of the hydraulic conditions were necessary, before realistic costs could be given. Inflation since 1998 suggests that those costs which were enumerated have now increased by at least 25%. [2015]

The bathymetric surveys carried out by the ATFL in 2008 (Figure 3) and the LIDAR surveys of the estuary commissioned by Ceredigion County Council, provide an improved indication of the bathymetry, rate of channel migration, sediment volumes and the elevation of the water surface in the channels. However, in spite of this improved data, the rapidity with which the channels constantly change their position and depth prevent precise estimates of the volume to be removed in 2015. Inevitably, there would be changes to any programme during its operational lifetime to account for the dynamic changes within the estuary. Current indications therefore suggest that the extracted material necessary to produce a suitable channel would be in the range of 100,000 to 500,000m^3. Analysis of changes in the position of the channels based on the LIDAR surveys (Section 2.2) suggests that many thousand cubic metres of sediment are displaced every year by bank and channel erosion. In addition, similar volumes are probably moved diurnally by tidal currents as the bedforms on the banks are formed and reformed. These volumes suggest that any dredged channel would be partially infilled within a matter of weeks unless afforded adequate protection from retaining structures.

This corroborates those findings elucidated in the HR Wallingford report that dredging alone would not be the solution; and that maintenance dredging would always be necessary. Further, although Atkins only examined the dredging options they came to more or less the same conclusion; that maintenance dredging would be needed after capital dredging. The frequency of maintenance dredging is uncertain. However, with the additional data provided by the annual LIDAR survey adding to the current understanding of channel dynamics, annual and post storm events would appear to be sensible estimates.

The HR Wallingford proposal for training walls and/or groynes to stabilise the channel, adds expense and would engender several environmental challenges, which in themselves would add further to the cost. Given the proximity to the Pembrokeshire Coast National Park and the area's high reliance upon tourism, both in jobs and income, such structures might prove environmentally unacceptable and a risk to the local economy.

4.4 An Evaluation of small scale, local approaches to channel maintenance

Over the last 10 years attempts have been made by the Afon Teifi Fairways Limited to investigate methods of dredging the channel which are local and sustainable. One approach was to drag a scallop dredge across a shallow section of the channel during the maximum ebb flow. The dredge churned up the channel bed with the expectation that the suspended sand would be moved down channel in the strong currents. This is only able to work for short distances, possibly tens of metres or less. The ebb flow naturally sustains the seaward movement of sediment in the form of bed load and suspended load. Continued further agitation of the channel bed adds sediment to the water column at a rate that exceeds the available current energy. Therefore, the water being unable to mobilise or suspend any more sediment allows the surplus sand to drop back to the bed. Some local deepening and/or shallowing might have been achieved over a tide cycle, but the initial equilibrium depth would be easily restored over subsequent tide cycles.

Another approach investigated was the use of a jet pump, a system commonly used to deepen localised sections in muddy harbours. This moved small volumes of sand a short distance and was not a viable system to move the volumes required to significantly deepen a channel tens of metres wide. However, the jet pump would be the obvious solution to create the required water depth where the channel is mud-lined. For example, in front of the retaining wall at Cardigan to enable vessels to tie up alongside.

Informed advice suggests that a small suction cutter dredger offers the most appropriate potential in this estuary. However, given the local physical constraints its efficiency would be impaired. So although relatively cheap (The cheapest suction cutter dredger costs about £500,000 see -http://www.ihcbeaverdredgers.com/equipment/ihc-beaverr-series/.) the protracted nature of the dredging programme would inflate operating costs. The investment would be in the order of £500,000 - £1,000,000 with operating costs of about £100,000-£200,000 per year (people, plant, permits etc.). Hiring a trailer vessel to dispose of the dredged sand would be a substantial additional cost. However, without the necessary engineering structures to prevent channel migration and sediment infill, it is difficult to see how dredging alone will produce a sustainable channel.

4.5 Comments on the management and disposal of dredged sediment

4.5.1. Commercial exploitation

A significant local issue is the controlled disposal of dredged sediment. Any potential sale of the dredged material is greatly determined by the extraction costs and quality. Suction dredgers working offshore may dredge and fill their holds over a half tidal cycle. They then return to port to discharge the cargo before returning to the dredge site. This would not be possible in the Teifi, as the small dredger required to work within the confines of a shallow estuary would not have the capacity to move an economically viable cargo to the nearest port, probably Swansea. Its operational time in the river would also be restricted to two hours either side of HW and it would be unable to work on the smaller neap tides at some locations. Therefore, the time taken to complete the programme would be protracted and expensive. The product would therefore be expensive compared to those alternatives with lower production costs. In addition, the medium to fine-grained sand found within the estuary is of relatively low value. Any commercial extraction would therefore have to be focussed to a local demand and a low cost means of extraction.

4.5.2. Sediment disposal within the estuary or immediately offshore

The alternative, to dump the sand offshore or on the estuary flanks, would present significant environmental challenges. However, if training walls are to be built, then dumped sand would not substantially further deteriorate the vista; and may well be incorporated into the landscaping of the reclaimed areas. Sand can be pumped many kilometres with booster pumps, but this system is only cost effective when it can operate for sustained periods of time. A more appropriate solution here might be to use a trailer to take it from a small cutter suction dredger.

Of note, the sediment being dredged in the Teifi estuary, although mostly sand, does contain a low proportion of mud. The dredging operation tends to put this mud into suspension and commonly a plume of mud surrounds the dredger. The plume is then moved away from the dredging site by the tidal flow, to be deposited elsewhere. In the Teifi, this increase in the suspended sediment could have a significant environmental impact on local beaches and fisheries.

Concern has been expressed that the dredging might unearth sediment with a high level of metal pollutants (lead and zinc) derived from the north Cardiganshire ore fields at the river head. This is considered unlikely as most of the sediment being dredged would have been turned over naturally by the movement of the channels across the estuary, over the past century or so. This reworking of the sediment would have removed most pollutants by natural sorting.

It should be noted that dredging in estuaries is only likely to be allowed when economic returns are high. For example, the Mersey leading to Liverpool, the Stour/Orwell at Harwich docks, or the Dee to produce a channel to allow Airbus wings to be transported out by sea. Prior to any permissions being obtained, detailed numerical modelling is required of the dredge site and any proposed spoil sites. This is to ensure that there would be limited opportunity for dredged material to migrate back to restore equilibrium conditions. Similar modelling would be required to ensure that dredging and/or construction of training walls in the Teifi would not cause detrimental impact to Poppit Sands, the Poppit dune system and the Gwbert foreshore.

Permissions to dredge the estuary would need to be obtained from a range of bodies including the Crown Estate, DEFRA, Natural Resources Wales and the Pembrokeshire Coast National Park. No examination is made in this report of the likelihood of obtaining such permissions. However, the Teifi estuary's proximity to a National Park, its Site of Special Scientific Interest status along with its Special Area of Conservation designation does not make it a strong candidate for consideration.

4.6 Conclusion

The conclusion from the three estuary based studies is that capital (a one-off event) dredging alone of a channel would not be sufficient and maintenance dredging would be necessary. Channel stabilisation and the reduction of sediment transport necessitate the construction of training walls and groynes, essentially from St Dogmaels to the bar. In addition, considerable environmental and landscape impacts are envisaged.

More recent LIDAR and bathymetric data corroborates those earlier findings and is able to provide an insight into the rates of change and the volume of sediment involved.

At present, the cost of implementing a channel management programme which involves both dredging and containment structures, is far greater than the identified economic gain obtained by increasing the number of fishing vessels able to reach Cardigan.

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