Mapping the Teifi estuary

Chris Evans, Tim Wright, Colin Moore, David Maynard
Robin Young and Nick Newland

January 2010

A report prepared by the Afon Teifi Fairways Committee
for the Countryside Council for Wales (CCW)
SUMMARY

2009 saw a continuation of the data collection started in 2008, however poor weather curtailed some of the activities. The data collected on September 7 and 9th allowed a bathymetric map to be created of the estuary, which has been corrected to Ordnance Datum, Chart Datum and low water river depths. Copies of modified versions of these maps will be made available in the spring to river users. The major change taking place in the river is the growth of the Bryn-du meander on the Pembrokeshire side and the consequent decrease in cross-sectional area of the Nant-y Ferwig meander. If this continues it may lead in a few years to almost complete atrophy of the latter meander which could reduce flow in the channel in front of the Teifi Boat Club.

In late 2009 Ceredigion County Council made available to the group LIDAR data collected every year between 2006 and 2009 of the area from Poppit Sands to Bryn-du. This has allowed detailed analysis of changes in the period to Pen yr Ergyd spit and Poppit Sands. Changes to the spit in this interval have been largely due to human intervention, following a major overtopping event in March 2008 and the removal of the recurve in July/August 2009. These interventions more or less mask any natural changes taking place during the interval. The interventions are an attempt to prevent the spit breaching; to date they have been successful, but will need to be continued in future to preserve the feature. The Ceredigion County Council consultants, Royal Haskoning, talk of the spit breaching; this may be the case over a long time scale as sea level rises, but it is our opinion that minor regrading the crest will be adequate to maintain the feature for perhaps the next 10 -20 years. However, nature is unpredictable, and a series of severe storms could breach the feature. Therefore a discussion should take place between all interested parties to agree a policy for managing the spit over the next decade or so.

Changes are taking place at Poppit Sands where sand is accreting on the northern part of the beach and the spit on the southern part is undergoing continuous erosion. This spit is in danger of breaching during a storm event which would further endanger the saltmarsh in front of the Webley Hotel. Little can be done to limit the erosion except to close off some of the man–made paths through the spit.

The group aims in the coming year to continue monitoring a number of features in the estuary to improve our understanding of possible future change. The LIDAR surveys of the area are the most useful but need to be supplemented by field observations of specific areas, such as the Pen yr Ergyd spit nose, the Poppit spit, the Bryn-du scarp and Poppit Sands.
1. Introduction

This report describes some of the work carried out in the Teifi estuary between 2008-10 by the Afon Teifi Fairways Committee as part of a project funded by the Countryside Council for Wales. Specifically this reports on that part of the project describing “Mapping the estuary”. The work was carried out by Chris Evans, Tim Wright, Colin Moore, David Maynard and Robin Young with Nick Newland as Project Manager.

This report has three aims: to provide a readable description of the estuary morphology and hydrodynamics, to provide as appendices descriptions of the methods used to collect the data, and to preserve digitally raw baseline data which may be used in any future study of coastal change.
2. Mapping the estuary

2a Collecting data

The bathymetry in the estuary was collected on three occasions in both 2008 and in 2009, and details of the technique used are included in Appendix A. The data were collected an hour or two either side of high water. Simultaneously, the tidal level was measured at the Sewer Outfall Beacon at Patch (Figure 2). The top of the flange at this beacon had been surveyed in at 1.13m above Ordnance Datum (OD), and placing a marked survey pole on the flange allowed measurement of the height of the water relative to OD.

Figure 2. Flange at Patch sewer outfall, its top is 1.13m above Ordnance Datum

During the collection of bathymetric data the tide height was collected every 15 minutes and a tidal curve produced (Figure 3). The bathymetric depths from the data collected by the survey vessel were then corrected to provide values relative to OD.

On August 23 2009 tidal curves were produced for a 12 hour period at both the Patch and Cardigan Bridge (Figure 3) using, at the latter, a height scale tied in to OD that had been inserted into the wall of Prince Charles Quay by the Environment Agency. The data collected provided a better understanding of the progress of the tidal wave up the estuary and an indication of the changes in water level up estuary as the tide flooded and ebbed.

The data were processed in the Global Mapper geographical information software programme to produce many of the figures below.
2b Bathymetry of the estuary

Appendix B describes how the bathymetric data were corrected to produce a map of the estuary water depth relative to OD. However, users might want the data shown to different datums. Those using Admiralty Charts might want the data relative to Chart Datum which is 2.44m below OD, whilst those using only the river might prefer data showing the river depths at low water. Figures 6, 7 and 8 show the data to OD, Chart Datum and river depths respectively. The first two were relatively easy to produce using the available software, but the production of a map of the river depth is more problematic.

2c Producing a map of the river depths in the estuary

The simplest way of producing a map of the river depth is to collect the data at low water by wading in the river, and this was done on three occasions in selected areas. But the level varies with the volume of water in the river, and visual estimates suggest that there is a difference in the level of about 0.6m between summer “dry weather” and winter “flood” events. Another problem is that there is a gradient in the river water surface from the bridge down to the sea - this is why the water flows in that direction (Figure 4). The tidal curve for 23 August 2009 (Figure 3) showed the river level at Cardigan Bridge was -0.57m OD and that at Patch was -0.87m OD, a fall of 0.3m and there is a further fall towards the bar (where the river enters the sea) estimated from Figure 5 to be about 0.7-0.8m.

How do these data in Figure 3 compare with the predicted tides? The Admiralty predicted tide for 23 August for Cardigan Bar was low water at 5.11hrs BST at a height of 0.4m above Chart Datum or -2.04m OD; and high water at 1019hrs BST 4.9m above Chart Datum or +2.46m OD. This compares with obtained values of low water at the sewer outfall of -0.87m OD and high water at 2.59mOD. The 2007 LIDAR data showed a fall of 0.4m in river level between Cardigan Bridge and Pen yr Ergyd spit, and on August 23 2009 this was measured as 0.3m (Figure 3). Between Pen yr Ergyd and the open sea the 2009 LIDAR data show a fall of about 0.8m (Figure 4), putting the level in the open sea at -1.67m OD. It is this fall in the level of the river which generates the standing waves seen in Figure 5 and explains why the tidal flood starts at the Narrows about 90 minutes after predicted low water.
Figure 4  Fall in river level from Pen yr Ergyd to the sea

![2007 LIDAR water level Pen yr Ergyd to the sea](image)

**Distance north from Pen yr Ergyd in metres**

<table>
<thead>
<tr>
<th>Water level to OD</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 Standing waves in river channel north of Patch, water depth less than 0.7m

The map showing the river depth, was created by taking the data reduced to Ordnance Datum and inserting a compensation for the fall in the river surface down estuary. The compensation was produced by dividing the river into a number of segments and the compensation in each segment was:

- Cardigan Bridge to St Dogmaels Netpool: -0.4mOD
- St Dogmaels Netpool to Bryn Du: -0.5mOD
- Bryn Du to Pen yr Ergyd: -0.6mOD
- Pen yr Ergyd to the Bar: -0.7mOD

This manipulation of the data was done in *Global Mapper* which also allowed the removal of some obviously spurious data and the manual inclusion of points with zero values such as cliff edges which marked the channel limits. These additional points allowed the contouring software in *Global Mapper* to create a more realistic effect in Figures 6, 7, and 8.

As mentioned above the depths in the river change with the seasons as do parts of the river bed, therefore Figure 8 is a reasonable representation for the river depths in late summer 2009 but by 2010
may be less accurate for some parts of the river. It is certainly more representative of the river form than the last published bathymetry by the Hydrographic Office in 1969.

For convenience the bathymetry of the estuary is divided into two areas; namely from the Bar to about the Ferry Inn St Dogmaels, and from the Ferry Inn to Cardigan Bridge. Only the river depth map (Figure 9) is shown for the latter, upper section of the estuary

3. The bathymetry of the estuary

3a Background

Figures 6, 7, 8 and 9 have been prepared from the same data set and show essentially the same features. These figures clearly show the estuary divided into areas with a complex of sand banks and river channels, and other areas with simpler more stable, linear channels.

3b The main river channels

Over the past 10 years the position of the river channel has kept reasonably constant from Cardigan Bridge to near Bryn-du, and from the Narrows off Pen yr Ergyd to the bar (Figure 1). The sand banks on the Ceredigion shore off Glantefion have varied slightly in location during this time, and the bar has developed on a number of occasions a secondary minor channel at its northernmost end to leave a small triangular-shaped sand bank under the Cliff Hotel (Figure 10).

Figure 11 using LIDAR data run by Ceredigion County Council shows changes to the Bar between 2006 and 2009. All the surveys were run in early August and show that this minor secondary channel is a transient feature. Figure 10 was collected in June 2009 and shows the channel, but it is absent on the LIDAR for that year collected in early August.

A series of sand banks and meanders occupy the estuary between Bryn-du and the Narrows off Pen yr Ergyd spit (Figure 1). The river in this section is presently divided into two channels, a large meander bending towards the Ceredigion side (named the Nant y Ferwig meander), and a smaller channel which hugs the Pembrokeshire shore off the Webley Hotel (named the Bryn-du channel) see Figures 1 and 8. Very shallow sections (<0.75m and locally less than 0.5m) occur at the confluence of the two channels. At these locations turbulent eddies that formed during the tidal ebb have generated a complex local bathymetry with small pools up to 1m deep and intervening very shallow sections, to create a very confusing changing form to the river bed (Figures 12 and 13). These areas are almost unpassable even by a rowing boat during summer low water. Visual and floating buoy data suggests that the flood tide predominantly follows the Bryn Du channel while the ebb tide favours the Nant y Ferwig channel.

Over the past few years the Bryn-du channel has increased in size and has developed at its southern end into a more sinuous meander which is slowly moving down stream. Comparison between the 2006 airphoto and 2009 bathymetry (Figure 14) shows that the meander has moved downstream 40-60m in the past 3 years. At the same time the Nant y Ferwig channel has reduced in width and its downstream edge has moved 30m to 60m in a northerly direction. If this downstream movement of the Bryn-du meander continues, it will join the Nant y Ferwig channel near the Webley bend in a few years, and in so doing may capture much of the flow presently in that channel, leading to a reduction in the flow in the Nant y Ferwig channel.

This possibility could present the Teifi Boat Club with a problem as the flows in the shallow channel – the gut- in front of the club would reduce thus making it more difficult to leave or gain access to the boat moorings.
Figure 6 Bathymetry of the estuary to Ordnance Datum - about mean sea level
Figure 7 Bathymetry of the estuary to Chart Datum, which is 2.44m below Ordnance Datum
Figure 8 Bathymetry of the estuary at low water

Produced by the Afon Teifi Fairways Committee with a grant from the Countryside Council for Wales

The low water depths in the river vary with the river flow and the monthly tidal cycle. During the summer the maximum depths may be up to 0.25m lower and in the winter over 0.5m higher. The low water at Poppit Sand is some 0.25m lower than at Patch which is the control point for the tidal corrections.

Work carried out by Chris Evans, Tim Wright, Colin Moore, Nick Newland, Robin Young and David Maynard

River depths in the Teify estuary, late summer 2009. River level 1.5m below OD.
Figure 9 Bathymetry of the river at low water between the Ferry Inn and Cardigan Bridge

This figure has been generated using Global Mapper software. Over 700 bathymetry points were available, tidal corrections were applied to reduce the depth to OD values, and this level was reduced further by 0.4m as the river level in summer at the bridge is at about this amount below Ordnance Datum.

The contouring package presents a slightly unreal pixilated coloured image but the contours are are more realistic.

The airphoto was taken in 2006.

Figure 10 Cardigan bar showing development of a secondary channel
Figure 11 LIDAR images of Poppit Sands 2006-09 showing changes to the Bar.
Figure 3 Irregular bedforms exposed at low water on the Webley bend- location at the top righthand corner of Figure 12

Figure 4 Microlight photograph of the nose of the Pen yr Ergyd spit and Webley bend showing the bedforms formed during the ebb
The currents in the river channels are highly variable; the flood tide move sediment up stream while the following ebb moves it back down stream. The channels do not under go major rapid – daily – change indicating that the volume of sediment moved on each flood and ebb tide is more or less equal. However, the volume of sediment moved during any tidal cycle is large, as indicated by the bedforms exposed at low water and visible in the shallowest water (Figures 12 and 13). Major changes may occur more rapidly during winter flood events when the ebb greatly increases in strength and possibly duration.

Figure 13 shows an image captured from a microlight of the Webley Bend to the Narrows. The ripples shown have a wavelength of a few metres and an asymmetry indicating that they were formed during the tidal ebb. The sand in these areas is commonly very loose down to a few decimetres suggesting that it is resuspended during the tidal cycle.

The occurrence of large sand ripples – megaripples – in these areas is evidence that large volumes of sand move in the channels and on the bank margins every tidal cycle and anything but major dredging of these areas would be futile as the sand would return to reoccupy the dredged areas after a few tide cycles. However, a major dredging project would have disastrous effects on the adjacent shorelines as sediment moved down from the shore to refill the dredged area.

3b The Bryn-du scarp

For some 600m along the western side of the Bryn-du channel there is an almost linear steep scarp, nearly 2m high at low water with a top at about 1.5mOD (Figure 15). This scarp is eroded into a well bedded, muddy fine sand unit, rich in shells and locally rootlets (Figure 16) part of an extensive saltmarsh which occupied this area decades ago. Wave erosion undercuts the sander layers in the scarp to release blocks of muddier sediment onto its face. The scarp is obviously undergoing erosion, but the accumulation of green algae on some blocks indicates that erosion is not continuous. Comparison of the 2006 air photographs, the 2007 LIDAR image and 2009 field data suggests that the scarp has retreated between up to 10m in that time. Erosion is however episodic, and GPS measurements before and after flood events in the autumn of 2009 suggested that locally the scarp had retreated 2-4m in 6 weeks.
There may be further erosion on this scarp as the Bryn–du channel increases in importance but significant future erosion is considered unlikely as the river channel already flows in a nearly straight line from off Gianteifi to the Narrows (Figure 8).

3c Poppit spit

Comparison of 1960s photographs and maps show that the Poppit spit is much smaller than it was about 40 years ago. Along the northern part of Poppit Sands the high water line is generally some
distance from the dune frontage but about 100m south of Y Nydd the line abuts against the eroding edge of the spit (Figures 17).

Erosion of the spit is continuing (Figure 18) and comparison of the 2006 air photographs and a 2009 GPS survey suggests that about 6 to 8 m has been eroded off its nose in the past 3 years. Sand is accumulating on the higher parts of the intertidal zone on Poppit Sands, but the accumulation in front of the spit may be restricted by the rock revetments built around the two dwellings in the dunes, and the increasing strength of the tidal ebb flow as the Bryn-du channel enlarges.

Figure 19 shows a cross-section along the spit and the low points at about 37.5m are vulnerable during a major storm event. If the spit was breached at any of these points the saltmarsh behind would be rapidly eroded. These low points are created naturally but some have become access points to the beach for walkers and this leads to the lowering and widening of the feature. Some sensitive barriers should be put in place to limit access along these lows.

Figure 7 Boundary of high water mark – the blue line - along Poppit Sands, reaches the dune frontage only at the southern end at Poppit spit.
In August 2009 the recurve at the end of the Pen yr Ergyd spit was removed (see Section 3e below). Soon afterwards the owners of the two dwellings in the dunes became concerned that the area of gravel on the foreshore fronting the Poppit spit had suddenly expanded (Figure 20) thus increasing the threat to their dwellings. This gravel is poorly sorted with polymict clasts up to 20cm across of lithologies similar to those that occur on Pen yr Ergyd. The clasts extended up to the high water mark and showed no evidence of a preferred orientation. On the lower part of the foreshore the gravel is covered with algae indicating that it has not been moved recently by the tidal currents. At the southern end of the area the gravel is finer and better sorted suggesting that it is mobile. The conclusion is that the poorly sorted gravel is a lag deposit formed as a result of removal of the surface sand. It has not been deposited since August 2009.
The gravel is visible on photographs of the area taken in 2006 but its precise extent at that time is not known. The edge of the gravel was mapped in September, November and December 2009 and the results plotted onto the 2006 air photographs (Figure 21). It can be seen that the foreshore was gravelly in 2006 but the area had increased in size by September 2009 only to revert back in size in December to near its 2006 limits. The extent of the gravel is probably related to a number of factors; the strength of the ebb current, which varies with the monthly tidal cycle, the volume of river flow, which may enhance the ebb flow, and the increasing importance of the flow in the Bryn-du channel. Changes in the flow regime in the Narrows resulting from the removal of the recurve on Pen yr Ergyd may have increased the current on the Poppit spit foreshore, but it is only one of a number of processes which influence the form of that part of the foreshore.

The extent of the gravel will continue to be monitored to assess future changes.
3d Poppit Sands

Historic photographic evidence shows that sand has been accumulating on the upper beach face on Poppit Sands for at least 30 years, leading to a seaward expansion of the dunes on the northern end of the beach and the burying of the rocky platform along that margin. The LIDAR data collected in 2006 to 2009 by Ceredigion County Council provides a means of assessing changes to the beach profile over the past three years.

Figure 22 shows a profile across the southern part of Poppit Sands from 2006-09 derived from the LIDAR data; its location is given in Table 1. The low water mark is between the zero and 80m on the horizontal axis. All the profiles were collected in August except for the black AFTC profile which was collected in February 2007. Note that on all the summer profiles the beach is divisible into a steeper upper sector and a slightly flatter lower sector, with a distinct boundary (between about 400 -500m on the horizontal axis) between the two, also that the position of this boundary has fluctuated between 2006 and 2009. During this interval the position of the dune front has remained fixed and the level of the upper beach is unchanged. The elevation of the lower beach is more variable with annual differences of up to 0.4m. The boundary between the upper and lower beach may mark the groundwater line in the beach with the upper beach being above the groundwater level.

No distinct break into an upper and lower beach sector is recognised from the February 2007 profile, probably because wave energy is higher in the winter resulting in a flattening of the longshore bars that form on the lower beach sector in summer.

Figure 23 is a profile using the same LIDAR data across the northern part of Poppit Sands. Change over the period from 2006-9 is minimal except that there is a build up of about 0.4m on parts of the upper beach (75m on the horizontal axis) and a loss of about the same on the middle and lower beach (140m and 300m respectively).
3e Pen yr Ergyd spit

The Afon Teifi Fairways Committee (ATFC) is concerned that the spit will breach during a storm and that the shallow channel -the gut- from the spit nose to the Teifi Boat Club is silting up. Mr Greg Guthrie of Royal Haskoning, the consultant to Ceredigion County Council, reiterated at a Shoreline Management Plan meeting in Cardigan in December 12 2009 that the spit was thinning and would, in time, breach. It was revealed at the meeting by Mr Richard Edwards of Ceredigion County Council that they had run four LIDAR surveys over the general area between 2006 and 2009. This was not known to the AFTC and the team who prepared this report. If it had been known then the Feb 2007 LIDAR survey would not have been run.

Figure 24 shows a 2006 LIDAR section through the spit from the seaward river channel on the left to the water in the “gut” on the right. Note that the vertical scale is in mm, not m, and that the water level is at about -0.25m OD. The asymmetric form of the spit is shown with a steep inner face and a concave seaward face steepening only at the crest the and low water mark. These slopes are steeper where the sediment is coarser. The shape of the seaward, left hand, side of the spit is controlled by waves moving the sediment southwards towards the nose. The shape of the inner, right, side is controlled by waves overtopping the spit and sending a fluidised mass of gravel–rich sediment cascading inland.

Figure 24 Section across Pen yr Ergyd spit, seaward side on the left.
Five profiles (Figure 25) were generated across the Pen yr Ergyd spit from the 2006-2009 LIDAR data using *Global Mapper*, with Section 1 the most landward and Section 4 nearest the nose. The table below shows the start and finish points of each section.

Table 1 Location of Profiles derived from the 2006-09 LIDAR data

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poppit Sands southern end</td>
<td>215659 249250</td>
<td>215 440 248 607</td>
</tr>
<tr>
<td>Pen yr Ergyd Section 1</td>
<td>216000 248500</td>
<td>216040 248 465</td>
</tr>
<tr>
<td>Pen yr Ergyd Section 2</td>
<td>215976 248473</td>
<td>216006 248439</td>
</tr>
<tr>
<td>Pen yr Ergyd Section 3</td>
<td>215961 248446</td>
<td>215992 248419</td>
</tr>
<tr>
<td>Pen yr Ergyd Section 4</td>
<td>215943 248428</td>
<td>215974 248397</td>
</tr>
<tr>
<td>Pen yr Egyd Long Section</td>
<td>216040 248500</td>
<td>215934 248386</td>
</tr>
</tbody>
</table>

Figure 25 Sections 1 to 4 across Pen yr Ergyd spit

Care must be taken in reaching conclusions from changes to the cross-section form of the spit from this data, especially the crest position as there had been significant human intervention to the crest in March 2008 following major overtopping, and in late July 2009 when the recurve at the nose was removed.

Cross-section 1 shows little change in the profile between 2006-2008, but a major rise and the creation of a flattened crest in 2009. This change was the result of placing material from the recurve onto the crest in late July 2009.

Cross-section 2 shows similar changes to 1 except that the crest height was similar in 2008 and 09. Changes on the innerside of the spit are negligible on these two sections.

Cross- sections 3 and 4 show significant changes to the inner side of the spit due to the removal of the recurve in July 2009. Elsewhere the changes follow no coherent trend.

The profiles along the crest of the spit (Figure 26) show the inner, landward part between 0-90m having been raised in height by nearly a metre between 2006 and 2009 and this is almost wholly due to human intervention. From about 90m to 120m there has been little change. The changes from about 120m to 150m show a build out of the recurve between 2006-2008 and a reversal in 2009 due to its removal.
In early 2009 the AFTC sought and received permission from Countryside Council for Wales (CCW) to remove the recurve formed at the nose of the spit (Figure 27) with the aim of increasing the flow of water through the gut so as to reduce the need to dredge out the turning circle in front of the Patch pontoon.

The work was carried out in late July to early August using a mechanical digger (Figure 28) and the spoil was placed on the seaward face of the spit (Figure 29), in an attempt to reduce its rate of cross-sectional thinning. Some 7000 tons were said to have been moved consisting of very approximately 30% gravel and cobbles and 70% sand. Figure 30 shows the area of the spit nose removed. Precise measurements are not possible as the water line at the spit varies with the volume of water in the river and the state of the tide.
Figure 11 Recurve at Pen yr Ergyd prior to its removal in early August 2009

Figure 12 The end of Pen yr Ergyd spit after removal of the recurve

Figure 13 Sediment from removal of the recurve placed on the seaward face of Pen yr Ergyd spit
Figure 30 Changes to the nose of Pen yr Ergyd spit 2009

It was known that this placed sediment would be reworked by waves during spring tides into a more natural angle of repose (Figures 31 and 32) by first eroding a cliff into the dumped material and then creating a gravel apron to seaward from which the sand had been winnowed out. The sand was initially moved onto the lower beach by wave action, and was then carried away but it is not known where it was finally deposited.

Figure 31 Changes to the sediment placed and graded on the seaward face of Pen yr Ergyd spit, August and November 2009.

Subsequent movement of the gravel by wave action during spring tides would transport the gravel back towards the nose of the spit, and by late November a mound had accumulated on the inner side of the spit nose which is an early manifestation of a new recurve forming.
Has the removal of the spit recurve had its desired effect? Monitoring up to the end of 2009 suggests that the recurve is slowly reforming, probably from the sediment placed on the seaward side of the spit in August 2009. Monitoring of the area in 2010 may provide the answer.

The main driver of change on the spit is wave action, and especially during spring tides; and natural changes to the spit occur in two ways. There is horizontal movement of sediment—especially gravel—along the upper part of the spit and the volume moved depends on the wave energy. Changes to the spit due to this process have led to its extension and the growth of the recurve.

Major change to the spit also occurs during extreme events such as March 10 2008 when there was an exceptionally high tide. During this event wave overtopping fluidised sediment on the crest and created a series of delta fronts on its landward side (Figure 33). This was a classic example of the rollover mechanism for the landward movement of the feature. Such events in time would lead to breaching of the spit but within two days permission was obtained from CCW for the ATFC to regrade the crest to raise its height back to its previous level. This regrading repaired the storm damage (Figure 34).

Figure 33 Gravel deltas produced when waves overtopped the spit on March 10 2008
Major changes to the spit occur during extreme events, such as March 10, 2008, and this event changed the spit form more than any event in the previous nine years. No such conjunction of spring tide and high waves has occurred since then, but when such an event occurs the spit is likely to suffer further, rapid modification. Discussions should take place soon before such an event between the relevant authorities (Ceredigion County Council, Pembrokeshire County Council, Countryside Council for Wales, Crown Estates and Afon Teifi Fairways Committee) to decide on what action might need to be taken should the spit be severely modified. Should it be allowed to breach, should it be repaired, should plans be made to strengthen it?

Mr Greg Guthrie (Royal Haskoning) the CCC’s consultants states that the spit will breach, but he is looking at time scales of 50 years or more. In time it will breach, but it will be sooner if there is no human intervention. Presently the regrading of the crest following a major event has prevented a breach, the view of the authors of this report is that continuing intervention on this scale can prevent a breach for the next 10 to 20 years. However nature can spring surprises and a plan should be agreed with the interested parties as to what action could be taken following an extreme event.

Presently the ATFC carry out sporadic intervention after permission is obtained from CCW. There needs to be an agreement between CCC, PCC, CCC Crown Estates and the ATFC outlining the long term policy for maintenance of the spit.

4. Quaternary geology

The 2008-09 report on this project described the extensive occurrence of a grey stiff plastic diamict at or very near the surface of the intertidal zone between The Patch Caravan Park northwards nearly to the Cliff Hotel. Further investigations on this area in 2009 have shown that the diamict extends across the foreshore to under the river channel. North of the Perch large boulders litter the river bed and only thin sand covers the diamict. Figure 35 shows this area with the dark river bed and foreshore to the top (to the east) having a minimal cover of gravel and boulders above the diamict. Note the sharp edge of Poppit Sands at the bottom of the picture with a sand tail formed seaward of the Perch. The boulders in this area have been left after the clay in the diamict has been winnowed away by the river and tidal flows. It would be interesting to know the level of the top of the diamict under Poppit Sands. Note that this diamict would be very difficult to dredge and would require a different technique from that used to dredge loose sand- if this was ever considered.
5. Future investigations

Baseline data need to be collected to allow future investigators to assess rates of change to a number of features. These include the Poppit spit, the Bryn-du and Nant y Ferwig channels, the Pen yr Ergyd spit and the form of the bar. Ceredigion County Council will presumably collect LIDAR data in the coming years and access to this will allow evaluation of changes to many of these locations. In addition the group will continue to monitor change using GPS surveys and field observations. Additional information will be collected to refine the existing tidal data over a number of neap and spring tide 12 hour cycles.
Appendix A: DESCRIPTION OF EQUIPMENTS DEVELOPED AND THEIR CAPABILITIES.

During 2008 and 2009 the Afon Teifi Fairways Committee, supported by financial contributions from the Countryside Commission for Wales (CCW) carried out hydrographic surveys in the Teifi estuary.

In order to achieve these objectives in a very cost-effective manner, the survey group designed, developed, proved and used some new aids to the process of hydrographic survey and current measurement.

While of specific application to the initial task – that of learning more about tidal behaviour in the Teifi estuary - two of the developed systems are considered of significant potential use to several other river authorities and inshore coastal management groups.

In this brief paper two developed systems are described and their capabilities are listed.

These are :-

1. A sonar based hydrographic survey system.

2. A system of free floating buoys from which accurate surface tidal current may be determined in both speed and direction.

The SONAR based Hydrographic Survey System.

The requirement was to produce accurate hydrographic data across the Teifi estuary and the channels out to the open sea.

In order that any soundings may be related to a national datum, two parameters must be measured in respect of any single point surveyed. These are :-

1. The instantaneous water depth at the surveyed location and
2. The instantaneous surface water height (given the state of the tide etc.) relative to a suitable datum.

Taken together, these two data enable the level of the seabed at each surveyed point to be related to the selected datum. Given this and given a knowledge of a parameter such as Mean Low Water Springs (MLWS) at the site relative to the same selected datum it becomes possible to generate a chart of the area surveyed which may prove a valid aid to navigation.

Thus the project became split into two halves. The first was to establish and accurately survey with respect to the selected datum fixed tide poles which would allow the instantaneous tidal height to be measured. These measurements were carried out manually and tabulated by observers during all periods of hydrographic measurement.

The second requirement was that of a mobile sonar depth-sounder capability which could log position, time and instantaneous water depth.

Having studied the market for suitable systems, that selected was the SONARMITE ("Sonarm8") equipment marketed by a UK company named OHMEX.

This equipment comprises of a small sonar head which was attached to a temporary vertical beam mounted over the stern of the survey vessel and an electronic processing unit which converted the measured sonar water depth information into a form which a logging computer could read and log readily. (The data format was the familiar RS232 serial convention).

The second essential sensor was an integrated GPS receiver mounted on the cabin-top which, by means of the satellite system, continuously plotted the position of the survey vessel
to an accuracy of, typically, 7 metres. The GPS receiver also outputted its data in computer readable RS232 serial format.

The third element of this system was a small (laptop) computer which was configured to receive, log and display both the sonar (depth) information and the instantaneous position of the vessel. Also, to aid the survey skipper, graphical displays were produced of the depth profile beneath the vessel so that channels could be followed and explored accurately.

The computer ran under a program specifically written for the project (but which is equally suitable for any similar survey situation).

The data output from a survey run was a continuous tabulation (usually every 10 seconds, but user changeable) of lat-long position and water depth beneath the keel. Each log entry was also time-stamped with UTS, date and year (see Appendix B). The tabulated output was available through the special software in a number of standard formats (eg. EXCEL, ACCESS, Text).

The sonar selected measured depths in the range of 0.75 to 75 metres. Accuracy was of the order of ±10 cms.

In the system as developed for the Teifi, a second laptop made use of a second GPS antenna to log lat-long plus time independently. During the survey, this second computer displayed a large scale moving map upon which the track of the survey vessel was plotted. The second display was a further aid to the survey skipper to follow a pre-determined channel or route, and also greatly assisted him in going back over areas of particular interest. The software run in this second computer was also specially written / adapted for the task, but is also applicable to any other geographical region.

With the exception of the sonar sensor and the cabin roof mounted GPS antennae, all of the equipment is contained within a rack of size 44 inches (w) * 17 inches (d) * 15 inches (h) which can be installed in any suitable cabin area (Figure 1). It was preferable that it was mounted in the wheelhouse so that the survey skipper had optimum access to all the available displays. The rack contained the necessary voltage converters for the different equipments. The whole system operated from a single 12vdc supply derived from the survey vessel’s engine. Current drain was typically 5 amps with everything working.

For the project, the survey vessel was a local inshore fishing boat of length 26 feet having a single diesel engine (and 12 volt electrics). The choice of vessel was determined firstly by availability and secondly by the sea conditions in the areas to be surveyed. For the Teifi, it was a requirement that the survey could be extended out to sea beyond the bar, and hence a larger vessel was needed. For a strictly in-river sphere of operation, a much smaller cabin fitted boat would suffice.

![Figure 1 Laptops recording the data inside the survey vessel](image-url)
The surface tidal flow measuring system.

A second objective of the survey was the measurement of surface current velocity at different tidal states and in different areas.

Again a bespoke solution was decided upon, and as with the sonar system it is easily deployed in a wide number of other locations / situations.

The principle was the simplest of all – the poo stick! A floating object released into a surface current will be borne along by that current. Its track and speed will thus provide an accurate indication of the speed and direction of the surface current – and it is the surface current with which vessels seeking to navigate are principally concerned.

Once more recourse was made to the GPS system. A small buoy was designed and built. It was a tube 4.5 inches in diameter and 30 inches long, ballasted at its base so as to float vertically with 18 inches of it below the waterline (Figure 2). Although not essential, an additional buoyancy collar was fitted at the waterline point to ensure that it continued to float even were water to enter its lower region.

On the top of the buoy was attached a separately water-tight short cylinder about 4 inches high and 1.75 inches in diameter. Within this upper compartment was installed a HOLUX M-241 miniature GPS receiver and position logger. Once started, the HOLUX device measured the buoy position every 5 seconds and recorded this (as lat/long + date/time) in an internal memory. The device operated from a single “AA” battery for up to four hours (which could be extended by using a larger battery).

After recovery, the HOLUX unit was connected to a computer (via. an USB interface) and the log downloaded, the HOLUX device was then reset ready for the next sortie.

Software, again specially written for the project, then processed the buoy logged data into a number of tabular output formats. These included the 20 and 40 second averages of the track and speed-over-ground of the buoy. It was also possible to plot the buoy’s track graphically onto large scale maps of the region traversed.

Thus a GPS poo-stick can be released at one point and recovered at another some hours later and the analysis of its GPS record permits calculation of just what the surface current was doing throughout.

Whereas these buoys, having a draught of just 18 inches, were fine for any potentially navigable waterway area, for this survey additional data was required in even more shallow water to aid understanding of the manner in which the tides gave rise to the movement of mud and sand. To this end a special variant of the buoy was built – of similar materials and construction but having an length of only 10 inches and a draught of 7 inches. In all other respects, especially the GPS unit, this extra-shallow buoy resembled the original.

Both types of buoy have been deployed, to advantage. Clearly once deployed the progress of the buoys needs to be monitored to ensure that they do not go aground, become snagged or be lost. This was achieved by having small boats, compatible with the local sea conditions, drift with the buoys. Inside the Teifi estuary an 11 foot rowing boat equipped with a small outboard was perfectly adequate. Equally suitable might have been canoes.

Figure 2 Tide buoy floating in the river
Appendix B. CORRECTING THE BATHYMETRIC DATA

Typical simplified output of the data collected by the survey boat is shown in Table 1.

Depth is water depth in metres, ID is the fix number, Date is date of collection, Time Zulu is time of data collection in GMT, and Latitude and Longitude are as derived from the survey boat GPS. No lay-back was included as it measured only about 3 m less than the accuracy of the GPS.

Table 1 Typical output from bathymetric survey

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>ID</th>
<th>DATE</th>
<th>TIME</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.67</td>
<td>2</td>
<td>070909</td>
<td>073228</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.66</td>
<td>3</td>
<td>070909</td>
<td>073242</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.64</td>
<td>4</td>
<td>070909</td>
<td>073300</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.67</td>
<td>5</td>
<td>070909</td>
<td>073312</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.67</td>
<td>6</td>
<td>070909</td>
<td>073326</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.71</td>
<td>7</td>
<td>070909</td>
<td>073340</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.68</td>
<td>8</td>
<td>070909</td>
<td>073350</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
<tr>
<td>2.67</td>
<td>9</td>
<td>070909</td>
<td>073408</td>
<td>52.10387</td>
<td>-4.687208</td>
</tr>
</tbody>
</table>

The first task was to use the Ordnance Survey GridQuest programme to convert the Latitude and Longitude values into Ordnance Datum co-ordinates. This was done because it was simpler to use these co-ordinates in the Global Mapper GIS software used to construct the maps and cross-sections.

Next task was to correct the depths to Ordnance Datum by removing the effects of the tide. On 23 August 2009 the tidal curves at the Patch Sewer Outfall and Cardigan Bridge were measured simultaneously over a 12 hour cycle. All the bathymetric surveys were collected about two hours either side of high water, and Figure 1 shows the difference in the tidal levels between the two stations during this interval. High water on Figure 1 was at 10.5 (10.30am) when the tidal level at both stations was within a few centimetres of each other. At 9.5 ((9.30hrs) there was difference of about 20cm between the two stations and at 11.5 (11.30hrs) the difference was a few centimetres.

From this it is concluded that for an hour either side of high water the difference in tidal elevation between the bridge and the sewer outfall is less than 20cm. Most of the bathymetric data have been collected in the lower part of the estuary where the tidal level from the sewer outfall would be applicable. Therefore the data from the sewer outfall can be applied to all the data collected with the understanding that some in the upper estuary – St Dogmaels to Cardigan- may be up to about 20cm out.

A tidal curve (Figure 2) was collected between 7.15hrs and 1200 hrs BST on 7th September when part of the bathymetric data being corrected was collected. The bathymetric data were collected between 8.32 and 1140hrs BST with 753 fix points.

The raw bathymetric data – Fix number, time, water depth and OD grid references were divided into half hour segments and tidal corrections applied for each segment. Thus from Figure 2 the tidal level between 9 and 9.5 (9.00 and 9.30hrs BST) is seen to be 2.05m at 9.25 (9.15hrs) above Ordnance Datum. Then using EXCEL the depth values collected between 9 and 9.5 (9.00 and 9.30hrs BST) were reduced by 2.05m to obtain the water depth in that sector relative to Ordnance Datum. Similar corrections were carried out for each 30 minute sector of the data. Thus the final data set is reduced Ordnance Datum and was saved as a txt. file (Table 2).

The data on 7th and 9th September were reduced in this manner and the corrected files combined. Although data were also collected on 12th August and in 2008 these were not included as there river channels might have changed slightly in that period.
How accurate is the final data set? The horizontal accuracy of GPS positioning is probably accurate to 7 metres at worse and probably better than half this value. The estuary is about 4km in length and a map at 1:5000 scale of this area is about 80 cm from north to south. At 1:5000 scale 1m on the ground is 0.2mm on the map so on a map 80 cm high the positioning of a point would be accurate to a little under a millimetre. Most maps of the estuary would be smaller than 80cm north to south, thus the horizontal accuracy would be adequate for most users.

Vertical accuracy is more difficult to determine. Most tidal corrections are probably accurate to within about 10cm with some in the upper estuary being up to 20cm out. Fixes are taken about 12-16 seconds apart and at 4knots this is about 24 to 32m apart. Between each fix the river bed is likely to vary by a few decimetres –if only due to ripple marks etc. It is concluded that the OD corrected depths are generally accurate to within 10-20 cm and this is fit for the purpose of
supplying information to river users. Additionally there is no point calculating the tidal corrections to an accuracy of greater than about ±10cm for this is the accuracy of the echosounder.

Table 2 Water depth corrected to Ordnance Datum

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Datum (m)</th>
<th>Correction (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>215288.4</td>
<td>248511.7</td>
<td>-4.454</td>
</tr>
<tr>
<td>215290.1</td>
<td>248544.6</td>
<td>-4.798</td>
</tr>
<tr>
<td>215302.5</td>
<td>248576.2</td>
<td>-5.996</td>
</tr>
<tr>
<td>215337.9</td>
<td>248648.7</td>
<td>-5.059</td>
</tr>
<tr>
<td>215340.4</td>
<td>248663</td>
<td>-3.813</td>
</tr>
<tr>
<td>215346.1</td>
<td>248689.8</td>
<td>-3.452</td>
</tr>
<tr>
<td>215350.9</td>
<td>248726.9</td>
<td>-3.23</td>
</tr>
<tr>
<td>215234.2</td>
<td>248656.3</td>
<td>-3.906</td>
</tr>
<tr>
<td>215232.1</td>
<td>248647.2</td>
<td>-4.193</td>
</tr>
<tr>
<td>215228.5</td>
<td>248631</td>
<td>-4.926</td>
</tr>
<tr>
<td>215223.7</td>
<td>248605</td>
<td>-5.8</td>
</tr>
<tr>
<td>215227.3</td>
<td>248580.2</td>
<td>-5.717</td>
</tr>
<tr>
<td>215227.3</td>
<td>248580.2</td>
<td>-5.717</td>
</tr>
<tr>
<td>215227.6</td>
<td>248580.7</td>
<td>-5.707</td>
</tr>
<tr>
<td>215228.1</td>
<td>248580.4</td>
<td>-5.72</td>
</tr>
<tr>
<td>215227.9</td>
<td>248579.9</td>
<td>-5.724</td>
</tr>
<tr>
<td>215288.4</td>
<td>248511.7</td>
<td>-4.454</td>
</tr>
</tbody>
</table>