Appendix 4.1.B – Portbury Wharf flood risk review

Wessex Water

September 2018

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Portbury Wall
Risk & Effect of Tidal Overtopping

November 2016

Anthony D Bates Partnership LLP
Laburnham Farm
Sparrow Hill Way
Upper Weare
Axbridge
Somerset
BS26 2LE

tel: +44 1934 732380
e-mail: info@anthonybates.co.uk
web: www.anthonybates.co.uk

Project Nr
470

Report on Risk and Effect of Tidal Overtopping of Portbury Sea Wall – D9794C

Client :	Wessex Water Services Ltd - Project D9794C
Project :	Overtopping Report
Title :	Risk & Effect of Tidal Overtopping

	Prepared by:	**Reviewed by:**
DRAFT	**NAME**	**NAME**
	A Bates	C M Sheehan
DATE	**SIGNATURE**	**SIGNATURE**
20/10/2016		

	Prepared by:	**Reviewed by:**
Final	**NAME**	**NAME**
	A Bates	M Maloney
DATE	**SIGNATURE**	**SIGNATURE**
16/11/2016		

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Cover Picture: 26 April 2016, view along Sea Wall, east aspect, high water

Executive Summary

Portbury Wharf STW relies on protection from tidal flooding by the Portbury Sea Wall which is the responsibility of Portbury Wall Commissioners. This is a simple earthworks structure. However, the height of the wall in not sufficient to prevent minor overtopping on the very highest predicted tides and not nearly high enough to prevent overtopping on a significant surge tide, of which there have been 12 in the last 42 years, although not all of these reached sufficient height to cause serious, or any flooding.

In recent times the highest surge tide recorded at Avonmouth was in December 1981. It reached a level of 15.25m above Chart Datum (CD), which compares with a level of 14.51mCD for the lowest point in the existing sea wall. A surge tide level of 15.25mCD has a theoretical return period of 25 years. If a similar surge occurred today the tide level might be 0.14m higher due to sea level rise. Even neglecting sea level rise, it is estimated that a tide level of 15.25m CD would result in a flood level of 8.72mOdnance Datum (OD). Levels within the STW range from a low of approximately 6.5mOD to around 8.5mOD. Hence the STW ground area would be fully submerged. A lower surge tide with a height of 15.05mCD, with a return period of only 10 years, could be expected to result in a flood level of 8.29mOD resulting in a maximum depth of water in the STW of about 1.7m.

If flooding of the STW is to be prevented it will be necessary to provide a higher level of protection, either by raising the level of the existing sea wall, or by the construction of an independent defence around the perimeter of the STW. Only raising of the existing sea wall is considered in this report.

Various methods of increasing the height of the sea wall have been considered. The favoured methods are: adding to the existing earthwork profile to a height of 15.70mCD; adding a post and plank structure to a level of 16mOD; adding a driven sheet pile wall in steel, heavy PVC, or Cement Fibre, also to a level of 16mOD.

Increasing the earthwork profile would be a satisfactory method from both aesthetic and durability considerations, but is the most costly method by far at an estimated cost of £2.23million. The high cost is due to the assumed cost for suitable imported clay fill, but the cost could be much lower if a local borrow pit, or source of low cost good clay fill material is found. Planning consent may not be required, but if required might be gained without undue difficulty. However, there may be environmental objection if access to the

saltmarsh for construction traffic is necessary, because the saltmarsh is a SSSI. Protection of the saltmarsh is possible and is included in all cost estimates.

At the other extremity of cost, a post and plank wall comprising concrete posts and timber plank infill is estimated to cost only £296,000. Such a construction might be achieved without access to the saltmarsh, but might face planning objections. Greater detail of all options is provided in the main body of the report.

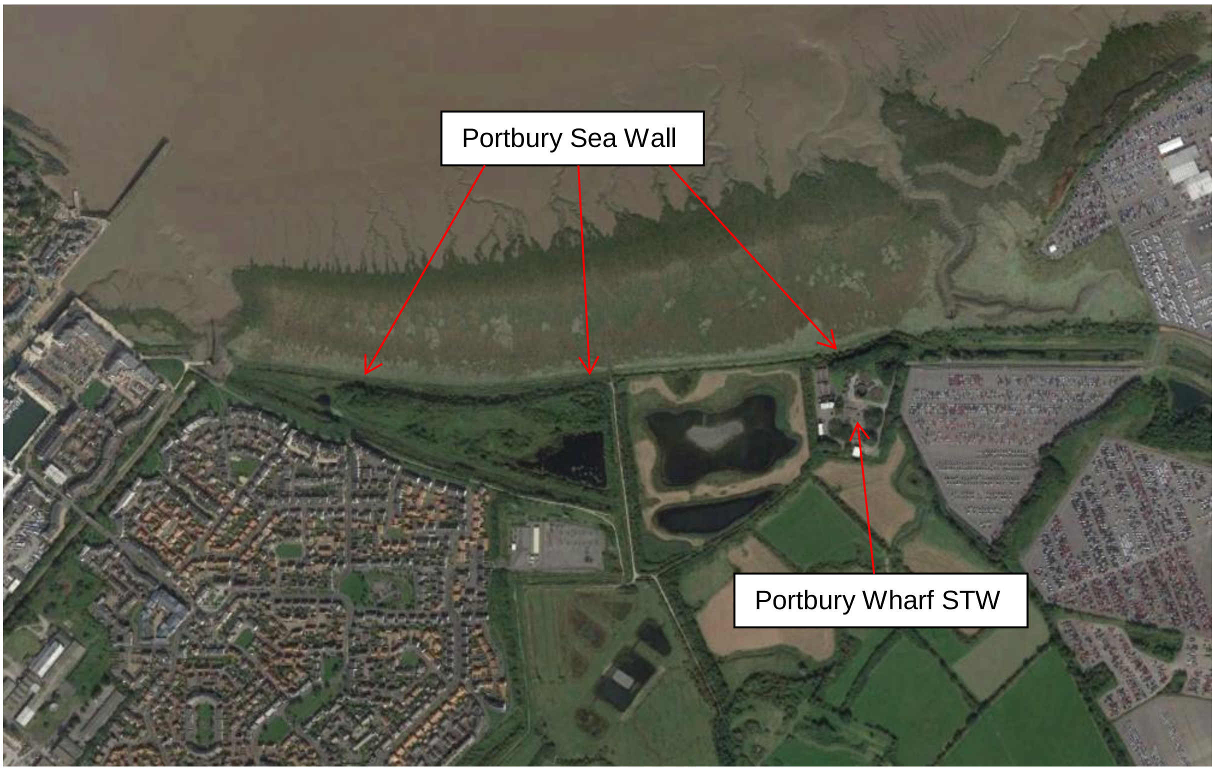
1 Introduction

This report is the subject of Purchase Order 60004594 dated 19th July 2016. The PO was issued in response to a proposal dated 29th July 2015 originally submitted by ADBP to the Portbury Wall Commissioners.

Wessex Water own and operate a significant asset, Portbury Wharf STW, located behind the Portbury Sea Wall. The sea wall provides protection against the risk of tidal flooding of the asset which is located below the level of high tides in the Bristol Channel.

This report addresses a number of issues, as listed below:

- Risk of overtopping;
- Extent of flooding if overtopping occurs;
- Condition of the existing sea wall;
- Potential changes to the wall to reduce the risk of overtopping;
- Estimated cost of potential changes.



Portbury Warf STW and Seawall location (*Source Google Earth*)

1.1 Height and structure of the existing wall

This original proposal for a report on the risk of overtopping was submitted to the Portbury Wall Commissioners and hence this report is focussed primarily on that length of sea wall that is the responsibility of the Portbury Wall Commissioners. However, it is important to note that to provide full protection to the Portbury Wharf STW it will also be necessary to undertake limited work beyond the eastern and western limits of the Commissioners wall.

At the eastern limit work will be necessary on land controlled by the Bristol Port Company (BPC) in order to tie the improved wall in with higher level land on BPC property. It is expected that BPC would wish that such work be carried out to protect their own interests. BPC may be willing to meet or contribute to the cost.

At the western end there is an area of land that at present is slightly lower than the lowest point on the Commissioners existing wall. The western low area is in the vicinity of the drainage outfall which drains surface water from the immediate catchment including much of the new housing developed by Persimmon and others. The lowest ground level in this area in respect of flood protection has a level of approximately 8mOD, or 14.5mCD, which is marginally lower than the lowest point in the Commissioners wall. The ground level in this area would therefore also need to be raised to match that of the improved length of the Commissioners wall. It is understood that the land is currently owned by Persimmon and it may be that it would be their responsibility to undertake the necessary work, or to meet or contribute to the cost.

Generally the elevations referred to in this report are in metres relative to Chart Datum (CD). Chart Datum is the standard reference used for tidal observations and is usually, and in this case, equal to the level of the lowest astronomical tide (LAT). However, where appropriate levels are also referenced relative to Ordnance Datum (OD), which at Portishead is 6.5m above Chart Datum. Ordnance Datum is approximately at the mean tide level.

The sea wall is in the form of an earth embankment believed to have been originally constructed in or about, or soon after the year 1798 under an Act of Parliament.

The seaward side of the wall is fronted by extensive saltmarsh which has a level of approximately +13.2mCD.

The earth seawall is roughly trapezoidal in section. Seaward and landward slopes vary but are approximately 1V:3H on the seaward side and 1V:2H on the landward side. The landward side profile includes a berm with width of about 2m. Average crest level of the wall is +14.77mCD with a crest width varying from 2m to 3m. The landward side slope, which includes a low level berm, terminates in a drainage ditch with a bed level of approximately +12mCD. Water level in the ditch various depending on recent rainfall and ground water levels.

The lowest ground level within the Portbury Wharf STW is approximately 6.45mOD, or 12.95mCD. This is approximately 2.2m lower than the highest recorded tide (15.15mCD December 1981). Some underground structures may be at lower levels.

1.2 General Condition

At the time of the most recent inspection of the sea wall in September 2016 the wall was considered to be in reasonable condition. No significant shrinkage cracking of the structure was evident at the time, although longitudinal cracking caused by prolonged dry weather had been recorded on previous inspections. See Figure 1. Longitudinal cracking as witnessed on earlier inspections is not considered to be critical because, in contrast with any transverse cracking, intrusion by tidal water is unlikely unless the wall is overtopped.

Figure 1. Longitudinal Cracking on crest of wall in dry conditions

The wall enjoys a significant degree of protection from wave attack due to a frontage of extensive saltmarsh with a level of approximately +13.20mCD (See Figure 2). The average level of the wall crest is approximately +14.77mCD. The average height of the wall above saltmarsh level is therefore only 1.57m.

Figure 2. Salt marsh on seaward side of the wall

With the exception of the crest, the wall is well covered by vegetation comprising mixed grasses, wild plants and, on the landward slope, scrub (See Figure 3).

Figure 3 Picture showing scrub on landward side of the wall

The vegetation is expected to provide a reasonable level of resistance to erosion in the event of tidal overtopping of modest depth and duration.

In contrast to the slopes, the crest of the wall in places is devoid of vegetation due to erosion by pedestrian traffic. Pedestrian traffic, and hence surface erosion, has in recent years increased significantly as the extent of local housing development and occupancy nears completion. The foot tread erosion can be clearly seen in Figure 3 above. In places surface erosion has exposed a plastic reinforcing membrane (geogrid) along the western half of the wall (see Figure 4).

Figure 4. Exposed Geogrid on crest of wall

The depth of erosion has been limited by the near surface layer of the geogrid, but it is not thought that the geogrid is continuous over the whole length of the wall. Additional work may be necessary in future if the crest erosion becomes significant. An effect of surface erosion is that the clay structure dries more quickly during prolonged warm dry weather resulting in the propagation of localised linear shrinkage cracks to a depth of up to half a metre. At present, neither the surface erosion nor the cracking are considered to be a threat to the stability of the wall, but this may change if erosion or cracking is increased. .

1.3 Height of wall crest

The crest level varies throughout its overall length of approximately 1.2km as below:

Average crest level	+14.77mCD
Maximum level	+15.17mCD
Minimum level	+14.51mCD

A longitudinal sequence of crest levels is provided in Appendix 1.

2 Tide levels

2.1 Highest recorded tides

Tide levels in the Bristol Channel are amongst the highest in the world. The predicted tide levels at Portishead range from -0.20mCD at lowest water Spring Tides to +14.65mCD on highest predicted Spring Tides(1). The lowest point in the sea wall of +14.51mCD is therefore 0.14m (14cm) below the level of the highest predicted astronomical tide.

Predicted tide levels are derived from the Lunar cycle, but actual tide level is also influenced by air pressure, wind direction and wind strength. During the period of our inspections, July 2013 to April 2016, the predicted tide level has on occasions; February 2014 (+14.65mCD) and February 2016 (+14.64mCD); been slightly higher than the lowest level of the wall crest, but the wall was not overtopped because air pressure was high and wind speed low and blowing from the east, resulting in the tide not reaching the predicted level.

Records of the actual recorded exceptional (significantly higher than predicted) tide heights at Avonmouth have been provided by Bristol Port Company for the 32year period 1974 to 2006(2). Predicted tide height at Portishead is 0.10m lower than at Avonmouth.

The 11 highest tides (relative to predicted level) recorded at Avonmouth during this 32 year period are shown in Table 1. All of these tides are higher than the maximum predicted level at Avonmouth (HAT) of 14.69mCD. All of these tides would have resulted in a degree of overtopping of the sea wall. The tide in December 1981 is understood to be the highest ever recorded at Avonmouth.

The 2 columns in Table 1 listed under 'Occurrence' represent the following:

No>than is the number of the listed exceptional tides within the 32 year period that were higher than the recorded 'Actual' height in each row. Hence, for the tide listed in the first row, that on 09/02/1974, there are 11 recorded 'exceptional' tides that reached or exceeded a height of 14.72mCD in the 32 year period covered by the table.

The last column is the **return period** for tides of 14.72mCD or greater height and is found by dividing 32 by 11 = 3.

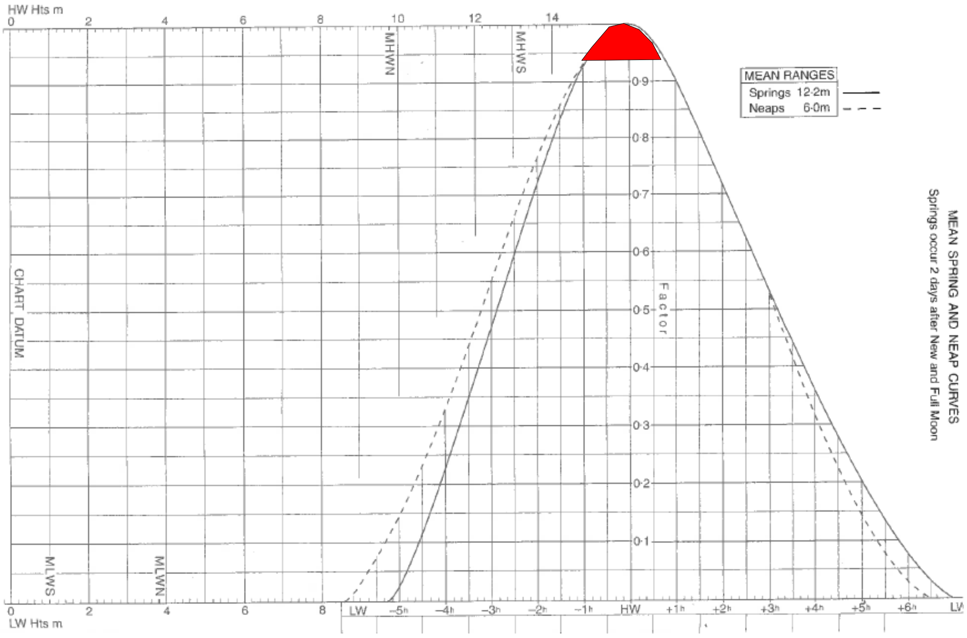
	Date	Predicted Highest Tide (m)	Actual Highest Tide (m)	Exceedance	Percentage that the Actual Highest Tide Exceeded the Predicted	Occurrence	
		mCD	*mCD*	*m*	*%*	No>than	I in Yrs
1	09-02-74	14.50	14.72	0.22	1.52%	11	3
2	30-01-75	14.40	14.73	0.33	2.29%	10	3
3	17-03-80	14.40	14.70	0.3	2.08%	12	3
4	13-12-81	13.59	15.25	1.66	12.21%	1	32
5	26-02-90	13.50	15.00	1.50	11.11%	2	16
6	04-12-94	14.10	14.97	0.87	6.17%	3	11
7	28-10-96	13.80	14.84	1.04	7.54%	6	5
8	10-02-97	14.60	14.93	0.33	2.26%	4	8
9	24-02-97	12.70	14.79	2.09	16.46%	8	4
10	30-03-98	14.60	14.78	0.18	1.23%	9	4
11	30-03-06	14.50	14.85	0.35	2.41%	5	6
12	08-10-06	14.50	14.80	0.30	2.07%	7	5
No Yrs	**32**						

Table 1. Highest Recorded Tide Levels for Avonmouth

Although the tide of December 1981 was the highest in living memory, a catastrophic flood is recorded in 1607[(4)(5)(6)(7)]. No reference to tide height has been found, but it is recorded that flood water reached a level of 5 feet (1.52m) in All Saints Church at Kingston Seymour, which is approximately 17km southwest from Portbury and approximately 2.5km inland from the nearest coastline. It is reported [(4)] that the flood level was marked by a line chiselled into the stone masonry of the church. We have visited the church, but failed to find any such mark. However, we have established by topographical survey the level of the church floor and hence the flood level based on 5 feet of water and calculate the flood level to have been 7.6mOD, or 14.1mCD. However, there are a number of unknowns: accuracy of the 5ft measurement; relationship between flood level and tide level; the level of contemporary tidal defences; and the subsequent effect of climate change. The level should therefore be treated with caution.

It can be seen from Table 1 that the highest tide more recently recorded at Avonmouth was +15.25mCD on 13th December 1981, or +15.15mCD if corrected for Portishead. Assuming there has been no change in wall level between 1981 and when surveyed in 2014, on that occasion in 1981 the lowest point in the seawall at Portbury would have been overtopped to a depth of 0.64m. By reference to the tide curve (Figure 5) it can be found that the duration of overflow would have been approximately 1hr 40mins. Overflow would have commenced about 50mins before high water and continued rising to a maximum depth of 0.64m until the tide turned reducing the depth of overflow to zero after a further 50mins. The total inward flow of seawater over this period would have been substantial. It is known that extensive flooding occurred on this occasion with some local loss of farm animals. A local farmer, Andrew Hardwick, has provided his recollection of events. See extract below.

"As I remember the flood water escaped from the nature reserve and followed the ryhnnes, it appeared just short of the Portbury hundred. Opposite Portbury Church, but did not cross the hundred or the motorway.
Historically I think there was a Roman Port at Portbury, so maybe finding its old Path.
Also water appeared at Marsh Lane flooding the road to the plaster board factory, which must have existed then. A lorry came off the road here because it could not see the road. Memory is a bit vague.
There were no car parks in the Docks then, so no damage was done".



*Indicative 1981 overtopping duration shown in red

Figure 5. Avonmouth tide curve

Because the level of the crest of the Portbury sea wall varies, the depth of overflow in 1981 will have varied along the length of the wall. The highest part of the wall is at +15.17mCD and hence during the 1981 event almost the entire length of the wall will have been overtopped to depths of up to 0.64m.

2.2 Frequency of occurrence of highest tides

It should be noted that the frequency of occurrence as described in Section 3.1 is not a true statistical analysis. This is because the basis of analysis of the tides over the 32year period listed in Table.1 does not refer to all tides during the period, of which there were more than 23,000, but only a selection of tides that are recorded as having exceeded the highest predicted tide level (HAT) by a significant amount.

It can be seen from the 1st graph in Figure 6 that, for example, on 3 occasions during the 32years of records, the predicted tide height was exceeded by over 10%. Even a 10% increase, if occurring on a mean high water spring tide (MHWST) of 13.1m CD, would amount to an increase over predicted high tide height of approximately 1.3m. Analysis of the 11 highest tides as recorded over the 32 year period 1974 to 1995 can be made in various ways, as is shown in Figure 6.

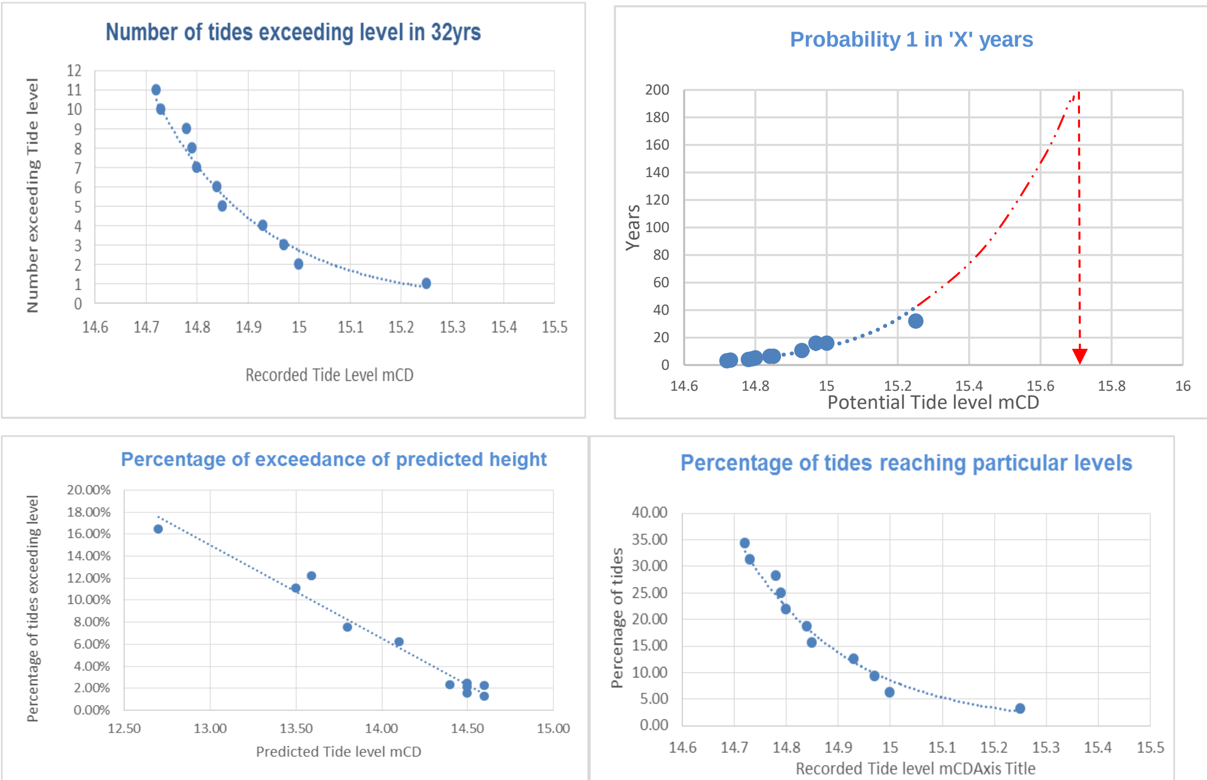


Figure 6. Various Analysis of Tidal data – Predicted Versus Actual

The basis of the graphs in Figure.6 is restricted to only the exceptional tides recorded over the 32 year period, but it is required in this report to extend the risk to a 1 in 200 year event. This has initially been done above by extrapolating the curve in the top right graph in figure.6, but a more satisfactory basis will be to use data extracted from a report funded by Defra, SEPA, the Scottish Government and the Environment Agency, Project: SC060064/TR2: Design Sea levels [(8)]. The report covers the entire UK coastline, but includes data specific to Avonmouth.

The data for Avonmouth has been extracted and used to further assess the probability of a range of surge tide heights, as shown here in Figure.7. The result for a 1 in 200 year event is found to be more or less the same as that independently arrived at by extrapolation in Figure.6. Note that tide height in the following Figure.7 and Table.2 is referenced to OD not CD and hence to compare with Figure.6 it is necessary to add 6.5m to the tide height. Figure 7 plots recorded data (blue) and theoretical extension to longer return periods (green).

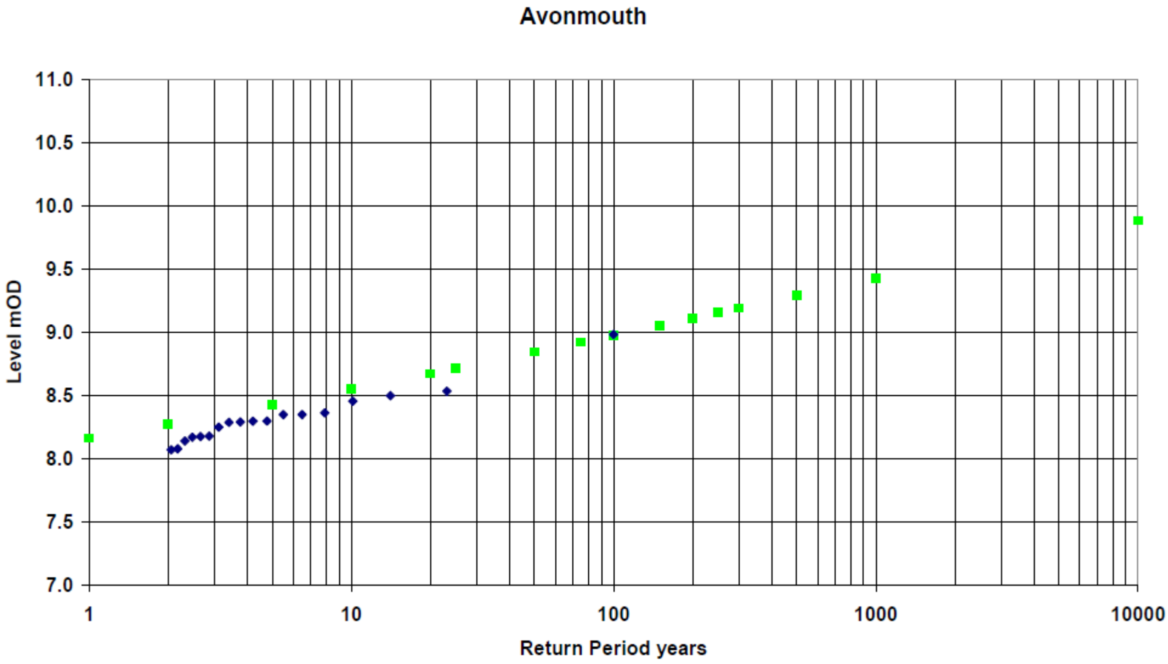


Figure 7. Tide height v Return Period of 1 to 10,000 year events
Blue is recorded data and green is 'smoothed' theoretical extension

Detailed data from the same source(3) is shown in Table.2 to which we have added conversion to Chart Datum and the potential effect of climate change assuming a maximum rise of 3.34mm a year.

2.3 Effect of Climate Change

The analysis of historical and recent records of tide height have demonstrated beyond any doubt that sea level is rising. Numerous studies across international boundaries have been made, all of which reach broadly similar conclusions. The information relied upon in this report is that produced by Alexander Edmeades for the Bristol Port Company dated 04/12/2015(3). See also references(9)(10). The report examines tide level at Avonmouth over the period 1924 to 2015 and includes the following figures.

"sea level has risen by 1.23mm yr^{-1}, with upper and lower 95% confidence limits of + 1.59mm yr^{-1} and – 0.93mm yr^{-1} respectively."

The report also found that the rate of sea level rise over the past 30 years has been increasing.

"An increase in the rate of MSL rise, or acceleration, has been detected in the past 30 years. From 1924 – 1983 a rate of 0.85mm yr^{-1} was determined. For the past 20 – 30

years rates of 2.01 and 3.34mm yr^{-1} were found, respectively. The magnitude of this acceleration is similar to global increases, which rose from 1.7mm yr^{-1} for the past century, to 3.2mm yr^{-1} for the past 15 years. Determined trends for the past 20 –30 years are in line with current guidelines provided for flood risk management and planning from 1990 - 2010, which are derived from the UK Climate Projections 2009 (UKCP09) report."

If assuming an average rate of $0.5mm^{-1}$ from 1607 to 1924 and $0.85mm^{-1}$ from 1924 to 1981, the increase in tide height due to climate change since 1607 might be 0.21m, thus indicating that repetition of the 1607 tidal surge might have resulted in a surge level of 14.3mCD in 1981. Whilst these are only a rather rough estimates, given that the highest recorded level in 1981 was 15.25mCD, it suggests a rather dramatic increase in surge tide levels.

When considering future risk it will be appropriate to add the effect of rising sea level to the highest tide levels recorded in the past. Maximum risk will be reflected by the higher range of recent increase due to climate change, taken as 3.34mm yr^{-1}. The Highest predicted Astronomical tide Level (HAT) at Portishead is 14.69mCD. If taking the highest estimated annual rate of increase in local sea level of $3.34mm^{-1}$ the increase over periods of 10, 25, 50 and 200 years will be:

Period yrs	Increase mm	Tide height HAT mCD
10	33.4	14.72
25	100.	14.78
50	167	14.86
200	668	15.37

Alternatively, if taking the highest tide level recorded at Avonmouth of 15.25mCD on 13th December 1981, the addition of 200yrs increase due to climate change would give a level of 15.93mCD at Avonmouth, or 15.83mCD at Portbury.

In fact, although the expected increases due to climate change are significant, it can be seen that the increase is less than that which can occur due to adverse meteorological conditions. For example, in can be seen from Table 2 that on 24th

February 1997 the tide reached a level of 14.79mCD which was 2.09m, or 16.46%, higher than predicted.

The following table. 2 shows tide heights for a 1 to 200 year range of return periods with and without the addition for sea level rise. For convenience tide levels are shown relative to both OD and CD. The maximum predicted increase in sea level of 3.34mm^{-1} is used, but with a limit of 30 years increase, as agreed in discussions with Wessex Water staff.

Tide level		Probability	Inflow	Flood level		Add for Climate change	
mOD	mCD	No in yrs	m3	mOD	mCD	mOD	mCD
8.16	14.66	1	0	none	none	none	none
8.27	14.77	2	53,058	6.38	12.88	6.39	12.89
8.43	14.93	5	332,796	7.39	13.89	7.40	13.90
8.55	15.05	10	811,936	8.29	14.79	8.33	14.83
8.67	15.17	20	1,643,054	8.67	15.17	8.74	15.24
8.72	15.22	25	2,405,712	8.72	15.22	8.80	15.30
8.85	15.35	50	4,092,115	8.85	15.35	9.02	15.52
8.92	15.42	75	5,417,977	8.92	15.42	9.17	15.67
8.98	15.48	100	6,741,130	8.98	15.48	9.31	15.81
9.06	15.56	150	8,447,241	9.06	15.56	9.56	16.06
9.11	**15.61**	**200**	**9,687,891**	**9.11**	**15.61**	9.78	**16.28**
9.16	15.66	250	10,955,967	9.16	15.66	10.00	16.50
9.19	15.69	300	11,509,221	9.19	15.69	10.19	16.69
9.29	15.79	500	13,418,608	9.29	15.79	10.96	17.46
9.43	15.93	1000	16,252,742	9.43	15.93	12.77	19.27
9.89	16.39	10000	26,761,327	9.89	16.39	43.29	49.79

Note: Addition for climate change limited to maximum of 30 years.

Table 2. Surge tide levels v return period with addition for climate change.

2.3.1 Maximum Potential Tide Level

The theoretical maximum potential tide level is that given by a combination of highest predicted tide, maximum increase due to climate change and maximum exceedance of predicted level recorded since 1974.

Maximum 25 year predicted tide level (HAT) including addition of:

- 25yrs climate change 14.78mCD
- Maximum recorded percentage increase due to meteorological conditions, plus 16.46% 17.13mCD

However, the probability of a level of 17.13mCD occurring is extremely low. To reach this level requires that the very highest predicted tides, which generally only occur during 2 periods a year (Spring and Autumn Equinox), or 1 in 182 high tides/year, plus the maximum 25 year rise due to climate change, plus the maximum recorded percentage exceedance of predicted level which occurred only once in 32yrs, all coinciding.

Hence the statistical probability of occurrence of a 17.13m tide is only 1 in 5,824 years (182 x 32).

Over the 32yrs analysis of highest tides the tide height exceeded the predicted level by a significant margin (>1m) on only 4 occasions, all in mid-winter, late October to late January. This is not surprising as it is the period with the greatest occurrence of low pressure depressions and strong westerly winds.

In contrast, the highest predicted tides in the 20year period 2005 to 2025 occur in March and February. Therefore the risk of coincidence of high predicted tides and very low pressure appears to be fairly low, although weather patterns may change as a consequence of climate change or jet stream fluctuations.

2.4 Duration of overflow

The approximate duration of overflow for any combination of tide level and wall level can be estimated from the tide curve shown in Figure 5. Estimates of overflow time may have significant error because the shape of the curve provided in Admiralty Tide Tables are not the same as that for a surge tide. In surge tide conditions the tide curve is typically wider, meaning that high water persists longer than normal. This effect may feature in several tides before and after the highest surge.

In Table.3 the duration of overtopping for each increment of 10cm below the peak level of Mean High Water Spring tide has been estimated by reference to the Tide curve in Figure 5. For example, if tide height exceeds wall level by 30cm, from the graph the duration of overtopping is 65mins. When applied to different top levels of the sea wall the duration of overtopping for a given combination of tide and wall level can be found.

M Below HW	On chart	Duration	Duration
m	factor	hrs	mins
0.1	0.0122	0:40	40
0.2	0.0244	0:50	50
0.3	0.0366	1:05	65
0.4	0.0488	1:25	85
0.5	0.0610	1:35	95
0.6	0.0732	1:45	105
0.7	0.0854	1:55	115
0.8	0.0976	2:00	120
0.9	0.1098	2:05	125
1.0	0.1220	2:10	130
1.5	0.1830	2:30	150
2.0	0.2440	3:10	190
2.5	0.3050	3:15	195

MHWST range = 12.2m. Therefore each whole vertical division on tide curve = 1.22m

Table 3. Duration of tidal overflow for each increment of depth of flow

Because the crest level of the wall varies, the wall has been divided into 6 varying lengths with average crest levels ranging from +14.5mCD to +15.1mCD. The depth of overtopping has been found by comparing a range of tide levels with average wall level for each separate length of wall. The level of the wall has been found from the topographical longitudinal section as measured in September 2014 and reproduced herein in Appendix A.

2.5 Volume of tidal overflow

The results from Section 3.4 have been used to calculate the flow rate and total volume of overflowing water for each different tide level up to a maximum tide level of 15.7mCD which, if neglecting sea level rise, is in excess of a 200 year event. The flow rate has been calculated on the basis that the wall acts as a very long undrowned broad crested weir. The results are shown graphically in Figure 8.

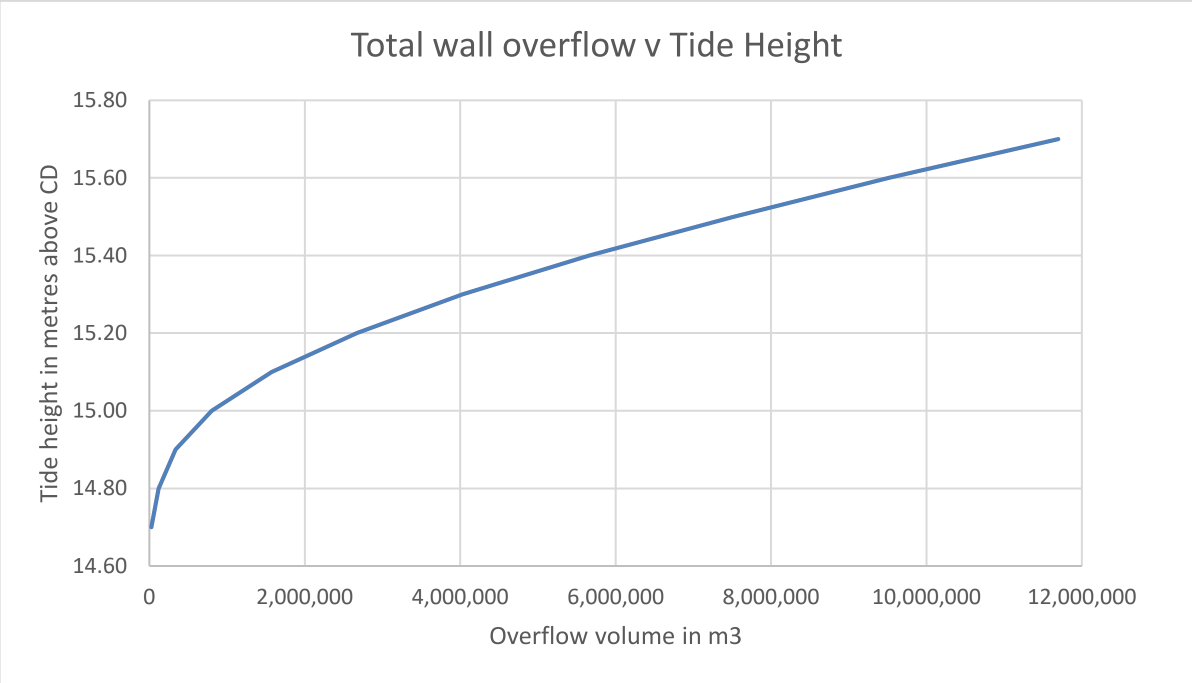


Figure 8. Overflow Volume versus Tide Height

2.6 Breached Sea Wall

The flow volumes calculated in Section 3.5 assume that the wall is not breached. The risk of breaching is considered to be small for depths of overflow up to 30cm (14.81m tide) and a duration of overflow of up to 1 hour. For greater overflow depth and duration the risk of breaching is likely to increase. However, whilst the risk is unknown, it is noted that no breach is recorded in December 1981 when the maximum depth of overflow at the lowest point in the wall was 0.64m and the duration estimated to have been 1hr 40mins.

From the cores recently taken, the lowest depth below wall crest level that non plastic soil was encountered was in BH. No.3 (see results of Soil investigation in Section 4.1.1 and Appendix B)) where dry highly friable clay extended to a depth or 1.4m below crest level, or a level of 13.35mCD. This level is therefore chosen as a 'worst case' scenario for the invert of a breach. No attempt has been made to estimate the overall width that a breach might achieve at this level, but flows have been calculated for breach widths of 5m, 10m and 20m. The 20m results are given in Figure 9.

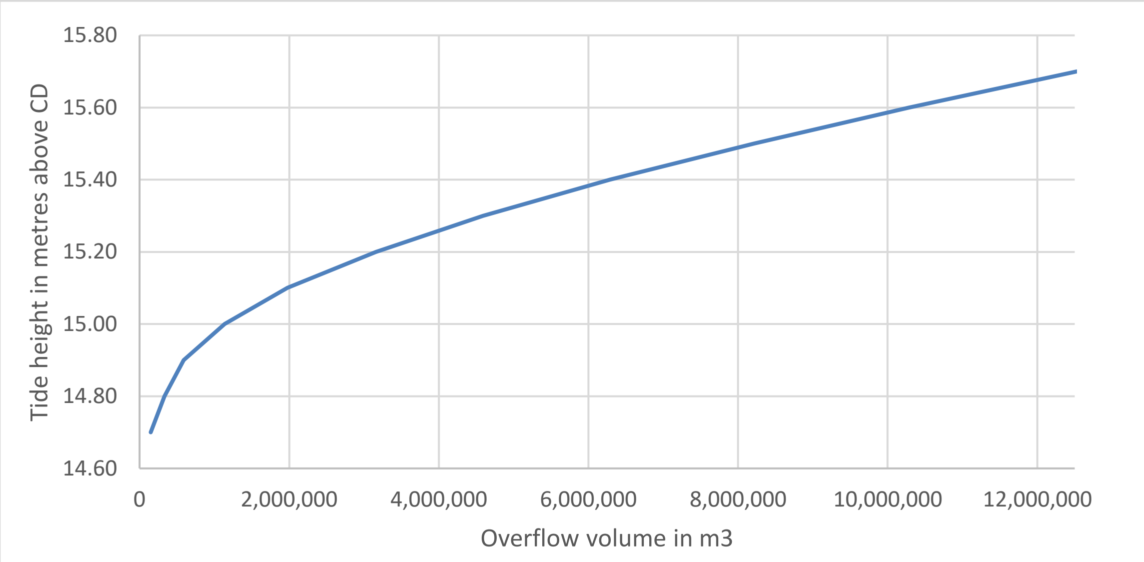


Figure 9. Total wall overflow v Tide Height with 20m breech

Although the risk of a substantial breach in the wall appears to be small, the total flood volume assuming a 20m wide breach has been calculated for a range of tide levels, as for the wall without breach. The maximum additional inflow for the highest tide considered of 15.7mCD is relatively small, 832,122m^3, or a 7% increase relative to overtopping without breach for the same level of tide.

3 Extent and Level of Flooding

The area behind the sea wall that is vulnerable to flooding has been surveyed and the volumetric capacity calculated for a range of different flood levels. Area and depth of flooding are based on contours of the land within the flood plain. The contours are as measured from a combination of topographical survey carried out specifically for the purpose, supplemented by levels within low lying areas in the Port of Bristol property that lies to the east of the Portbury Wharf STW derived from LIDAR survey data publically available on the Environment Agency website.

The spatial extent of potential flooding to a maximum level of 15.7mCD, or 9.2mOD is shown in Figure 10. The main areas below tide level are not large totalling only 600,000m^2. Hence the storage capacity is limited at 1,307,649m^3. In the event of significant tidal overtopping the area would fill quickly. There are areas of flood plain that extend beyond the maximum limits shown in Figure 10, but penetration of these areas by flood water is restricted by the size of physical structures, such as culverts, and relatively small gaps in counter walls, or between areas of raised land. Because the duration of overtopping of the seawall is limited by a period about high water there may not be sufficient time for these additional areas to absorb a substantial volume of flood water. In consequence, once the whole available area is flooded the flood level within will rise quickly with only very small increasing area until flood level and tide level are the same and subsequent flood level matches the increasing tide level.

Note: Area in Blue would be susceptible to an overtopping/flood event Ground level in areas coloured red or orange are lower than the general land level.

Figure.10 Potential Maximum Flood Area

By combining the results of the volume of overflow, as shown graphically in Figures 8 & 9, with the capacity of the flood plain at different flood levels, the impact of different tide levels and depth of overtopping can be found.

Table 4 which follows provides the calculated volume of water overflowing the sea wall for different heights of tide and the capacity of the flood plain for the same water levels.

It can be seen that for a tide level of 15.0mCD the volume overflowing the wall is almost as large as the flood plain capacity at the same level. For increasing tide level the inflow volume is greater than the flood plain capacity and hence flood level and tide level are the same.

Tide Level mCD	Potentials Overflow - no Breach m^3	Flood Plain Capacity m^3
14.8	117,990	833,898
14.9	338,391	891,543
15.0	803,147	949,694
15.1	1,573,393	1,008,325
15.2	2,673,836	1,067,403
15.3	4,032,248	1,126,891
15.4	5,659,278	1,186,777
15.5	7,518,436	1,247,036
15.6	9,517,523	1,307,648
15.7	11,695,678	1,368,606

Table 4. Potential tidal overflow in relation to available capacity

The lowest level within the STW is 6.55mOD. From the earlier Table.2 in Section 3.3, it can be seen that it is estimated that a 1 in 25 year flood would flood lowest area in the STW to depth of 2.18m and a 1 in 200 year event to a depth of 2.56m.

3.1 Wall construction – Investigation 15th September 2016

In order to assess the risk of breaching of the seawall simple hand auger boreholes were drilled on 15th September 2016. Each borehole was drilled at the landward edge of the wall crest to a depth of approximately 1.6m, this being below the level of the saltmarsh on the sea side of the sea wall. The simple auger method employed did not facilitate the taking of undisturbed samples, but the soils encountered were assessed and described at regular depth intervals. A single borehole was also located in the saltmarsh. Borehole logs and a location plan are provided in Appendix 2.

A common feature of all boreholes in the seawall is that the soil, a sandy clay or loam, at the time of investigation was dry and highly friable to a depth of approximately 1m. The total lack of cohesion was such that the soil captured in the auger when tipped to a horizontal position either fell out freely, or crumbled to a mixture of crumbs and dust when disturbed. See Figure 11.

Figure 11. Loose soil recovered from upper 1m of wall

The lack of cohesion suggests that if the soil in the wall structure is exposed during overtopping erosion would be likely and possibly quite rapid. However, it is considered unlikely that erosion would continue to a significant depth below that of the salt marsh which would therefore define the maximum depth of flow entering a breach. The soil encountered in the boreholes increased in plasticity with greater depth to the extent that soil below about 1m depth could be hand rolled into a string of about 5mm diameter.

It is possible that the moisture content of the upper metre of the wall at the time of investigation in mid-September was exceptionally low, being at the end of a relatively dry summer, but if such dryness is characteristic of the late summer early autumn period it is likely to coincide with the equinoxial tides when the risk of overtopping logically may be greatest, but as stated previously, the risk of coincidence of spring Tides and surge conditions appears to be low. This is supported by the historical records, which show that all but one of the recorded historical tides that have exceeded the wall height occurred during the winter period. See analysis of tide heights in Section 3 above.

4 Possible improvements to increase the sea wall height

The risk of overtopping or breeching of the wall could be reduced, or eliminated, by raising the wall height to a level above the highest anticipated tide plus a margin to account for potential wave action and sea level rise. It is not considered that wave overtopping is particularly important as wave height will be significantly limited by the level of the saltmarsh and the duration and volume of additional flow is likely to be relatively small.

There are a number of means by which the wall height could be raised including the following:

- Adding soil to raise and increase the wall section,
- Adding timber or concrete post and plank construction,
- Adding 'cement fibre or plastic driven corrugated sheets,
- Adding a sheet steel piled wall.

Only those construction methods that are considered to be most acceptable are considered in reasonable detail.

All of the above methods will be hampered to some degree by restricted access to the wall for construction plant. The more easily accomplished and potentially least expensive methods are therefore likely to be those that do not require the frequent passage of heavy plant. Construction methods that create a vertical barrier could comprise a single wall, or a double row with soil infill. Subject to the allowance for sea level rise and wave overtopping, the maximum height of a vertical barrier relative to the top of the existing wall crest will be approximately 1m but a higher level might be appropriate for reasons that follow.

Factors influencing the choice of a preferred method of construction are considered to be:

- Safety
- Environmental impact
- Ease of construction
- Cost
- Durability
- Maintenance
- Aesthetics

4.1 Increasing the wall section

To increase the wall height and section it would be necessary to carry out the following operations:

- Strip and place aside existing vegetation and topsoil to a depth of approximately 0.15m to form a key.
- Import suitable clay soil, place and compact to new profile, about 20,730tonnes,
- Supply and fix a suitable geogrid to reinforce soil and resist erosion by pedestrian and other light traffic,
- Import and apply topsoil to the new profile, or use previously stripped soil if suitable,
- Seed the new exposed soil surface, or supply and lay turf.

Construction would require a wide tracked 12t hydraulic excavator to strip surface vegetation and soil and to place and compact imported clay to new profile. It would also require a means of importing and distributing clay over the entire length of the wall.

The distribution of imported clay may be difficult because the wall top width is too narrow for the safe passage of conventional tipper vehicles, but a mini-dumper as shown later in Figure 10, or perhaps larger 4-wheel drive dumper, could be used, especially if levelling the top of the existing wall at the start of work.

Except when exceptionally dry, the salt marsh is too weak to support the repeated passage of heavy traffic. The problem might be overcome by the use of low ground pressure plant, such as tractor and trailer with balloon tyres running on the saltmarsh, but success could not be guaranteed and the risk of damage to the saltmarsh would be high. The salt marsh is a SSSI and hence avoidance of damage would be necessary.

The salt marsh surface could be protected by the provision of a temporary running surface such as ‘Trackway’. See Figure 12. This would add significant cost, but might be necessary regardless of the method of raising height adopted.

Whilst not tested, it is considered that a requirement for planning consent for an earth structure of similar, but increased profile, is unlikely.

Figure 12 Example of Trackway temporary road across a SSSI

4.2 Timber or concrete post and plank wall.

If considering only the requirement to prevent significant overtopping, a wall with top level of about 16mCD would suffice. Over the highest sections of the existing earth wall with a level of 15.1mCD the wall height above ground would be 0.9m. This may be satisfactory as the standard height for railings in pedestrian areas is also about 0.9m. If this level is adopted the wall height at the lowest point in the existing wall would be 1.5m.

As the name implies, post and plank construction comprises vertical grooved posts located at appropriate intervals of about 2m throughout the length of the sea wall and infilled between posts with planks slotted into the preformed grooves in the posts. Posts and planks may be of suitable durable timber, or concrete. See Figure 13. Planks may also be of a compressed composite material. A wall could be a combination of concrete posts and timber infill panels, which could provide the optimum combination of durability and aesthetic appearance.

At the western end of the wall and at the junction of the wall with the access track from Sheepway, provision for pedestrian access would be required. This could take the form of steps or a closed stile, or self-closing tide gate.

Figure 13. Wooden and Concrete Post and Plank Systems

The advantage of post and plank construction, especially a single wall design, is that the components are relatively lightweight and do not require substantial mechanical plant to transport materials and install posts. Transport along the wall could be manual using a wheeled cart, or a mechanical tracked barrow as sown in Figure.14, or 4-wheel drive dumper, might also be suitable for moving soil in the profile raising option discussed in 5.1 above.

Figure 14. Tracked Barrow or mini-dumper

Post hole boring could be undertaken manually, but this would be very slow. Manually operated mechanical augers could be used and would be more effective, or alternatively a tractor mounted unit could be used, potentially with access along the wall crest as in the case of scrub clearance machinery. If penetration depth of the posts is sufficient, perhaps a minimum of 0.6m, concreting in may not be essential with compacted soil as an alternative, but for longevity, a compacted concrete dry mix would be preferable.

In our opinion the optimum combination would be a single post and plank wall mounted on the wall crest comprising concrete posts with timber or composite infill planking. This would provide simple construction, minimum environmental impact, reasonable aesthetics and relatively low cost. The alternative of using concrete planks would be less attractive, but more durable. Double wall construction with a vertical drop on each side would present a safety risk, especially for cyclists and is not considered further.

It is possible that planning consent might be required for a post and plank wall, but if constructed in suitable materials and of modest height, it is not expected that gaining consent would be too difficult.

4.3 Trench Sheeting

The use of interlocking trench sheeting is a common method of construction for a vertical wall, usually to retain soil. See Figure 15. Sheeting is most commonly steel, but is also available in PVC, the latter being lighter and less expensive, but less strong. Both materials are strong enough to be driven mechanically subject to the use of a suitable pile cap. Steel would require periodic maintenance, but unless damaged, PVC would not. A capping would be required to add rigidity and to maintain alignment. A timber capping would improve appearance and is likely to be more acceptable to the public, but may be more costly. Subject to material strength and wall height, a timber or steel waling might also be required, but for a maximum wall height of only about 1.5m this is may not be essential.

Figure 15. Steel and PVC interlocking trench sheeters

Although steel sheet walls are common in the construction of sea defences, given the sensitive nature of the local environment and the close proximity to people walking for leisure, the use of steel may be resisted by planners and environmental groups. PVC sheeters may be more acceptable if formed in material of a suitable colour. PVC sheeters would be more vulnerable to damage than steel, but as the site is not normally accessible to mechanised vehicles, the risk is probably small. Unlike steel, PVC would not require periodic maintenance, but the period between maintenance for steel is would be long, perhaps requiring recoating at intervals in excess of 10 years.

4.4 Construction Costs

Detailed estimates of construction cost have not been made, but the preliminary estimates provided in the following matrix are considered to be sufficient to allow comparison of the relative costs of different methods. Ultimately cost will be influenced by a number of factors including: planning restrictions; environmental impact; public perceptions; weather; construction method, etc. For this reason, as stated above, cost estimates should be used only for relative assessment, not as budget cost.

Within each of the estimates, although possibly not essential, the cost of approximately £105,000 of providing protection to the saltmarsh during construction has been included. Provision is also included for work in areas beyond the eastern and western limits of the Commissioners wall, but as these involve third parties, no accurate measurements, or assessment, has been made. Instead provision is included by adding a assumed 10% increase in the overall length of wall to be raised.

Although provision is included in the cost estimates, subject to the actual construction method, special measures to protect the saltmarsh may not be necessary and the cost of works beyond the eastern and western limits of the Commissioners wall may be met by others.

To the overall cost of construction work percentage additions have been made for overhead and other costs as follows:

Risk	20%
Design	7%
Prelims and supervision	15%
3rd party costs	5%
Overheads and profit	10%

These additions, are those which are understood to be those typically adopted by Wessex Water for similar works. The additions and not compounded.

	Score from 5: 1 = very poor, 5 = very good											
Construction method	Construction time	Durability assessment	Maintenance requirement	Appearance assessment	Safety assessment	TOTAL	%	Estimated comparative costs				
								Material	Plant	Labour	On-costs	TOTAL
Raise profile in earthwork	1	5	5	5	5	21	**84%**	1,192,001	144,900	81,200	808,317	2,226,418
Single timber post and plank wall	5	3	4	4	4	20	80%	23,248	119,400	45,886	107,465	**295,999**
Double timber post and plank wall	3	3	3	3	3	15	60%	46,497	133,750	80,700	109,890	370,837
Corrogated cement fibre wall	2	3	3	3	4	15	60%	18,224	126,853	46,180	109,017	300,274
Corrogated PVC wall	2	3	3	4	4	16	64%	28,507	127,306	65,555	126,180	347,548
PVC interlocking trench sheeter wall	2	3	3	4	4	16	64%	85,675	136,680	92,990	179,747	495,092
Steel interlocking sheet wall	2	4	4	2	4	16	64%	61,517	136,787	93,142	166,124	457,570
Notes												
Earthworks cost may be reduced significantly if consent for local borrow pit.												
All cost and time estimates are very approximate and should be considered for relative assessment only, not reliable estimates.												

Table 5. Evaluation & Cost Matrix

5 Conclusions and recommendations

On the basis of past events and future projections it must be assumed that the Portbury Wharf STW is exposed to significant risk of inundation from tidal water overflowing the existing sea wall. The height of the existing wall is not sufficient to prevent minor overtopping even from the highest predicted tides and is likely to suffer serious overtopping in the event of a significant surge tide.

Lowest ground levels within the STW are only approximately 6.5mCD. A flood level of 6.5mOD has a statistical return period only slightly over 2yrs, a level of 7.5mOD has a little over 5yrs and a 8.5mOD flood level a return period a little over 7 years. Inundation by tidal water to a level of 6.5mOD would begin to affect the STW, albeit only marginally.

It is therefore surprising that serious flooding of the STW has not occurred before. The reason that is has not is probably due to the very strong influence of meteorological conditions on tide height. It seems that recent conditions have been particularly favourable. No significant surges have occurred in the last 10 years, whereas 8 occurred in the previous 25 years. A surge tide of a height that would cause serious flooding may be overdue. The requirement for a higher level of protection may therefore be urgent. It is therefore recommended that appropriate action be taken.

Improved protection could be provided either by appropriate construction encircling the entire STW, which it is understood has been considered, or by raising the level of the existing Portbury Sea Wall. This report has only addressed the latter solution.

Of the variety of potential forms of construction to increase the height of the existing sea wall that have been considered, the most common form would be the addition of soil to increase the wall profile. This may be the most natural and hence widely acceptable method and does not present any significant engineering challenges, but it is estimated to be the most expensive solution by far.

This is because the cost of importing, distributing and placing suitable clay soil into the improved wall profile will be expensive. The method also carries significant risk of causing unacceptable environmental damage. Although in our opinion any damage is likely to be relatively short term, the fact that the site has multiple layers of environmental protection. Including; SSSI, SAC and SPA, is likely to result in strong opposition.

The alternative is to add height to the existing wall by the construction of a post and plank wall. This could take the form of vertical grooved posts infilled with timber, plastic or concrete planks, or driven interlocking sheets or piles of PVC, Cement Fibre, or steel. In each case to provide a satisfactory level of protection the vertical wall would need to be constructed to a level of approximately 9.5mOD (16mCD), although a lower level would suffice if minor overtopping of short duration is acceptable. The height of the existing earth wall varies from approximately 8mOD to a maximum of 8.7mOD. Thus the vertical height of a wall if constructed to a level of 9.5mOD would vary from 0.80m to 0.80m to 1.5m.

The components of a post and plank wall are not heavy and in consequence the construction could be achieved by a combination of relatively lightweight mechanical plant and manual labour. The risk of damage to the local environment would therefore be small relative to bulk earthmoving, but objections might arise on aesthetic grounds. Of the post and plank forms considered, a combination of concrete posts and timber planks is likely to be most acceptable, but would be less durable that steel. It is also estimated to be the least expensive.

Construction using driven corrugated PVC or cement fibre sheets, or steel sheet piles, may require heavier mechanical equipment than post a post and plank wall, but the risk of damage to the environment could be minimised by various means.

If increasing the height of the existing sea wall is the favoured method of increasing protection to the STW, it is recommended that the initial focus be on a concrete post and wooden plank wall and that consultations be held with key stakeholders to determine acceptability and level of objection if any.

It is also recommended that Bristol Port Company and builders Persimmon both of whom may have a financial interest.

Anthony D Bates Partnership LLP

Laburnham Farm

Sparrowhill Way

Upper Weare

Axbridge

Somerset

BS26 2LE

01934 732380

www.anthonybates.co.uk

November 2016

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Appendices

1 - Crest levels of Portbury sea wall

The Portbury Sea Wall Commission
Topographical Survey Report

348230.2	177193.6	14.82	348847.3	177258.2	14.71
348246.9	177193.8	14.72	348850.5	177259.1	14.65
348256.5	177194.2	14.69	348855.9	177260.8	14.74
348267.4	177194.7	14.72	348856.2	177259.5	14.82
348281.5	177195.7	14.70	348861.6	177262.9	14.73
348292.4	177196.4	14.68	348866.1	177264.7	14.76
348303	177197.8	14.76	348867.8	177265.3	14.87
348311.7	177198.6	14.62	348870.4	177266.3	14.72
348316.5	177199.4	14.68	348874.7	177268	14.80
348320.5	177199.8	14.71	348876.5	177269.3	14.88
348327	177201	14.75	348879.5	177270.3	14.89
348337.5	177202.6	14.71	348884.3	177272.1	14.88
348353	177204.6	14.68	348889.4	177273.7	14.91
348364.3	177205.9	14.61	348890.8	177274.5	14.96
348374.4	177207.4	14.64	348894.5	177275.6	14.96
348385.6	177208.8	14.58	348898.8	177276.8	14.93
348399.6	177210.6	14.51	348903	177278.5	14.94
348412.9	177212.4	14.60	348904.5	177278.6	14.81
348424	177213.7	14.56	348909.3	177280.5	14.82
348455	177217.3	14.61	348914.2	177281.8	14.81
348459.7	177218.1	14.60	348915.6	177282	14.85
348464.4	177220	14.89	348917.8	177282.3	14.86
348469.4	177220.3	14.75	348921.3	177282.8	14.86
348480.8	177220.8	14.72	348923.5	177282.9	14.92
348497.9	177221.9	14.72	348925.3	177283.4	14.85
348512.4	177223.7	14.75	348929	177284	14.79
348528.9	177225	14.82	348931.8	177283.8	14.79
348541.4	177226	14.76	348942.7	177283.1	14.84
348558.7	177227.3	14.71	348954.1	177280.4	14.84
348572.6	177228.2	14.71	348962.6	177278.5	14.80
348589	177229.5	14.71	348969.2	177276.3	14.89
348603.2	177230	14.78	348974.9	177276.4	15.17
348617.2	177231	14.75	348982.1	177278.2	15.10
348630.4	177232.2	14.76	349023.6	177284	15.02
348643.8	177233.1	14.70	349027.9	177284.8	15.11
348656.5	177234.5	14.77	349033	177287.3	14.80

2 – Results of soil investigation

Appendix 2: Borehole Layout Drawing

BH Location plan

Borehole logs

BH.1

Project	470					
ID	BH-01			Location	348447.7	177216.5
Date	15-Sep-16			Position	51°29'29.505"N	002°44'38.155"W
Time - Start	10:59			Description	Wall Crest - 1m to South	
Time - End	11:55			19.3m West from Footpath Sign		
				(Wharf Lane junction with Wall)		
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		14.55			0	
Turf removed	0.08				0.08	
	0.10	14.47	14.37		0.18	Friable Clay
	0.10	14.37	14.27		0.28	Friable Clay
	0.08	14.27	14.19		0.36	Friable Clay
	0.17	14.19	14.02		0.53	Friable Clay
	0.29	14.02	13.73	0.67	0.82	Stiff Friable Clay Polished face in sampler
	0.19	13.73	13.54	0.86	1.01	Stiff Friable Clay Polished face in sampler
	0.21	13.54	13.33	1.07	1.22	Stiff Friable Clay Polished face in sampler
	0.36	13.33	12.97	1.43	1.58	Stiff Friable Clay Polished face in sampler
	0.10	12.97	12.87	1.53	1.68	Stiff Friable Clay, Cohesive Plastic Limit - Short Rolled Thread
	0.10	12.87	12.77	1.63	1.78	Stiff Friable Clay, Cohesive Plastic Limit - Long Rolled Thread

BH.2

Project	470					
ID	BH-02			Location	348313.6	177199.3
Date	15-Sep-16			Position	51°29'28.906"N	002°44'45.101"W
Time - Start	12:07			Description	Wall Crest - 1m to South	
Time - End	12:38			Approx 170m West from Footpath Sign		
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		14.64			0	
Turf removed	0.15				0.15	
	0.16	14.49	14.33	0.16	0.31	Friable Clay
	0.29	14.33	14.04	0.45	0.60	Friable Clay
	0.50	14.04	13.54	0.95	1.10	Friable ClayMarginally more cohesive
	0.15	13.54	13.39	1.10	1.25	Friable ClayMarginally more cohesive
	0.25	13.39	13.14	1.35	1.50	Friable Clay Plastic Limit Increasing
	0.25	13.14	12.89	1.60	1.75	Stiff Friable Clay, Cohesive Plastic Limit - Short Rolled Thread
	0.10	12.89	12.79	1.70	1.85	Stiff Friable Clay, Cohesive Plastic Limit - Long Rolled Thread

BH.3

Project	470					
ID	BH-03			Location	348167.8	177197
Date	15-Sep-16			Position	51°29'28.783"N	002°44'52.660"W
Time - Start	12:58			Description	Wall Crest - 1m to South	
Time - End	13:33				Directly opposite large tree trunk	
					Top layer infill approximately 0.04m on top of geo-mesh	
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		14.81			0	
Turf removed	0.10				0.10	
	0.12	14.71	14.59	0.07	0.22	Top Soil
	0.10	14.59	14.49	0.17	0.32	Very Friable Dry Clay
	0.38	14.49	14.11	0.55	0.70	Very Friable Dry Clay
	0.34	14.11	13.77	0.89	1.04	Friable Clay, Slight polish on sample edge, Marginally more cohesive
	0.18	13.77	13.59	1.07	1.22	Friable Dry Clay Plastic Limit Slightly Increasing
	0.20	13.59	13.39	1.27	1.42	Friable Dry Clay Plastic Limit Slightly Increasing
	0.16	13.39	13.23	1.43	1.58	Stiff Friable Clay Plastic Limit - unable to roll
	0.34	13.23	12.89	1.77	1.92	Stiff Friable Clay Plastic Limit - Long Rolled Thread

BH.4

Project	470					
ID	BH-04			Location	348170.2	177216.3
Date	15-Sep-16			Position	51°29'29.410"N	002°44'52.544"W
Time - Start	13:40			Description	15m to North of Wall Crest	
Time - End	14:00			As BH03 in alignment with tree trunk		
					Sample taken in salt marsh	
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		13.49			0	
Turf removed	0.00				0.00	
	0.30	13.49	13.19	0.15	0.30	Soft grey clay with organic intusions
	0.15	13.19	13.04	0.30	0.45	Soft grey clay with organic intusions
	0.15	13.04	12.89	0.45	0.60	Soft med grey clay, with reducing organic intusions
	0.10	12.89	12.79	0.55	0.70	Lighter grey clay, with continued reduction in organic intusions
	0.15	12.79	12.64	0.70	0.85	Lighter grey clay Plastic clay / limited organic content

BH.5

Project	470					
ID	BH-05			Location	348637	177233.2
Date	15-Sep-16			Position	51°29'30.108"N	002°44'28.350"W
Time - Start	16:06			Description	Wall Crest - 1m to South	
Time - End	16:52				175m East from Wharf Lane	
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		14.66			0	
Turf removed	0.15				0.15	
	0.15	14.51	14.36	0.15	0.30	Friable Dry Clay
	0.33	14.36	14.03	0.48	0.63	Less Friable Dry Clay
	0.40	14.03	13.63	0.88	1.03	Less Friable Dry Clay
	0.22	13.63	13.41	1.10	1.25	Friable Clay Marginally more cohesive
	0.25	13.41	13.16	1.35	1.50	Less Friable Dry Clay, Plastic Limit Increasing, Can roll to short thick strings
	0.40	13.16	12.76	1.75	1.90	Less Friable Dry Clay, Plastic Limit Increasing, Can roll to short thick strings
	0.15	12.76	12.61	1.90	2.05	Increased % of Red Clay Plastic Limit - long rolled thread

BH.6

Project	470					
ID	BH-06			Location	348791.1	177249.2
Date	15-Sep-16			Position	51°29'30.677"N	002°44'20.368"W
Time - Start	17:11			Description	Wall Crest - 1m to South	
Time - End	17:47			4m west from sewage works street light alignment		
					On west edge of outfall trench through wall	
					Generally, slightly higher clay content than previous wall cores	
	Sample Depths (GL)	Top of Sample (CD)	Bottom of Sample (CD)	Top of Sample Related to GL	Bottom of Sample Related to GL	Description
Top		14.6			0	
Turf removed	0.15				0.15	
	0.15	14.45	14.30	0.15	0.30	Friable Dry ClayLight Brown
	0.15	14.30	14.15	0.30	0.45	Friable Dry ClayLight Brown
	0.08	14.15	14.07	0.38	0.53	Friable Dry Clay 5% red clay deposits, Med Brown
	0.27	14.07	13.80	0.65	0.80	Similar but also includes small proportion of grey clay deposits
	0.10	13.80	13.70	0.75	0.90	Less Friable Dry Clay Higher % clay
	0.15	13.70	13.55	0.90	1.05	Less Friable Dry Clay, Plastic Limit Increasing, can roll to short thick strings
	0.24	13.55	13.31	1.14	1.29	Less Friable Dry Clay, Plastic Limit Increasing, can roll to short thick strings
	0.32	13.31	12.99	1.46	1.61	Seams grey Clay Plastic Limit - long rolled thread
	0.14	12.99	12.85	1.60	1.75	Seams grey Clay Plastic Limit - long rolled thread