Oath to Burrowbridge Dredging and Associated Activities

Volume 3: Appendices Part 7

APPENDIX 6J: STRATEGIC ECOLOGICAL MITIGATION

Water Level Management Mitigation Measures

SOMERSET DRAINAGE BOARDS CONSORTIUM

INCORPORATING THE AXE BRUE AND PARRETT DRAINAGE BOARDS

Area	Description	Type	Responsible Body	When	Comments
Aller Moor	Remedial Work at Beer Wall	Structures	EA	Autumn 2019	Not part of Sowy scheme mitigation but as completion of Beer Wall project.
	WLMP change – winter penning levels for Aller Moor	Operational protocols WLMP – at least 300mm of water in ditches at winter pen	EA/IDB	Winter 2020/21	Use EA structures Church Drove, Oxleaze Drove and IDB structure Stathe Drove to pen winter level. Operate IDB weirs Lucas Rhyne, Black Withies and Leazeway to hold water in winter. Maintain a 30 cm ditch water level.
	Operation of Langacre and Beer Wall	Operational Protocols	EA	Completion of beer wall 2019/20	Operate to effect 'no change' in winter months. ('no change' baseline - before the culverts were put under the road).
	Monitoring & WLMP update	Monitoring & WLMP update	IDB	2020 – 2022	Ecological and Monitoring plan.
King Sedgemoor (Non SSSI) Butleigh and Walton Moor, 18 ft rhyne	Telemetry to be installed at Nythe structure	Telemetry	IDB	Autumn 2019	Telemetry installed at Greylake.
	Monitor using telemetry at greylake and nythe structure	Monitoring	IDB	2020 – 2022	If effect seen then investigate operate Greylake sluice differently (environmental trigger). Or alternative option: purchase a piece of land and create new RWLA.
	Consider Operation of Greylake sluice Consider Nythe structure or other alternative.	Operating Protocols (Monitoring & Mitigation)	IDB	2022	If required and feasible, as informed by monitoring.

Area	Description	Type	Responsible Body	When	Comments
West Sedgemoor (SSSI)	Monitoring compliance of existing WLMPS	Operating Protocols (Monitoring & Mitigation)	EA	2020/21	Monitoring to trigger operational protocol of pumping stations.
Long Load (King's Moor and Witcombe Bottom)	Monitoring	Overwintering bird survey and existing data review	IDB	2019/20	
Long Load (King's Moor and Witcombe Bottom)	Operation of Long Load pumping station and syphon	Environmental Trigger points	2 year approach to affect.		Only if effect seen through monitoring? Operate to effect 'no change' in winter months. Retention of ecologically beneficial water.
Wet Moor (non SSSI)		Monitor		Effect after two years	Water levels, telemetry, levels and duration
Wet Moor (non SSSI)	Operate North barrier bank and sluice. Operate HEPs for the West	Environmental Trigger Points			Operate to effect 'no change' in winter months. Retention of ecologically beneficial water. Only if effect seen through monitoring?
West Moor (SSSI)	Replace RWLA structures	Structure	EA to install, IDB to operate	2020/21	Replace 4 stock structures, modification of 2 tilting weirs) approx. £100k Alternative Option: Possibility to extend the RWLA, re resilient wet grassland project.
West Moor (SSSI)	WLMP	WLMP review			

Area	Description	Type	Responsible Body	When	Comments
Huish Level	Assess potential WLM options.	Study	IDB/EA	2021	
Moorlinch RWLA	Refurbish the existing RWLA, Consider minor extension to the east	Construction/Appraisal	EA – Construction IDB – Future operation	2021 -2023	
King Sedgemoor SSSI	Monitor site conditions	Monitoring	IDB / EA	2020 ONWARDS	
Curry Moor SSSI	Monitor site conditions	Monitoring	IDB /EA	Continuation of existing	Monitoring already in place for Curry moor,

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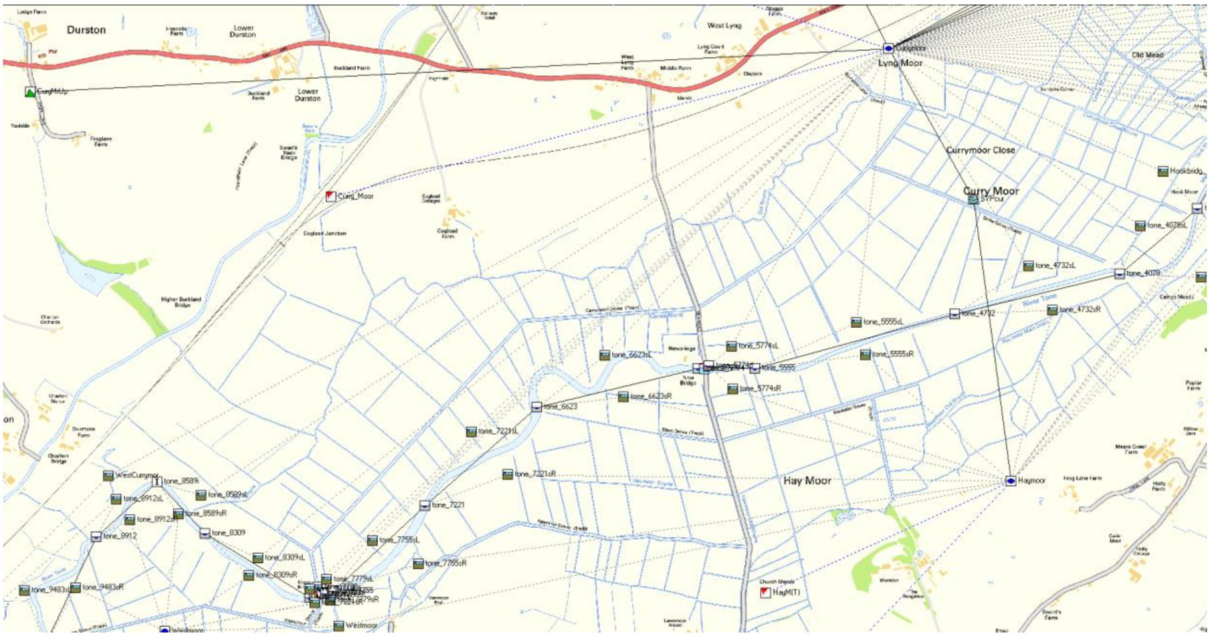
APPENDIX 7A: FURTHER DREDGING ASSESSMENT

Somerset Drainage Boards Consortium

River Parrett - Further Dredging Assessment

Hydraulic Modelling

FINAL



Date: 15/02/18

AW Water Engineering

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5	**17/03/17**	**FINAL**
6	**27/06/17**	**FINALV2**
7	**03/07/17**	**FINALV3**
8	**31/10/17**	**FINALV4**
9	**01/02/18**	**FOR COMMENTS FOLLOWING REVIEW**
10	**15/02/18**	**FINALV5**

1 EXECUTIVE SUMMARY

AW Water Engineering have been appointed by the Somerset Drainage Boards Consortium to assess the hydraulic impacts of proposed additional dredging works, and other related interventions, on the River Parrett. The hydraulic model was updated to include all improvements that have been completed in the area, including the pioneer dredging work and the pump station improvements. This model is almost identical to that being used for the Sowy study, with the only main difference being the inclusion of the additional 750m of dredging downstream of Northmoor Pumping Station on the River Parrett in this study, which is not included in the River Sowy study.

The baseline model demonstrates that if the 2013/14 flood event were to occur again, flooding would be much reduced from that observed in the event. The pioneer dredging has reduced peak flood levels by 1.5m on North Moor during an extreme flood event, with the duration of flooding to the A361 reduced from 30 to 20 days. The additional pumping, if deployed, will reduce this peak flood level by a further 2m and reduce the duration of flooding to the A361 to zero.

Four different flood events have been considered

1. The Winter 2013/14 event, as this represents the most extreme event that has been assessed.
2. An event comparable to the Winter 2012/13 event, as this represents a Tone catchment dominated extreme event.
3. An event comparable to the Spring/Summer 2012 event, as this represents a more minor flood event that might be expected every five years or less.
4. An event comparable to the Winter 2015/16 event, as this represents a more recent minor flood event, that has occurred since the recent improvement works.

The inflows for the winter 2013/14 event (which are also used in the River Sowy study) are taken from observed data in this event. The other three events have been produced by scaling the inflows from the 2013/14 event based on an analysis of respective flow volumes in the different events.

This work showed:

1. **The Winter 2015/16 event was relatively similar to the Spring/Summer 2012 event, yet resulted in far less flooding. This demonstrates the effectiveness of the various works that were undertaken prior to this event.**
2. **Flooding in the pre 2014 events is all substantially less than observed.**
3. **If any of the flood events were to occur again, with the exception of the winter 13/14 event, no flooding is predicted to the Westover Trading Estate.**

A number of scenarios have been considered in the modelling. A full description of this scenario testing is contained in the main text of this report. In summary the results of this scenario testing is as follows:

If no future maintenance was to be undertaken on the dredged reaches and they were allowed to return to their 'pre-dredge' profiles then there would be an increase in flooding throughout the system, most significantly in Curry and North Moors.

A comparison has been made of the relative impacts of the pioneer dredging and additional pumping that is now in place, and the interactions between these two interventions. This has shown that maintaining the pioneer dredged section may be necessary to ensure that the maximum reduction in flooding can be gained from the additional pumping and that the pumping does not increase upstream flooding. Through maintaining the dredged sections, the reliance on pumping is also reduced, which will reduce the impact on flooding if pumps were not able to be installed in the future.

Maintaining the pioneer dredged sections provides a significant reduction in flooding to Curry Moor especially in more regular flood events, with frequency, depth and duration of flooding being reduced. The additional pumping will have little impact on the more frequent flood events.

If further pioneer dredging on the River Parrett can be undertaken, and maintained, upstream of the Tone confluence to Allermoor spillway and downstream of the last currently dredged reach to the M5 motorway, then other than a small increase in flooding to Curry Moor, there is a small reduction in flooding to all other moor areas, with the largest reduction in Aller Moor.

The model results assume that vegetation is allowed to establish similar to pre-dredge levels. If the channel is kept smoother than this, then there is a potential reduction in flooding to a wide area, although it is only in Curry Moor where the impact is measurable.

Channel survey data was collected in October 2016 and March 2017 along the dredged reach. This shows that the siltation in the channel results in increased flooding downstream of Langport. The increase in risk is less than the risk if the sections were allowed to return to their pre-dredge profiles. The March 2017 survey shows a reduction in flooding from October 2016, which will be partially a result of the dredging trials undertaken inbetween the two surveys, although there was also a period of high fluvial flows which would have scoured some of the channel. This demonstrates the importance of keeping the lower parts of the cross sections free of silt.

The River Sowy scheme will give similar reductions in flooding in the moors upstream of Langport to those shown with the additional pioneer dredging on the River Parrett. In Curry Moor the River Sowy scheme does show a small reduction in flooding, although the change is within the model tolerances in larger events. If the River Sowy scheme is done alongside further dredging then, on the moors upstream of Langport, there is additional reduction in flooding. On Curry Moor the River Sowy scheme is very close to offsetting the increase in flooding that comes from the dredging scenario. There is likely to be a scenario with less dredging where the River Sowy scheme will fully offset any disbenefits.

2 INTRODUCTION

AW Water Engineering have been appointed by the Somerset Drainage Boards Consortium to assess the hydraulic impacts of additional dredging works, and other related interventions, on the River Parrett. The first stage of this assessment, which is described in this note, involves utilising the existing hydraulic model of the area to evaluate any changes to flooding in key locations throughout the study area. It concludes by recommending additional work that could be undertaken to further improve the understanding.

AW Water Engineering have been assisted by Edenvale Young Associates in completing this study.

3 BASELINE MODEL

3.1 MODEL IMPROVEMENTS

It was agreed that the first stage of the assessment was to confirm that there is a baseline model of the lower Parrett catchment. Previous assessments of dredging were undertaken in 2014/15 using the available modelling at the time. Since this date a number of improvements have been completed in the area, most notably:

- Completion of the dredging of the 8km reach between Hook Bridge on the River Tone and Northmoor Pumping Station on the River Parrett.
- Dredging of the 750m reach of the River Parrett downstream of Northmoor Pumping Station.
- The Asset Recovery Programme (ARP) improvement works to the flood banks.
- Improvement works to several pump stations, including the works associated with bringing in temporary pumps.
- The revised operating rules for the pumping stations following the 'Trigger point' project.
- Works at Beer Wall (A372) to increase the capacity of the culverts under the road.
- Changes to the operation of the River Sowy and Kings Sedgemoor Drain during flood events.

The Environment Agency and their consultants have provided their latest modelling data along with information on all these works to allow this revised baseline model to be produced. This model is referred to as the 'baseline' model throughout the rest of this report, with all other scenarios tested against it. It should be noted that due to the mobile nature of the channel in this area, the model will never be truly reflective of the current situation, and therefore a 'snapshot' in time has to be taken to use as this baseline model.

It was considered whether the proposed works on the River Sowy should be included in the baseline model. However, due to the stage of the project and the limited modelling that has been undertaken, it was decided not to currently include this in the baseline model. Instead a separate assessment has been made on the potential impacts the Sowy scheme may have on the impacts on any further dredging.

3.2 MODEL RESULTS

Figure 1 shows the locations of key features in the area. To assess the baseline level of flooding and the impacts of any dredging, the inflows from the Winter 2013/14 flood event have been principally used rather than using any theoretical annual probably design events. The advantage of this is that it allows comparison to be made against a recent, recorded flood event. The disadvantage is that this only provides a dataset for one flood event. This is discussed further later in this note.

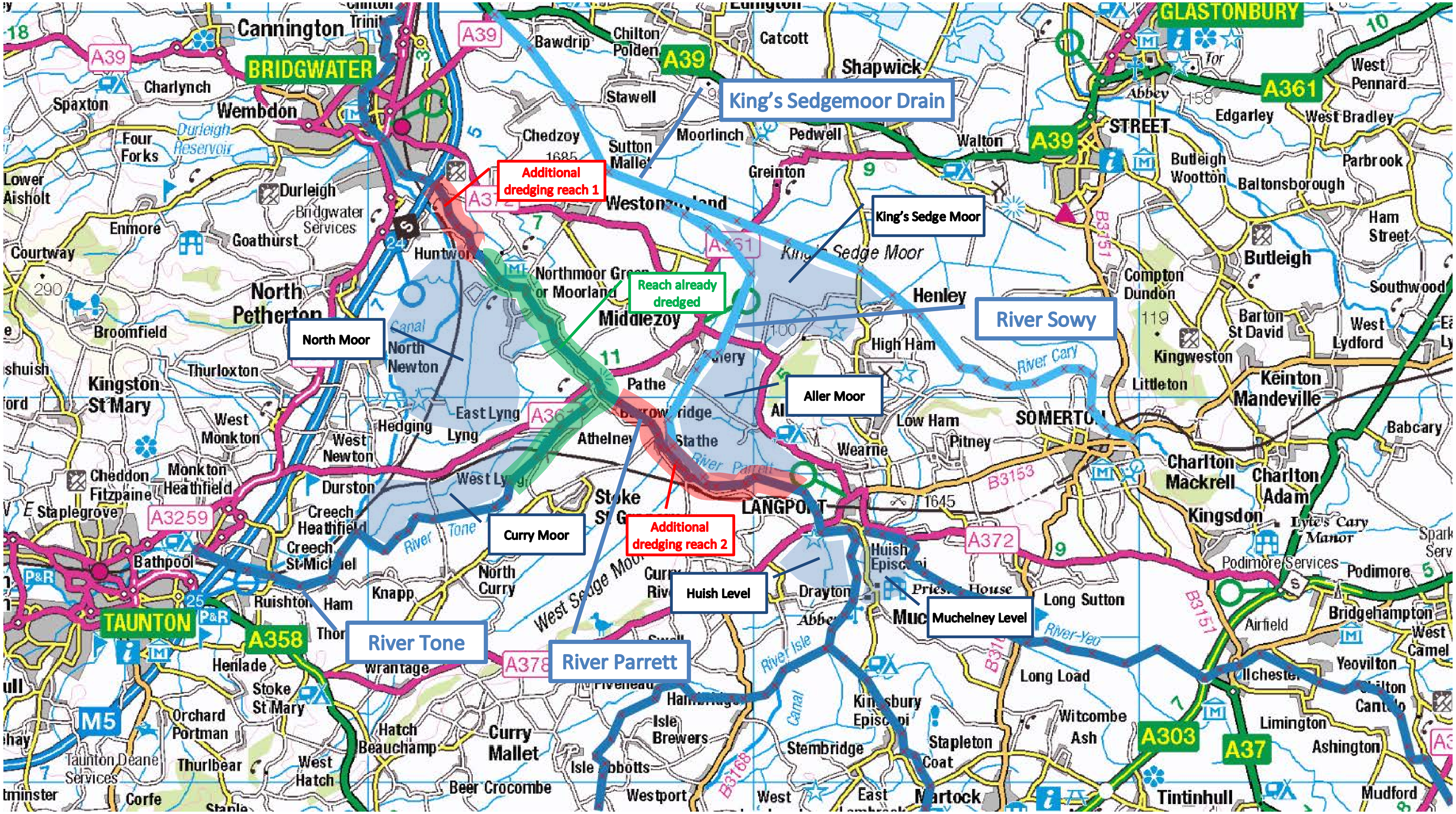


Figure 1 – Location Plan

Table 1 shows results from the modelling for selected moors. This table compares the results from the modelling undertaken as part of the previous dredging assessment in 2014/15 with that from the current baseline model. This is presented to demonstrate the changes to the baseline flooding that are due to the improvements undertaken in the area. In the previous baseline, the only improvement that is described in Section 3.1 that is included in the model was the 8km dredging reach.

Table 1 – Baseline modelling results

Moor	Peak Level (mAOD)		Duration of flooding (days)	
	Previous baseline	Current baseline	Previous baseline	Current baseline
Curry Moor	8.12	7.65	95.7	74.1
North Moor	5.69	3.63	151.1	0
Aller Moor	5.12	5.19	131.9	113.1[1]
Kings Sedgemoor	4.43	4.33	44.5	66.0
Muchelney Level	8.92	8.66	90.2	80.8
Huish Level	8.90	8.60	64.1	27.5

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.4m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate). These are based on when flooding may occur to properties or infrastructure.

The key result to note here is the reduced risk to Curry and North Moors. The dredging that has been completed significantly reduces the amount of water entering Curry Moor. It also allows flood levels to recede quicker on the river, which in turn allows Currymoor Pumping Station to be turned on earlier in an event.

This, combined with the increased capacity of the pumping stations, means that the peak level in Curry Moor is reduced by almost 0.5m compared to the previous modelling. For comparison, the actual observed peak level during the 2013/14 flood event was 8.2mAOD. The duration of flooding, especially at the higher levels, is also significantly reduced.

These reduced flood levels in Curry Moor are even more significant when considering the flow into North Moor. Whilst North Moor does receive some flood water from its own catchment, the vast majority of floodwater in the 2013/14 flood event came from overtopping from Curry Moor via Athelney spillway or Lyng cutting. These are at a level of around 7.1mAOD. The amount of time that Curry Moor is above this level is significantly reduced, to the extent that the volume of water entering North Moor from Curry Moor is only a small fraction of that observed in the 2013/14 flood event. Again for comparison, the actual observed peak level in North Moor during the 2013/14 flood event was 6.1mAOD.

The differences elsewhere are much less significant, with the main change being seen in the moors upstream of Langport. Here, a combination of the increased flows down the River Sowy, and the earlier pumping throughout the system, results in lower peak levels and reduced durations of flooding.

[1] In the revised baseline model, the flood levels remain above 4.4mAOD at the end of the run, due to flow being prevented from leaving the moor at this level. The comparisons of duration of flooding is therefore not relevant for Aller Moor in this table. For the remaining tables a level of 4.6mAOD has been considered instead.

3.3 NOTES ON THE USE OF MODELLING RESULTS

Throughout this report selected results are presented from the hydraulic modelling. Results exists for a far greater geographical area, and these can be made available. There will always be some uncertainty in quoting absolute values from the modelling, as there are a number of unknowns that could occur that will affect these values. However, the modelling is used to help demonstrate the relative impact of a number of interventions that have been made, or might be considered in the future.

The model will have a high accuracy when considering these relative changes, and greater confidence can be placed in these relative results than the absolute values. However, it is still necessary to consider what the model tolerance may be. Values are quoted for peak levels and flood durations within selected moor areas. Due to the large volume of water stored in these moors, a relatively large change in the volume of water entering the moor may only result in only a small change in flood level. Therefore, the relative significance of any change in flooding should be measured by both the change in flood level and the flood duration. It is suggested that if a change in peak flood level of less than 10mm **and** a change in flood duration of less than 5% is predicted this is probably within the modelling tolerances. Any change greater than this should be considered measurable. The significance of any change will also be a function of what receptors there are in the area.

When quoting the duration of flooding in the moor areas, this is a reflection of the period there will be standing water above this level. It is recognised that in several of the moor areas there will also be overland flow across the moors which may act to increase the durations of flooding in localised areas. This is of particular relevance in North Moor. Here the duration of flooding is based on when flood levels are above 4.0mAOD, which is approximately the lowest point of the A361, and the lowest commercial property threshold level. However, due to overtopping from Curry Moor resulting in overland flow over the A361, there will be time when the flood level is below 4.0mAOD and there is still some flooding to the road. This period of time will be limited though, and the depth of flooding will be low.

4 REPRESENTATION OF DIFFERENT FLOOD EVENTS

The results presented above have focussed on the winter 2013/14 flood event. This was deliberate, as this was an actual event that people can relate to, and it represents an extreme flood event. However, it is recognised that almost every flood event that occurs on the Parrett catchment is different, either due to the magnitude of the rainfall, or the geographical spread of the rainfall, or both.

It was considered important to understand whether considering different flood events will influence the conclusions made on the different interventions. Due to time constraints, it was not possible to extract and analyse rainfall data from previous flood events. Instead a more simplistic method was used to obtain approximate inflows for four different recent flood events:

- Winter 2000/01
- Spring/summer 2012
- Winter 2012/13
- Winter 2015/16

To do this flow volumes were analysed for all events at the main upstream gauging stations[2] for maximum rolling 10, 20, 30, 40, 60 and 90 day periods[3].

These volumes were compared against the volumes from the 2013/14 event to choose a suitable ratio, which can then be used to adjust the inflows in the model.

This method will produce inflows that are representative of these other events, but they are not exact replicas of the events. They will not represent all the detail of the events, especially in the relative timings of the peak flows. Ideally, if there is further budget available, this assessment should be repeated with a more detailed assessment undertaken of the observed rainfall and flow data.

4.1 ANALYSIS OF THE EVENTS

Figures 3-6 show the outputs from an analysis of the peak 30, 60 and 90 day flow volumes during a number of recent flood events. These peak volumes are presented as a ratio of the peak volumes recorded during the 2013/14 flood event.

The analysis does ignore the relative timing of when the peak occurs. For example, in Winter 2000/01 the peak 90 day volumes occurred on 27th January on the River Tone, but on the River Parrett it was the 6th January.

Key conclusions from this assessment are:

- Winter 2000/01 was a long duration event with fairly similar levels of relative catchment domination to 2013/14, but with a slightly greater emphasis on the River Tone.
- Spring/summer 2012 was a shorter duration event that was dominated by the Tone and Cary flows.
- Winter 2012/13 was another long duration event that, on the Tone, was very similar to 2013/14, but was less significant on the other catchments.
- The more minor winter 2015/16 event was mainly Tone dominated, but did have some significant flows on the other catchments. On the Tone it was a relatively similar magnitude to spring/summer 2012. This shows the benefits of the work that has been done as the flooding durations were much shorter.

[2] The two stations at Bishops Hull for the Halse Water and River Tone, Pen Mill on the River Isle, Chiselborough on the River Parrett, Ashford Mill on the River Yeo and Somerton on the River Cary.
[3] At every data interval (typically 15 minutes) the total volume over the preceding 10-90 days was calculated, with the maximum value over the entire data period being produced.

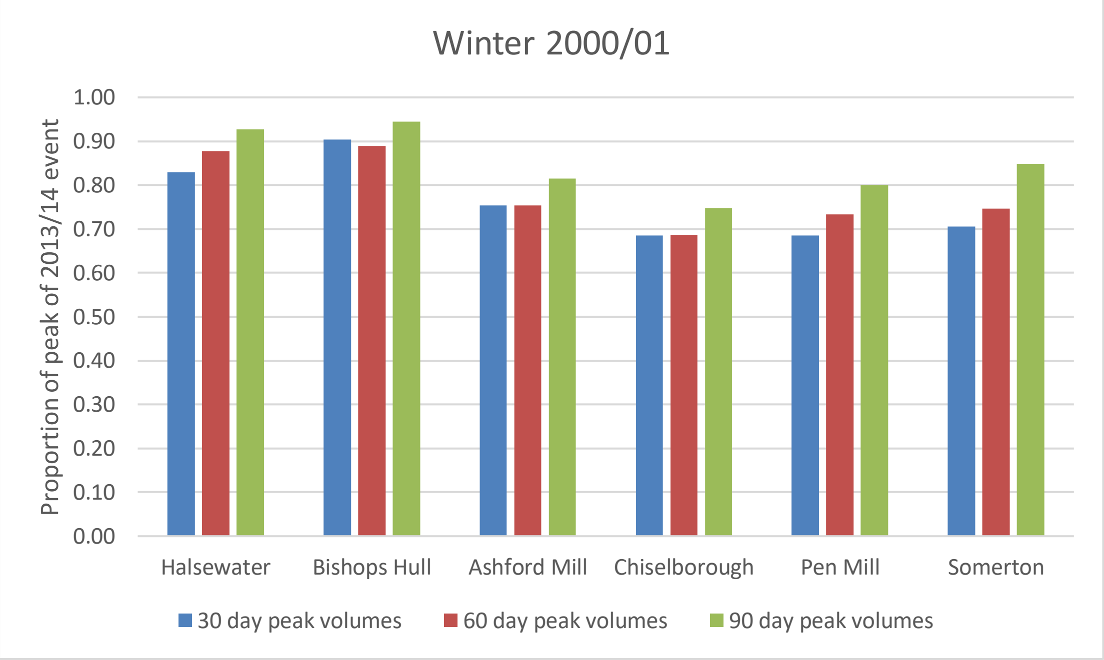


Figure 2 – Winter 2000/01 event

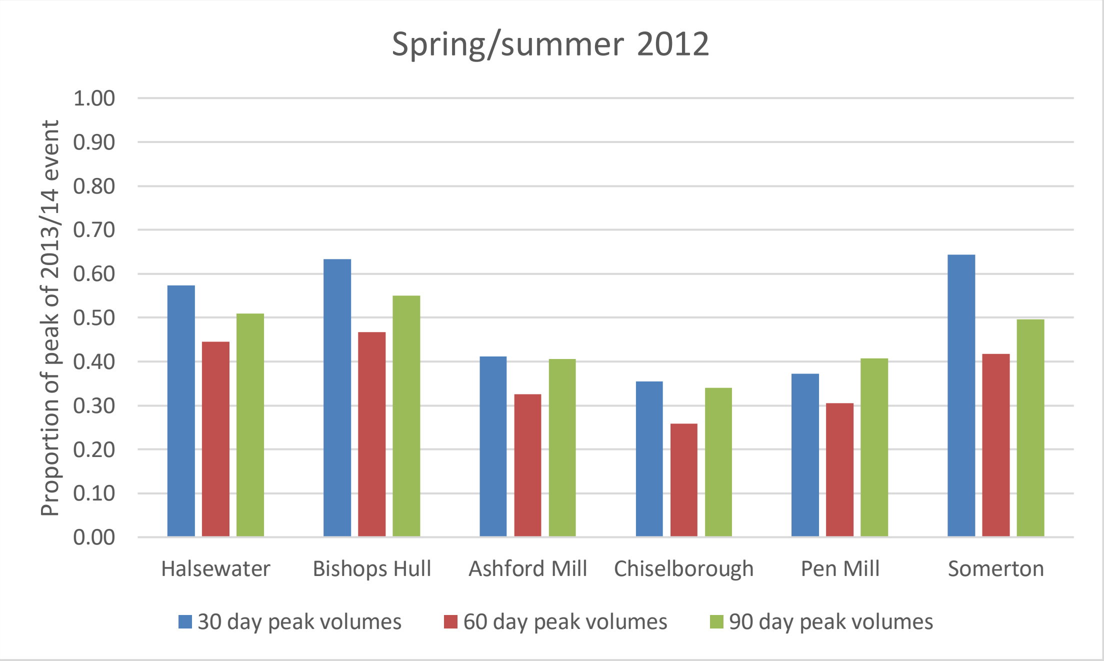


Figure 3 – Spring/Summer 2012 event

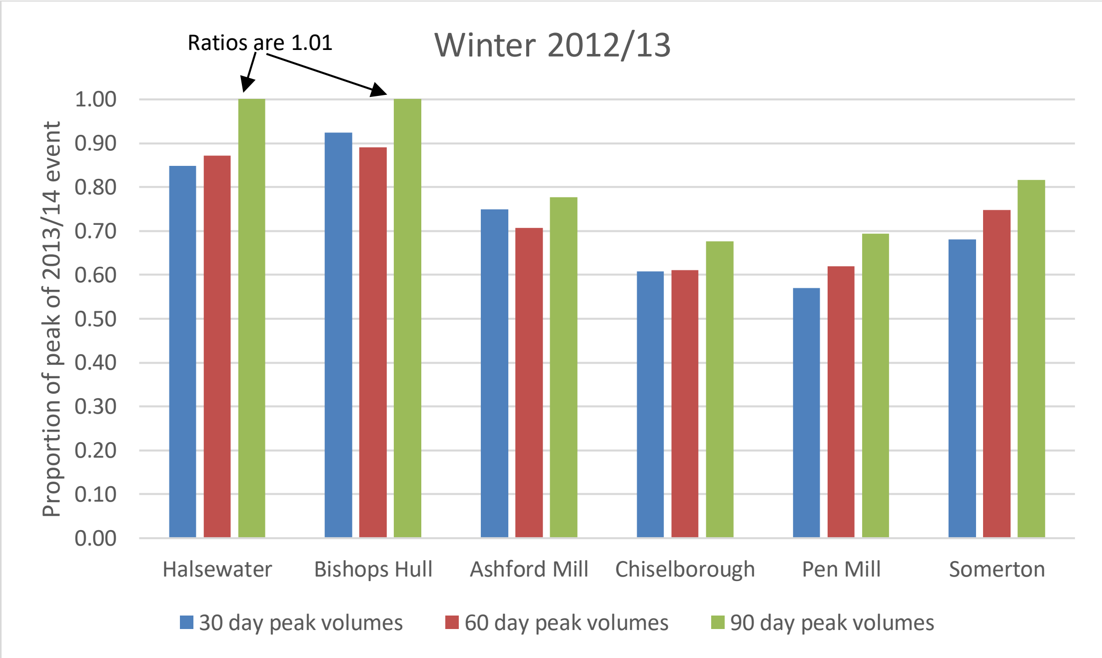


Figure 4 – Winter 2012/13 event

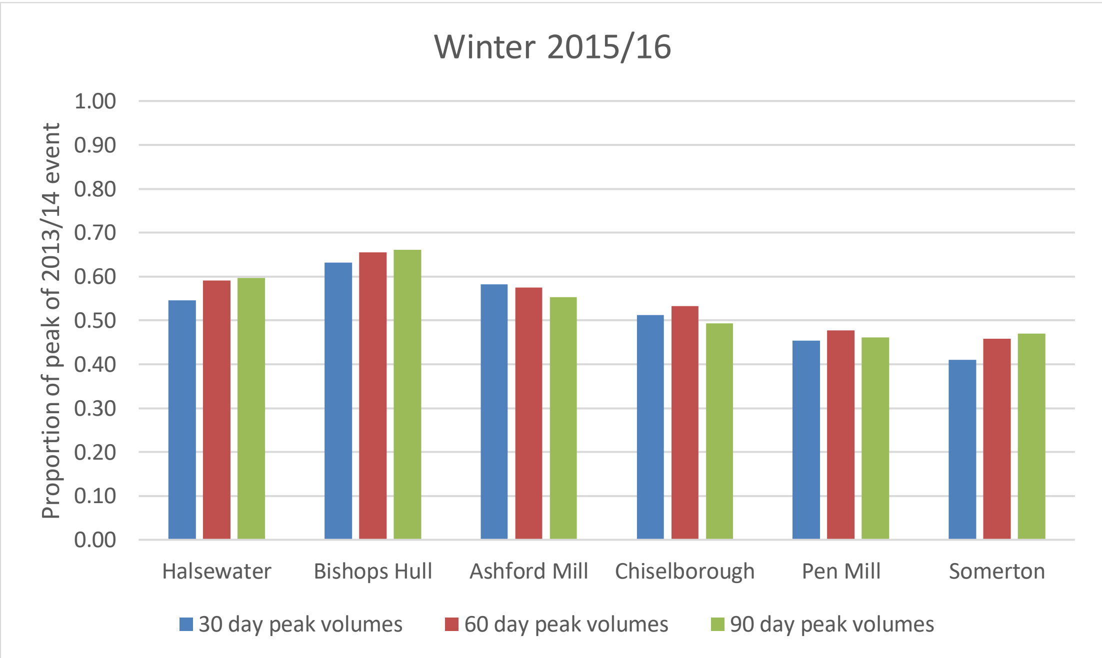


Figure 5 – Winter 2015/16 event

4.2 RATIOS TO USE IN THE MODELLING ASSESSMENTS

The following table summarises the different ratios that have been used in the modelling work to create flood events, based on the 2013/14 event, that will give similar volumetric characteristics to recent historic events.

For the Tone catchment an average of the Halsewater and Bishops Hull gauges has been used. For the moors downstream of Langport the Cary/KSD ratio is used when factoring rainfall inputs.

Table 2 – Ratios to use in model to represent other events

		Flood event			
		Winter 2000/01	Spring/ summer 2012	Winter 2012/13	Winter 2015/16
Volume duration used to select ratio		*90 day*	*30 day*	*90 day*	*60 day*
Catchment	Tone (Bishops Hull/Halsewater)	0.94	0.60	1.01	0.62
	Isle (Ashford Mill)	0.81	0.41	0.78	0.57
	Parrett (Chiselborough)	0.75	0.36	0.68	0.53
	Yeo (Pen Mill)	0.80	0.37	0.69	0.48
	Cary/KSD (Somerton)	0.85	0.64	0.82	0.46

4.3 ANALYSIS OF TIDAL DATA

As this assessment is principally focussed on fluvial flooding, less time has been spent analysing the tidal data. However, the observed tide data from Hinkley has been obtained. This allows peak tide levels from each of the flood events to be tabulated. The same transformation used in the model has then been used to obtain an approximate equivalent tide level at Steart.

Table 3 – Comparison of Tide levels

Event	Peak Level at Hinkley (mAOD)	Peak level at Steart (mAOD)
Winter 2000/01	6.61	6.66
Spring/summer 2012	6.78	6.83
Winter 2012/13	7.18	7.24
Winter 2013/14	7.45	7.52
Winter 2015/16	7.16	7.22

As a simple way of ensuring the tide is not having a significantly greater impact than it would have done in the actual event that is being simulated, the 2013/14 tide levels have been used with maximum values capped at these observed peak levels. For example, to simulate the winter 2000/01 event, wherever the tide level is greater than 6.66, it has been lowered to 6.66. Whilst this won't accurately reflect the periods where the duration of high tides affected the ability of the system to discharge, it should give a similar overall impact.

4.4 RESULTS FROM MODELLING WORK

The model has been run for the baseline scenario only to enable a comparison of results to be made for these different flood events. These are summarised in Table 5 and below. These results can be seen to represent the approximate degree of flooding that would happen if these events were to occur now.

Table 4 – Comparison of modelled results from different flood events (peak levels)

Moor	Peak Level (mAOD)				
	Winter 2000/01	Spring/Summer 2012	Winter 2012/13	***Winter 2013/14***	Winter 2015/16
Curry Moor	7.61	5.60	7.65	***7.65***	5.71
North Moor	3.59	3.52	3.58	***3.63***	3.43
Aller Moor	4.89	4.70	4.86	***5.19***	4.76
Kings Sedgemoor	4.15	4.09	4.13	***4.33***	4.07
Muchelney Level	8.39	6.91	7.98	***8.66***	7.47
Huish Level	7.52	6.54	7.27	***8.60***	6.79

Table 5 – Comparison of modelled results from different flood events (Duration of flooding)

Moor	Duration of flooding (days)				
	Winter 2000/01	Spring/Summer 2012	Winter 2012/13	***Winter 2013/14***	Winter 2015/16
Curry Moor	65.3	18.4	70.5	***74.1***	23.5
North Moor	0	0	0	***0***	0
Aller Moor	32.9	3.0	29.1	***46.7***	11.0
Kings Sedgemoor	55.7	45.8	54.3	***66.0***	38.2
Muchelney Level	71.3	12.4	58	***80.8***	24.8
Huish Level	0	0	0	***27.5***	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The results from some of these runs are quite different from what was experienced during these flood events, but we cannot say yet how much this is due to the method used to simulate these events or the improvements that have been made to the system since the events.

Key results to note from this work:

- The flooding in Curry and North Moors in the 2000/01 and 2012 events is substantially less than observed.
- The Spring 2012 event shows relatively minor flooding, and generally quite similar to that experienced at the beginning of 2016. This analysis does not take into account though the seasonality differences between these two events.
- In all events, especially the two more minor ones, the flooding to Aller Moor is reduced substantially compared to the 2013/14 event, but the flooding to Kings Sedgemoor stays relatively similar. This is most likely a reflection of the methodology used to represent the tidal boundary, with the amount of time Dunball Sluice is closed for remaining quite similar over all events.

- The models show no flooding to Westover Trading Estate in any of the additional events tested. This is due to the combined works resulting in the pumps being able to operate for longer upstream of Langport, combined with the reduced overtopping into these moors.

When looking at some of the flood risk options below it has been agreed to use up to three different flood events. These are:

1. The Winter 2013/14 event, as this represents the most extreme event that has been assessed.
2. The Winter 2012/13 event, as this represents a Tone catchment dominated extreme event.
3. The Spring/Summer 2012 event, as this represents a more minor flood event that might be expected every five years or less.

5 MAINTENANCE OF DREDGED REACH

In order to better understand the impact of the pioneer dredging, it is necessary to quantify the hydraulic impact of allowing the dredged reaches to return to their 'pre-dredged' situation. Clearly this is not a desired outcome, but does represent the ultimate potential situation if no maintenance work was undertaken.

This also allows an assessment to be made of the hydraulic impacts of all the other interventions without the dredging in place. This model is based on the baseline model with the dredged sections returned to their pre-dredge shape, and is run for all three flood events being considered.

The results of these tests are shown in Table 7, Table 6 and below.

Table 6 – Maintenance of dredged reaches modelling results for the spring/summer 2012 event

Moor	Peak Level (mAOD)		Duration of flooding (days)	
	Baseline	Dredge sections returned to 'pre-dredge' profiles	Baseline	Dredge sections returned to 'pre-dredge' profiles
Curry Moor	5.6	6.5	18.4	42.5
North Moor	3.52	3.52	0	0
Aller Moor	4.7	4.73	3	4.8
Kings Sedgemoor	4.09	4.09	45.8	45.8
Muchelney Level	6.91	7.05	12.4	14.3
Huish Level	6.54	6.55	0	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

Table 7 – Maintenance of dredged reaches modelling results for the 2012/13 event

Moor	Peak Level (mAOD)		Duration of flooding (days)	
	Baseline	Dredge sections returned to 'pre-dredge' profiles	Baseline	Dredge sections returned to 'pre-dredge' profiles
Curry Moor	7.65	8.03	70.5	85.5
North Moor	3.58	4.28	0	13.3
Aller Moor	4.86	4.94	29.1	34.5
Kings Sedgemoor	4.13	4.16	54.3	57.3
Muchelney Level	7.98	8.08	58.0	66.4
Huish Level	7.27	7.34	0	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

Table 8 – Maintenance of dredged reaches modelling results for the 2013/14 event

Moor	Peak Level (mAOD)		Duration of flooding (days)	
	Baseline	Dredge sections returned to 'pre-dredge' profiles	Baseline	Dredge sections returned to 'pre-dredge' profiles
Curry Moor	7.65	8.03	74.1	86.0
North Moor	3.63	4.36	0	14.9
Aller Moor	5.19	5.24	46.7	53.3
Kings Sedgemoor	4.33	4.42	66.0	69.4
Muchelney Level	8.66	8.67	80.8	84.8
Huish Level	8.60	8.61	27.5	29.8

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The key result to gain from this work is that, if the dredged sections are not maintained, there will be a substantial increase in flooding to Curry and North Moors especially, but there will also be impacts throughout the system.

The more frequent the flood event, the greater the proportional increase in flooding there is to Curry Moor. This shows how important maintaining the dredged sections are to more regular flood events, as these are the events where the other interventions have less impact.

These results also show how effective the other interventions are at reducing the flooding in the area, especially in North Moor. This is demonstrated by comparing the 'without dredging' results with the previous baseline results in , or against the actual observed peak flood levels in the 2013/14 event (8.2m AOD and 6.1mAOD in Curry and North Moors respectively).

6 COMPARISON OF ADDITIONAL PUMPING AND PIONEER DREDGING

The model has been used to compare the relative impacts of the pioneer dredging *(i.e. the 8km reach between Hook Bridge on the River Tone and Northmoor Pumping Station on the River Parrett and the 750m reach of the River Parrett downstream of Northmoor Pumping Station)* and the additional pumping that is now available *(i.e. the improvement works to the pumping stations, the temporary pumping and the 'trigger point' operational procedures)*. The purpose of this is to better understand the relative impacts of both interventions, and to also understand how they interact with each other.

The following scenarios have all then been run for the winter 2013/14 flood event:

- Pre-works model – no additional pumping and no pioneer dredge
- Dredging model – no additional pumping, but with the pioneer dredge
- Pumping model – additional temporary pumping and trigger point work, but no pioneer dredge
- Combined model – with additional temporary pumping and trigger point work, and with the pioneer dredge

For all of these model runs it has been assumed that the Asset Recovery Improvement works to the flood banks, and the works at Beer Wall are included. Table 9 summarises the results from this assessment for the four different model scenarios.

Table 9 – Comparison of pioneer dredging and additional pumping modelling results 2013/14 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Pre-works model	Dredging model	Pumping model	Combined model	Pre-works model	Dredging model	Pumping model	Combined model
Curry Moor	8.02	7.91	8.03	7.65	104.8	97.7	86	74.1
North Moor	7.07	5.65	4.36	3.63	207.8	142.1	14.9	0
Aller Moor	5.22	5.19	5.24	5.19	51.3	45.1	53.3	46.7
Kings Sedgemoor	4.44	4.38	4.42	4.33	70.0	67.2	69.4	66.0
Muchelney Level	8.66	8.65	8.67	8.66	81.8	80.5	84.8	80.8
Huish Level	8.60	8.59	8.61	8.60	27.3	23.2	29.8	27.5

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The key messages from this assessment are:

Upstream of Langport – all changes are relatively small and potentially within the modelling accuracy, but when compared against the Pre-works model, the pumping model actually shows a small increase in flood levels and durations. This is likely to be due to the pumping on its own increasing levels within the river channels throughout the area. The dredging model shows small reductions both in terms of peak flood levels and durations. The combined model also shows small reductions. ***Therefore, maintaining the pioneer dredged sections is necessary to allow the additional pumping and trigger point operations to be undertaken without increasing upstream flooding.***

Aller Moor/KSM – The results are very similar to those shown for upstream of Langport, with impacts being limited but measurable. However, the reduction in flooding shown from the dredging model is more significant than the increase in flooding shown from the pumping model. The combined model therefore shows a greater overall reduction in flooding than for the areas upstream of Langport.

Curry Moor – The pumping model shows a small increase in peak level (+1cm), compared to the dredging model showing a reduction in peak level (-11cm). However, when considering flood durations, the pumping model shows a greater reduction (-19 days) compared to the dredging model (-7 days). Interestingly the combined model shows both a greater reduction in peak level (-37cm) and flood duration (-31 days) than the sum of the two model results. This is because the dredging allows for the pumping to be operated more efficiently. ***Therefore, for Curry Moor, maintaining the pioneer dredged sections is vital in ensuring that the maximum flood reduction can be gained from the trigger point agreements and the additional pumping.***

North Moor – The pumping model shows a significantly greater reduction in flooding than the dredging model for both peak level reduction (-2.7m against -1.4m) and flood duration (-193 days against -66 days). The combined model shows a reduction in flooding that is less than the sum of the two model results (-3.4m and -208 days). ***Therefore, the additional pumping on its own reduced flooding more significantly than the dredging on its own. However, the combined flood reduction demonstrates the effect of both works to be undertaken.***

7 FURTHER DREDGING

It is currently proposed that new 'pioneer' dredging could be undertaken on the River Parrett in two locations, as shown on Figure 1. These are:

- **Dredging reach 1 -** Downstream of the recently completed dredging to the M5 motorway crossing. This is a length of approximately 2.3km.
- **Dredging reach 2 -** Between Allermoor spillway and the Tone confluence. This is a length of approximately 6.8km.

In the emerging dredging strategy, it was proposed that the amount of dredging is optimised to ensure a consistent cross sectional area below a certain level, and also any physical and environmental constraints are considered. It also proposed that the amount of dredging in the two new reaches is balanced, with the aim of not increasing flooding in North Moor. Whilst this is also the ultimate aim of this project, it was agreed that as a quick first step data from the previous assessment should be used alongside the revised baseline model to update the understanding of the impacts of the dredging.

In the previous assessments in 2014/15 the following scenarios were considered:

- Widening of the channel by either 2m or 4m in dredging reach 1
- Widening of the channel by 4m in dredging reach 2
- A combination of widening by 2m in reach 1 and 4m in reach 2

The results from these scenarios were summarised in the Dredging Strategy report in a Figure which is repeated below. These showed relative changes in peak flood level from the baseline modelling used at the time.

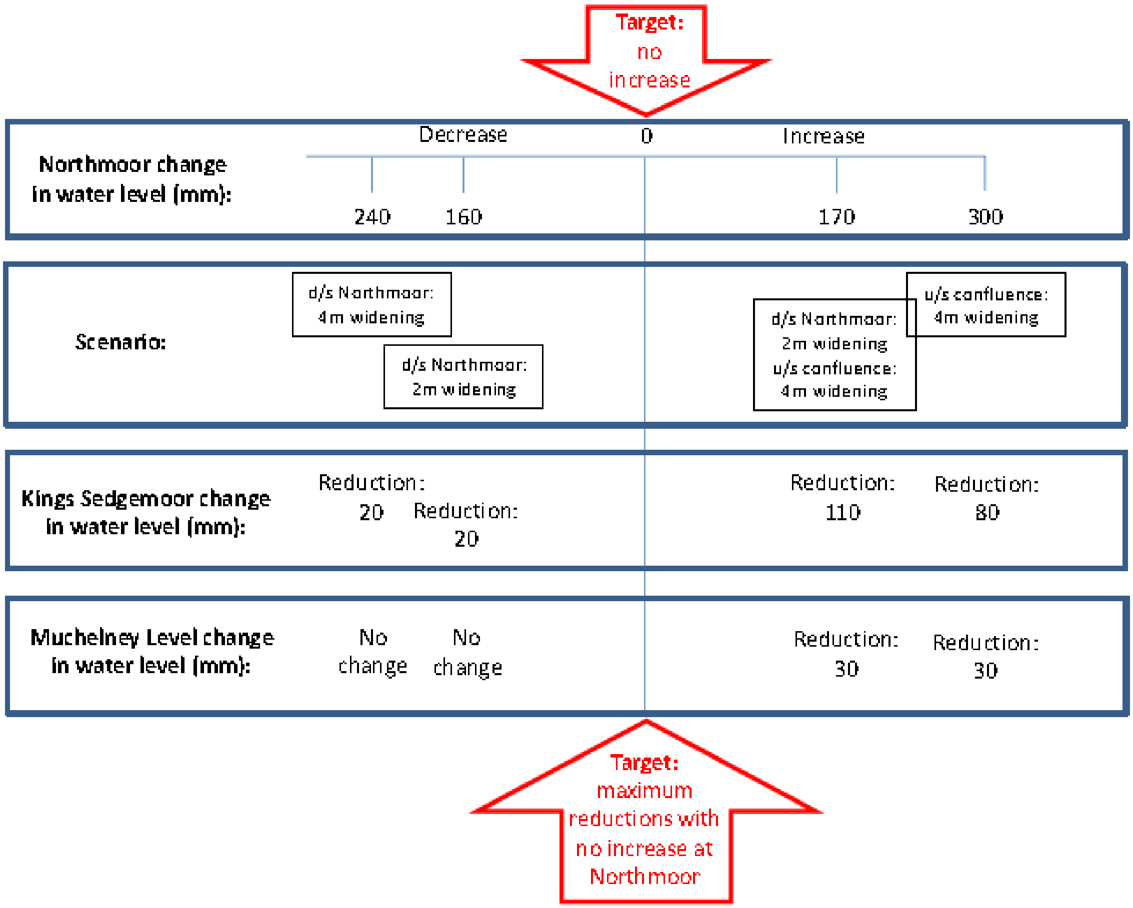


Figure 6 – Impacts of further dredging taken from previous assessment (HR Wallingford, 2016)

In order to allow a comparison of results with this previous assessment, the test with a combination of dredging in the two reaches has been repeated. In addition, a different combination has also been tested as follows, along with dredging only occurring in the upstream reach.

- **Further dredging scenario 1 –** widening by 2m in reach 1 and 4m in reach 2
- **Further dredging scenario 2 –** widening by 4m in reach 1 and 4m in reach 2
- **Further dredging scenario 3 –** widening by 4m in reach 2

With the revised baseline model being used in this study, this has allowed the previous assumptions on the relative flooding impacts of dredging to be revisited. Tables 10 - 12 summarise the results from this assessment for the three different events being considered. For the 2013/14 flood event all three dredging scenarios have been assessed, but for the other two events only scenarios 1 and 3 have been considered.

Table 10 – Dredging scenario modelling results Spring/Summer 2012 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3
Curry Moor	5.6	5.66	-	5.76	18.4	19.6	-	23.8
North Moor	3.52	3.52	-	3.52	0	0	-	0
Aller Moor	4.7	4.54	-	4.54	3	0	-	0
Kings Sedgemoor	4.09	4.09	-	4.09	45.8	45.8	-	45.8
Muchelney Level	6.91	6.87	-	6.88	12.4	4.6	-	5.3
Huish Level	6.54	6.52	-	6.52	0	0	-	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

Table 11 – Dredging scenario modelling results 2012/13 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3
Curry Moor	7.65	7.68	-	7.71	70.5	72.9	-	74.9
North Moor	3.58	3.58	-	3.58	0	0	-	0
Aller Moor	4.86	4.71	-	4.74	29.1	9.1	-	14.9
Kings Sedgemoor	4.13	4.1	-	4.1	54.3	53.5	-	53.6
Muchelney Level	7.98	7.8	-	7.83	58.0	44.6	-	47.3
Huish Level	7.27	7.09	-	7.11	0	0	-	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

Table 12 – Dredging scenario modelling results 2013/14 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3	Baseline	Further dredging scenario 1	Further dredging scenario 2	Further dredging scenario 3
Curry Moor	7.65	7.77	7.71	7.87	74.1	76.3	75.8	77.8
North Moor	3.63	3.63	3.63	3.76	0	0	0	0
Aller Moor	5.19	5.11	5.1	5.12	46.7	31.1	29.6	33.2
Kings Sedgemoor	4.33	4.23	4.22	4.25	66.0	63.7	63.5	64.3
Muchelney Level	8.66	8.63	8.63	8.63	80.8	76.3	76.3	77.0
Huish Level	8.60	8.55	8.55	8.55	27.5	16.1	15.1	18.7

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The only increases in flooding shown in any dredging scenario is in Curry Moor. It can therefore be concluded that widening of the Parrett channel upstream of the Tone confluence by 4m results in an increase in flooding to Curry Moor, irrespective of the amount of widening of the Parrett channel downstream of North Moor. This conclusion applies to all flood events that have been assessed, with the change in duration becoming slightly more pronounced at the most frequent event. There will potentially be ways to mitigate this increase in risk, which should be investigated as part of the next phase of work.

These results show crucially that none of the dredging scenarios result in any significant change in flooding on North Moor, despite the slight increase in risk on Curry Moor. This is due to the increased volumes of floodwater entering the moor being able to be conveyed by the increased pump station capacities.

The reduction in flooding to the other moors are broadly in keeping with previous studies. The risk to Aller Moor and Kings Sedge Moor is decreased almost equally in both scenarios, indicating that it is relatively insensitive to the amount of dredging downstream of Northmoor PS. However, it is noted that the extra downstream dredging does have the greatest impact on flood duration on Aller Moor.

The risks to Kings Sedge Moor are almost identical in all scenarios, for all events considered. This will be a reflection of the key driver for flooding on Kings Sedge Moor being the period of tide lock, rather than the incoming fluvial flow.

For the moors upstream of Langport there is a small reduction in risk. The reduction in duration of flooding is most significant at the more regular flood events.

It should be noted that in all dredging scenarios, and across all events there are some moors that appear to benefit in a greater way than those shown above. In particular, these are West Sedge Moor (peak level reduction ~ 300mm) and West Moor - Midelney (peak level reduction ~ 250mm). West Sedge Moor benefits due to the reduction in River Parrett levels adjacent to the pumping station, which reduces a lot of the restrictions on pumping. West Moor benefits because, based on the operational rules, it is able to pump earlier due to the downstream spillways stopping running earlier and other pumping stations also finishing pumping earlier. In reality, the operating rules may be changed during an event to provide a wider benefit, and therefore results from these moors are not presented separately here.

8 ROUGHNESS TESTING

In the previous modelling, the assumption was made that the roughness values used for the channel sections where dredging was undertaken was kept as the baseline model. This was based on the assumption that the vegetation in the channel would re-establish, and to allow for any uncertainty in the final dredged sections. In reality, there is at least a short period of time, when the dredged channel will be smoother than pre-dredge. To test the impact of this assumption, model runs have been undertaken with the roughness values in the dredged reaches reduced.

The choice of roughness value is based on a number of parameters including vegetation, obstructions, channel uniformity and channel sinuosity. For this channel the roughness value will be mainly dependant on the channel profile, especially during the winter. Therefore, the vegetation may have only a minor impact on the overall roughness value during certain periods.

The tests detailed here should therefore be considered mainly as a sensitivity test of any results to the assumptions made within the modelling. Testing has been undertaken on the new baseline model only, and only for the winter 2013/14 flood event. The following runs have been completed:

- **Baseline –** Includes roughness value of 0.035 within the channel
- **Roughness test 1 –** Roughness value in the dredged reaches reduced to 0.030
- **Roughness test 2 –** Roughness value in the dredged reaches reduced to 0.025

The results of these tests are shown in **Error! Reference source not found.** below.

Table 13 – Roughness tests modelling results

Moor	Peak Level (mAOD)			Duration of flooding (days)		
	Baseline	Roughness test 1	Roughness test 2	Baseline	Roughness test 1	Roughness test 2
Curry Moor	7.65	7.60	7.13	74.1	62.5	50.6
North Moor	3.63	3.63	3.63	0	0	0
Aller Moor	5.19	5.19	5.18	46.7	45.5	44.0
Kings Sedgemoor	4.33	4.32	4.31	66.0	65.5	65.1
Muchelney Level	8.66	8.65	8.65	80.8	79.9	78.8
Huish Level	8.60	8.59	8.58	27.5	24.3	22.8

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

These results show that, unsurprisingly, the biggest impact from the change in roughness is at the same place as where the dredging has the biggest impact, i.e. Curry Moor. The impacts are limited at North Moor due to the limited flooding in the baseline. Elsewhere the differences in results are relatively small and generally within any modelling accuracies. The main conclusion from this assessment are:

- Care should be taken in quoting results from any dredging assessment, as they may be very sensitive to the assumptions made in the modelling.
- There is a hydraulic benefit in maintaining the channels to be as smooth as possible. However, a certain degree of vegetation should be allowed to return to the area to provide valuable habitat and also assist in stabilising the banks.

9 SURVEY DATA FROM OCTOBER 2016 AND MARCH 2017

Channel cross section data was collected in September and October 2016, and then again in March 2017 along the 9km reach of the River Parrett and Tone that has been recently dredged to allow an understanding to be made of the degree of siltation. This has also enabled the impact of this siltation to be represented in the model.

The discussion on the degree of siltation is reported elsewhere. The model has been run for the winter 2013/14 flood event only with these cross sections updated. All other elements of the model are as the baseline model.

The results of these tests are shown in below.

Table 14 – October 2016 and March 2017 survey modelling results

Moor	Peak Level (mAOD)			Duration of flooding (days)		
	Baseline	Oct 16 survey	March 17 survey	Baseline	Oct 16 survey	March 17 survey
Curry Moor	7.65	8.00	7.98	74.1	84.9	82.1
North Moor	3.63	4.18	4.07	0	7.4	3.9
Aller Moor	5.19	5.23	5.22	46.7	52.2	50.3
Kings Sedgemoor	4.33	4.40	4.38	66.0	68.6	67.6
Muchelney Level	8.66	8.67	8.66	80.8	84.6	83.7
Huish Level	8.60	8.61	8.61	27.5	29.4	28.8

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

These results show that the siltation that has occurred in the channel following the dredging has increased the flooding throughout the catchment, although the changes upstream of Langport are within the model tolerances. The most notable increases are on Curry and North Moors. A comparison can also be made against the model with the pre-dredge survey (Table 7). This would suggest that the flooding on the moors has increased, but not to the level of flooding that there would be if the sections were returned to their pre-dredge amounts.

It should also be noted that the March 2017 survey suggests a reduction in the flooding from October 2016. This is a reflection of the increase in cross sectional area over this period. This was in part due to the dredging trials that were undertaken inbetween the two surveys, but is also a function of the high fluvial flows that occurred during this period scouring out parts of the channel. This demonstrates the importance of maintaining the fluvial conveyance area of the River Parrett channels, which is generally in the lower part of the sections.

10 IMPACT OF PROPOSED RIVER SOWY SCHEME

There are currently proposals to increase the capacity of the River Sowy, so that under normal conditions the maximum flow passed from the River Parrett through Monks Leaze Clyse is increased from 17m^3/s to 24m^3/s. Information on these proposals is contained within other reporting and is not repeated in detail here.

Requests have been made to understand the impact of the interventions described in this report alongside the proposed River Sowy scheme. At the time of this analysis there was not a model of the River Sowy scheme available that included the wider catchment, and therefore a number of assumptions have been made to allow the Sowy scheme to be represented.

A relatively simple change has been made in the model to 'force' it to allow 24m^3/s through Monks Leaze Clyse rather than 17m^3/s. No attempt has been made within the model to increase the capacity of the River Sowy itself, and therefore the model results within the River Sowy and the upper part of the Kings Sedgemoor Drain and associated moors are unlikely to be correct. These are therefore not quoted in this report.

There does remain a number of uncertainties in this assessment, and therefore the results quoted below should be seen as indicative only. This assessment should be repeated once there is a more detailed model available for the River Sowy scheme. In particular, the following issues will need addressing:

- What operating rules are used for Monks Leaze Clyse, in particular when there is overtopping of Allermoor spillway.
- The maximum flow that can be passed through Monks Leaze Clyse. When there is only 30-40m^3/s of flow upstream on the River Parrett, what is the maximum flow that can pass into the River Sowy?

The model has been run for the following scenarios, with and without the River Sowy scheme. The models have been run for the winter 2013/14 and spring 2012 flood events.

1. Baseline (see Section 3)
2. Additional pioneer dredging between Allermoor spillway and Tone confluence (see Section 7)
3. Additional pioneer dredging between Allermoor spillway and Tone confluence, and downstream of Northmoor PS (see Section 7)

The results from these tests are as follows.

Table 15 – Peak levels from winter 2013/14 flood event

Moor	Peak Level (mAOD)					
	Baseline		Dredging upstream of Tone confluence		Dredging upstream of Tone confluence and downstream of Northmoor PS	
	Without Sowy	With Sowy	Without Sowy	With Sowy	Without Sowy	With Sowy
Curry Moor	7.65	7.64	7.87	7.72	7.77	7.69
North Moor	3.63	3.63	3.76	3.63	3.63	3.63
Muchelney Level	8.66	8.61	8.63	8.58	8.63	8.58
Huish Level	8.60	8.50	8.55	8.38	8.55	8.34

Table 16 – Critical flood durations from winter 2013/14 flood event

Moor	Duration of flooding (days)					
	Baseline		Dredging upstream of Tone confluence		Dredging upstream of Tone confluence and downstream of Northmoor PS	
	Without Sowy	With Sowy	Without Sowy	With Sowy	Without Sowy	With Sowy
Curry Moor	74.1	72.2	77.8	76.0	76.3	74.8
North Moor	0	0	0	0	0	0
Muchelney Level	80.8	75.8	77.0	71.7	76.3	69.3
Huish Level	27.5	9.3	18.7	3.1	16.1	3.0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

Table 17 – Peak levels from spring 2012 flood event

Moor	Peak Level (mAOD)					
	Baseline		Dredging upstream of Tone confluence		Dredging upstream of Tone confluence and downstream of Northmoor PS	
	Without Sowy	With Sowy	Without Sowy	With Sowy	Without Sowy	With Sowy
Curry Moor	5.60	5.56	5.76	5.66	5.66	5.61
North Moor	3.52	3.52	3.52	3.52	3.52	3.52
Muchelney Level	6.91	6.85	6.88	6.82	6.87	6.81
Huish Level	6.54	6.52	6.52	6.49	6.52	6.49

Table 18 – Critical flood durations from spring 2012 flood event

Moor	Duration of flooding (days)					
	Baseline		Dredging upstream of Tone confluence		Dredging upstream of Tone confluence and downstream of Northmoor PS	
	Without Sowy	With Sowy	Without Sowy	With Sowy	Without Sowy	With Sowy
Curry Moor	18.4	14.2	23.8	17.5	19.6	15.0
North Moor	0	0	0	0	0	0
Muchelney Level	12.4	4.3	5.3	2.2	4.6	2.0
Huish Level	0	0	0	0	0	0

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The key results from this analysis are:

- The River Sowy scheme will give similar reductions in flooding in the moors upstream of Langport to those shown with the additional pioneer dredging on the River Parrett.
- The River Sowy scheme does show a small reduction in flooding to Curry Moor, although the change is within the model tolerances in larger events.
- If the River Sowy scheme is done alongside further dredging then, on the moors upstream of Langport, there is additional reduction in flooding. At larger events the total reduction is similar to the sum of the reductions from the individual options. At more frequent events the additional reduction is less.
- On Curry Moor the River Sowy scheme is very close to offsetting the increases in flooding that come from the dredging scenario. There is likely to be a scenario with less dredging where the River Sowy scheme will fully offset any disbenefits.

11 SUMMARY OF RESULTS

- The modelling has been updated to produce a revised 'baseline' model that incorporates all work that has been undertaken in the modelled area.

- This baseline model demonstrates that if the 2013/14 flood event were to occur again flooding would be much reduced from that observed in the event.

- Flow data has been analysed to allow approximations of different recent flood events to be represented in the model by modifying the 2013/14 event inflows. This work showed:
    - The Winter 2015/16 event was relatively similar to the Spring/Summer 2012 event, yet resulted in far less flooding. This demonstrates the effectiveness of the various works that were undertaken prior to this event.
    - Flooding in the pre 2014 events is all substantially less than observed.
    - If any of the flood events were to occur again, with the exception of the winter 13/14 event, no flooding is predicted to Westover Trading Estate.

- The pioneer dredging has reduced peak flood levels by 1.5m on North Moor during an extreme flood event, with the duration of flooding to the A361 reduced from 30 to 20 days. The additional pumping, if deployed, will reduce this peak flood level by a further 2m and reduce the duration of flooding to the A361 to zero.

- If no future maintenance was to be undertaken on the dredged reaches and they were allowed to return to their 'pre-dredge' profiles then there would be an increase in flooding throughout the system, most significantly in Curry and North Moors.

- A comparison has been made of the relative impacts of the pioneer dredging and additional pumping that is now in place, and the interactions between these two interventions. This has shown that maintaining the pioneer dredged section is necessary to ensure that the maximum reduction in flooding can be gained from the additional pumping and that the pumping does not increase upstream flooding. Through maintaining the dredged sections, the reliance on pumping is also reduced, which will reduce the impact on flooding if pumps were not able to be installed in the future.

- Maintaining the pioneer dredged sections provides a significant reduction in flooding to Curry Moor especially in more regular flood events, with frequency, depth and duration of flooding being reduced. The additional pumping will have little impact on the more frequent flood events.

- If further pioneer dredging can be undertaken, and maintained, upstream of the Tone confluence and downstream of the last currently dredged reach, then other than a small increase in flooding to Curry

Moor, there is a small reduction in flooding to all other moor areas, with the largest reduction in Aller Moor.

- The model results assume that vegetation is allowed to establish similar to pre-dredge levels. If the channel is kept smoother than this, then there is a potential reduction in flooding to a wide area, although it is only in Curry Moor where the impact is measurable.

- Channel survey data was collected in October 2016 and March 2017 along the dredged reach. This shows that the siltation in the channel results in increased flooding downstream of Langport. The increase is less than if the sections were allowed to return to their pre-dredge profiles. The March 2017 survey shows a reduction in flooding from October 2016, which will be partially a result of the dredging trials undertaken inbetween the two surveys, although there was also a period of high fluvial flows which would have scoured some of the channel. This demonstrates the importance of keeping the lower parts of the cross sections free of silt.

- The River Sowy scheme will give similar reductions in flooding in the moors upstream of Langport to those shown with the additional pioneer dredging on the River Parrett. In Curry Moor, the River Sowy scheme does show a small reduction in flooding, although the change is within the model tolerances in larger events. If the River Sowy scheme is done alongside further dredging then, on the moors upstream of Langport, there is additional reduction in flooding. On Curry Moor the River Sowy scheme is very close to offsetting the increased flooding that come from the dredging scenario. There is likely to be a scenario with less dredging where the River Sowy scheme will fully offset any disbenefits.

12 NEXT STEPS

A number of further assessments could be undertaken in the hydraulic model. These are described in the following sections

12.1 FURTHER DREDGING SCENARIOS

It has been shown that 4m widening between Allermoor spillway and the Tone confluence is likely to lead to an unacceptable increase in flooding in Curry Moor, without mitigation from other interventions. It may be beneficial to consider a reduced widening in this area, perhaps 2m and 1m. This could be looked with and without the dredging downstream of North Moor.

12.2 INCLUDING THE FINAL PROPOSED RIVER SOWY IMPROVEMENTS

Once a final River Sowy scheme has been developed it will be beneficial to retest the combined impact of this and the other interventions.

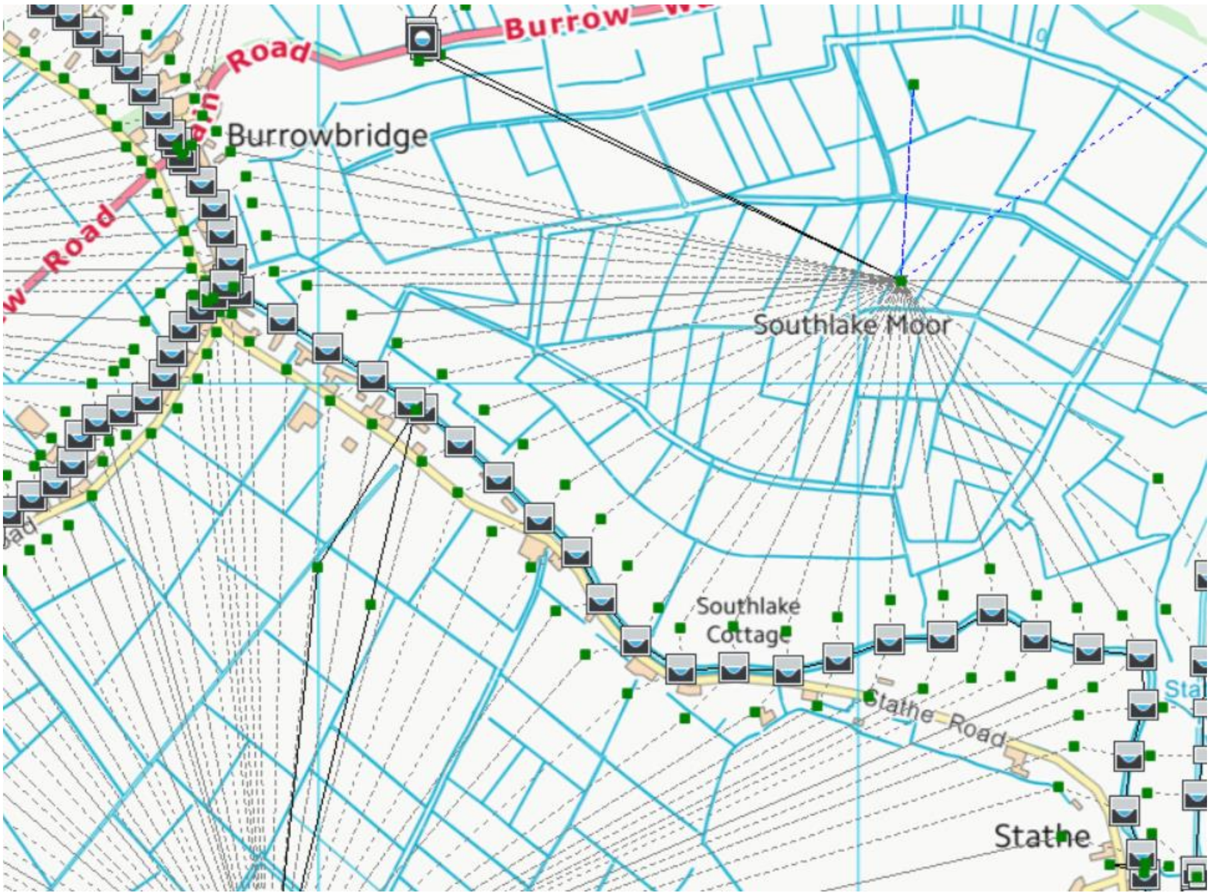
APPENDIX 7B: OATH TO BURROWBRIDGE HYDRAULIC ASSESSMENT

Parrett Internal Drainage Board

Oath to Burrowbridge Dredging

Hydraulic Assessment

FINAL



Date: 17/06/19

AW Water Engineering

Contents

REPORT VERSION	DATE	STATUS
1	**17/06/19**	**FINAL**

1 INTRODUCTION

AW Water Engineering have been appointed by the Parrett Internal Drainage Board to assess the hydraulic impacts of proposed dredging between Oath and Burrowbridge on the River Parrett. This assessment has been undertaken to support the design and appraisal work being undertaken by others. The focus of this report is fluvial flooding to the moor areas.

Separate reporting has been produced to consider how the results from the hydraulic modelling can be used to assess the effects of the proposed works on regular flooding to the designated moor areas.

2 PREVIOUS STUDIES

2.1 RIVER PARRETT – FURTHER DREDGING ASSESSMENT

The River Parrett – Further Dredging Assessment[1] study, completed in 2018, contains information on the hydraulic model that has been used to assess flood risk in this area, and a number of possible interventions to reduce the flood risk. The detail of this report is not repeated here, but it includes background data on the modelling and how much confidence can be placed in the modelling outputs.

As part of the interventions that were tested in the model, additional dredging was considered on the River Parrett both between Northmoor Pumping Station and the M5, and between Allermoor spillway and the Tone confluence. These were relatively simplistic appraisals of the impacts of dredging, with a consistent amount of widening assumed throughout the reach.

The conclusions from this dredging assessment were as follows:

The only increases in flooding shown in any dredging scenario is in Curry Moor. It can therefore be concluded that widening of the Parrett channel upstream of the Tone confluence by 4m results in an increase in flooding to Curry Moor, irrespective of the amount of widening of the Parrett channel downstream of North Moor. This conclusion applies to all flood events that have been assessed, with the change in duration becoming slightly more pronounced at the most frequent event. There will potentially be ways to mitigate this increase in risk, which should be investigated as part of the next phase of work.

These results show crucially that none of the dredging scenarios result in any significant change in flooding on North Moor, despite the slight increase in risk on Curry Moor. This is due to the increased volumes of floodwater entering the moor being able to be conveyed by the increased pump station capacities.

The reduction in flooding to the other moors are broadly in keeping with previous studies. The risk to Aller Moor and Kings Sedge Moor is decreased almost equally in both scenarios, indicating that it is relatively insensitive to the amount of dredging downstream of Northmoor PS. However, it is noted that the extra downstream dredging does have the greatest impact on flood duration on Aller Moor.

The risks to Kings Sedge Moor are almost identical in all scenarios, for all events considered. This will be a reflection of the key driver for flooding on Kings Sedge Moor being the period of tide lock, rather than the incoming fluvial flow.

For the moors upstream of Langport there is a small reduction in risk. The reduction in duration of flooding is most significant at the more regular flood events.

[1] AW Water Engineering (2018), *River Parrett – Further Dredging Assessment, Somerset Drainage Boards Consortium*

It should be noted that in all dredging scenarios, and across all events there are some moors that appear to benefit in a greater way than those shown above. In particular, these are West Sedge Moor (peak level reduction ~ 300mm) and West Moor - Midelney (peak level reduction ~ 250mm). West Sedge Moor benefits due to the reduction in River Parrett levels adjacent to the pumping station, which reduces a lot of the restrictions on pumping. West Moor benefits because, based on the operational rules, it is able to pump earlier due to the downstream spillways stopping running earlier and other pumping stations also finishing pumping earlier. In reality, the operating rules may be changed during an event to provide a wider benefit, and therefore results from these moors are not presented separately here.

This report builds on this previous work and looks at the dredging upstream of the Tone confluence in more detail.

3 ASSESSMENT METHODOLOGY/LIMITATIONS

For any modelling assessment a baseline scenario has to be established. For this work, to be consistent with the other disciplines being assessed, the baseline has been taken to be the situation as it was when this study commenced. It therefore includes the following items of work that have all been completed since the 2013/14 flood event.

- Completion of the dredging of the 8km reach between Hook Bridge on the River Tone and Northmoor Pumping Station on the River Parrett, and the assumption that these profiles will be maintained.
- Dredging of the 750m reach of the River Parrett downstream of Northmoor Pumping Station.
- The Asset Recovery Programme (ARP) improvement works to the flood banks.
- Improvement works to several pump stations, including the works associated with bringing in temporary pumps.
- The revised operating rules for the pumping stations following the 'Trigger point' project.
- Works at Beer Wall (A372) to increase the capacity of the culverts under the road.
- Changes to the operation of the River Sowy and Kings Sedgemoor Drain during flood events.

This does mean that when considering the impacts of these further dredging scenarios, they are being compared against what the risk is now, and not what the risk was at the time of the 2013/14 flood event. The works detailed above have substantially reduced the risk to key locations within this study, especially the Curry Moor and North Moor areas.

The key limitations of this assessment are linked to the hydraulic modelling used to inform the analysis. There are several necessary uncertainties in the hydraulic modelling due to the approximations that are required to estimate flows over this wide a catchment, and in simulating the hydraulic flow mechanisms of the system under a variety of conditions.

To reduce this uncertainty, observed flood event data is used to produce inflows to the model. These are based on the winter 2013/14 flood event and the Spring 2012 flood event. The 2013/14 flood event is used to represent a major flood event, whereas the Spring 2012 event represents a more regular flood event.

No attempt is made to quote what the annual probability of these events would be, as this will vary greatly depending on the location and variable (e.g. flow, peak level or flood duration) that is being considered. Instead impacts are quoted in terms of their relative difference during these events.

During the more significant flooding, when large areas are inundated, the model can be considered to be of high accuracy, as this is what it was intended to simulate, and what it has been calibrated against. During more regular flooding, the model will be less accurate in certain areas. This is mainly due to elements of the local drainage system within the moors not being fully represented.

When assessing the impacts at more regular flooding the results from the modelling are used alongside more detailed local knowledge to produce final conclusions. The model is based on the topographical survey data that was available at the time of the assessment. The system is highly mobile and therefore the results represent those that would have occurred at a set moment in time.

4 FURTHER ASSESSMENTS

A number of different dredging scenarios have now been tested within the hydraulic model. The first change that was made from the previous assessment was that no dredging was considered upstream of Oath Lock. This is due to the size of the channel in this reach and the influence Oath Lock has on upstream water levels. The following scenarios were tested:

1. A 'small' dredge from Oath Lock to Burrowbridge (Scenario 1)
2. A 'large' dredge from Oath Lock to Burrowbridge (Scenario 2)
3. A 'large' dredge from Stathe Bridge to Burrowbridge (Scenario 3)

The results from these scenarios are presented in the table below for selected moors for the winter 2013/14 event and the spring 2012. For further details on how these events are represented refer to the River Parrett – Further Dredging Assessment report, but they are taken to be representative of a regular flood (2012) and a more extreme event (2013/14).

Table 1 – Comparison of dredging scenario modelling results - 2012 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Baseline	Dredging Scenario 1	Dredging Scenario 2	Dredging Scenario 3	Baseline	Dredging Scenario 1	Dredging Scenario 2	Dredging Scenario 3
Curry Moor	5.60	5.67	5.77	5.77	18.4	20.5	24.5	23.9
North Moor	3.52	3.52	3.52	3.52	0	0	0	0
Aller Moor	4.70	4.66	4.55	4.60	3.0	1.5	0	0.1
Kings Sedgemoor	4.09	4.03	4.09	4.09	45.8	45.7	45.7	45.7
Muchelney Level	6.91	6.90	6.88	6.89	12.4	8.2	4.6	5.0
Huish Level	6.54	6.54	6.52	6.53	0	0	0	0

Table 2 – Comparison of dredging scenario modelling results – 2013/14 event

Moor	Peak Level (mAOD)				Duration of flooding (days)			
	Baseline	Dredging Scenario 1	Dredging Scenario 2	Dredging Scenario 3	Baseline	Dredging Scenario 1	Dredging Scenario 2	Dredging Scenario 3
Curry Moor	7.65	7.70	7.89	7.86	74.1	75.2	78.3	77.8
North Moor	3.63	3.63	3.79	3.69	0	0	0	0
Aller Moor	5.19	5.18	5.13	5.15	46.7	43.6	34.6	38.0
Kings Sedgemoor	4.33	4.30	4.25	4.26	66.0	65.0	64.2	64.4
Muchelney Level	8.66	8.65	8.64	8.64	80.8	79.0	76.5	76.9
Huish Level	8.60	8.58	8.56	8.56	27.5	23.9	18.8	20.6

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The main observations from these results are:

- Undertaking the larger dredge gives greater impact throughout. This impact is a reduction in risk to all areas except Curry Moor, where there is an increased risk.
- Dredging scenario 3 shows that the majority of the impacts from undertaking the larger dredge from Oath Lock to Burrowbridge can be achieved by only undertaking works from Stathe Bridge to Burrowbridge. The reason for this is that any increased channel capacity upstream of Beazleys spillway will just result in an increased flow over the spillway during flood events, rather than much of an increased flow downstream. As this is flow that would otherwise be passing over Allermoor spillway, this also does not result in a significant change in the volume of water entering the River Sowy.
- The peak flows through Burrowbridge during low tides are increased by about 2m3/s with the first dredging scenario. With the second and third scenarios the increase is 4-5m3/s.
- There will be locations where the impacts are more pronounced than those shown above, especially where flooding is controlled by pump station capacities alone (e.g. West Sedge Moor).

5 ASSESSMENT OF THE SOWY SCHEME

The proposed scheme to increase the capacity of the River Sowy has also been tested in the hydraulic model to allow the in-combination effects of the two schemes to be assessed. The Sowy scheme that has been tested was based on information provided by the Environment Agency and is for a scheme that increases the normal flows on the River Sowy by $7m^3/s$.

This has been tested in the model alongside dredging scenario 3 discussed in the section above. The results from this are presented below for the 2012 and 2013/14 flood events. The results for dredging scenario 3 are repeated in this table for ease of comparison.

Table 3 – Comparison of dredging scenario 3 and Sowy scheme modelling results - 2012 event

Moor	Peak Level (mAOD)			Duration of flooding (days)		
	Baseline	Dredging Scenario 3	Dredging Scenario 3 + Sowy Scheme	Baseline	Dredging Scenario 3	Dredging Scenario 3 + Sowy Scheme
Curry Moor	5.60	5.77	5.67	18.4	23.9	17.3
North Moor	3.52	3.52	3.52	0	0	0
Aller Moor	4.70	4.60	4.54	3.0	0.1	0
Kings Sedgemoor	4.09	4.09	4.09	45.8	45.7	45.8
Muchelney Level	6.91	6.89	6.83	12.4	5.0	2.0
Huish Level	6.54	6.53	6.49	0	0	0

Table 4 – Comparison of dredging scenario 3 and Sowy scheme modelling results – 2013/14 event

Moor	Peak Level (mAOD)			Duration of flooding (days)		
	Baseline	Dredging Scenario 3	Dredging Scenario 3 + Sowy Scheme	Baseline	Dredging Scenario 3	Dredging Scenario 3 + Sowy Scheme
Curry Moor	7.65	7.86	7.76	74.1	77.8	76.5
North Moor	3.63	3.69	3.63	0	0	0
Aller Moor	5.19	5.15	4.93	46.7	38.0	9.1
Kings Sedgemoor	4.33	4.26	4.22	66.0	64.4	64.0
Muchelney Level	8.66	8.64	8.63	80.8	76.9	70.1
Huish Level	8.60	8.56	8.54	27.5	20.6	9.2

Duration of flooding is taken as above 4.5m in Curry Moor, 4m in North Moor, 4.6m in Aller Moor, 4m for Kings Sedge Moor, 6.5m for Muchelney Level and 8.1m for Huish Level (Westover Trading Estate)

The main observations from these results are:

- Combining the two schemes shows greater impact than either scheme on its own.
- The greatest benefits of combining both schemes is on Aller Moor.
- As the Sowy scheme does not actually provide much benefit to Curry Moor, this does not fully offset the disbenefits from the Oath to Burrowbridge dredge. However, it does partially offset the disbenefits.

6 FINAL SCHEME

6.1 BACKGROUND

A final scheme has been developed for the reach between Stathe Bridge and Burrowbridge that involves removing an amount of material (22,000m^3) in this reach that is between the amount assessed in Dredging Scenario 1 (16,000m^3) and Dredging Scenario 3 (38,000m^3). Rather than running the model again for this design, the results have been interpolated from these different volumes. Due to the uncertainties in the modelling approach this is considered acceptable, but the justification for this is detailed below.

For the majority of the areas it is considered suitable to use the results from Dredging Scenario 1 to simulate the final scheme. This will result in a precautionary approach to the benefits. In the key location (Curry Moor) where flood risk is predicted to increase it is necessary to have a better understanding of the actual risk.

6.2 AVAILABILITY OF MODELLING DATA

The model has been run for a series of different scenarios for both the winter 2013/14 flood event and the Spring 2012 event. The matrix below summarises what information is available and what can be interpolated from the available data. The same data is available for both flood events.

Table 5 – Data availability for final scheme

	Without Sowy scheme	With full (7m^3/s) Sowy Scheme
Baseline	✓	✓
Smaller (16,000m^3) dredge	✓	Can be confidently interpolated using combination of without and with Sowy scheme data
Larger (38,000m^3) dredge	✓	✓
Final (22,000m^3) dredge	Can be confidently interpolated using without Sowy scheme data	Can be confidently interpolated using with Sowy scheme data

6.3 DATA ANALYSIS

The data has been presented on graphs (included in Appendix A) to determine the trends with the data and to allow interpolations to be made. These have shown that both flood levels and durations of flooding can be confidently interpolated from the existing data.

The following table summarises the flood levels and durations on Curry Moor for different flood events for these scenarios. Where data has been interpolated this is shown in red italics. The duration of flooding is based on typical field levels.

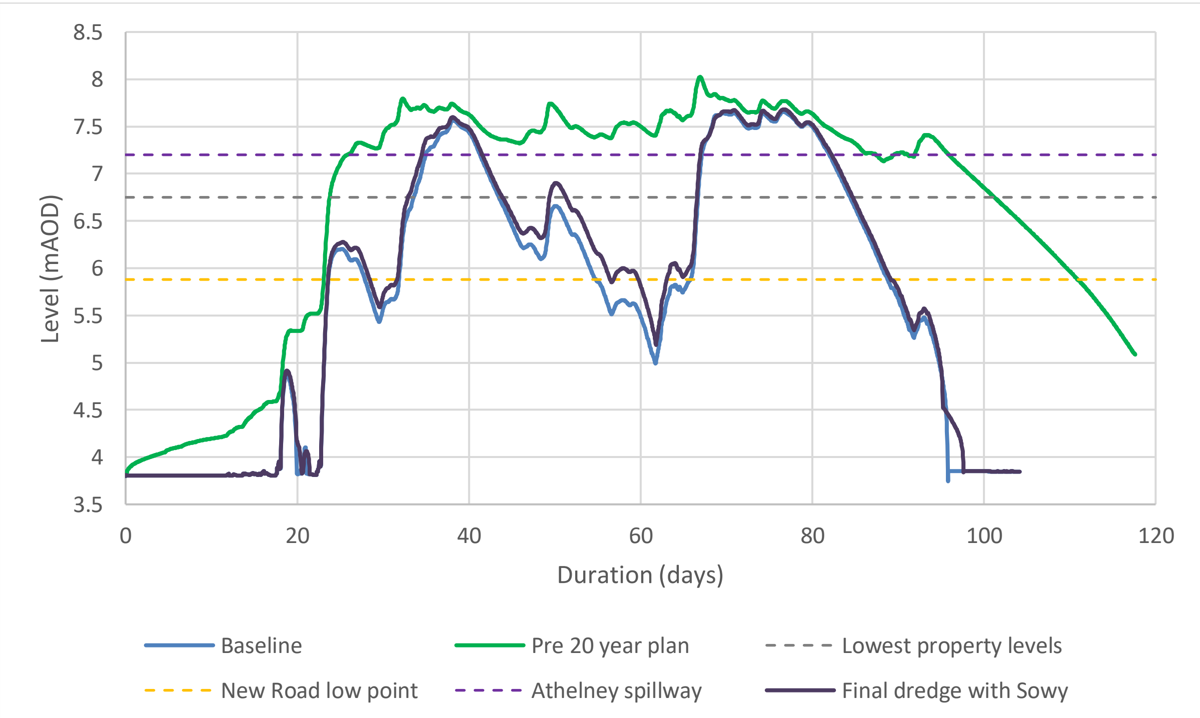
Table 6 – Interpolation for Curry Moor

Scenario	2014 event		2012 event	
	Peak level (mAOD)	**Duration (days)**	**Peak level (mAOD)**	**Duration (days)**
Baseline	7.65	74.1	5.60	18.4
Smaller dredge	7.70	75.2	5.67	20.5
Larger dredge	7.86	77.8	5.77	23.9
Final dredge	*7.73*	*75.8*	*5.70*	*21.4*
Baseline with full Sowy scheme	7.65	73.4	5.56	14.3
Smaller dredge with full Sowy scheme	*7.68*	*74.3*	*5.61*	*15.4*
Larger dredge with full Sowy scheme	7.76	76.5	5.67	17.8
Final dredge with full Sowy scheme	*7.69*	*74.8*	*5.62*	*15.8*

In addition, hydrographs have been produced to show the flooding on Curry Moor in the 2014 flood event in more detail. In a similar approach, where modelling data is not available this has been interpolated from available data. Graphs showing this interpolation are shown in Appendix A.

The following graph shows the hydrograph on Curry Moor with the pre-20 year plan levels, the current baseline, and with the final dredge and Sowy scheme. Also shown are the approximate levels of the lowest property, New Road and Athelney spillway. This graph shows that there is minimal difference between the baseline and final scheme. The duration of flooding to properties is increased from 27.6 days to 31.1 days, but this is only during the middle of the event.

Figure 1 – 2013/14 hydrograph on Curry Moor



The 2012 event can be analysed in a similar manner, but there is no flooding to properties shown with any of the dredging scenarios.

6.4 SUMMARY OF RESULTS

The table above suggests that if the final dredge is undertaken on its own then the peak level will be increased on Curry Moor by 80mm and 100mm in the 2014 and 2012 events respectively. The duration of flooding would increase by 1.7 and 3.0 days in these events.

If the final dredge is considered alongside the full Sowy scheme, then the peak levels are increased on Curry Moor by only 40mm and 20mm in the 2014 and 2012 events respectively. The duration of flooding is increased slightly by 0.7 days in the 2014 event but is actually decreased by 2.6 days in the 2012 event. These changes could be further mitigated, if required, by other works. This is discussed in the following section.

The duration of flooding to properties on Curry Moor in the 2014 event is increased by 5 days. With the Sowy scheme also included the increase is reduced to 3.5 days. The duration of flooding to New Road on Curry Moor in the 2014 event is increased by 13.9 days. With the Sowy scheme also included the increase is reduced to 8.4 days.

7 POTENTIAL MITIGATION

7.1 METHODOLOGY

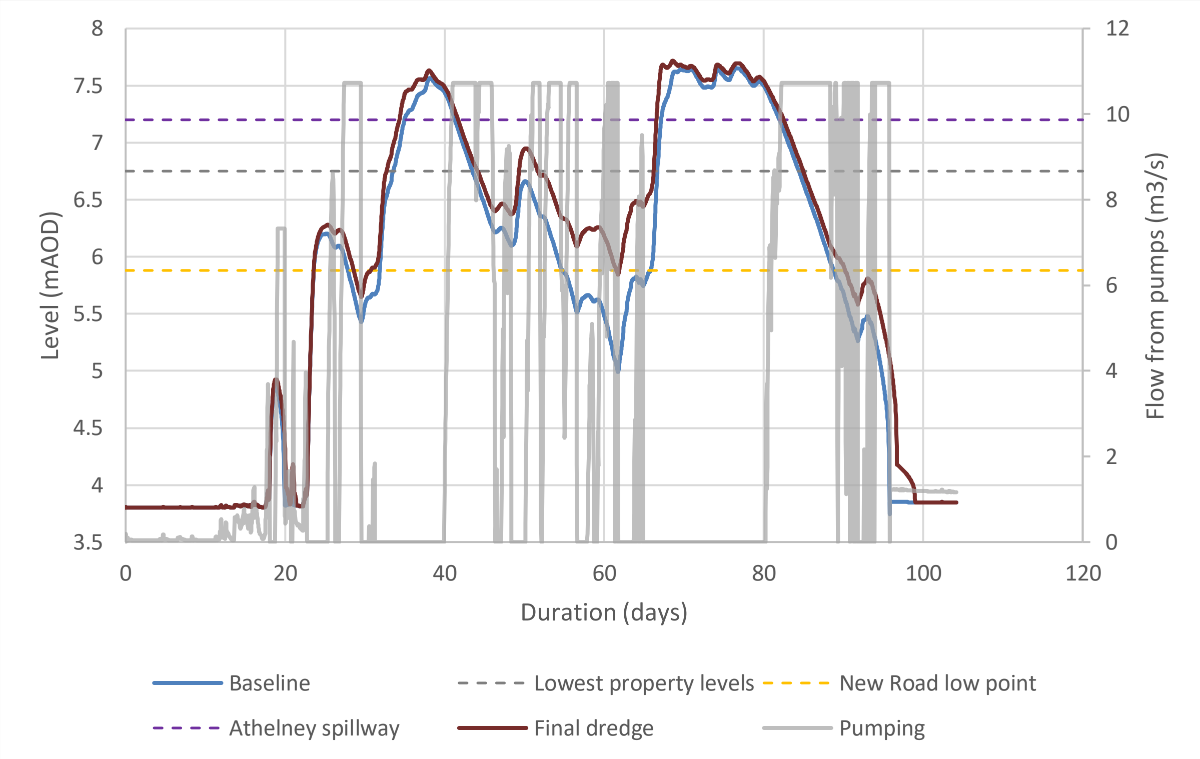
As discussed above the final scheme does result in a slight increase in risk to Curry Moor compared to the post 2014 baseline. The risk is still substantially reduced compared to the situation pre-2014. It is still required to mitigate this risk. As discussed above the Sowy Scheme will partially offset this increased risk, but not fully.

To fully offset this risk it is necessary to increase the pumping capacity at Curry Moor pumping station. To determine how much additional pumping would be required the following analysis has been completed. This is assessed with and without the Sowy Scheme included.

7.2 DATA ANALYSIS

The hydrograph below also shows the times when Curry Moor pumps are running. This shows there are substantial times when the pumps are running at full capacity and the amount of pumping could be increased.

Figure 2 – Pumping on Curry Moor



It has been assumed that it would be possible to increase the amount of pumping when the pumps are currently able to pump at maximum capacity. Using the level/volume relationship for Curry Moor it is possible to equate this increased pumping to a reduced water level. This allows a theoretical hydrograph to be plotted with different amounts of increased pumping.

The following hydrographs shows the impact of allowing extra pumping alongside either just the final dredge design, or with the Sowy Scheme also included. The results up to around 70 days are likely to be realistic, but the data after that may not be so reliable due to the impacts of larger volumes of flow over Athelney spillway in the baseline.

Figure 3 – Impact of additional pumping on Final dredge scenario

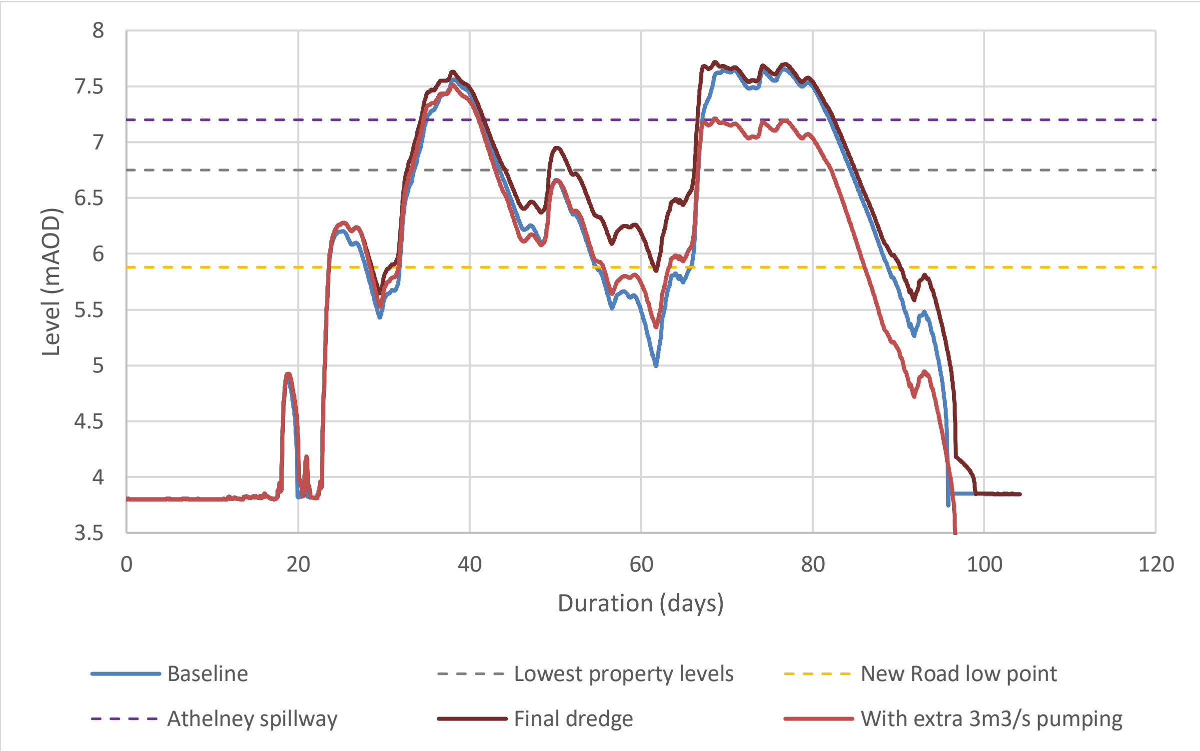
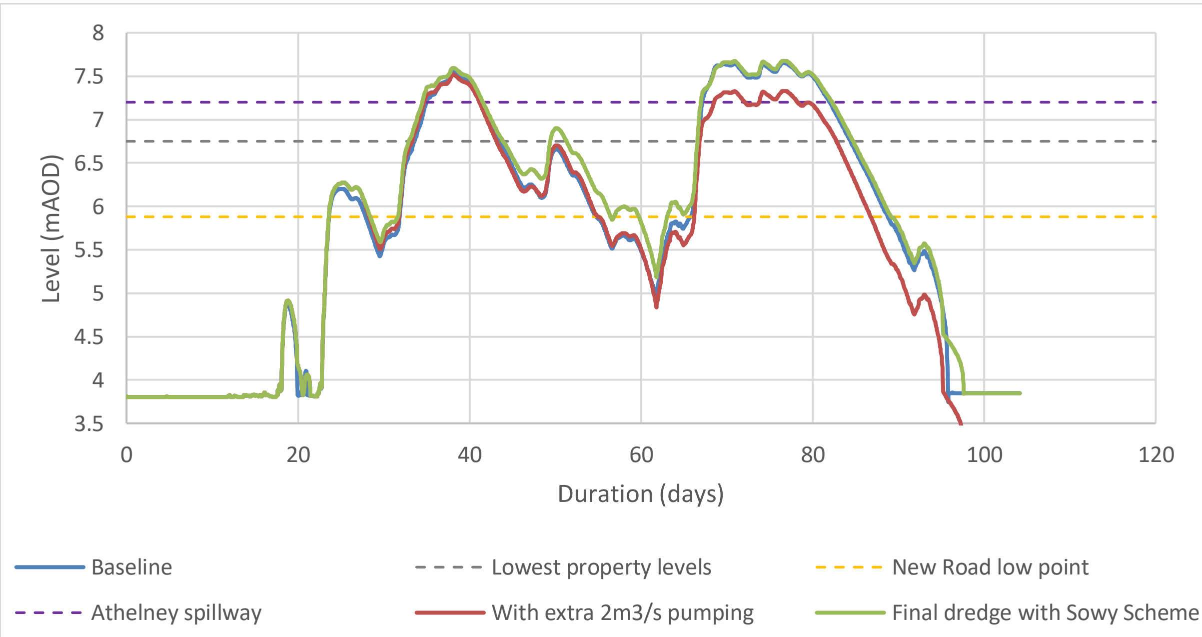


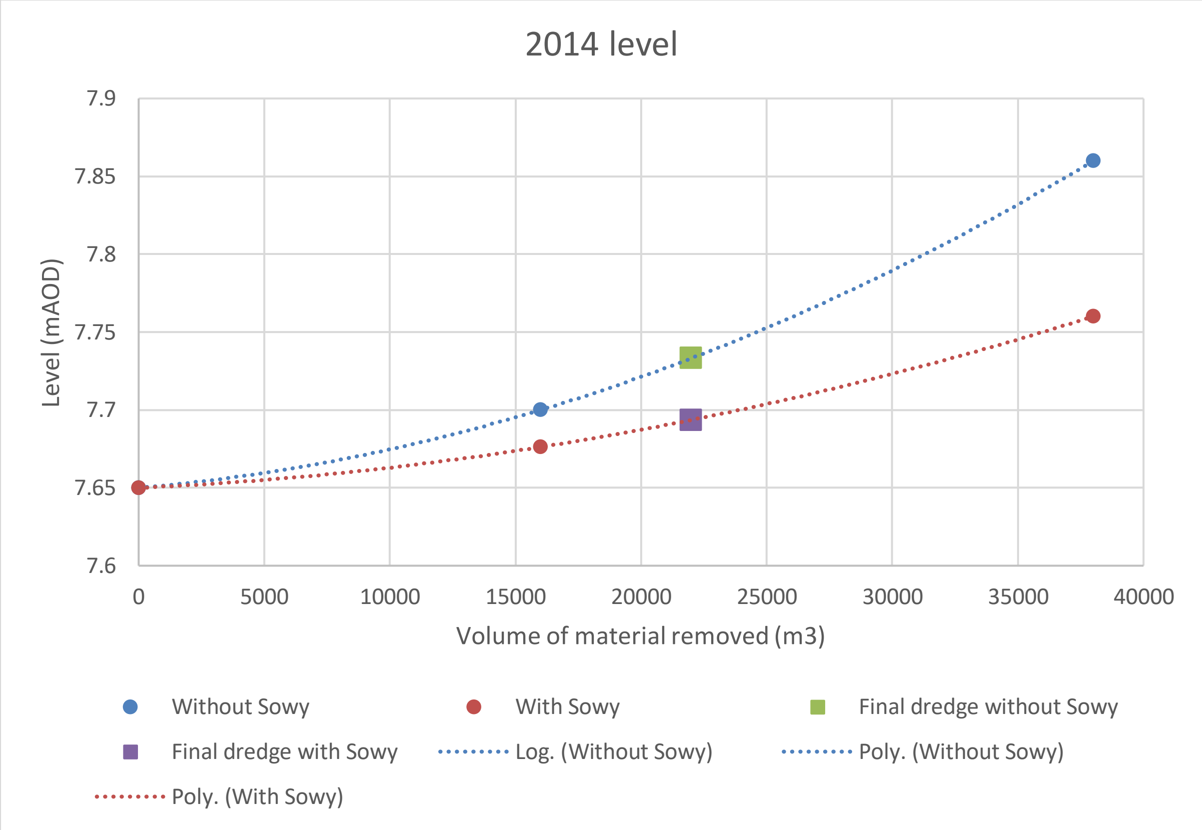
Figure 4 – Impact of additional pumping on Final dredge scenario with Sowy scheme included

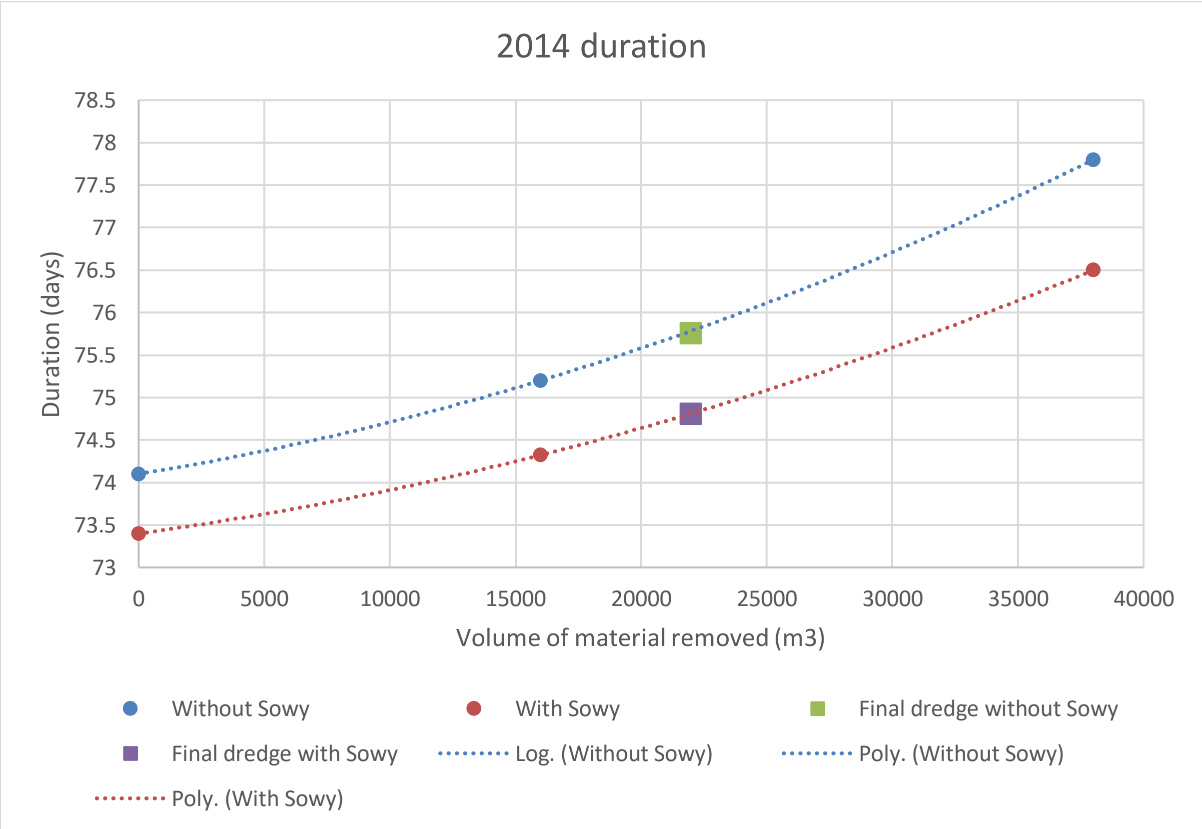


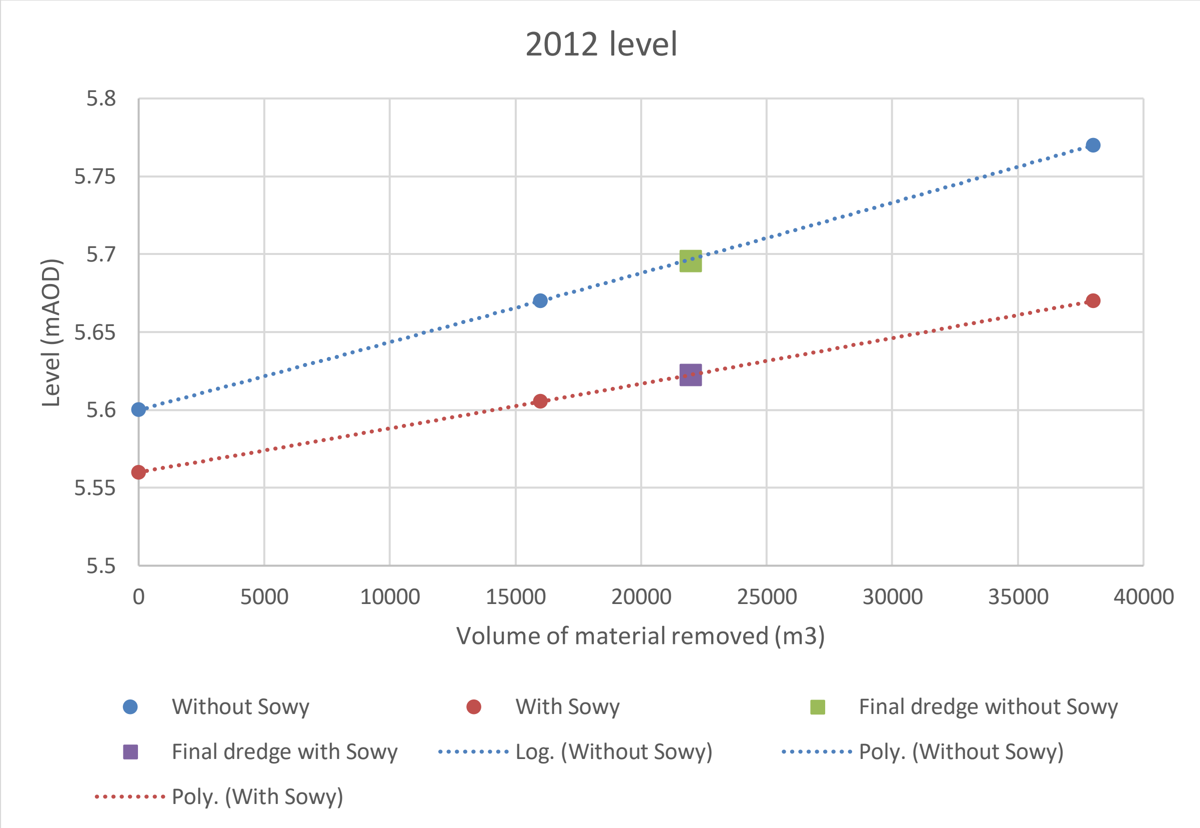
This shows that an extra pump capacity of $3m^3/s$ is probably sufficient to mitigate any of the reduced benefits on Curry Moor when considering the final dredge design on its own. If the Sowy scheme is also included as mitigation, then it will only be necessary to have an extra pump capacity of $2m^3/s$. This additional pumping will reduce the peak water level as well as the duration of flooding. It may well provide an overall betterment due to the reduction to the second peak.

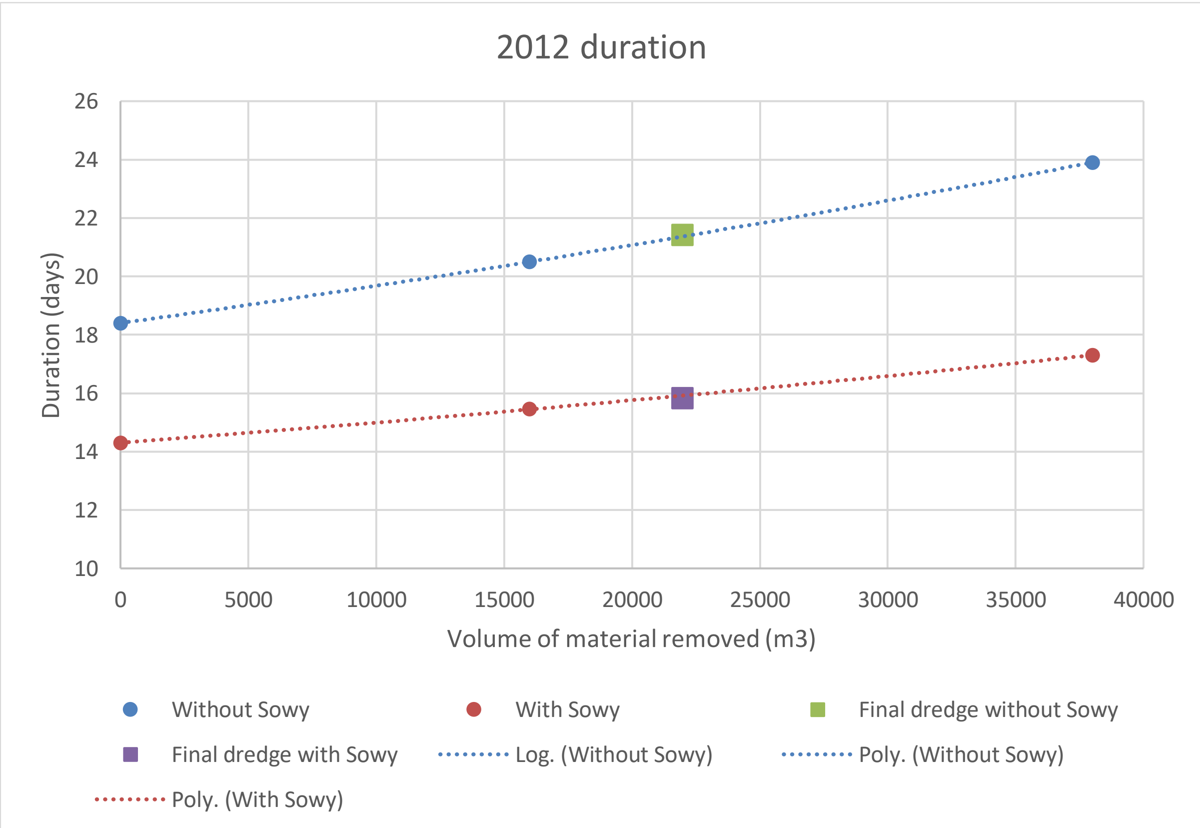
Whilst this extra pumping will provide benefits at smaller flood events, the scale of benefit will reduce with the increased frequency of the event. However, this extra pumping will be sufficient to offset the reduced benefits at other events.

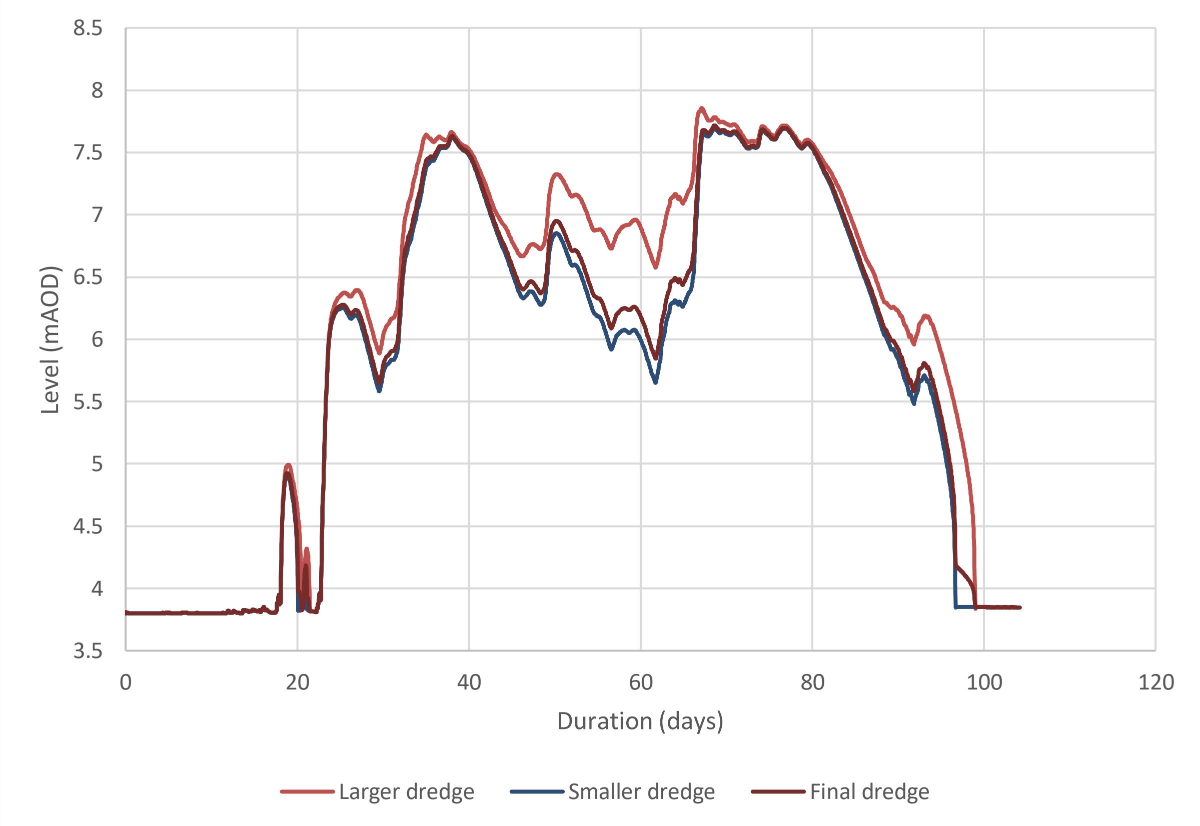
Appendix A – Interpolation trend graphs and Curry Moor hydrographs

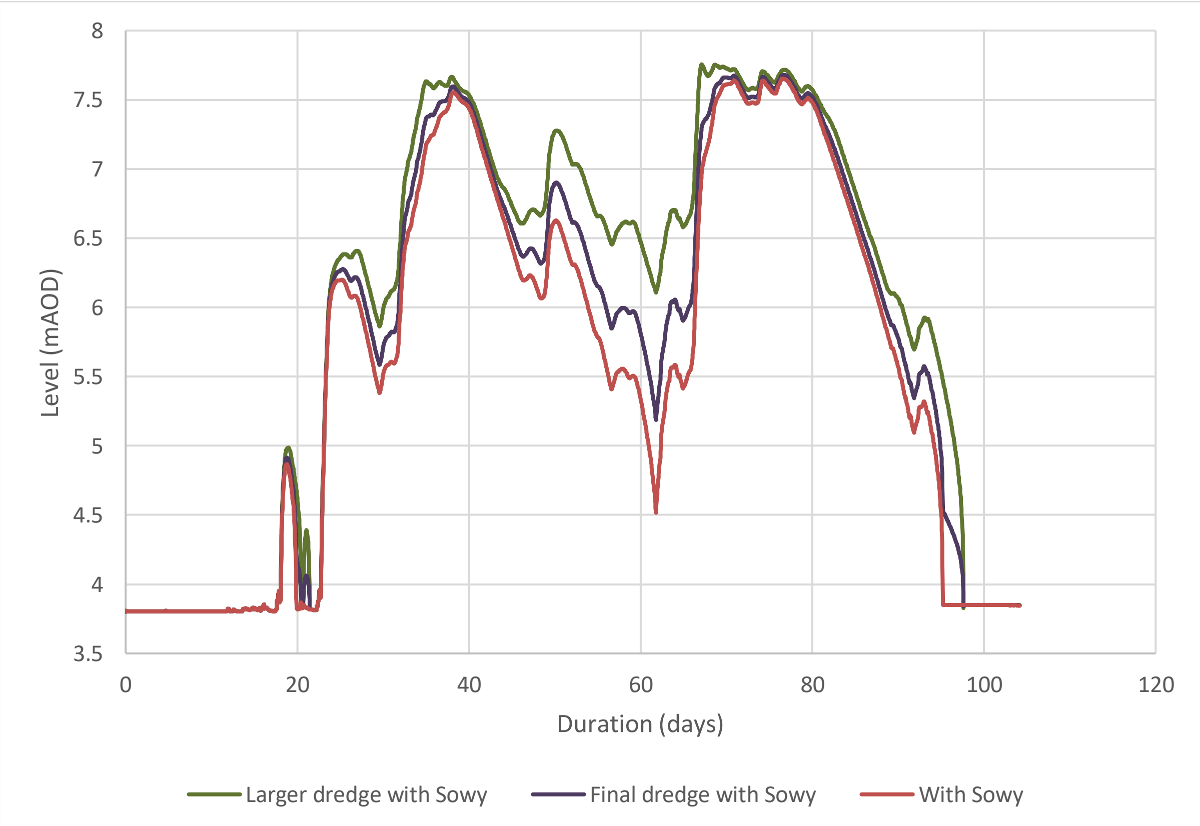

2014 level
Level (mAOD)
7.9
7.85
7.8
7.75
7.7
7.65
7.6
0
5000
10000
15000
20000
25000
30000
35000
40000
Volume of material removed (m3)
Without Sowy
With Sowy
Final dredge without Sowy
Final dredge with Sowy
Log. (Without Sowy)
Poly. (Without Sowy)
Poly. (With Sowy)

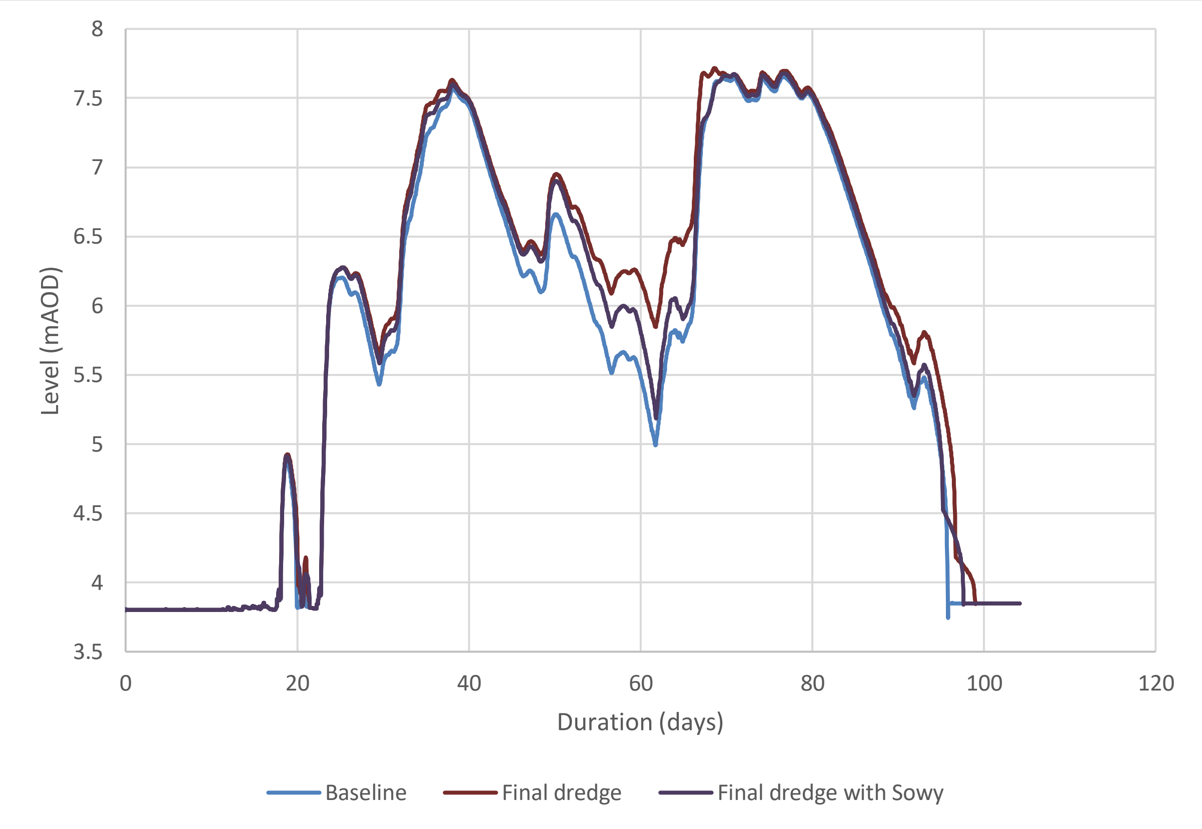

2014 duration
Duration (days)
78.5
78
77.5
77
76.5
76
75.5
75
74.5
74
73.5
73
0
5000
10000
15000
20000
25000
30000
35000
40000
Volume of material removed (m3)
Without Sowy
With Sowy
Final dredge without Sowy
Final dredge with Sowy
Log. (Without Sowy)
Poly. (Without Sowy)
Poly. (With Sowy)


2012 level
Level (mAOD)
5.8
5.75
5.7
5.65
5.6
5.55
5.5
0
5000
10000
15000
20000
25000
30000
35000
40000
Volume of material removed (m3)
Without Sowy
With Sowy
Final dredge without Sowy
Final dredge with Sowy
Log. (Without Sowy)
Poly. (Without Sowy)
Poly. (With Sowy)


2012 duration
Duration (days)
26
24
22
20
18
16
14
12
10
0
5000
10000
15000
20000
25000
30000
35000
40000
Volume of material removed (m3)
Without Sowy
With Sowy
Final dredge without Sowy
Final dredge with Sowy
Log. (Without Sowy)
Poly. (Without Sowy)
Poly. (With Sowy)


8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
Level (mAOD)
0
20
40
60
80
100
120
Duration (days)
Larger dredge
Smaller dredge
Final dredge


8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
Level (mAOD)
0
20
40
60
80
100
120
Duration (days)
Larger dredge with Sowy
Final dredge with Sowy
With Sowy


8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
Level (mAOD)
0
20
40
60
80
100
120
Duration (days)
Baseline
Final dredge
Final dredge with Sowy