Flood Management Design
for the former Tredegar Park Golf Course Development

Summary Report

Report Nr 06009.3

November 2011

MK2 DESIGN
WITH FLOOD STORAGE ON THE FORMER TREDEGAR PARK GOLF COURSE
AND
RE-POSITIONING OF THE FLOOD EMBANKMENT ON THE TREDEGAR PARK SPORTS FIELD

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Contents

	Page
Contents	1
Status & Revision History	1
Contributors	1
1 Overview	2
2 Basis of selection of the final Mk2 design	4
3 Layout and key elements of the proposed Mk2 design scheme	8
4 Performance of the final Mk2 design – including flood consequences assessment	14
Overview of the performance of the Mk2 flood works design	14
Floodwater level impacts in extreme events	14
Flood extent maps	15
No worsening of flood risk downstream of Ebbw Bridge	15
No worsening of flood risk upstream of the development	16
5 Checklist of scheme performance against planning conditions and other constraints	23
6 Provisions for future management of flood management works	25
General explanatory notes	26
end	27

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Contributors

All of the hydrological and hydraulic modelling work undertaken in connection with the work described in this report was undertaken by HR Wallingford. All of the outline engineering designs presented herein were also prepared by HR Wallingford, except as explicitly stated to the contrary, where they were prepared by Arup Ltd. CFonstream acted as the Client's Managing Agent for the work undertaken by HR Wallingford, but that work was undertaken under HR Wallingford's own commercial terms and conditions, under direct contract to the Client. CFonstream acted as the Client's Managing Agent for the project; as the Client's expert witness at the public inquiry; and as the lead author of this report and various supporting documents.

Flood Management Design for the former Tredegar Park Golf Course Development

Summary Report

(1) Overview

1 This report describes works that will be provided to control flood risk on, upstream and downstream of the former Tredegar Park Golf Course (TPGC), following the development of a new housing estate on part of the TPGC.

2 Outline planning permission for the development was granted on appeal to the Welsh Government (WG; then the Welsh Assembly Government, WAG) by the decision letter dated 22 March 2007, subject to conditions to manage flood risk to residents on, upstream of and downstream of the development.

3 A flood works design that met all of the stipulated conditions, and additional ones requested by Newport City Council (NCC) and the Environment Agency Wales (EAW) was presented to NCC and EAW in 2009. This design is known as the Mk1 design. It involved the construction of floodwater storage facilities on both of the TPGC and TPSF, to compensate for raising the proposed housing site above the level of the 1 in 1000 years extreme flood, and to reduce flood flows and levels downstream. Floodwaters would have been retained in those reservoirs with a design frequency of once every 50 years for the TPGC facility, and once every 100 years for the TPSF facility.

4 A revised design has since been developed, to meet NCC's preference for not using the TPSF as a flood storage facility as part and parcel of the design. This Mk2 design involves storage of floodwaters on the TPGC (as before), but moving the existing flood embankment of R Ebbw on the TPSF in-field, to create a larger two-stage flood channel facility on the river-side of the embankment instead of a storage reservoir behind it. This idea was proposed by Gary Purnell of EAW. We have tested its viability, and following examination of many design variants, we have developed a final Mk2 design of this type that meets all of the WG's planning conditions, all of the EAW's requirements in respect of flood risk management and all of NCC's preferences for land use. This design performs at least as well as its Mk1 predecessor is all respects, and in the critical matter of reducing flood risk in Duffryn (compared to its present level), it outperforms the Mk1 design; with the proposed Mk design, exposure to flood risk in Duffryn is reduced from around 1:100 years (a 1% per annum chance) to around 1:180 years (a 0.56% per annum chance).

5 We have designed and tested the performance of the Mk2 scheme in flood events with return periods (RP) ranging from 50 years to over 1000 years, using estimates of 344 m3/s, 418 m3/s and 440 m3/s as Q1000, Q1000+ and Q1000++ estimates of the extreme 1 in 1000 years flood event. All tests have been undertaken with a well calibrated and well verified computational hydraulic model that determines flood water levels for defined flood flows to an accuracy of around ±15 mm. The model – an InfoWorks RS model developed initially by Halcrow and extended and improved by HR Wallingford – has been examined and reviewed by seven different expert parties, and has been accepted as fit for purpose by all, including the EAW.

6 The tests we have conducted have shown that the Mk2 design delivers:

- **protection against the risk of flooding to the residents of the new housing development site to a standard of at least 1:1000 years** (compared to the 1:100

years condition required by prevailing policy for fluvial flood risk, as set out in Technical Advice Note 15 (TAN15) and Planning Policy Wales (March 2002)), by raising the base level of the development site to that of the 1:200 year flood plus a further 600mm;

- **no adverse effect** (no exacerbation) on flood levels and flood risk **upstream** of the development, in events up to and including the once in a thousand years flood estimate (Q1000) of 344 m3/s, and (as a sensitivity test) in an event as extreme as 440 m3/s (herein referred to as the EAW's Q1000++ estimate);

- **no adverse effect** (no exacerbation) on flood levels and flood risk **downstream** of the development, in events up to and including the Q1000 estimate of 344 m3/s, and in the EAW's Q1000++ extreme test flood estimate of 440 m3/s;

    - **with flood levels in Duffryn post-works being significantly reduced** compared to present (pre-works) flood levels **in all events up to and including the Q1000 event estimate of 344 m3/s**; **and in the EAW's (Q1000++) event estimate of 440 m3/s** (with Q1000++ floodwater levels in the ten relevant flood cells being 34mm lower (±15mm) on average, post-scheme compared to pre-scheme (range of difference in levels from -11mm to -58mm, all ±15mm);

    - **with no adverse effect (exacerbation) on flood levels and flood risk in Maes Glas**, downstream of Ebbw Bridge, including in St Brides Gardens (SA_12) and in the low lying area around Dingle Cottage, upstream of the Docksway Bridge (SA_11), in events up to and including the Q1000 flood of 344 m3/s, and in the EAW's Q1000++ estimate of 440 m3/s);

and, **notably**,

- **a substantial improvement in the standard of protection against flooding in Duffryn**, **from around 1:100 years to around 1:180 years** (analyses undertaken show that flooding into Duffryn now occurs in a flood of >240 m3/s but <245 m3/s (>Q100<Q105), but that post-works it would first occur in a flood of >265 m3/s (Q160) but <275 m3/s (Q200)).

7 The performance of the Mk2 scheme is accordingly considered to be overwhelmingly positive, and fully compliant with the terms of the conditional planning approval granted to the forerunner design, in all material respects, notwithstanding the design substitution of a two-stage channel for a storage reservoir on the TPSF, as proposed in the original design accepted by the WG.

8 This summary report (CFonstream Report 06009.3) includes information on the key features, performance and benefits of the final Mk2 floodworks design.

9 A separate main technical report (CFonstream Report 06009.2) provides full details on the features, performance and benefits of the final Mk2 floodworks design, including:
- design layout (chapter 5)
- flood consequences assessments (chapter 6)
- design details (chapter 7)
- outline engineering specifications and drawings (chapter 8).

10 A free-standing executive summary describing the key features of the Mk2 design has also been produced (CFonstream Report 06009.4).

(2) The basis of selection of the final Mk2 scheme design

1 The final design of the Mk2 flood management works on the TPGC and TPSF was selected following examination of the feasibility and performance of multiple combinations of options. Some design values were fixed by the conditions of planning permission (such as the level at which the residential development site is to be built), but many others offered various degrees of freedom, and hence multiple possible combinations of options. The variable components of the design included:

- the level of inflow into storage in the TPGC flood detention reservoir
- the level of the floodwater retaining bund on the TPGC (that of the realigned bund on the TPSF being constrained to the same elevation as the existing bund)
- the areal extent of the TPGC storage reservoir and of the two stage flood channel on the TPSF
- the dimensions of the flood conveyance channel on the TPGC
- the level of the right bank embankment above Pont Ebbw
- the location of the inflow weir for taking floodwaters into storage on the TPGC, so as to avoid the disruption and cost associated with relocating the Dwr Cymru sewer embedded within the Tramway embankment
- *the level of the river bed at Pont Ebbw (this option was removed post-Inquiry, at the EAW's request)*

2 All feasible combinations of the available design options were considered, by simulating their performance with a well-calibrated, well-verified and well-reviewed computational hydraulic model of the river and floodplain of R Ebbw between Bassaleg and its confluence with the R Usk. The hydraulic model was set up and run to determine the performance of the scheme against the objectives and constraints set upon it. In all cases, the performance of each scheme set up was evaluated by comparing simulated floodwater volumes and peak levels in key storage areas on the floodplain in Duffryn and Maes Glas post-works compared to pre-works, in flood events ranging from the 1 in 50 years return period flood (the Q50 event) to the 1 in 1000 years return period flood (the Q1000 event). Those schemes delivering a reduction in floodwater levels and volumes in the key storage areas shown in Figure 2.1 and Table 2.1 below were selected for detailed investigation, with iterative analyses being used to determine the net best scheme overall. Separate tests were conducted to ensure that selected designs did not create any worsening of flood risk upstream of the development site, in line with the WG's planning condition in that regard.

3 Many different scheme designs were examined, and many hundreds of runs of the hydraulic model were used to determine the set up delivering the net best performance, across the full range of relevant flood flows; these being not just the 1 in 1000 years events required by the EAW as tests of impact in extreme flood flows, but also the range of flows from Q100 to Q200, so as to determine the threshold of flooding into Duffryn (and the flood risk gains to be had there) under different set ups. The full range of design flows used to test different design schemes is shown in Table 2.2 below. The return periods attached to flows of a given magnitude by different parties at different points during the investigation are shown in the different rows of Table 2.2

4 The key design flows that were used for testing the performance and refining the design of the Mk 2 flood works design were:

- the 282 m3/s flow, taken to be the 1 in 200 years flow (Q200) throughout the analysis, which was used for purposes of defining the required base level of the development site (this being the level of the Q200 flow as it varies across the development site, plus a further 600mm); it may be noted that the resultant development level is above computed levels of the Q1000 flood;

- the 344 m3/s flow, taken to be the base estimate of the Q1000 flood flow used for impact evaluations; with the EAW's estimate of 440 m3/s of the Q1000 also being used as an extreme test value of the Q1000 flood; for ease of reference, the 440 m3/s extreme flood is denoted as the Q1000++ event (the EAW's forerunner estimate of 418 m3/s of the Q10000 was used until August 2009, and was denoted as the Q1000+ event).

5 The modelling work undertaken showed that the key to delivering the required flood risk management performance hinged, in the round, upon:

- first, the capacity and the point of usage of flood storage on the TPGC (in a new detention storage reservoir behind the old tramway embankment) and on the TPSF (in the enlarged two stage channel adjacent to R Ebbw, so as to (more than) compensate (on a level for level basis) for the loss of floodplain storage to the development site on the left bank of R Ebbw in the TPGC reach;

- second, raising the level of the right embankment on the TPSF immediately above Ebbw Bridge, to limit overtopping of flows from R Ebbw in events of >100<200 years return period into the car park, over the A48 and into Duffryn.

6 The improvement in exposure to flood risk in Duffryn (achievable through the second of the above) is limited by its direct impact on exposure to flooding downstream, in Maes Glas. In practice, the best final design represents a compromise between improving flood risk in Duffryn in floods of intermediate to high magnitude, on the one hand, and exacerbating flood risk in extreme flood events in St Bride's Gardens, downstream, on the other. Raising the level of the right bank embankment above Ebbw Bridge benefits Duffryn, but costs Maes Glas, in the form of conveying higher flows through Ebbw Bridge and creating higher flood levels immediately downstream of it. In effect, the Mk2 design is that which best satisfies the trade off between the planning condition of no exacerbation of flooding in Maes Glas (in events as severe as the EAW's Q1000++ flood) and maximising the improvement in flood protection to Duffryn.

Figure 2.1: Location and numbering of the floodplain storage areas in the post-development model (differs from the pre-works model only in the division of the TPGC area). Note that storage area SA1 is a designated flood storage cell at present, and that increases in water level in that cell (post-works versus pre-works) is of no significance.

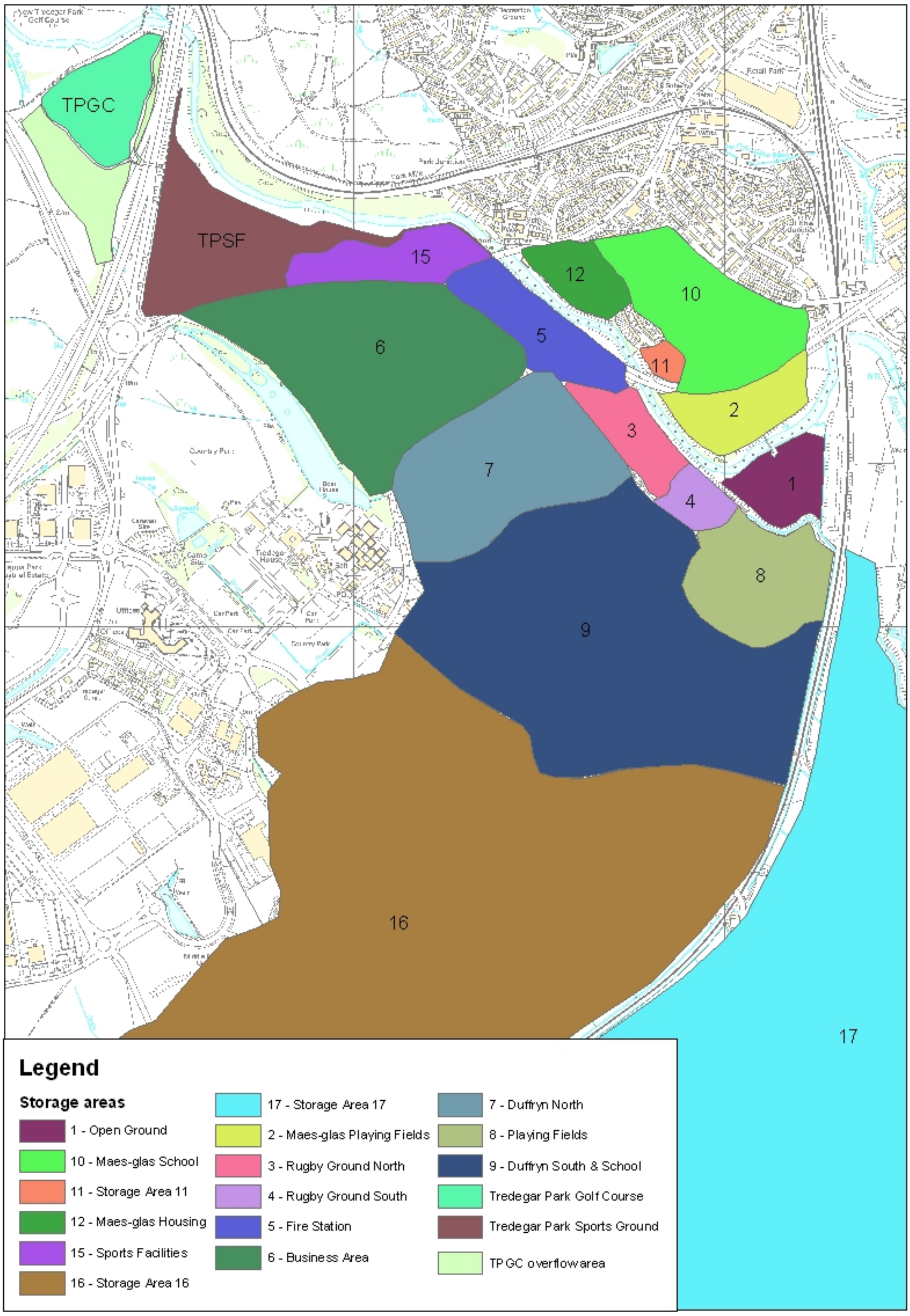


Table 2.1: Key floodplain storage areas used for pre-works versus post-works comparisons of flood levels and volumes (see Figures 2.1 for locations).

TPGC	Res1_Reser
TPSF	Sport14_Reser
Car Park (SA 15)	SA_15
Duffryn Fire Station	SA_5
Duffryn Offices	SA_6
Duffryn Estate	SA_7
Duffryn S	SA_9
Rugby Gd N	SA_3
Rugby Gd S	SA_4
Open Ground	SA_1
Duffryn Playing Fields	SA_8
Maes-G housing	SA_12
Lower Maes-Glas	SA_11
Playing fields	SA_2
Churchmead	
Park Row	

Table 2.2: Flood flows used in hydraulic modelling, with their approximate return periods

Flow	Qpk	m3/s	210	240	245	250	256	261	265	275	282	293	328	344	418	427	440	512
Return Period estimate by:																		
CF/HRW		y	50	100	105	115	130	145	160	200				1000				
JBA (1) March 2006		y								100			200					1000
JBA (2) October 2006		y				100						200				1000		
EAW (1) Jan 2008		y		100							200				1000			
EAW (2) Sept 2009		y				100						200					1000	
				indicates modelling has been undertaken using this design flow							n=12							

(3) Layout and features of the proposed Mk2 design scheme

1 The key elements of the proposed Mk2 flood management scheme (model code VB11_03a) are shown on Figures 3.1 (TPGC and TPSF combined), 3.2 (TPGC reservoir) and 3.3 (TPSF embankment) below.

2 The key features of the design are:

On the former TPGC:

- a flood control storage area of up to 146,133 m3 capacity (at 17.5 mAOD crest level) built into and behind (S & E) the existing Tramway embankment, with an inflow weir[1] taking floodwaters into storage at the 1:50y year level (16.35 mAOD), and a screw-gate penstock outflow structure allowing manually operated drainage of impounded floodwaters after a flood[2]. The inflow weir is located downstream of the Tramway, along the line shaded green on Figure 5.1, so as to avoid disturbing the Dwr Cymru Welsh Water sewer which runs within the Tramway embankment[3]. Various layouts and capacities of the storage area were modelled. The selected layout is Option 1 Design B (as shown in drawing RE2292-12), which is shown below as Figure 3.2. The perimeter of the new bund is shown in brown in Figure 3.1.

- a new flood conveyance channel (shaded light blue on Figure 3.1) running between the line of the main river to the west and the residential development area to the east, with width and depth varying along its length to provide hydro-geomorphological and ecological value as well as flood conveyance benefits.

- ground levels over the residential development area on part of the former TPGC (shaded pink on Figure 5.1) raised to the pre-works level of the 1:200y flood (taken to be 282 m3/s, per the EAW's 2008 analysis) plus 600mm, which raises the level to beyond that of the Q1000++ flow.

On the TPSF:

- a re-positioned and re-aligned flood embankment running along the right bank of the R Ebbw, to the line shown on Figure 3.3: the red lines show the position of the existing embankment, and the blue and purple lines show the line of the new embankment. The new embankment takes the line of the existing one downstream of the playing field area, alongside the access road from the car park. The profile of the new embankment corresponds to Design A for the section shown in blue, and Design B for the sections shown in purple. The top height of the new embankment will match that of the existing embankment.

- the top level of the existing flood embankment upstream of Ebbw Bridge is to be raised to correspond to profile RB3 of Figure 3.4 below, between chainages 4372.9m to 4064.9m (corresponding to distances 751m to 1019m on Figure 3.4), to infill the local low point via which floodwaters now flow from R Ebbw into the Tredegar Park

[1] A weir structure is hydraulically preferable to the use of culverts bored through the Tramway
[2] A manually operated arrangement is deemed preferable to an electronic one on reliability and maintenance grounds
[3] Hydraulic modelling with a longer weir located midway along the Tramway, as originally intended, as against in the reach between the Tramway footbridge and the M4 embankment revealed some deterioration in hydraulic performance with the weir in the latter position, but not to a limiting extent.

Sport Field car park and then over the A48 into Duffryn, to a level which provides improved protection to Duffryn without causing flooding in Maes Glas[4]

3 It should be noted that some of the works that were included in the preliminary Mk1 designs presented to the Appeal Inquiry in 2006 (and that were accordingly approved as part and as conditions of the planning approval granted by the WAG in 2007) have since been removed from the scheme design, to meet the requirements of the EAW and NCC, respectively, These are:

- no reduction in the bed level of R Ebbw in the reach around Ebbw Bridge, by clearance of accumulated materials (as modelled in one of the design options presented at the Appeal Inquiry);

- no construction of a flood storage reservoir on the TPSF, in favour of re-positioning of the existing linear flood embankment on TPSF in-field, to create a two-stage channel providing for increased flood storage and improved in the TPSF reach.

[4] The final elevation profile of the raised reach has been carefully determined by hydraulic modelling. Detailed levels are provided in Chapter 6 below.

Figure 3.1: Layout of the final Mk 2 design for flood management works

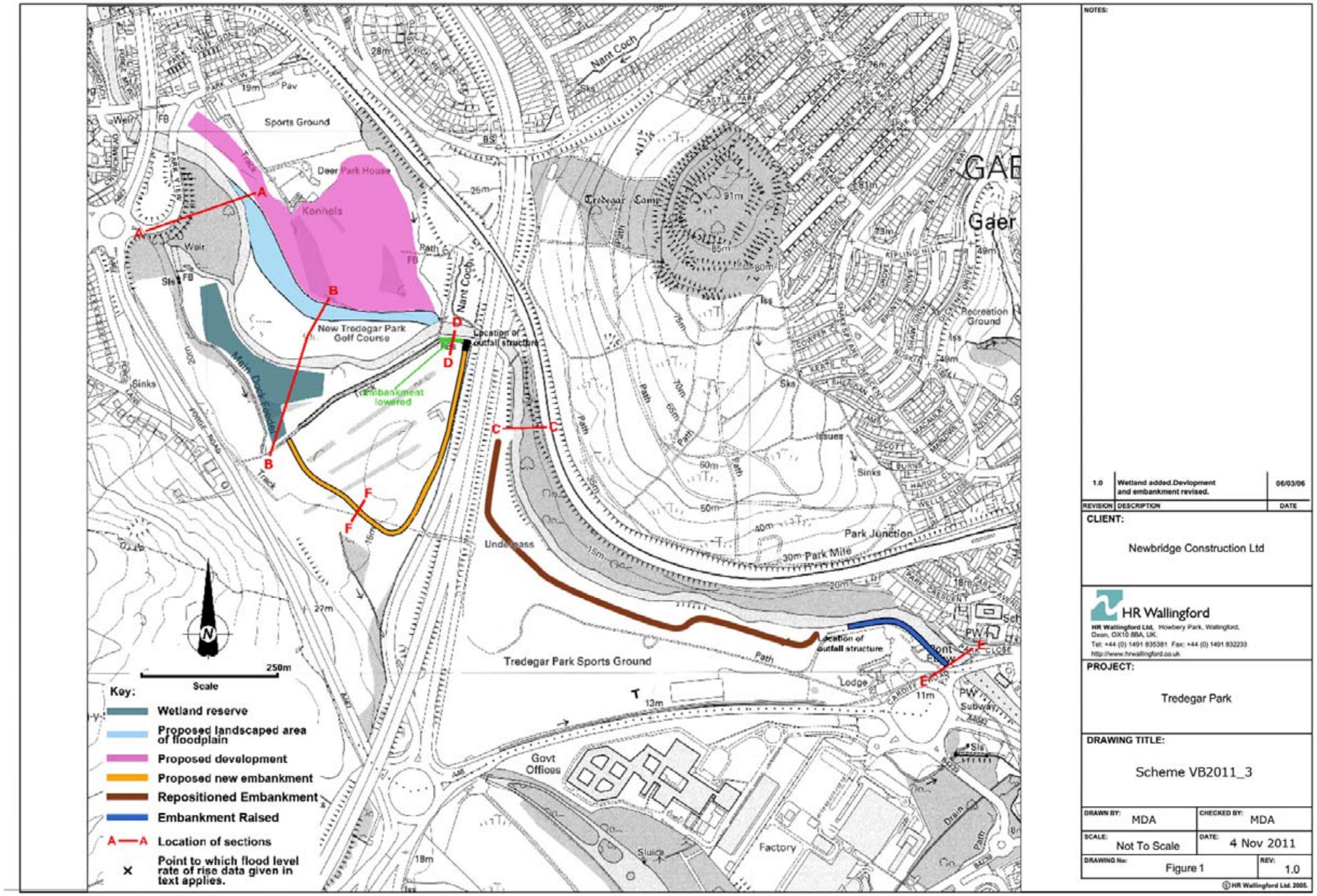
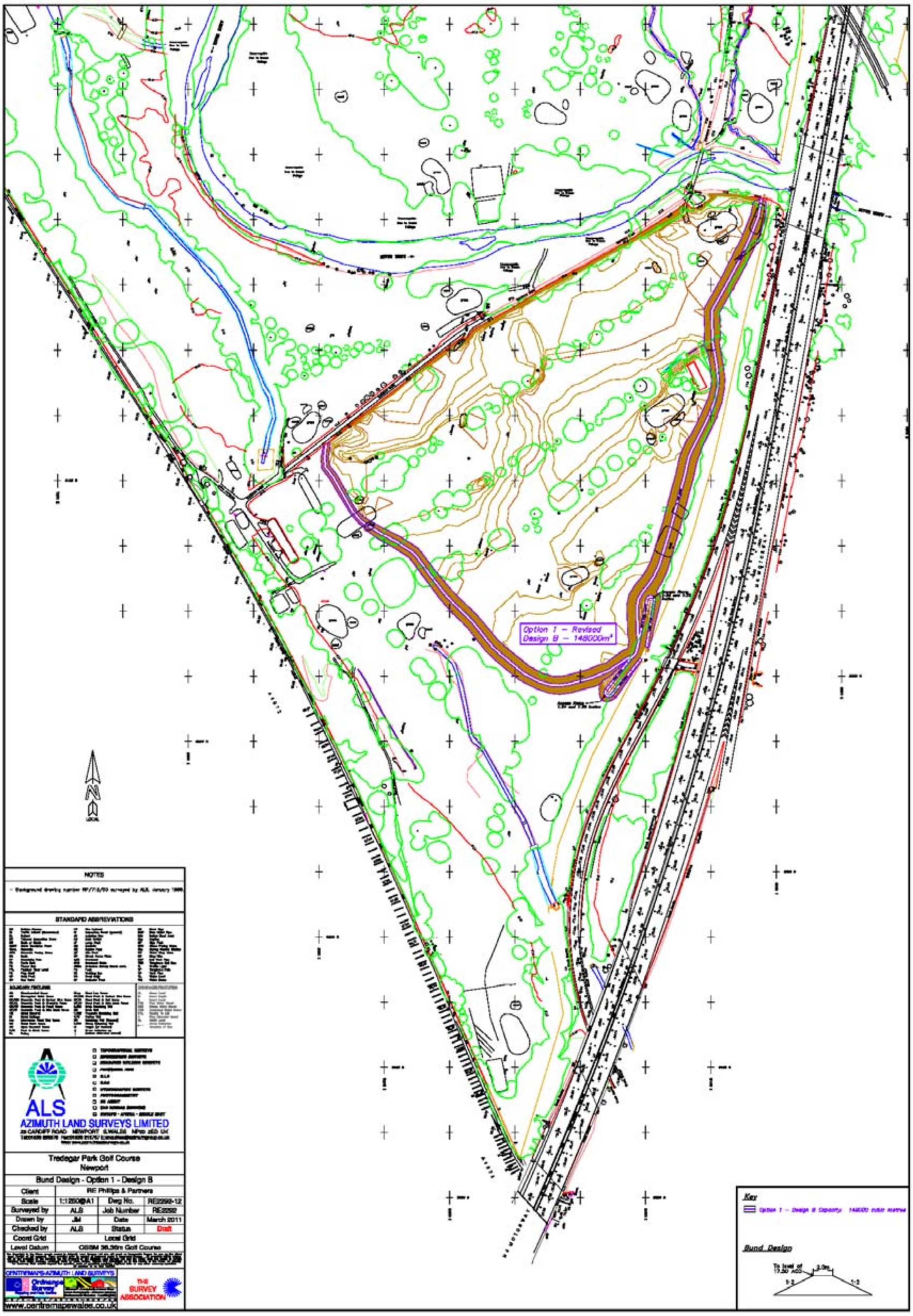


Figure 3.2: Layout of the Mk2 design storage reservoir on the TPGC (Option 1).



Note that the capacity of the TPGC reservoir to embankment top (17.5 mAOD) is 146,133m3, not the 148,000m3 estimate shown on the diagram (this estimate is from a MOSS model of the design)

Figure 3.3: Realignment of the flood embankment on the TPSF.

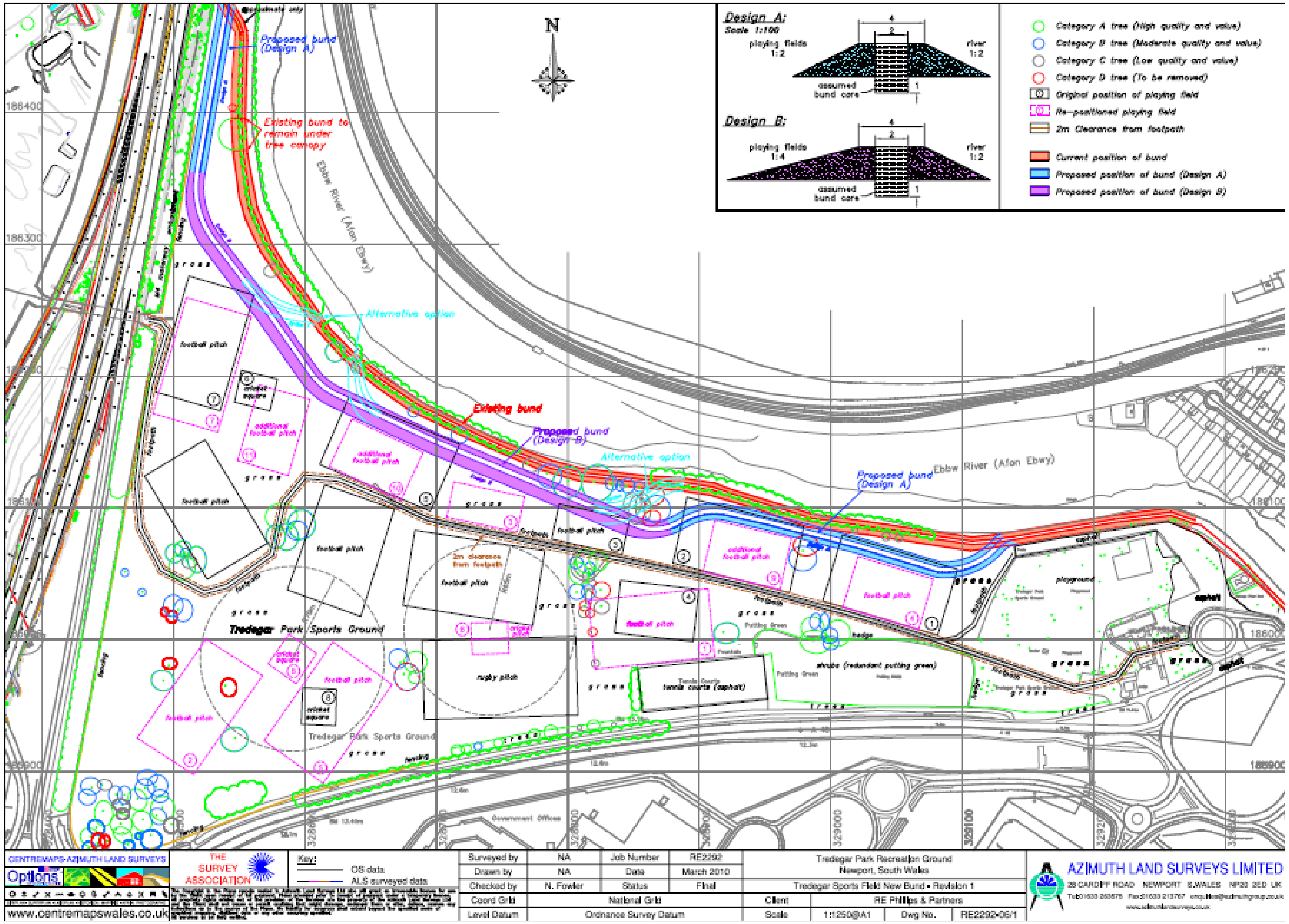
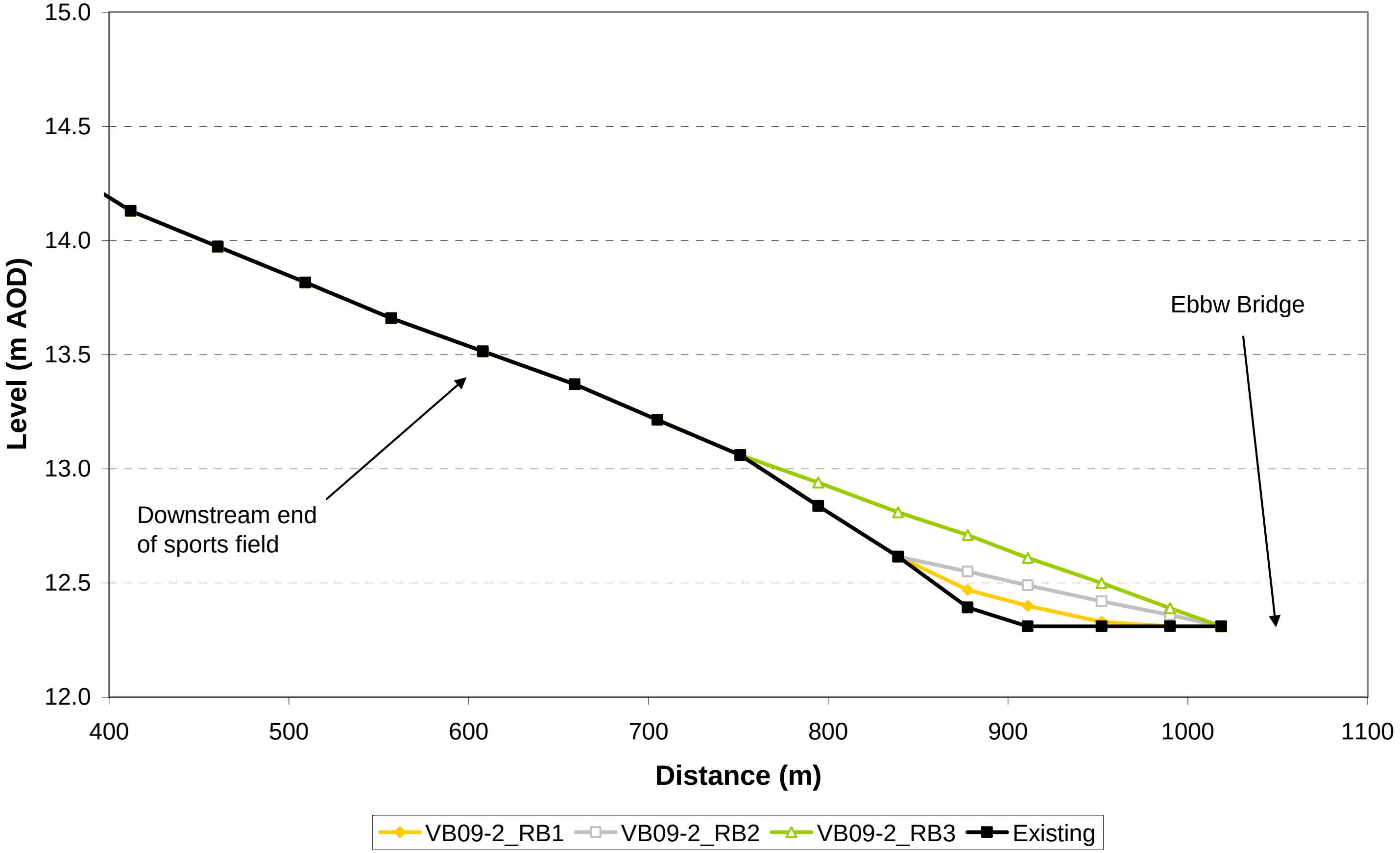


Figure 3.4: Existing and design profiles of the top of the right bank above Ebbw Bridge. The Mk2 design (VB11_03a) uses the RB3 profile



(4) Performance of the final Mk2 design

Overall performance

1 The proposed final Mk2 design produces the required performance characteristics in respect of all of the planning conditions stipulated by the WG, whilst complying with the additional constraints requested by the EAW and NCC.

2 With the VB11_03a Mk2 layout and design parameters defined in outline in section 3 above, the proposed scheme of flood management works delivers:

- no exacerbation in flood levels upstream of the development, in events up to and including the Q1000, Q1000+ and Q1000++ flood flows of 344 m3/s, 418 m3/s and 440 m3/s, respectively;

- an improvement in the threshold of flooding into Duffryn, from around the Q100 flood event to around the Q180 flood event (>240m3/s<245m3/s to >265m3/s<275m3/s).

- lower flood water levels within Duffryn than is now the case, in all flood events up to and including the Q1000 event of 344 m3/s;

- significantly lower floodwater levels within Duffryn than is now the case in the 440 m3/s flood events (with average floodwater levels in the ten relevant flood cells being 56mm lower post-scheme compared to pre-scheme (min -58mm, max -11mm), within an error band of ±15mm);

- no exacerbation in flood levels downstream of Ebbw Bridge, in either St Brides Gardens (SA_12) or in the low lying area around Dingle Cottage (SA_11), in events up to the Q1000, Q1000+ and Q1000++ flood flows of 344 m3/s, 418 m3/s and 440 m3/s, respectively;

Floodwater level impacts in extreme flood events

3 Table 4.1(a) below shows estimated floodwater levels on the TPGC, on the TPSF, in Duffryn and in Maes Glas, for the pre-works (baseline) and the Mk2 design post-works situations in the 344 m3/s Q1000 event, and in the 440 m3/s Q1000++ (sensitivity test) flood event. Table 4.1 (b) shows the corresponding differences in floodwater level in the post-works versus pre-works conditions. The flood cells codes are explained in Table 3.1 above. Minus values in Table 4.1(b) indicate a reduction in floodwater levels post-works versus pre-works, whilst positive values indicate an increase in levels. The flood cells coded Res1_RESER and SA_1 are flood storage cells that are designed to take floodwaters into storage in the Mk2 design, so increases in depth in those cells is intended, and is of no concern. Sport14_RESER is the code given to the Mk1 design reservoir on the TPSF; it is not used as a design storage cell in the Mk2 model,[5] and the name is simply a hang-over from the Mk1 modelling work previously undertaken.

4 It can be seen from Tables 4.1(a) and (b) that there is no flooding in the St Bride's Gardens (SA_12) or Dingle Cottage (SA_11) areas of Maes Glas in either the 344m3/s or the 440 m3/s flows (Q1000, Q1000++, respectively), post-works. The data also show that

[5] Except in flows of >200y return period, when the embankment will be overtopped 'naturally', as it is now.

floodwater levels in Duffryn are significantly lower, post-works compared to pre-works in the 344 m3/s Q1000 event (and indeed in all events lower than that flow, as can be confirmed from the flood maps presented below), and also in the (EAW's preferred) 440 m3/s Q1000++ event.

Flood extent maps in flood events from Q100 to Q1000++

5 Figures 4.1 and 4.2 show the extent of flooding in the 1:100 (Q100) and 1:105 years return period events under existing (baseline, pre-works) conditions. It can be sent that Duffryn does not flood in the Q100 event, but does flood in the Q105 event. Its current standard of safety for flooding is >240<245 m3/s (that is, between 100 and 105 years return period).

6 Figure 4.3 shows the extent of flooding in the 265 m3/s (Q160) event, under pre-works (upper diagram) and post Mk2 works conditions (lower diagram). It can bee sent that whilst the extent of flooding into Duffryn in this event under existing (pre-works) conditions is significant, no flooding into Duffryn occurs under the Mk 2 post-works design.

7 Figure 4.4 shows the extent of pre-works and post-works flooding in the 282 m3/s (Q200) event. Duffryn experiences flooding in this event under the post-works design, but to a far lower extent (and depth) than under pre-works (existing) conditions. The threshold of flooding into Duffryn post-works is between 265 m3/s and 282 m3/s (>Q160<Q200), compared to between 240 m3/s and 245 m3/s pre-works (>Q100<Q105).

8 Figures 4.5 and 4.6 show pre-works and post-works flood extent maps for the 344 m3/s (Q1000) and 440 m3/s (Q1000++) events, respectively. The extent and depth of flooding into Duffryn is smaller post-works than pre-works in both events.

9 These results show that the proposed Mk2 scheme produces tangible reductions in flood risk (improvements in flood protection) in Duffryn, in terms of both (a) raising the threshold event in which flooding occurs (from just over the 1:100 years event to around the 180y event)[6] and (b) decreasing the depth of flooding above the inundation threshold (as noted above). In all events up to and including the extreme Q1000++ estimate of 440, m3/s, no deterioration in flood risk (post-works versus pre-works) occurs either downstream in the SA_12 (St Brides Gardens) area of Maes Glas (in fulfilment of condition A18 d), or upstream, in the Churchmead (R bank) or Park View (L bank) areas around Bassaleg Bridge (in fulfilment of condition A18 e), without any remedial works being needed in either case. Details showing the situation to be so are provided in the main technical report on the work undertaken (CFonstream Report Nr 06009.2, November 2011).

No worsening of flood risk downstream of Ebbw Bridge

10 Condition A18d of the WG approval specifies that "Measures to ensure that there is no increased risk of flooding to St Brides Gardens, Maes Glas" must be proposed and approved prior to the commencement of works. The condition arises from the observation made in evidence presented to the Appeal Inquiry, in October 2006[7] that the proposed works, as then modelled, led to slight overtopping of the left flood embankment below Ebbw Bridge in the Q1000, 344 m3/s, event[8] and thence to localised flooding in St Brides Gardens, Maes Glas.

[6] The event that that is known to produce flooding in Duffryn now (pre-works) is the 105y (245 m3/s) flood, and that which does so post-works is the HRW 200y (275 m3/s) flood.
[7] Ref document CF/1, chapter 8.
[8] But not in events of lower magnitude / higher frequency

11 The final Mk2 design for flood works - with the right bank above Ebbw Bridge raised to the RB3 profile to protect Duffryn in Q100 to Q180 scale events - ensures that no overtopping of the left flood bank below Ebbw Bridge and no flooding in St Brides Gardens, in fulfilment of condition A 18d. It does so not just in the 344 m3/s Q1000 event that produced flooding into St Brides Gardens under the designs presented at the Inquiry, but in the much higher 418 m3/s (Q1000+) and 440 m3/s (Q1000++) events, too. The final design also provides for no flooding over the right flood bank upstream of Ebbw Bridge in events as high as the Q180, to the considerable benefit of Duffryn, whilst achieving the required conditions of delivering no exacerbation of flooding in the SA_12 (St Bride's Gardens) and SA_11 (Dingle Cottage) storage areas in Maes Glas.

No worsening of flooding upstream of the development

12 Condition A18e of the WAG approval specifies that "Measures to prevent the exacerbation of flood water levels upstream of the former Tredegar Park Golf Course by the development hereby approved" must be proposed and approved prior to the commencement of works. The condition arises from the observation made in evidence presented to the Appeal Inquiry, in October 2006[9] that the proposed works, as then envisaged and hydraulically modelled, led to a small increase[10] in floodwater levels at and upstream of the residential development site. Assurances were made at the Inquiry that the cause of the apparent increase in water depth would be determined, as between the possibilities of it being either real or merely an artefact of prediction instability at the model boundary. Assurances were also made that should the conclusion be the former of the two options, appropriate measures would be proposed to ensure that there would be no consequential deterioration in exposure to flooding for people and properties in the upstream reach.

13 The situation has been examined since, first by undertaking backwater curve analyses to determine the upstream propagation distance of any increase in water level due to the proposed scheme, and then, for reasons of greater accuracy given the availability of appropriate survey data, by extending the hydraulic model upstream, by 850m.

14 Detailed field investigations of flood sources, pathways and possible receptors in the reach upstream of the development site have been undertaken, to identify sites that might be placed at increased exposure to flood risk from an increase in floodwater levels of the modelled extent, throughout the affected reach – which extends upstream to but not beyond the weir at Bassaleg Bridge.

15 Three sites at potential risk of an increased exposure to flooding were identified in initial analyses: the Ambulance Station and Funeral Directors premises on Park View; the properties along Park Row; and the properties along Churchmead, on the right bank of R Ebbw upstream adjacent to Bassaleg Bridge weir, upstream of the A467 road bridge. The area on the left bank of R Ebbw, between the Park View and A467 bridges was resurveyed, to provide reliable data on the levels of the existing riverbank flood wall and the land beyond it, towards Park Row.

16 The conclusions reached from comparing surveyed levels and simulated floodwater levels are that none of the three potentially at risk sites are in fact at risk of an increased exposure to flooding due to the development and its associated works, in events up to and including the Q1000+ flow of 418 m3/s (and the Q1000++ flow of 440 m3/s). In the case

[9] Ref document CF/1 v6.4, Proof of Evidence of Dr Colin Fenn on Flood Risk and Related Matters
[10] Then estimated, in the 344 m3/s (Q1000) event, to be 81mm at Point A, by the development site and 50 mm at the head of the model, below Park View bridge.

of the Ambulance Station site, there are preventative measures in the development site design to remove the flood pathway to that Ambulance Station site. Inspection of the flood maps given as Figures 5.4 to 5.12 above confirm the improvement in flood protection that the proposed works produce for this site. In the case of the properties along Park Row, the lowest height of the existing flood wall on the left bank of R Ebbw between the Park View and A467 road bridges is above the level of the predicted Q1000+ (and Q1000++) flood level, hence no flood pathway exists to create a flood risk in even that exceptionally extreme event. In the case of the properties along Churchmead, the scheme provides positive benefit in reducing peak flood water levels in the pertinent part of the reach, in all events to and including the Q1000+ (and the Q1000++) flood. Full details are provided in CFonstream Report 06009.2, November 2011.

Table 4.1: (a) Floodwater depths and (b) floodwater depth differences on the floodplains of the TPGC, the TPSF, Duffryn and Maes Glas, final Mk2 design scheme versus baseline. See Figure 3.1 for locations of the storage areas.

(a) Floodwater depths in defined flood cells in the 344 m3/s and 440 m3/s floods, post-works Mk2 design scheme

Storage Areas	Bank	344 m^3/s	440 m^3/s
SA_12	Left	0	0
SA_11	Left	0	0
SA_2	Left	0	0
SA_10	Left	0	0
Res1_RESER	Right	2.840	3.334
Sport14_RESER	Right	0.555	0.832
SA_15	Right	1.214	1.491
SA_6	Right	0.786	1.055
SA_5	Right	0.850	1.169
SA_7	Right	0.803	1.046
SA_3	Right	0.813	1.051
SA_4	Right	0.555	0.697
SA_9	Right	0.777	1.101
SA_1	Right	3.127	3.159
SA_8	Right	0.482	0.850
SA_16	Right	1.228	2.675
SA_17	Right	0.171	0.520

Note that no flooding occurs in SA_12 (St Bride's Gardens) or SA_11 (Dingle Cottage)

(b) Difference in floodplain water depths for the post-works Mk2 design compared to existing conditions

Storage Areas	Bank	344 m^3/s	440 m^3/s
SA_12	Left	0	0
SA_11	Left	0	0
SA_2	Left	0	0
SA_10	Left	0	0
Res1_RESER	Right	1.439	-0.416
Sport14_RESER	Right	-0.053	-0.054
SA_15	Right	-0.053	-0.054
SA_6	Right	-0.049	-0.047
SA_5	Right	-0.046	-0.036
SA_7	Right	-0.038	-0.033
SA_3	Right	-0.036	-0.032
SA_4	Right	-0.020	-0.018
SA_9	Right	-0.049	-0.014
SA_1	Right	0.076	0.081
SA_8	Right	-0.032	-0.011
SA_16	Right	-0.296	-0.034
SA_17	Right	-0.053	-0.058

Figure 4.1: Flood extent map, pre-scheme 240 m3/s, Q100 flood event

PRE-WORKS 240 m³/s, Q100

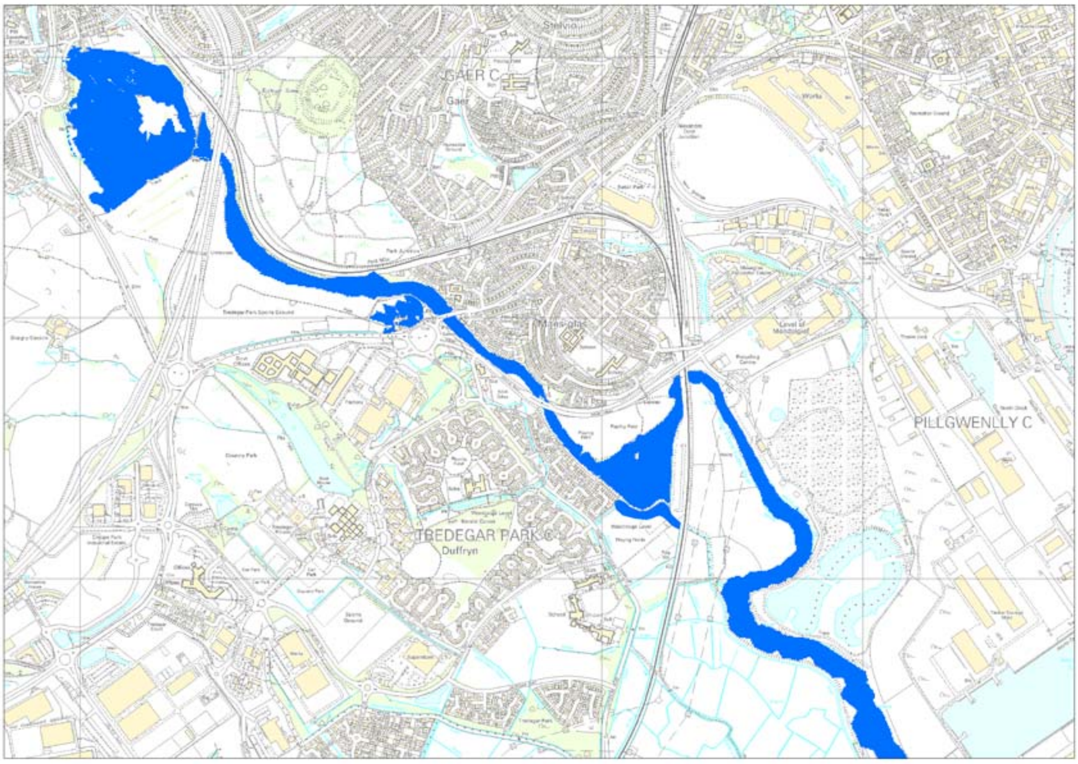


Figure 4.2: Flood extent map, pre-scheme 245 m3/s, Q105 flood event

PRE-WORKS 245 m³/s, Q105

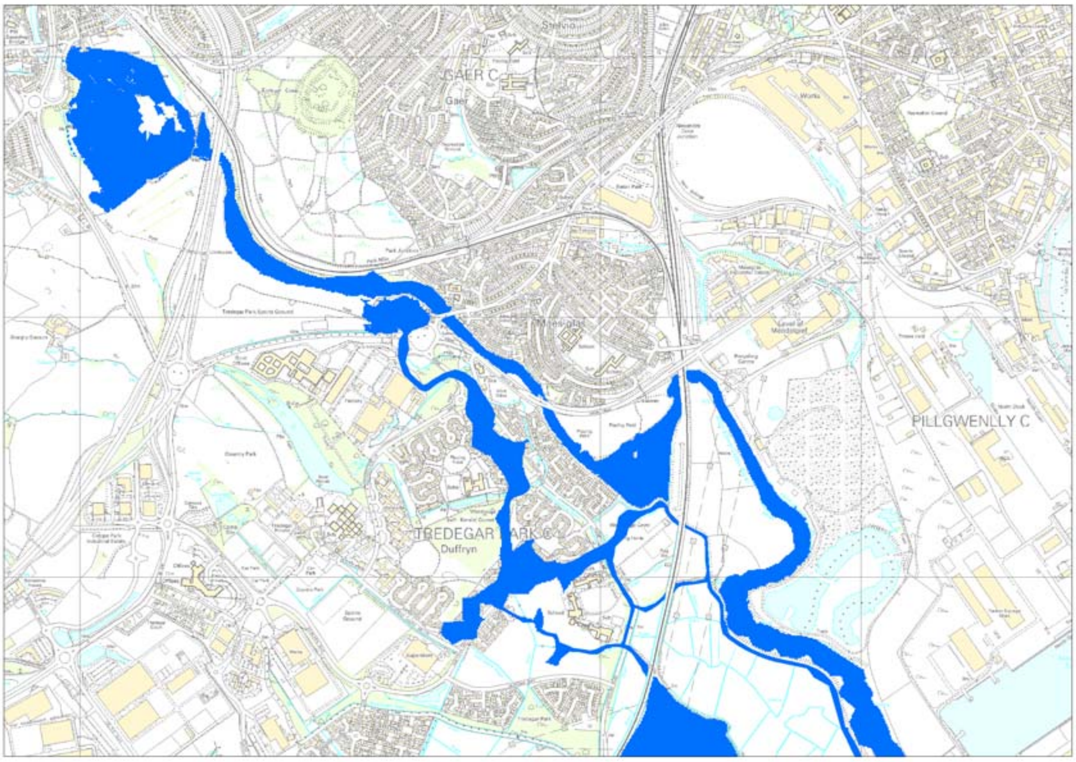
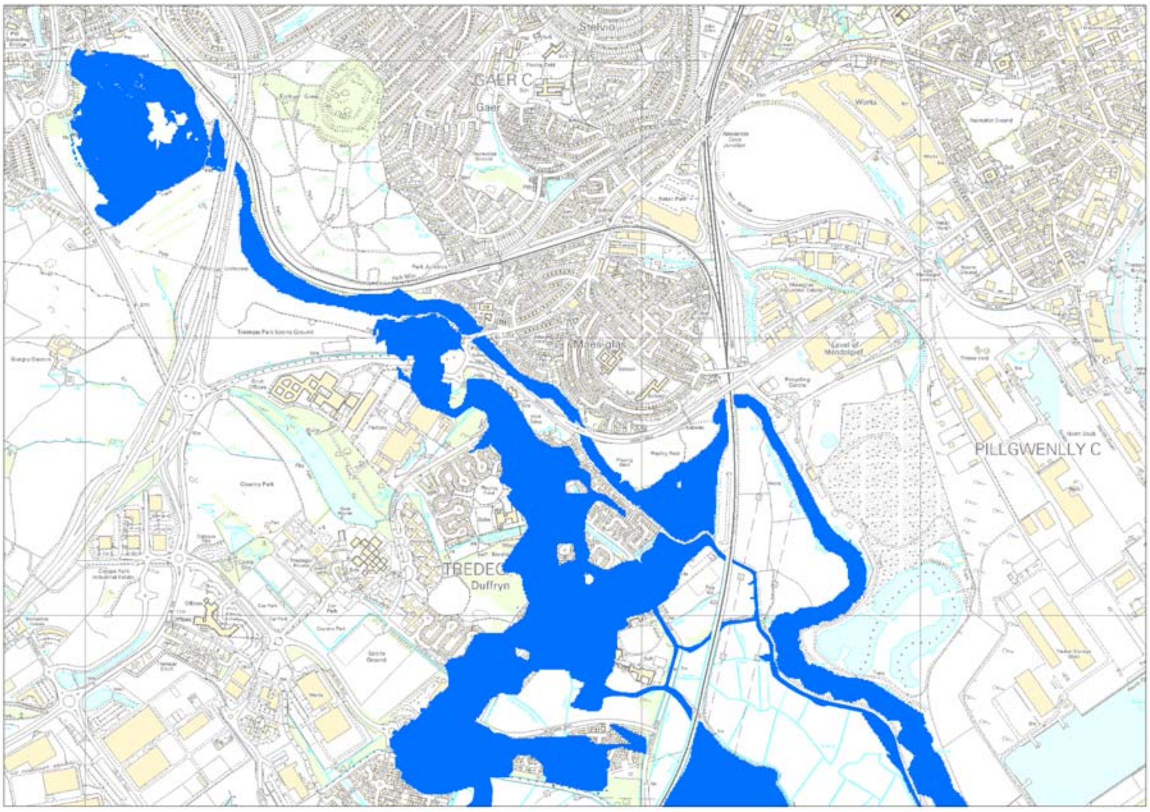


Figure 4.3: Flood extent maps, pre-scheme (top) and post-scheme (bottom), 265 m3/s, Q160 flood event, VB11_03A design

PRE-WORKS 265 m3/s Q160



POST-WORKS 265 m3/s, Q160

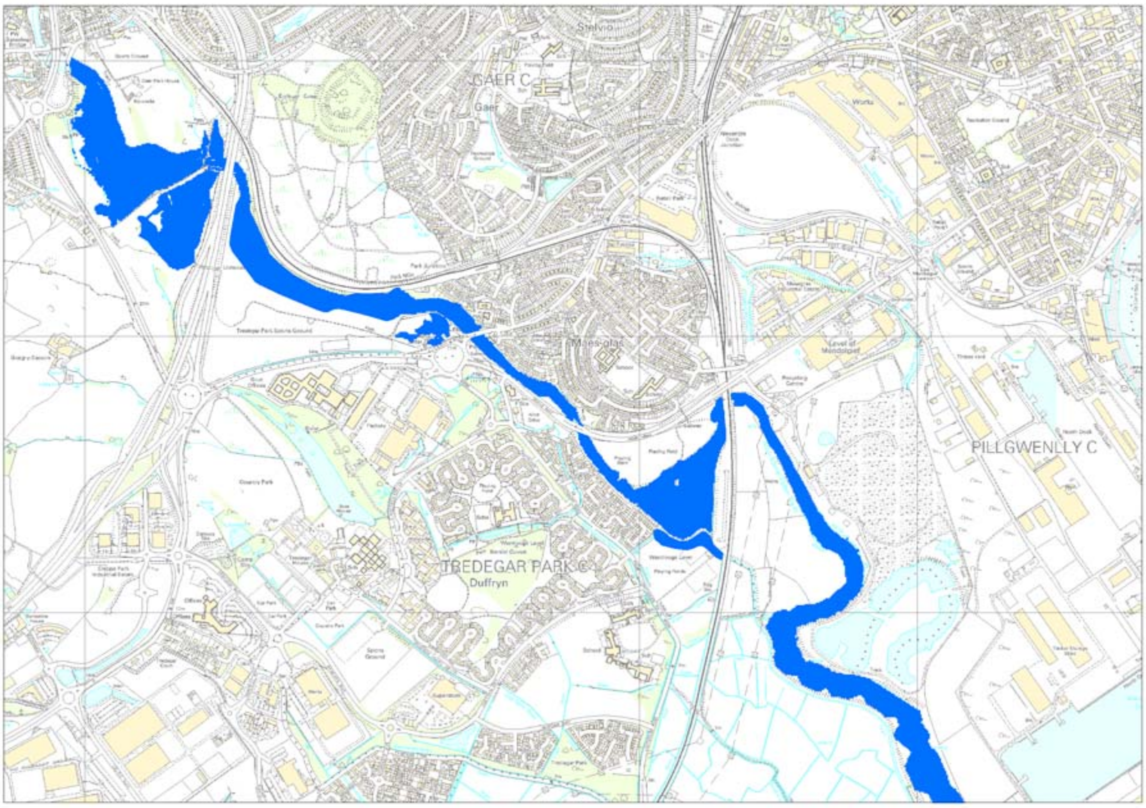
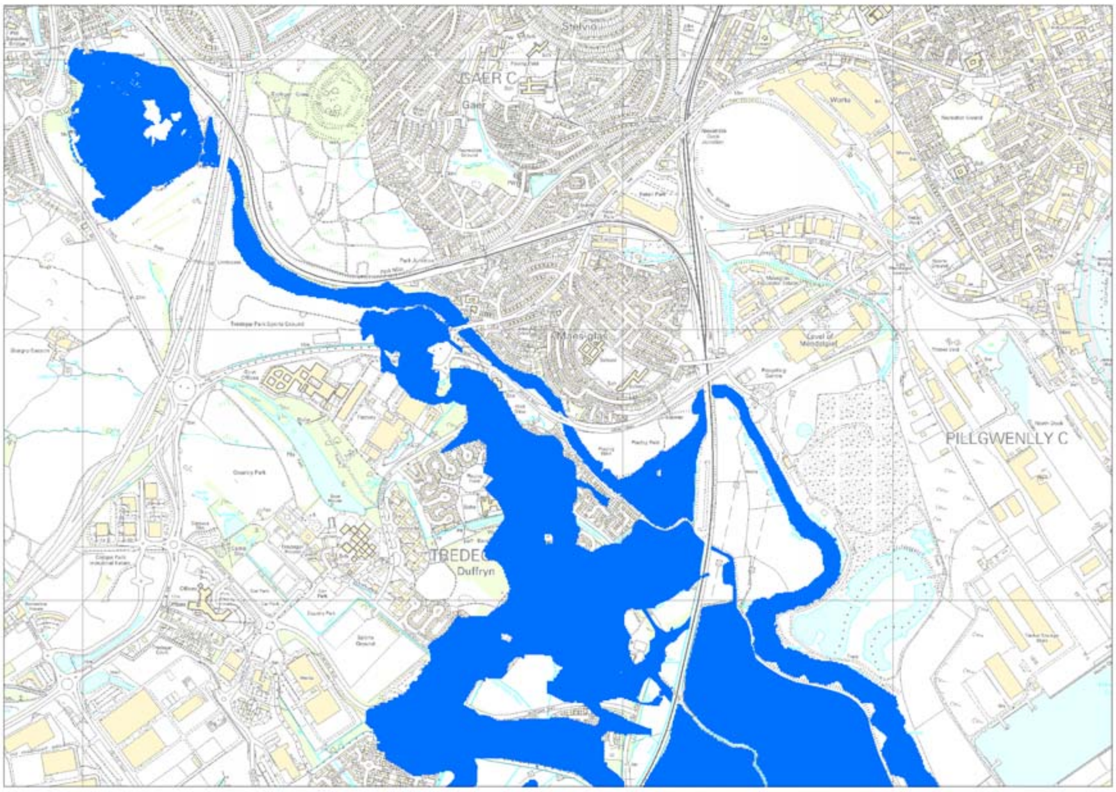


Figure 4.4: Flood extent maps, pre-scheme (top) and post-scheme (bottom), 282 m3/s, (EAW) Q200 flood event, VB11_03A design

PRE-WORKS 282 m3/s Q200 (EAW)



POST-WORKS 282 m3/s, Q200 (EAW)

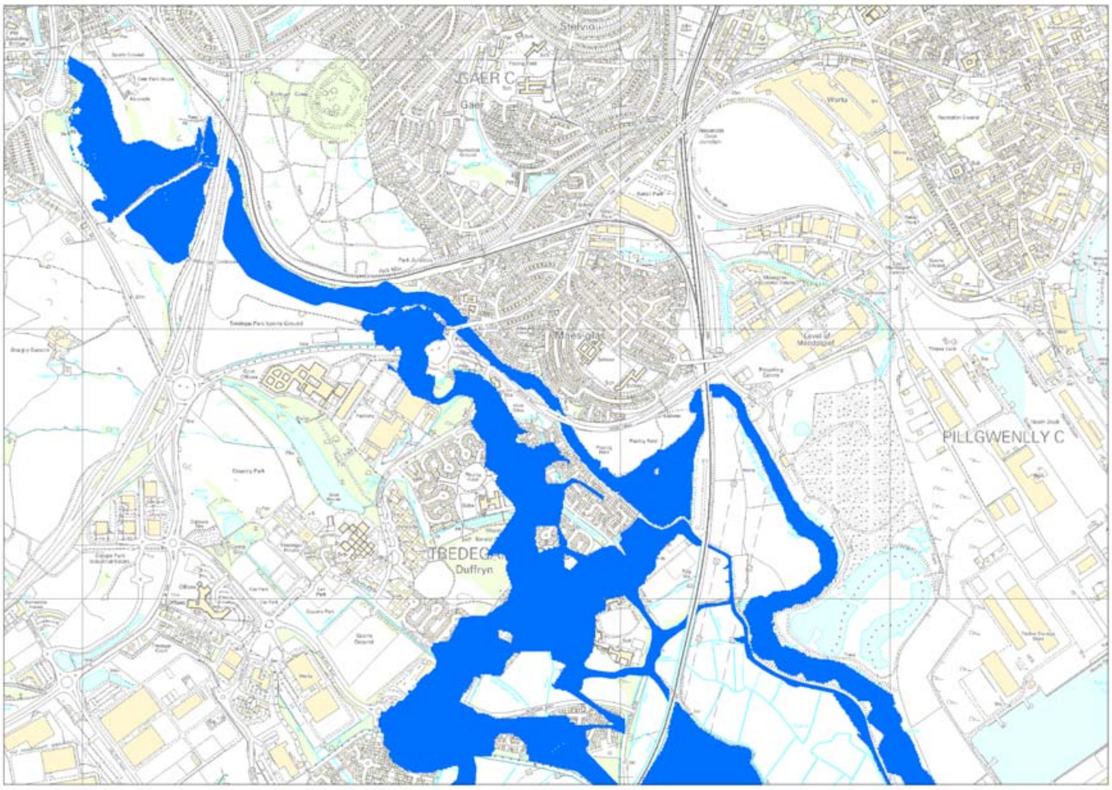
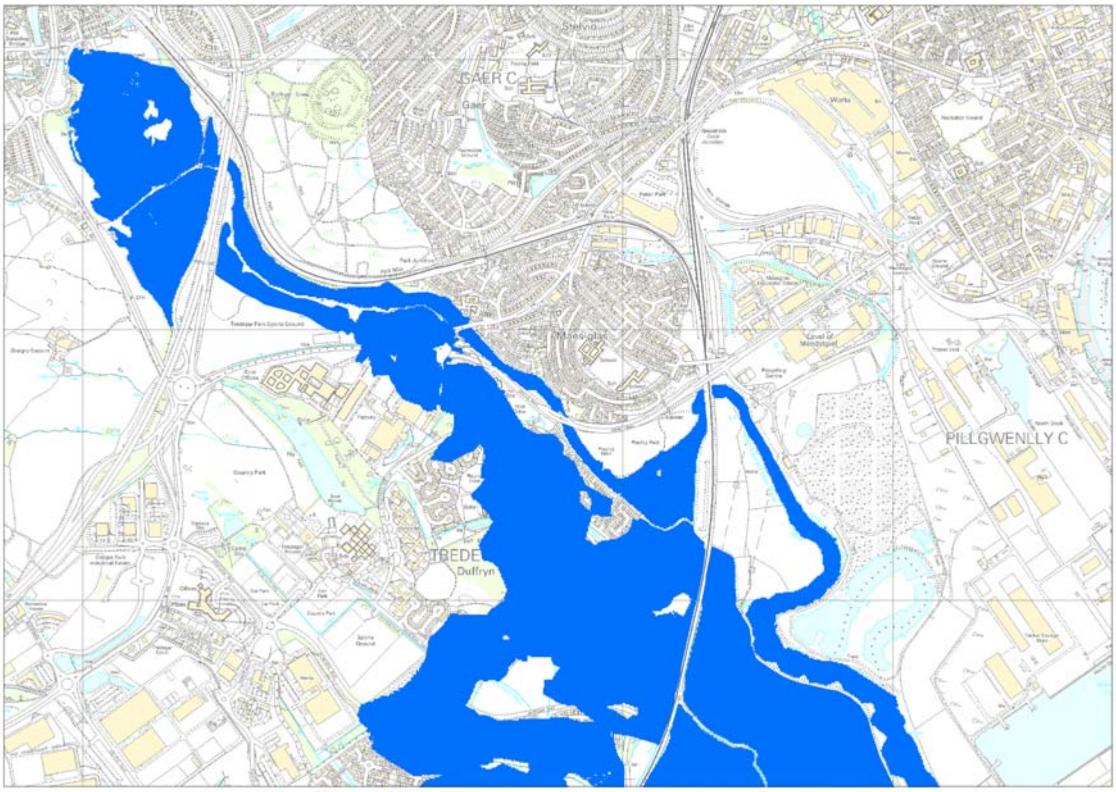


Figure 4.5: Flood extent maps, pre-scheme (top) and post-scheme (bottom), 344 m3/s, Q1000 flood event, VB11_03A design

PRE-WORKS 344 m3/s, Q1000



POST-WORKS 344 m3/s, Q1000

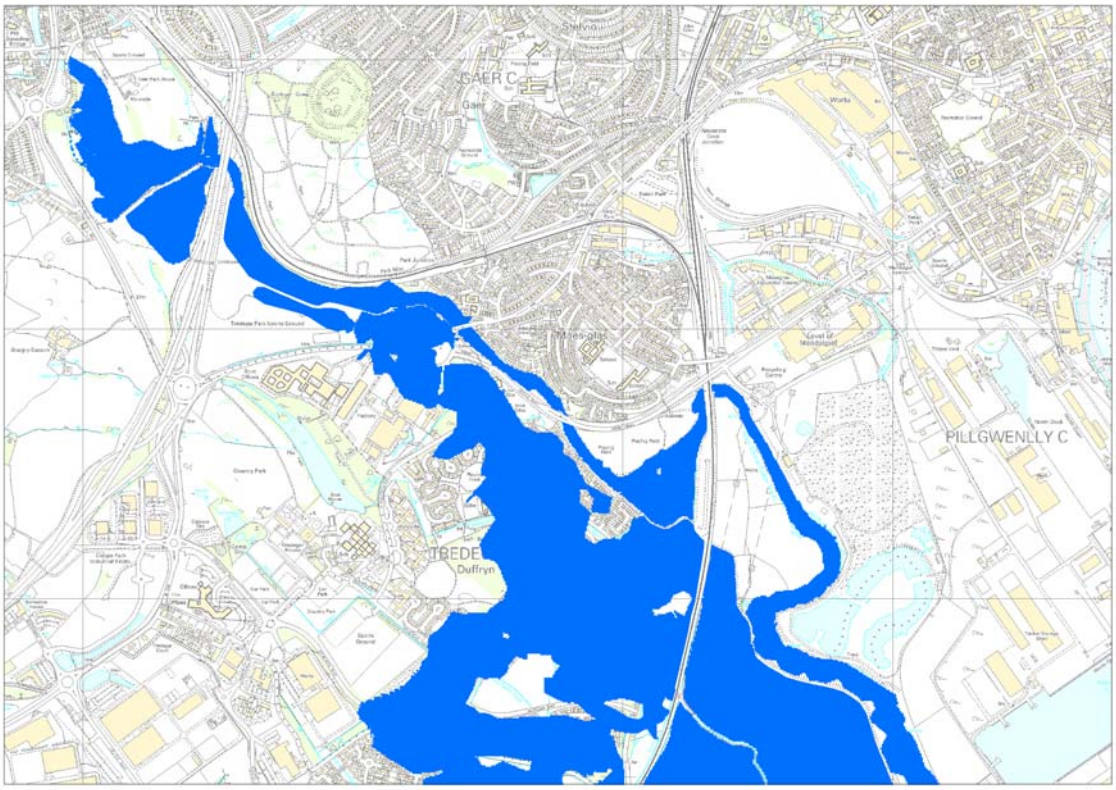
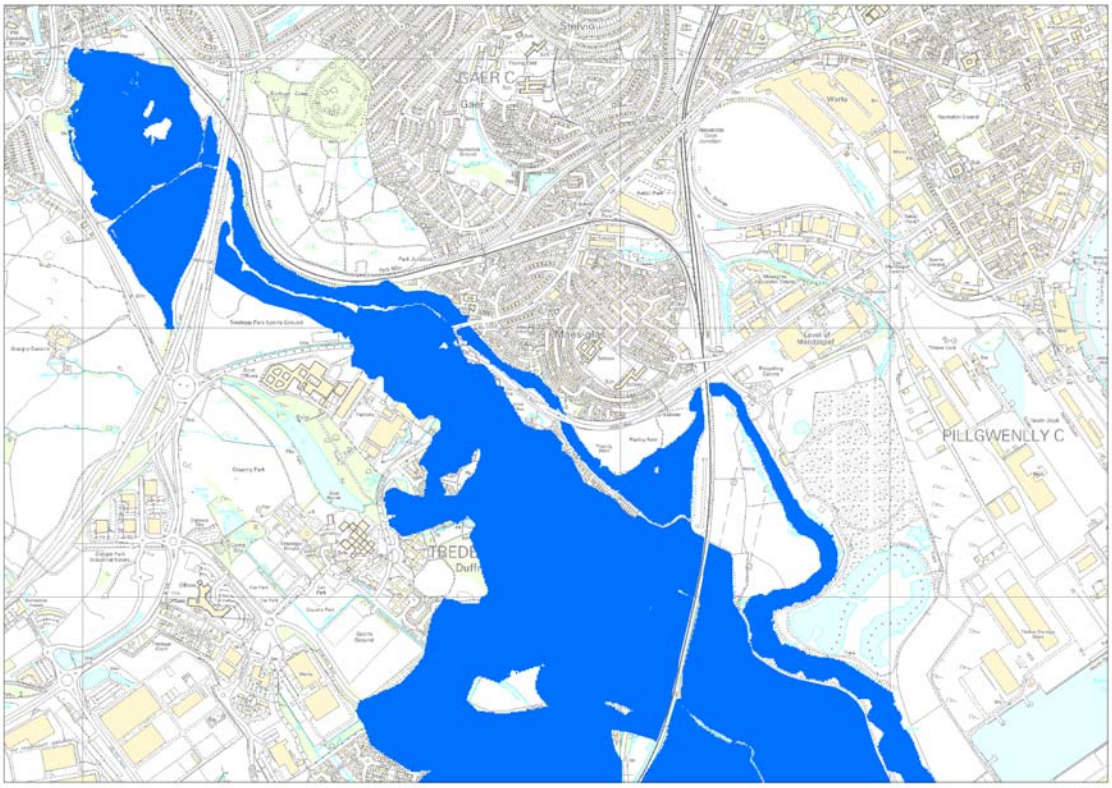
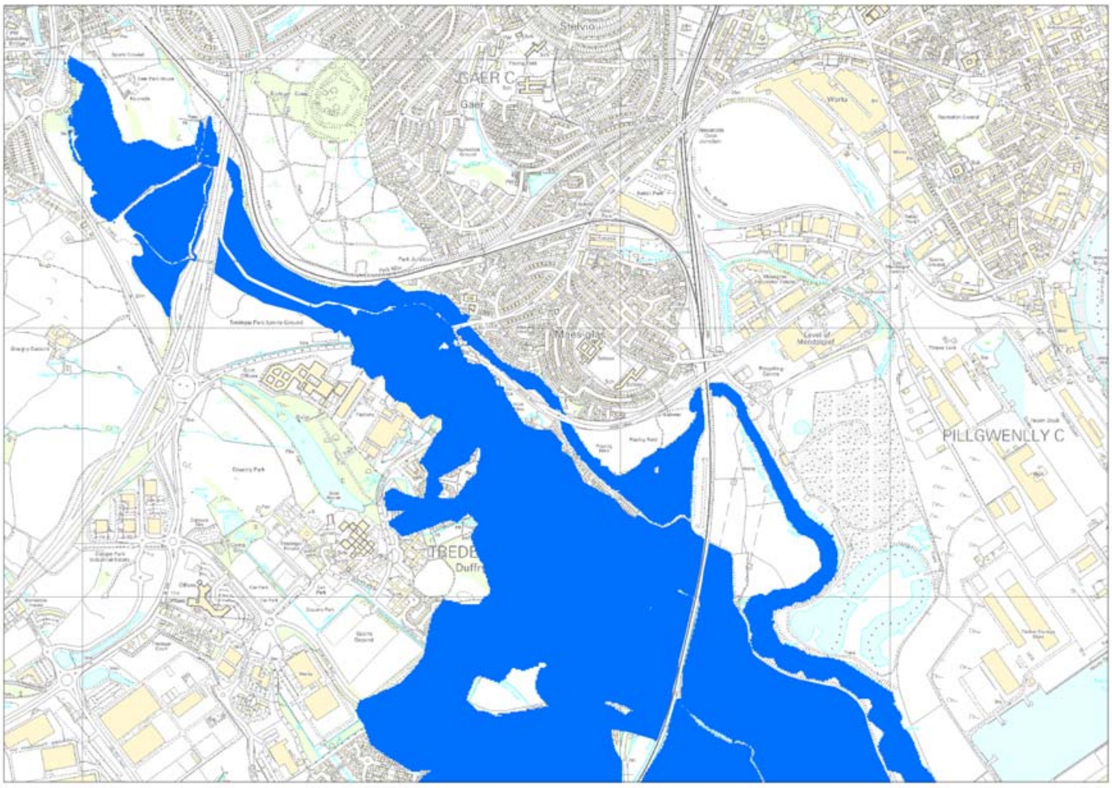


Figure 4.6: Flood extent maps, pre-scheme (top) and post-scheme (bottom), 440 m3/s, Q1000++ flood event, VB11_03A design

PRE-WORKS 440 m3/s, Q1000++



POST-WORKS 440 m3/s, Q1000++



(5) Checklist of performance against planning conditions and other constraints

1 Table 5.1 below summarises the performance of the final Mk2 design against the conditions laid down by the WAG's approval letter of 22 March 2007, and against the additional conditions requested by the EAW and NCC. All of the requirements specified by the WAG, the EAW and NCC have been met, whilst delivering an improvement in flood risk protection to the people, properties and businesses of Duffryn without detriment to flood risk standards elsewhere, both upstream and downstream of the development.

Table 5.1: Summary checklist of final Mk2 flood management design measures compared to the planning conditions specified by the WAG and the additional stipulations made by the EAW and NCC – flood management works on the TPGC and TPSF combined

Conditions in WAG planning consent, or set subsequently by the EAW/ NCC		**Means and extent of incorporation into the final Mk2 design of flood management works**
A5, B3	Prior to the commencement of development, full details of the means of securing and implementing the future management of flood defence works [on the TPGC and the TPSF] shall be submitted to and approved in writing by the local planning authority. The flood defence works shall then be maintained in accordance with the approved management plan.	Chapter 7 provides outline design specifications for all of the flood management measures proposed. Detailed designs will be provided separately. Chapter 8 of this report provides a maintenance plan for the proposed flood management works.
A18, B11	Prior to the commencement of development, full details of the proposed flood alleviation works [on the TPGC and the TPSF] shall be submitted to and approved in writing by the local planning authority. The submitted details shall include:	To be provided separately, in a detailed design report to be prepared on the basis of the overall design proposed in this report and using the outline engineering specifications provided in this report.
A18a)	The raising of the residential area to the level of the existing 1:200 year flood event level (0.5% probability event) peak flow of the River Ebbw plus a further 600mm;	Provided for fully in the Mk 2 final design proposed in this report. Figures 6.3 and 6.4 show the base level of the residential development area, and the volume of fill required to achieve that base level. (using a value of 282 m3/s for the Q200 flood flow). *Comment: This condition is taken to mean that the base level of the housing site is to be at the pre-development level of the 1:200y (282 m3/s) flood, plus a further 600mm.*
A18b)	Full details of the proposed works to the tramroad embankment and the proposed associated bund, including details of all discharge outlets, to provide a flood water storage capacity of 101,600 cubic metres or more.	The final design provides for flood storage on the TPGC of 127,121 m3 capacity, net of appropriate freeboard (146,133 m3 gross), with retaining bunds having 1:2 side slopes built to a top level of 17.5 mAOD. The inflow level to storage is set at 16.35 mAOD, the level of the 1:50y flood. The inflow weir is located between the tramway footbridge and the M4 bridge, to avoid the Dwr Cymru pipeline set within the main length of the tramroad. Outline design specifications of the inflow weir and the outlet structure are provided in chapter 5 of this report. Detailed designs are to be prepared using the outline engineering specifications provided in this report.
A18c)	Provision of a corridor of land between the housing development and the main channel of R Ebbw to provide an overflow channel to ensure improved conveyance of out of bank high flows on the river (to incorporate wetlands), as shown on the Concept Masterplan appended to the Design Statement dated Jan 2006;	The Mk2 final design provides for a flood conveyance channel as specified, with average dimensions of 25~30 m width and 1.5~2.0 m depth, varying along the channel to provide hydrogeomorphological and habitat value. Appropriate erosion protection will be provided for the bed and banks of R Ebbw and the flood channel, in the inlet and outlet reaches.
A18d)	Measures to ensure that there is no increased risk of flooding to St Brides Gardens, Maes Glas;	Provided for fully in the proposed Mk2 final design, with the embankment below Ebbw Bridge set to a minimum elevation of 11.9.0 mAOD. The proposed design has no adverse impacts in SA12, the St Brides Gardens area of Maes Glas, or in SA_11, around Dingle Cottage, in the Q1000 event of 344 m3/s, and above, including at 440 m3/s.
A18e)	Measures to prevent the exacerbation of flood water levels upstream of the former Tredegar Park Golf Course by the development hereby approved.	Provided for fully in the proposed Mk2 final design. The proposed design has no adverse flood risk impacts in areas upstream of the development site, on either the right bank or the left bank of R Ebbw, up to and above Bassaleg Weir, in events up to and including the Q1000 flood event of 344 m3/s and 440 m3/s.
B11a)	Details of the timings, frequency and measures to secure the clearing of gravels from the river bed at Pont Ebbw;	Made redundant by adoption of the EAW's request to remove the option of clearing gravels from Pont Ebbw.
B11b)	Full details of the proposed lowering of the existing flood defence embankment and the proposed bund on the sports ground, including details of all outlet structures, to provide a flood water storage capacity of 163,200 cubic metres or more.	Abandoned. Replaced by re-positioning the existing flood embankment on the right bank of R Ebbw through the TPSF in-field, This creates a two stage flood channel along the TPSF, which increases storage and improves flood conveyance. This Mk2 design meets the request of NCC Leisure Department to avoid use of the TPSF as a flood storage location in events less severe than at present. The new embankment will be constructed to an approved design and to the same height as the existing embankment that it will replace. A construction method statement to ensure flood risk protection during construction will be provided. Detailed designs are to be prepared using the outline engineering specifications provided in this report.
EAW	No removal of gravels from the river bed at Pont Ebbw, except as already managed by the EAW	Adopted fully.
NCC	No use of the TPSF flood storage area in floods of <1:200y magnitude (282 m3/s)	Adopted fully.

(6) Provisions for future management of flood management works

1 The proposed flood management works entail the following additional requirements in respect of operation, maintenance and up-keep of the facilities provided:

- mowing of grass within the new flood bypass channel on the former TPGC
- periodic inspection and clearance of the flood by-pass channel, to maintain conveyance at design levels
- management of grass on the new flood embankments on the TPGC
- management of grass on the re-positioned flood embankment on the TPSF (provisional agreement has been made for this obligation to be taken on by the EAW, given their pre-existing obligation for the existing embankment)
- periodic inspection and maintenance of the outlet culvert, screw-gate valves and flap gates of the outflow structure on the TPGC
- periodic inspection of the new flood embankments, in fulfilment of Reservoirs Act (1975) and Flood and Water Management Act (2010) requirements; full inspections by an Inspecting (Panel) Engineer would be required once every 10 years, at an estimated cost of £2,000 per visit; annual inspection and issuing of an annual statement by a Supervising Engineer, at an estimated cost of £500 per visit (£800 for the first visit).
- drain down of floodwaters impounded in the TPGC flood storage area, post- flood events of a frequency greater than 1:50y

2 Clearance of flood-borne debris deposited in the TPGC storage area would need to be undertaken more often than at present (after a 1:50y flood, compared to around once every 200y now). The TPSF would be flooded no more often than it is now, under the Mk2 scheme. Flooding of the TPSF car park, playground and changing rooms, though, would occur less often, and to a lower depth than at present, such that the cost of clearing up after floods is likely to be lower, in the round, than is the case now. And that is without taking the significantly reduced costs of flood damage and clear-up in Duffryn, post-scheme compared to pre-scheme, into account.

3 Arrangements for the periodic inspection and maintenance of such stormwater drainage and storage (SuDS)[11] facilities as need to be provided on the residential development site would be the responsibility of the House Builder.

4 All tasks except for inspection of embankments and associated inflow and outflow structures under the requirements of the Reservoirs Act (1975) and the Flood and Water Management Act (2010) are within the competence of term engineering contractors.

5 A commuted sum will be paid by the Developer to the Local Authority (NCC) and/or to the local Drainage Board (the Caldicot and Wentlooge Drainage Board) to undertake the required tasks on behalf of the Developer, to the levels of service required, in perpetuity.

[11] The acronym SuDS stands for Sustainable urban Drainage System

General explanatory notes

A note on the terminology used to define the frequency with which floods of a given size (magnitude) are likely to occur, over the long run.

The likelihood of occurrence, or recurrence, of a flood of a stated size is variously described and denoted as its frequency, its recurrence interval, its return period and its probability of exceedance or non-exceedance.

The frequency with which a flood of magnitude X (generally defined by the peak flow of that event, at a given place, in m^3/s) is likely to occur in a time period of T years may be stated in the following ways: as the once in T years flood, or event; as the one in T years event; as the 1:T years event; as the 1:T event; as the QT event; as the T years Return Period event; as the T years Recurrence Interval event; as the 1/T probability (of annual exceedance) event; as the 1/T x 100% probability (of annual exceedance event; as the 1-(1/T) probability (of annual non-exceedance) event; as the (1-(1/T)) x 100% probability (of annual non-exceedance) event.

Thus, for example, the flood of size X m^3/s that occurs only once in a hundred year time period, on average, may be referred to as the once in a hundred years event, the one in a hundred years event, the 1:100y event, the 1:100 event, the Q100 event, the 100y return period (RP, or sometimes Tr) event, the 100y recurrence interval (RI) event, the 0.01 probability (of exceedance, annually) event or the 1% probability (of exceedance, annually) event. The terminology is interchangeable, since all of the definitions refer to the same event and are intended to mean the same thing.

A number of these conventions are used in this report, interchangeably, to describe flood frequency.

A note on the use of the terms 'onset of flooding' and 'standard of protection (SoP) against flooding

Herein, the term 'onset of flooding' is used to define the frequency or the magnitude of the flood event that results in flooding of a particular area (generally the area of Duffryn downstream of the TPGC and TPSF). The term 'standard of protection (SoP) against flooding' defines the related state in which flooding is just avoided. Noting that the flood levels and extents estimated herein show that under existing (pre-works) conditions Duffryn is not flooded in the 245 m^3/s flood event (which is judged to have a frequency of 1:105y) but is flooded in the 250 m^3/s (1:115y) event, the onset of flooding into Duffryn is deemed to be around the 1:110y event, whereas the standard of protection that Duffryn now enjoys is deemed to be the 245 m^3/s (1:105y) event. The standard of protection against flooding is generally taken to be the highest calculated flood magnitude/frequency known not to cause flooding, whilst the onset of flooding is either the next highest calculated value that does cause flooding (a safe, but possibly high estimate), or the average between the events shown not to and to cause flooding.

A note on the accuracy of data

The accuracy of the ground levels reported herein is considered by those responsible for their survey (Azimuth Ltd) to be ±100 mm (based on RTK GPS survey techniques).

The accuracy of flood flow measurements and estimates depend upon a range of factors, and varies with the magnitude of the flow, especially above the modular limit of any gauging structure that may be present and particularly above the bankfull flow level. The accuracy of all flow values, and especially of flood flow values is accordingly difficult to specify, in either percentage or absolute terms. The lower range of flood flow values used in this report are derived from measurements of water level (at Rhiwderin) that are converted to flow using a stage-flow rating equation; this applies to flows of up to 130 m3/s (which is well below the lowest of the flood flow values used within this study). Beyond that, the estimates of the higher flood flows used in the report are estimated from those lower range values (and from values from other like stations) using Flood Studies Report (FSR) and Flood Estimation Handbook (FEH) methods. The accuracy of gauged flows at Rhiwderin (to 130 m3/s) is around ±10% (Hi-Flows UK). Higher flows are unlikely to have an accuracy of estimation of better than ±20%.

The accuracy with which computational hydrodynamic models are able to estimate flood water levels from values of flood flows (which in this context are assumed to be without error) is at best ±10 mm, and more likely to be ±15mm in extreme flood events.

A note on the comparison of flood level estimates and of flood level and ground level estimates

Taking account of the accuracy of the data involved, the following limits of accuracy (uncertainty) apply to comparison of estimates.

(1) Comparing different values of the same variable with the same accuracy range (e.g. one water level estimate against another, or one ground level estimate against another). When comparing two different values (a, b) of the same variable (e.g. water level), it is tempting to take the difference between the two values (a-b), without regard to their accuracy limits; but in fact, the real difference between the two values, taking (in)accuracy into account, could be as great as ((|a-b|)+x), or as little as((|a-b|)-x), where x is the accuracy range of the values (which for say ±10mm is 20mm). To be certain that two flood water levels with accuracy limits of ±10mm are truly different, the difference between the two values must be greater than 20mm. A more pragmatic judgement as to whether any difference in best estimate values is significant or not would be to compare that difference in best estimates to the maximum error range (or tolerance). Here, a difference in best estimates of say 7mm might be considered to be well within the maximum error band of 20mm, and judged to be insignificant, whereas a difference of say 17 mm might be considered to be close enough to the maximum error range of 20 mm to be considered to be significant.

This is the situation that applies when comparing a pre-works and a post-works flood level estimate, when the flood flow values of the pre- and post-works estimate is unchanged and when the ground levels used for both the pre- and post-works hydrodynamic modelling is unchanged. It is the relativity of the two flood level estimates that counts here, with the accuracy of those water level estimates alone taken into consideration, irrespective of the accuracies of the ground level and flood flow estimates. It would not be valid to combine the accuracy bounds of the ground level, the flow and the flood level estimates in judging the significance of any difference between the two water level estimates.

On the basis of the above considerations, differences between the best estimates of pre-works and post-works flood level are taken to indicate the following:
Differences of less than 10 mm: no significant difference between the two estimates
Differences of 10 mm ~ 14.9 mm: possibility of some difference
Differences of 15mm ~ 19.9 mm: probability of some difference
Differences of >20mm: certainty of a difference

(2) Comparing estimates of different variables, or of the same variable with different accuracy ranges. (e.g. a water level estimate with a ground level estimate). When comparing say a surveyed ground level (a) with an estimated floodwater level (b) measured in the same units and to the same datum (e.g. mAOD), the difference when taking account of errors could be as great as ((|a-b|)+(x + y)/2)), or as little as ((|a-b|)-(x + y)/2)), where x is the total error band of the ground measurement and y that of the floodwater level value. To be certain that a ground level estimate with an accuracy of ±100mm and a floodwater level estimate with an accuracy of ±10mm are truly different, the difference between the two values must be greater than 110mm. But to be more pragmatic, again, we should take account of sub-maximum error ranges, too, and compare the difference between best estimates to the maximum error range in a less rigid way. Here, the relativity that counts is that between the ground level estimate, and its error range, and the water level estimate, and its error range. Given the wide error band of ground level values, a difference in best estimates of water and ground levels with a value as ostensibly high as say 40mm might be considered to be well within the maximum error band of 110mm, and judged to be insignificant.

On the basis of the above considerations, differences between best estimates of floodwater levels and ground levels are taken to indicate the following:
Differences of less than 50 mm: no significant difference between the two estimates
Differences of 50 mm ~ 79.9 mm: possibility of some difference
Differences of 80mm ~ 109.9 mm: probability of some difference
Differences of >110mm: certainty of a difference

A note on chainages

Chainage is a term used by Engineers to define distance from some fixed point. Herein, chainage is mostly used to specify the longitudinal distance of a particular point on the R Ebbw upstream of its junction with R Usk. Thus chainage 0m is at the confluence of R Ebbw and R Usk; Ebbw Bridge (Pont Ebbw) is at 4065m, the M4 Bridge over R Ebbw is at 5300m; the A467 Bridge is at 6214m and Bassaleg Bridge is at chainage 6297m. Where chainage is used to define position from any other point – e.g. as a distance measured across the floodplain, from the edge of the proposed housing development – it is specifically defined so,

A note on units

All areal, volumetric and flow values cited herein are in units of square metres (m^2), cubic metres (m^3) and cubic metres per second (m^3/s) whether written as m^2, m^3 and m^3/s or as m3, m3 or m3/s.