Llyn Bran Reservoir Discontinuance Project

B4501 & A543 Roads: Flood Risk and Embankment Stability

July 2021

Final - Revision 1

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Contents

1 Background & Scope

1.1 General

Llyn Bran Reservoir is situated approximately 12km south-west of Denbigh in the county of Denbighshire. The reservoir has a capacity of 257,000m^3 and is therefore within the ambit of the Reservoirs Act 1975. The reservoir has been designated as “high risk” within the meaning of the Act, due to the two locations downstream of the dam where the B4501 road crosses the flood path. The road is at risk of flooding during extreme flood events or from the uncontrolled release of water in the event of a breach in the dam.

Studies carried out in relation to another reservoir discontinuance project for Dŵr Cymru Welsh Water (DCWW) at Llyn Anafon identified Llyn Bran, in its original natural lake form, as a suitable compensation site for the loss of habitat area resulting from the discontinuance of Llyn Anafon Reservoir. DCWW is therefore investigating, in parallel with the ongoing discontinuance of Llyn Anafon, the option for discontinuing Llyn Bran in its current form. The project would have the additional advantage of removing the prevailing risk presented by Llyn Bran as a large raised reservoir, noting that the reservoir is no longer required to support DCWW’s water supply operation and requires significant capital investment in the near future to bring it up to UK dam safety standards.

The feasibility study concluded that there were no significant issues associated with the discontinuance of Llyn Bran Reservoir and therefore DCWW has decided to proceed with the planning and detailed design of the reservoir discontinuance. Complete removal of the entire dam structure to original ground level has been selected as the preferred option for discontinuance by DCWW. The intention is to carry out the removal of the dam during the summer of 2022, subject to obtaining the necessary consents.

1.2 Downstream Flood Risk: B4501 Highway Embankment

A high-level review of the downstream flood risk related to the reservoir was undertaken during the discontinuance feasibility study. Two locations were identified downstream of the reservoir where there is a risk of flooding to the B4501 road during extreme flood events, noting that the road at both locations where it crosses the watercourse is on raised embankments.

The existing reservoir provides significant flood attenuation. It is anticipated that this level of attenuation will be reduced once the reservoir has been discontinued.

In light of the likely increase in flood risk to the B4501, the highways authority, Denbighshire County Council (DCC), were contacted for advice on the potential impact on the highway and the assessments needed to properly understand and address the issue. An initial video-conference meeting was held with Mr Jim Hall who is a senior highways engineer with DCC. It was concluded during the meeting that a site visit was required to properly discuss all the issues and to afford Mr Hall the opportunity to visually observe the B4501 culverts. A site visit was undertaken on 26th November 2020.

Following further discussions with DCWW and DCC, it was concluded that a more detailed flood assessment should be carried out to quantify the increase in flood risk at the first B4501 culvert due to the removal of the dam structure at Llyn Bran Reservoir. The second culvert location was excluded from any further studies as DCC were satisfied that there would not be a significant flood risk issue here due to the large size of the culvert.

Further, in view of the anticipated increased frequency of deeper flooding held against the upstream (eastern side) of the road embankment following reservoir discontinuance it was agreed that a detailed stability assessment should be carried out to determine whether the retention of flood water would affect stability.

Finally, in terms of the B4501 road embankment, it was noted at the time of the site visit in November 2020 that there is a second, smaller culvert, a short distance to the south of the watercourse culvert. This second culvert appears to provide additional drainage to the road and eastern verge area. The culvert was checked at its upstream and downstream ends and found to be at least partially blocked. Mr Hall noted that DCC Highways would carry out a more detailed survey and any follow up maintenance or improvement works associated with this culvert.

1.3 Upstream Bank Stability: A543 Highway Embankment and Revetment

In conjunction with discussions around potential flood risk impact to the B4501 embankment DCC Highways also raised, as a separate issue, minor concerns about the future stability of the low embankment at the upstream (north) end of the reservoir. This embankment supports the A543 highway. At present the southern slope of the embankment is partially submerged by Llyn Bran Reservoir. DCC Highways have asked for confirmation that, with the reservoir discontinued, with water no longer held against the embankment slope, there would be no adverse effect on the stability of the road embankment.

1.4 Flood Risk and Embankment Stability Assessments: Terms of Reference

Stillwater Associates has been commissioned to carry out a detailed flood study for the catchment draining to the B4501 culvert along with stability assessments of both the B4501 and A543 road embankments to determine whether or not the discontinuance of Llyn Bran Reservoir could have an adverse effect on embankment stability in either case.

The flood study is required to properly understand the change in the hydrology, and therefore the change in frequency and volume of flooding affecting the B4501 culvert and embankment. The study has been carried out using current industry practice based on Flood Estimation Handbook (FEH) catchment parameters and InfoWorks modelling software.

The stability assessments were generally divided into the following categories for each embankment, with analyses carried out to reflect future (post-discontinuance) conditions in each case, and comparing the results with the existing conditions (where considered necessary). The scenarios considered reflect specifically the concerns raised and requests made by Denbighshire County Council Highways Team, with reference to their e-mail dated 9th November 2020 (Appendix A) and discussions at the subsequent meeting on site held on 26th November 2020:

Ref	Details	Purpose
A	**B4501 Road Embankment and Culvert**	
A.0	Hydrological and hydraulic modelling	Confirm the relevant flood events. Understand the reservoir/lake attenuation benefits pre- and post-discontinuance to inform the change in flood risk at the B4501 embankment. Develop relevant flood hydrographs affecting the B4501 embankment and culvert to inform the pertinent stability assessments.
A.i	Seepage assessment	Determine the estimated profile of the phreatic surfaces through the road embankment during extreme flood conditions.
A.ii	Potential for internal erosion	Determine the potential for internal erosion and the estimated resulting likelihood of an embankment failure. Requested by DCC Highways.
A.iii	Slope stability assessment	Determine the safety factors against a slip failure of both the upstream and downstream embankment slopes, including the scenario where the culvert is partially or completely blocked. Requested by DCC Highways.
A.iv	Sliding stability assessment	Determine the safety factors against a sliding failure of the embankment along its base. Requested by DCC Highways.
B	**B4501 Road Embankment and Culvert**	
B.i	Seepage assessment	Determine the estimated profile of the phreatic surface through the embankment due to the existing top water level in Llyn Bran Reservoir.
B.ii	Slope stability assessment	Determine the safety factors against a slip failure of the downstream (southern) face of the embankment. Requested by DCC Highways.

In the case of the A543 embankment the stability question relates to the removal of the reservoir water. This would not be expected to have a significant influence on the potential for groundwater flows through the embankment and therefore the risk of internal erosion has not been considered further. Similarly, with no loading against the northern slope, it is considered that there would be no significant change in the embankment stability with respect to sliding.

It is also noted that embankments will be inherently stable in terms of the risk of sliding. However, the analysis is straightforward and has been carried out at the request of DCC Highways to demonstrate that this is the case and to provide reassurance of the embankment stability.

2 Site Location

Llyn Bran Reservoir is situated in the County of Denbighshire about 12km southwest of Denbigh and 10km north of Cerrigydrudion as shown in Figure 2.1 below.

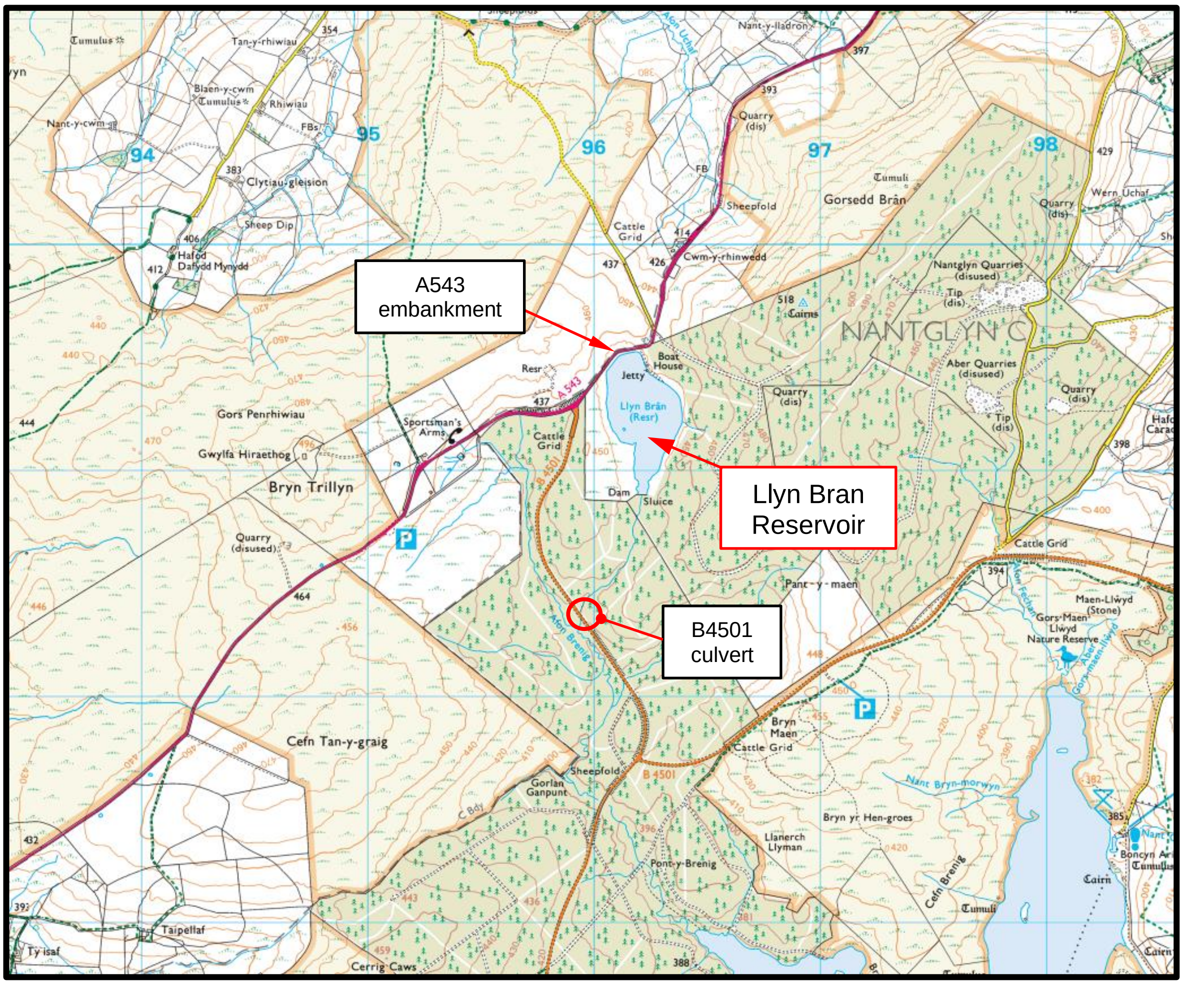

Figure 2.1: Location of Llyn Bran Reservoir (courtesy of Streetmap)

3 Details on Llyn Bran Reservoir

Llyn Bran Reservoir is a natural lake, historically raised and impounded by a small gravity dam at the southern end of the reservoir, built around 1899 to supply water to North Wales Hospital in Denbigh. It is reported that the construction of the dam raised the level of the original lake by 8ft (2.4m). It is understood that the reservoir has not been used for water supply for many years and that the draw-off arrangements have long since been abandoned.

The reservoir in its current form is a large raised reservoir within the ambit of the Reservoirs Act 1975. Under this legislation, and in view of the prevailing risk presented by this reservoir, DCWW are required to have in place a strict supervision and inspection regime, and to keep the dam maintained to meet current reservoir safety standards. Significant improvement works, identified at recent inspections, will be required to the dam if the reservoir is to be retained.

Further, and as noted above, the discontinuance of Llyn Bran reservoir is a necessary requirement to reconnect the watercourse at Llyn Bran with the original natural lake waterbody such that it can become a suitable compensation site for the discontinuance of Llyn Anafon.

A summary of the key features relating to Llyn Bran Reservoir, including levels and dimensions, is provided in Table 3-1 below.

Table 3-1: A summary of the key features relating to Llyn Bran

Feature	Value	Source / comment
Location: National Grid Reference	SH 9621 5890	2011 Section 10 Report (confirmed on mapping)
Location: nearest postcode	LL16 5SP	Internet
Reservoir surface area at TWL	125,400m^2	Prescribed Form of Record
Reservoir volume at TWL	257,000m^3	Prescribed Form of Record
Maximum dam height	4.42m	2011 Section 10 Report
Total freeboard	0.72m	Measured on site, 18th September 2018
Top Water Level	434.43m AOD	Prescribed Form of Record
Crest level	435.15m AOD	2011 Section 10 Report
Flood category	C	2011 Section 10 Report
Catchment area	0.69km^2	FEH Online Service
Date built	1899	2011 Section 10 Report

3.1 Dam

The dam is a concrete wall with a crest width of 1.22m and a base varying in width up to 2.44m at the highest section, 4.42m high. The upstream face and the top 1.37m of the downstream face are vertical, below which the downstream face batters out at 2H:5V (see Figure 3.1).

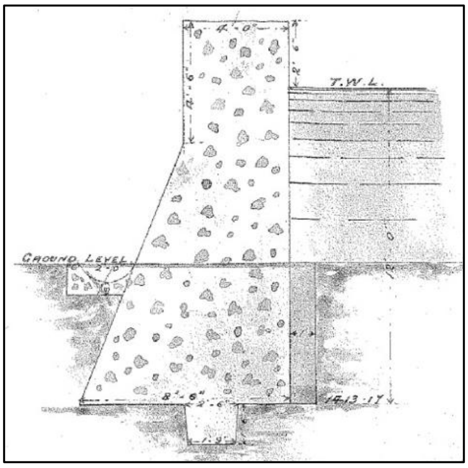

Figure 3.1: Cross section of dam

3.2 Overflow

The dam incorporates a central overflow weir, shown in Figure 3.2 below. Flows from the reservoir pass over this weir and continue down the original watercourse downstream of the lake, eventually flowing into Llyn Brenig Reservoir about 2km to the south.

The overflow is a 3.45m wide concrete weir, 750mm below the dam crest with a steep chute into a stilling basin. The stilling basin narrows in plan before joining the natural watercourse approximately 7m downstream of the weir.

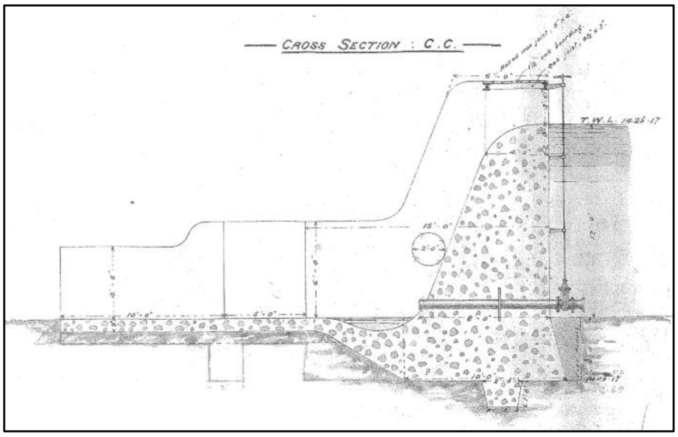

Figure 3.2: Cross section of the overflow weir structure

3.3 Downstream Features

3.3.1 Forestry Track

Approximately 310m downstream of the dam the natural watercourse passes below an unnamed forestry track via a low level 300mm diameter culvert. At this location, the forestry track has been constructed on a raised embankment, with a height of approximately 2.5m above the stream bed.

3.3.2 B4501 Road

Approximately 620m downstream of the dam, the natural watercourse passes below the B4501 road via a 1.2m diameter culvert. At this location, the B4501 road has been constructed on a raised embankment, with a heigh of approximately 3m above the stream bed.

4 Downstream Flood Risk Assessment

4.1 Existing Arrangements

4.1.1 Approach and Sources of Data

Catchment parameters for the catchment to Llyn Bran Reservoir were initially obtained from the FEH (Flood Estimation Handbook) Web Service during the discontinuance feasibility study in 2018.

For the purpose of the current study, catchment parameters for the gross catchment to the B4501 were also obtained. This catchment was then used to derive appropriate parameters for the respective sub-catchments which would drain to the forestry track culvert and the B4501 culvert. Derivation of sub-catchment parameters is usually done partly by area-weighted averaging between adjacent parameter sets and partly by using minor tributary characteristics more likely to be representative of the sub-catchment. In this particular case, the sub-catchments are reasonably similar to the gross catchment and only the catchment area and DPLBAR (mean drainage path length) values were adapted for each sub-catchment.

Rainfall estimates for the catchments were also obtained from the FEH Web Service using the “FEH2013” rainfall depth model. Rainfall-runoff flow estimates and reservoir flood routing were carried out using InfoWorksRS (IWRS), version 16.0.

Construction details, including dimensions, for the concrete dam impounding Llyn Bran reservoir are available, and have been checked and confirmed on site.

LIDAR data for the area is not available. Locally to particular features associated with the modelling, in particular the embankment and culvert structures, topographical surveys and dimension surveys were commissioned and carried out in early 2021. More generally OS mapping and Google have been used to estimate ground levels, stream gradients and the catchment topography.

4.1.2 Catchment

The gross catchment boundary to the B4501 culvert as given by the FEH Web Service, was reviewed against the OS contours, and found to be largely consistent with the elevation data. The FEH catchment area was therefore adopted for the study.

The gross catchment area was divided into the following sub-catchments for the purpose of the flood assessment:

- The direct catchment area draining into Llyn Bran Reservoir (shown as green shading in Figure 4.1 below) – *note this catchment area was previously downloaded during the feasibility study of 2018 and therefore no derivation work was required to determine the catchment characteristics*.
- The direct catchment area draining to the forestry track culvert (shown as blue shading in Figure 4.1 below) – *catchment characteristics were adapted from the gross catchment to the B4501 road culvert.*
- The direct catchment area draining to the B4501 road culvert (shown as red shading in Figure 4.1 below) - *catchment characteristics were adapted from the gross catchment to the B4501 road culvert.*

Figure 4.1 below shows the sub-catchment areas considered during the flood assessment, overlain on OS mapping with the latest version of the OS contouring added.

The catchment areas and DPLBAR values assumed for each sub-catchment are summarised in Table 4-1 below.

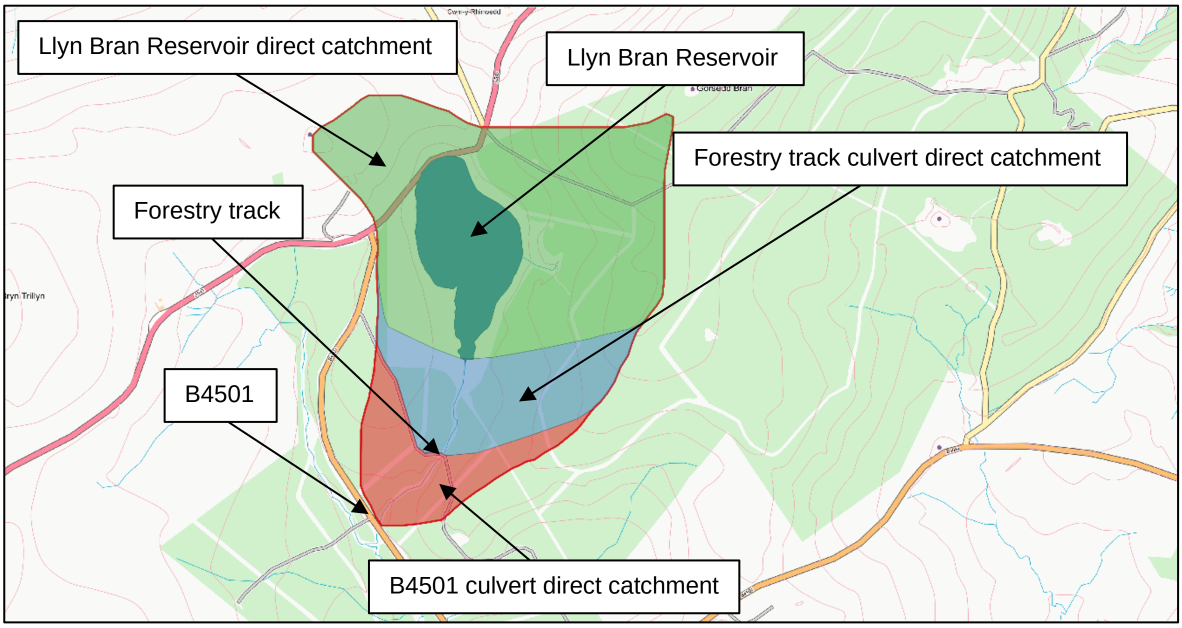

Figure 4.1: The various sub-catchment boundaries overlain on OS mapping and contours

Table 4-1: Summary of catchment areas and DPLBAR values adopted for the flood assessment

Sub-catchment	Parameter		Source / justification
	Catchment area	DPLBAR	
Llyn Bran Reservoir	0.69km^2	580m	FEH website
Forestry track culvert	0.18km^2	392m	OS mapping and adapting DPLBAR from the gross catchment to the B4501 culvert
B4501 road culvert	0.13km^2	329m	OS mapping and adapting DPLBAR from the gross catchment to the B4501 culvert

4.1.3 Flood Routing Characteristics and Model Build

(a) Storage Areas

The surface area of Llyn Bran Reservoir from OS mapping is approximately 125,400m^2.

During significant flood events, water is expected to impound behind both the forestry track embankment and the B4501 embankment, as the respective culverts become drowned out due to increasing flood flows. In the absence of any LIDAR data in this area, an estimate of the storage areas behind each of the embankments was made using the information from the February 2021 topographic survey and Google Earth. It was assumed that the surface area of the stored water would increase linearly as the water level rises within each of these storage areas. The maximum surface area for each storage feature was estimated using Google Earth, and has been summarised below (see also Figure 4.2 below):

- Forestry track embankment storage maximum surface area = 3,500m^2
- B4501 embankment storage maximum surface area = 2,000m^2

Once the impounding embankment in each case starts overtopping, flood storage was assumed to increase linearly with increasing elevation (i.e., surface area of the storage assumed to remain constant at and beyond the point of embankment overtopping).

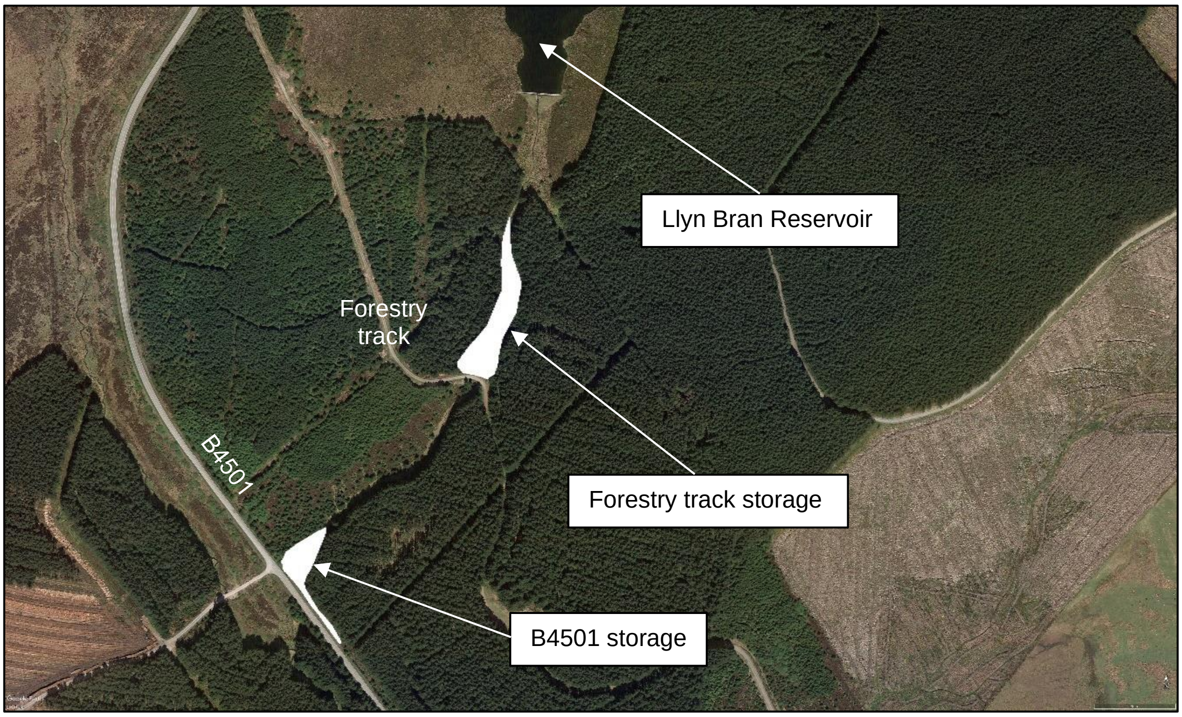

Figure 4.2: The estimated maximum storage areas downstream of Llyn Bran Reservoir

(b) Impounding & Conveyance Structures

The results of the 2021 topographic survey (Reservoir and Water Services, February 2021) were used to obtain the dimensions and profiles of the various structures and long sections that are required as inputs to the hydraulic model. A summary of how each of the overflow components has been modelled is provided in Table 4-2 below. The respective areas modelled are shown in Figure 4.3, Figure 4.4, and Figure 4.5 below for clarity.

Table 4-2: Description of overflow components within hydraulic model

Feature	Component	Model assumptions
Llyn Bran Reservoir (Figure 4.3)	Overflow	The overflow structure was conservatively modelled as broad-crested weir with a standard C_d of 1.7.
	Dam crest	The dam crest was modelled as a broad-crested weir with a standard C_d of 1.7.
Forestry track (Figure 4.4)	Low level culvert	The 300mm diameter culvert was modelled as an orifice with a standard C_d of 0.8.
	Track surface	The track surface was modelled as a broad-crested weir with a standard C_d of 1.7.
B4501 road (Figure 4.5)	Low level culvert	The 1.2m diameter culvert was modelled as an orifice with a standard C_d of 0.8.
	Natural overflow into gulley adjacent to road	The gulley overflow adjacent to the B4501 road was modelled as a broad-crested weir with a standard C_d of 1.7.
	Road surface	The track surface was modelled as a broad-crested weir with a standard C_d of 1.7.

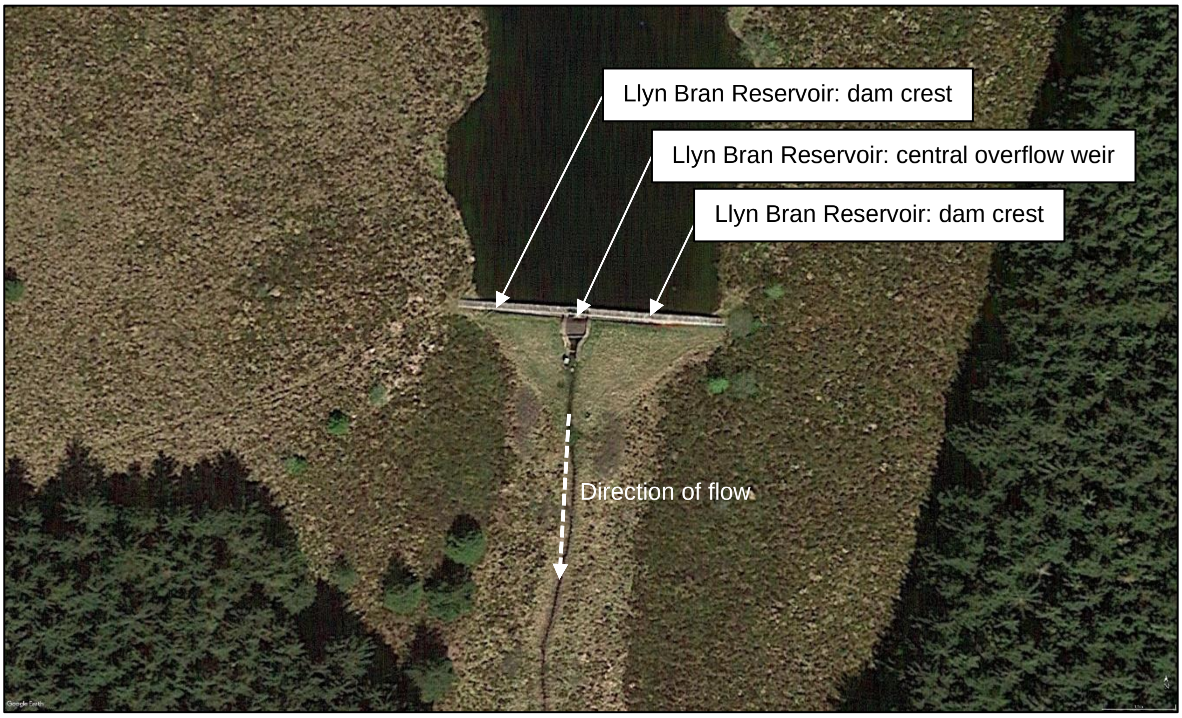

Figure 4.3: Modelled overflow components relating to Llyn Bran Reservoir

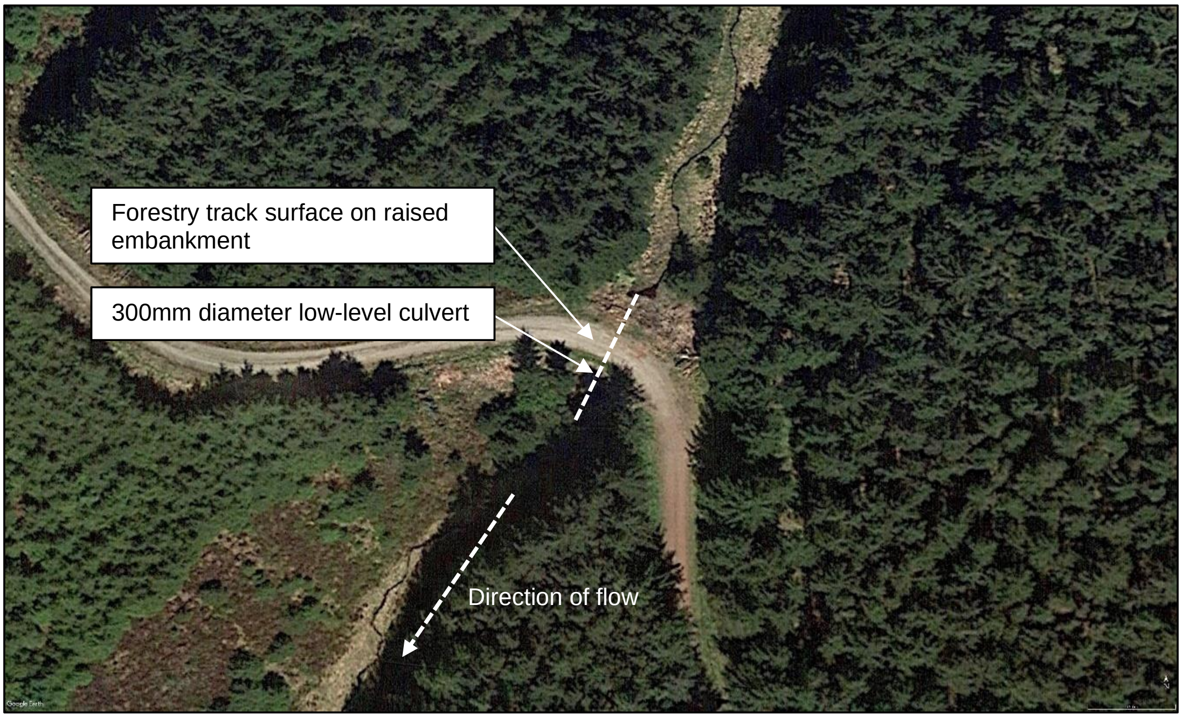

Figure 4.4: Modelled overflow components relating to the forestry track

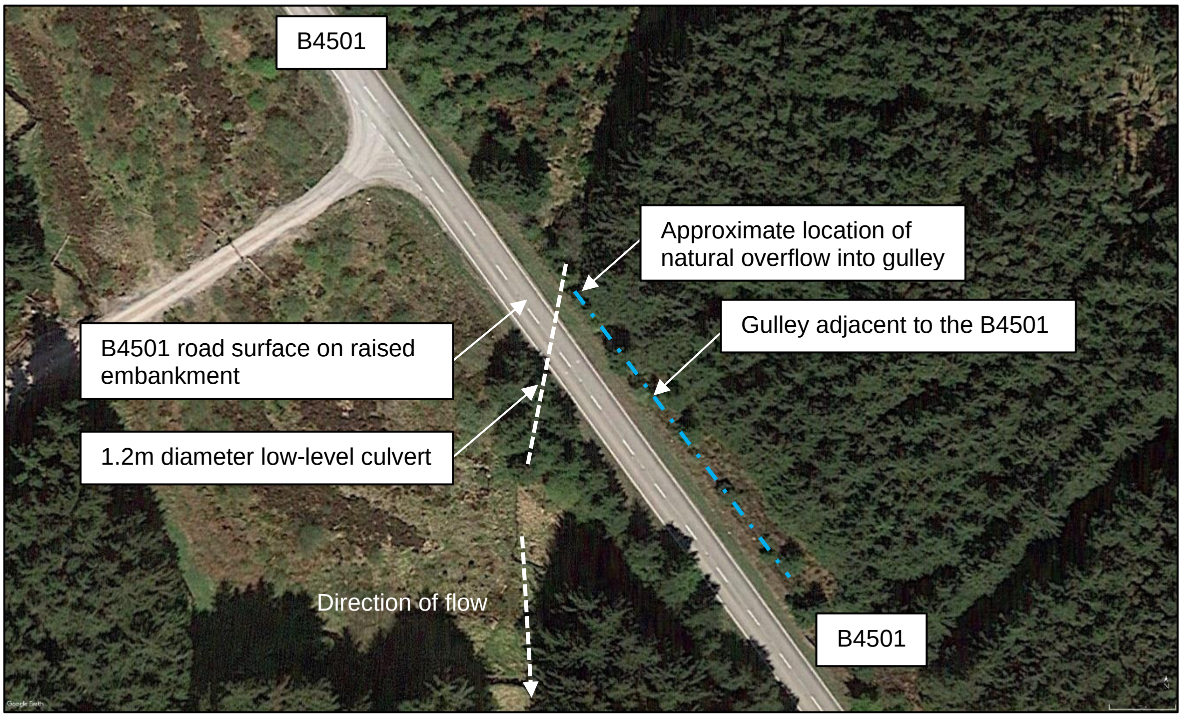

Figure 4.5: Modelled overflow components relating to the B4501 road

4.2 Flood Assessment – Arrangements after Reservoir Discontinuance

4.2.1 Approach

A similar approach to the existing arrangements (described in Section 4.1) was followed.

4.2.2 Catchment

Once again, the gross catchment area was divided into the following sub-catchments for the purpose of the flood assessment:

- The direct catchment area draining into the residual lake following the removal of the dam structure (shown as green shading in Figure 4.6 below) – *catchment characteristics were adapted from the gross catchment to Llyn Bran Reservoir*.
- The direct catchment area draining to the forestry track culvert (shown as blue shading in Figure 4.6 below) – *catchment characteristics were adapted from the gross catchment to the B4501 road culvert.*
- The direct catchment area draining to the B4501 road culvert (shown as red shading in Figure 4.6 below) - *catchment characteristics were adapted from the gross catchment to the B4501 road culvert.*

Figure 4.6 below shows the sub-catchment areas considered during the flood assessment, overlain on OS mapping with the latest version of the OS contouring added.

The catchment areas and DPLBAR values assumed for each sub-catchment are summarised in Table 4-3 below.

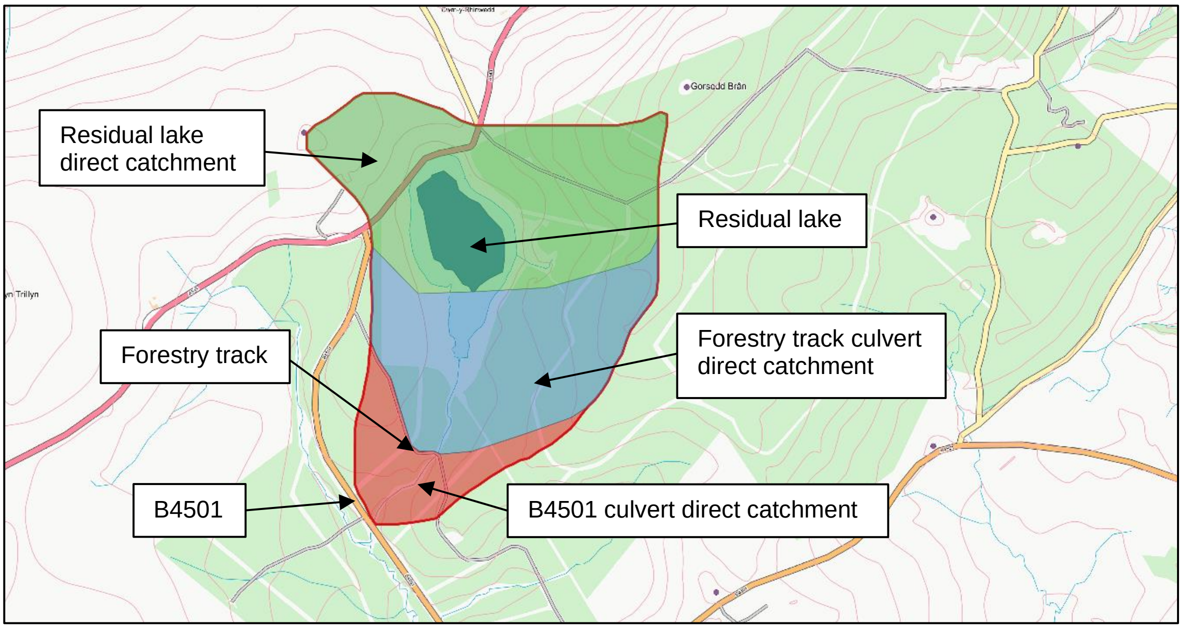

Figure 4.6:The various sub-catchment boundaries post discontinuance overlain on OS mapping and contours

Table 4-3: Summary of catchment areas and DPLBAR values adopted for the flood assessment

Sub-catchment	**Parameter**		**Source / justification**
	Catchment area	**DPLBAR**	
Residual lake	0.69km^2	580m	OS mapping and adapting DPLBAR from the gross catchment to Llyn Bran Reservoir
Forestry track culvert	0.18km^2	392m	OS mapping and adapting DPLBAR from the gross catchment to the B4501 culvert
B4501 road culvert	0.13km^2	329m	OS mapping and adapting DPLBAR from the gross catchment to the B4501 culvert

4.2.3 Flood Routing Characteristics and Model Build

(a) Storage Areas

The surface area of residual (natural) lake, following reservoir discontinuance, has been estimated as 61,500m^2.

The rationale behind the adopted surface areas for storage related to the forestry track embankment and the B4501 embankment, described in Section 4.3.1, applies here as well.

(b) Impounding & Conveyance Structures

The ground levels at the downstream end of the residual lake were obtained from historical contour drawings of Llyn Bran Reservoir (RS 34/8 & RS34/9). These ground levels were used to prepare a section profile which would represent the overflow from the residual lake into the downstream watercourse. This natural overflow from the residual lake was modelled as a broad-crested weir with a coefficient of discharge (C_d) of 1.5.

The remainder of the overflow structures downstream of the residual lake were modelled as described in Section 4.3.2, noting that the concrete dam structure is assumed to have been removed completely to discontinue the reservoir.

4.3 Results and Comparison

4.3.1 Flood Routing

The 150-year, 200-year, 500-year and 1,000-year floods were routed through the model for both the existing and post reservoir discontinuance scenarios.

4.3.2 Comparison of Flood Flows at the B4501 Road

The following table compares the results obtained during the flood routing of the two scenarios (i.e., existing compared to post-discontinuance).

The following levels should be noted whilst reading the below table:

- B4501 culvert invert level = 415.822m AOD
- B4501 culvert soffit level = 417.022m AOD
- B4501 road surface level above culvert = 420m AOD

Table 4-4: Comparison of routing results for the B4501 road embankment

Consideration	Flood Assessment Results	
	Existing (pre-scheme)	**Following Reservoir Discontinuance (dam removed)**
150-Year Flood		
Peak discharge (m^3/s) at B4501 culvert	1.56	3.17
Level of stored water u/s of B4501 culvert (m AOD)	416.80	417.40
Head of water above B4501 culvert invert (m)	0.98	1.58
Head of water above culvert soffit (m)	N/A	0.38
Freeboard* to B4501 road (m)	3.20	2.60
200-Year Flood		
Peak discharge (m^3/s) at B4501 culvert	1.58	3.19
Level of stored water u/s of B4501 culvert (m AOD)	416.81	417.40
Head of water above B4501 culvert invert (m)	0.99	1.58
Head of water above B4501 culvert soffit (m)	N/A	0.38
Freeboard* to B4501 road (m)	3.19	2.60
500-Year Flood		
Peak discharge (m^3/s) at B4501 culvert	2.06	4.00
Level of stored water u/s of c B4501 ulvert (m AOD)	417.00	417.78
Head of water above B4501 culvert invert (m)	1.18	1.96
Head of water above B4501 culvert soffit (m)	N/A	0.76
Freeboard* to B4501 road (m)	3.0	2.22
1,000-Year Flood		
Peak discharge (m^3/s) at B4501 culvert	2.39	4.65
Level of stored water u/s of B4501 culvert (m AOD)	417.13	418.13
Head of water above B4501 culvert invert (m)	1.31	2.31
Head of water above B4501 culvert soffit (m)	0.11	1.11
Freeboard* to B4501 road (m)	2.87	1.87
***Note: Freeboard is the distance in metres below road level to the water level upstream of the culvert**		

Figure 4.7 below presents a comparison of the estimated height of water impounding against the road embankment during the range of flood events considered. This shows the expected increase in water height for the post discontinuance scenario.

The graph shown in Figure 4.8 provides a comparison of the estimated 1 in 1,000-year inflow and outflow hydrographs along with the associated water levels, for the existing and post discontinuance scenarios.

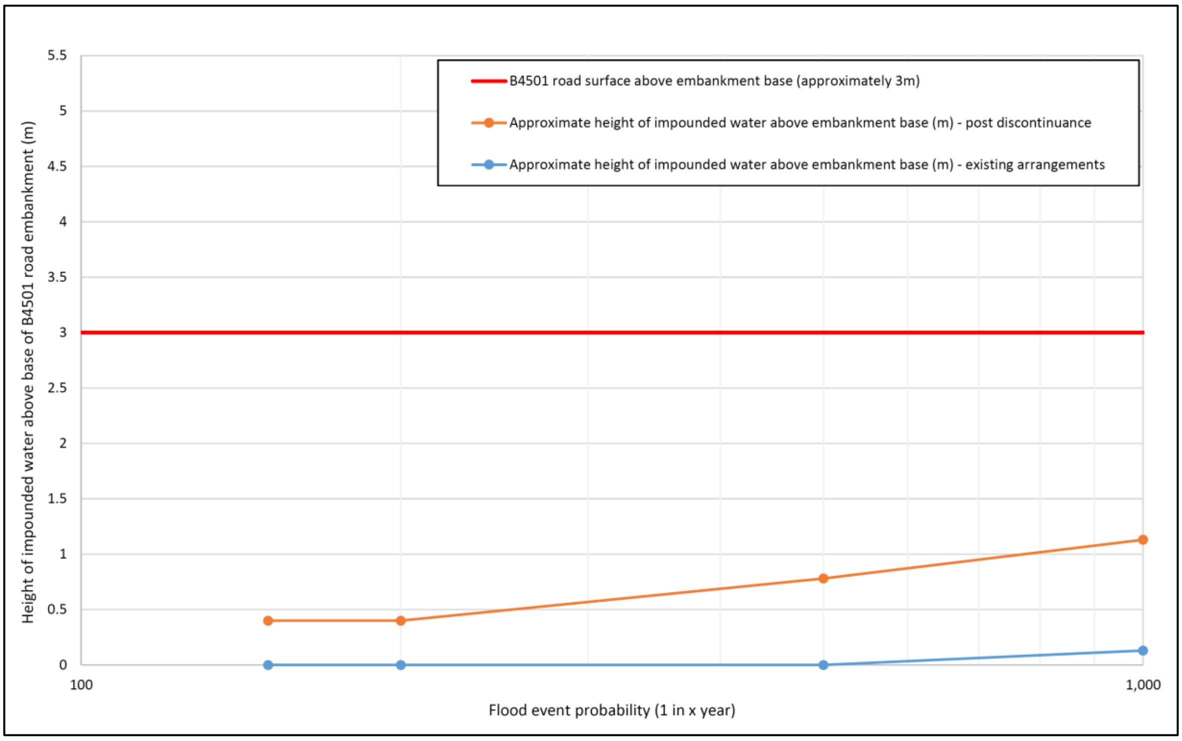

Figure 4.7: A comparison of expected heights of impounding water against B4501 road embankment for various flood events

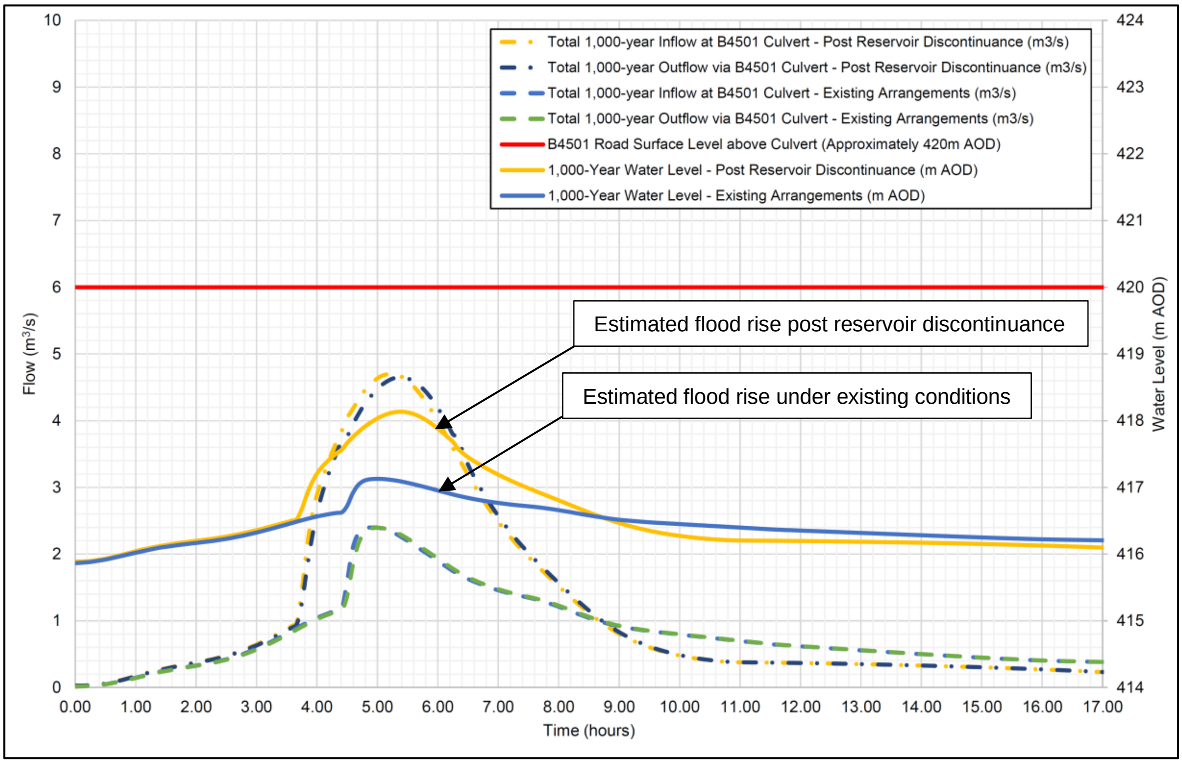

Figure 4.8: Comparison of the 1,000-year inflow & outflow hydrographs and associated impounding water levels at the B4501 culvert

4.4 Flood Assessment Conclusions

The following summary conclusions can be drawn from the flood assessment:

- The likelihood of water impounding against the B4501 road embankment can be expected to increase as a result of the removal of the dam structure at Llyn Bran Reservoir [for example, the likelihood of just over 1m depth of water impounding against the embankment will have an estimated annual probability of 1 in 1,000 after reservoir discontinuance, compared to the probability prior to discontinuance (existing case) less than 1 in 1,000].
- For both the existing and post discontinuance scenarios, all floods up to the 1 in 1,000 annual probability event are expected to be passed by the 1200mm diameter culvert without flooding the road surface.
- It is therefore concluded that the existing 1200mm diameter culvert has sufficient capacity to pass the increased flows that can be expected after the reservoir has been discontinued and there is no need to increase the hydraulic capacity (e.g., by installing a larger culvert).
- The increased frequency of water impounding against the embankment may cause localised scour on the upstream face of the embankment as water is drawn into the culvert, although this effect would be expected to be similar to the current situation.

4.5 Recommendations

- The existing 1200mm diameter culvert has sufficient capacity to accommodate increased flood events following reservoir discontinuance, and there is no need to increase flow capacity beneath the B4501 road.
- To protect against the possibility of increased scour associated with future increased flows it is suggested that localised scour protection could be provided on the upstream face of the embankment around the culvert headwall, for example up to the estimated 1 in 200-year flood level. The scour protection could take the form of a geotextile mat with large rip-rap stones on top, laid up the face of the embankment in the vicinity of the culvert opening. The details can be refined further during the detailed design of the discontinuance works in discussion with DCC Highways.

5 Embankment Stability Assessment for B4501 Road

5.1 Approach and Sources of Data

As noted in Section 1 of this report, DCC raised a concern about the stability of the B4501 road embankment when water is impounding against it during a flood event, especially given the increased likelihood of impounding events demonstrated in Section 4 of this report.

Stillwater Associates were therefore commissioned to carry out stability assessments of the B4501 road embankment to determine whether sufficient stability would remain following the discontinuance of Llyn Bran Reservoir.

The stability assessments were generally divided into the following categories for the B4501 road embankment:

- Seepage assessment – determine the estimated profile of the phreatic surface during extreme flood conditions.
- Potential for internal erosion – determine the estimated likelihood of an embankment failure due to internal erosion.
- Slope stability assessment – determine the safety factors against a slip failure of both the upstream and downstream faces of the embankment.
- Sliding stability assessment – determine the safety factors against a sliding failure of the embankment along its base.

These analyses are based on the results of the flood assessment after dam discontinuance, as detailed above in Section 4.

The finite element packages SEEP/W and SLOPE/W have been used for these analyses, following initial hand calculations.

Data for the modelling was obtained from the following sources:

- Topographical Surveys (Reservoirs & Water Ltd, February 2021).
- Soil data and groundwater conditions: Ground investigations carried out in February 2021, reported in March 2021.
- Assessment of flood risk, detailed in Section 4 of this report.

5.2 Methodology

5.2.1 Embankment Cross Section

Data for the embankment cross section (see Figure 5.1 below) was taken from the Topographic Survey by Reservoir and Water Services Ltd. dated February 2021, while water levels and the soil properties were taken respectively from the Downstream Flood Risk Assessment (see Section 4) and from the Ground Investigation Factual Report (dated March 2021).

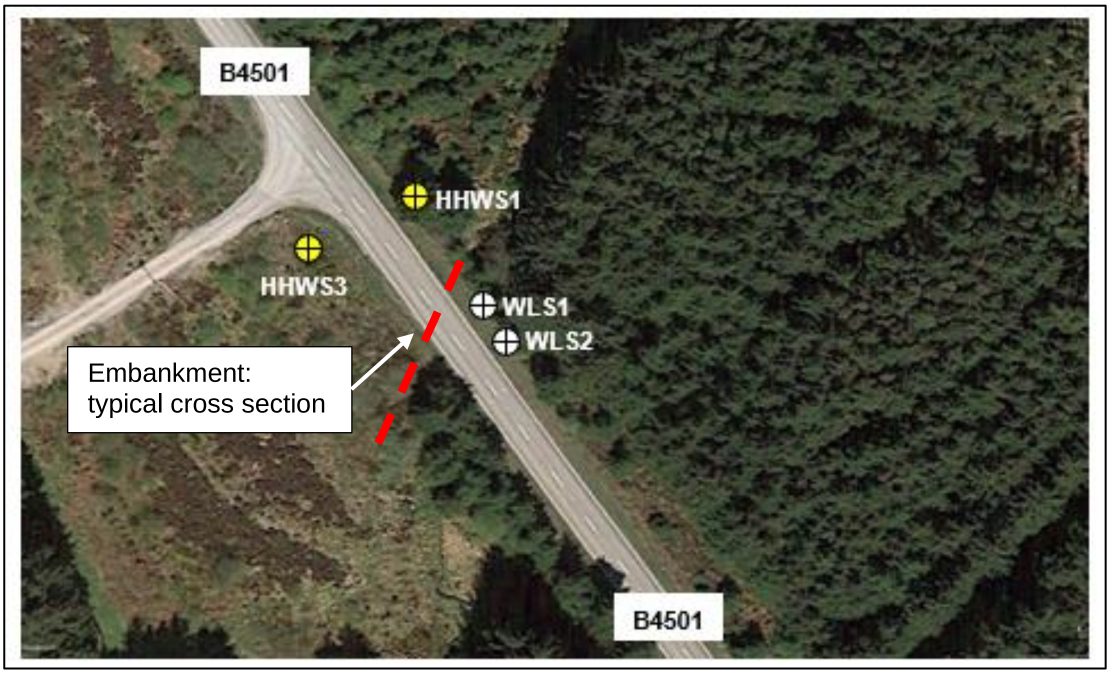

Figure 5.1: The location of the typical cross section of the B4501 road embankment that was used for the stability analyses – the relevant boreholes from the ground investigation are also shown.

5.2.2 Embankment Material Properties

For this stability assessment, only the results of boreholes WLS1 and WLS2 were analysed, as these were considered to best represent the embankment construction and its foundation.

Table 5-1 and Table 5-2 below summarise the soil properties for the embankment that were obtained from laboratory testing as part of the ground investigation.

Table 5-1: Summary of particle size distribution testing

<table>
<tr><th>Borehole</th><th>Location</th><th colspan="2">Sample depth</th><th>Cobble</th><th>Gravel</th><th>Sand</th><th>Silt</th><th>Clay</th></tr>
<tr><td>WLS1</td><td>Adjacent to the B4501 road</td><td>1.2 – 2m</td><td>Embankment fill</td><td>0%</td><td>79%</td><td>15%</td><td colspan="2">6%</td></tr>
<tr><td rowspan="3">WLS2</td><td rowspan="3">Adjacent to the B4501 road</td><td>1.65 – 2m</td><td>Embankment fill</td><td>0%</td><td>76%</td><td>16%</td><td colspan="2">8%</td></tr>
<tr><td>4.5 – 4.75m</td><td rowspan="2">Foundation</td><td>0%</td><td>47%</td><td>15%</td><td>22%</td><td>16%</td></tr>
<tr><td>5.6m</td><td>0%</td><td>27%</td><td>18%</td><td>31%</td><td>24%</td></tr>
</table>

Table 5-2: Summary of shear box test results

<table>
<tr><th>Borehole</th><th>Location</th><th colspan="2">Sample depth</th><th>Angle of shearing resistance θ</th><th>Effective Cohesion</th></tr>
<tr><td>WLS1</td><td>Adjacent to the B4501 road</td><td>2 – 3m</td><td>Embankment fill</td><td>47°</td><td>21kPa</td></tr>
<tr><td rowspan="3">WLS2</td><td rowspan="3">Adjacent to the B4501 road</td><td>2 – 3m</td><td>Embankment fill</td><td>36°</td><td>23 kPa</td></tr>
<tr><td>4.0 – 4.5m</td><td rowspan="2">Foundation</td><td>30°</td><td>22 kPa</td></tr>
<tr><td>5 – 6m</td><td>28°</td><td>30 kPa</td></tr>
</table>

From the Ground Investigation Factual Report information in the above tables, it was possible to identify three distinct layers that form the highway embankment. The information used during the stability assessment is summarised in Table 5-3 below.

Table 5-3: Summary of the embankment layers' properties used during assessment

Layer	**Top**	**Middle**	**Lower**
Material	Gravel	Gravelly silt	Sandy gravelly Clay
Reference borehole	WLS1, WLS2	WLS2	WLS2
Sample depth	0 – 4m	4.0 – 4.5m	4.5 – 6m
Unit weight [kN/m^3]*	20	19	18
Angle of shearing resistance θ	41	30	28
Effective Cohesion [kPa]**	0	0	0
Hydraulic conductivity K [m/s]*	10^{-3}	4×10^{-4}	10^{-5}

Notes:

* Typical values obtained from literature.

** Although the shear box test results produced relatively high cohesion values throughout, zero cohesion was conservatively assumed for the stability assessment given the known granular nature of the materials.

The values for the hydraulic conductivity, K, were taken from literature (R. F. Craig, Soil Mechanics, Fifth Edition, 1991). Typical values for the unit weights were derived from information available online (such as https://mathalino.com/reviewer/geotechnical-engineering/unit-weights-and-densities-soil).

5.2.3 Software

In addition to hand calculations, two finite element software products from Geoslope International Ltd. were used during the stability assessment:

- The SEEP/W package was used to determine the estimated profile of the fully developed phreatic surface through the embankment given the upstream water level.
- The SLOPE/W package was used to determine the safety factors against a slip failure of both the upstream and downstream faces of the embankment.

5.2.4 Seepage Assessment

The first step in the stability assessment was to determine the extent to which seepage is expected to migrate through the embankment, given the limited time that flood water is expected to impound against the upstream face and given the nature of the embankment materials as obtained during the ground investigations of February 2021.

It is likely that the road embankment material is well compacted as it has been in existence for many years with frequent traffic load from vehicles using the road. Also, given the fact that the material ranges from sandy gravel to finer silty clay, it is considered that the average hydraulic conductivity would not exceed 10^{-3} m/s based on typical parameters for these material types.

Hand calculations were carried out to estimate the profile of the phreatic surface through the embankment for the 1,000-year flood post discontinuance scenario, assuming a constant average hydraulic conductivity value of 10^{-3} m/s. The results are provided in Table 5-4 and Figure 5.2 below – it should be noted that the expected duration for each water depth considered was obtained from the hydrographs developed as part of the flood risk assessment described in Section 4 of this report.

Table 5-4: Expected extent of seepage migration for an average hydraulic conductivity of 10^{-3}m/s

Parameter	**Input value / calculated value**		
Hydraulic conductivity, k [m/s]	**10^{-3}**		
Porosity, n	0.22		
Depth of impounding water on upstream face, DH [m]	1.13	1.0	0.5
Length along base of embankment, L [m]	23	23	23
Hydraulic gradient, i = DH/L [m/m]	0.05	0.04	0.02
Duration of impounding depth, T [hours]	0.5	1	2
Velocity of seepage migration, v_s [m/s]	2.2×10^{-4}	2.0×10^{-4}	9.9×10^{-5}
Expected horizontal length of seepage migration, L_seepage [m]	0.4	0.7	0.7

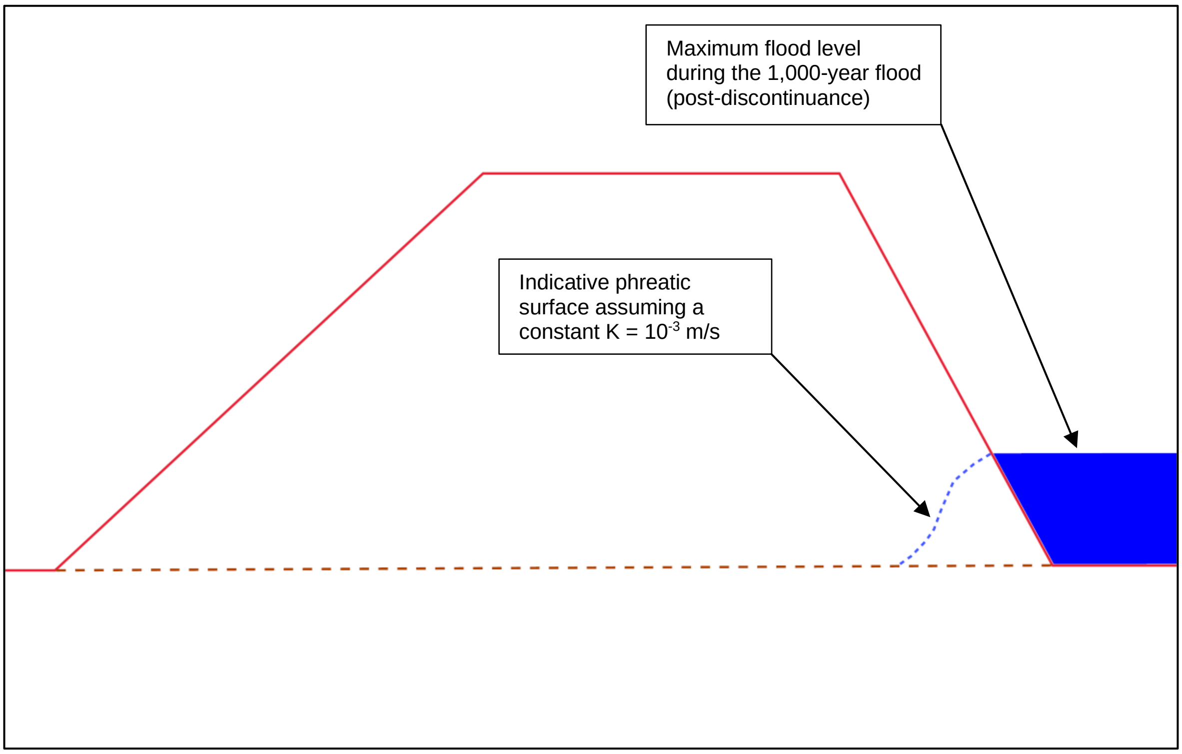

Figure 5.2: The calculated phreatic surface for K = 10^{-3} shown indicatively

From these results it can be seen that the phreatic surface is not expected to daylight at the downstream toe of the embankment and would be fully contained within the embankment itself.

5.2.5 Potential for Internal Erosion

Internal erosion is the phenomenon during which solid material particles are washed out under or through an embankment due to the hydraulic force of seepage water. Ongoing washing out of solid particles eventually results in the formation of a 'pipe' at which stage the seepage would significantly increase, washing away more material until the embankment is destabilised or breached. Internal erosion would normally be expected to occur over long periods of time, weeks, months or even years, and would rely on a static upstream water level to maintain the hydraulic forces of the seepage water. Any deformities present in the embankment would increase the opportunity for materials to be washed out.

The seepage assessment showed that the phreatic surface through the embankment during the 1,000-year flood post discontinuance scenario is not expected to daylight at the downstream toe of the embankment and would be fully contained within the embankment itself. The likelihood of internal erosion occurring in this case is therefore considered to be very low.

Further, given the fact that internal erosion often develops over long periods of time (usually a matter of weeks, months or even years), the relatively short duration of impounding water during the flood events (several hours at most) is unlikely to result in any significant washing out of embankment material.

The geometry of the embankment provides further resilience as it has a reasonably wide crest and footprint along the base and therefore, a significant volume of material would have to be displaced before any significant breach is likely to form.

In light of the above, it is considered that the increase in the depth of impounding water as a result of the discontinuance of Llyn Bran Reservoir would not result in any significant increased potential for internal erosion.

5.2.6 Slope Stability Assessment: flood event with unrestricted flow through culvert

Using the SLOPE/W finite element model, it was possible to analyse both the downstream and the upstream slip surfaces, as follows:

- The downstream face critical slip surface was determined by importing a worst case phreatic surface from SEEP/W obtained by assuming the steady state phreatic surface (fully developed phreatic surface, which daylights on the downstream face) with the water level at 418.13m AOD, corresponding to the estimated 1 in 1,000-year post discontinuance peak flood level.
- The upstream face critical slip surfaces were determined by considering the following two scenarios:
  - With a static water level at 418.13m AOD (worst case) to represent the peak of the 1,000-year flood during the post-discontinuance scenario.
  - With the water level completely drawn down after the 1,000-year flood event had subsided, while assuming that the upstream face was still fully saturated up to the maximum flood level of 418.13m AOD (worst case). This analysis was carried out to help understand the potential for upstream failure due to rapid drawdown of the upstream storage area after the flood event had subsided.

In all cases, an appropriate live load was added to the embankment crest to cater for vehicle loading on the highway.

An example of the typical graphical output returned by SLOPE/W is presented in Figure 5.3.

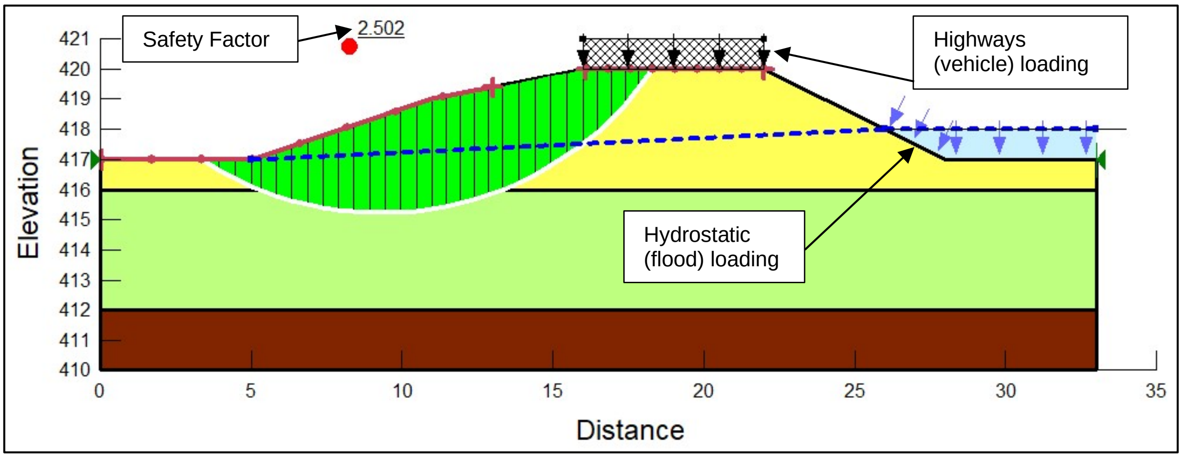

Figure 5.3: Example of SLOPE/W graphical output for H = 418.13 m AOD and downstream critical slip circle.

The program returns a fundamental parameter, the Factor of Safety for slope stability (number next to the red dot in Figure 5.3). This parameter, which is the ratio of the stabilising forces to the destabilising forces, helps to quantify the expected resistance of the embankment material against a slip circle failure. For example, a Factor of Safety of 1.0 would represent marginal stability. For confidence in steady state stability a Factor of Safety of at least 1.5 would be expected.

The results of the analysis for slope stability are presented in Section 5.3 below.

5.2.7 Slope Stability Assessment: Culvert Partially or Fully Blocked

It is acknowledged that during any flood event debris from the upstream catchment will be washed into the opening of the culvert beneath the highway, raising the risk of a partial or full blockage which would result in flows backing-up and impounding against the highway embankment. It is also recognised that the discontinuance of Llyn Bran Reservoir will increase the frequency of more significant flood events and therefore raise the risk of increased frequency of blockage.

In the absence of relevant data, it would be impossible to assign a level of risk of blockage or to attempt to estimate the increased risk of a blockage occurring as a result of increased flood risk.

An assessment of the embankment stability has therefore been undertaken assuming under any flood event, whether pre- or post-discontinuance the most extreme case that the culvert becomes sufficiently blocked during a flood event such that water impounds on the upstream side of the embankment. It has been assumed that an extreme event would overtop the embankment, flooding the road, and in which case steps would be taken within a few hours to clear the blockage and release the impounded water. The stability analysis has been undertaken assuming a phreatic surface establishes through the embankment to the full head of the depth of impounded water, i.e., to the top of the embankment, as shown in Figure 5.4 below, as a worst case scenario.

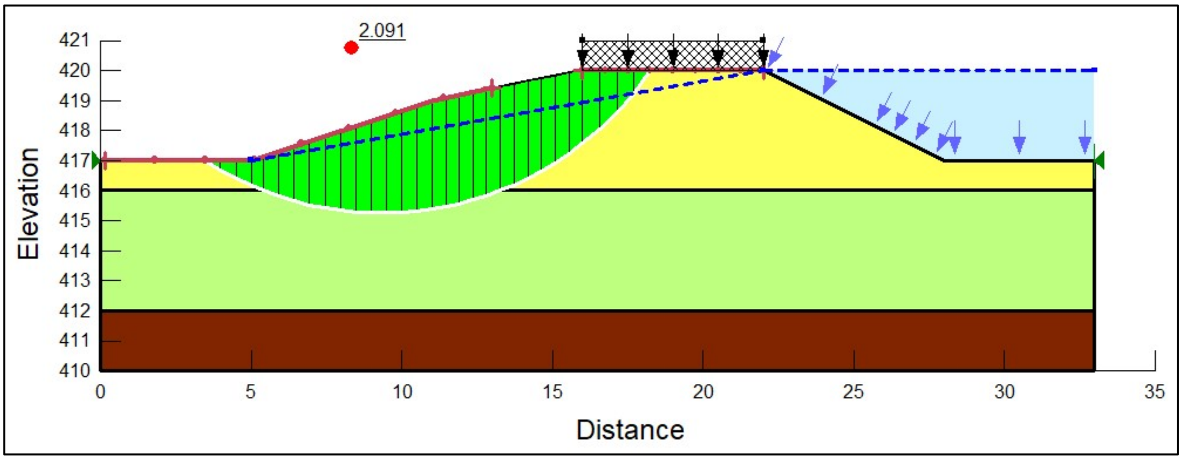

Figure 5.4: SLOPE/W output for scenario with culvert blocked allowing a full head of water to establish on the upstream side of the embankment.

The assessment returns a safety factor of 2.1 confirming satisfactory stability under this scenario.

5.2.8 Sliding Failure Mechanism (Hand Calculations)

Hand calculations were carried out to determine the safety factor against a sliding failure of the embankment along its base.

A free body diagram of the embankment for the purpose of the sliding stability calculations is presented in Figure 5.5 below.

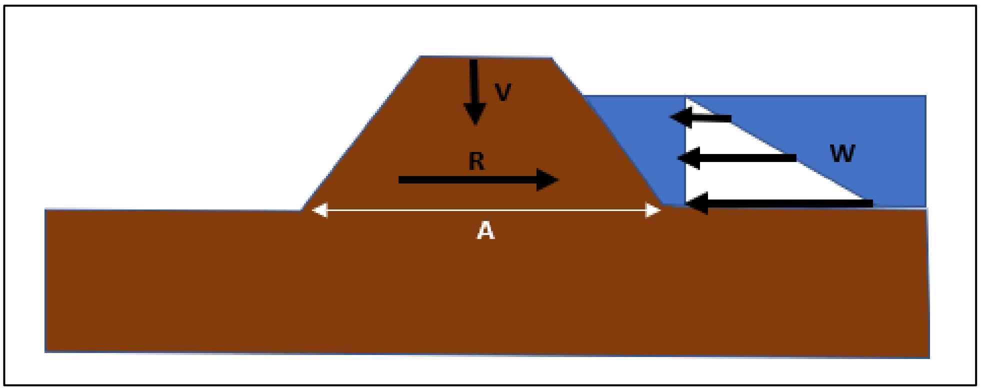

Figure 5.5: Free body diagram for the sliding failure mechanism.

The equations that govern the safety factor against sliding are the following:

$R = c \times A + \sum_1^3 V_i \times tan\emptyset$	[this represents the shear resistance force along the base of the embankment]
$H = W$	[this represents the total horizontal force which would tend to cause the embankment to slip – in this case, the force of the impounding water against the upstream face during the 1 in 1,000-year flood]
$SF = \frac{R}{H}$	[this represents the safety factor against sliding, i.e., stabilising forces divided by destabilising forces]

For the sake of simplicity, a homogenous embankment was assumed when calculating the weight of the embankment using the top layer properties (refer to Table 5-3 above).

The results of the analysis for stability against sliding failure are presented in Section 5.3 below.

5.3 Results

5.3.1 Downstream Slope Stability Assessment

The results obtained during the slope stability assessment of the downstream face are summarised in Table 5-5 below.

Table 5-5: Results for the downstream face of the embankment

1,000-year flood conditions (post-discontinuance)	
Impounding water level [m AOD]	**Factor of Safety**
Culvert Assumed to Discharge Flows	
418.13	**2.5**
Blocked culvert scenario with water impounding to road level (see Figure 5.4 above), representing a worst-case scenario both pre- (existing) and post-discontinuance	
To road level (over-tops embankment)	**2.1**

The results for all scenarios indicated a Factor of Safety in excess of 1.5 demonstrating satisfactory stability against failure of the downstream embankment slope. It should be noted that the current assessment also conservatively assumed zero cohesion for all embankment materials.

5.3.2 Upstream Slope Stability Assessment

The results obtained during the slope stability assessment of the upstream face are summarised in Table 5-6 below.

Table 5-6: Results for the upstream face of the embankment

1,000-year flood conditions (post discontinuance)	
Impounding water level [m AOD]	**Factor of Safety**
418.13	1.65
No impounding water but fully saturated u/s face [rapid drawdown scenario]	1.45

As can be expected, the worst-case scenario occurs with rapid drawdown on the upstream side of the embankment, after the flood event has subsided, with the embankment upstream face still possibly fully saturated. Even under this scenario, where a reduced factor of safety, still greater than unity, might be acceptable the minimum factor of safety is just below 1.5, again demonstrating a good level of confidence that the embankment slope will remain stable.

5.3.3 Embankment Sliding Stability

The results obtained during the embankment sliding stability assessment, as requested by DCC Highways, are summarised in Table 5-7 below.

Table 5-7: Embankment sliding stability results

Case No.	**Water Pressure [kN]**	**Weight of embankment [kN]**	**Factor of Safety**
No.1 (post discontinuance scenario) (1,000-year flood level = 418.13m AOD)	6.4	910	~80
No.2 (existing scenario) (1,000-year flood level = 417.13 m AOD)	0.1	910	>>100

The resulting factors of safety indicate that the embankment even under raised flood conditions following reservoir discontinuance will remain stable against sliding, as would be expected.

6 Embankment Stability Assessment for A543 Road

6.1 Approach and Sources of Data

In similar fashion to B4501 road stability assessment, a stability assessment of the A543 road upstream of Llyn Bran Reservoir was undertaken.

For the A543 embankment the stability assessment was generally divided into the following categories:

- Seepage assessment – determine the estimated profile of the phreatic surface through the embankment due to the existing top water level in Llyn Bran Reservoir.
- Slope stability assessment – determine the safety factors against a slip failure of the downstream (southern) face of the embankment.

An initial assessment of possible scenarios to be investigated concluded that there would be no increased risk of internal erosion of this embankment following reservoir discontinuance since there is normally no groundwater flow through the embankment itself, assuming the existing drainage from upstream is maintained. Equally, with no loading against the upstream slope, again reflecting the normal situation with satisfactory drainage, it is considered that there would be no change in the embankment stability with respect to sliding.

The finite element package SLOPE/W has been used for these analyses, following initial hand calculations.

Data for the modelling was obtained from the following sources:

- Topographical Surveys (Reservoirs & Water Ltd, February 2021).
- Soils data and groundwater conditions: Ground investigations carried out in February 2021, reported in March 2021.

6.2 Methodology

6.2.1 Embankment Cross Section

A typical cross section of the A543 road embankment was produced by Reservoir and Water Services Ltd. during a topographic survey in February 2021. The location of the cross section is shown in Figure 6.1 below, including the positions of boreholes that were put down during the ground investigations that were carried out in February 2021.

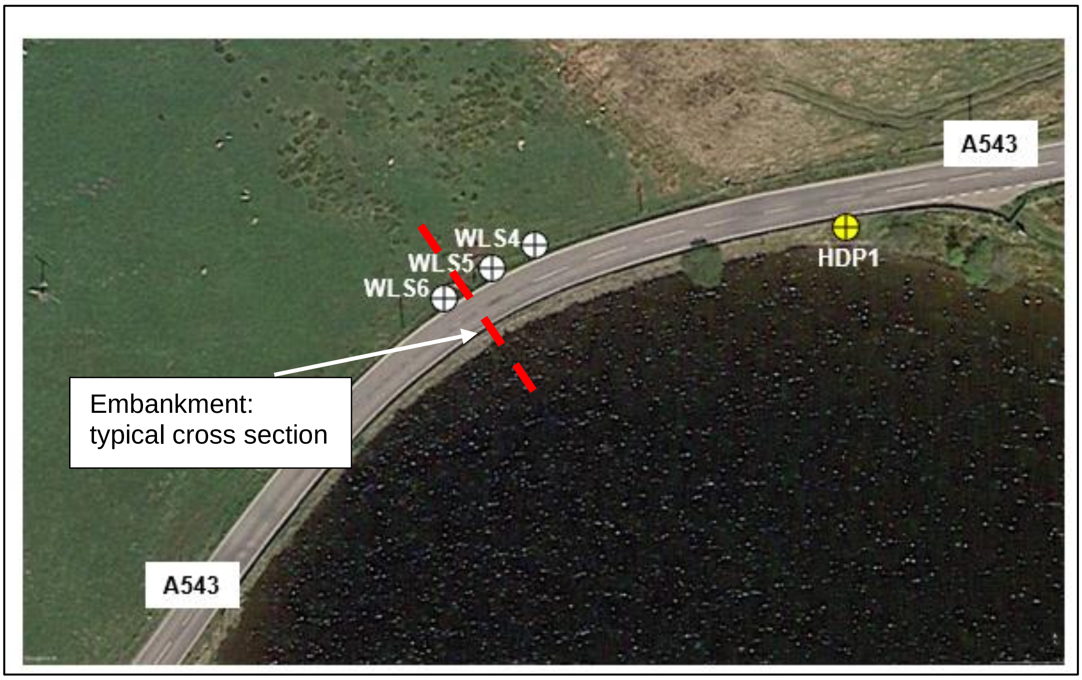

Figure 6.1: The location of the typical cross section of the A543 road embankment that was used for the stability analyses – the relevant boreholes from the ground investigation are also shown

6.2.2 Embankment Material Properties

For this stability analysis, only the results of boreholes WLS1 and WLS2 were analysed, as these were considered to best represent the embankment and its foundation.

Table 6-1 and Table 6-2 below summarise the soil properties for the embankment that were obtained from laboratory testing as part of the ground investigation.

Table 6-1: Summary of particle size distribution testing

Borehole	Location	Sample depth		Cobble	Gravel	Sand	Silt	Clay
WLS5	Adjacent to the A543 road	1m	Embankment fill	0%	86%	13%	1%	
		1.5 – 1.75m	Foundation	0%	12%	31%	36%	21%
		2.55 – 2.8m		0%	55%	39%	6%	
WLS6		0.7m	Embankment fill	0%	74%	21%	5%	

Table 6-2: Summary of shear box test results

Borehole	Location	Sample depth		Angle of shearing resistance θ	Effective Cohesion [kPa]
WLS5	Adjacent to the A543 road	1.2 – 1.5m	Embankment fill	31	9
		1.75 – 2m	Foundation	35	6
		2.8 – 2.9m		42	15
WLS6		0.6 – 1.2m	Embankment fill	35	13

From the Ground Investigation Factual Report information in the above tables, it was possible to identify three distinct layers that form the highway embankment. The information used during the various stability analyses is summarised in Table 6-3 below.

Table 6-3: Summary of the embankment layers' properties

Layer	Top	Middle	Lower
Material	Gravel	Sandy Clay	Sandy Gravel
Reference borehole	WLS5, WLS6	WLS5	WLS5
Sample depth	0 – 1.5m	1.5 – 2.3m	2.3 – 5m
Unit weight [kN/m^3]*	22	22	20
Angle of shearing resistance θ	34	34	42
Effective Cohesion [kPa]**	0	0	0
Hydraulic conductivity K [m/s]*	10^{-2}	10^{-4}	10^{-3}
Notes: * Typical values obtained from literature. ** Although the shear box test results produced relatively high cohesion values throughout, zero cohesion was conservatively assumed for the stability assessment given the known granular nature of the materials.			

6.2.3 Seepage Assessment

A similar approach to the B4501 road was followed to obtain the extent of the steady state phreatic surface through the A543 road embankment due to the water from Llyn Bran Reservoir impounding against the southern face. This phreatic surface was then used during the slope stability analysis of the embankment southern face for the existing scenario (see Section 6.2.4 below).

6.2.4 Slope Stability Assessment

Two scenarios were modelled in SLOPE/W as follows:

- Existing scenario: the southern embankment face critical slip surface was determined assuming a water level of 434.5m AOD (this corresponds with the normal top water level in Llyn Bran Reservoir) and a fully developed phreatic surface (from Section 6.2.3).
- Post-discontinuance scenario: the southern embankment face critical slip surface was determined with the water in Llyn Bran Reservoir completely removed (i.e., no phreatic surface with impounding water level removed).

In all cases, an appropriate live load was added to the embankment crest to cater for vehicle loading on the highway.

An example of the typical graphical output returned by SLOPE/W is presented in Figure 6.2 below.

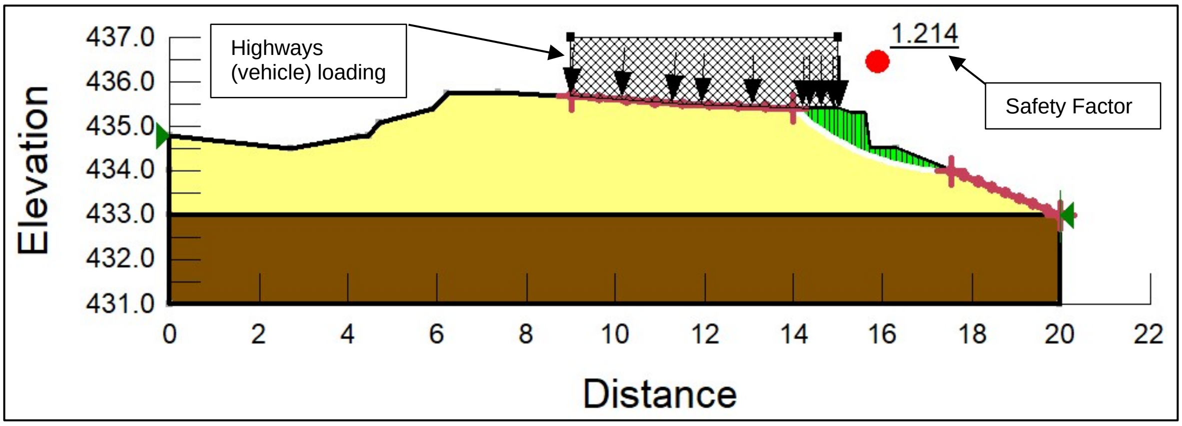

Figure 6.2: Example of SLOPE/W graphical output for the southern critical slip circle.

The results are presented in Section 6.3 below.

6.3 Results

6.3.1 Southern Slope Stability Assessment

The results obtained during the slope stability assessment of the southern face are summarised in Table 6-4 below.

Table 6-4: Results for the southern face of the A543 embankment

Impounding water level	Height of impounded water against embankment	Factor of Safety
434.5m AOD	1.5m	1.1
No impounding water and dry embankment	0	1.2

The results show that the withdrawal of water from the southern side of the A543 embankment following discontinuance of Llyn Bran Reservoir would have no notable effect on the stability of the embankment. In both cases a low factor of safety was obtained, which could be attributed in part to the assumed zero cohesion of the embankment material.

A sensitivity check was therefore carried out and it was found that the factor of safety values improved significantly with even marginally increased cohesion values, as shown in Table 6-5 below.

Table 6-5: Sensitivity check for cohesion of the embankment fill material

Cohesion	Factor of safety (Existing case)	Factor of safety (Discontinuance case)
0	1.1	1.2
2.5 kPa	1.4	1.5
5 kPa	1.7	1.8

As can be seen from the results in Tables 6-4 and 6-5 the stability of the southern slope increases with the removal of water following reservoir discontinuance (Noting that the lowering of water levels will be carried out slowly to avoid any rapid drawdown issues).

7 B4501 Culvert: Blockage Risk Assessment

7.1.1 Blockage Potential from Catchment Debris

The catchment upstream of the B4501 culvert is a mixture of grazed agricultural land, heathland and pine plantation. It is recognised that vegetation and loose timber can be carried by flood flows and transported to the B4501 culvert. This raises the risk of blockage of the culvert, noting that this is an existing risk, which can be expected to increase to some extent following reservoir discontinuance. It should be noted that from inspection on site there is no evidence of blockages of this nature at the site, and Denbighshire County Council highways department has no record of blockages occurring and/or having to be cleared from the culvert. This would suggest that debris is generally being captured upstream of the culvert and/or debris is simply being washed through the culvert. It is reasonable to assume that the existing risk of blockage of the culvert is low, and the risk would remain low after discontinuance.

However, an assessment has been undertaken to help understand the potential impacts on the highway embankment should a blockage occur.

A worst case scenario has been assumed as 80% blockage of the culvert. The results of the assessment indicate that for post-discontinuance flood events up to the 1 in 150-year event flows can be expected to impound against the embankment, with low flows passing along the existing roadside drainage, in a south-easterly direction, without necessarily flooding onto the road. For floods in excess of the 1 in 150-year event greater flows might spill on to the road. The vertical alignment of the road, with a gradient towards the south-east will ensure that any spilling flows would spread out quickly resulting in a shallow overtopping flow across and along the road. These flows would not be expected to present a significant hazard to road users under these rare and extreme conditions.

Further, the stability assessment reported in Section 5.2.7 above has demonstrated that impounding water on the upstream side of the road embankment, in this instance as a result of the partially blocked culvert, would not be expected to threaten the stability of the road embankment.

Measures to achieve a reduction in the likelihood of blockage, such as replacing or supplementing the existing culvert with a larger culvert, are not considered proportionate to the relatively small change in risk compared to the existing situation, noting that the existing risk of blockage is already apparently small.

7.1.2 Forestry Track Embankment

There is a forestry track embankment on the route of the watercourse between the reservoir and the B4501 embankment, located approximately 300m upstream of the B4501. The watercourse passes through this embankment by means of a 300mm diameter culvert. Flood modelling has shown that, even when operating with no other restriction, the small diameter of this culvert will cause flood flows to impound on the upstream side of the forestry track embankment under even modest flood conditions, and significant overtopping can be expected, for example during the 1 in 150-year event.

High level estimates indicate that the forestry track embankment could begin overtopping during the 1 in 10-year flood under existing conditions (pre-discontinuance) and during the 1 in 5-year flood following reservoir discontinuance.

Significant and prolonged overtopping can be expected to fail this embankment. Embankment failure would result in the rapid and uncontrolled release of approximately 3,000m^3 of water in addition to the prevailing flood flow at the time of failure. The failure would also involve the mobilisation of fill material from the embankment. By inspection on site the embankment is most likely to be of generally granular fill material.

Noting that failure of the embankment would occur at some point after embankment erosion had been initiated by overtopping flood flows, it would be reasonable to assume that water would already be impounding downstream at the B4501 road embankment. Flow approach velocities upstream of the B4501 would therefore be low and suspended granular fill material would tend to settle out of suspension. It seems unlikely that transported fill material in any great quantity would reach the B4501 culvert. Any material remaining in suspension would be expected to be washed through, bearing in mind the large diameter of the culvert in relation to the small size of particles from the forestry track embankment. Failure of the forestry track would not be expected to contribute to blockage of the culvert beneath the B4501.

8 Summary

The discontinuance of Llyn Bran Reservoir will result in an increase in the flood risk to the downstream B5401 road. It will also result in the loss of impounding water against the A543 road embankment along the northern edge of the reservoir. Following concerns raised by the local highways authority, Denbighshire County Council (DCC), Stillwater Associates were commissioned by Dŵr Cymru Welsh Water to carry out assessments to quantify the increase in flood risk to the B4501 road and to check the possible effects of discontinuance on the stability of both the B4501 and A543 road embankments.

The flood risk assessment yielded the following results:

- The likelihood of flood water impounding against the B4501 road embankment can be expected to increase as a result of the removal of the dam structure at Llyn Bran Reservoir. As an example, the likelihood of just over 1m depth of water impounding against the embankment will have an estimated annual probability of 1 in 1,000 after discontinuance, whereas the probability prior to discontinuance (existing case) is estimated to be less than 1 in 1,000.
- For both the existing and post discontinuance scenarios, whilst flood water might impound against the road embankment all floods up to at least the 1 in 1,000-year event are expected to be passed by the 1200mm diameter culvert without overtopping the embankment or flooding the road surface.

The stability assessment of the B4501 road embankment yielded the following results:

- Potential for a failure of the embankment due to internal erosion: ***it was found that the likelihood of an embankment failure due to internal erosion is highly unlikely for both the existing and post-discontinuance scenarios.***
- Stability of the upstream and downstream faces of the embankment following the discontinuance of Llyn Bran Reservoir: ***both the upstream and downstream faces were found to be sufficiently stable, modelling having shown satisfactory factors of safety against slipping during or following extreme flood events.***
- ***The embankment remains stable under a blocked culvert scenario with water impounding to the full height of the embankment to road level.***
- Stability of the embankment against a sliding failure: ***modelling has shown high factors of safety against sliding failure of the embankment under any flooding scenario.***

The stability assessment of the A543 road embankment yielded the following results:

- Stability of the southern face of the embankment: ***It was found that the southern face of the A543 road embankment is sufficiently stable and that the works to discontinue Llyn Bran Reservoir would have no notable effect on the stability.***

In terms of the risk of blockage of the culvert through the B4501 embankment, the following conclusions have been drawn:

- Discontinuance of the reservoir would be expected to marginally increase the risk of blockage as a result of flood transported debris, mainly large vegetation and timber, although this risk already exists and there is no evidence of such a blockage ever having occurred. **The risk of blockage of the culvert would remain low even after discontinuance.**
- Failure of the forestry track embankment, upstream of the B4501 embankment, would not be expected to result in an increased risk of blockage of the B4501 culvert.
- A significant blockage of the B4501 culvert would result in water impounding against the upstream side of the road embankment, with the potential for water to spill onto the road, although the vertical alignment of the road is such that water would tend to flow along as well as across the road and the depth of flow would be small, not likely to present a hazard to road users.
- The stability assessment confirms that the B4501 embankment remains stable even when water is impounding against the full height of the embankment.

Appendix A

E-mail dated 9th November from Denbighshire County Council Highways Department

From: James (Jim) Hall <james.hall@denbighshire.gov.uk>
Sent: 09 November 2020 14:37
To: Jon Holland
Cc: gwenno.evans@dwrcymru.com
Subject: Llyn Bran Discontinuance

Hello Jon

Sorry for the delay in responding to you and Gwenno following last weeks meeting. November is business planning month, so alas that tends to dominate my attention at this time of year.

Denbighshire County Council, highways concerns about the Llyn Bran Discontinuance are as follows:

1. Have you considered the support offered to the A543 to the north of reservoir?
2. Have you considered the highway drainage from the A543 to the north of the reservoir?
3. Have you considered the water course crossing of the A543 and discharge to the north of the reservoir?
4. How frequent will flood events overtop the road?
5. Have you considered the structural stability of the B4501?
6. How frequently will the culvert be over topped?
7. We are concerned that if the loss of attenuation increases the flood water against the highway embankment, that the culvert diameter is inadequate and the angle is wrong?
8. We are concerned that the upstream watercourse is already eroding to the north of the upstream culvert headwall?

As I mentioned in the meeting I am very happy to meet you on site, to ensure that we are all aware of the actual matters. My diary has very few fixed dates at the moment, simply because of the business planning commitments, so I am flexible for this month.

Regards

Jim Hall, MCIHT
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