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St Blazey Flood Storage Reservoir: A Case Study on the Importance of a Holistic Approach to Reservoir Risk Assessment

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SYNOPSIS The St Blazey Flood Storage Reservoir was situated to the north of the town of St Blazey, Cornwall and was impounded by Highway Dam, which crossed the Treffry Canal. The right side of the reservoir was also contained by a sandy railway embankment supported by a masonry wall. Following a Section 10 inspection and failure of a section of the masonry wall retaining the railway embankment, an Inspecting Engineer recommended that the risk posed by the presence of the reservoir be assessed.

AtkinsRéalis undertook a qualitative risk assessment considering the existing arrangement and options to upgrade or discontinue the reservoir, and also performed a high-level strategic review to enable the owner (the Environment Agency) to assess the best solution for the local population. As a result of the assessment, the project team determined that the reservoir presented an unacceptable risk to life and should be discontinued through the removal of Highway Dam.

This paper discusses the methodology used to determine discontinuance as the preferred solution, focusing on how a holistic view on risk versus benefit was adopted, supported by flood modelling to quantitively assess the benefits provided by the reservoir. Furthermore, the paper discusses how consideration of the societal benefit created by the presence of a reservoir is critical in assessing the tolerability of the risk to life, rather than limiting consideration to the likelihood and consequences of failure alone.

BACKGROUND

The St Blazey Flood Storage Reservoir (FSR) was located to the north of the town of St Blazey, Cornwall. The reservoir formed, with Treesmill FSR, part of the Par flood relief scheme, which was constructed in 1976. It was owned and operated by the Environment Agency (EA).

The reservoir was formed by the Highway Dam, located across the line of the Treffry Canal (Figure 1). The reservoir was also retained by a single-track railway embankment on its west flank, carrying the Atlantic Line from Par to Newquay. This embankment was reportedly made of “pure sand” and was not designed to retain the reservoir. The Par River (northwest) side of the railway embankment is supported by a masonry wall.

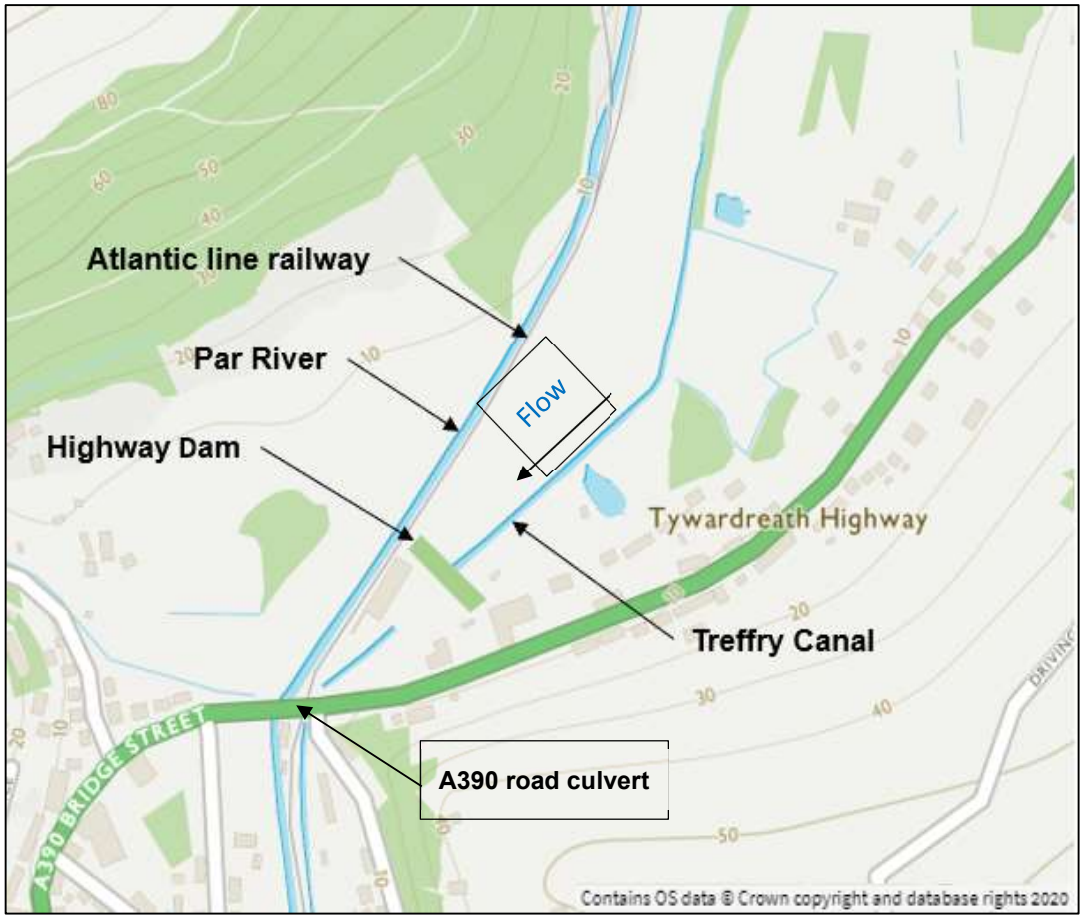

Figure 1. Site plan of St Blazey FSR

The Highway Dam retained water 1.9m above the flood plain level, providing a reservoir capacity of approximately 155,000m^3. The reservoir primarily provided protection in the lower return period events, with the spillway crest (at ~7.9mAOD) starting to operate for flood events between the 50% and 10% Annual Exceedance Probability (AEP) and the dam crest (at ~8.5mAOD) overflowing for floods greater than the 10% AEP event.

The lowest railway embankment level adjacent to the reservoir was 8.7mAOD resulting in the railway embankment overflowing for all flood events greater than the 5% AEP event. The extent of the railway embankment overflowing increased with larger (more infrequent) flood events, as the peak flood level in the reservoir increased.

CONTEXT

An inspection of the FSR, under Section 10 of the Reservoirs Act 1975, was requested by the undertaker due to concerns about the construction materials used in the railway embankment following some repairs to a redundant section of embankment upstream at Ponts Vale. The inspection was undertaken in August 2019. Following heavy rain in October 2019, a section of the masonry wall retaining the railway embankment, around 95m upstream of the dam, failed. The Section 10 inspection report stated that this was reported as a reservoir safety incident to the Enforcement Authority as the railway embankment retains the reservoir during impounding events.

Following the inspection and the reservoir safety incident, the Inspecting Engineer made a recommendation as to Measures to be Taken in the Interests of Safety (MIOS) to review whether the risk posed by the presence of the reservoir was tolerable as defined by the *Guide to Risk Assessment for Reservoir Safety Management* (RARS) (EA, 2013).

To address this recommendation, a Tier 1 reservoir risk assessment was carried out, in accordance with the guidance provided in RARS. Three potential options, established through an options study, were considered: retaining the existing arrangement; improving the reservoir by building a line of sheet piles between the reservoir and the railway embankment; and discontinuing the reservoir.

In parallel with the risk assessment, the project team carried out hydraulic modelling of the options to support the Environment Agency's Strategic Outline Case (SOC), required to obtain funding for future project stages. This hydraulic modelling, which considered other proposed flood risk improvement works in the catchment, provided a quantitative assessment of the operational flood risk benefits of the reservoir.

This paper discusses the importance of considering any changes to flood risk management in the catchment when assessing the benefits provided by a flood storage reservoir and of considering those benefits when assessing the tolerability of the societal risk posed by the reservoir.

RISK ASSESSMENT

Existing arrangement

A Tier 1 risk assessment, as outlined in RARS (EA, 2013), was carried out to evaluate the societal risk associated with the uncontrolled release of the reservoir contents, caused by failure of the railway embankment.

The likelihood of failure of the railway embankment, due to crest overflowing and downstream face instability was assessed as **Extreme** because the embankment had no spillway and the masonry wall had been reported to be in "poor condition" during a 2019 structural survey. The potential magnitude of the consequences, considering the human, economic, environmental and cultural receptors within the inundated area, was designated as **Level 3** because the number of residential properties affected would be more than 30 and less than 300 (assessed considering EA reservoir flood mapping).

RARS provides a methodology for qualitative assessment of the level of risk, by plotting the likelihood of failure of the railway embankment with the magnitude of potential consequences on a simple risk matrix (Figure 2). This indicates that the initial level of societal risk associated with a reservoir breach due to failure of the railway embankment was **Unacceptable**.

Managing Risks for Dams and Reservoirs

Likelihood of dam failure	Potential magnitude of consequences				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extreme	ALARP	ALARP	ALARP	Unacceptable	Unacceptable
Very high	Tolerable	ALARP	ALARP	ALARP	Unacceptable
High	Tolerable	Tolerable	ALARP	ALARP	ALARP
Moderate	Tolerable	Tolerable	Tolerable	ALARP	ALARP
Low	Tolerable	Tolerable	Tolerable	Tolerable	ALARP
Very low	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

Figure 2. Simple Tier 1 risk matrix (adapted from RARS (EA, 2013))

An Unacceptable rating means that "the risks are generally believed by individuals and society to be not worth taking, regardless of the benefits" (RARS). Therefore, the reservoir could only be used as a flood storage reservoir if its condition was improved.

Alternative arrangements

As discussed above, the societal risk associated with retaining the reservoir in its existing arrangement and condition was Unacceptable. Two viable alternative arrangements were established to address the risks associated with use of the railway embankment to retain the reservoir:

1. Full discontinuance of the reservoir through removal of the Highway Dam so that it no longer caused water to impound upstream.
2. Retaining and upgrading the reservoir by installing a sheet pile wall along the western side of the reservoir so that the railway embankment no longer formed part of the reservoir impounding structure. This piling could not withstand overflowing.

The societal risks associated with the two alternative arrangements are discussed in more detail below.

The discontinuance option would remove the risk of an uncontrolled release of water from the reservoir, as there would no longer be a reservoir following the removal of the Highway Dam.

Retaining the reservoir would intrinsically retain the risk of an uncontrolled release of water, which could endanger life. However, upgrading the reservoir by installing a sheet pile wall along the western side would reduce this risk from Unacceptable to Tolerable. The level of risk was assessed on the following basis:

- The installation of a sheet pile wall between the reservoir and the railway embankment would make the sheet pile wall part of the reservoir retaining structure, rather than the railway embankment. The new sheet pile wall, designed to retain water, would have a Very Low likelihood of failure.

- The Highway Dam was a clay core embankment with a low hydraulic gradient and with a foundation cut-off. The dam was generally maintained to a good standard, the surveillance was adequate and there were no signs of adverse behaviour. In flood events where the dam overflowed; overflow velocities were assessed to be low and not likely to cause erosion of the downstream slope. The Highway Dam was therefore judged to have a Low likelihood of failure.
- The area inundated in the event of a breach would not change (the flood extents for breach of the railway embankment and Highway Dam are very similar), so the consequence designation would remain at Level 3, as above.
- Referring to Figure 2, a Low or Very Low likelihood of dam failure, combined with a consequence designation of Level 3, results in a societal risk associated with failure of the reservoir that is **Tolerable**.

The outcomes of the qualitative risk assessment of the two alternative arrangements are summarised in Table 1 below.

Table 1. Summary of risks associated with alternative arrangements

Risks	**Discontinue the reservoir**	**Retain and upgrade the reservoir**
Societal risk associated with breach of the railway embankment/ western side of the reservoir	No risk associated with the reservoir, as reservoir removed	Tolerable
Societal risk associated with breach of the Highway Dam	None as dam removed	Tolerable

Risk assessment findings

The Tier 1 risk assessment highlighted that the societal risk associated with retaining the reservoir, in its existing arrangement and condition, was unacceptable. An assessment of alternative arrangements concluded that installation of a sheet pile wall between the reservoir and the railway embankment would reduce the societal risk associated with breach of the reservoir to a Tolerable level and that discontinuance of the reservoir would remove the societal risk posed by the reservoir.

ASSESSMENT OF SOCIETAL BENEFIT

The assessment of the benefits provided by the reservoir was carried out as part of a business case produced to demonstrate that any works recommended would represent a good use of public money. One element of the business case is the Economic Case, for which the cost/ benefit ratio of any options under consideration are presented. For flood risk projects, such as the St Blazey FSR, the benefits are assessed by creating a hydraulic model of the potential options and simulating a range of storm events to understand and compare the expected flood extents and depths at receptors within the catchment for each scenario.

Catchment context

The St Blazey FSR was integrated within a complex hydraulic system which includes the Treffry Canal passing through the reservoir site, the Tywardreath and Treesmill Streams passing through the smaller adjacent Treesmill Reservoir, and the Par River passing to the west of the St Blazey FSR and then through the town of St Blazey.

Managing Risks for Dams and Reservoirs

Simultaneous to the St Blazey FSR project, the detailed design of flood risk management works in the town of St Blazey, downstream of the reservoir, was being carried out. The works formed part of the St Austell Bay Resilient Regeneration (StARR) scheme, which was developed to address flood risk in the area, as it was one of the major influencing factors preventing regeneration to the deprived communities of Par and St Blazey. The key components of the works included defence improvements and culvert replacement along the Par River, floodplain reconnection and surface water management. The EA led on the delivery of main river interventions, whilst Cornwall Council led on the surface water and ordinary watercourse interventions with support from key delivery partners.

Recognising the complex hydraulic connectivity in the catchment, and therefore the potential for the StARR scheme works to impact on the outcomes of the hydraulic modelling for the St Blazey FSR options, the project team decided to consider the StARR scheme works in all modelled scenarios.

Modelled scenarios

Hydraulic modelling was undertaken for flood events from 50% AEP (annual exceedance probability) to 0.5% AEP. Three scenarios were considered in the hydraulic model:

- The existing arrangement, before the implementation of any works. Although this option could not be taken forward (due to the unacceptable societal risk associated with the existing arrangement), it formed the baseline against which the other options were compared.
- Retaining and upgrading the reservoir, through the addition of a sheet pile wall between the reservoir and the railway embankment. This was represented as a glass wall in the model (on the basis that the top of sheet pile level would be set to prevent overflowing in all design events).
- Discontinuance of the reservoir. This was represented by modifying the ground profile within the dam footprint so that the ground levels aligned with those upstream and downstream.

Results of the hydraulic modelling

The total number of properties modelled to experience internal flooding during each event is presented in Table 2, allowing the flood impacts associated with the two feasible arrangements to be compared. The flood impacts of the existing arrangement are not included as it was not a feasible option.

Table 2. Number of properties modelled to experience internal flooding

Event	**50% AEP**		**10% AEP**		**5% AEP**		**2% AEP**		**1% AEP**		**0.5% AEP**	
Property type	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res
Discontinue	2	10	36	37	73	59	126	88	186	124	379	203
Retain and upgrade	3	7	43	46	88	67	135	91	197	126	387	207
Difference	+1	-3[1]	+7	+9	+15	+8	+9	+3	+11	+2	+8	+4

[1] Garage buildings located immediately downstream of the Highway Dam, for whom individual mitigation measures were implemented.

The results show that the number of properties modelled to experience internal flooding was greater with the reservoir retained and upgraded, compared with the discontinuance option. A key reason for this is that with the Highway Dam removed (reservoir discontinued), the shape of the downstream hydrograph is altered, with more water passing downstream outside the peak of the flood, reducing peak water levels. This option therefore better utilises the increased capacity in the Treffry Canal downstream of the reservoir, provided by the StARR scheme. This results in reduced bank overtopping downstream or reduced maximum flood levels in the area upstream of the A390 road, depending on the flood event.

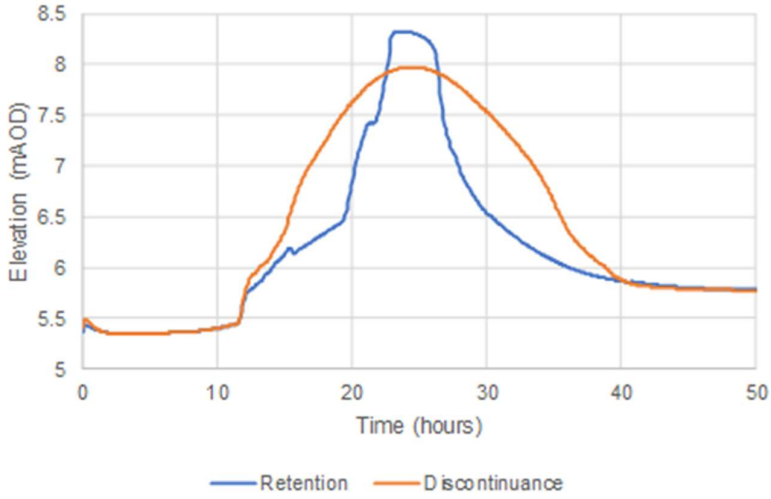

Figure 3. 10% AEP event modelled stage hydrographs just upstream of the A390 road culvert

DISCUSSION

The societal risk associated with breach of the retained and upgraded St Blazey FSR was assessed considering the likelihood and consequences of failure of the Highway Dam and found to be Tolerable. A Tolerable level of risk is defined as "individuals and society are willing to live with the risks so as to secure certain benefits". Therefore, considering only the outcome of the Tier 1 risk assessment, the preferred option would have been to retain the reservoir, on the basis that it was (assumed to be) providing flood risk benefits to the downstream communities in Par and St Blazey.

However, the hydraulic modelling demonstrated that with the StARR scheme works in place, the reservoir provided less flood risk benefits than if it was discontinued. As the presence of any raised reservoir upstream of a populated area creates a risk of loss of life associated with the potential failure of the dam and release of the impounded water, the presence of a reservoir cannot be justified (i.e. the risk cannot be considered tolerable), if the reservoir does not provide any benefits. Therefore, the outcome of the reservoir risk assessment, when considering not only the societal risks posed by the reservoir but also the benefits provided by each arrangement, was that the reservoir should be discontinued.

It is important to note that when sensitivity testing was carried out to model the options without the StARR scheme in place, a greater number of properties were shown to experience internal flooding in the discontinuance option than for the retain and upgrade option. In this scenario, the assumption that the reservoir was providing flood risk benefit and thus the original finding of the risk assessment, that the reservoir should be retained and upgraded,

would have been valid. The sensitivity test, therefore, highlighted the importance of taking a holistic approach to catchment flood risk management, considering the impacts that schemes can have on the efficacy of other measures implemented in the same catchment. The test also highlighted the need for aligned project delivery; if the StARR scheme works were not implemented before discontinuance of the St Blazey FSR, the populations of Par and St Blazey would have experienced increased flood risk in the short term.

By taking a holistic approach to the assessment of the societal risks and benefits associated with the St Blazey FSR, the project team was able to bring about increased flood risk benefits over and above the StARR scheme works, whilst removing the public safety risks and the Undertaker's legal obligations associated with the statutory reservoir. The scheme also enabled the culverted section of the Treffry Canal passing through the Highway Dam to be returned to an open channel and environmental enhancements in line with the Water Framework Directive requirements to be carried out within the dam footprint.

Figure 4. Images of the completed St Blazey FSR discontinuance

CONCLUSIONS

Reservoir risk assessments on existing reservoirs are often carried out only considering the likelihood and consequences of failure, based on the (reasonable) assumption that if the reservoir was built it must be providing some societal benefit. Therefore, the risk assessments seek to determine whether the risk associated with the presence of a reservoir is tolerable, or if works need to be done to ensure that the societal risks are as low as reasonably practicable but do not tend to question whether the presence of the reservoir is justified.

The case study presented in this paper has demonstrated the importance of taking a more holistic approach to reservoir risk assessment, ensuring that it does not simply become an exercise of following a methodology to achieve a risk rating. This is of particular importance for flood storage reservoirs, for which consideration of the benefits provided by the reservoir as part of the assessment of the tolerability of risk to life may prove vital in achieving the optimal outcome, particularly if the other flood risk management measures implemented in the catchment have changed since the reservoir was constructed or last assessed.

REFERENCE

EA (2013). *Guide to risk assessment for reservoir safety management*. Environment Agency, Bristol, UK