## Forestry England

# Cannop Ponds

## Dam Safety Assessment Report

Reference: 286412-ARP-XX-XX-RP-CX-6102

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# Executive Summary

In February 2021 a small sinkhole formed adjacent to the spillway wall of Lower Cannop Dam. This necessitated a Section 10 dam safety inspection to be carried out under the Reservoirs Act 1975. The resultant mandatory safety measures and sequence of findings since have led to the remaining operational life and long-term viability of both Upper and Lower dams needing to be carefully considered.

This report details the safety measures stipulated in the inspection reports, findings to date, and further considerations now required. In summary; there are three overarching safety issues applicable to both dams:

1. All earth dams must be capable of safely passing enough water in adverse flood events so as to not overflow or limit overflow to an acceptable level. Without this ability, there is a serious threat of the embankment being eroded in a storm and the dam breaching. If allowed to breach, there would be a threat to life in the downstream communities and sudden loss of, and damage to, the environment.

   Both Upper and Lower Cannop spillways (the structures beneath the existing bridges) are significantly undersized. Flood Studies have shown that both dams have insufficient capacity to protect against overflowing and therefore would be at risk of a potential dam breach in storms with annual probability of occurrence as high as 1 in 150 years (0.67%). This does not meet current safety guidelines, and it poses an unacceptable level of risk to the downstream communities and designated habitats.

2. There is a long and repeated history over the past 120 years of leakage from the dams. In the late 1950s, leakage was sufficient to raise concerns at Upper Cannop as it would nearly dry out in summer months when leakage was exceeding the inflows from Cannop Brook. Seepage flows in Lower Cannop dam have also led to numerous voids forming in the embankment and beneath the spillway.

   Whilst remedial works have repeatedly been undertaken to address and halt further issues, it is evident that so far these efforts have only slowed the continued degradation of the earth embankments and have not yet reduced to an acceptable level, the risk of the dams failing.

3. In the event of emergency, failure of a dam can be averted or consequences reduced by quickly drawing down (lowering) the reservoir level. This reduces both the seepage flow rate and the destabilising load on the dam embankment.

   Neither dam has any permanent drawdown facility. While pipework within the dams did to exist, these have long since become inoperable and likely decommissioned. To drawdown either reservoir in an emergency would therefore be entirely dependent on the availability and mobilisation of high volume pumps. These can take days to setup, potentially resulting in the critical period for averting failure being missed.

The outstanding safety measure on Lower Cannop dam is to 'Replace the Spillway'. Similar measures for Upper Cannop are now required, likely necessitating a replacement spillway or second spillway to be constructed at that Pond.

The wording of these measures does not reflect the scale of the replacement spillways which would be required, nor the disruption the works would have to Cannop Ponds. A sufficiently sized spillway at both dams would need a weir length roughly three to four times longer than existing and spillway chute constructed from reinforced concrete.

Findings since the safety measures were set mean that replacing the spillways alone would be unlikely to adequately reduce the risk of the dams failing. Extensive investigations and remedial works would be required to locate and address seepage and / or voiding in the dams and permanent drawdown facilities would need to be installed.

Given the extent of the works, nature of the additional findings, and impacts on the Ponds, Forestry England are investigating other possible solutions with the potential to provide improved public access, reduced flood risk downstream, and achieving a positive outcome for nature.

# 1. Location

Upper and Lower Cannop Ponds are two reservoirs located along Cannop Brook, within the Forest of Dean. Situated 1.8km southwest of the Speech House, 2.8km north of Parkend, and 3km east of Coleford; the reservoirs have been a feature within the centre of the Forest of Dean for many years, dating back to the early 19th century.

The reservoirs are now part of a popular visitor destination, offering amenity for various groups including walkers, runners, bird & bat watchers, and anglers (subject to lease), whilst also providing links to cycle routes and scenic picnic areas. The lower reservoir is utilised by the Forest of Dean Stone Firms to power a small hydro-electric scheme that supplements the power used by the stone cutting plant.

# 2. Dam Construction

All dams are slightly porous with water seeping slowly through them. It is important in their design to ensure these seepage flows are slow enough that the finer portion of the earth material making up the dam (silt/clay - also referred to as fines), cannot be carried through and washed away. If fines are lost, normal seepage flows worsen to leaks, voids form, and as these become larger, the risk of sudden failure of the dam increases.

Modern earth dams are typically constructed with a clay core, significantly reducing the rate at which water seeps through. Upstream and downstream of this core, graded (carefully sized) material is placed to act as a fine filter, enabling seepage water to pass through the dam while holding the clay core in place.

Lower Cannop embankment was originally built to carry a tramway. It was not designed or constructed of materials specifically intended to retain water. Upper Cannop was also constructed during a period pre-dating the common use of clay cores. It is therefore likely that both embankment dams were originally constructed from homogeneous earth fill (a uniform fill material throughout) with no watertight core.

Homogeneous type dams rely upon on the materials used and overall thickness to slow seepage flows enough to stop the washout of fines. If this is not achieved, seepage flows will continually result in a loss of fines and leaks and voids will be able to form over time.

There have been numerous issues with leakage and voids within the Cannop embankment dams over the past century. This is most likely a direct result of their original construction methodology and age. Therefore, as the dams continue to age, they are at an ever-increasing risk of failure.

# 3. History of the Cannop Dams

Lower and Upper Cannop Pond were constructed in 1825 and 1829 respectively as earth embankments. Originally constructed to support the increasing power demands associated with the expansion and modernisation of the Parkend Ironworks, they have since also served the needs of the stone cutting, mines workings, wood distillation, and railways industries.

During this industrial period, particularly in the 1900s, the reservoir waters were subject to inflow of high-iron deposits, silt-laden mines drainage, black water, and chemical processing waste. This pollution is reported to have repeatedly killed aquatic life within the reservoirs and has the potential to have caused degradation to the concrete / masonry structures. It was not until the 1970s that these industrial uses and presence of pollution came to an end and the reservoirs were able to naturalise. However, issues with silt levels have meant Upper Cannop had very little surface area or depth remaining due to silt build up until around 1984 when modification works were undertaken to construct a causeway which divided the reservoir into the silt settling lagoon (now part of Cannop Bridge March Reserve) and fishing pond we see today.

There is significant history of safety issues, repairs, and modifications to the dams over their lifetime. These safety issues are becoming more frequent and grander in scale, leading to the current concerns over the remaining lifespan of the dams.

## 3.1 Timeline of Events

The below timeline has been built up from available historic records. There are references to further records of additional events which are unable to be found. This timeline outlines the historic safety issues with the dams, and the increasing frequency of these safety issues in modern times. It also covers silt and pollution issues with the reservoirs which may need to be accounted for with silt management and structural assessments for any dam works.

The events have been highlighted as applicable to Upper, Lower, or Upper and Lower (U&L) Cannop Pond in red.

Around **1810** the Bixslade Tramway embankment was constructed; crossing Cannop Brook.

**1825 -** Lower **-** the earth embankment forming Bixslade Tramway and the crossing to Cannop Brook was altered to form **Lower Cannop Pond**; flooding a disused quarry and the upstream valley.

**1829 -** Upper **-** An earth embankment dam was constructed upstream across Cannop Brook; flooding the upstream valley and forming **Upper Cannop Pond**.

**Mid / late 1800s -** No records regarding the dam condition or construction methodology have been able to be located for the 1800s.

**1900s -** While specific details of works are limited or lost, historic maps, letters, and records show evidence of significant repairs and modification to address leaks throughout the 1900s. Notably, two major historic repair works (as engraved in the Lower Cannop spillway stones) were necessary and complete in 1907 and 1976.

**1907** - U&L **-** following reports of leaking, low water levels, and pollution, both dams were in a poor condition. Significant repair works and modifications were undertaken to make the dams safe and to raise the water level in both by approximately 4ft, enabling additional use by the Bixlade Stone Works (now the Forest of Dean Stone Firms Ltd).

**1911 -** U&L **-** Fishing permits were released for 4 years. Failed attempts preluded eventual success to stock the ponds with fish in 1908. These permits however ceased in 1914 owing to nothing being caught by the 13 permit holders that year, and pollution from the new Wood Distillation Plant (opened in 1915) leading to the death of the few hundred fish which were present in the Ponds.

**1960s -** Upper **-** towards the end of use of the reservoirs for industrial purposes (Wood Distillation Plant demolished in 1966), Upper Cannop reservoir was largely infilled with silt (Cannop Colliery pumped silt-laden mine drainage into the upstream water course until around 1968). This issue was exacerbated by leakage, leading to only a minimal area and depth of water remaining.
Lower - Lower Cannop remained at its raised level, but surface area had also been lost to silt.

**1965** - U&L **-** Concerns about leakage from the ponds were raised with remedial measures likely to be significant. Due to the combination of leakage and no more water being pumped into the upstream watercourse from the Cannop Colliery, there were concerns around Upper Cannop drying out altogether in summer months.

**1968** - U&L **-** Major pollution incident caused the loss of thousands of fish (mainly carp and roach) and several eels and ducks.

**1970** - Lower - The screen across the spillway (installed to retain Grass-Carp - a non-native species) blocked, leading to a dangerous rise in water level of approximately 0.75m.

**1972** - U&L **-** Both dams reported to be in a 'rather dilapidated condition' with large areas of both reservoirs having been lost to silt and water levels fluctuating considerably with the seasons due to leakage rates.
Upper - serious leakage through the embankment were present.
Lower **-** the stone and concrete spillway had been 'undermined completely' by leakage flows.

**1973 -** Upper **-** Repair works to Upper Cannop dam were undertaken to address the 1972 leakage flows.

**1974 -** Lower **-** The screen across the spillway blocked, leading to a dangerous rise in water level of approximately 0.6m. The screen was replaced later that year. During the works, the 1973 repairs to leakage around the spillway were found to have not been entirely successful.

**1976** - Lower - Repair works (recorded in the stonework of the spillway) to Lower Cannop spillway were undertaken.

**1978** - Lower - boreholes into the dam identified a number of large voids which are likely to have occurred because of reservoir water leaking through the embankment and washing out embankment material. The voids were filled, then a clay blanket was placed over the upstream (pond) side of the embankment to try to limit seepage and leakage rates. A geotextile was placed on the downstream slope to help prevent erosion in the event of overtopping.

**1981** - (Location Unknown) **-** Repairs carried out to the embankment

**1984** - Upper - around this time, Upper Cannop reservoir appears to have been dredged to reduce silt and the present causeway constructed; dividing the reservoir into a silt settling lagoon (North) and fishing pond (South). The pipework which would have enabled an emergency drawdown without pumps appears to have been decommissioned at a similar time, likely due to having become dysfunctional due to the silt depth. Record of the details of these works have not been located.

**1986** - Lower - repair works were undertaken to the upstream clay layer with gravel and rock placed to protect it from erosion. Upper - concerns raised by Inspecting Engineer (during inspection of Lower) due to presence of seepage, uneven dam crest, and insufficient freeboard.

**1992 -** Lower - a large void developed behind the wall of the spillway, again due to loss of fine materials. This was infilled with clay.

**1993 -** Lower - further settlement and a new hole appeared at the same location of the 1992 repairs. Subsequent repairs were undertaken.

**1994** - Lower - the walls to the spillway were repaired due to structural issues.

**1995** - Lower - a large void opened in the embankment close to the 1978 repairs suggest significant ongoing loss of fine material from the dam. Further repairs were undertaken.

**2001-04** - Upper **-** Pond unable to be fished for 4 years due to silt reducing water depth and subsequent reed growth (reeds grow in waters less than 2m deep).

**2003 -** Lower - further settlement and voiding was found at the location of the 1992 spillway wall repairs. Some 9m$^3$ of concrete was needed to infill the holes.

**2009** - Lower - dam safety inspection (Section 12 - advisory rather than legal recommendations) advised erosion at the toe of the spillway should be repaired and the fish screen removed due to risk of blockage and water levels accidentally being raised.

**2015 -** Lower - Inspecting Engineer identified 'quite large' flows discharging at the toe of the dam from the beneath the base of the spillway. Monitoring of these flows undertaken. These flows are likely to have been the cause of the findings in 2020.

**2019** - Upper - works undertaken to upstream embankment to form protection against erosion through the formation of a randomly placed stone revetment.

**2020** - Lower - a void appeared adjacent to the spillway. Forestry England called for a Section 10 Inspection Report by an All Reservoir Panel Engineer (ARPE). The inspection report outlines a number of Measures In The Interest of Safety (MITIOS). Forestry England have been addressing the measures, but the outcomes of the studies and findings from the works are raising significant concerns over the long-term safety of the dam.

**2020 to Present -** U&L **-** the findings following this event are outlined in more detail in the subsequent sections of this report

# 4. Forestry England's Responsibilities

## 4.1 Reservoirs Act

Across the UK, between 1810 and 1925, 14 dam failures resulted in the deaths of 426 people. Notably, in 1925, two reservoirs in North Wales failed in cascade, resulting in the Dolgarrog disaster. This led to Parliament passing the Reservoir Act 1930, legislating requirements for safety inspections every 10 years, certification of construction of new dams, and monitoring records to be kept for existing dams.

While dam failures within the UK have not resulted in a loss of life since, continued failures, near misses, and overseas failures leading to loss of life led to the updating and passing of the Reservoirs Act 1975. This Act is still in effect today with a number of amendments made over time to remain current.

Under the legal requirements within the Act, the Undertaker (Owner) of any large raised reservoir in England (those retaining more than 25,000$m^3$ above natural ground level) is responsible for ensuring their dam is:

- Inspected by an All Reservoirs Panel Engineer at least every 10 years. This is known as a Section 10 inspection.
- Inspected by a Supervising Engineer at least annually. This is known as a Section 12 inspection.
- Safely maintained in line with any measures from the Section 10 report and monitored for any signs of deterioration in accordance with directions given in Section 12 reports.

The Environment Agency is the Enforcement Authority in England for ensuring all undertakers comply with their legal obligations under the Reservoirs Act.

## 4.2 Cannop Ponds

Forestry England are the Undertaker of both Upper and Lower Cannop Ponds. Upper Cannop Pond contains 28,000$m^3$ of water above natural ground level. Lower Cannop Pond contains 72,000$m^3$. Both ponds are therefore deemed 'Large Raised Reservoirs' and are registered under the Reservoirs Act 1975 legislation.

As the Undertaker, Forestry England have ultimate and legal responsibility for the safety of the reservoirs. As part of their duty of care to the public, and in light of the deteriorating condition, Forestry England must now consider whether or not the dams can be made safe through repair works alone, or whether an alternative solution must now be sought.

## 4.3 Floods & Reservoir Safety

A flood study was undertaken by Binnies in 2022 in accordance with the guidance document Floods and Reservoir Safety, 4th Edition. This study considered the inflows from varying storm events and the ability of the spillway to safely pass these inflows without posing a risk to the stability of the embankment. If an earth embankment is allowed to overtop, it can erode and lead to a breach, endangering the lives of those within the dam breach flood extents.
Note - A flood study differs from a 'Flood Risk Assessment' which considers the outflows from the dams and risk of flooding in the downstream watercourse and communities.

Lower Cannop has been considered by one Inspecting Engineer to pose a Category C risk to the downstream area as the result of an uncontrolled release of water - *a dam where no loss of life can be foreseen as a result of a breach and very limited additional flood damage would be caused.*

Upper Cannop has been considered by another Inspecting Engineer to pose a Category B risk - *a dam where a breach could endanger lives not in a community, and / or could result in extensive damage downstream.*

While it is possible for two reservoirs in cascade (where one lies upstream of the other) to be categorised with different consequence categories, it is unusual for the downstream reservoir of greater size to have a lower risk category. Since the initial inspection of Lower Cannop, the latest Environment Agency Flood maps[1] have been able to be reviewed and the results suggest a Category B risk may be more appropriate for both Upper and Lower Cannop: i.e. the flood maps show properties, roads, railway, and public recreational areas would be flooded in the event of a breach from either reservoir.

The safe flood conveyance standards for dams with these risk categories are outlined in Table 1 below. The outline results from the studies are listed and discussed in further detail in Sections 5.3 and 6.3.

| **Flood Study Checks** | **Design Flood** | **Safety Check Flood** |
|---|---|---|
| Category B (Upper Cannop) | 1 in 1,000 year event | 1 in 10,000 year event |
| Category C (Lower Cannop) | 1 in 150 year event | 1 in 1,000 year event |
| Basic design requirement | No overtopping occurs and adequate freeboard maintained to avoid erosion of embankment from waves | The inflow beyond which the safety of the dam cannot be assured - i.e. no overflowing or overflowing limited as to not lead to significant erosion of the earth embankment |
| **Flood Study Results** | **Design Flood** | **Safety Check Flood** |
| Upper Cannop | Overflowing occurs | Overflowing occurs |
| Lower Cannop | Insufficient freeboard | Overflowing occurs |

Table 1 - Flood study safety requirements and outline results

## 4.4 Drawdown Capacity for Reservoir Safety

UK guidance for reservoir safety (Guide to drawdown capacity for reservoir safety and emergency planning, DEFRA 2017) provides basic recommended rates for lowering of the water level in a reservoir in the event of emergency. The ability to lower water levels is essential to reduce the loading on the dam and/or spillway which may avert a failure or significantly reduce the impact on the downstream area if a breach occurs as a lesser volume of water would be released.

Whilst the dams both historically had pipework installed which would have enabled emergency drawdown had the event arose, these outlets have been decommissioned and / or removed at unknown dates in the past. The drawdown of the reservoirs would therefore be entirely dependent on bringing temporary pumps to site.

For a Category C dam (current consequence category for Lower Cannop), to meet the basic recommended standard for drawdown rate, the initial water level should be able to be lowered by 2% of the reservoir depth per day.

For a category B dam (Upper Cannop) the initial water level should be able to be lowered by 3% of the reservoir depth per day (or a minimum of 0.3m per day for low height dams). A minimum of 50% of this required capacity should come from installed pipework or similar at the site. Only the remainder may come from pumps due to the risk of them not being able to be brought to site quickly enough.

Owing to the insufficient flood capacity of both dams' spillways and their history of deterioration, there would be no basis to relax these basic drawdown rate requirements, but more onerous ones could foreseeably be justified.

[1] Publicly accessible version - https://check-long-term-flood-risk.service.gov.uk/map - see Flood Risk From Reservoirs - Extent of Flooding

| **Flood Risk Category** | **Basic Drawdown Rate Required** | **Actual Rate Required** (Approx. $m^3$/day equivalent excluding inflow) | **Maximum recommended drawdown coming from pumps** |
|---|---|---|---|
| Category B (Upper Cannop) | 3% of reservoir depth per day with a minimum requirement of 300mm/day for low height dams | 300mm per day (Upper = 3,900$m^3$/day) (Lower = 6,750$m^3$/day) | Up to 50% |
| Category C (Lower Cannop) | 2% of reservoir depth per day | 140mm per day (Lower = 3,150$m^3$/day) | Up to 100% |

Table 2 - Recommended drawdown capacity rates for flood risk category B and C dams

## 4.5 Toddbrook Incident

In August 2019, Toddbrook reservoir in north-west England, following damage resulting from two extreme storms (one smaller storm, then a 1 in 100 year event), was on the brink of collapse, leading to the evacuation of 1,500 residents of Whaley Bridge. Interventions helped save the dam from failing, but the significance of the event led to the government commissioning the 'Toddbrook Reservoir Independent Review Report'; investigating the series of events and factors which led to this near miss.

While there were many findings, two factors were of particular note in relation to Cannop Ponds:

- there were limited construction records of the spillway, and where they did exist, the spillway had not been designed and constructed to an appropriate standard, and
- measures to investigate the condition of the spillway advised by the Supervising Engineer and Inspecting Engineer had not been undertaken.

# 5. Lower Cannop Dam Condition

## 5.1 Dam Safety Inspection

Following the appearance of voids in Lower Cannop dam in 2020, a Section 10 inspection was undertaken with a subsequent report issued in May 2021. The outcome of the inspection report identified in a number of safety measures for studies and works required to make the dam safe. These measures are outlined below.

## 5.2 Measures In The Interests Of Safety

The 2020 inspection report outlined the following measures to be undertaken as a matter of urgency on Lower Cannop dam:

**Within 3 months:**

1. Remove the screen and placed stones within the spillway channel which artificially raised the water level in the pond.

**Within 6 months:**

2. Repair the spillway walls and slab - the walls had cracked and deformed, and the spillway base slab, from visual observations, appeared to have some voiding beneath due to washout of fine material.
3. Carry out a flood study and routing exercise to determine whether or not the spillway and dam would be at risk of failing in extreme storms.

**Within 18 months:**

4. Replace the entire spillway and walls.

## 5.3 Subsequent Works & Findings

1. The screens and placed stones were removed, returning the water level to the weir of the spillway. The ARPE required this in order to lower the top water level back to the spillway weir level with the intent of reducing: undue load on the dam, flood risk in the event of failure, and likelihood of blockages raising water levels further.
2. During investigations to prepare for works to repair the walls and spillway slab, large and extensive voids were found beneath the majority of the spillway slab. Furthermore, the slab itself was found to be made from unreinforced concrete and only roughly 100mm thick (or less in some locations). Note - A modern design for a spillway slab of similar size would be reinforced with steel and between 300-500mm thick.

   This posed a significant threat to the safety of the dam and emergency works were undertaken. The spillway slab was opened in a number of locations and large volumes of mass concrete were pumped into the voids to provide temporary support and limit further erosion.

**Picture 1 & 2 ©Forestry England** - Left - example of voids found beneath spillway. Right - grouting undertaken to make safe in short-term.

3. A reservoir flood study was undertaken by Binnies in 2022 to determine if the spillway is capable of safely passing the storms outlined in the UK guidance - Floods and Reservoirs Safety 4th Edition. For this dam (assuming Category C):

   - In a storm event with **1 in 1,000** chance (0.1%) of occurring in any given year, the spillway should be able to safely pass inflows without the risk of the dam breaching.

     *The flood study has showed that in such an event there would be significant depth of water overflowing both the dam and spillway walls which would cause erosion and potentially lead to breach of the dam embankment.*

   - In a storm with **1 in 150** chance (0.67%) of occurrence, safe freeboard (the height between flood water level and dam crest) must be provided to ensure no overtopping and subsequent erosion of the dam.

     *The flood study has shown there is insufficient freeboard to safely protect against wave overtopping, risking a potential breach of the dam embankment.*

   - If the category of the dam is amended to Category B, these checks would be against storm events with a chance of **1 in 10,000** and **1 in 1,000** respectively. Being more onerous; these safety checks are also not met.

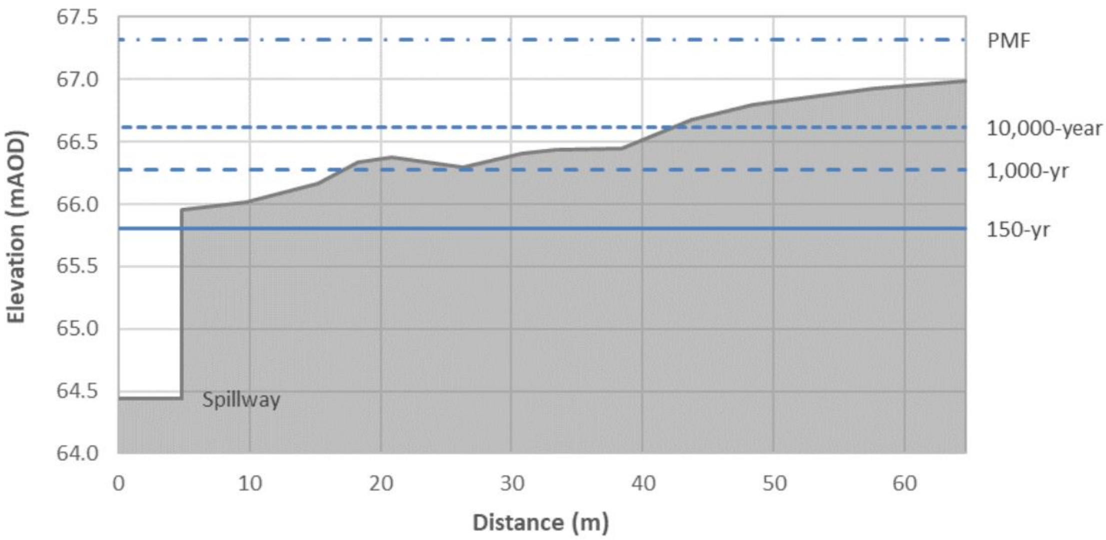


**Figure 1 - *Lower Cannop Pond Flood Study, Binnies, Jan* 2022** - Graphical results of flood rise relative to spillway weir and dam crest level in storm events. Results show insufficient freeboard in 150yr event and overtopping in 1,000yr and over events.

4. The option to replace the spillway with one of sufficient capacity to safely pass these storms is now being investigated. If the spillway was to simply be scaled up, based on the predicted inflows, the weir would need to be roughly three times longer than the existing. The flows would also necessitate the use of reinforced concrete as the main construction material.

   However, considering the increasing issues with voiding in the dam, the findings and subsequent remedial works undertaken, and the outcomes of the flood study; even if the spillway was replaced, the dam is not likely to remain safe for long without substantial additional works.

### 5.4 Additional Considerations

In the 2021 Section 10 report, the Inspecting Engineer considered that arrangements to provide drawdown capacity relying solely on temporary pumps were adequate based on the dam posing a Category C flood risk. However, as a responsible Undertaker, Forestry England would seek to install permanent drawdown facilities as part of any remedial works so that less reliance is placed on mobilisation of pumps in an emergency.

The site is unlikely to be suitable for the installation of siphons for providing drawdown capacity (pipework over the top of the dam), owing to the desire for public access. Substantial and intrusive works would therefore also be required to install drawdown facilities through the dam embankment or spillway.

## 6. Upper Cannop Condition

### 6.1 Dam Safety Inspection

Upper Cannop was previously believed to hold less water than the required threshold level for needing to be registered and inspections undertaken under the Reservoirs Act 1975. However, a bathymetric (reservoir basin) survey undertaken in 2021 found the retained volume was in fact greater than this threshold. As a result, Forestry England registered the reservoir and instructed a Section 10 inspection to be undertaken in May 2022.

This report and the measures in the interest of safety have been reviewed. Measures associated with record keeping and preparation of emergency plans owing to the reservoir being newly registered have been omitted, however all measures required to address dam safety concerns have been included below.

### 6.2 Measures In The Interests Of Safety

The relevant measures to be undertaken on Upper Cannop dam from the 2022 inspection report have been paraphrased below:

**Within 12 months:**

1. Following vegetation clearance, undertake an inspection of the stone wall and old outlet structure at the toe of the embankment to look for signs of seepage and / or instability.
2. Following vegetation clearance, undertake an inspection of the embankment face to look for signs of seepage and / or instability.
3. During a dry period of no flow into the spillway, undertake an inspection of the stilling basin and toe of the spillway chute to look for signs of erosion or damage to the structure.

**Within 18 months:**

4. Remedial works be carried out to prevent the leakage into the spillway, near to the weir.
5. Undertake repairs / replacement of the missing or loose masonry and masonry pointing on the spillway chute walls and floors.
6. Repair the stilling basin weir by filling the voids under the weir and by replacing any missing / displaced masonry.

**Within 3 years:**

7. Install permanent drawdown facilities with capacity to lower the water level by at least 0.15m/day in the event of an emergency (this reflects the basic drawdown rates outlined in Section 4.4).

**Within 4 years:**

8. Following inspections and further assessments, there should be investigations and / or works carried out to alleviate any concerns identified regarding:
   - stone wall / outlet structure stability and / or seepage, or
   - embankment stability and / or seepage, or
   - the condition of the stilling basin and toe of the spillway chute.
9. Upgrade works are carried out to ensure that the flood capacity of the reservoir meets guidance (see Section 4.3), or alternatively, and if appropriate an As Low As Reasonably Practicable (ALARP) risk assessment study be undertaken followed by implementation of any required improvement works which are proportionate in cost relative to the reduction in risk achieved.

## 6.3 Consequential Works Required

The measures to be undertaken **within 12 months** initially only require inspections by a suitably qualified dam engineer. However, these have been recommended due to concerns over the likelihood of these defects being present. The scale of subsequent works as part of the measures to be undertaken within 4 years could be anywhere from minor maintenance upkeep to major civil engineering works.

The measures to be undertaken **within 18 months** are all related to maintenance works to the spillway structure. These are not dissimilar to those which led to the identification of far more substantial voiding issues with Lower Cannop Spillway. Whilst larger defects may not be present, the similarity between age and construction of the dams means there is a risk there may be similar findings during these works.

Solutions for incorporating permanent drawdown capacity **within 3 years** would need careful consideration. The site is unlikely to be suitable for the installation of siphons for providing drawdown capacity (pipework over the top of the dam), owing to the desire for continued and unobstructed public access. Substantial and intrusive works would therefore be required to install drawdown facilities through the dam embankment or spillway.

The upgrade works to be carried out **within 4 years** to ensure sufficient flood capacity would be substantial. The findings of the flood study undertaken by Binnies in 2022 to determine if Upper Cannop spillway had sufficient capacity were:

- In a storm event with **1 in 10,000** chance (0.01%) of occurring in any given year, the spillway should be able to safely pass inflows without the risk of the dam breaching.

  *The flood study has showed that the dam would overflow in some locations in a storm with 1 in 150yr chance (0.67%). There would be substantial overflowing in a 1:1,000yr and 1:10,000yr storm.*

- In a storm with **1 in 1,000** chance (0.1%) of occurrence, safe freeboard (the height between flood water level and dam crest) must be provided to ensure no overtopping and subsequent erosion of the dam.

  *The flood study has shown there would be overflowing (no freeboard) in storms as likely as 1 in 150yr chance (0.67%) of occurring in any given year.*

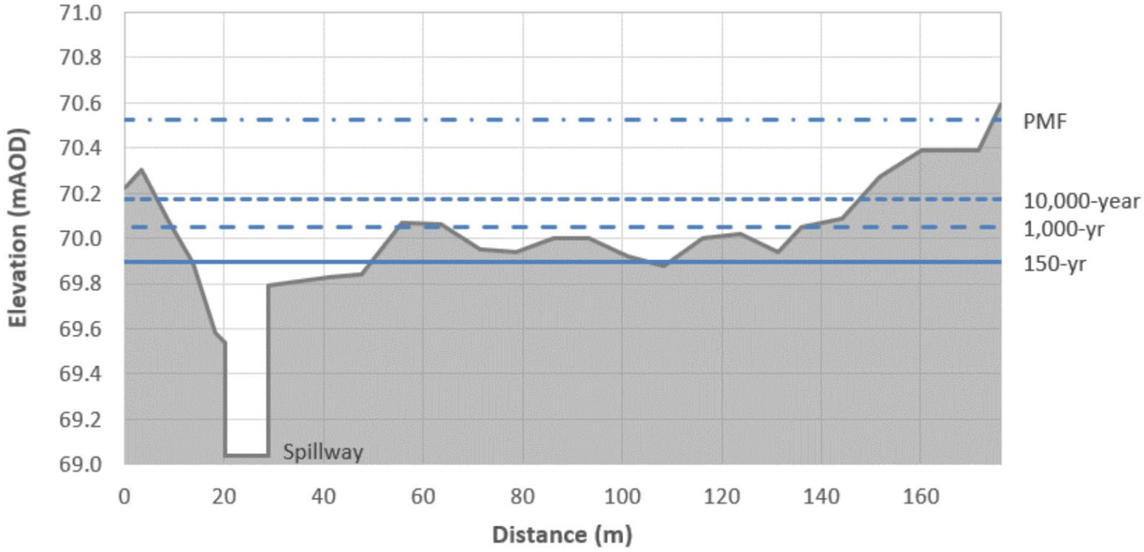


**Figure 2 –** *Upper Cannop Pond Flood Study, Binnies, Jan* 2022 – Graphical results of flood rise relative to spillway weir and dam crest level in storm events. Results show overtopping in 150yr and over events.

These results show the existing spillway is substantially under capacity. A much larger replacement or secondary spillway would therefore likely be need to be designed and constructed. If the spillway was to simply be scaled up, based on the predicted inflows, the weir would need to be roughly four times longer than the existing. The flows would also necessitate the use of reinforced concrete as the main construction material.

An ALARP assessment in accordance with Risk Assessment for Reservoir Safety, DEFRA, 2013 (RARS) may show that the cost of works associated with meeting these guidance standards is disproportionate. However, considering the flood risk category and current spillway capacity, it is unlikely a substantial reduction in required works would be justifiable from a risk based perspective and upgrade works would still be required to some extent.

# 7. Conclusion

The process of inspection and reporting under the Reservoirs Act has placed a legal obligation on Forestry England to ensure the safety of the Upper & Lower Cannop dams, or alternatively to discontinue them and renature the valley to remove any risk posed. If Forestry England were to not undertake works in some form to address the safety issues, the Enforcement Authority (Environment Agency) would take enforcement action and undertake the necessary works at the site on behalf of Forestry England in order to ensure the safety of the downstream population.

Both Upper & Lower Cannop dam were constructed at a time where modern embankment dam construction was in its infancy and poorly understood. Neither were constructed of materials specifically designed to retain water. As a result, there have been repeated issues with leakage and voiding which threaten the long term safety and integrity of the dams.

Lower Cannop spillway has suffered a lengthy history of structural distress and voiding behind and underneath the structure. The spillway was at risk of failure in 2021 and has been made safe in the short term by works to stabilise the structure. The embankment itself is also nearly 200 years old and the problems encountered over the past 40 years of repeated voiding show that it is nearing the end of its serviceable life.

Whilst the history and current condition of Upper Cannop is less well understood, the required works and challenges faced are similar in both scale and magnitude. The reservoir itself has also suffered from silt build up and loss of water depth. Without dredging, this would only continue to worsen due to the dam having severed the natural passage of silt in the watercourse.

The risk of failure of both dams is further exacerbated by their inability to safely pass the design flood, and the lack of emergency drawdown facilities within either embankment. If Upper and Lower Cannop dams are to be made safe and current water bodies retained, the only long-term solutions would, as a minimum, involve either:

- Replacing the existing spillway structures, undertaking major remedial and upgrade works to the earth embankments, and fitting emergency drawdown pipework within both, or

- Replacing the dams and associated structures in their entirety.

The alternative option - to discontinue the reservoirs - would require permanent alteration of the dams to ensure the volume of impounded water cannot exceed 10,000m$^3$ (to protect against likely future reduction in the Reservoir Act registration thresholds). This would ensure long-term safety for the downstream population. However, returning the reservoir basins back to a restored brook alone is unlikely to meet planning requirements such as Biodiversity Net Gain or pass Habitats Regulations Assessment. To ensure a nature positive outcome whilst also restoring amenity value, an active regeneration of the valley would instead be required.

Beyond restoring the brook, consideration should therefore be given for design options incorporating cascades of smaller ponds, a mosaic of varying wetland and terrestrial habitats, open corridors for bat foraging, boardwalks for public access, and natural flood management solutions to manage downstream flood risk. The options considered should all be evaluated based on providing: a positive outcome for nature, improved public access, and managing downstream flood risk.