TODDBROOK SPILLWAY FAILURE

Review of the reports into the failure and damage to the dam on July 31st. 2019

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The additional data provided in the Expert Reports and the Seminar on the failure of the spillway are reviewed. These reports confirm that the spillway was constructed by British Waterways with serious engineering design and construction faults, and that for 30 years maintenance of the reservoir systems have been superficial or non-existent. The record shows that there has been a catalogue of defects and reactive 'fixes' to the 1970's Spillway. A review of the inspection records has exposed inherent general weaknesses in the operation of the Inspection Regime at Toddbrook. Unfortunately the Expert Reports fail to recognise the fundamental characteristics of the original reservoir overflow design which caused the Auxiliary Spillway to be constructed in error in 1970. Nevertheless the Incident was extremely beneficial to the Community by dramatically revealing the dangerous physical and operational defects of the auxiliary spillway which have, for the last 50 years, increasingly threatened the school and town of Whaley Bridge. It is therefore vital that the Community should heed this serious warning and ensure that, this time, any proposed repairs or modifications are fundamentally safe, technically valid and approved by Independent Professional Engineers acting for the UK Government which carries the ultimate responsibility for Reservoir Safety in England.

Contents

References.

GA1: Toddbrook Reservoir Report 51	G. Aldred	30 Sept 2019.
GA2: Toddbrook Damage Analysis 2.1	G. Aldred	15 Dec 2019.
GA3: Toddbrook Modification Proposal 12	G. Aldred	16 Feb 2020.
DB1: Final Toddbrook Reservoir Review Report	Prof. D Balmforth	10 Feb 2020.
AH1: Report on Toddbrook Reservoir (41505)	Prof. A Hughes	10 Feb 2020

Quotations from or references to the various reports relate to the documents above.

Thus DB1/23 refers to page 23 of Prof. David Balmforth's report.

GA2/13 refers to page 13 of my second document. Etc.

Summary.

This report reviews the data provided by the two official reports and by some of the presentations in the ICE video seminar (July 2020) into the damage to the Toddbrook dam in July-August 2019. We ask the basic question "Was the damage and potential breach of the Toddbrook Dam avoidable? " The wide swath of evidence and analyses provided by the Experts concludes that damage to the dam was inevitable due to the many errors and negative factors in the design, construction and maintenance of the Auxiliary Spillway. The most astonishing error by British Waterways Engineers is their failure to recognise that water would inevitably pass underneath the Apron which was actually constructed 12-18in. below the top water level defined by the original primary Cill. This vindicates my earlier analysis (GA1) which concluded that the destruction of the original safety margin of the Dam *(Appendix 2)* and the defective design of the spillway were fully responsible for the damage to the dam. The heavy rain event itself was not the cause it simply activated the damaged spillway that was supposed to cope.

However it is obvious that the damage was in fact avoidable because it was caused by the ill-considered installation in 1970 of a fundamentally defective auxiliary spillway on the crest of a clay cored dam. Even if this spillway had been perfectly designed, constructed and maintained the installation was a dangerous mistake and a totally incorrect solution to the fundamental problem. The actual problem is the inability of the <u>original</u> Primary Reservoir Overflow to operate in high flood conditions unless there is human management on site to deal with the flood <u>as it develops</u>. The 'unmanned' solution will be to redesign the Primary Overflow System to remove the deficiencies. *(See GA3 for details.)*

There are some passing references to the Primary Overflow characteristics in some historic inspection reports but unfortunately the Experts did not recognise their crucial significance to the near disaster. Rather than challenge the reason why the auxiliary spillway was installed in 1969 they were led instead to investigate why, it having been installed, it failed.

All the evidence in the expert reports shows that an over crest spillway, which is added as a modification to an existing earth clay dam is a continual source of concern, of self inflicted faults and danger. It generated speculative fixes and then more fixes to the fixes. Proper engineering records of the fixes and how they should be inspected and maintained were not kept. Drains and pressure relief arrangements are added over time, become neglected and blocked with soil and weeds. There was no certainty as to where the under slab water was actually coming from, the fixes were treating the symptoms not the cause. It left a legacy of unresolved causal faults and, most important, for the last 50 years, the concrete spillway has covered and hidden the predictable degradation and settlement of the critical middle section of the dam structure itself.

This is careless engineering because it progressively complicates the original but flawed design of the spillway. The fundamental principle is that an earth/clay dam must always be carefully isolated from any water that flows. This 'Law of Reservoirs' is why reservoirs of this type operate safely. This is exactly how Toddbrook reservoir was originally conceived in 1830 and how it was operated safely for 130 years until 1969.

The Expert Reports and the Seminar confirm my own observations that there were no cautionary discharges made in the several days prior to the event despite the fact that the auxiliary spillway was in prolonged and exceptionally heavy flow never seen before, that weather warnings were issued, and

especially that the structural condition of the dam had just been officially but belatedly downgraded *by the CRT* from "Fair" to "Poor" as a result of the most recent 10 year Inspection (carried out in Nov. 2018).

Unfortunately the experts did not ask the CRT what additional precautionary safety management a "Poor" condition spillway and dam should be given in exceptional heavy flow. A downgrade of status should have been notified promptly to all staff involved with any High Risk reservoir and it must demand additional cautious response to extremes of dam loading otherwise it is meaningless. There is no evidence that the downgrade of status resulted in any additionally cautious management in anticipation of this event. Nor did it demand caution during the event when the only active discharge valve was inexplicably closed at 11am on 31 July just when the auxiliary spillway was *in the middle* of its 40-50 hr. massive unprecedented and destructive flow.

The data from the Experts exposes the deficiencies of the legislation and especially its application in practice at Toddbrook and no doubt other reservoirs. There are many issues to consider that led to the incident. There is the historic mistake of constructing an ill designed spillway over the crest of an earth dam rather than to recognise the inability of the original overflow system to operate at high flood volume without human management. But there are also the current dangerous weaknesses in the reservoir oversight and inspection system. There seems to be a cultural and possibly historic problem in which the Owner is not proactive enough and the Safety Inspectorate is too deferential. Neither party is urgently reacting to the authority that a Safety Inspectorate would be given in any other industry which operates such dangerous infrastructure which threatens life.

Reflection.

A thoughtful reader will recognise that if it had not rained quite as much on Sunday 28 July 2019, the Toddbrook Time Bomb would still be ticking. The erosion channels would still be active under the Apron, being enlarged each day by the waves driven under them on the full reservoir. All the other reservoir components would still be in their neglected and ineffective state. The huge mud banks and the weeds which have choked and impeded the feed weir, the Bypass and the Convergence Basin for at least 25 years would not have been removed as they had to be so urgently in the first hours of the crisis and completed later in months of post incident haste. The next 10 year Inspection would be a comfortable 9 years away.

Walkers on the footbridge crossing the Dam would see the usual seasonal crop of water loving weeds and shrubs growing out of unexplained cracks and panel joints in the concrete. They might observe that the LH panels were always wet and wondered why. Perhaps some would see, as I have, water driven right underneath the Apron by waves, hissing and bursting out from cracks and joints on the upper concrete spillway at the LH side. The happy shouts of 244 children playing in the school yard would be heard just 305 yards away from the foot of the Dam. This much ravaged dam, 180 years old, 77 ft. high, would still be managing to hold back 1.4 million tonnes of water…….Everything would be just as it was for the last 50 years.

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Introduction.

Sometime after the Toddbrook auxiliary spillway failure two investigations were commissioned. The first was ordered by the Environment Agency to be led by Prof. David Balmforth. The second, running in parallel, its existence never clearly advertised until mid December 2019, was initiated by the CRT to be led by Prof. Andrew Hughes. The scope for both was primarily the same:- To investigate what caused the failure of the emergency spillway. Both reports are excellent and very informative, addressing the question from complementary perspectives.

Their reports were issued in March 2020. They provide important information that has hitherto remained hidden from the Public. The reports vindicate all the conclusions documented in my own reports and confirm that the school and town have been in growing lethal danger for the last 50 years. They expose the inadequacies of the reservoir safety legislation and its operation and confirm that the safety inspection regimes as operated at Toddbrook are below the standards of any other industry which can threaten lives and property. The technical evidence and analysis shows how dangerous and misguided it was to install an over crest concrete spillway on the earth/clay dam at Toddbrook, exacerbated by an inherently flawed design, deviant construction and careless or nonexistent maintenance.

Both reports explain how the safety of reservoirs in the UK is supposed to be managed under current law and they provide some specific history and, at last, some details of the historic inspection regime and the findings at Toddbrook over the last 20 years. In particular they reveal **some** of the results of the last '10 year' Inspection in Nov 2018. The report of this inspection was initially withheld by the Environment Agency. 'Publication' was forced under pressure of an FOI request but the document was insultingly published with 100% redacted sheets of black paper on the highly dubious and now obviously false grounds of a 'threat to national security'.

The first analytic Report in three parts with wider scope was produced by me and issued progressively from Dec 2019 (GA1, 2, 3). All the parts of my report were circulated to local community Friends, Env. Agency, CRT, Local Govt., MPs, various media and submitted to both Review Panels. Recent feedback has indicated that my input was appreciated by one of the Experts and was found to be 'very useful'. This is important not only because it recognises my considerable efforts but because my analysis of the inadequacies of the concrete spillway, my technical familiarity with the Toddbrook System and witnessing of the events on 1st August are a considerable endorsement of their own findings.

Now it is necessary to examine these Reports. But the extensive detail available and my own very limited resources mean that a review must unfortunately be selective. One approach is to select certain key topics for review and then refer to the reports and July seminar presentations.

Chapter 1. The Seeds of Disaster

1.1 Why was the Auxiliary Spillway constructed?

GA1/10

Heavy rain in 1964 resulted in a large volume of water in the Bypass Channel (Appendix 1) such that the channel masonry was damaged. It is not known if there was a Keeper in place in 1964 to carry out pre-emptive discharge actions to lower the reservoir prior to the overload. British Waterways then made a fundamentally disastrous decision which compromised the safety of the dam, the consequence of which has only just been exposed in July 2019, 54 years later. They decided to completely destroy the safety margin of the dam (Appendix 2: Original Design 1830) in order to create a 250ft. secondary concrete overflow on the top of the Earth Dam which would provide an additional overflow route 12-15in. higher than the original Primary Cill. This is the worst modification that could possibly be carried out on an old earth clay dam.

DB /15.

On the 12th December 1964, an extreme rainfall event damaged the original (primary) spillway. This led to the Inspecting Engineer requiring the overflow capacity to be increased considerably. Between 1969 and 1970, an auxiliary spillway 76m long and 0.26 m above the original spillway crest, was constructed on the face of the embankment.

AH/15.

The Inspecting engineer in 1965 reported on the flood of the 12th December 1964 which occurred at 5 pm when the spilling water was a few inches above spilling over the crest (of the original main spillway). He described that by 8 am on the 13th December the head over the weir was 3 ft 4 inches (1 metre) and it remained at that level for approximately 24 hours taking another two days to fall back to spillway crest level. The outflow was estimated as 700 cusecs (19.80 cumecs) and damage was caused to the lower part of the spillway.

The Inspecting engineer reported in a letter on the 9th December 1966, that the owner had undertaken to prepare a scheme and invite tenders for a new emergency spillway near the centre of the dam. A 250 ft long spillway with a crest level of 612.35 ft (186.644 metres) AOD over the top of the dam was proposed.

In his report of 28th September 1970, the Inspecting Engineer reported that the damage noted from the report from the last inspection had been repaired satisfactorily. He notes:-

"The new emergency spillway has been constructed in accordance with the drawings proposed by the Owner and approved by me".

All the evidence now shows that this was clearly not true!

Comment.

GA. Thus the seeds of the inevitable disaster were so carelessly sown in 1968 due to the failure of British Waterways (BW) to investigate the real cause of the inability of the reservoir to overflow successfully without pre-emptive action by a warden. The BW Senior Engineers failed to recognise the requirement for radical modifications and maintenance at the Primary Cill, Convergence Basin and Bypass Channel.

Instead the careless decision was made :-

1) to destroy the entire safety margin of the dam, which had been effective for 130 years.
2) to fail to protect the clay core of the dam.
3) to overload the old dam structure by raising the reservoir level by 12-15 in. before effective overflow.
4) to invite water to flow over the crest of an earth dam and inevitably underneath the spillway.
5) to approve an over crest spillway of which the design was fundamentally flawed,
6) to allow construction to radically depart from the specified (but flawed) design.
7) to provide only intermittent supervision and inspection of the actual construction itself.
8) to ignore the future implications of cracking in the Apron panels caused by natural settlement of the dam and inadequate provision of expansion joints.
9) to ignore the complex structural implications of both loading and supporting the Apron panels with the long heavy footway which acts as a beam. .
10) But, above all, without any formal independent safety review, British Waterways chose to construct the auxiliary spillway which massively increased the undeniable lethal risk for the School and Town of Whaley Bridge, of which the Community has been totally unaware for the last 50 years.

It is astonishing that the modern Reservoir Industry has not expressed any robust critical dismay at what British Waterways Senior Engineers actually did at Toddbrook and possibly 7 other Reservoirs. Most Engineering Design Offices then were ruled by very formidable Chief Engineers, they were the guardians of the Company's reputation, quality, safety and costs. Unfortunately this was apparently not the case at British Waterways.

Unfortunately the expert investigators were drawn away from considering the *reason* for construction of the spillway towards the more academic challenge of analysing the defects of the flawed design, deviant construction and token maintenance of the defective concrete spillway. Their analysis is focused on a retrospective critique of the spillway design and on the details and sequence of its delayed but inevitable failure.

Prof. Balmforth's team carried out their investigations by the more indirect methods of experienced deduction rather than by direct physical examination of the available evidence which can only be readily exposed by the *forensic* dismantling of the entire concrete structure. Prof. Hughes carried out a complimentary and more practical site examination of the poor engineering of the structure yet perhaps his opportunities were frustrated by resources and conflicts of site control during his investigation.

For example, the inspection holes he was using to assess the extent and depth of the erosion channels under the Apron were sealed up in the middle of his investigation.(AH/26). Thus access to the most crucial and probable cause of the frightening disaster was denied prematurely. This is a failure by the Environment Agency who did not appoint an Accident Manager with total authority to control all activities on this 'Near Miss' site for the duration of the Investigation (GA1 and GA2)

Nevertheless the Experts' careful analyses provides abundant evidence to reinforce my own analysis that the concrete spillway is a dangerous ill judged engineering mistake both in principle and in implementation (GA1, GA3).

1.2 The Primary Overflow Deficiency

Photo GA1. The very shallow Convergence Basin viewed from Reservoir Road showing the upper end of the primary weir with a drop into the Basin of only 4 in. overall. The Bypass flow here is about 2 in. deep. A large mud bank is in the foreground taking up valuable capacity..

Photo GA2. Here the Bypass flow has risen, now full to the brim at about 4 in. deep, flowing to the left. If it rises by another 3 in. it will flow over the Primary Cill 'backwards' to fill the reservoir !

This report asserts that the fundamental problem at Toddbrook is that the main overflow at the primary Cill will be blocked or 'drowned out' at the most critical times of major overflow. If the Bypass channel is even in moderate flow then water cannot leave the reservoir, it has nowhere to go. There are two reasons for this.

1) The reservoir overflow has to **share** the Bypass channel which is a dangerous and rare feature in historic reservoir design, it does not have its own dedicated channel. In addition the critical capacity of the 'very shallow' convergence basin is reduced to around 50% caused by at least 25 years build up of mud banks, reed beds, trees and shrubs, stones, branches and various debris.

2) The fall (or drop) of the main reservoir overflow into the Bypass is insufficient at only about 4 in. at the crucial RH upstream end of the Overflow Cill (*at the steps in photo 2*). This is where the powerful bypass flow is being guided to turn by the side wall. But the wall ends, so the Bypass flow stops turning and will flow unimpeded into the reservoir. If the reservoir is attempting to overflow at the same time it will be blocked. That is the state reported in 1964 (and witnessed in 2019 by me and others) with the reservoir level 1m. above the primary cill.

The Primary Overflow system is in its original state as conceived in 1830 and completed in 1840. It is further compromised by being at right angles to the Bypass channel and has never been capable of functioning adequately at high bypass flow volumes without pre-emptive human support. For the first 130 years the reservoir level was managed safely by a resident warden using anticipatory valve discharges, open Bypass flow and the security of a safety margin in the clay core of the dam 5 ft. higher than top water level defined by the primary Cill. But now the warden has been removed and, crucially, the clay core safety margin of the entire dam *above the cill* was destroyed in 1969 to construct the Auxiliary Spillway, but the sharing of the ill maintained Bypass Channel and the lack of reservoir fall from the Primary Cill is just as it ever was.

Photo 3. The view upstream showing a modest low volume overflow from the reservoir over part of the Primary Cill. *(Photo ex July Seminars)*

The photo clearly shows that the primary cill is not level as might be expected. I believe that about half of the primary cill was deliberately tapered towards the downstream end by about 6in. Probably ordered after 1840 by John Wood the Design Engineer to alleviate the overflow contention upstream as we have just described. Here, at the downstream end, the fall from the primary cill into the Bypass is more than 18in. (because the convergence basin floor itself was built sloping downwards). The lowered Cill defines where the initial reservoir overflow occurs and the greater drop temporarily avoids the flow contention at the shallow upstream end seen as a patch of dry weeds in the photo above.

The alert warden would see the overflow creep up the tapered cill to signal that he must stop as much Bypass flow as possible by shutting the Bypass gate at the feed weir, and open the compensation weir fully to discharge any residual bypass flow into the reservoir. He would already have had both discharge valves wide open. It is vital to remove the hydraulic conflict in the convergence basin to ensure maximum efficient overflow from the reservoir. It is obvious that as Bypass level rises the primary reservoir overflow will be blocked by a wall of fast flowing bypass water and then the reservoir will continue to be filled by the input at the feed weir which has never been stoppable. This is the dilemma with the existing overflow design.

Without such intelligent management the reservoir level has been reported at levels of up to 1m *above* the Primary Cill as I saw it on 1st. Aug. The reservoir water is placid, mirror like and stuck, unable to overflow. Without its own dedicated Overflow Channel, it is blocked by the fast flowing wall of Bypass water which is itself impeded by the hydraulic inadequacies, careless modern modifications and maintenance neglect of the Convergence Basin and Bypass channel immediately downstream.

Photo GA4 shows the imminent critical state at the RH end (viewed from Reservoir Road). The reservoir is already overflowing at the LH end as in photo 3, currently only wave wash is coming over the primary cill which is higher at this RH end. The Convergence Basin in the foreground is only about 5in. deep here it inherently has insufficient capacity further exacerbated by mud banks and weeds seen here. Eventually the Bypass flow blocks the Reservoir overflow.

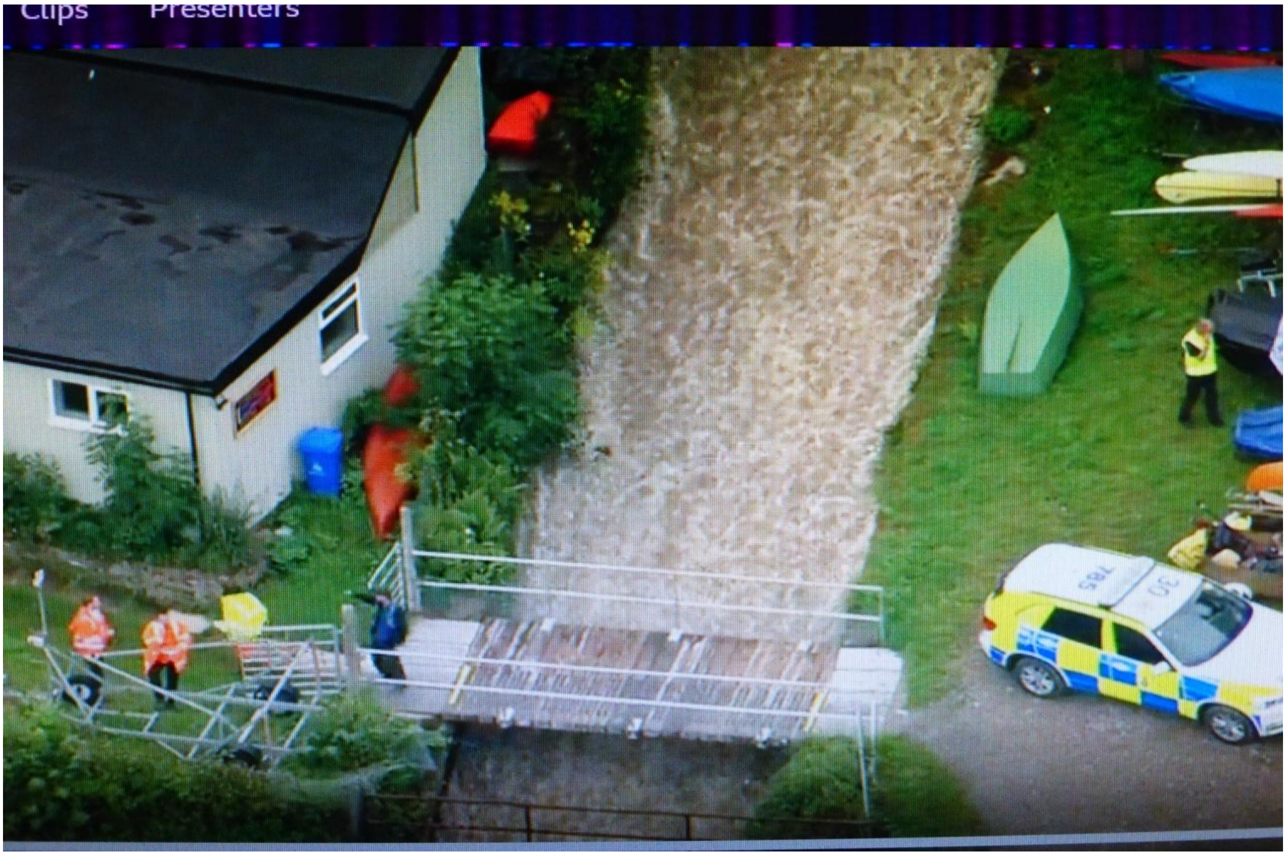


Photo 5 illustrates the potential volume of water speeding downstream of the Convergence Basin (Aug1). Here the Bypass channel is 4m wide and at least 1.5m deep. It is this mass of high energy water which completely blocks the Primary Reservoir Overflow. Exactly the same blocking effect is repeated at the two discharge culverts from the valves immediately lower down.

Obviously the existing primary overflow will never function without human management unless it is given much more free fall (at least 1.5 m.) and it will not function unless it is given a huge increase of dedicated Bypass channel capacity. Lowering the reservoir level permanently (1.5m.) and deepening of an overflow Channel is a standard, cost effective practical modification carried out on unmanaged reservoirs with earth/clay dams. (*Also proposed by Mott Macdonald in 2008)*. Destruction of the dam by the addition of a defective auxiliary concrete spillway is not a solution to the functional inadequacy of the primary overflow design. It was not the solution in 1970 and it will not be the solution now in 2021.

The Bypass capacity problem is described in more detail with solutions in GA3/2-5 . In summary:-

1) The Reservoir is progressively prevented and blocked from overflowing at the Primary Cill as the Bypass level rises and flow rate increases.
2) This is because the drop for overflow from the reservoir into the basin is totally inadequate. It varies from 5in to 18 in.
3) There is no dedicated reservoir overflow channel for sole use unlike the majority of reservoirs.
4) Inadequate flow engineering and ill judged modern modifications in the downstream bypass channel inhibits outflow rate from the convergence basin.

5) Capacity has been reduced by obstructions in the basin and bypass caused by weeds, mud banks and stones due to systemic neglect and lack of maintenance of all reservoir system safety controls over many years.

Photo 6. Emergency pumping arrangements further illustrate this deficiency as described.

This shows that accumulated mud bank material which had to be urgently cleared from the basin to increase capacity was beneficially exploited to provide a temporary wall to prevent the Bypass flowing into the reservoir in the first 1-3 days. This temporary wall also gave the pump discharge pipes some beneficial elevation above the Bypass flow, equivalent to deepening the convergence basin (which is what is required). Note the sandbag wall behind that was required earlier to prevent water from flowing back into the reservoir when the Bypass was 1m.above the Primary Cill (as in photo 5).

Photo 7. The Weir Blocks of the Primary Cill.

The Emergency Team had to prevent the Bypass from filling the reservoir at the RH end as shown in photo 6 but at the same time had to assist the outflow from the reservoir at the LH end of the Cill, this was where the cill had been cranked down long ago. Once the lower cill limit was reached natural outflow would stop. Quite logically the Team decided to extract the weir blocks at the LH to lower the reservoir by another 3-4 in.

Although it was very necessary in the emergency this means that the exact amount of 'cranked' drop of the cill cannot ever be measured now. The cill was not level, it had a 'knee joint' . I believe this was deliberate as explained above but it has wider ramifications which relate to the construction of the Auxiliary Spillway which is said to be a vague '12-15in.' higher than the primary cill defined by these weir blocks. But the weir blocks slope downwards (either by settlement or design). This slope makes the datum used for the Aux Spillway weir quite uncertain!

Photo GA8. Here are the many tonnes of mud, weed and stone that had to be cleared from the convergence basin immediately in the crisis, critical to saving Whaley Bridge from considerable destruction. It illustrates the huge loss of capacity and the undeniable systemic neglect of routine maintenance at Toddbrook in all the channels and culverts which are fundamental to the effectiveness and safety of the system. (see *GA2 many other photos*)

Photo GA9. The discharge culvert for Valve 1 into the Bypass provides a clear demonstration of the Primary Overflow dysfunction but on a smaller scale.

Downstream of the Convergence Basin, this is the discharge culvert for Valve 1 (not discharging here). The Bypass water is only a few inches deep but very fast. At the RH end there is no 'drop' so water runs unimpeded into the mouth of the culvert, collects itself at the LH end and falls out. But imagine that the Bypass flow is 1.0 -1.5 m high as in photo 5, the wall of very fast high energy water will flow across mouth and block the culvert. This is exactly what happens at the Primary Cill but on a much larger scale. Here the Bypass flow will prevent the discharge by Valve 1 at exactly the time when Valve 1 should be in maximum discharge to draw down the reservoir. Discharge culvert No2 suffers from an even worse blocking a little further downstream.

Summary. The existing system cannot function without human management. In GA3 I have described a radical modification in detail which will resolve this Primary Overflow failure and remove any requirement for an over crest spillway. The Reservoir TWL must be lowered and so must the Convergence basin.

1.3 The Overloaded Bypass Channel.

The problem is the capacity and hydraulic design of the Bypass channel which in high flood has shown that it fails completely because it is overloaded. The Bypass channel provides the sole overflow/bypass facility for Toddbrook Reservoir. It has to accept four inputs in close succession which are conflicting and which either create chaos and blockage in the main bypass flow or are themselves blocked due to careless flow design, ill judged modern modifications and fundamental lack of capacity exacerbated by lack of maintenance. The inputs to the Bypass are:-

1) The basic input flow at the feed weir a mile upstream to provide river compensation.
2) The main reservoir overflow at the 40m. long Primary Cill with a minimum drop of only 100mm (4in.) The Overflow is at right angles into the Bypass flow, consequently it is easily blocked or 'drowned out' as experts and inspectors have all confirmed but apparently have not realised the crucial significance.
3) The discharge from Valve No.1 via an angled open culvert with virtually no drop on RH side of bypass flow. (Photo 9)
4) The discharge from Valve No2 via angled open culvert on LH side of bypass flow adjacent to massive auxiliary spillway input.
5) These historic discharges are then completely overwhelmed by the modern (1970) massive turbulent overflow from the Auxiliary Spillway 80 m long fed at right angles to the Bypass channel.
6) The Bypass Channel is then running exactly in the opposite direction to the River Goyt. It does get turned through 90 deg. (but over runs its bank). It then attempts to join the river Goyt, once again, at right angles to the river flow, strong enough in Jul-Aug 2019 to even 'back up' the river Goyt.

Video footage shows this misaligned overload. A huge wall of water from the Aux spillway, flies over the overfull Bypass channel, crosses the children's playground, flows 'on top' of the water in the flooded park, then 'stands' on the river Goyt and smashes into the trees on the far side heading for the School. Unfortunately that video has been taken down. It actually shows a huge wall of water 20-25ft. high moving so fast that it cannot collapse, it defies gravity. This was just 'normal behaviour' of the output from the Spillway, this happened on Wednesday before the panels started to crash the next day.

It is unfortunate that this video has not been viewed more widely by all those involved with Toddbrook. We cannot blame the rain, rather blame an appalling design that was never reviewed, whose operational behaviour were never seriously evaluated or modelled even 50 years later. It is evident that there has been little concern about how a massive flow from the Spillway is supposed to get into the river Goyt.

1.4 Discharge Valve Options.

The output from each valve was designed to feed either the River Goyt or the canal system, the choice is made by manual deployment of blocking planks in the discharge culverts downstream of the valves Discharge to canal basin should always be chosen in an emergency drawdown because it reduces the hydraulic flow chaos and capacity demand on the overloaded Bypass Channel. Furthermore the canal network is the best and safest place to dump excess water because it provides huge discharge capacity far away from the flood zone because it extends for many hundreds of miles.

The Experts examined the historic Inspection Reports and in the summary of Incidents and Investigations, there is one with special relevance. Two facts with no mutual connection are stated in one sentence. An Inspecting Engineer wrote:-

*" In 1999 the channel at the base of the auxiliary spillway was rebuilt in reinforced concrete **and the take off to the upper feeder was sealed**."* (DB/18).

The reason for sealing the canal feeder was not provided by the Inspector in 1999. Unfortunately therefore this removes 50% of the potential Bypass load reduction from the discharge pipes. This is a significant reduction in the safety assets of the reservoir .This deficiency has apparently been accepted for the last 20 years by Inspecting and Supervising Engineers without any explanation. It cannot be a main culvert issue because Valve 2 (Scour) is used as the (only) canal feeder. So the problem is very local within the park in valve 1 culvert and capable of easy resolution. It should be investigated and repaired not ignored.

1.5 Confirmation of the Primary Overflow Dysfunction.

It seems that thirty five years ago the 1985 Inspecting Engineer' recognised the 'inept arrangement' of reservoir overflow at the convergence basin *(AH/16)* but he fails to understand the serious implications "He predicts "*flooding taking place at the confluence with the side spilling (=primary cill) and river channels (=bypass channel) due to the rather inept arrangement here*". He identifies the fundamental problem but misses the implications for effective primary reservoir overflow.

Prof. Hughes confirms this issue but unfortunately does not pursue the fundamental implication. *"The wide (main) spillway crest discharges to a __very shallow__ tumble bay (=convergence basin)" (AH/8)*.

In 2008 Mott Macdonald recognised the problems of the blocked main outflow at the convergence basin. They report that "the crump weir, just downstream of the weir (*= primary cill*), causes the 'main' overflow (*=reservoir primary overflow*) to **__drown out__** at outflows exceeding 5 cumecs." (AH 11). The inspector did not investigate the crump weir but if he had he would have found that it was part of a derelict monitor and should have been removed long ago.

Comment (GA). If a rate of 5 cumecs were achieved across a 41.2m long primary cill, the predicted 'drown out' would occur when the height of water above the primary cill was as little as 0.12m (4.5in.)

which is a trivial level at which any normal reservoir overflow system would be expected to easily operate .....provided of course that the water had somewhere to go.

(Seminar 6th July). Further evidence is reported by the post event emergency team. Eleven years after Mott Macdonald, they also recognised the blocking effect caused by the crump weir as they desperately fought to maximise the Bypass flow leaving the basin. First they had to clear the extensive mud banks choking the convergence basin due to zero maintenance for 25 years then they had to smash out the extensive concrete crump weir with a mobile 'pecker'.

The 'Crump Weir' was a V shaped concrete structure across the whole width (4m.) of the Bypass at the exit of the convergence basin. It is part of a redundant and derelict measuring system not used for many years for which a mains electric cable crosses the Bypass about 18in. above the channel floor. This gets immersed in any high flow in the Bypass, certainly it was August 2019 (it is still there now despite my written reminder to the CRT.) The cable powered a chart recorder housed in a cabinet in the ex Wardens yard which is still there.

This is another example of the very limited scope of the Toddbrook safety inspection regime. This dangerous redundancy has never been recognised during the last 20 years at any level in the Inspection regime so that the dangerous, probably live, cable and the obstructing crump weir were never removed. This was another ill considered installation by British Waterways contemporary with the concrete spillway, both of which demonstrate astonishing ignorance of the hydraulic consequences to high volume flow.

1.6 Other Reservoirs with Auxiliary Spillways.

Perhaps there was one Senior BW Engineer in the late 60s who was a robust advocate of over crest Auxiliary Spillways on earth dams. The faulty design and deviant construction suggest that Toddbrook may have been the prototype. The Secy. of State, EA, informed the House (Sept.4 2019) that there were 8 other earth/clay dams which have had auxiliary spillways installed over the crest. FOI requests for their locations have been defensively rejected by the EA, on the unsubstantiated but now familiar grounds of 'a threat to national security'. However at least one reservoir is now known, also now owned by CRT, it is the Carr Mill Reservoir. *(DB /62).*

Chapter 2 The Auxiliary Spillway.

2.1.0 Assessment of the Design.

(AH/33) (*bold text for emphasis*)

"Fundamentally the original design does not follow recognised best practice and is seriously flawed; it has features within it or that have not been provided which have led to the failure which occurred on 1st August 2019**. It is likely that flows took place under the slab almost from day one, when the water level in the reservoir was high enough.**

In my opinion the original design was flawed and so the situation was an incident/ accident waiting to happen – it was just a question of how, when and to what degree, unless some intervention was taken in the meantime.

"In summary, the flaws in the design were:

- **there was no cut-off into the core/crest of the dam**
    - **there were only water bars in the horizontal joints**
    - **there were no water bars in the vertical joints**
    - **there was very minimal reinforcement in the slabs**
    - **the wall/floor slab joint was poor**
    - **there were very few relief holes through the slab**
    - **the wall foundations were very shallow in places**
    - **there is no under drainage**
    - **the joints between slabs were poor**
    - **there was no anchorage**

The fundamental issue of concern with the design is that no cut-off was provided into the core beneath the slab. This has resulted in a situation where continued settlement of the embankment beneath the slab has led to a gap and a passage of water beneath the underside of the slab and the crest of the dam/core which has increased with time (if one accepts most embankment dams settle 1 or 2 mm per year), with water passing over the crest and core and beneath the slab."

"This process could erode the fill/core increasing the size of the gap. This could focus in a particular area once it had occurred and the evidence would suggest this is at the extreme left-hand end of the spillway where the cracking is most severe. There is cracking along at least half of the crest of the spillway where the crest concrete slab has probably been left unsupported."

"Other elements of the design considered to be poor practice included:

- **water bars have been provided on horizontal joints but not on vertical joints, which of course allows water to flow beneath the slabs when over the crest, but also allows water to exit from below the crest, when joints are open.**
- **'plums' which disturb the flow.**
- **very minimal reinforcement steel in the slabs.**
- **small number of connecting dowels between slabs and only on horizontal joints.**
- **no pressure relief to the slabs (a small number of holes were provided to some of the lower slabs at a later date).**
- **the wall floor slab joint was poor with little 'embedment' and cut-off.**
- **a convergent wall on the left-hand side leading to increased pressures and turbulence along the base of the wall."**

DB/23 "The spillway appears to have been poorly designed. The key deficiencies in design are:

- **The concrete slabs of the spillway chute are too thin**
- **The slabs do not have sufficient reinforcement, either structurally or for surface crack control**
- **The dowel bars[5] in the transverse joints are inadequate**

- **There are no dowel bars or water bars[5] in the longitudinal joints**
- **There is no under drainage to the spillway.**
- **There is no cut-off between the concrete spillway crest and the puddle clay core of the dam.**

Dowel bars are steel bars that join one slab to the adjacent one. They help to prevent movement of one slab from the next. Water bars are flexible membranes between slabs that are designed to prevent water penetrating beneath the slabs. Both are installed at the time of construction. At Toddbrook, dowel bars and water bars are only fitted to the transverse joints in the spillway chute."

DB/62 "The comparison between the spillway at Toddbrook and Carr Mill dams is both interesting and relevant as both are owned by CRT and are only 40 miles apart. However, while Toddbrook was designed by the BWB with advice from Halcrow, the much more substantial design at Carr Mill was done only 5 years later by Halcrow, on behalf of the BWB. With the same Owner and Engineer involved in both dams only 5 years apart it is unclear why the BWB did not query the need for the more substantial design at Carr Mills, or if they accepted the design at Carr Mills, why they did not then question whether the works at Toddbrook were still adequate"

2.1.1 LH Side Wall Design

AH/11 "The asymmetrical shape of the spillway is unusual, and it is not known why the left- hand wall was not kept parallel to the right-hand wall. It may have been some attempt to save money, but it is likely that the spillway was not model tested which might have identified hydraulic and energy dissipation problems particularly at the junction of the spillway channel and the auxiliary spillway channel. <u>The design adopted would suggest a lack of understanding of basic hydraulics by those involved in the British Waterways design at the time.</u>

Clearly water tends to run downhill in straight lines and so if there is a wall running obliquely to the slope the water is bound to hit the wall and accumulate against it with associated forces, turbulence and cross waves etc. In addition, 'plums' on the face are likely to disrupt flows, cause turbulence and negative pressures"

Comment **(GA). Some possible reasons for the ill judged LH Wall.**

1) **The Design Engineer was trying to 'steer' the flow to join the Bypass flow in a more rational direction. A straight wall delivers a high energy flow which considerably opposes the bypass flow. In fact even the current arrangement fails, it causes the emergency flow to run over the full bypass channel straight into the children's play ground and park.**
2) **A straight wall would go too close to the lower valve house and the complicated underground culvert which goes underneath the Bypass channel. There is also a sump tank with a breather pipe directly in the 'straight' path.**
3) **In particular the 'straight' discharge from the auxiliary spillway would directly block the discharge flows from both the valve culverts into the Bypass channel. The valves should always be fully open if the emergency spillway was in operation.**

4) Cost and delay. Fewer spillway panels were required, 26 panels were eliminated saving 143 cu m of concrete plus other materials, labour costs and overall project delay.

The debris field in the grass indicates where a straight wall would have to be and it exposes the other complications of making the LH guide wall, straight and parallel with the RH wall. This photo also reveals the appalling 'saw tooth' side wall footings which provide numerous paths for erosion channels to make an easy side exit onto the embankment and eventually to carry away an estimated 600-700 tonnes of fluidised earth, clay and stones from the dam itself as the debris field shows.

2.2.0 Assessment of the Construction.

2.2.1 Preparatory Groundwork

Prof. Hughes wondered how the embankment was prepared before the panels were laid. Once again it was not serious engineering. A gang of labourers armed with spades dug off the layer of turf to expose the bare embankment shoulder. It was not in-filled to ensure a single pair of flat inclined planes nor was it compacted. AH/28 shows the overall variation of slope due to the inadequate groundwork.

The Construction Specification

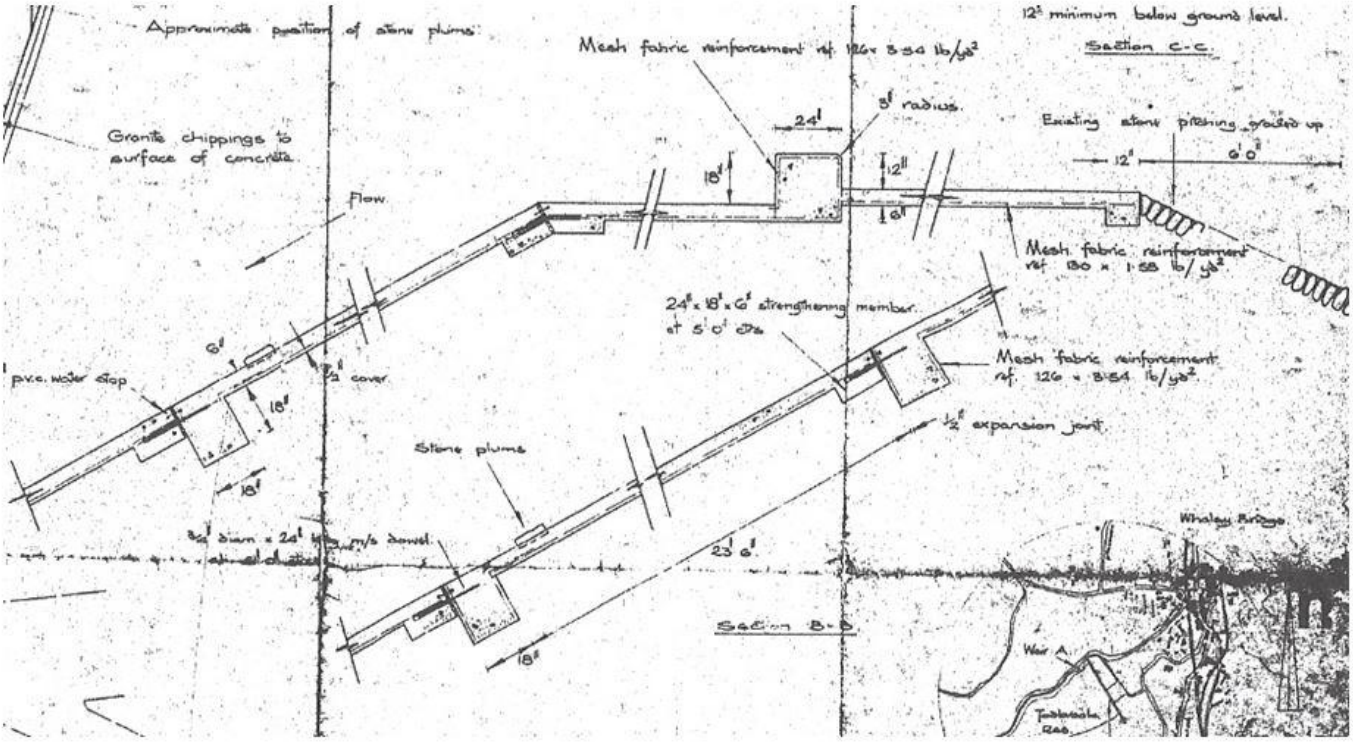


Fig 1. This poor incomplete drawing suggests how the auxiliary spillway was supposed to be constructed. It is hard to believe that this was the only specification of such a major destructive project to a Dam. It lacks numerous details defining the Apron. It would be expected that the BW Archive of Documents which the CRT inherited should have many other relevant documents including, Design Approval and especially a Risk Assessment. This is the drawing being referenced when it was claimed by the Inspecting Engineer (in 1970) that:-

"The new emergency spillway has been constructed in accordance with the drawings proposed by the Owner and approved by me",

This drawing initiated the reckless destruction of an otherwise safe earth clay dam in 1970. This was a modification that has subsequently caused a continuous catalogue of failures and defects on the dam from the outset and which led directly and irrevocably to the near catastrophe in Aug 2019.

Therefore it is worth considering the details of the design and the difficulty of actually constructing the spillway to this specification and consequently why unofficial and radical changes to the design were inevitably made on site at the outset of the work.

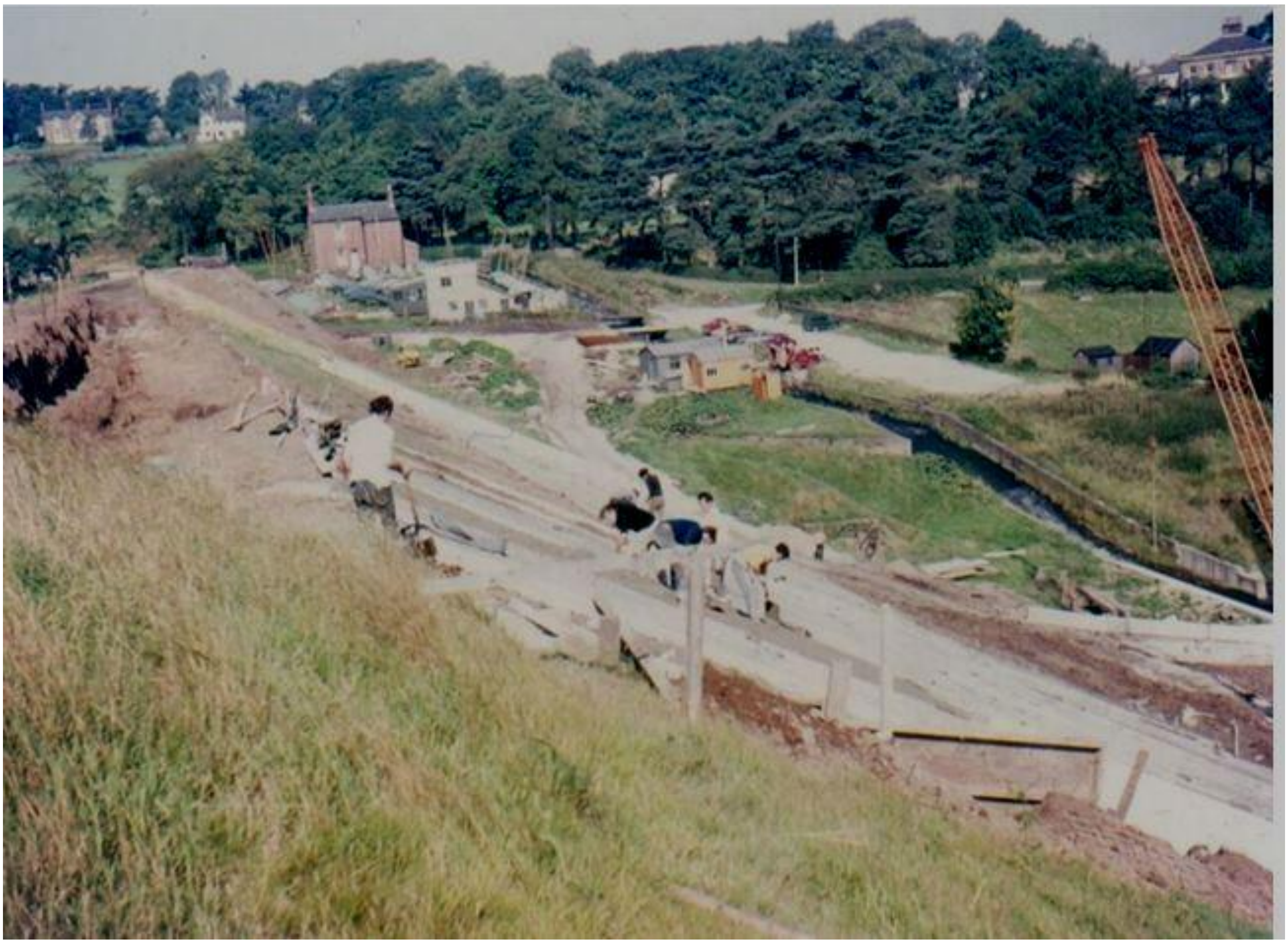


Fig 2 A gang of only 6 men are at work on the steepest part (26 deg.) of the Toddbrook Dam on a rare sunny summer day. The rich colour of the clay core (top LHS) is exposed at the crest, partially dug out as the vital safety margin of the dam is destroyed. The infamous angled LH side wall, originally very low, is partially constructed with a gap for the crane to escape. The construction roadway had to bridge the discharge culverts and avoid the valve houses. *(Photo DB/16)*.

I was fortunate to meet and talk with one of the men who worked on this job for its duration as a young man, perhaps he is in this picture.

Fig 3. indicates the construction sequence (top down) for casting the spillway panels and the unavoidable damage to structure at the foot of the dam done by the crane. The earth fill of the shoulder exposed here contains a surprisingly high proportion of big stones which provide excellent routes for erosion channels to develop. (Photo ex July seminars)

2.2.2 The Spillway Panels as specified.

(GA) On the spillway there are about 160 panels, said to be 25ft. long x 12.5ft. wide, but only 6in. thick, (the size of a large garage floor). Each panel on the slope was specified to have strengthening ribs of concrete on the underside that were to be cast integral with the panel i.e. all one piece of concrete. The lower rib was specified at 18 in. deep x 18in. wide x 12.6 ft. spanning the whole panel width.

On the top edge of each panel three individual ribs were specified 6in. deep x 18in. wide x 24 in. long, one at each side and one in the middle. These ribs were also supposed to be cast into the panel together with protruding reinforcing dowels which would subsequently be cast into the bottom rib of the next upper panel, attempting to provide stability and connection for the whole spillway.

Now consider the operations the specification required to prepare and cast a panel. Each panel covers 35 sq.yds. (29 sq m).

1) The rib profiles of 4 trenches would have to be excavated accurately in the earth bank of the dam, to provide an un-shuttered negative image of the ribs in exactly the right places required by the panel. This would produce 1.2 cu m of soil per panel which been just 'lost' adjacent to the panel.

2) A layer of 'Building Paper' was specified which would have to be forced into the prepared rib trenches and laid out across the whole panel site (and held down somehow in the wind.)
3) Then ½ inch Derbyshire basalt was supposed to be spread onto the paper at the rate of 153 kg. per panel. (The paper and the basalt were to act as a 'blinding' to stop the water draining from the concrete while it sets.)
4) Steel mesh sheet was specified to be laid and (somehow) formed manually into the rib profile trenches (virtually impossible). This mesh provided the only reinforcement for the relatively thin panel. It was supposed to be embedded in the bottom of the panel. This placement would not prevent thin panel to collapse or 'hinge' downwards under its own weight in cantilever loading exactly as happened last August.
5) During this process shutter boards would have to be fitted and supported to define the boundaries of the new panel.
6) The top water bar and the top dowel rods would have to be laid and held securely in position prior to the concrete being poured and distributed.

All these preparations had to be carefully done in wet cold windy conditions, by men slipping and sliding, with boots heavy with caked mud, trying to keep their balance on a 26 deg slope, whilst doing heavy spade work at speed because, like the Tide, 'setting concrete waits for no man'. Such conditions would inevitably exhaust the men and would therefore compromise the quality of the work.

This utterly impractical construction as specified was doomed not to happen.

2.2.3 Spillway panels as actually constructed.

It is not surprising that the construction was simplified. These practical and considerable departures from the specified design were described to me by one of the men who actually worked on the Spillway and Apron for the whole duration of its construction.

The complexity of integral ribs was promptly abandoned, it was far too complicated to implement in practice which is another indictment of the BW Design Office who specified such an impractical design. The strengthening ribs were replaced by a number of pre cast concrete blocks (18 x 18 x 6 in.) which were simply laid into holes excavated in the embankment where the ribs should be. Additional blocks had to be distributed in various places under the centre of the panel because compaction of the concrete caused the un-compacted earth embankment underneath to sink which then caused the panel to 'dish' in the middle.

The mesh and the dowel bars were wired to the pre cast blocks. This would result in a weak and ineffective dowel installation, located at a junction between a muddy precast block, mesh and poured concrete. My contact who worked on all the Spillway and Apron panels has no recollection of Blinding Paper, Derbyshire Grit and, most particularly, any Water Bars.

The Foreman and the Supervising Engineer must have known and condoned what was going on.

(AH/10) *quotes from the official BW report* "Mowlem provided full-time supervision by an Agent/Engineer and General Foreman. A British Waterways 'Supervising Engineer' (not within the meaning of the current Act) visited twice weekly, presumably to check the quality of construction."

2.2.4 The Missing Waterbars.

(GA) "Waterbars" were specified for all edges of each panel, spanning the expansion joint, above the reinforcing rods. It was a flat length of plastic material, perhaps 12in. wide. The outer edges must be embedded in both the adjacent panels across the expansion gap, just about 3 in. below the surface, because the panel is only 6 in. thick. The concrete panels can expand using the gap but water ingress is prevented by the waterbar. A filling strip was to be fitted above the waterbar, simply to prevent build up of earth to stop weed growth, it was not expected to stop water getting under the panels.

Although specified for all the edges none had been fitted on the 'vertical' joints. Some transverse waterbars were found on the RH side far away from the damaged panels but there is no evidence that transverse waterbars were fitted extensively because no parts of any waterbars appear anywhere in any of the large number of photos and videos that focus on the collapsed panels given that the waterbars were supposed to be trapped in the concrete when it was cast.

Further evidence of missing transverse waterbars is the extensive weed growth which appears in many photos over the years in both 'vertical' and transverse joints. Weeds, shrubs and small trees would not survive in just 2in. of soil above the waterbar. As any gardener knows healthy strong weeds and trees have deep roots, in this case into the earth embankment itself. The weed evidence shows that most waterbars were either absent or not effectively trapped in the concrete.

But some transverse water bars were fitted because Prof. Hughes found some at the top on the far RH side of the spillway. Photos showing one flange of a water bar and one dowel bar protruding below it. Pieces of sealing strip are visible near the cables. Photos (AH/27)

My contact who worked on this job has no recollection of the 'water bars' as described and depicted in the photos above which is surprising because his many other memories are clear, given that trying to fit the waterbars would have been an exasperating task. There should have been approximately 2250 ft. of 'waterbar' in flat coils just for the transverse joints alone so there would have been a large quantity on site, always in need of handling and therefore difficult to forget. But no parts of waterbars were revealed at any of the damaged panel joints on the LH side given that they should have been trapped in both edges of the concrete panels and obvious in photos. (p. 40.) This strongly suggests that waterbars were almost totally omitted in construction, reliance was placed on the dirt seals and their adhesive alone which failed often and were rarely replaced. Careful forensic removal of spillway panels would confirm the many departures in construction including the missing waterbars, especially the currently hidden damage to the dam itself.

DB(47)"Prior to the 2018 inspection there had been four inspections of the reservoir since the construction of the auxiliary spillway." ..."Apparently, none of these Inspecting Engineers had reviewed the drawings of the spillway design."... "In preparation for the 2018 inspection, the Supervising Engineer compiled comprehensive information on the reservoir and provided it to the Inspecting Engineer prior to the inspection"....."**It is remarkable that, over the 50 years that the auxiliary spillway has existed, it is only the last Inspecting Engineer that questioned the design of the spillway."**

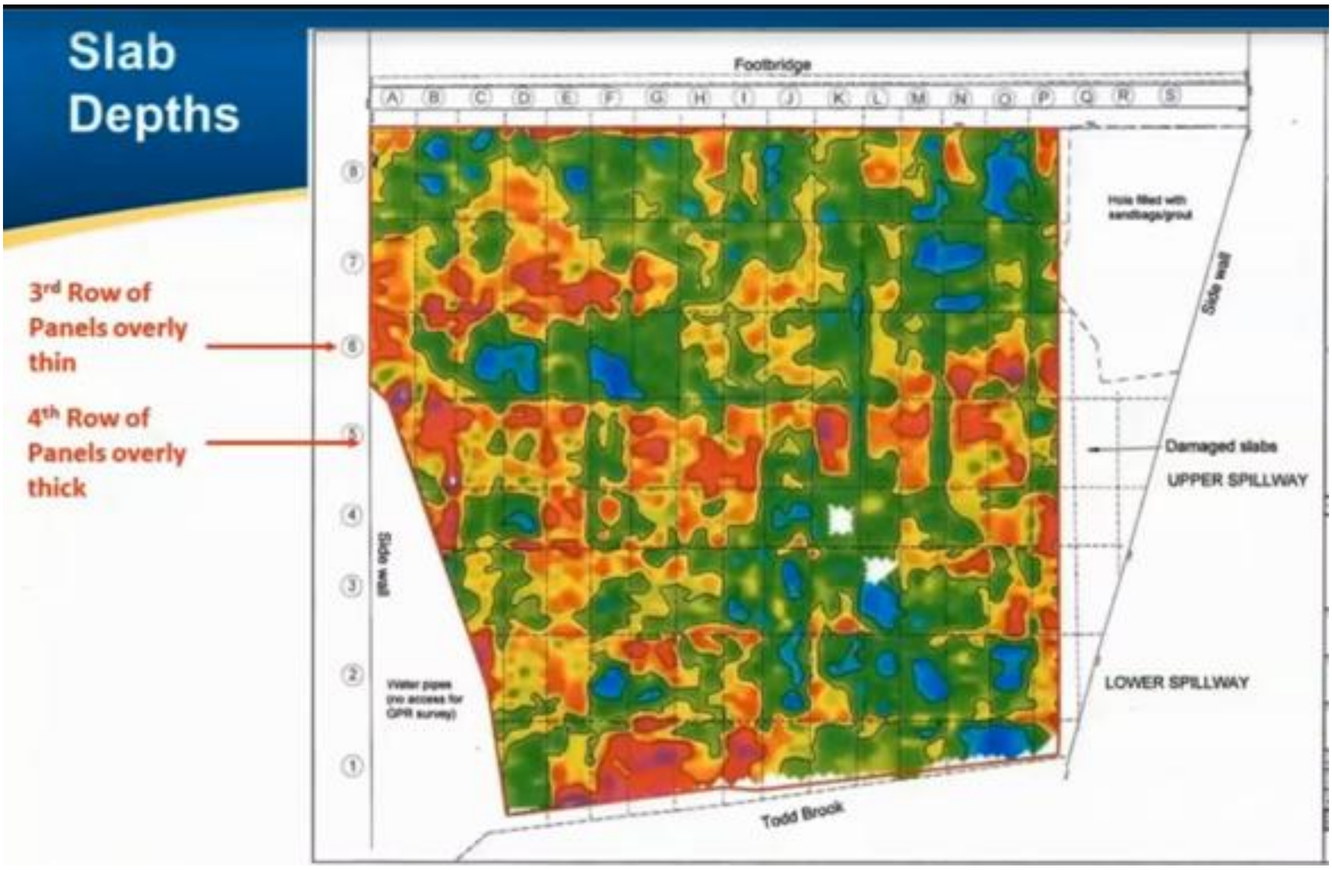
2.2.5 The Concrete.

(GA) **The concrete was mixed off site, a 'stiff' mix was specified to have only a 1 inch slump in a cone test, each delivery was tested at intervals during use. This stiffness specification was to try to stop it slipping down the slope. Each panel required 5.5 cu m of concrete which is a huge amount of concrete for men to try to distribute evenly and then compact whilst trying to stand and work on a 26 deg. slope. It was delivered by crane to most of the slope panels. Despite the slump test, the concrete was often too wet and the men had to try to shovel it uphill because it kept 'slumping' downwards. Moving the concrete while it is setting has a very detrimental effect on the strength of the concrete and this would have contributed to the failures.**

The crane could not reach to upper panels so the concrete was delivered by dumper truck along the crest of the dam, tipped and then manually 'thrown' by spade into the prepared panel box. Therefore the top two rows of critical spillway panels were possibly even more compromised in their construction than the lower panels.

The image below shows a GPR survey of the varied concrete thickness of the panels that were accessible after the incident *(Peter Mason, July Seminar.)* **It covers a range from Green/blue thin, about 70mm, (3in.) to red/orange, thick around 200mm (8in.) This image confirms the huge difficulties of laying slabs manually on a 26 deg slope. It confirms the predominant thinness of the top two rows. These panels, without proper reinforcement, were as brittle as wafer biscuits for their size, many of them had parts only 3in. thick with little or no chance that a waterbar would be embedded and therefore would leak.**

Blue, green and light yellow mean that the concrete is thinner than the required 6 inches.



2.3.0 Assessment of Maintenance.

(DB/47).”The intermittent maintenance of the spillway at Toddbrook reservoir is particularly concerning. This occurred despite repeated requests from Supervising Engineers. It seems that, apart from routine operational work (e.g. grass cutting and vegetation clearance), little work was done **at the reservoir** unless expressly required under statute by an Inspecting Engineer. Had full maintenance and repair to the spillway been completed prior to the event, as required by the IE, it is possible that the failure might have been avoided.”

“A key finding of this Review is that the elements in the process of inspection, supervision, and delivering remedial action are at times disconnected. There is a need for better communication at all levels, but particularly between the Inspecting Engineer, the Supervising Engineer, and the Owner following the inspection of a reservoir. The Owner should be left in no doubt as to what MIOS (Measures in the Interests of Safety) and maintenance measures are required, their urgency, and whether any precautionary measures are needed whilst they are completed.”

(AH/27) “Relief wells were noted in some of the lower slabs. These seem to have been drilled sometime after construction of the spillway. However, these relief wells were seen to be obstructed either by root systems of saplings/coarse vegetation or by stones/ gravel and clearly had not been cleaned for many months/years.

In some ways unfortunately, but necessary at the instruction of the IE, a grouting exercise, presumably to fill voids under the crest slab, was undertaken before my investigations.

In addition, maintenance has been intermittent over the life of the spillway, and this is likely to have contributed to its deterioration. In particular, the (Investigating) Panel noted:-

Lack of sealant in some of the joints between the spillway chute slabs

Lack of repair to cracks in the chute slabs and the spillway crest

Vegetation growing in cracks and joints

Saplings and small bushes growing in cracks and joints. This vegetation must have been deep rooted in order to have survived the flood event"

2.3.1 Owner's responsibility for maintenance.

(AH/14) "An owner of a dam has a duty to maintain its dam and its appurtenant structures to ensure it remains in a safe and operational state. This will include things such as grass cutting, removal of weeds, saplings and trees, operation of valves and penstocks, repairs to wave walls, to upstream protection systems (pitching), repairs to spillways and by washes etc.

"Good practice with respect to dam safety includes having trained staff visit the sites several times a week and after 'extreme' events. Currently best practice would dictate visits every 48 hours by trained staff for a dam with high consequence of failure predicted. Many companies have trained staff visit their sites twice a week."

"The Author (AH) believes that most water companies' budget of the order of £15k per reservoir/per annum for maintenance works but this is a very general figure and larger dams and those with problems associated with poor design, vandalism, particular forms of construction etc. can need greater levels of expenditure per year"

Comment (GA) **The Experts are very critical of the lack of maintenance and neglect of the auxiliary spillway. Prof. Hughes confirms that, in addition, the Owner must maintain all the other related safety systems:- feed weir, bypass gate, bypass channel, convergence basin, discharge culverts which were choked with mud banks and vegetation at the time of the serious Incident.**

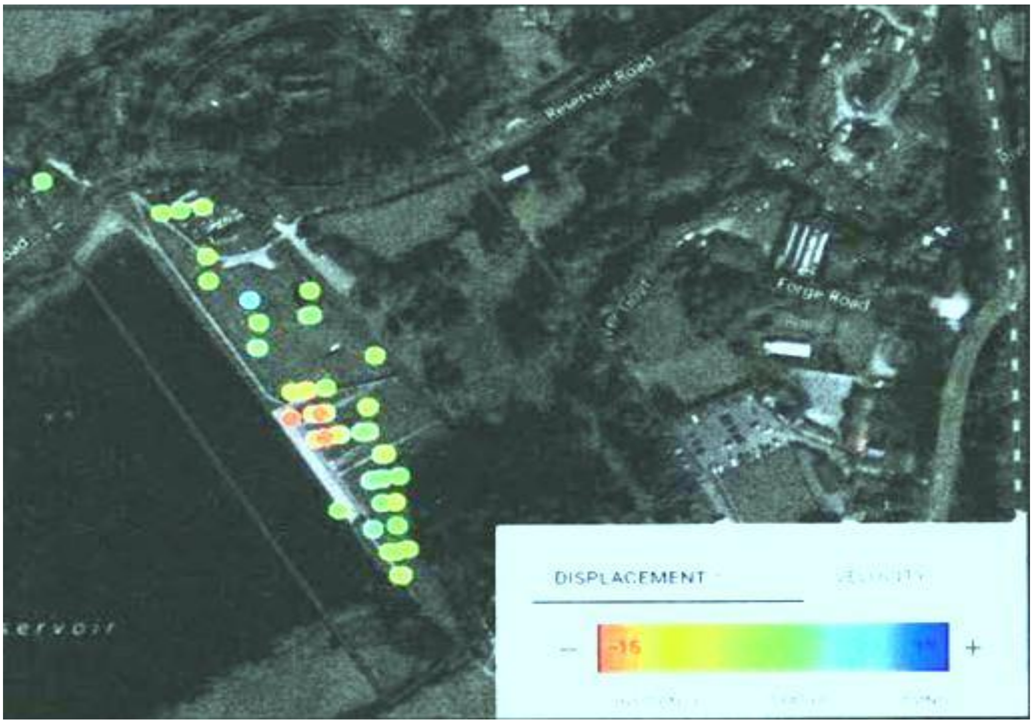
2.3.2 Monitoring the Settlement of the Dam.

Even though the Dam is 180 years old it can continue to settle for various reasons. There are 23 survey pins located in various places on the downstream face of the earth dam and possibly 12 more on the concrete spillway of which only 9 are monitored occasionally (AH/20). As the dam settles the new position of the pins can be detected on a surveying instrument and then plotted. These measurements are absolutely fundamental for the assessment of safety and stability of the dam and are an essential part of maintenance of the Dam. But this data shows that both British Waterways and then CRT have failed to do this consistently. Pins have disappeared or are ignored especially on the spillway.

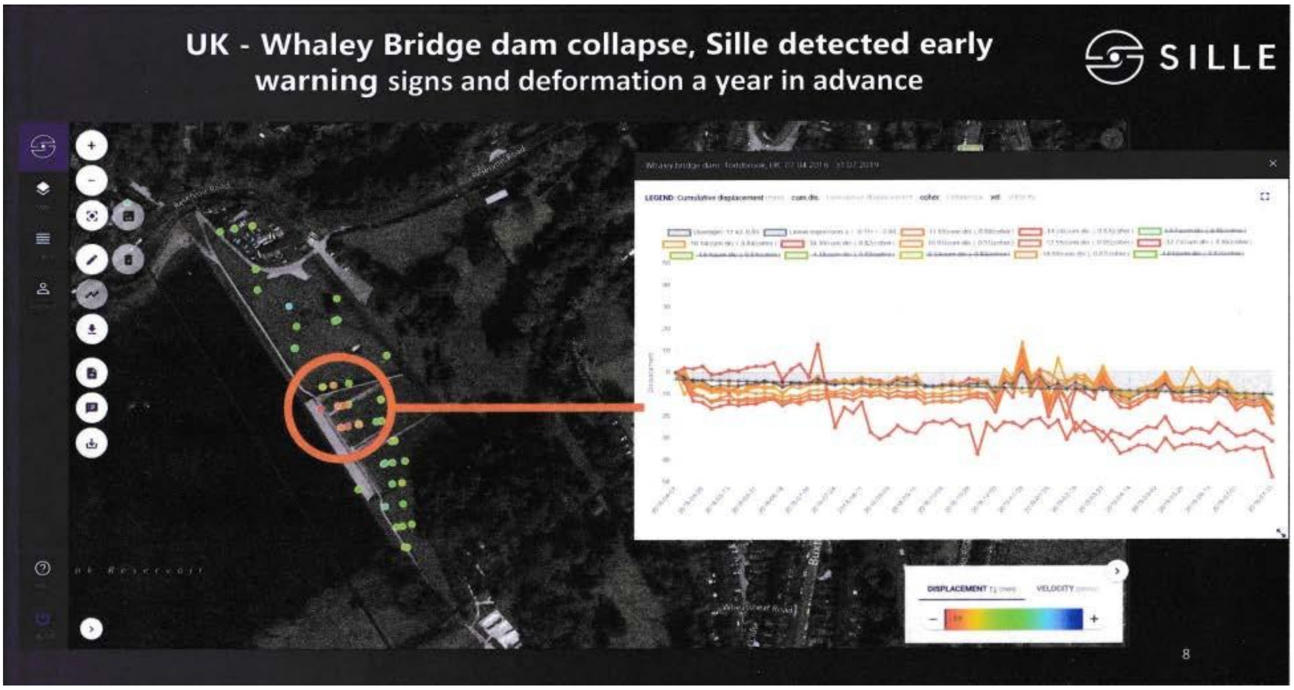
The plot below shows the changes for the last 20 years. If all the pins indicate the same small downwards movement there may be less reason for alarm. It is the differences in individual Pin behaviour that should demand prompt investigation and explanation because this could provide an early warning of differential movement and instability of the dam.

Looking downstream, the group of pins in the middle, SO1-9, are on the Auxiliary Spillway. For some reason their records only start in 2010 and have only been read **3 times** since then. Pins SP1 to SP15 are on the LH side where the damage occurred, with up to 9 records from year 2000. Pins SP16 to SP23 are on the RH side.

SP15 which is adjacent to the LH abutment wall has dropped 30 mm in 19 years, SP 16 at the RH side is nearly as bad. This strongly suggests greater local slump due to erosion channels exploiting the cross dam trench dug for the construction of the abutment walls. This is almost certainly a critical cause of the damage, evidence that has been available for 10 years but not physically investigated (on both sides of the abutment wall), despite extensive cracking of the Apron there. All the other pin variations demand an explanation especially SP04 (which is behind the sailing clubhouse), it has dropped 80mm since 2001. SP1 to 3 are never read for some reason even though they are on the dam embankment, critically near the Bypass channel.



Copernicus Satellite surveillance has been used to duplicate terrestrial surveys of the pins (AH/45). (taken before the damage event.) The location of the pins on the dam is shown on this satellite picture. The yellow and red pins have all moved noticeably in the LH corner where the damage <u>was to occur</u> in future.



The fuzzy graph (screen photo) shows that most pins are behaving roughly the same as each other but two pins have dropped (ie parts of the dam dropped) in July 2018 and Jan 2019 by 30 mm, both on the LH side of the spillway. This indicates that there were significant drops in the dam structure 11 and 7 months before the Aug 2019 so there was a warning a year in advance of deformation which was not heeded by, at least, drawdown. This raises some questions:- What caused the Toddbrook Dam to be monitored by satellite for over a year ? Who requested it? Was the CRT aware of these drops ? Was dam survey pin data given the attention it merited?

2.3.3 Routine Exercising of Drawdown Facilities.

This is functional safety maintenance which is far more important than mowing the grass on the dam. The operational condition of these facilities did not get any significant consideration in the reviews and seminars. It is not known if these records were audited in the 2018 Inspection as required in Part 16.

Drawdown facilities require that discharge valves should be opened **fully** every six months and the total performance of the discharge system, pipes, culverts and blocking planks should be checked in maximum operation for any defects or weaknesses. This procedure is especially important for brand new valves exactly as fitted at Toddbrook about 10 years ago to replace the 170 year old valves. This type of valve, especially when new, can 'stick' for mechanical reasons and do have to be periodically fully opened to exercise them. It was reported that 'stuck' valves delayed the already belated discharge actions at Toddbrook at 10 am on Aug. 1st. because the valves could not be opened to maximum until the 'the heavy gang' in the Emergency Team arrived later in the afternoon of 1st. Aug. after the damage to the dam had occurred.

For reservoirs designated as 'high-risk' under the Reservoirs Act 1975 it is a legal requirement to record such details in Part 16 of the Prescribed Form of Record. Valves and gates should preferably be exercised over their full range of travel (i.e. fully opened and closed again). (See App. 3)

Chapter 3 Rainfall Events.

3.1 Rainfall at Toddbrook prior to the Event.

There are no rainfall instruments in the Toddbrook catchment or a flow gauge at the feed weir. Therefore the rainfall data presented at the July seminars has been estimated from other rain gauges located some miles away in other catchments. This seriously weakens the value of any models or charts because the rain fall in this hilly area is very specific to location. Furthermore the seminar charts display the estimated rainfall <u>rate</u> in mm per hour which is not a useful indicator of the volume of water. This can be seen in Fig. 1 by comparing rain rates and volumes for the 28th with the 31s, clearly volume is not a simple function of rate. The seminar charts even had different rainfall data from each other and careful study suggested they were not a credible base for models and drawdown speculation.

Given that there are no recorders in the Toddbrook catchment it is strongly recommended that at least 4-6 wireless rain gauge recorders are installed at points around the periphery of this extensive and complex Toddbrook Catchment. Proper flow telemetry is required at the feed weir and bypass channel because there never has been any.

Despite knee jerk media claims at the time of the Incident the Expert Reports do not blame the rain or Climate Change. The Reservoir System should have coped. But the damage was caused by the progressive development of erosion channels under the Apron and side walls during the last 50 years, which was finally completed when the dam was heavily overloaded on Wednesday 31 July 2019.

We are familiar with very heavy rain in this hilly area which can be very localised. Roads, bridges, driveways can be destroyed as they were recently on 31 july 2019. There was a storm on 22 June 1989 when a local man in his car was swept off the A5002 road into the Todd *Brook* at Reeds Bridge and drowned. Other 'big rain' events are recorded in the mid 1930s and 1870s.

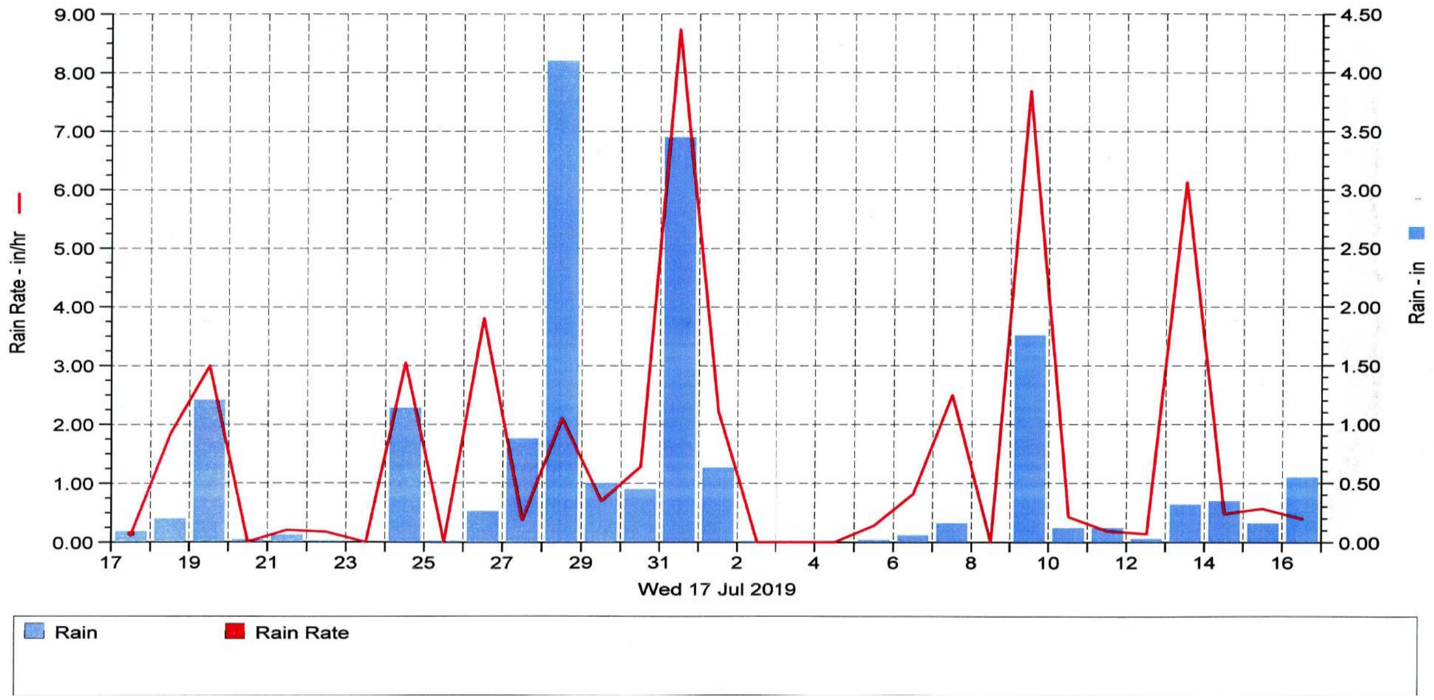


Fig. 1 Local Record showing the 2 rain events on 28th and 31st July. Note the 7 virtually rain free days that immediately followed the collapse and allowed the reservoir to be slowly drawn down and thus saved Whaley Bridge. *(I have permission to use these records of a local climatologist who lives just north of the catchment.)*

To investigate the response of the CRT it is important to consider the rainfall and reservoir level before the two major rain events of 28th and 31st. July. This is because the Emergency Spillway was already flowing on the 26th.July and this should have triggered precautionary discharge actions by the CRT most particularly in recognition of the downgrade of the Dam to 'Poor' structural condition, but in fact no precautionary discharge was initiated then.

June 2019 had been a wet month with more rain in early July. The poor weather would have reduced leisure use of the canals and the demand for water by locks. Natural filling of the canal network by heavy rainfall and streams would have further minimised potential demand on the Toddbrook supply. So, with little recent use and with no precautionary discharge actions, Toddbrook was already 'full' but continued to fill beyond the capability of the primary cill. It must have reached around 15in. above the 'drowned out' primary cill because the emergency spillway began to flow in the early afternoon of Friday 26th.

As the records in Fig. 1 show, starting on Saturday evening there was about 36 hours of continuous very heavy rain, a total of 130 mm was recorded with the majority, 104 mm. on Sunday 28th. It was this monsoon (plus a further 25 mm of rain in the next two days) that arrived progressively from the catchment area and amplified and maintained the massive unprecedented auxiliary spillway flow.

The spillway ran with enormous energy for over 40 hours, the powerful flow accessed and enlarged existing erosion channels underneath the Apron and side walls, it exploited cracks and deficiencies in the spillway. Exit pathways were created by lifting panels and enlarging existing channels under the defective LH side wall. This allowed the high energy flow to excavate and fluidise the structural fill and vital clay core of the dam. The rich brown colour of clay in the water was disguised in the chaotic air filled turbulence of the water constricted by the madly convergent LH wall during the flow on Wednesday. It was not until Thursday morning that the distinctive rich clay colour from the clay core was recognised in puddles, pockets and flow tracks after the spillway flood had subsided. This evidence contradicts the belief that the clay core has not been damaged and eroded (*Photos GA/13)*. This is a major justification for the removal of the whole spillway and apron; the clay core must be evaluated and repaired before the dam is loaded again.

The experts agree that the damage that caused the panels to collapse on 1st. Aug. occurred during the high energy flow on the spillway during the previous day (Wednesday). It is therefore reasonable to exclude the rainfall of Wednesday (88 mm) because that occurred too late to reach the reservoir from the catchment to contribute to the massive flow which caused the damage.

Although there was rain all day on Wednesday the local heavy rainstorm only occurred at about 17:00 for about 20 mimutes. Rain from the upstream catchment area would take several hours to reach the reservoir and this was well after the erosion damage had already occurred. The catchment area is about 17.4 sq km. Although it is steep sided it has a wide marshy bottom, and the water flow is therefore slow. The southern end is about 11km. away from the feed weir. My past experience is that normal rainfall can take 12-18 hours to arrive at the reservoir feed weir. Ref. (GA1/21). Therefore I argue that the rainfall on Wednesday late afternoon did not erode the dam structure. This had already happened during the previous 36 hours. Wednesday's rainfall simply added to the dangerous volume of water on its way to enter the reservoir. From Thursday onwards this water only increased the load on the now damaged dam, just more water for the emergency services to pump out.

Therefore the focus should be on the rainfall of the 26th -29th July; this was the cause of the damage.

3.2 Reservoir level management prior to the event.

This rainfall record shows that the CRT had the opportunity from the 26th. July onwards to open the discharge valves and maximise the bypass flow but nothing was done until late morning of the 1st. Aug. This was after the panels had fallen into the voids excavated the day before and the flow over the damaged spillway had virtually stopped.

It is known that the water was spilling over the LH end of the Aux spillway on Friday 26th July. This is such a rare event it would be expected that there would be some reaction or interest from the CRT. Auxiliary spillway flow means that the reservoir level has progressively increased by at least 30-40 cm.(10-15in.) above the original Primary Cill. It means that the reservoir is filling because the overflow at the Primary Cill is unable to function, the reservoir is then above its TWL design limit and the already weakened dam is Overloaded.

A reservoir engineer would see that the reservoir water level was standing ***above*** the primary cill, blocked by the bypass flow and the narrow constricted exit downstream from the convergence basin. He/she should have then opened both discharge valves on the 26th July, 5 days prior to the event. This did not happen because the CRT does not have any precautionary drawdown procedures, (GA3/10) full trust is placed on the operation of the recently downgraded, hardly ever used Auxiliary Spillway, (4 times in 50 years), the technical performance of which in high continuous load had not ever been analysed. The long catalogue of faults detected over its life and summarised in the Inquiry Reports (DB1/17-18) and (AH1/15-23) provides this evidence in detail.

The Nov.2018 Inspection had led to the down grading of its Condition Status from FAIR to POOR (DB/xx) 3 months before the damage. This downgrade ought to have had alarms sounding in the senior management levels of the CRT whenever the Emergency Spillway became operational, given that the state of this High Risk, Category A Spillway, *"Structurally significant defects leading to loss of stability…"*, was the reason for the downgrade. It is unfortunate that the Experts of both Inquiries did not ask the CRT what extra cautionary operational procedures were mandated for Toddbrook now that the condition status was downgraded to POOR ? Downgraded status should require the reservoir to be managed at a vigilant more stringent level of alert caution than previously but it was not.

3.3 Discharge actions prior to the Emergency..

DB/19. *"At about 11am on the 31st July, a member the Operations Team at CRT visited Toddbrook Reservoir and closed the valve to the canal feed"*.

Comment (GA) It is astonishing that on Wednesday 31 July a reservoir engineer actually looked at the massive chaotic spillway overflow, the blocked and overloaded bypass channel, the flooded park and the blocked river Goyt and then closed the only discharge valve to the canal that could have done something useful. This statement must refer to No. 2 valve because the canal feed ability of No. 1 was blocked deliberately in 1999 (as previously discussed). No 1 valve (only able to feed the Goyt) must also have been already closed for some unknown period because it is reported 24 hours later that on 1 Aug. that both valves were opened.

DB/21 *"At 10:00am Aug 1st CRT Operations staff arrived on site and opened the draw-off (No1) and scour valves (No.2).*

"DB/30 "The reservoir draw-down facilities appear to have been operational (i.e. able to function) *as both valves were fully opened on the morning of the 1 st·August, though this was towards the end of the event."*

DB/30 *"In addition to drawing down the reservoir level, there are facilities to divert the inflow away from the inlet to the reservoir and into the by-wash channel, and also to block off the by-wash flow from returning to the reservoir via a side weir* (river compensation)*. These were not operated until the afternoon of the 1st . Aug".*

I was an unintentional witness at around 11:30 a.m. 1 Aug. to the belated panic stricken efforts to open the locked Bypass gate (no key) which had been virtually closed for many years. It was far too late by then, the damage was done, the panels had been undermined during the previous 30 hours, now they were falling and smashing into empty cavities, the rain had stopped. Described in Ref. (GA1/16)

So in the days prior to and during the massive spillway overflow there was no coherent drawdown in operation using the pipes and no maximum reduction of reservoir fill using the Bypass. Clearly there are no defined Precautionary Drawdown Procedures (GA3/10) at Toddbrook either for Condition "Fair" or "Poor".

3.4 Post Event Flow Modelling

DB/30. *"The CRT, assisted by Mott MacDonald, has used their latest computer model of the reservoir and upstream catchment to investigate what might have been achieved if this flow diversion had been brought into play earlier. The results show that with the draw-off valves open and the inlet flow diverted* *into the by-wash channel, the peak flow over the auxiliary spillway would have been reduced from about 9.5m³/s to 8.3m³/s, the spill volume reduced from about 423000 to 164000m³ and the duration of spill reduced from about 100hours to 40hours.*

It is not possible to say for certain, but it is likely that it would still have been possible for the auxiliary spillway to have failed in some way even if these measures had been taken. Moreover, the additional flow passing along the by-wash, when added to the flow from the primary spillway, may have created its own problems, both in the vicinity of the reservoir and downstream."

Comment (GA).

The results even using the Mott rate are very significant .With the spill volume over the Auxiliary Spillway reduced by 62% and the duration in time of spillway flow reduced by 60%, I contend that it is therefore highly probable that the extensive damage could have been avoided particularly if early use of the discharge valves and bypass channel had been initiated. It is not stated what date the Mott model is started from. However I argue that precautionary discharge actions should actually have been initiated from Friday 26th July onwards when the 'Poor Condition' Auxiliary Spillway first started to flow. That was before the 36 hours of rain of 28th that eventually damaged the dam on the 31st.July.

My own calculation last year (*details GA1/12*) produces similar results to the Mott MacDonald model. Two discharge pipes together can deliver 1.35 cum/sec and the Bypass channel could deliver between 1-2 cum/sec, possibly compromised by the convergence basin defects although the Bypass flow generally beats the reservoir overflow. However my conservative estimate of a rate of 1.35cum/sec compares with the Mott value of 1.2 cum/sec.

If the Bypass had only been opened to maximum during peak flow over the Auxiliary spillway, the Primary overflow would have been blocked at the convergence basin thus increasing the flow over the Aux. Spillway. But the discharges from both valves are fully independent of any blockage in the convergence basin being both down stream (and down hill) of it. So even if Bypass flow is ignored, the use of both discharge valves at a total rate of 1.35cum/sec for 4.5 days from 26th. July would have discharged 525,000 cu m which is equivalent to lowering the reservoir level by around 3m.

This would have progressively offset the rise due to simultaneous infill from the first rain event and very probably would have avoided damage to the Dam. Unfortunately the CRT had no plan for precautionary discharge to be activated when the recently downgraded "Poor Condition" spillway started to flow. A chart of model results presented in July which considers early drawdown scenarios has several inconsistencies which affect its credibility.

Chapter 4. Administration

4.1 Reservoir Law

There are several Acts starting in 1863 which have been subject to many amendments over time. There are caveats, footnotes and cross references, mostly only intelligible to a reservoir expert and that is an unfortunate weakness of this batch of legislation. The applicable legislation, developed over the years is as follows:- The Waterworks Clauses Act 1863, The Reservoirs (Safety Provisions) Act 1930, The Reservoirs Act 1975, The Water Act 2003 and The Flood and Water Management Act 2010. The Water Act 2003 was introduced when it was concluded that the enforcement system was *'variable in quality'* which speaks volumes. In addition to these Acts, there are important 'Guide Lines' documents written by modern Reservoir Experts and published by the Environment Agency/ICE but they are not 'the law' although they do provide practical guidance to those responsible for managing reservoir safety.

There is a strong case for a modern Reservoir Safety Act. It should be distilled from the 160 years of historic Acts and Guidelines and then redrafted to apply unambiguous modern standards of safety management and technology to these very old and potentially very dangerous constructions.

4.2 How is the Safety of Reservoirs managed?

This was a revelation. In the UK there is a cohort of qualified Reservoir Engineers, listed in 'Panels' or groups from which certain classes of reservoir Inspectors are selected or appointed to meet the various requirements of reservoir legislation. The safety of a Reservoir must be assessed at least every 10 years and this is carried out by an 'Inspecting Engineer' (IE), who is a member of the 'panel' of the most experienced and qualified. A 'Supervising Engineer' (SE) may have similar qualifications and they are asked to carry out two inspections every year. The SE can be a full time employee of the 'Owner'. Reservoir Systems are also visited by 'Trained Staff' supposedly every 48 hours. It is not known what else they actually do except perhaps to measure the reservoir level *Ref. AH (12-14).*

Therefore in the 7 years of CRT ownership prior to the near breach of the dam, Toddbrook should have had 700 'visits' by 'Trained Staff', 14 searching inspections by Supervising Engineers and 1 Major Inspection by an IE.

Current formal safety inspection across the Reservoir Industry (not just the CRT) is inexcusably lax. Typically a major inspection of a 180 year old reservoir system that is rated in the 'most dangerous' class in the UK is only required once every TEN years, (although the previous IE or SE could ask for one sooner). After the Inspection the IE has up to 6 months to compose and deliver the report and he typically takes the whole 6 months. After that the Owner has 18 months *to complete* any required work on a fault that could be possibly, by then, be about TWELVE years old. Yes, this is very lax, it i does not compare with for example, the Chemical Industry which has a more rigorous view of inspection frequency, documentation, specific records and fault repair.

4.3 How should the Safety of Reservoirs be managed ?

Prof. Balmforth has recognised many serious deficiencies in the drafting and operation of reservoir safety legislation and has made some appropriate proposals to the Environment Agency for a more rigorous system, generally applicable. However I go further. The CRT is responsible for the safety and management of 72 of the oldest reservoirs in the country yet there is no Safety Director at Board level which is a major organisational defect. The Safety Director should have greater authority than the CEO on all safety matters just as he/she would have in any other equivalently dangerous industry.

The focus should be on continuous safety assessment for every reservoir. It should not have to wait for a dam to be nearly breached, a town centre at risk of destruction, 1500 people evacuated at short notice from their homes and businesses for the requirement for a £10 million radical modification to be belatedly and accidentally recognised. There is no defence. The CRT Safety Director should be present at every Major Safety Review, and at every twice yearly SE review for every reservoir. He/She should be proactive and insist on a preliminary meeting with the IE or SE within 1 week of the Inspection in order to be informed of all Issues and concerns. He/She should be legally responsible for the authorisation and operation of all safety procedures of every reservoir in the Owners group. The records of these safety procedures should be included in all the Inspection Schedules and made available to the Inspecting Engineer.

It is proposed that the Reservoir Industry must operate inspection and safety controls equal to any other UK industry whose operations can kill, injure or destroy property. It is also proposed that the reservoir safety procedures themselves should be subject to critical external comparative review by experts from other similar industries e.g. Chemical, Nuclear, Aviation, Transport etc. There is considerable commonality in all safety and operational procedures across all industries regardless of their different functional operations.

The Reservoir Industry, although old and insular, must endeavour to learn how other industries manage Public Safety down to the last detail. The current reservoir Inspection system is an archaic legacy of a safety system which relied on a dedicated resident warden who intelligently operated time tried procedures for both routine maintenance and high volume floods.

4.4 The Reservoir as a System.

This report strongly argues that a reservoir is not exclusively a dam although the dam is the most dangerous element, it must be regarded and inspected as a System. The System has many other components, all of which must be critically inspected and be kept in full functional order both for normal use but particularly for management of heavy and prolonged floods. The System should include specific formal documented procedures, authorised by the CRT Safety Director, for every aspect of normal and extreme management of a given reservoir. There is no evidence that such procedures exist at Toddbrook, because, quite by chance, I witnessed the panic on the morning of Aug.1 . (GA1/16)

The physical components of the Toddbrook System are the Feed Weir, the Bypass Gate, the Bypass Channel, the Compensation Weir, Vehicle access to the feed weir one mile from the dam (none existent, this was a major and critical problem at the incident), the Convergence Basin, the Discharge pipes, Discharge Valves, Extensive canal feed and river discharge culverts, Culvert diversion controls. All of which were in a neglected and semi derelict state at Toddbrook in August 2019. GA2/(21-33) Their unready state, as reported and confirmed in the July Seminars, heavily compromised the emergency actions to drain the reservoir. These impediments were quite independent of the Auxiliary Spillway with all its own major hidden defects.

The Status of the whole System should be defined on a Toddbrook System Safety Certificate and critically inspected <u>every year</u> exactly as an MOT inspects and tests <u>*all*</u> the safety components and systems on every road vehicle (all 41 million) in the UK every year. Failure of any critical component should result in immediate draw down by a prescribed amount just as failure in a vehicle MOT denies further road use. This then provides the strong incentive for the owner to rectify the defect promptly or repair it as soon as it is detected, usually before its MOT Test, this must become the ethos of Reservoir Industry.

4.5 The Benefits of the River and Canal System in England.

(GA) Around 2010-11, it was recognised that the cost of maintenance of the old waterways was growing at an alarming rate. In an attempt to avoid this liability and to save money the Govt. decided to 'privatise' British Waterways by devolving all its liabilities and responsibilities to a new Charitable Trust, the CRT. A 15 year grant package was set up which reduces progressively while the CRT is expected to generate sufficient revenue from boating activities to compensate for the reduction. An unbalanced experiment doomed to fail.

Thus the CRT acquired responsibility for 72 of probably the oldest reservoirs in the country. Each year the current legislation requires 7 “10 year” Inspections by an IE (on average), 144 searching Inspections by an SE, and 7200 visits by ‘trained staff’ to be carried out. Given the neglected state of the Toddbrook System the effectiveness of this Inspection Regime and this Owners response should be critically examined. Overall this is a huge inspection burden with manpower and administration costs to be added to those for routine maintenance and for both predicted and emergency repairs. Therefore legal safety of the reservoirs alone demands a large annual budget which must be committed and ring fenced because reservoirs with their dams are the most dangerous high energy assets in the system of canals and rivers.

Currently the CRT has to employ a fund manager (paid more than the CEO) to invest in the general stock market in order to generate sufficient funds to keep the CRT afloat. This is a tenuous and unpredictable source of income which must lead inevitably to general cost cutting. Yet maintenance and repairs of all High Risk reservoir systems, (with scope as in 4.4,) must be carried out and be given the highest funding priority to ensure Public Safety.

The CRT has two distinct functions:-

1) The core Engineering function to ensure Public Safety by maintaining and repairing the huge distribution of 200 year old historic and dangerous assets which are decaying every day.
2) The Recreational, Heritage and Leisure function to provide public access to healthy green amenities, nature and water which is of considerable benefit to health and wellbeing.

British Waterways was to blame for the fundamental error that nearly destroyed the dam and the town. The Toddbrook Incident shows that neither the CRT itself nor the reservoir system maintained by the CRT was ready for extreme conditions. The evidence strongly suggests that the CRT does not have the funding, skills or resources to manage the Engineering Function for the whole canal system with the 72 reservoirs to the necessary standards and to carry out all the inspections, maintenance and fund all the repairs demanded by the Reservoir Acts. Therefore the decision of 2012, which gave the CRT full responsibility for both maintaining the decaying infrastructure and managing the recreational use should be revised.

The Secretary of State, DEFRA, should therefore consider splitting these two functions by returning the Engineering responsibility to a dedicated Waterways Engineering & Maintenance Authority (WEMA), closely funded and overseen by the State. The system of canals, rivers and reservoirs is a unique National Asset, fundamental to the health and history of the Country. Public Safety must not be put in potential jeopardy determined by perhaps shrewd but fallible investments on the stock market. The engineering service that Network Rail provides for the Train Operators is a potential model for this proposed arrangement of a split between Recreation and Engineering on our waterways.

4.6 Reservoir Types and Risk Categories.

(DB/12) “Reservoirs are normally categorised by the consequences of failure, as described in the Institute of Civil Engineers (ICE) guide, “Floods and Reservoir Safety”

The categories are as follows:

- A – where a community downstream could be affected
- B – where isolated individuals (not in a community) could be affected

- **C – where loss of life is unlikely but there could be significant infrastructure damage**
- **D – where downstream consequences are likely to minimal**

"Category designations in this form are used by Panel Engineers to decide on the most appropriate flood standard for which the dam spillway should be designed. These categorisations do not form part of the Reservoirs Act......"

"Note that the categorisation of reservoirs described above is different from the designation of a reservoir as 'high-risk'. 'High-risk' in the context of the Act refers to whether the EA takes the view that, in the event of an uncontrolled release of water from a large raised reservoir, human life could be endangered. It is designated by the EA using all relevant information/documents they hold and advice from an independent panel engineer Toddbrook Reservoir is categorised as **Category A** and designated **High-Risk**."
(**DB35)** "In a meeting with the CRT Principal Asset Engineer and CRT Regional Engineer the Panel was told that as a result of the inspection, the reservoir moved down condition grade C to D....The Grades vary from A to E. Condition Grade C is denoted "**Fair**" by CRT and described as "Minor defects may develop into structurally significant defects in long term (generally > 10years) "and Grade D is denoted "**Poor**" and described as "Structurally significant defects leading to loss of stability in the medium term (generally 5 to 10 years)".

Comment. (GA)

High Risk.

'High Risk' is the assessment, under the Reservoir Act 1975, of the extent of harm and damage that can be caused if the dam is breached. It classifies the possible effect of a dam breach on the people and the local environment but does not describe the structural condition of the Dam itself nor the probability of breaching. Currently that is covered by a 'Condition' assessment made by the Owners themselves.

Condition.

This is a fundamental flaw in Reservoir Safety. The condition assessment should be the sole responsibility of the independent Inspecting Engineer who has just carried out an inspection of the whole Reservoir. He should define the condition of the dam and indeed that of all the safety systems of the whole reservoir. The Owner of a fleet of trucks does not have the option to define their safety condition, much as he might so desire, that is done by the commercially unbiased MoT inspector.

Categories.

The 'Categories' define the capability that a reservoir/spillway system should have for various reservoir locations of increasing risk. Therefore the 'High Risk' Toddbrook Reservoir should have a Category A spillway due to its location. The many video images show that the spillway was inherently incapable of dealing with such massive flows and energy due to its defective design :- plumb stones, the convergent LH wall, the lack of capacity of the Bypass channel to receive even fractions of 164 cmsec. massive energy flows across the children's playground and into the public park, ill designed contra flow connection of the Bypass to the River Goyt (GA3/8-9). The spillway just dumps water at will anywhere into the 'locality at High Risk' totally out of control. Although built 50 years ago, the Toddbrook Reservoir spillway could have been assessed and modelled retrospectively to see if it met the required Cat. A design criteria. But there is no law which requires a Cat A spillway at Toddbrook. This is another illustration of the optional nature of 'good reservoir practice' in the reservoir industry which should be addressed in a new Reservoir Act.

<u>Probabilities</u>.
Predictions that defer an adverse event to sometime vaguely in the future like "5 to 10 years away" are not safe or useful. To illustrate this, the new "Poor" condition, *'structurally significant defect of the Dam leading to loss of stability in the medium term (generally 5 to 10 years)"* was actually only 4 months away as the events of 31st. July 2019 demonstrated. For such a definition to have any value at all it must be continually reviewed and updated. After 3 years have passed "5 to 10 years" should become "2 to 7 years" but nobody ever does this even though the defect has presumably been developing for last 3 years. On paper the developing defect remains defined comfortably but dangerously wrong at "5 to 10 years" away in the future for ever !

Assessment of a probability should therefore never involve 'Future Time' as a substitute for a (guessed) current low probability which is expected to get higher in future. The simple rule for a Serious Safety Defect, however improbable the occurrence is, should be: **If you know about it, Fix it Now !**

So in summary, the Toddbrook Reservoir is designated by the Env. Agency **High-Risk =** loss of life, the over crest Spillway and reservoir system should meet **Category A standards** by the ICE guide due to High Risk designation, and the Dam is in **Condition grade D = Poor** assessed by the Owner, CRT, rather than the Inspecting Engineer.

Chapter 5 Investigation processes

5.1 Missed Opportunity to Examine the Evidence.

Unfortunately the analytic expertise of the Inquiries has not been focused on the Primary Overflow deficiency which had caused the Auxiliary Spillway to be built and then fail. The narrow terms of their brief, set by the Environment Agency and the CRT, required analysis of the inevitable failure of the Auxiliary Spillway which was known to be a dangerous and ineffective modification to the dam.

It is unfortunate that the Experts did not insist upon a complete supervised forensic dismantling of the defective Spillway and Apron to be fully under their control for the duration of their Inquiries. This would have confirmed so much and provided a clear unambiguous route, a pathway of facts, from the design, through the degraded construction and superficial or non -existent maintenance leading to the final failure on July 31st 2019.

There is a repository of evidence that has not been tapped or investigated, that lies buried under the concrete whilst, inexplicably, even more 'temporary' concrete is added by the CRT which will make access more difficult. Where lives and property have been seriously threatened, theories of cause should be confirmed or rejected whenever possible by physical investigations of the widest scope on the actual object, in this case, the defective auxiliary Spillway and Apron.

This failure to access the evidence directly is particularly astonishing because Dr. Tedd (a member of the Prof. Balmforth's team) was co-author in 2011 of an excellent paper which analysed all the dam failures and incidents in the last 200 years. The resulting document defined certain terms and principles that the Environment Agency should adopt when investigating dam incidents. (*'Lessons from historical dam incidents'. Published Aug 2011) The study concluded:-*

"Near misses' are incidents which have not caused casualties or property damage, but which might have done had there been no human intervention; typically a near miss

incident requires emergency action such as __rapid reservoir drawdown__, the implication being that without such emergency action a breach would be likely."

"An uncontrolled release of reservoir water is generally associated with a breach of the dam and evidence of the cause of failure is likely to be destroyed in the failure. With a 'near miss' the evidence still exists and can be fully investigated"

According to these definitions there was a 'Near Miss" at 'High Risk' Toddbrook and the evidence of cause is still there, but it has not been accessed. We have to question why, in this investigation, 'deduction' is considered to be superior to forensic examination of the easily accessible evidence. There is no point having excellent learned papers produced unless the good practice which they define is actually implemented when appropriate failures occur.

5.2 Control of the Site and Investigation.

Unfortunately there has been nobody in overall charge of the Toddbrook Investigation which I have repeatedly called for since August 2019 (GA1/19). Setting up two autonomous enquiries into the failure mechanisms of the spillway that could have wiped out the centre of a small town and its school is not enough, it is far too narrow. The Toddbrook Dam should have been treated as an industrial accident site solely under the control of Environment Agency Incident Investigators in which the 'Owners', the CRT, would only be required to provide practical support at the explicit requests of the Investigators.

Unbelievably the CRT has remained in full control of this very empty, automatically draining reservoir basin with its feed weir blocked. This is despite the fact that the CRT was responsible for its management, inspection and poor maintenance for 8 years leading up to the damage. Prior to the Expert Reports and any official decision about the future of the Reservoir, an unjustified modification has been implemented on the Apron, which is the prime suspect for investigation. This expensive modification is presumptuous because it provides a cut off wall which would only be required for the original top water level. In Oct. 2019 how could the CRT know that the Reservoir was not to be permanently lowered for safety reasons to reduce loading on the 180 year old damaged dam?

Started in Jan 2020 the necessity for such haste is questioned, because it has destroyed so much precious evidence which would confirm real state of the crest and the extent of erosion. This would not happen in any other Industry after such a dangerous 'Near Miss'. This ambiguous arrangement has even managed to prevent one of the Experts, Prof. Hughes, appointed by the CRT, from the freedom to continue his investigation regarding the fundamentally important depth and extent of the erosion cavities under the LH end of the Apron. (AH/23).

Nevertheless physical evidence still exists on the Toddbrook Dam. The concrete Spillway and Apron are, in any case, defective and, without doubt, must be removed completely because they are hiding the unknown state of a dam that has always been classed in the 'most dangerous' category due to it location and proximity to the village school and small town. This is an180 year old earth clay Dam of which the structure has been recklessly modified, abused and neglected for the last 50 years. If this High Risk reservoir is to be filled again the dam itself must be properly inspected, repaired and certified Safe Terrestrial and Satellite survey data show serious dam events which must be investigated (see Para.2.3.2)

What would be revealed and confirmed by forensic removal of the Spillway __and Apron__ structure?

1) The extent of physical loss of material and damage to the dam structure caused by the construction of the spillway.
2) The extent of the loss of the clay core and earth caused by the recent failure of the spillway.
3) The real cause of the 180 ft. longitudinal continuous crack in the Apron. This is a serious indicator of dam crest material loss on the whole downstream edge.
4) The real extent of erosion channels under the Apron and Spillway which would challenge the Contractor's dubious grouting Table which reported a very improbable 2 mm gap under every panel (AH/31).
5) The footings of the abutment walls on the Apron which provide the most starkly obvious cross-dam erosion channel route which is most frequently under water.
6) The extent of unofficial changes and omissions made during the construction of the spillway.
7) The absence of the water bars, steel mesh, dowels and seals.
8) The viability and effectiveness of various desperate measures taken to try to manage the ingress of water under the spillway for the last 50 years (e.g. pressure relief valves, drains, sumps etc.)
9) The extent of root growth under the structure exposing the in-effectiveness of irregular 'weeding'.

5.3 The LH Abutment Wall Erosion Channel.

(Photo AH). The LH abutment wall is the horizontal white wall under the majority of men. Due to its unequal loading by the surviving crest of the original dam, this wall should have required deep footings (1-1.5m) and steelwork. These deep *cross dam* footings provide a deliberate trench, cut through the clay core in 1970, from the wet side to the dry side of the Dam, the very worst thing you would do to an earth clay dam. These footings are without any cut off as is the whole of the 80m.long spillway. They are more frequently underwater more than even the Apron itself because they have to be much deeper, so they provide the most probable and most well developed erosion channel site on the whole dam.

The dark earth track on the outside of the wall in the photo at the very top is evidence of the powerful exit flow under the cross dam footings. Inspectors over the years have reported 'leakage and wet earth' exactly there. This led to various pressure monitors being installed there but these failed in 2008 when the LH wall was being heightened and never worked since. Prof. Hughes describes how this exit channel was disguised for some time under the turf. But no investigative digging was carried out behind the wall to the footings. The video footage of 31 July shows a huge fountain bursting out at the top of the crest on the greenside, confirming the existence of erosion channels under the side wall on the slope. This high pressure flow would have rapidly excavated the saw-tooth footings of the sloping LH side wall from the outside to provide exits for water from under the panels.

The whole footing of this cross dam wall should have been dug out and examined for erosion channels. Given the desperately poor engineering quality of the 'saw tooth' side wall footings constructed on the same job (*photo p.23 this doc*) the quality of these footings is in grave doubt. They should be considered defective until proven good but now might not be even inspected.

Thus the blind attitude to safety initiated by British Waterways in 1970 will continue. The only way to prove this is wrong to remove the wall and excavate the cross dam footings under the forensic control of an independent Inspecting Engineer (not the CRT). This should be done regardless of the cost and any effect on the work already prematurely carried out by the CRT in 2020 when an unauthorised 'cut off' wall was constructed across the Apron of the empty Reservoir. This was planned and initiated 4 months before the expert reports were issued and demonstrates the fundamental disconnection and the absence of a single Authority in control of this dangerous incident investigation at Toddbrook.

Prof. Hughes clearly recognises the danger and weakness of any abutment walls:-

"Any spillway that is built into a dam, and certainly one that is fitted as an addition, cuts through and is effectively breaching the core and then provides a potential path for water to 'leak' through to the downstream side." (AH/33).

5.4 Engineers Reports and Statements 1965-2019.

5.4.1 Issues of Safety and Maintenance.

During my work on a potential footbridge at the feed weir (2015-2018) I identified a number of issues which affected the operational safety of the reservoir particularly if there was an emergency. These are listed and described in full in GA1/(22-25) they include the impossibility of vehicular access to the reservoir path, the broken pedestrian bridge that provided the only access, the massive leak from the bypass channel into the reservoir amongst others. Despite my polite efforts to raise these issues my contacts in the CRT were unresponsive. I was not made aware of the inspection regime nor in three years did I ever detect it. Effectively I was acting as an unpaid Inspecting Engineer on all the crucial parts of Toddbrook that SE's don't reach. This experience fully endorses my suggestion in Para 4.5 that the Engineering and the Recreational Functions of the CRT should be split. The lesson from Aug 1st. is that Safety and Maintenance cannot be neglected it must be managed and funded independent of income, i.e. by the Government.

5.4.2 Experts Reviews of Inspection Records.

Prof. Hughes has provided a careful summary of this sequence of reports which can be read as a free-standing section in his report (AH/(15-22) followed by his related Conclusions (AH (46-50).

Any reader who wants to understand the appalling consequences of fitting an auxiliary spillway on top of an earth/clay dam is urged to study these pages. His summary reveals a continuous catalogue of defects and degeneration of the spillway, leakages, speculative diagnoses, repeated evidence that water was able to get under the Apron and below the spillway panels, developing cracks in the Apron, lack of maintenance and many others.

The records show that the same defects and symptoms were repeatedly reported over the years but no radical investigations or actions were triggered by the Owners (BW up to1960- 2012, CRT 2012 –to date). The last 10 year inspection (Nov. 2018) was the most thorough, the Inspector at last recognised the serious state in the spillway and the danger this created for the dam. But due to the tolerant drafting of the Reservoir Act these serious concerns were not urgently communicated to the CRT and the CRT made no urgent reaction when they were eventually informed. The reservoir level should have been lowered by 2-3 m. immediately (Nov. 2018) and maintained at that level using the discharge valves and Bypass facilities. This prudent response alone would have prevented the disaster.

The record reveals a rather deferential approach taken by the IEs and the SEs with the Owner exacerbated by the fact that the Supervising Engineer is employed by the CRT which puts him in a difficult position regarding measures with negative commercial consequences,. A 10 year inspection for a whole reservoir system could apparently take place in only one day, when the water could be well below top level eg -4m. in 2018 and -1.2m. in 2010 ! That cannot be an appropriate level for a 10 year Inspection of a 180 year old reservoir in the "Most Dangerous" class. There should be an annual test with an Inspection Schedule with pass/ fail criteria for every system component of the reservoir just like there is for a familiar MOT test.

The entire focus of the Toddbrook inspections has been on the state of the auxiliary spillway, a self inflicted wound to the Dam, which inevitably is a distraction from the state of the rest of the reservoir system components. Their resultant derelict and unmaintained state had a huge negative effect in the emergency is described in detail with photographs in the following references. *(All photos GA1,2,3),* It is also verified by the Emergency Team in the Seminars as cited in this report.

Chapter 6. Review.

6.1 Conclusions

1) The inability of the Primary Sill to function with even modest Bypass flow is fundamental. Failure to recognise and analyse the cause of this defect caused British Waterways to make the disastrous error of constructing an over crest auxiliary spillway on the earth clay dam and thus create a much more dangerous weakness by destroying the 130 year old clay core safety margin.

2) The inadequacies of the hydraulic design, the several misaligned in-feed arrangements, the maximum flow performance and working capacity of the Bypass Channel and its inability to discharge into the River Goyt have never been recognised and analysed.

3) The Dam was badly damaged and nearly breached because an Auxiliary Spillway with

many design errors was installed on the crest of this earth clay dam in 1970. The major design error was the astonishing omission of a water proof ‘cut off’ to extend below the underside of Apron. The inherent design caused the underside of the Apron to be under water even before top water level was reached. Almost immediately from 1970 onwards water created erosion channels under the Apron and flowed under the spillway. The development of these channels was assisted by the natural settlement of the dam crest itself over the last 50 years (50-100mm *AH/30).* The footbridge structure acting as a beam tends to hold up some Apron panels as the dam crest sinks thus providing more headroom for the erosion channels.

4) The actual construction of the auxiliary spillway deviated radically from the specified but flawed design of the spillway and this exacerbated the inevitable failure.

5) There was no independent critical review of the integrity of the auxiliary spillway design and its implementation in 1970. There was no assessment of the increased Risk to the Community of breaching caused by removal of 29,000 cu. ft. of clay core *from 2-3ft. below top water level*. The Government carries the ultimate responsibility for the safety of all infra-structure even if it has appointed and funded an organisation to manage this responsibility as, for example, British Waterways in 1960 or the CRT in 2012.

6) The maintenance of the auxiliary spillway was intermittent or non-existent. Speculative draining and venting ‘fixes’ were made but not documented. Therefore they were not inspected or maintained so became blocked and ineffective. The maintenance of the In-feed weir, the bypass channel, the compensation weir, the convergence basin and the discharge culverts has been non-existent for many years. The derelict state of these channels radically increased the danger to the town when the emergency started. These facilities had to be made capable of operation in the most extreme conditions of dangerous flow before they could be used with any purpose to begin to draw down the reservoir.

7) There are no comprehensive maintenance and inspection schedules for the whole Reservoir System as there are be for example, in an MOT.

8) The focus has been solely on the Dam to the detriment of all other system and safety components of the Reservoir.

9) The absence of emergency vehicular access to the Bypass channel track to reach the in-feed weir was a fundamental issue at the outset of the Emergency. I had predicted this requirement in 2018 in a letter to the CEO of CRT. *(GA1/22).* This need was confirmed by the Emergency Team in the July Seminars. Many hundreds of sand bags heavy tools and equipment had therefore to be hand carried for 1 mile in order to start the first critical task which was to stop the reservoir filling and to run the Bypass above maximum otherwise the dam “*would have breached*” (*July Seminar*). It is believed that later the Chinook helicopter continued the service.

10) There was no defined plan for the management of the reservoir discharge in anticipation of high volume flood, weather warnings or auxiliary spillway flow. These and other signals

were ignored and 4-5 days of maximum discharge using existing reservoir resources were lost prior to the overload which created the damage and seriously threatened the town. Timely use of existing drawdown resources could have avoided the near breach.

6.2 Recommendations.

1) The design and safety of any proposed modifications to the reservoir as a result of the 2019 'Near Disaster' must be approved technically and risk assessed by independent engineers acting for the Community and the Government. The Government must then underwrite these modifications and formally take full responsibility for safety. This did not happen in 1970.

2) All the concrete of the Spillway, the Apron, the Side walls and the Footbridge itself should be removed so that the damaged and much depleted dam structure can be properly inspected, repaired and fitted with all appropriate modern sensors. Removal of all this spurious concrete will enable a proper engineering investigation and reinstatement of the dam to its safe design state to take place.

3) Nevertheless the Top Water Level of the Toddbrook reservoir should be lowered permanently by at least 1.5m as a necessary precaution on this High Risk Dam. The Dam is 180 years old, the highest of all 18C canal feed dams. It has been recklessly and destructively modified and recently badly damaged as a consequence, It has known pre-existing weaknesses and has been built on a network of old mine shafts. Recent survey data just prior to the event exposes unexplained anomalies.

4) Wireless Rain gauges should be installed in at least 4 cardinal positions in the Toddbrook catchment area, currently there are none. It is not appropriate to use the Cat& Fiddle gauge because it is in the different Goyt catchment area. Instrumentation to measure Inflow at the feed weir is required. Seminar graphs and models were presented based on guesses and extrapolations from instruments many miles away.

5) The reason for the official closure (1999) of the canal feed culvert by Valve 1 should be investigated and understood. This ability to feed the canal by both discharge culverts should be reinstated by installation of a pipe to bypass the blockage which is almost certainly <u>in the park</u> at the rear of the former Congregational Church. This is a safety issue, it provides the ability to effectively dump water remotely in an emergency drawdown and reduce the load on the overloaded Bypass channel.

6) A metal bridge at an angle from Reservoir Road across the Bypass channel should be installed to allow small groundwork vehicles, tools and materials to reach the Reservoir Path to access the Bypass Channel and In feed Weir 1 mile upstream in an emergency. It would be normally locked, a single pedestrian footbridge exists already. No alternative vehicle access is possible unless the reservoir is 5m. below TWL, which is most improbable in an emergency.

7) The CRT as 'Owner' of 72 of the oldest reservoirs should appoint a Safety Director with authority higher than the CEO to act in caution above any commercial considerations, to

draw down a reservoir and to be legally responsible for all safety matters as is the case in other regulated industries whose operations can kill people and destroy property.

8) The current reservoir inspection process as operated has many weaknesses and should be revised. It is most important is that the frequency of the 10 year inspections should be increased, perhaps to every 2-3 years, on very old reservoirs listed 'most dangerous' like Toddbrook. The reports of Prof. Balmforth and Prof. Hughes recognise these issues and they have made similar recommendations.

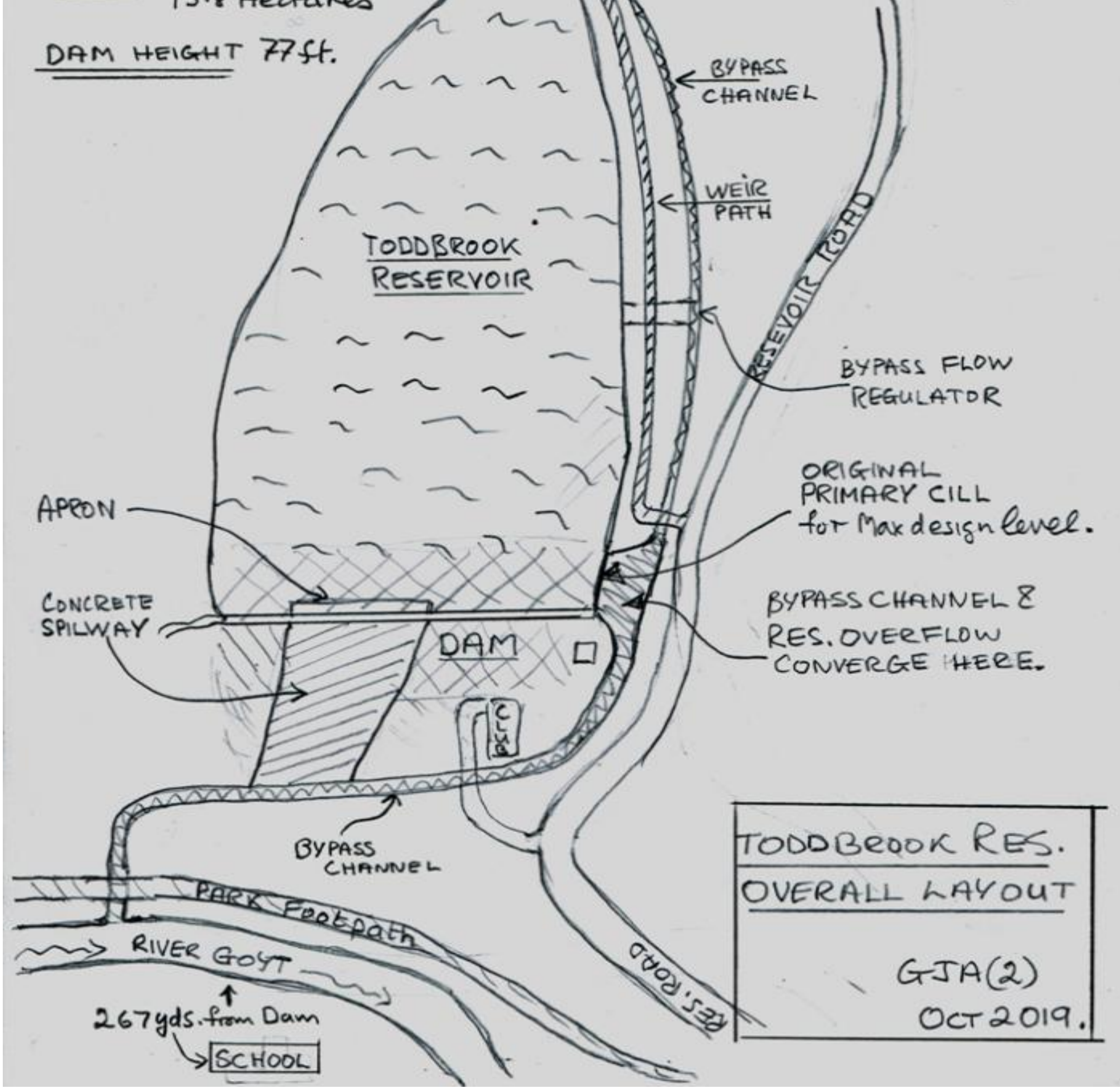
9) A dedicated Safety Director should be proactive and alert to every Inspection. Inspecting Engineers should be prepared to review their draft findings and concerns (however insignificant) personally with the Safety Director within 2 weeks of the end of the Inspection. The formal inspection report, which is might to revise these initial findings, would follow within six weeks.

10)"Dam Condition" should be defined by the Inspecting Engineer not the Owner. The considerable difficulties of assessing the "Condition" of a High Risk Dam should be openly acknowledged, but the temptation the resort to a feeling in the lower intestine for enlightenment should be avoided. It must be scientific, based on a strict ongoing assessment using technology and regular experienced physical inspection. Caution and doubt should always be expressed by drawing down the reservoir by a set amount to reduce loading and pressure on the Dam.

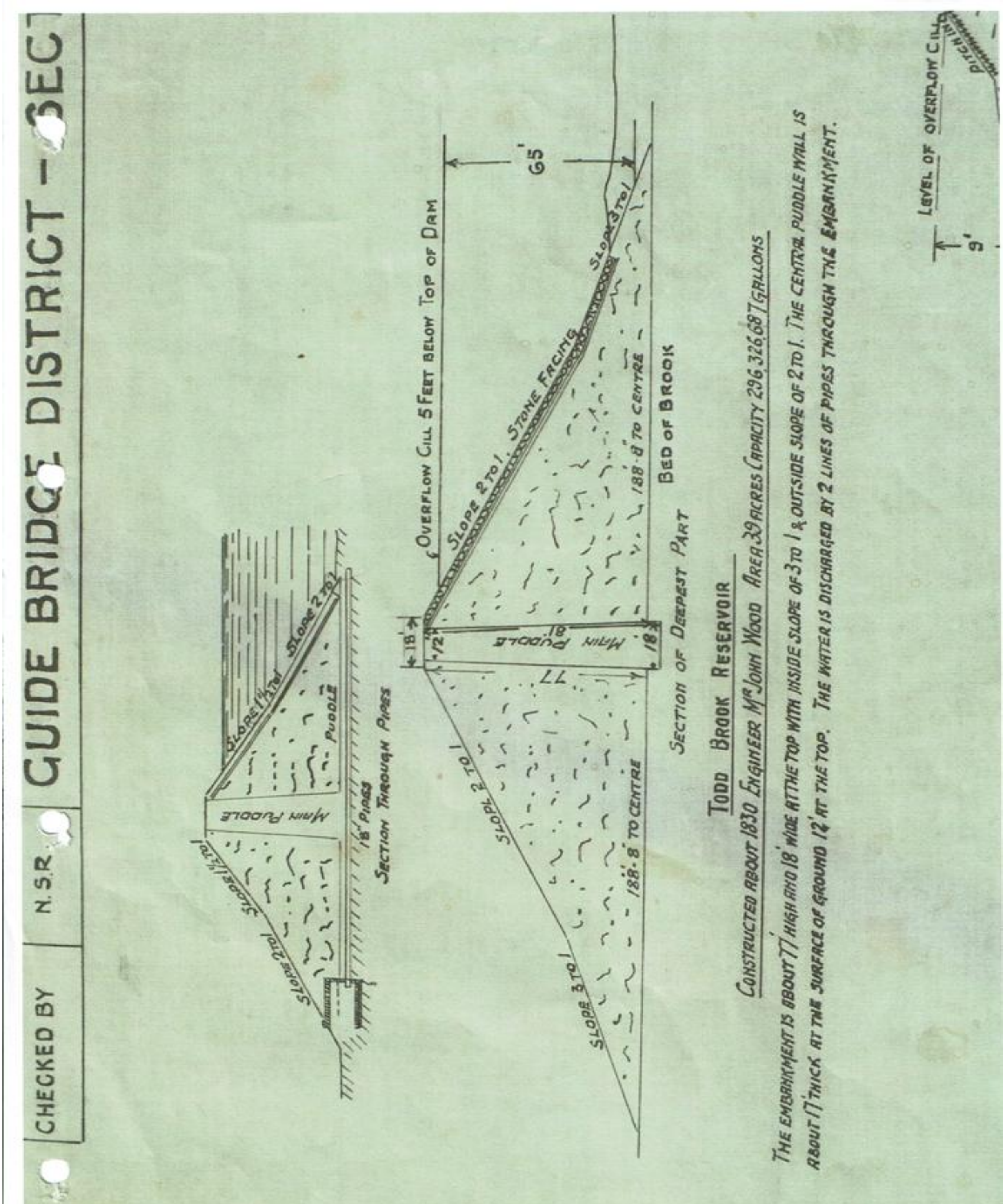
11) A new Reservoir Act should be produced to replace and supersede all the existing legislation, six Acts, one of which is 157 years old. The New Act should incorporate all the various excellent modern 'guide line' papers and elevate their status. The New Act should recognise and encourage the use of satellite technology and various wireless devices to monitor and record the changing state of the dams and systems. It should require the Owners to make available all Inspection Schedules and Inspection Records together with all reservoir specific documentation prior to any mandatory Inspection to ensure that the Inspecting Engineer can prepare for his Inspection.

12)The CRT is a financial experiment contrived in 2012 in order to devolve the cost of Public Safety liabilities from the State. After the Toddbrook near catastrophe, the Secretary of State, DEFRA should seriously consider returning the full Engineering and Maintenance responsibility from the CRT to a dedicated State funded Authority. Network Rail and the Train Operators provide an apt and plausible model for such a split between State and the Private sector. This would ensure Public Safety in perpetuity by guaranteeing funding from the State with additional CRT contributions from recreational use of the Rivers and Canals. If the Nation cannot afford to operate these decaying 200 year old historic assets and ensure Public Safety then the canals and reservoirs should all be emptied and made safe.

Appendix 1 : Sketch of Toddbrook Reservoir.



Appendix 2: Original Dam Design 1830 by John Wood.



Note the vital Safety Specification ." *Overflow Cill 5 feet below Top of Dam.*" This safety margin was destroyed by British Waterways in 1971 by construction of the concrete Spillway.

Appendix 3: Mandatory Drawdown Testing.

Quotation below from *: SC130001 Volume 1….Environment Agency. Aug 2017.*

"**2.3 Routine exercising of facilities**

If not operated routinely there is a risk that valves and penstocks may become seized and therefore not be available in an emergency. Similarly, low-level outlets may become silted up with equal consequences. To mitigate these risks it is recommended that valves and gates on all drawdown facilities are regularly exercised. Many reservoir owners exercise the valves at 6-monthly intervals. For reservoirs registered under UK reservoir legislation, regular valve exercising is frequently a statutory direction by the inspecting engineer. It is good practice to maintain a record of valve operations along with a comment on the ease of operation and any issues found. **For reservoirs designated as 'high-risk' under the Reservoirs Act 1975 it is a legal requirement to record such details in Part 16 of the Prescribed Form of Record. Valves and gates should preferably be exercised over their full range of travel (i.e. fully opened and closed again).** If valves are only exercised over part of their range there is a risk they will not open beyond this range in an emergency. Other hazards associated with operating valves partially open are discussed in Section 2.1.2 (Low-level outlets). When exercising valves they should ideally be left open for a few minutes, until the discharge becomes clear, in order to flush any silt or debris through the outlet and thus ensure a good seal when the valve is closed again. However, it is acknowledged that in some cases fully opening a low-level outlet may cause localised flooding downstream or cause undesirable environmental impacts. These issues need to be managed as described in Sections 2.4 and 2.5 and should not generally be an excuse for not properly exercising drawdown facilities. However, this may be easier said than done in some situations, and where major issues prevent routine exercising of critical valves under full head then advice should be sought from an inspecting engineer"