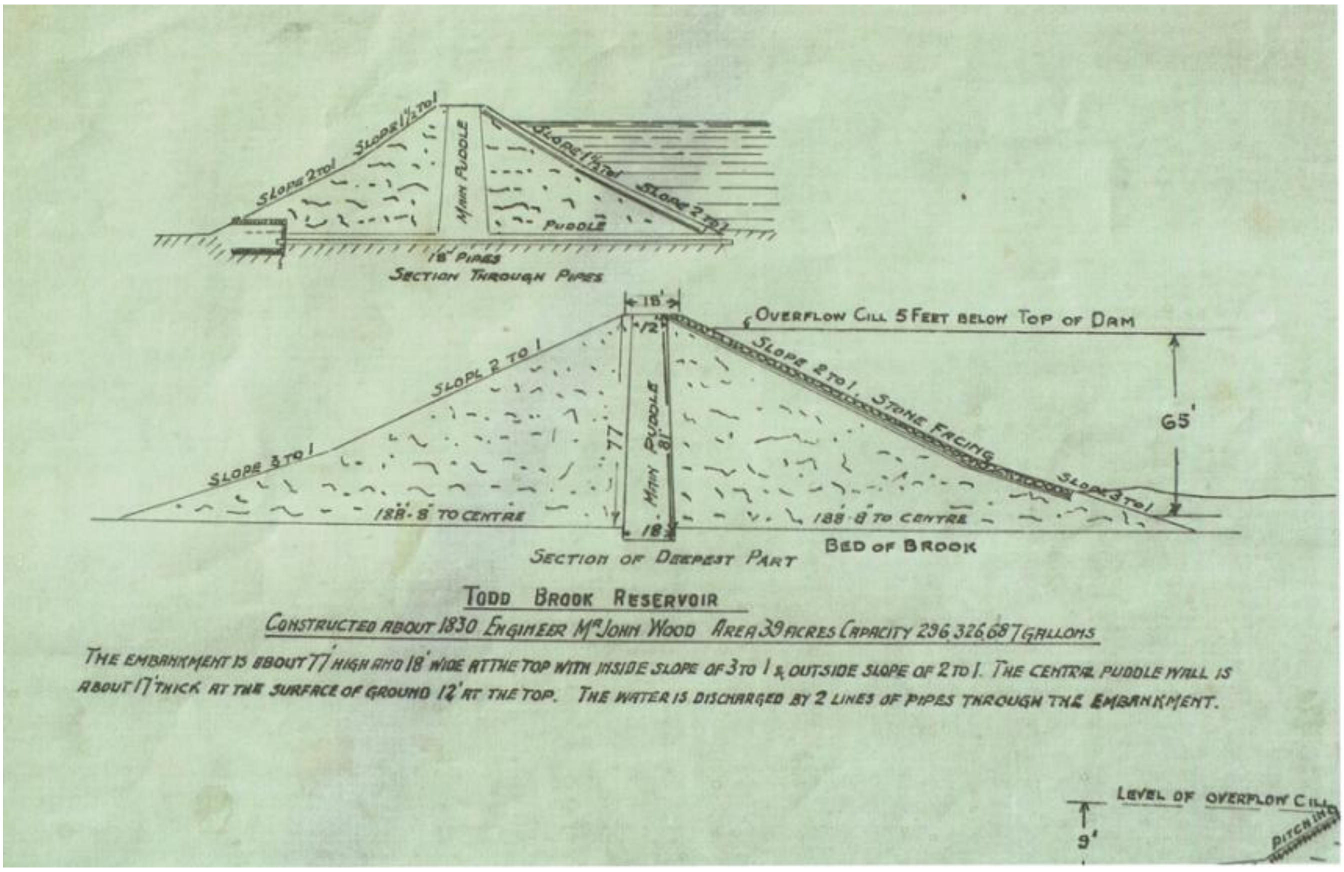

The Design Specification for the Toddbrook Dam (1830).

Editorial Summary.

This paper reviews the recent event of damage to the Toddbrook dam, it identifies the cause and describes the sequence and process of the damage with evidence.It proposes straightforward modifications which will greatly improve the safety of the reservoir system and will eliminate the cause of the damage. These modifications are necessary because the modern concrete overflow structure (1971) installed on the dam is fundamentally flawed both in principle and in implementation. It must be disabled, not repaired, it should be removed rather than leave it as an ugly monument to engineering folly.

I have critically surveyed all the other components of the Reservoir System and listed their current deficiencies and neglected state which is inconsistent with the apparently successful Reservoir Inspection of Nov 2018 overseen by the Environment Agency and any previous inspections carried out since 2012.

This reservoir is a unique but dangerous feature located virtually within the town which the majority or residents do want to keep on the condition that it is made much safer

and, from now on, properly maintained and managed. Public Access provides us with a healthy and social recreational space for sailing, fishing, swimming and walking but all these activities are fundamentally secondary to the safety of the village school and the lives and property of the Town Community.

There should be an Independent Enquiry to officially expose the causes of this very serious incident and to agree the principles of future operation of the Reservoir. The Community should be provided with professional technical representation.

The CRT must then apply for planning permission for whatever work or modifications they propose to carry out, bounded by the conclusions of the Enquiry. This application must be processed against all the criteria that normally would apply to big and dangerous civil engineering projects with particular opportunities for challenge by the Community.

Thus it is hoped that our 'Friends and Partners' in the Canal & Rivers Trust and in the Environment Agency will understand and respect the requirements of the Community and ensure that the reservoir is made much safer so that it may remain a very attractive feature of Whaley Bridge.

The statements and conclusions expressed in this paper are those of the author alone. This is my independent analysis and the results of many hours of effort. It includes critical but fair observations of the Reservoir Control System. I am also glad acknowledge conversations and memories shared by residents who have lived in the Community long before my time here.

An A4 size copy of the original Design Specification is on Page 26.

Graham Aldred B Sc (Eng) 30 Sept. 2019

These quotations are from 'Lessons from historical dam incidents'. Published Aug 2011 (ref1). This excellent document reviews all the dam failures and incidents in the last 200 years and defines certain terms and principles that the Environment Agency uses when investigating dam incidents.

"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**."

"In recent years modern telemetry and remote sensing equipment has reduced surveillance frequency at some dam sites. **This trend is not widely welcomed as remote monitoring is not an effective substitute for trained personnel regularly visiting dam sites. The demise of the Victorian approach of having a reservoir keeper for each dam (often housed at the dam) is lamented by many in the industry."**

The number of casualties arising from a breached dam can be greater than from most other kinds of technological disaster. Maintaining reservoir safety has considerable importance for the public in a country such as Great Britain where a number of dams pose a high hazard, being located **upstream of heavily populated and industrialised areas.** Thus, although the probability of failure of a dam is generally low, the consequences of failure could be great**. As most reservoirs constitute a low probability/high consequence scenario, careful management of these risks is essential.**

Contents.

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Part 1. Introduction.

1.1 Summary.

The purpose of this document is to record some thoughts and facts regarding the recent damage to the Toddbrook Dam. Already the official spin has been to blame the event on the dam for being old or the rain for raining too much. It is important to understand that the dam itself did not fail but it was in danger of being progressively damaged and then potentially breached if the rain had continued and active drainage had not been started.

The damage was caused by the British Waterways decision in 1971 to install a large concrete secondary overflow structure over the top of the earth and clay dam. This modification is fundamentally flawed in principle and dangerous in practice. It should never have been implemented on any dam of this type because the entire concrete system must be watertight and it must have a perfect watertight seal with the clay core underneath it. Otherwise, water will gradually create undetected erosion channels under the flat concrete panels at the top of the dam. It is impossible to guarantee the integrity of the seal underneath the concrete because it cannot be inspected nor can it be tested.

The installation of this 200ft. long secondary overflow required the removal of the top 5-6 ft. of the original clay core, which happens to be the entire extent of the safety margin of the original Dam design. This paper describes how the failures of the concrete structure caused serious damage to the earth dam.

This paper will argue that there should be an independent enquiry before any repairs are carried out. After that the Canal & Rivers Trust (CRT) must then submit a full planning application to the relevant authorities with details of any repairs and modifications before any work starts. The vulnerable residents of Whaley Bridge should make sure that they are consulted and strongly supported by their representatives in local and national government in respect of the future revisions and repairs, water level and safety management of the Reservoir.

The general state of neglect of the vital reservoir controls and services is also discussed. The operational condition of these controls is entirely inconsistent with a rigorous regime of successful reservoir inspections as claimed by Richard Parry (CEO of CRT) on Newsnight 1st. August.

Patient readers who are unfamiliar with reservoirs might benefit from reading Part 7 now. In Part 7 there is some history and a description of the reservoir construction and its system components. It defines some terms and should help to explain how the reservoir was originally designed and how it should be operated.

The consequences of recent heavy rain due to the avoidable overfilling of the reservoir should have been anticipated and managed by the responsible Authority with local staff working to Approved Operational Procedures. During the exceptionally wet week prior to 1st. August no timely actions were taken to fully open the two discharge valves and set the Bypass channel to maximum divert. Consequently the Reservoir was progressively overfilled and had no spare capacity available in the last 3-4 days. The concrete overflow structure was then tested for the first time in its 48 year life and it failed miserably and dramatically.

1.2 Whaley Bridge under Threat

Thankfully the potential catastrophe has passed without loss of life, physical injury or destruction of property although income has been lost whilst fixed business costs continued. Residents are greatly relieved to have returned safely to their own homes after a week of disruption, anxiety and stress. But now, quite naturally, many are questioning what actually happened. It is only necessary to praise the valiant and successful efforts of the emergency services. But the Fire pumps and the Chinook were the dramatic response to the damage after the event not the cause. Their efforts are not discussed in this paper.

An official investigation is required. Blaming the Dam (which did not fail) for being old, climate change and the apparently unanticipated increased flow of the Todd Brook during a week with 2 days of exceptionally heavy rain would evade the real issues completely .The scope of the investigation should be to ask “What happened ?, Why ? Could it have been prevented? and How should the Reservoir made much safer in future?”

However it is not necessary to wait for an official enquiry, there are facts and events which are best shared now whilst memory is ‘fresh’. Many residents have known the Reservoir all their lives and I have frequently used the reservoir footpaths and the Dam footbridge during the last 30 years.

1.3 The Major Benefit

Much has been reported during the event with the easy media focus on the drama of draining the reservoir and the temporary patching the damage on the dam. But the major consequence, however inconvenient at the time, is that the massive potential energy stored in the reservoir has been dramatically demonstrated.

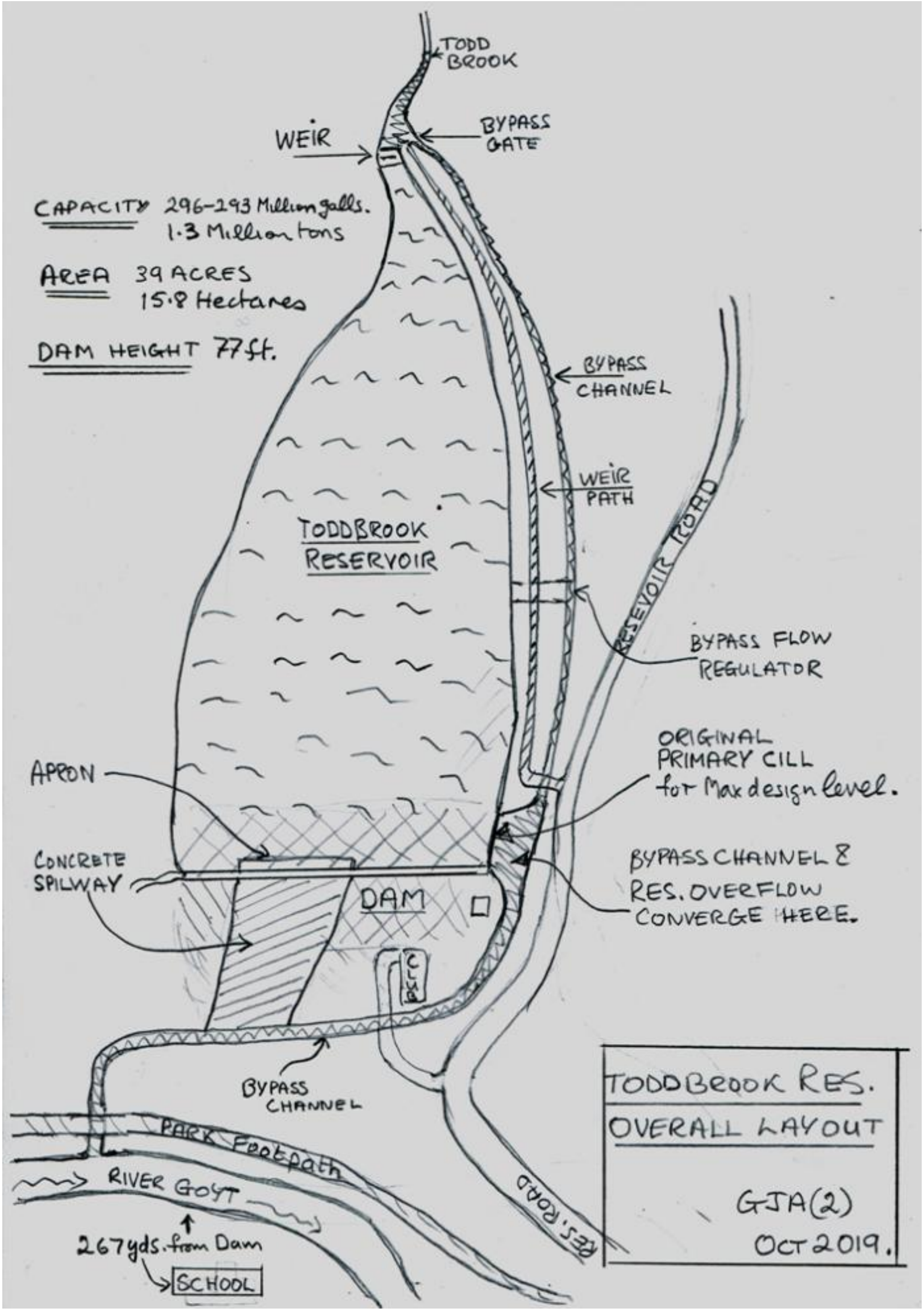
Reservoirs are unnatural, they are not lakes, and are much more dangerous than canals. Behind a huge man made wall, an enormous amount of destructive energy is stored all in one place that can be released in a few minutes. Whereas a canal stores much less energy and the storage is distributed over many miles. If breached a canal will run more like a river, releasing its energy relatively slowly over some hours.

The Toddbrook Reservoir is almost certainly the most dangerous and potentially lethal asset in the Canal Estate, the safety of which is the responsibility of the Canal & Rivers Trust and the Environment Agency. Toddbrook is recorded as the canal supply reservoir with the highest earth Dam in the UK at 75ft (Ref 2). The Dam actually faces east towards the town. If the Dam is breached the potential energy of 293 million gallons of water with an initial height of 75 feet weighing 1.35 million tonnes is aimed directly (with nothing to stop it) at the village school only 850 ft away (260 m) from the Dam.

The inundation would crash into the school in which there could often be 240 little children and all their teachers. This risk is starkly emphasised if you stand on the dam footway looking down directly at the school just across the river Goyt. The school was empty on at 10:00 am on 1st. August. But two weeks earlier, at the same time, it was full of children.

Well, we must be very thankful that the Dam itself was not breached. However the unacknowledged and undetected inadequacies of the concrete structure and the damage it can cause to the Earth Dam have now been dramatically demonstrated, fortunately without catastrophe or loss of life.

The huge risk has now been exposed: the requirement to operate and manage the Reservoir very publically at least within the original design limits or at an even higher safety margin cannot now be ignored or deferred. The major benefit of the Event is that the awesome energy stored in the reservoir has been demonstrated and now the Community has been made fully aware of this dangerous hazard .


TODD BROOK
WEIR
BYPASS GATE
CAPACITY 296-293 Million galls.
1.3 Million tons
AREA 39 ACRES
15.8 Hectares
DAM HEIGHT 77ft.
BYPASS CHANNEL
WEIR PATH
TODDBROOK RESERVOIR
RESERVOIR ROAD
BYPASS FLOW REGULATOR
ORIGINAL PRIMARY CILL for Max design level.
APRON
CONCRETE SPILWAY
DAM
BYPASS CHANNEL & RES. OVERFLOW CONVERGE HERE.
CLUB
BYPASS CHANNEL
PARK Footpath
RIVER GOYT
267yds. from Dam
SCHOOL
RES. ROAD
TODDBROOK RES.
OVERALL LAYOUT
GJA(2)
OCT 2019.

Part 2. The Seeds of Disaster.

2.1 Heavy Rain in 1964.

There are numerous reports of heavy rain, thunder and floods in other years during the lifetime of the reservoir in this area and in the Goyt valley during the 1870s and 1930s. There also must have been many episodes of heavy rain in the previous 125 years which are not recorded. There are no reports of issues with the Dam itself after heavy rainfall so it can be assumed that the resident Reservoir Manager or Warden ensured that timely discharges using the valves to control the level were made in advance *because that was his job* !

In 1962 British Waterways (1962-2012) become responsible for Reservoir Safety. Heavy rain in 1964 resulted in a large volume of water in the Overflow Channel such that the channel masonry on the bend after the Wardens house was dislodged and damaged. It is not known whether there was a Keeper in place in 1964 to carry out timely discharge actions to lower the reservoir prior to the overload. The Overflow Channel was repaired in 1965. There were no reports of any damage or any serious issues with the Dam itself at the time of this event, only with the Bypass channel capacity.

2.2 The Disastrous Concrete Overflow Structure 1969-71.

Out of concern for the Bypass channel capacity, British Waterways made a fundamentally disastrous decision which compromised the safety of the earth dam, the consequence of which has only just been exposed in Aug 2019, 48 years later. They decided to create a 200ft.long secondary concrete overflow near the top of the Earth Dam (!) to provide an additional overflow route. This is the worst modification that could possibly be done to an earth dam. It must have been before Risk Assessments were required in the Safety Approval Process for Public Works.

This secondary overflow was arranged to operate only if the reservoir height rose 12-15 in. above the original design limit set by the primary Cill. This meant that the secondary overflow would not start to operate until there was another half million tonnes of water in the reservoir. Given the time it takes to accumulate that amount of water the secondary overflow clearly did not solve the problem of relieving the overloaded Bypass channel. It just allowed the dam structure to be overloaded as well.

This concrete overflow structure consists of two major parts:-

The **Spillway** consists of about 170 concrete panels which were cast in situ onto the sloping earth embankment. The flat spillway slope has an irregular shape angled towards the end of the bypass channel in a vain attempt to ‘steer’ the overflow. However the overflow water, driven by gravity, inevitably chooses to flow down the steepest gradient so it is determined to leave the concrete and attack the adjacent earth shoulder, as proved in August.

The **Apron** consists of about 60 panels cast in situ with an integral raised Cill, these are laid horizontally under the long footbridge. They hide the fundamental weakness of the structure which caused the damage in August.

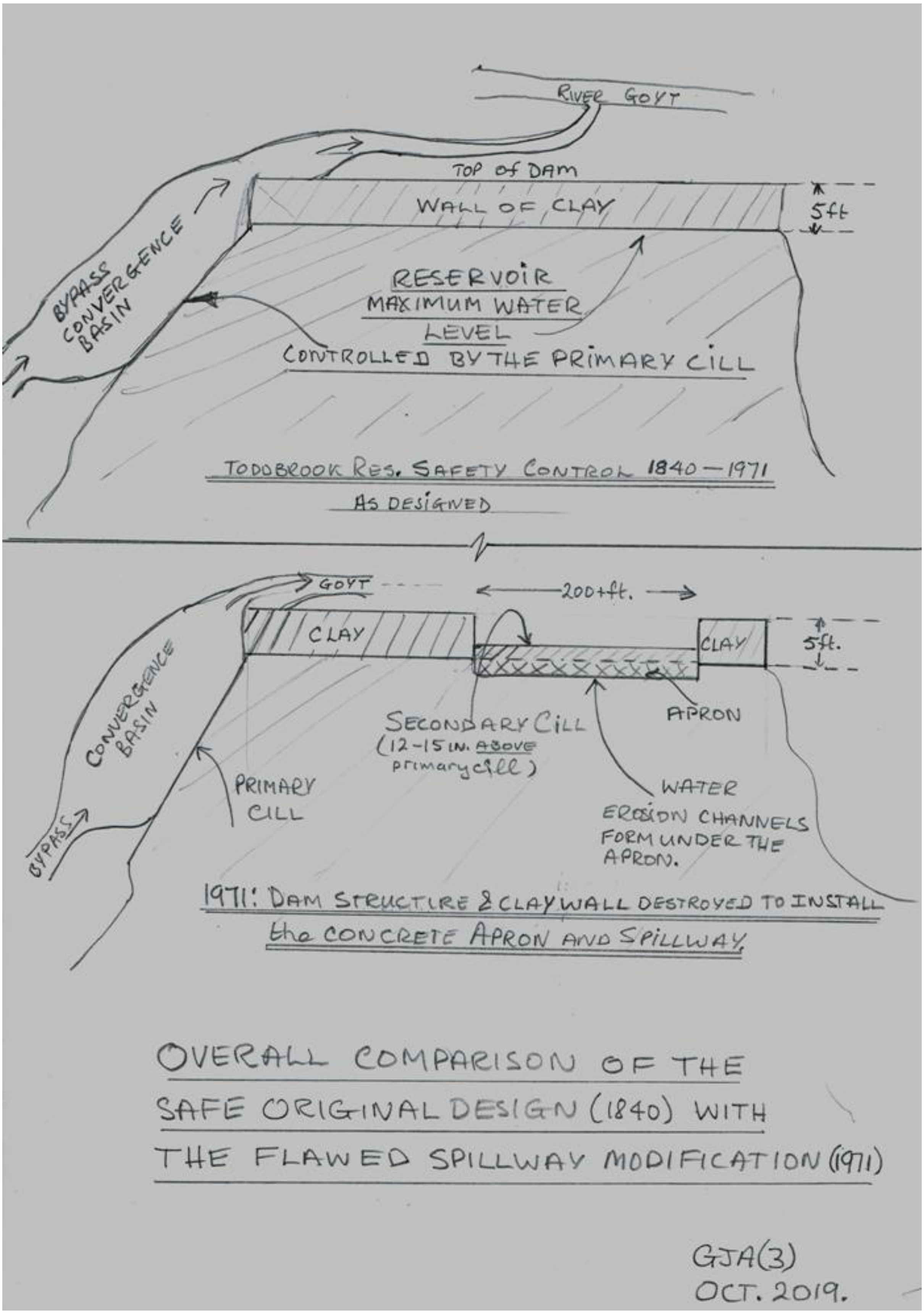
British Waterways had committed the cardinal error of deliberately inviting water to flow over an existing **earth dam** structure but without providing any means to monitor or inspect the watertight integrity between the entire underside (200ft.) of the new concrete Apron and the vital waterproof Clay Core.

It is not known how clay and concrete can form a 100% watertight seal 12 feet wide and 200 ft. long. It is astonishing that, since 2012 when they took over, the CRT who have carried out numerous dam inspections at Toddbrook have apparently not investigated the most vital seal in the whole reservoir system on which the safety of the Town fundamentally depends.

The construction of this concrete structure required the waterproof clay core at the top of the dam to be lowered by more than 6ft. to allow the secondary Cill to operate. At least (200 x 6)ft. of the vital clay wall had to be dug out and discarded in order to accommodate the new concrete Apron. The Apron had to be at a position to locate the secondary Cill about 12 inches above the original primary Cill. This act completely removed the whole original safety margin defined by the Primary Cill.

After 1971, whenever water reached or overflowed over the original Primary Cill, the water in the reservoir was/is now at the same level (or above) the top of the clay core that lies **underneath** the new concrete Apron. For a 200 ft. length the safety margin has gone. **That is where the invisible water erosion channels are created**.

In summary, the primary Overflow Cill was designed to keep the maximum water level **5ft below** the top of the Waterproof Clay Core. This safety margin was specified to protect the earth dam and to ensure that **water should never go above the clay core and flow over the Top of Dam itself**. In standard earth dam design Overflow water is **always** to be discharged over a Cill into a dedicated Overflow or Bypass Channel which is isolated from the Dam and its foundations. It is not known if there any other Earth Dams in the UK were modified with such a dangerous arrangement.


RIVER GOYT
TOP OF DAM
WALL OF CLAY
5ft
BYPASS
CONVERGENCE BASIN
RESERVOIR MAXIMUM WATER LEVEL
CONTROLLED BY THE PRIMARY CILL
TODDBROOK RES. SAFETY CONTROL 1840 — 1971
AS DESIGNED
GOYT
200+ft.
CLAY
CLAY
5ft.
CONVERGENCE BASIN
SECONDARY CILL
(12-15 IN. ABOVE primary cill)
APRON
PRIMARY CILL
WATER EROSION CHANNELS FORM UNDER THE APRON.
BYPASS
1971: DAM STRUCTURE & CLAY WALL DESTROYED TO INSTALL the CONCRETE APRON AND SPILLWAY
OVERALL COMPARISON OF THE
SAFE ORIGINAL DESIGN (1840) WITH
THE FLAWED SPILLWAY MODIFICATION (1971)
GJA(3)
OCT. 2019.

2.3 Water Erosion under the Apron.

Water is frequently driven in waves powered by wind down the centre of the reservoir. These are aimed straight at the underside of the Apron. Consequently all the weaknesses of the 1971 sealing method (whatever it was) between Apron and Clay Core have been under attack by water for the last 48 years. Water has progressively created and enlarged channels under the Apron and then continued down **beneath** the spillway panels. The earth Dam itself did not fail in August. But the integrity of the Dam was seriously threatened by the inherant defects of the concrete spillway placed on the Dam.

This serious flaw has been officially unsuspected despite thorough inspections of the reservoir system every 2 days (!) (*CRT on TV*). It has apparently not been even considered in any of the mandatory dam inspections including the most recent major one in November 2018. Yet this fundamental flaw has been apparent to those of us who analyse what we observe. There is no means of checking the current effectiveness of the Apron -to -Clay seal under the Apron. But the existence of water erosion channels can be inferred from the observable evidence on the spillway.

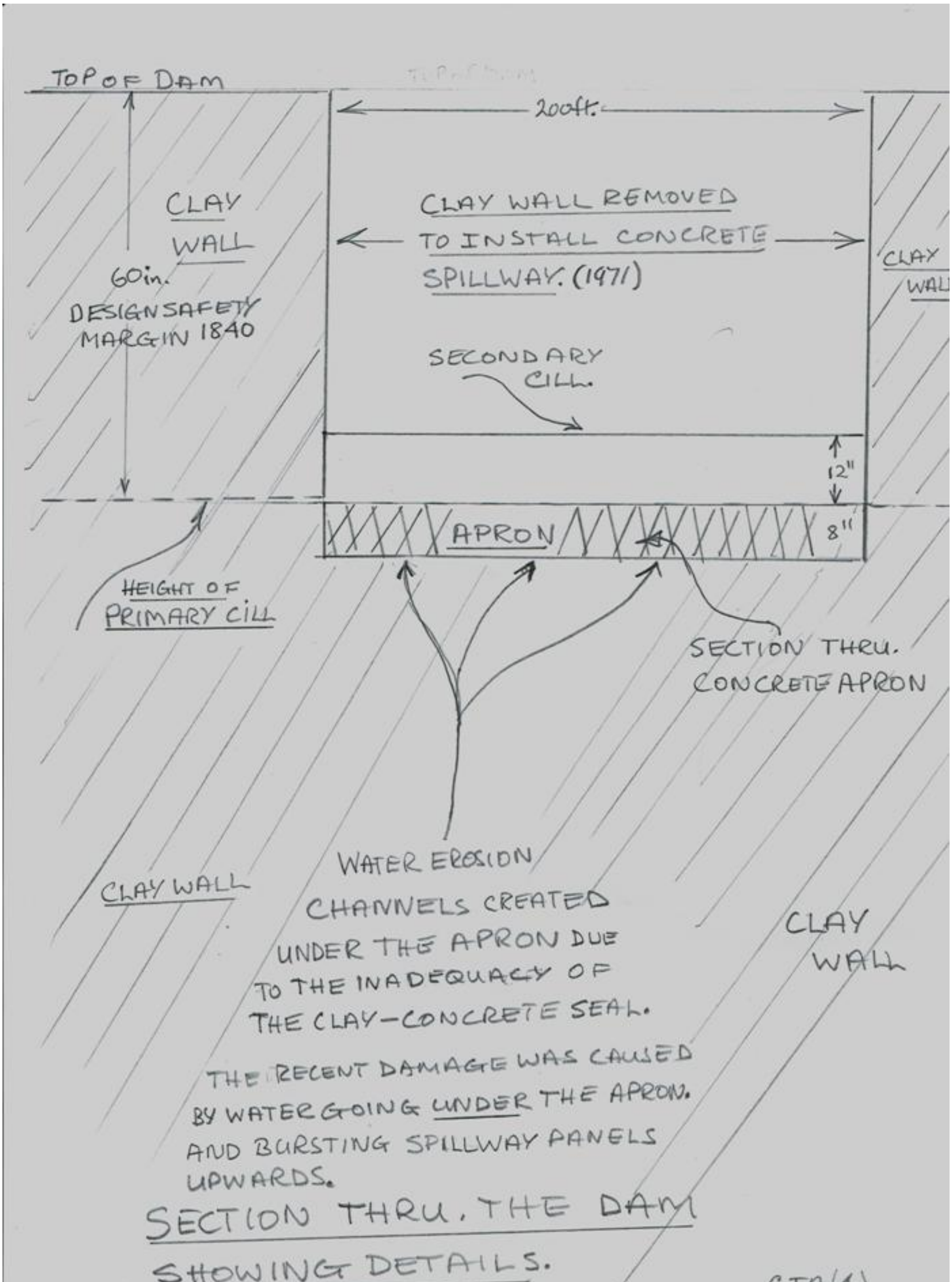
2.4 The Evidence.

Many local people use the walkway over the concrete structure. Most will confirm that they have never seen water actually flow from the reservoir over the Apron, a few have seen a small flow, while many more have seen waves wash over the Apron on the reservoir side (which is not overflow).

I am confident that there are significant water erosion channels under some Apron panels because on occasions I have seen pulses of water mixed with air, hiss and bubble and burst out of the spillway panel gaps at the LH corner where the first panels were lifted. It happens when the reservoir is high enough for strong waves to be hitting the underside of the Apron with enough pumping power to provide these observable pulses on the spillway. This is the fundamental evidence for the cause of last month's near catastrophe….there were water erosion channels underneath the concrete Apron. Forensic examination after careful lifting of various panels will confirm their existence. But will that happen?

Further evidence is provided by numerous local users of the Dam footway who, like me, have also seen that the top panels in the LH corner of the spillway are very often wet when all of the Apron and other Spillway panels are dry, evidence of erosion channels **underneath** the panels. There is another pair of panels in the centre, halfway down the spillway which are wet when all others are dry. This is even visible on recent media video and photos.

The question is :- Should the safety of the School and Whaley Bridge town rely on the observations of ramblers and dog walkers or should the most dangerous asset in the entire CRT Estate have a full time dedicated reservoir warden to patrol, to observe and manage the whole system with full authority to err on the side of caution and use all the reservoir controls to discharge water in accordance with an Authorised Procedure?



Part 3. The Damage to the Dam.

3.1 The Recent Sequence of Rain and Water.

Using rainfall figures measured by a local climatologist as a guide, there were two days of very heavy rain. There was over 24 hours of continuous heavy rain throughout Sunday 28th July. Tuesday had more heavy monsoon bursts and particularly on Wednesday 31st July, heavy rain all day. But prior to these days the reservoir was already at maximum and it was allowed to continue filling without any precautionary actions to divert and discharge water to the Goyt

Sometime after midnight on Tuesday 30 July the water began running over the concrete Apron and surging down the spillway. This was the start of an increasingly dramatic and exciting period as the volume of water increased. Many people came to view it and some very dramatic videos were produced. Water at this volume over the concrete spillway had never been seen before in the lifetime of residents, in 48 years it had never happened which means that the waterproof integrity of the concrete overflow structure had never ever been tested.

High speed water exploited the pre -existing channels underneath the Apron. These channels were progressively enlarged which allowed a much greater volume of water to surge underneath the Apron. Eventually at about 10:00 am on Thursday 1 Aug. the underflow was sufficiently strong to lift one of the upper spillway panels upwards into the massive flow that was coming over the top of the Apron. The unbalanced forces caused the brittle concrete panel to snap like a biscuit at its junction with the Apron. Once free it was pushed aside by the power of the top flow. The noise of the panel being snapped was heard by witnesses 100 yds. away

Water over the top then scoured the exposed cavity of earth and clay and rapidly enlarged the hole underneath the displaced panel. This allowed more water to come from the reservoir under the Apron. The combination of powerful water jets, below and above, lifted more spillway panels and scoured bigger cavities in the earth structure. The earth dam structure itself had not failed but it was now under serious and dangerous attack caused by the deliberate decision made in 1971 to arrange for water to flow over the top of an earth dam.

3.2 Management of the Reservoir Level prior to the damage.

It appears that despite the exceptional rainfall and the consequent reservoir level there was no coherent and planned action to anticipate and manage the level in the 8 days prior to the onset of damage on Thursday 1st. Aug . Monitoring of the primary stone Cill level should have triggered the precautionary opening of the bypass gate and both discharge valves to maximum. This is how the reservoir was managed by David Frith (and his predecessors), who, as reservoir keeper for 11 years, lived with his family in the Warden's house. Now, under CRT control there is just a reliance on a 48 year old spillway with obvious leaks that had never been tested or used before.

If water was crashing over the concrete structure from midnight of Tuesday then the reservoir was by then at least 2ft. above the top of the original Primary Cill. This means that water must have been above the Cill for at least two days even before the weekend of 24 hours of continuous rain. The primary stone Cill defines the maximum operational height for which the reservoir was designed. If the reservoir continues to rise after the stone cill overflows then the manual discharge actions should be taken immediately. Therefore there were several days of obvious warnings to open the discharge valves and Bypass gate to lower the water level but they were not heeded.

3.3 Time Line....Thursday 1 Aug.

10:00. A very loud crack was heard, the first spillway panel was lifted and broken. The serious damage to the Dam had started. The damage accelerated, more panels were soon also lifted.

10:30 One discharge valve to the river Goyt was only opened 30 minutes after the panels were lifted, 34 hours after the water started to run over the untested concrete spillway. It is not known when or if the other discharge valve was opened.

11:20 I arrived at the reservoir because I wanted to see how high the water was at the Weir with regard to the potential footbridge. I was not allowed on the Dam, I was not even aware that it was damaged, I saw that the water level was about 2 ft. above the Primary Cill. I walked up to the weir and was very surprised to see only a normal flow in the bypass channel, it was less than 1 ft. deep. Also the Bypass regulator throat was open allowing water to return to the reservoir !

11:30 I arrived at the Weir, the water level over the weir (28 ft wide) was then about 2 ft deep and very fast. Debris indicated that the level had recently been about 3ft, so a huge volume of water had been allowed to enter the reservoir. Very surprised to see that the bypass gate had not been lifted from the 6 in. slot that it always has. For all the preceding days of heavy rain the bypass channel had been virtually shut, forcing most of the Todd to overfill the reservoir rather than the river Goyt. The gate control was locked with a small brass lock, strangely not an industrial padlock.

12:00 As I walked back from the weir there was a sequence of men rushing about a mile between Dam to Weir,(inaccessible to a vehicle see 5.2), a debacle of wrong keys, hacksaws that would not cut, missing crank to raise the gate, and eventually a bolt cutter to cut the lock to allow the bypass gate to be opened hopefully to its fullest extent from 6in. to 36in.using a Stillson wrench instead of a crank. The gate screw was very stiff, it never had been opened fully for years. .

12:30 With the gate fully open the bypass channel level then rose dramatically to about 3.0-3.6 ft. Only then did the bypass channel become effective, at about 12:30 on Thursday 2.5 hours after the dam had been damaged.

If domestic bath was filling too much, you would immediately pull the plug out AND turn off the tap. Reservoirs are very much the same. You don't wait till the house is flooded unless, of course, you are not watching the water level.

The discharge valves and the Bypass gate were only operated AFTER the Event. After the spillway panels had been lifted, after 8 days of rain, after nearly 34 hours of a spectacular waterfall rushing over the untested apron and spillway. This is a most serious indictment which exposes the fact that the CRT has no operational procedure to monitor the water level and to react to it in anticipation of potential danger. This was not a flash flood that could not have been anticipated but it was the progressive accumulation of water in the Reservoir over many days which was both observable and avoidable yet no action was taken until too late.

3.4 Unused Discharge and Drainage options prior to the damage.

It is interesting to calculate how much water can be discharged and bypassed by the reservoir's own systems without recourse to 18 Fire Service pumps. The two cast iron discharge pipes that come under the dam to the valve houses are 18in. in dia. Clean pipes this size can each pass 10,000 gallons per minute in laminar flow, possibly much more under the hydrostatic pressure of 40-65 ft. of water.

These cast iron pipes were coated to reduce flow friction when the valves were changed 10 years ago. This would reduce the diameter and the valve gate even fully open would add some additional impedance to the flow. So, with a cautious estimate, the potential flow might be reduced to 8900 gals per min (4.54 x 8900= 40,406 litres /min) which is 40.4 Cu m/min.

Together the fully open discharge pipes could discharge 80.8 cu. m/min. In 6 days this would be 1440 x 6 x 80.8 = 698,112 cu m. This could have lowered the 15ha area reservoir by 698,112/150,000 = 4.7 m .....Just under 0.75 m per day.

The Bypass channel is about 1 m deep by 2 m wide. If the gate is fully open and the average flow rate is only 0.5m/sec it will pass 60 cu m /min. In fact the flow rate could be at least double that because it is a straight channel with a gradient and the inlet water is pushed by the strength of the Todd in flood.

If the bypass channel gate had been fully open for 6 days (60x 1440 x 6) = 518,400 cu m would have flowed directly into the Goyt instead of going into the reservoir where it would have added 3.5 m to the level if there was no drainage at the Primary Cill.

Therefore perhaps a reduction of 1.35m per day (despite continued net overall filling) could have been achieved during the 6 days **before** the crisis using the reservoir's own controls all fully open which might have even avoided the crash. Unfortunately no discharge action was taken until about 2 hours after the damage to the dam had occurred.

For comparison, according to the Fire Service website, their 10 High Volume Pumps, started on 2 Aug., could extract 1.7 Cu m/sec which is 102 cu m/min, whilst the reservoir's own systems if fully working could dump 140 cu m/min.

3.5 Actions taken by the Emergency Team in the following days.

For the record it is worth listing the actions taken by the Emergency Team who took over sometime on Thursday afternoon. They used the reservoir's own controls to drain and stop filling the reservoir in conjunction with external pumping efforts. A very important additional fact is that it did not rain until the 9 August, 8 rain free days while the reservoir was drained and pumped down. This is what I saw when I walked to the weir on 8 Aug. after the reservoir had been virtually drained.

1 There is doubt about use of the discharge valves. Each discharge pipe can empty the reservoir by 40.6cu m/min. The ongoing culvert system from <u>each</u> valve house allows water to be dumped into the Bypass channel or sent to the canal. The canal would be the better option to avoid the obvious congestion at the River Goyt, but the lower valve culverts show no evidence of recent use (?) . It is hoped that the incident report should clarify which valves were operated, how much and when, were all these resources operational at the time of the emergency. ?.

It has been stated that one <u>new</u> valve was partially 'stuck' on 1 Aug , when the damaged started. This may well be the case because these are 'brand new' ex factory valves (2009) and it is essential that new valves of this type are fully 'cycled' often because they tend to seize up if not used. The visible culverts are choked with loose stones and weeds (as of 17 Sept). One culvert to the canal is said to have been fully blocked for some years which if true reduced the drainage rate considerably.

2 The Primary Stone Cill was deliberately smashed and/or removed to lower the overflow level by about 6 in. to allow the reservoir to continue to drain into the Bypass. This sensible action meant that the reservoir could drain another huge volume naturally in parallel with all other discharges and pumping.

3 Some Bypass Channel Regulator planks had been missing before the damage. New much larger planks were installed to ensure that most bypass water could not get back into the reservoir. The small regulator Cill in the bypass channel was smashed off to ensure that water flow was not impeded there.

4) The vital Bypass gate at the weir was finally raised to be fully open (36 in.) And most important, the ancient mud banks that blocked direct access to the bypass culvert were dug out to ensure a direct flow of the Todd into the bypass culvert. (See 5.6)

5) Eventually the weir itself, 28ft. wide, was blocked with Gabions brought by Chinook to virtually prevent any flow into the reservoir. The blocking planks could not be used due to defects in the slotting system. (*Gabions are wire cage cubes filled with stones.)*

6) Bypass channel was fully exploited, the team had been running it full 'to the brim and over'. All along the reservoir path sandbags had been arranged to stop the Bypass channel overflowing back into the reservoir.

7) Two weeks after the event the last 80 m of the Bypass channel, the Convergence Basin, was cleared of all obstructions, huge mud banks, weeds and loose stones just where the Primary Cill discharges. This has now created a very large space and volume for the both the Bypass and Reservoir overflow to converge which is exactly what is required for this simultaneous demand in flood conditions. This large convergence area is another feature of the original careful design which has been badly neglected and not exploited for at least the last 25 years. It can be asked why a near catastrophe is needed before the requirement for routine maintenance is recognised and then belatedly carried out. At the same time all the weeds and small trees were removed from the concrete spillway.

Part 4. The Future of the Toddbrook Reservoir.

The damage to the Dam clearly shows that the installation of the concrete overflow structure was a disastrous engineering mistake and that this structure should not be reinstated. It has seriously compromised the dam since 1971 and therefore has threatened the safety of the Village School , Whaley Bridge and the Goyt Valley communities downstream. Future use of the concrete structure as a secondary overflow cannot ever be justified.

4.1 Public Consultations and Planning Permission.

In 2019 planning permission would **never** be granted to authorise a new dam retaining more than 293 million gallons of water weighing 1.3 million tons with a dam located 310 yards from a village school and a small town. But the paradox is that the reservoir was here before the school, before planning permission and risk assessments. Many residents want to keep the reservoir as an attractive healthy green amenity but they want it to be much safer and properly and visibly managed. That means that all repairs and revisions to the dam must now be authorised by the full planning and risk assessment processes of the local authorities before any work starts. The CRT cannot assume that they can carry out an unauthorised repair which compounds all the same mistakes which recently could have destroyed Whaley Bridge.

In 1831 when construction started there was no consultation with the residents who lived in the small community at Whaley Bridge. The Todd Brook valley from Kishfield Bridge to the Goyt was just sold by the landowner to the canal company. The town was smaller, there was no school or railway bridges close to the Dam. There was no planning permission and risk assessment in the modern sense. But the civil engineering of the day was excellent, designs erred on the side of caution with huge safety and loading factors. It is a great credit to the engineers and navvies that today we all still use their infrastructure on railways, roads, bridges and rivers all over the UK.

In 2019 the dam has been damaged. It appears that the CRT may want to attempt to 'repair' the leaks under the concrete structure possibly by doubtful grout injection. It appears that they may want to re-operate the reservoir in exactly the same dangerous state for commercial reasons because the water is 'needed' at Marple Locks (*said on TV recently by CRT).*

Now, at last, after 190 years, the vulnerable residents of Whaley Bridge, the parents, the grandparents, the young people who are the future parents have the opportunity to **insist** that they are consulted and given independent technical representation. Given that the Toddbrook Reservoir in 180 years has never undergone any planning controls or risk assessment this is the first opportunity which must not be missed.

Residents must be allowed a strong voice, supported by their representatives in both local and national government to agree an acceptable safe revision of the overflow system, the revised water level and safety management of the Reservoir. The safety of the town should not be a unilateral choice of the CRT, the residents must have the opportunity to respond and challenge even though this is not a 'new build'. The CRT must enter the planning process and submit a full publicly available planning Application to the appropriate authorities and seek full technical and social approval **before** they do anything.

5.0 Radical safety modifications .

This is a summary of all the modifications that I believe are essential and should be carried out to radically increase the safety of the Dam and the Reservoir. The Bypass channel should be made deeper, the maximum level of the reservoir should be reduced. The Concrete structure should be disabled forever and removed. The original 5ft. safety margin of clay core should be reinstated right across the top of the dam.

5.1 Deepening and re engineering of the end of the Bypass Channel.

In order to keep moving water quite separate from the Earth Dam the reservoir overflow was originally designed to run into the end of the Bypass channel over the primary stone cill (near where the boats are launched). If the reservoir level is not actively managed and anticipated by operating the discharge valves, as we have just seen, there can be a capacity and congestion problem when the Bypass flow is high and the reservoir wants to drain. This is because the convergence trough is too shallow (=1.5ft.). Therefore the Bypass channel should now be deepened by perhaps 2 m. for the last 100m at the Reservoir Road end in order to provide this increased capacity. This would beneficially reduce the steep gradient of the descent to the River Goyt (which is also a problem) and the bend would be re-engineered and contoured properly in concrete.

Deepening the overflow channel here is necessary for the safety of the Dam because the entire reservoir overflow must always use the Bypass channel, water should never be routed over the Earth Dam. This modification will allow the maximum reservoir level to be lowered by (say) about 1.5m (5ft.) so the reservoir would start to overflow into the bypass about 1.5m (5ft). below the original Primary level. This will reduce the loading on the dam and most importantly it doubles the safety margin of the waterproof core from 5ft. to 10ft.

This proposed option should have been implemented in 1971 instead of constructing the vastly expensive, difficult and dangerous concrete overflow structure over the earth dam. This was and is a much safer, much cheaper option. It would not have destroyed the safety of the Dam at all and should be seriously considered now. It is just a standard Civil Engineering project with minimum disruption. For exactly the same reason circa 1999 the Bollinghurst Reservoir in Lyme Park now has an excellent modern example of Overflow Channel enlargement, with deepening and contouring. It was carried out by Askam Engineering. A similar scheme is essential at Toddbrook.

5.2 Disabling of the dangerous concrete structure for ever.

The dangerous concrete structure on top of the dam should be disabled as an overflow system and the original 5ft. safety margin of the waterproof core should be reinstated **right across the Dam** to fill the gap under the footbridge. This means that water would not ever be intentionally routed over the top of the dam. Ideally the many hundreds of tons of redundant concrete of the spillway structure should be removed and the missing earth on the shoulder should be replaced.

5.3 Maximum water level lowered.

The water level should be lowered, maintained at a maximum level defined by a new Cill perhaps 5ft. lower than the original Cill. This lower overflow would be enabled by the deepening of the re-engineered Bypass channel (described in 5.1)

5.4 Repair and refurbishment of the Weir.

The Weir is an obvious mess with deficiencies far too numerous to list here. Flow into the weir is badly obstructed. The Bypass gate must be replaced. Any experienced Civil Engineer will recognise the serious and dangerous state it is in, given that it is one of the most important reservoir safety controls in the system.

5.5 Toddbrook Reservoir Management and Operational Procedure,

This must be introduced and visibly operated by the CRT. It should be fully available to the Public. Water must be discharged using the drain valves and the Bypass whenever certain critical rainfall events or pre defined measures, indicated on new height gauges, are reached or about to be exceeded.

Summary.

I strongly recommend all these modifications, they radically increase the safety, are fully justified, and easy to achieve. I urge that these changes are vigorously demanded by the community. It is your children who attend the Village School not the children of the CRT, not the children of Environmental Agency.

A slightly lowered reservoir that is much much safer would still provide the scenic vista of water in Whaley Bridge as an excellent public green amenity, together with boating and angling facilities as before. Pathways could easily be extended in the new permanently dry waterside margin to provide a 'round the reservoir' circuit.

Part 6. Issues of Safety & Maintenance.

6.1 My association with Toddbrook.

For over three years 2015-18 I devoted considerable time and effort to the proposed installation of a Memorial Footbridge across the Weir to commemorate the life of David Frith, friend of many, a former reservoir keeper. The footbridge would have allowed the weir to be crossed predictably and safely to connect with other footpaths. As an Engineer I became very familiar with the reservoir construction and its controls on my frequent visits to evolve the bridge design and work to improve the paths. In my frustrated contacts with CRT I drew attention to several important safety and maintenance defects but to no avail. I never encountered a CRT warden at the reservoir during in the whole 3 year period.

My proposed footbridge needed a Flood Risk assessment to be conducted on site by a Flood Risk Assessor. As an experienced Waterways Officer, he was astonished to recognise for himself some of the issues that I have listed below (which have little to do with the footbridge). He was so concerned that subsequently he raised some of the issues with CRT informally although it was outside of his remit. Since he was a Local Authority official the CRT was forced to take notice, consequently issues 6.3 & 6.4 were eventually repaired due to his critical intervention. Both of these repairs made a very positive contribution after the dam was damaged so my £50 fee was well spent.

There follows a list of neglected devices and safety concerns in the Reservoir System.

6.2 Vehicular access from Reservoir Road to the Weir.

If there is an emergency at the weir it is not possible to get a vehicle/crane or tractor onto the wide weir pathway unless the reservoir is drained down by 3m. which is not the most probable state of the reservoir in an emergency. I suggested that there should be a small metal ramp bridge from Reservoir Road angled across the Bypass channel onto the weir path. The cost of replacing the derelict footbridge No.2 would have provided some cost offset.

The idea was not seriously considered by the CRT, 'it would never be required'.......Well, not until 1st. Aug 2019 when there was a desperate need to get vehicles to the weir, to belatedly fully open the bypass gate, sandbag the bypass channel and block the weir to prevent the reservoir filling faster than it was being emptied, all of which needed vehicles.

Some days later and after a lot more water over the weir, there was a Chinook Helicopter available to get materials and equipment to the weir, so the ill judged gamble of not needing a vehicle bridge was not fully exposed. I made the suggestion in 2016 because I saw it as a major safety and maintenance deficiency. To be unable to take men and equipment quickly to take action and/or service the weir is serious when the weir provides the only means of controlling the input to the reservoir.

6.3 No. 2 Footbridge from Reservoir road

This bridge was so rotten that it fell apart and the handrails fell into the Bypass. Clearly it had never been inspected. Yet this was the bridge I used to take certain senior CRT managers to the weir, they made no comment, it seemed that Reservoir issues were not in their remit. This pedestrian bridge is the only way for a person to get onto the weir path. The path is wide and level, suitable for vehicles, a legacy from the building of the reservoir started in 1831. The footbridge was replaced by an identical one after the intervention of my Flood Risk Assessor and was invaluable as the only access to the weir (for pedestrians) during the current crisis.

6.4 The Weir Path subsidence.

There was a huge depression (12 x 8 ft x 3 ft) deep in the weir pathway at the half milestone due to subsidence caused by a massive leak from the Bypass channel into a field drain culvert that passes underneath the Bypass Channel. This leak had been running for **several years**. The subsidence pit would prevent any vehicle reaching the weir in an emergency, always assuming that the vehicle could get onto the weir path initially. Bypass water continually poured out of the field drain culvert into the reservoir, I advised CRT but was told there was no money. However this leak was repaired and the pit was filled in after the intervention of my Flood Risk Assessor.

6.5 Weir base masonry collapse.

The weir was constructed on one of two natural rock waterfalls on the Todd Brook. Water for the reservoir is guided over a paved area between two abutments and then it drops about 25 ft. The base of the pitched slope has been badly smashed and under cut in previous floods. It has been in this state for at least 30 years to my knowledge. After Aug 2019 it is now in a greater smashed and derelict state with an additional collapse of a side wall. The weir structure itself is threatened. This is obvious evidence of long neglect apparently invisible to any Reservoir Inspectors. The state of weir is important, it is the vital ‘tap’ that controls the fill of the reservoir and the bypass. If the ‘tap’ is disabled there will be no control.

6.6 Bypass Gate Management

A large mud bank has been allowed to form and impede the direct flow of the Todd Brook into the mouth of the bypass culvert. It has been there for more than 25 years. It diverts water away from the bypass culvert entrance and takes the power out of the potential direct flow. Water has to meander by an indirect route but it is then obstructed by part of the gate. The weak flow under the narrow gate slot allows the entrance to be obstructed very easily with a build up of branches and leaves. Sometimes this debris stops the flow in the bypass.

In the recent emergency part of the obstructing mud bank was dug out to provide a fast direct route for the Todd into the Bypass channel, so at least this problem was recognised by other engineers. The input flow path of the Todd into the weir bypass and the weir itself has always been an obstructed and neglected mess that needs serious engineering repairs and annual maintenance. The bypass gate is always set to a minimum 6in.slot regardless of the large variation of flow in the Todd Brook i.e. it is never managed.

6.7 Weir Blocking Planks

These were to stop the flow into the reservoir. They were not locked, not stacked on a frame, not chained, and clearly not ever inspected, a prey to vandals, just a heap of expensive timber wet and covered in mossy slime, dangerous to handle. I reported the missing lock and chain but there was no response. Eventually the unchained planks were thrown down the weir by vandals. They were 'rescued' by a public spirited resident and his friends. But after re-chaining they are still stored in a slimy heap, not on a secure drying frame as seen on canal towpaths. In the recent emergency the planks could not be used due to a failure in the slot system on the weir.

6.8 Water Height Scales.

Apart from the step gauge (see 7.3) on the wet shoulder of the dam there are no other means to measure water height at other controls, no fixed scales to indicate the height of the water in small intervals. There have never been any, not at the weir for the flow to the reservoir, not at the bypass gate, not at the primary stone cill and not at the concrete structure. It is difficult to understand how any safety monitoring and control actions are initiated without any simple measuring scales to define when such actions are required. It is an indictment of the Reservoir Inspection Schedule that all the rigorous inspections of the reservoir have never recognised this fundamental deficiency.

6.9 Bypass to Goyt Connection.

This was only observed recently. The Bypass channel connects to the river Goyt virtually **at right angles** to the river flow. As is recorded on several videos of the incident with high volumes this actually impedes the flow of the Goyt itself and stops the Bypass channel, and the effect then backs right up the Bypass channel and the Goyt. Unnecessary contra flow and congestion sets in. Some recent video footage shows the high speed Bypass water running across the top of the river water heading straight for the school! This is not a trivial point.

Clearly some hydraulic modifications and structural engineering is required at this junction, the Bypass channel must be turned left by about 60 degrees and guided to join the Goyt in an orderly manner with both flows merging and going in the **same** direction rather than in opposition.

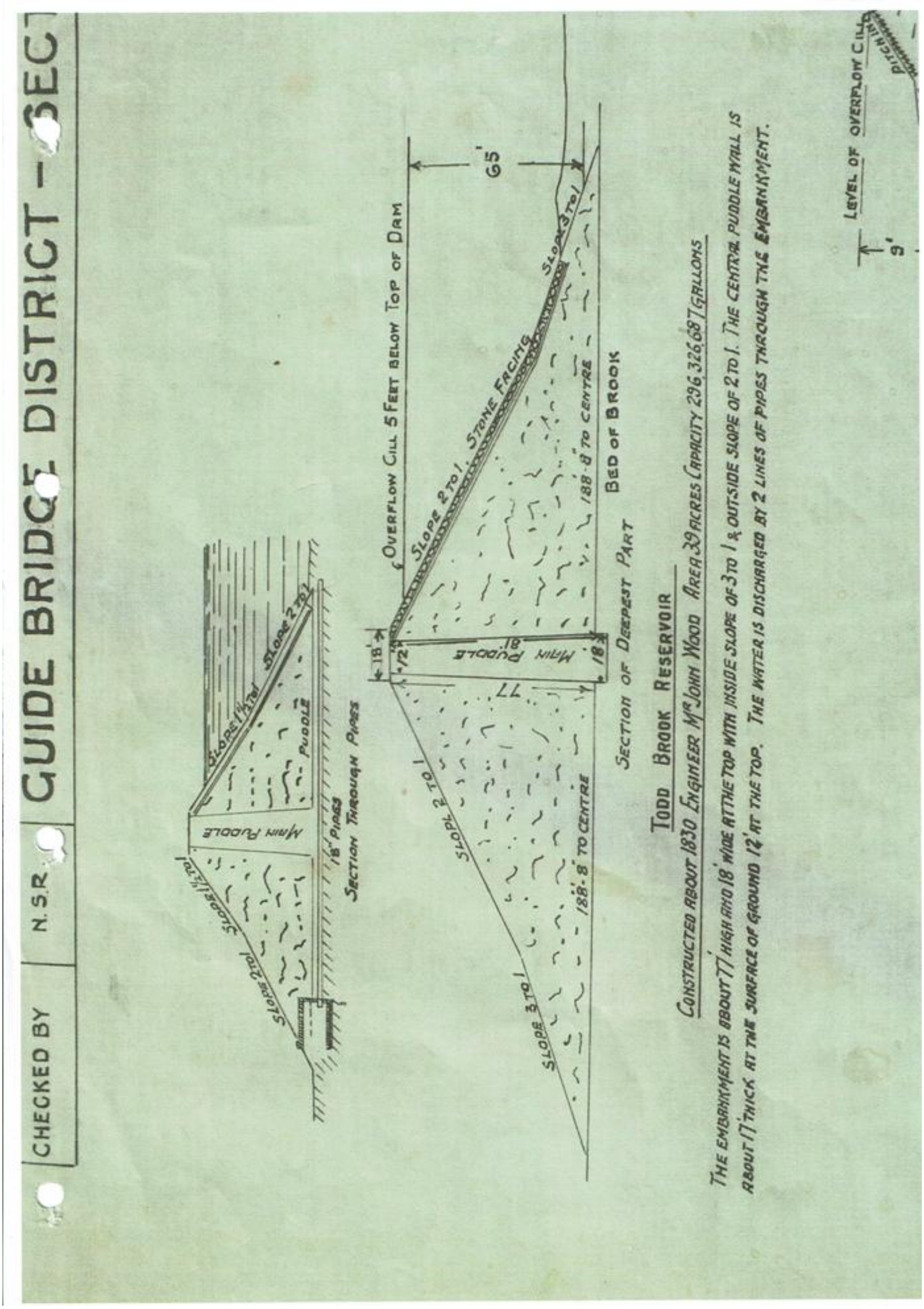
6.10 The Discharge Culverts.

As explained in 7.7 there are 4 culverts in the discharge system (examined on 18 and 20 Sept.) The two that discharge into the Bypass are open channels. The other two which feed the canal basin have short open sections but have to be covered eventually. It is believed that they merge under the park drive into one larger culvert which goes under Reservoir Road and emerges briefly at the side of the Railway Pub.

All the open sections reveal a high degree of neglect and lack of maintenance. The culverts are generally choked with mud, weeds, loose stones, decaying blocking planks and other debris. They are so overgrown with vegetation that they are invisible in places. What looks very strange is that they don't show any evidence of having been used recently with very high volumes of water? The switch between Bypass and Canal feed is achieved with blocking planks but the slotting arrangements and planks are missing ? Again there no evidence of recent use. On the lower canal culvert there is a derelict monitor without a sensor in the culvert, a tall padlocked box bolted to the ground, a photocell panel on its top is broken, corroded and damaged. It is without power, clearly this monitor does nothing except emphasise dereliction and neglect.

It would be interesting to know how much of the discharge system comprising two valves and four culverts was actually able to function on 1 August 2019. Its current state suggests that some parts were not able to function that the discharge system itself could not have been part of the Reservoir Inspection Schedule (Nov 2018). All valves of this type must be routinely <u>fully opened</u> and closed to ensure that they don't seize up. The new valves have been there for 10 years, we are curious to know if they have ever been exercised, given a reliable report that one valve would not open fully on the 1st Aug.

With all these deficiencies in the reservoir system, the controls and structure it will be very revealing to see a copy of both the Reservoir Inspection Schedule and a copy of the Report by the Inspectors (Nov 2018). These documents should amongst many others available at the Enquiry.


CHECKED BY
N.S.R.
GUIDE BRIDGE DISTRICT – SECT
MAIN PUDDLE
PUDDLE
SLOPE 2 TO 1
SLOPE 1½ TO 1
18" PIPES
SECTION THROUGH PIPES
OVERFLOW CILL 5 FEET BELOW TOP OF DAM
65'
SLOPE 2 TO 1. STONE FACING
SLOPE 3 TO 1
18'
12'
77'
188'.8" TO CENTRE
BED OF BROOK
SECTION OF DEEPEST PART
TODD BROOK RESERVOIR
CONSTRUCTED ABOUT 1830 ENGINEER MR JOHN WOOD AREA 39 ACRES CAPACITY 296,326,687 GALLONS
THE EMBANKMENT IS ABOUT 77' HIGH AND 18' WIDE AT THE TOP WITH INSIDE SLOPE OF 3 TO 1 & OUTSIDE SLOPE OF 2 TO 1. THE CENTRAL PUDDLE WALL IS ABOUT 17' THICK AT THE SURFACE OF GROUND 12' AT THE TOP. THE WATER IS DISCHARGED BY 2 LINES OF PIPES THROUGH THE EMBANKMENT.
LEVEL OF OVERFLOW CILL
9'

Part 7. Toddbrook Reservoir System and its Operational Controls.

7.1 Brief History of the Toddbrook Reservoir

In my search for information regarding the proposed footbridge I obtained a copy of the original design specification (1831) for the Toddbrook Dam by Mr John Wood, the Engineer in charge. This provides the dimensions, the construction details of the original dam design and particularly the safety margin of the original overflow system.

As the national canal system developed, the opening of the Marple lock system in 1804 progressively exposed the requirement for an additional water supply to supplement the supply from the Combs Reservoir. About 27 years later (!) construction of the Toddbrook Reservoir was started in 1831 but it did not become operational until 1840. It is ironic that by then the canal system and the requirement for water at Marple Locks had declined somewhat due to railway competition during the 36 years that it took to deliver Toddbrook. What supported the Peak Forest Canal was the insatiable demand for lime and lime stone from the Dove Holes quarries via Bugsworth and from Crompton for building projects especially in London and other cities and towns.

The dam is a standard puddled clay and earth embankment construction. Puddled clay is made by addling a lot of water to 'dug clay' and manually pounding it until it becomes plastic and waterproof. Clay is by nature very thirsty and once hydrated, the water will be retained provided evaporation and drying is prevented.

In view of the current very serious nearly catastrophic damage to the Dam it is worth checking a few facts about 'dams that are 180 years old' before declaring the dams themselves to be guilty rather than how they have been dangerously modified and/or mismanaged.

7.2 The Dam

The Toddbrook Dam was made watertight by progressively raising a wall of puddled clay, 77 ft. high above the footing and approximately 800 ft long (to extend the dam across the valley). This wall of clay is in section 18ft. wide at its base tapering to 12 ft. wide at the top. Initially a trench 18 ft. wide and 4 ft. deep was dug in the rocky valley floor to provide the footing and the vital watertight seal to prevent water seepage under the base of the dam. This clay wall or core was called the 'Main Puddle', 81 feet of total height.

Obviously the Main Puddle, being wet plastic clay, would collapse or distort under its own weight, so it had to be continually supported as its height was increased. This is done by progressively increasing the height of the triangular mass of earth on each side of the Main Puddle. It is probable that the Clay Core may also have been supported and contained by shuttering during construction to protect it from ingress of earth material whilst the earth embankments were themselves being elevated and compacted.

This construction would have taken years of heavy but careful work. The growing Main Core would have been kept hydrated, while additional puddled clay was added and compacted into the core. There would be no joints to worry about, the clays just integrate and form a continuous homogeneous waterproof wall 77 ft high and 800 ft long, keyed into the rock below.....calculations indicate that the clay wall alone weighs 55, 650 tons.

The earth and embankments, the 'bookends' that support the Main Puddle are therefore massive themselves due the weight of clay that they have to support and the protection they must provide. These shoulders give an earth dam its characteristic double triangle shape. Viewed in section they start 190 ft from the centre of the Puddle on each side, rising at 18 deg. for the first third then at a steeper 26 deg. to reach the Top of Dam. Each embankment could weigh over 276, 000 tons. The whole dam would weigh over 630, 000 tons. The wet embankment is protected by flat stones 'pitched' on edge into its surface. They are arranged and interlocked like the stones in a dry stone wall. Over time this prevents erosion of the earth shoulder by natural water currents, waves and level changes in the mass of water impounded in the reservoir.

During construction of an earth dam provision must be made for the stream/river which naturally runs at the bottom of the valley. Usually a temporary deep culvert is built under the footing of the clay wall for the stream to use during construction. Eventually this is deliberately blocked when the reservoir is filled, but it is always a potential weakness for leaks.

7.3 The Reservoir Water Height Gauge.

This gauge is most visible when the reservoir is empty. It is a series of about 70 stone steps , like a staircase, set into and lying on the wet shoulder of the dam. The 'risers' are exactly the same height as each other, very probably 12 in. (not allowed in the site to measure). Some but not all of the flat steps are marked with a number which identifies the height of the reservoir in feet if the water is just wetting that particular step. If it is between steps the level has to be estimated or measured in inches. This enables the reservoir keeper to know the height of the reservoir, which is of particular importance for the last 10 steps at the top of the stair case as 'Full' is approached.

We know that David Frith, a recent Reservoir Keeper for British Waterways spent 11 years managing the reservoir and he used to measure the depth with a ruler and record it. If the reservoir was over-filling he used to operate any of the available controls to discharge or divert water as discussed previously.

This step method is a crude derivative of the magnificent surviving white marble 'Nileometers' used in Ancient Egypt during the last 4000 years to measure the height of the Nile floods for taxation purposes.

7.4 The Weir and Bypass Channel.

The Todd Brook accumulates water from a large steep sided oval catchment area 5.5 miles long and 2.2 miles at the widest section. The masonry weir was constructed at a natural rock waterfall on the Todd Brook about 0.9 miles from the dam. Water for the reservoir is guided over a paved area between two abutments and then drops about 25 ft. By law, some water must be diverted into a Bypass channel to go directly to the river Goyt. The remaining water passes over the weir to fill the reservoir. The intake volume into the Bypass is controlled by a simple gate which can raised or lowered to adjust the entrance to the Bypass channel.

7.5 The Bypass Channel Regulator .

The Bypass channel itself has a volume regulator about 320 yards from the Dam. This has a Cill provided by 4 removable planks which allows a variable amount of Bypass water to be directed back into the reservoir. The Reservoir Manager would want to discharge only the minimum into the Goyt as specified and this facility gave him the opportunity to 'fine tune' the flow (not very easy at the weir). It is also a maintenance facility to allow the lower Bypass channel and Main Overflow Cill to be serviced by diverting all the bypass water into the reservoir.

However in an emergency if the reservoir must be drained urgently all the planks must be fitted to maximise the Bypass flow to the Goyt. This is the fourth control available to prevent filling the reservoir.

7.6 The Primary Overflow Cill.

The original overflow Cill or Curb is constructed at the LH side of the dam. It is a continuous line of raised stone about 100 ft. long which crucially regulates the reservoir water level by spilling excess water into the bypass channel which goes around the end of the dam and into the River Goyt.

Obviously if the volume of water running over the weir exceeds what is being discharged at the Cill the reservoir will continue to fill. This would then require alert and immediate human intervention to open the Discharge Valves (see later) and open the Bypass gate to direct maximum flow via the bypass channel directly to the Goyt.

The most important fact is that the Overflow Cill was designed and deliberately positioned to be <u>5ft below</u> the top of the Main Waterproof Clay Core. This was done to protect the earth dam and to ensure that **no water should ever go above the core and flow over the Top of Dam.** Excess water was **always** to be discharged over the Main Overflow Cill into the Bypass Channel **NEVER** over the top of the Dam.

7.7 The Discharge Pipes.

There are two pipes 18 in. diameter which pass <u>UNDER</u> the Clay Core footing to take water from two different low levels in the deepest area just close to the dam. The upper pipe is fed from a vertical culvert that drops 40 ft. below its intake grid. This drop is necessary for the pipe to pass under the footing. It is very important that the integrity of the core is preserved and that any culverts or pipes which inevitably provide a fundamental weakness, do not pass through the waterproof core itself. Ignoring this essential practice during construction has led to many Dam failures. (Ref1)

The pipes are connected to valves on the dry side of the dam which are located in two locked valve houses at low levels on the earth shoulder of the dam. The culvert arrangement leading from each valve house allows water to be dumped either via the Bypass channel into the Goyt or sent to the canal basin in Whaley Bridge Centre to supply the canal network and Marple Locks. The lower pipe will obviously drain the reservoir to a minimum for maintenance.

7.8 The Reservoir before 1971.

From 1839 there was a resident reservoir manager employed by the canal company with the authority to manage all facilities of the Reservoir especially the water level. He lived 'on the job' in the house halfway between the Dam and the Weir.. He was assisted by a warden who lived in the house at the Dam. The reservoir was therefore always supervised and monitored.

When the Reservoir was fairly full they would monitor the water level at the Step Gauge and the Overflow Cill and even anticipate, by experience, the delayed arrival of water from the catchment area. (It can sometimes take more than 24 hours to arrive at the weir.) They would operate the discharge valves and bypass gate in anticipation to start draining and stop filling even before this flood arrived.

They would feel secure knowing that the waterproof core inside the dam extended to 5ft. above the Cill, a large deliberate safety margin in the design. They had four control options for normal day to day level management :- they could open one or both of the discharge valves to discharge water, they could run the bypass channel at maximum by raising the paddle at the weir to stop the filling as much as possible, they could close any dumping back to reservoir at the Bypass channel regulator.

During the first 130 years there would have inevitably been various problems typical for this type of dam, leaks, water loss, blocked pipe intakes, concerns about water erosion under the dam and necessary maintenance. But in that long period the dam itself was basically safe with no serious defects that could have led to a catastrophe and destruction of Whaley Bridge and the downstream communities of the Goyt Valley.

Heavy rain must have occurred on numerous occasions during 130 years (some are recorded) but the water level was managed safely by alert wardens 'on the job' and active use of the discharge options.

Part 8. Modifications and Repairs.

Modifications

8.1 The Disastrous Concrete Structure 1971 (*Other details are in 2.2.)*

Several hundred of tons of concrete were required. The 170 Spillway panels were cast in situ on a 27 deg slope which would cause the wet concrete to run downwards. To mitigate this a 'stiff' mix would be used with a minimum of water which can compromise the concrete's strength. The panels are just abutted, not reinforced, and have no viable waterproofing in the inter-panel joints as shown by the weeds and trees that grow there. This long project would require good continuous quality control and supervision by the contractors plus further oversight by British Waterways, especially when casting the Apron panels which somehow they hoped would seal to the clay core. It is probable that in 1971 the residents were quite unaware of the new risks and that there was no consultation or public planning.

8.2 Concrete side walls.

In late 1970s British Waterways realised that overflow water would not stay on the spillway because of its irregular shape. They tried to solve it by building heavy concrete walls 4-6 ft high at each side of the spillway in an attempt to steer the water and keep it on the spillway to protect the adjacent earth embankments.

The effectiveness of the wall could never be tested until Aug 1 when it failed. Videos show that the water very dramatically just jumped 20 ft. over the wall and scoured the unprotected earth shoulder on the other side. This is another demonstration of the fundamental flaws of the concrete overflow structure. It is very probable that excavation for the wall footings has further damaged and depleted the clay core even more than the excavation for the spillway and this has assisted the water erosion in that corner of the Apron especially at the top.

8.3 2009 Discharge Valves.

Reservoir was drained to replace both of the discharge valves after 170 years. It is understood that the inside of the 18 in. cast iron pipes coming from the reservoir were also coated internally with a suitable chemical skin to smooth out the rust encrustations and reduce the flow friction.

8.4 Pressure Sensors. (Date unknown).

Two pressure sensors were fitted in the northern part of the earth embankment adjacent to the concrete structure. Pressure sensors monitor the pressure changes in the dam and could give a warning of excessive pressure changes in a given region of the dam. However there are none to monitor most vulnerable areas under the concrete structure!

There are two more sensors positioned about 1 m. apart at the very top of the dam on the earth side where the panels were lifted. This arrangement is rather odd and suggests that there were already concerns about the structure exactly where it failed.

These are wireless devices but it is not known who looks at the output readings and more importantly, what procedure would operate to warn the community if the pressure went up significantly. Perhaps a policeman would just knock on the door ? An independent enquiry should ask for the records from the 1st. July. to 6th Aug. from all the sensors

Note that the smaller Bollinghurst Reservoir Earth Dam at Lyme Park (circa 1870) and now managed by United Utilities, has about 10 pressure sensors and there is not a school or any property anywhere nearby.

8.5 Repairs.

All earth dams have problems and leaks during their long life (see ref1.) These can either be detected by careful monitoring , inspection and maintenance routines including periodically draining the reservoir right down to be able to inspect the upstream (wet) side of the dam and the reservoir basin. Or they will reveal themselves by a catastrophic breach or flood emergency.

There has only been one leaky problem in the Toddbrook Dam but it took **50 years** to resolve. Discharge pipes and the feeder stream culverts used during construction are very often where the leak path can occur even if these carefully pass under the clay core.

1880 It is reported that the reservoir basin not the dam was leaking into some old coal mine workings. Remedy not reported, assume it was resolved.

1930 Leak observed in the Dam toe downstream. Reservoir drained, matching depression in the upstream shoulder of the dam. Repair attempted 1931.

This is an extract from Ref 1; the success is a credit to the tenacity of British Waterways Engineers.

Incident Description.
November 1975. When the reservoir was low, a depression was noted in the same position on the upstream face as the 1931 depression. In Autumn 1977, 120 mm of subsidence was measured since 1975. The reservoir was emptied to inspect the full extent of the depression and revealed a crater approximately four metres across at the upstream toe partly in filled with silt and into which a tree appeared to have been sucked.

Investigations
1978-80. Extensive investigation included boreholes, sampling and piezometers. Exploratory shafts were sunk on the upstream and downstream faces between 1978 and 1980. In 1981, a 1.2-m diameter masonry culvert was found beneath the dam,

possibly for stream diversion during construction. Tracer tests showed this to have formed a leakage path through the dam.

Remedial works
In 1981, a compacted clay blanket was placed over the suspect area of the upstream toe and the bed of the reservoir. To solve the leakage problem, a single row grout curtain 60 m long within the clay core was formed using the tube-à-manchette system. The reservoir was refilled in December 1983.

Lessons
Until the reservoir was drawn down, the extent of the crater caused by erosion was unknown. <u>The good practice of periodic inspection of the upstream face of a dam is illustrated by this incident</u>

Part 9. References.

1 "Lessons from Historical Dam Incidents. 2011" Defra. Charles, Tedd, Warren.

An excellent analysis of all dam failures in the last 200 years.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290812/scho0811buba-e-e.pdf

2 A History of Dams. 1972 Norman Smith pp 171 , 193, 212,

3 Roman Aqueducts & Water Supply. 2nd ed 2002 A Trevor Hodge

Part 10. Selection of relevant quotations.

From " Lessons from Historical Dam Incidents." (ref1) *underscored by me for emphasis*

10.1 Reservoir Legislation

Since 1930, reservoir safety in Great Britain has been regulated by Act of Parliament. In the interests of public safety, the Reservoirs (Safety Provisions) Act 1930 required the owners of reservoirs with a capacity of more than five million gallons (22,700 m3) above the natural level of any part of the surrounding ground, to provide for their inspection by a qualified civil engineer who was a member of a panel of civil engineers constituted for the purposes of the Act. The Reservoirs Act 1975 went beyond the provisions of the earlier Act in a number of ways. Local authorities were designated as enforcement authorities, being required to keep registers of all raised reservoirs (defined as those with a capacity greater than 25,000 m3 above the natural level of any part of the land adjoining the reservoir) and to ensure that undertakers, usually the owners, complied with the requirements of the Act. The duties of Evidence Report – Lessons from historical dam incidents 3 undertakers, enforcement authorities and engineers appointed to the various panels were laid down in the Act or set out in regulations. <u>A major change in reservoir safety occurred in September 2004 when responsibility for the enforcement of safety legislation in England and Wales was</u>

transferred from a large number of local authorities to the Environment Agency under the provisions of the Water Act 2003, thereby ensuring a uniform application of safety legislation across the country. The Flood Risk Management (Scotland) Act 2009 transfers the Enforcement Authority role to SEPA. Further legislative changes are planned in the Flood & Water Management Act 2010.

10.2 Dam Failures.

Most of the failures which have caused loss of life can be attributed to the embankment breaching due to one of two causes:

- Overtopping of the embankment during an extreme flood. This hazard is largely within the province of hydrology and the selection and estimation of the design flood, and provision of appropriately sized spillway and freeboard.

- Internal erosion associated with processes such as piping or hydraulic fracture. In new dams this should be prevented by appropriately designed filters and careful design of the watertight element. Where overflow arrangements have been improved to meet modern flood standards, internal erosion is likely to be the major remaining threat to an old embankment dam which does not have filters designed to modern standards or which has a draw-off structure (culvert or unprotected pipe) passing through it or which has a deep clay filled cut-off trench

10.3 Maintenance, monitoring and surveillance In terms of public safety, it is particularly important to identify factors that prevent a 'near miss' becoming a catastrophic failure. Much depends on early identification of a developing internal erosion problem. In several incidents the problem was not detected during routine surveillance, but it would seem unwise to rely on the keen powers of observation of dog-walkers or of horse riders! Frequent surveillance visits are essential and a key issue is how frequent the visits should be. In recent years modern telemetry and remote sensing equipment has reduced surveillance frequency at some dam sites. This trend is not widely welcomed as remote monitoring is not an effective substitute for trained personnel regularly visiting dam sites. The demise of the Victorian approach of having a reservoir keeper for each dam (often housed at the dam) is lamented by many in the industry