Lack of Robust revetment: The transition from bridge to revetted side slope is very short. With the need to dissipate energy from Taplow Sluice, good practice would have seen the use of a heavy and robust revetment for a significant length downstream from the bridge.

Normal practice would be to use rock or gabion baskets. The actual material used was Dycel blocks which have been found by inspection to be inappropriate for the turbulent conditions.

3.3 Marsh Lane Weir

The Marsh Lane Weir is situated approx. 2km downstream of Taplow sluice. The Weir is reinforced concrete directly upstream of the Marsh Lane road bridge. There are two tilting gates which under normal condition are in a raised position. There is a fish pass that takes the low sweetener flow.

The damage to the bank of the Jubilee Channel was clearly visible downstream of the Marsh Lane Road Bridge during January 2003.

When flow passes through Taplow, the Marsh Lane gates operate automatically, lowering onto the bed of the structure.

Details of the condition were recorded in the Condition Assessment Report of May 2003.

The structure was designed so that the design flow of 215m3/second would pass through the two gates fully open.

Remedial works incorporating gabion mattress to the right hand bank and steel sheet piling and rock protection to the left hand bank were completed in the Summer of 2003.

In January 2003, during the flood, the Agency overrode the automatic control at Marsh Lane by setting the gate height at 50% open. This decision was taken to keep upstream water levels high and thus minimise damage at Taplow.

At Marsh Lane, damage was observed immediately adjacent to and downstream of the concrete bridge wing walls. Erosion of embankments occurred and if left unchecked, could eventually have resulted in undermining of the bridge.

The banks on both sides were unrevetted and suffered from erosion and toe scour. The left bank was of particular concern due to the loss of the Agency Access Road adjacent to the river.

The causes of this failure are similar to those at Taplow Sluice, with high-energy generated by flows through the partially open gates and bridge openings passing into the trapezoidal channel.

The primary inconsistency at this location between normal design practice and the constructed works concerns the extent of the revetment and protection to the main structure.

This issues now briefly discussed:

Bed armouring adjacent to the Marsh Lane Bridge. At Taplow Sluice, the lack of stilling basin is a major factor. However, at Marsh Lane, this is potentially less critical as the jet from tilting gates tends to be dissipated locally to the gates themselves. That said, the scour immediately downstream of the structure, is evidence that insufficient consideration was given to potential erosion.

Bank Protection adjacent to the Agency Access Path. The erosion of the unrevetted banks downstream of the structure would not be an issue if there was sufficient embankment. However, the Access has no erosion margin and any erosion could not be tolerated.

3.4 Manor Farm Weir.

The Manor Farm Weir was constructed using a central cut off core wall built of pre-cast concrete box culverts which carry the Roundmoor Ditch beneath the flood channel. A concrete crest was cast on top of the culverts and this culvert core was curved in a downstream (convex) plan which had the effect of diverging flows towards the sides of the channel.

The weir itself was constructed of cable tied revetment blocks overlying a geotextile layer, the infill of the weir being as-dug ballast.

In January 2003, there was massive damage to the weir structure and to the banks downstream.

The principal damage was:

- Loss of the Weir Apron.
- Loss of Material from the Weir.
- Extensive bank erosion on both banks downstream of the weir.

During our evaluation of these works, we estimate that the velocities on the downstream face of the Apron during a flood event would probably be very high, i.e. in the order of 6 – 7 m/s, during the January 2003 event.

This is significantly higher than recommended by RPC, the manufacturer of the Dycel Blocks for this works. In order to withstand these velocities a particularly robust structure would have been required. It was immediately apparent that the structure provided had a number of shortcomings; these are as follows:

- The Apron lacked durability and failed as a result of the high velocity flow and turbulence.
- There is some possibility that there was seepage beneath the culvert which caused uplift on the Apron.
- The convex plan shape of the weir created high-energy jets along the banks of the river. These jets would be aggressive and led to severe erosion of the embanked river sides downstream.

These points are now discussed.

Durability of the Apron: The use of cable tied concrete revetment blocks in a weir apron construction is unusual, though not unique. There are a number of factors which the blocks have to withstand such as velocity of flows down the apron and the turbulent forces exerted by the hydraulic jump as it moves upstream on the apron as the flow increases.

Most work on cable tied concrete block revetment has been carried out where the system has been used as bank protection work on channels.

In 1989 CIRIA published a book on the "Protection of River and Canal Banks", stating that concrete blocks:

The damage to the Apron of the Weir and the scour to the banks was clearly visible during the January 2003 event. The Environment Agency were concerned about the integrity of the right hand bank during the event and undertook piling and emergency sandbagging to prevent a breach of the embankment. The designers were asked to confirm whether the failure of the apron could cause collapse of the internal culvert.

Immediately after the flood event, the Agency instructed emergency works to be completed to the apron by filling the voids with concrete and making good the surface.

Details of the condition were recorded in the Condition Assessment Report of May 2003.

Remedial works incorporating a re-orientation of the weir, vertical wing walls, a new concrete slab apron and rock scour protection were completed in the Summer of 2003.

".....can be expected to be hydrodynamically stable in velocities in excess of 5m/s. However failures have been observed at lower thresholds mainly attributed to poor design of the underlayer, surface deformation and poor edge detailing".

In addition the guidance states:

".... such blocks may not be suitable for use in areas of particularly high turbulence such as occur locally downstream of weirs and stilling basins".

It seems that some consideration was given to the high loading as ground anchors were added to secure the apron surface.

The use of the Dycel block and ground anchors for the Weir apron is a design which has little track record and therefore its use was a novel one.

Within the constructed works, there were a number of potential shortfalls which could either individually or in combination lead to failure, as follows:

- The Dycel block system is flexible; ground anchors would only secure the particular block through which they were placed. The tensioning of the blocks would have made the surface uneven, potentially raising the edges of adjacent blocks.

- The apron blocks were anchored down into the gravel underlayer by Platipus anchors. These were inserted through a central hole in the revetment blocks at layered staggered spacing. The inserted anchors were intended to have a working load of 15kN. Testing, in July 2003 (21 months after completion), of similar anchors at Manor Farm Weir and Slough Weir have shown that at the time of testing the residual capacities varied from only 0.5 to 3kN.

- The anchor head arrangement was a stainless steel inverted top hat plate which sat inside the centre hole in the revetment. The stainless steel tendon from the anchor was threaded through the plate, stressed and then locked off by clamping a copper ferrule around the tendon. It is understood to be a failure of this ferrule to provide sufficient friction grip to take the load, either due to bi-metallic corrosion or in the initial clamping, that caused the anchor head to fail during testing.

- The central hole used for fixing the ground anchors was provided by introducing a block with 12 voids. The geotextile beneath was cut and the anchor pushed through. The resultant works, therefore provided a route by which fines (and water as a possible flushing agent) from the granular material beneath could migrate through the slits in the geotextile and through the voids in the Dycel.

Our preliminary view is that the most likely mechanism of failure was as follows:

- Increased velocities caused the Dycel blocks to move, either due to reduced pressures above the block surface or forces from the hydraulic jump moving along the apron.

- The blocks became displaced and were then subject to drag forces.
- The interlinking cables cause adjacent blocks to vibrate and displace.
- The mats start to vibrate and "pump" the saturated gravels below the apron.
- The saturated gravels began to slump down the apron retained by the geotextile fabric.
- As the sliding continued the geotextile is sliced by the anchor tendons, releasing the core ballast of the apron to wash away.
- The action of hydraulic forces caused the fill to be expelled from the slits in the geotextile that were made in order to insert the anchors.

Erosion Downstream: During the flood in January 2003, there was extensive erosion and undermining of the embankment immediately downstream of the protected sections on both banks. This would indicate that consideration had been given to the provision of bank protection, but the extent was too limited.

The causes for the wide extent of erosion are seen to be as follows:

- The Convex plan shape of the weir, arching downstream, is unorthodox. Normally the plan would be reversed so that the concentration of flow is centred into the middle of the channel, the weir structure thereby 'arching' upstream the better to resist the forces and the concentrated flows allows some energy dissipation. In this case clear jets were seen to form along the embankment.
- The weir is approximately 100m wide at its crest; however, the channel quickly narrows down to its nominal 35m, channel width. This narrowing over a short length would have contributed to the causes of failure.

3.5 Slough Road Weir

This weir is a 57m long broad crested crump weir that is curved in-plan in an upstream direction. The central cut off core of the weir is steel sheet piling driven into the clay sub-layer. The piling has a concrete capping which forms the crest of the weir and extends into the bank on either side of the weir.

During the January 2003 flood, some movement of the apron was witnessed, however, the structure did not fail.

The upstream apron has a slope of 1:2 and extends down into an 800 mm thick rip rap revetment with a 600-800mm grading size. The downstream apron slope is 1:5 and the block surface extends 19.65 m (measured horizontally) and is then tucked down into a 1200mm thick layer of 900-3000mm graded rip rap laid over a 400mm thick layer of 150-70mm graded stone.

During the summer of 2003, temporary remedial works were completed whereby additional platipus anchors were installed across the apron.

The apron is constructed using a cable linked articulated concrete blocks 500mm long, by 400mm wide, and of 100mm thickness. The blocks are laid over a geotextile layer to prevent the washing out of fine material from the ballast core. The blocks are held down by duckbill type anchors, supplied by Platipus, and installed on a 1 m grid. This block and anchor system was used for the bank protection adjacent to the weir.

Assessment Residual Anchor Strength

During the January 2003 flood, some movement of the apron was witnessed. However, the structure did not fail. Initial inspection after the flood found that over 50% anchors were loose when pulled by hand and could not take the load of 10kN as designed. 21 anchors had actually lost both the top hats and the ferrule that secured the top hat to the anchor cable.

Load tests were attempted on the anchors. Only 9 were found to offer sufficient resistance to allow the test to be conducted. All of the anchors tested failed to meet their design load.

Failure Mechanisms

This failure of the anchor system after one flood is of concern to the long term durability of the structure. Without remedial works, a failure mechanism similar Manor Farm Weir can be expected.

4 Flood Embankments

4.1 Desk Top Risk Assessment

In order to determine whether the embankments of Jubilee River would continue to be durable after completion of the remedial works, a desktop risk assessment has been undertaken. The purpose of this assessment is to remedy any areas of potential weakness in the embankments and to direct future maintenance.

The risk assessment has been undertaken by using a "Source → Pathway → Receptor" Risk Model, where the three elements are as follows:

- The SOURCE: The flow in the river is the source of risk (being a combination of high water level and erosion potential).
- The PATHWAY: The type of bank / embankment / wall and potential flowpath is the pathway to any Assets. (E.g. An embankment raised above the surrounding ground would become a pathway if the embankment were to breach.)
- The RECEPTOR: The Assets that may be affected by the source. (E.g. A property near the river.)

4.2 Classification

The pathway has been classified into three Categories as follows:

- CAT A: Low Resistance to Erosion - Steep Unrevetted Embankments (Critical).
- CAT B: Medium Resistance to Erosion - Steep Unrevetted Embankments (with some erosion allowance).
- CAT C: High Resistance to Erosion - Vertical Wall or Revetted Bank or Slack Landscaped Banks (erosion would not require action).

Receptor has been classified into three Categories as follows:

- CAT 1: High Consequence - Property or Commercial Activity adjacent to River or Low lying properties where there is a direct flowpath from the Jubilee River or Steep Hill / Embankment adjacent to River (A Steep embankment is deemed high consequence, should toe erosion undermine the slope and cause a bank collapse).
- CAT 2: Medium Consequence - Properties near the Jubilee River.
- CAT 3: Low Consequence - No identifiable Risk.

4.3 Outcome of Assessment

The analysis was based on inspection of the OS mapping, Agency Videos & Photos and records of site visits. The full analysis is presented in Figure 1,

The overall risk assessment results are as follows:

C. High Resistance	8.1%	3.1%	23.9%
B. Medium Resistance	19.9%	16.4%	24.6%
A. Low Resistance	3.1%	0.9%	0.0%
Consequence	1. High	2. Medium	3. Low

The 3.1% of A1 "Low Resistance / High Consequence" is situated in four areas. These are as follows:

- Both banks (i.e. 2 areas) downstream of Mill Lane for approximately 200m. In response the Agency is progressing with physical modelling of the Taplow Sluice, Mill Lane Bridge and downstream channel in order to determine the most appropriate structural solution. Until then the Agency is monitoring the situation and is able to respond if required.

This area of risk is due to the high turbulence caused by the Taplow Sluices.

Analysis using a physical model is proposed for this summer so that the extent of protection required can be determined.

- Left bank downstream of Myrke Footbridge (u/s of Pococks Lane Bridge) there is 300m of critical embankment. The Agency has a contingency plan in place and is undertaking remedial works this summer.

The need for remedial works to this embankment were first identified in November 2003 and are to be constructed this summer.

4.4 Comparison between Design Levels and 'As Built'

A review of the embankment levels has been completed at the locations limiting the capacity of the channel, these are as follows: Eton embankment (RHB) upstream of the Pococks Lane Bridge; upstream of the A355 (both banks) and at the offtake adjacent to Glen Island (RHB).

In these locations the surveyed bank levels are below the design level shown on the drawings. The findings are as follows:

Location	Length affected (m)	Design Level (m OD)	Typical Surveyed Level (m OD)	Shortfall (mm)
Glen Island	100	24.30	24.20	100mm
Chalvey (Left Bank)	600	20.68	20.45	230mm
Chalvey (Right Bank)	100	20.68	20.50	180mm
Eton Fields	300	20.18	19.98	200mm

The comparison of actual levels to design levels has been recently completed as part of the hydraulic review.

The surveyed levels have been derived from FLI-MAP. The levels for Eton Fields have been confirmed by reference to land survey data.

4.5 Stability of the Myrke Ditch Embankment, left bank upstream of Pococks Lane Bridge

Investigations and options for remedial work were completed between December 2003 and February 2004.

The Myrke Ditch Embankment is approx. 300m long, situated upstream of the Pococks Lane Bridge on the left bank. During extreme flows the embankment will serve to contain water levels in the Jubilee River above the surrounding land. It was built with side slopes graded at 1 to 1.5, using locally won material to raise the embankment above the local ground levels. The embankment does not contain any core, so some seepage would be expected.

The Desk Top Risk Assessment categorised the pathway as "CAT A: Low Resistance to Erosion - Steep Unrevetted Embankments (Critical)" and the receptor as CAT 1: High Consequence - Low-lying properties where there is a direct flowpath from the Jubilee River".

Atkins and the Agency carried out a visual inspection and identified visible signs of bank movement such as tension cracks along on the crest. In December 2003, further investigations were completed including topographic surveys, bathymetric surveys and ground investigation.

The steep side slopes will be subject to shallow slips failures and erosion, which could either abruptly breach during a high flow or gradually collapse with time. The narrow top width reduces the ability for safe access and increases concern over the long-term robustness of the embankment. The bank also shows signs of movement, possibly caused by the lateral loading of the high water level during the January 2003 flood.

Based on the surveys and analysis of the embankment, it is below standard and will require reconstruction. Construction works have started and are due for completion in October 2004.

5 Consequences of the Scheme

The construction of the Jubilee River and its associated works has altered the way floodwaters move and flow along the Thames floodplain.

There now follows a brief summary of the locations where the flooding in January 2003 may have been altered by the Jubilee River and its associated works.

5.1 Review of the flooding at Strande Lane, Cookham

As part of the Maidenhead Windsor and Eton Flood Alleviation Scheme, works were constructed along the right bank of the River Thames upstream of the Jubilee River. Their purpose was to protect properties at North Maidenhead from flooding.

Pre-feasibility Report completed in Dec 2003. Recommends works to Channel

The works included the following:

- A flood embankment built 1.2m high along the northern edge of Maidenhead.
- A control structure on the Maidenhead Ditch which limits flow down this watercourse.

A feasibility report is currently being prepared.

The works were completed after the previous flood of December 2000 and significantly changed the hydraulics of this area.

During January 2003, Cookham was affected by flooding. There was flooding of gardens, common land and Strande Lane was inundated. Whilst the event was recorded as the worst since 1947, there was concern from the local residents that the new works had made matters worse.

The Agency instructed Peter Brett Associates [PBA] to undertake a flood study and determine the cause of flooding and identify proposals for remediation.

The PBA study concluded that the 1998 works had increased the depth of flooding at Strande Lane and have identified a range of options to remedy the situation.

5.2 Roundmoor Ditch

As part of the construction of Manor Farm Weir, the Roundmoor Ditch required a 200m diversion channel to be built to extend the ditch so it could flow through the culvert within Manor Farm Weir and pass under the Jubilee River. Although the diversion channel was constructed, its left bank was not raised sufficiently to form a flood bund to prevent flood flows exiting the channel.

Flooding from the Roundmoor Ditch occurred in January 2003 and it was found that the ditch embankment had not been constructed as shown on design drawings.

During the January 2003 event, floodwaters overtopped the Roundmoor Ditch from the new diversion channel, flooding both a gas transfer station and a public footpath. Review of the works since construction has highlighted the following:

- The channel had migrated towards the left bank resulting in insufficient land, within the CPO boundary for easy construction of an earth embankment.

Subsequent implementation of the original design has been difficult due to a lack of working area.
Contingency plans were put in place for this winter.

Current proposals are being

- Water Voles had established a presence in the diversion channel and would require specialist measures for their removal.

discussed with Thames Water.

Following discussions with the Agency on the above issues an options report was produced which outlined different permanent design scenarios. This is currently being assessed by the Agency. The presence of water voles and the possible requirement for additional land purchase precluded the construction of the bund during Summer 2003.

5.3 Cole Norton Brook

Cole Norton Brook runs parallel to the Jubilee River for a length by Manor Farm. When the right embankment on the Jubilee River suffered severe erosion, emergency works were undertaken to stabilise the embankment.

Before the piling work could begin on the embankment dividing the Jubilee River & the Cole Norton Brook (& Eton Wick etc) 1 tonne builder's bags of sand were placed on the Cole Norton Brook side of the embankment to add immediate strength to the failing embankment. Piles were then driven through the embankment.

The effect of the builder's bags was to block the usual course of the Cole Norton Brook as it flowed at the toe of the embankment. The Agency created an emergency diversion for the Brook to allow it to flow round this obstacle. Plant was used to excavate a new channel.

5.4 Black Potts Viaduct

During the January 2003 event flood water overtopped from the eastern side of Jubilee River upstream of Black Potts Viaduct. The water flowed onto the adjacent public footpath and passed under the arch of the railway viaduct. Downstream of the viaduct an area of low ground extends to the east, adjacent to the railway embankment.

A temporary solution was implemented in summer 2003 by constructing a low bund.

A permanent solution is being considered.

6 Summary and Conclusions

This report has highlighted a series of issues relating to the performance of the Jubilee River and its associated structures. Many of these issues were addressed during the summer 2003. However, since then continued analysis has highlighted a series of potential shortcomings which will need to be investigated further. This has led to a series of ongoing actions, these are briefly as follows:

Studies and Investigations:

- Ongoing assessment of the Hydraulic Capacity and options to restore original capacity.
- A physical model is being developed to determine the revetment requirements downstream of Mill Lane Road Bridge.
- Design for works to Slough Road Weir, options for protecting the golf course downstream of the Black Potts Viaduct and Strande Lane.
- Discussions are in hand with Thames Water to address the flood risk from the Roundmoor Ditch.

Works proposed for this summer:

- Remedial Repairs to the Myrke Ditch Embankment.
- Reinstatement of the footpaths damaged by the remedial works at Manor Farm.