15 Years of Experience with a Dam Improvement Program

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Goulburn-Murray Water is a rural water corporation located in Northern Victoria. It has responsibility for 12 State dams and is also the constructing authority for the Murray Darling Basin Authority's Victorian assets.

Over the past 15 years G-MW has been engaged in a dam improvement program across its portfolio. To date 14 individual projects have been undertaken at 11 dams. The total expenditure is $125 million.

Starting from a base level of data at its inception in 1997, the program has encompassed all facets required for a dam improvement program. From early prioritisation to set the investigation program, through design reviews and risk assessments to develop the upgrading program and subsequent implementation. Some elements of the program were at the leading edge of practice at the time and a range of experiences along the way were character building as dam safety investment challenged other corporate priorities.

This paper sets out the lessons learned in developing the methodology and implementing the program of works, particularly relating to corporate adoption of the program, organisational capability, investigations, risk assessments, design and implementation.

Introduction

Goulburn-Murray Water (G-MW) is a large Rural Water Corporation located in Northern Victoria. It is responsible for the operation, maintenance, renewal and dam safety programs for twelve State dams and four Murray-Darling Basin Commission storages. The assets, including Eildon dam, the largest state storage and Dartmouth, the highest earth-rockfill dam in Australia, have a current replacement cost of $2.2 billion.

When G-MW was allocated responsibility for managing the dams in 1995, the Corporation was faced with several major challenges including: a number of design deficiencies across the portfolio; inadequate funds held by the Authority to quickly address the backlog of deficiencies; and a need to prioritise the necessary works.

G-MW chose to use a comprehensive Business Risk Assessment of all its dams as a framework for planning decisions on maintenance, renewals and dam safety reviews. The details of that process were published in ANCOLD Bulletin No. 107 (Howley and Stewart 1997). However, whilst strategic minor capital and maintenance programs were in place, no funding source had been identified for major design deficiency upgrading works.

In October 1997 the Victorian Government announced a State-wide Water Reform Package, that provided G-MW $18.5 million toward a five year Dam Improvement Program for the thirteen (at that time) State dams. A condition of the grant was that customers would contribute approximately an equal amount to the Program through price increases.

Early in the program a comprehensive risk assessment process established that the time required to complete the works needed would be well beyond what had been envisaged by Government at the time the initial funding was announced. Now, some 15 years later, G-MW has completed most of the major works for the improvement program.

Engagement with Decision Makers

Dam improvements are often expensive, do not normally deliver additional revenue for a business and therefore can be a somewhat unwelcome request for investment.

Usually the Board of the dam owning organisation is the key decision making body. However, just as importantly, careful consideration must be given to other stakeholders, such as those who will pay for the program, those impacted by the works, government, regulators, planning authorities, emergency response agencies and other key internal senior managers not directly associated with the program.

In establishing G-MW's program, a great deal of time was spent in building knowledge and confidence within the Board and senior management. Initially, an independent Expert Panel was assembled to review the proposed approach to developing the program and then to report directly to the Board on its findings. The three person panel was made of prominent professionals in the fields of dam safety, risk management and community consultation (Mr Mike Fitzpatrick (Panel Chairman and retired Deputy General Manager, Hydro-Electric Corporation, Chairman of ANCOLD 1988-91), Dr John Smart (Dam Safety Officer, USBR) and Dr Geoff Syme (Director Australian Research Centre for Water in Society, CSIRO).

It was recognised that the program would affect a diverse range of people, many of whom had little understanding of the risks posed by dams. For the process to be successful it was essential that broad acceptance of the risk assessment process and how it applied to the G-MW portfolio be gained by the wider community. Therefore, a stakeholder reference panel was established consisting of representatives of customers, affected local government, the dam safety regulator, police and emergency services, Farmers Federation and other government agencies with a potential interest in the program. (Davidson et al 2002)

The Stakeholder Panel also reported directly to the Board on its findings regarding the process of risk determination, risk-based priorities and the value of stakeholder involvement. Recommendations were made in relation to funding, emergency planning and ongoing communications with the community. This broad acceptance of the program assisted throughout its life as the focus moved from "why are you doing this work" to consideration of each project in providing value for money reduction in risk (McGrath et al 2006).

The initial information and education process with G-MW's Board was facilitated by there being a "Headworks" Committee that had the capability to review information in more detail than would normally be possible for the full Board. Also important was the skills basis of the Board, which included a retired engineer with a wealth of experience in dam construction, including with some of the dams in question.

Whilst there was general acceptance of the program by customers who were at that time funding 50% of the cost, it is fair to say that many customers were uncomfortable with investment in safety beyond their perceived requirement for water security. It was therefore important that they remained informed and engaged as works progressed. Ultimately, the success of this program could be measured by acceptance to pay 100% of the cost for later upgrades as government co-funding was used up.

Once key stakeholders had gained confidence in the basis for the program it was then critical that confidence be maintained in delivering the program through project by project success. This was achieved and is reflected in the Board's continued support for the program despite some variations to program and cost. This support has continued through changes to Board personnel, including, later on, when the Board no longer retained specific skill representation in relation to large infrastructure works with public safety implications.

G-MW's dam improvement program primarily focussed on addressing life safety risks in the first instance with reduction of other business or financial risks considered once high life safety risks had been reduced. Agreeing this approach with decision makers, funders and stakeholders was a critical early step in ensuring a clear direction for developing the subsequent works program. The risk assessment process and setting of staged risk reduction targets is described in Davidson et al (ANCOLD 2002).

Safety Evaluation

Where full, detailed safety reviews of dams have not been previously performed, the time required to complete the studies can be considerable and the costs high. Since this work is the foundation of the decision making process for upgrading works it must be tightly managed.

In undertaking safety evaluations, it was valuable to work through failure modes analyses at the commencement of the process. This focussed attention on those areas most likely to have safety issues and to direct design and site investigations accordingly. To gain the most value from this process it was important to ensure that all relevant design, construction and operations and maintenance data for the dam was available, including information from any personnel who worked on the original design and construction and field personnel who have operated and maintained the dam. Visits to the site by personnel with prior knowledge of the dam were found to be very useful.

Investigations are often expensive time consuming and can give rise to a slightly increased risk to a structure. It is therefore important that maximum value is obtained for the business from the effort put into collating existing dam data. This means that the data must be carefully logged and filed for future management use, rather than being seen only as an input to the improvement program. G-MW found it helpful to include the references in the dam safety review reports.

Site investigations are critical to providing greater confidence that issues of concern are exposed. On more than one occasion targeted exposure of the dam core and other trenching revealed significant cracking or features not previously known and critical to evaluation of the safety of the dam.

Figure 1 – Cracking discovered in Buffalo Dam core during site investigations (2001)

The question of bore hole and CPT investigations along with the installation of additional instruments into embankment dams is a serious one. Whilst there can be risks involved in undertaking the work, balanced against that is the potential to gain valuable data on the condition of the embankment. G-MW decided this on a case-by-case basis, aiming to ensure that the need for data was properly balanced with the risk of the work. In other words a targeted approach was employed.

If significant penetrations are to be made into the dam it is most important that the owner take direct interest in these activities. Key areas for focus are that the supervising engineer and contractor are suitably qualified and experienced in the work being undertaken and that the work is well understood and carefully supervised. Of course, the equipment must be correct for the purpose and in good condition, the technique for backfilling must be suitable and tested (e.g. bentonite mix) and the methodology must ensure that there is no potential for high pressure water or compressed air to be introduced into the hole.

A lot of time and effort was spent in analysis of outlet works. This was justified, but it was usually found that outlet works risks were business risks and therefore not at the highest priority in G-MW's portfolio. However, this is not to say that these and other mechanical and electrical components are not important. Through the program it was found that assumptions made about the reliability and adequacy of equipment could be proved to be quite wrong once detailed investigations were undertaken, particularly where risks associated with operators were properly included. If possible, these investigations and associated analysis should be run in parallel with the overall program.

G-MW gained great value by ensuring that expert reviewers were part of safety reviews and risk assessments. It was beneficial to gain their input as early as possible in the process so that there is not the possibility of losing ground if there were differences over aspects of the work. It is recommended that the reviewers be carefully selected for their expertise and retained, as far as possible, for continuity through the program. Precedent and current practice is an important consideration for owners' decisions. The expert panel can help with this through broad range of experience and current knowledge of industry practice.

In establishing expert advisory panels it is important to establish a sound understanding of the roles of each party – the owner, the experts and the consultants doing the work. Expert advisors are not decision makers -, only the owner can do that and it is important that the design team retain responsibility for their design.

To assist in the risk assessment and decision making processes to follow, G-MW found it useful for the safety review outputs to include concept based designs and preliminary cost estimates for works to address the main deficiencies.

Risk Assessment

Risk assessment was approached in a staged manner. Firstly, a "portfolio" level assessment was undertaken. These outputs were then used to identify priorities for detailed dam safety evaluations.

It is not possible to undertake a reliable detailed risk assessment required for decision making without the detailed information from site investigations and the consequent dam safety evaluation. If an owner has many dams, then it is unlikely that sufficient internal and external resources will be able to properly manage this process for more than a few dams at one time.

In effect, the program was developed in two stages, with the first priority dams investigated and a detailed risk assessment completed to derive priorities for works. Then while the works program for the first priority dams was underway the process was repeated for the remaining dams, a complete and updated risk profile produced for all dams, then priorities determined across the full portfolio.

The approach to prioritisation of works was to reduce risks above the limit of tolerability first, generally from highest to lowest, but also taking into consideration the level of risk. Therefore, at one particular dam, a first staged risk reduction project was undertaken as a priority due to very high risk. However, the second stage was not scheduled for several years later so that other high risks could be addressed in the interim. It is also a matter of balancing available resources within the business and industry to a realistic schedule of risk reduction. In addition, the practicality of works was also considered. For example, a small project which was nearby to a large improvement project was undertaken in conjunction with the larger project, since it was a small investment in time and could be undertaken most efficiently that way.

Where high risks were identified and structural works to reduce risk could not be quickly implemented, other non-structural interim measures were implemented. This included actions such as restricting FSL, upgrading and testing dam safety emergency plans, increased surveillance and stockpiling filter material and fill on site to enable emergency response to a piping incident should it be necessary.

G-MW's business risk management framework included sufficient granularity in evaluation to allow better comparison of dam safety risks against the more usual business risks (Stewart et al 2007). As dams with risk above the limit of tolerability scored as high risk, these projects received priority in addressing risks across the whole business. Once risk was reduced to a comfortable margin below the limit, then all dam life safety or dam related business risks were considered alongside all other risks. In other words societal or individual risk above the limits were addressed ahead of dam related business risks.

In relation to consequence studies, initially, as much time and effort was put into economic consequences as life loss. As the work progressed, it was found that the level of effort required to derive realistic estimates for economic consequences was much less than initially committed. More recently, much greater effort has been put into gaining the best possible data for life loss as this has been the primary driver for works. More sophisticated life loss methods, such as HEC-FIA, have been employed at two dams where estimates of risk are close to the limit of tolerability and the need for and timing of future upgrades are not clear cut (Lang et al 2011). Supplementing this is the use of much better survey data now available through newer technologies such as Lidar which enables development of higher resolution dam break and inundation mapping.

As an output from the consequence study, owners should ensure that the data on flood travel times, flood depths and building locations makes its way into the Dam Safety Emergency Plans as it is valuable for emergency management planning for potential incidents.

Owners' personnel need to have a solid understanding of the risk assessment results and therefore, it is helpful if the process of risk assessment and the methodology are as transparent as possible. This will assist in ensuring that the process can be adequately reviewed and communicated to stakeholders. In addition, the risk assessment outcomes must be able to be presented in a form that decision makers can readily understand and become familiar with. It is worth stressing that once a Board becomes informed in relation to the risk reduction process it is most helpful to ensure that the data continues to be presented in a consistent manner over time.

It was also important that that decision makers understood that whilst the risk assessment results were the best that could reasonably be achieved, the level of uncertainty applying to the results was high. As the risk reduction was being achieved with a long term target to reach a standards based outcome, this is acceptable, provided that recommended works were compatible with what would ultimately be required to address the deficiency. Given that the interim target was to achieve a level of safety below the limit of tolerability, the aim was therefore to achieve a reasonable "margin" below the limit of around a half to one order of magnitude.

Decision makers also need to understand that the safety review and risk assessment process is ongoing and necessary to demonstrate due diligence. Therefore, there should be an understanding that the calculated risk may well change over time as more information comes to hand.

An assessment was also made as to whether the works would meet the ALARP considerations set out in the 2003 Risk Guidelines (ANCOLD 2003). ALARP remains a challenging concept for the industry, particularly in regard to balancing CSSL against the other measures such as good practice, level of risk, societal concerns and the *de minimus* principle (Allen at al 2006), (Somerford et al 2007). To date, the question of whether it is satisfactory to upgrade all dams to a level just below the limit, as would be indicated by a purely CSSL approach, has not been resolved either way. G-MW took into account the inherent uncertainty in the risk assessment process and the views of its expert and stakeholder panels when formulating its program.

Figure 2 – Dartmouth Dam Model Study Project (2009).

Use of risk assessment models in assessing the relative merits of alternative upgrade options, the adequacy of interim upgrades in meeting risk targets and evaluating construction methodologies has been a fundamental component of the dam improvement program. Techniques to estimate risk have developed significantly over the duration of the program and it remains a valuable tool to interpret and compare engineering information and communicate this with key decision makers.

Personnel

It is essential that the owner has sufficient, experienced personnel to manage an improvement program and ensure that the decision making processes are developed and lead by the internal resources. It is not appropriate, or possible, to outsource this aspect of the program.

The program was structured to use a small tight knit group of technical staff, with a clear understanding of the objectives of the program and very focussed on achieving targets whilst maintaining dam safety.

Most importantly, clear accountabilities for outcomes were established within the team. Overall control was vested in one person, with internal audit provided by the independent dam safety engineer and external audit by the expert review teams. Once priorities for works had been established and a project identified, accountability for detailed design, planning, stakeholder management and construction/commissioning was vested in one person. This arrangement ensured that there was little chance for misunderstanding about where responsibilities for progress and outcomes lay.

Effectively, for each project a leadership team was established of the asset owner (operations and maintenance), the program owner and the executive (dams' business functional manager) whom the project manager reported to. The leadership team was supported by expert technical advisors and users of the asset, whilst the project manager was supported by the various off and on-site teams assembled to undertake the project.

This approach was developed for the program and later, when G-MW introduced an organisation wide project management system (Prince2), it was noted that the independently developed approach matched the Prince2 approach very well.

Community Engagement

Being located centrally within a rural customer base G-MW has always been well connected to its customers and has significant customer input into its general policy and decision making.

Previous experience with large projects had also taught senior managers the importance of engaging both with the stakeholders responsible for funding the program and those affected by each individual project. This logical, transparent process of establishing dam safety investigation and implementation priorities described above was also key to aligning internal stakeholders with local communities.

G-MW's dams and catchments are not closed and are part of and highly valued by their local communities. It was therefore quite natural for G-MW to establish a community reference group for its first major project with significant community affects; the Lake Eppalock embankment upgrade. Key lessons learnt on this project were the need to:

- Fully understand potential environmental issues and ensure that these had been well considered in project planning.
- Communicate by as many means as possible such as regular advertisements in the local papers, brochures, and letter drops, freecall lines, radio interviews, briefing local councils and simply meeting and talking to people to listen.
- Engage with a community reference group whose members were well connected to their local community, and,
- Respond quickly when an issue arose.

These principles were refined and given a different emphasis on each subsequent project depending on the issues at stake.

For instance works at Yarrawonga Weir required a strong community focus as the weir is located almost in the heart of a regional community whose economy is strongly linked to the water based activities that the Weir supports (Fox & Tansley 2003). Conversely many community issues at Lake Buffalo were legacy issues from the original dam's construction decades before and required a very different approach.

However, the $46.5M Eildon Dam Improvement Project required the Dam Improvement Program's largest community engagement effort.

G-MW understood that community issues could "make or break" this project, with the potential to delay or even prevent these essential works from being undertaken and that early community consultation was essential. This process commenced long before the start of detail design and construction activity.

The local community was initially engaged in the project through surveys, stakeholder workshops, a presence at community events, a project shop front in Eildon Village and through presentations to Council and local community groups. Following this initial consultation a carefully structured community reference group was established with key community leaders involved and regular media interviews and briefings kept the community up to date with the project status.

Figure 3 – Former Victorian State Premier – The Hon Steve Bracks officially opening the upgraded Eildon Dam in 2004

The outcome of this effort was that the project team understood the local communities' values very well in the project detail design phase when key approaches were being formulated.

This meant that alternative and cost saving approaches could be explored with the local community with confidence that they would be supported by Council.

The Eildon project directly benefitted by being able to

- Re-open an old quarry adjacent to the site, even though this quarry was subject to "Heritage View" zoning,
- Work two 10 hours shifts in this quarry, despite its proximity to Eildon and the potential to greatly exceed background noise levels,
- Establish cost effective borrow pits and haul roads,
- Close off valued recreation areas through the works without conflict, and,
- Generate considerable cost savings during construction by effective management of the local rock source.

Key indirect benefits came from being able to access a reliable supply of rock mitigating both a key dam safety risk and a significant program risk and by providing an ability to flexibly manage site construction issues that had the potential to affect production.

In particular the Eildon Dam Improvement Project demonstrated that effective community consultation can be fundamental to the success of a project and can provide significant time and cost savings, whilst facilitating community ownership of the project outcomes.

Throughout the Dam Improvement Program the overall support and goodwill of the local community was understood to be an essential component of project success and for that reason the community and environment aspects of each project were appropriately resourced. This emphasis on engagement with local stakeholders was an indispensable component of the success of each project, and as a result the overall program.

Construction Management

Management of construction was based on two key philosophies that guided all activity – processes must ensure a quality product that achieved the design intent and works were to be undertaken in a manner that did not impact the safety of the dam.

One of the most fundamental practices adopted was a direct management approach for site works. This approach was identified very early in the program as being the best to ensure project risks were assigned to the parties most able to manage them (Fox & Fyfe 2000).

Adopting the direct management approach provided the flexibility to adapt to changing project requirements without the potential commercial impacts associated with alternative contracting arrangements. Benefits of the direct management approach included:

- an ability to delay/accelerate works due to weather or storage requirements;
- a lower risk of cost variations due to disputes;
- tighter control over excavation/placement rates in embankment works;
- greater ability to respond to local community requirements if required;
- reduction in timelines to commence the construction phase due to reduction in tender documentation (important where a limited construction window existed due to storage level or other constraint or a high risk was identified with urgent remedial action desired)

A further issue to be considered was that many times "as constructed" drawings, where they existed, did not accurately represent what had been constructed. During the program this was found to be a common occurrence and one that usually resulted in additional rather than less costs. Often these works uncovered construction details that were thought to be acceptable at the time of construction but are now seen as undesirable given our current understanding.

To be successful this approach required a management team incorporating broad experience in dam design and construction. An essential part of this team was an experienced site supervisor directing construction resources in conjunction with the site based engineering team. This management structure also provided an excellent environment for the development of staff.

Extending this concept, G-MW endeavoured to have the same G-MW personnel manage the project through both the design and construction phases. This provided the construction team with insight into the design intent, planning and community issues and early identification of project risks. It also ensured that construction practicalities such as sequencing of works to manage construction risk, sourcing of materials and development of emergency response plans were considered during the design process.

While the appropriate team was established depending on the needs of each project G-MW mostly undertook earthworks by direct management of hired equipment and drew on specialist contractors to undertake activities such as structural concrete, installation of post tensioned anchors and specialist foundation treatments. Generally a small team comprising a project manager, supported by a resident engineer (managing all on-site activity), was responsible for the delivery of the project. This model of a small, focussed team with a single point of accountability and clarity in decision making responsibility was fundamental to the efficient delivery and success of the program.

Figure 4 – Yarrawonga Weir Remedial Works (2001). G-MW direct managed workforce were able to complete the critical downstream works during a quickly rising River Murray

Ensuring the construction workforce also had a strong commitment to delivering a quality product was a key focus of the site management team. Experience shows that providing the workforce with an understanding of the design intent and therefore an appreciation of the criticality of specific construction techniques was a powerful motivation (Reid et al 2009). Armed with knowledge about the importance of a particular element of the dam construction the workforce took greater responsibility and paid greater attention to detail to quality control.

The interface between the construction team and local dam operations staff is always critical and this was undervalued on early G-MW projects. To ensure clarity of roles and responsibilities formal asset handover processes between operations and the project were implemented. In addition operations staff retained key roles in visual surveillance and collection and initial analysis of surveillance data.

The only deviation from the direct management approach was the Eildon Project which was delivered under a Project Alliance (Fox et al 2005). This was the largest project delivered in the program and it was recognised that G-MW could not readily assemble the resources needed to deliver it by direct management. The alliance model was selected as it brought together a larger integrated team that was driven by similar ideals to the direct management approach. The Eildon Alliance included a number of key staff from within the G-MW implementation team ensuring the owner's perspectives were intimately considered in all critical project decisions.

Ensuring the quality of construction activity was fundamental to the success of every project. The inclusion of the design team in the construction process was essential to this outcome. For each project G-MW required the designer to confirm the design intent was achieved. This could only happen by having the designer intimately involved throughout construction. On all projects the designer conducted regular site inspections of critical activities, reviewed observed conditions against design assumptions, provided review of all quality and surveillance data and advised on any necessary design changes. On some of the more complex projects this required the designer to have a fulltime site presence.

In addition to the role of the designer, a Project Review Panel was convened to provide oversight and advice in relation to the project. Typically the review panel was a continuation of the panel convened during the design phase. However for some projects additional expertise was included in the panel to address specific project issues.

In determining appropriate construction methodologies, G-MW adopted a guiding principle that construction activity should not increase dam safety risk above the existing long term average risk, i.e. in implementing works to reduce dam safety risk; the works themselves should not create a higher risk than already existed. Achieving this outcome required careful consideration of construction methodology. Typical issues considered included:

- storage water level and the ability to control this during the project
- options to intervene in an emergency situation and the likely effectiveness of such action (e.g. potential to backfill excavations)
- minimum construction resourcing levels and emergency access to materials

Figure 5 – Buffalo Dam Project (2003). G-MW direct managed workforce completed the complicated construction sequencing on the Main Embankment

As part of the dam safety risk management approach for each project an addendum to the dam safety emergency plan was implemented. The addendum addressed the following information:

- Changes in emergency response roles as a result of the project works, including the role of project staff in any emergency response
- Revised surveillance regimes providing a greater chance that any developing issue would be detected early
- Instrumentation alarm levels including corresponding response actions
- Defined construction staging and associated emergency actions should a dam safety emergency issue develop.

Development of this addendum prior to commencing construction required consideration of possible scenarios that could lead to a dam safety incident. In many cases analysis and modelling of dam behaviour was undertaken to predict the potential response and set instrumentation alarm levels. Investing in this activity prior to construction provided a higher degree of confidence that an emerging issue would be identified and appropriate intervention could be undertaken. It informed construction sequencing (including the need to accelerate some critical activities) and in some cases dictated the level of resourcing on site.

For later projects probabilistic cost estimates were adopted. This estimating method includes explicit consideration of uncertainty in cost estimate unit rates and quantities along with consideration of project risks in terms of potential costs and likelihood of occurrence. Through ensuring continuity between design and construction teams the development of cost estimates drew on the broadest understanding of design and construction risks and ensured buy in of the complete project team to the basis of the cost estimate for the works.

The use of probabilistic estimating became a fundamental tool in communicating with key decision makers on project risks and proved beneficial in supporting the case for appropriate project estimate contingency allowances that in some cases exceeded what would have been allowed for under traditional estimating practices.

The estimating methodology provided continuity in understanding the build up of the risk based project cost estimate. In particular there was buy in early in the design process in relation to the selection of materials and subsequent borrow areas for construction. This also became critical in the development (and understanding) of construction sequencing arrangements for minimising dam safety risk during construction but more importantly if the emergency response plan was required to be enacted during construction.

Finally, cost estimation is a critical area for stakeholder information. During program development, it’s likely that concept level estimates are being used. These are based on incomplete information and major adjustments to budgets are possible as the further investigations are undertaken and new information comes to hand. Therefore it is essential to make sure that all stakeholders understand that there are risks around the estimates and that they will have to be updated as the program is implemented.

Commissioning

Many of the upgrades completed made significant changes to embankments or other assets. Following these upgrades commissioning or first filling procedures were established to ensure the assets were subject to appropriate testing and monitoring prior to being returned to normal service.

Completion of these procedures generally requires the storage to return to full supply so that the asset can be tested under the maximum head it will subject to during normal operation. This condition may not be achieved for an extended period (in the G-MW experience this was over a decade for some dams due to prevailing drought conditions) and so appropriate controls are required in the dam owner’s dam safety system to ensure this testing is completed as soon as the opportunity arises and before the asset is subject to those conditions during routine operation.

Figure 6 – Laanecoorie Dam in January 2011 Flood. Remedial works at the embankment /spillway interface carried out in 2009 were tested during the second rank flood in recorded history on the Loddon River

Commissioning procedures were developed as part of each dam improvement project and testing conducted to the extent storage level or other conditions permitted. Any outstanding testing was then documented and referred to the Dam Safety Unit for completion at a later time when the necessary conditions were met.

In developing commissioning procedures it was important to review any historic testing of the asset to identify any unusual outcomes previously observed. Where available, staff that participated in earlier testing also proved a useful reference. Consideration should also be given to the overall system in which the asset operates including confirming other components in the system have previously been successfully commissioned. Given the potential risks associated with commissioning appropriate review of the process and risks by suitably experienced personnel should be undertaken.

First filling regimes documenting dam safety surveillance requirements and if necessary limits on rate of rise (where this can be controlled) were also developed and provided to the Dam Safety and Operations staff for implementation.

Operations staff should be intimately involved in the planning, execution and debriefing of commissioning to ensure that the local knowledge is captured during planning and that staff are fully aware of information gained during commissioning that may result in changed operating procedures.

Summary

There were numerous lessons learned during the implementation of Goulburn-Murray Water's program. Following are the top 10 tips from 15 years of experience with a dam improvement program:

1. Engage with all relevant stakeholders and establish broad support for the proposed approach. Keep them up to date as the program develops.

2. Structure and manage safety reviews as tightly as all other parts of the program, taking into account review of high probability events affecting operating functions and recognise the importance of well planned and thorough site investigations.

3. Match the level of risk assessment to the importance of the decisions to be taken, accounting for uncertainty when making recommendations.

4. Structure the improvement team with clear accountabilities and appropriate support and advice from external experts and the internal resources responsible for the dam.

5. Ensure continuity of management, personnel, designers and review through design and construction phases.

6. Engagement with local communities, appropriate to the scale of the works, will provide benefits for project implementation.

7. Consider the most appropriate risk management process and risk allocation when deciding the project works implementation structure, remembering that outside parties will cost their risk.

8. Engage operations and maintenance staff in project implementation, surveillance and emergency response and ensure that appropriate handover and handback of the works are in place, with clear accountabilities for operations during the project.

9. Before the project commences determine how dam safety will be managed during the project. Consider what level of risk will be acceptable, the necessary amendments to the dam safety emergency plan and include response trigger levels in the plan.

10. Take great care with commissioning, ensuring that there is a complete review of any previous commissioning, a clear process with single accountability, sign off at critical milestones and adequate expert review.

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Table 1 - G-MW - Dam Improvement Program - Chronological list of projects

Dam Site	**Works Completed**	**Key Risks**	**Description of Works**	**Project Value ($M)**
All dams	1998-2006		• Design Reviews & Risk Assessment	13.7
Waranga Basin Major Outlet	2000	Structure Stability	• Structure Strengthening • Installation of new gates	2.7
Eppalock	2000	Embankment Stability	• Downstream filter buttress	7.6
Yarrawonga	2002	Earthquake	• Spillway Strengthening (anchoring & concrete) • Foundation treatment (stone & filter columns) • Downstream filter buttress & upstream rockfill weighting berm • Installation of erosion protection	13.0
Cairn Curran (Stage 1)	2003	Piping at Spillway /Embankment Interface	• Downstream filter buttress at Spillway interface with main embankment • Raising of Embankment • Spillway Strengthening (Anchoring & Concrete)	4.1
Buffalo	2003	Flood Overtopping	• Downstream filter buttress on main embankment & secondary embankments • Raising of Embankment • Spillway Works	6.4
Eppalock (Low Level Buttress)	2003	Embankment Stability	• Upstream rock buttress installed during low reservoir sequence to improve embankment stability	2.6
Hepburn's Lagoon	2003	Flood Overtopping & Embankment Stability	• Downstream filter buttress • Spillway Works	0.1
Eildon	2006	Flood Overtopping	• Downstream filter buttress on main embankment • Raising of Embankment • Spillway Strengthening Works • Replacement of mechanical and electrical equipment in Spillway	46.5
Tullaroop	2006	Embankment Piping – Left Abutment	• Downstream filter Buttress constructed on left abutment area of main embankment	1.0
Cairn Curran Stage 2	2008	Flood Overtopping Piping in upper section of embankment	• Downstream filter buttress on main and secondary embankments • Spillway Rockbolting • Spillway Gate Trunnion Beam Strengthening	10.0
Laanecoorie	2009	Piping at Spillway /Embankment Interface	• Downstream filter Buttress constructed at Spillway/Embankment interface • Strengthening of Spillway Training Walls	6.1
Goulburn Weir Anchor Replacement	2009	Structure Stability	• Installation of new cable anchors to replace failed bar anchors	1.1
William Hovell	2010	Flood Overtopping	• Downstream filter buttress on main and secondary embankments • Raising of embankments • Spillway Strengthening	7.1
Goulburn Weir Gate Locking and Superstructure Strengthening	2011	Over-rotation of gates & superstructure strengthening	• Downstream filter buttress • Spillway Works	3.0
			Total Cost to date	**125**