Assessment of Floating Hard Covers on Large Water Storages

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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Image

Trial of AquaArmour™ floating hardcover on farm dam north-west Victoria (Aqua Guardian Group).

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

This investigation has examined the development that has been taking place with hard covers suitable for the installation on large water surfaces to reduce the evaporation losses and its application to large dams in Queensland.

The investigation identified that there are several commercial products currently available in Australia for this application, but to date that their use has been limited to smaller dams only where the complete water surface of the dam has been covered. In concept, the covers could be utilised on larger dams provided that a containment arrangement can be provided to keep the hard cover units together. To date there have been no details provided on suitable containment systems. Overall, the application of hard covers to large water storages is still in a development phase.

To identify the issues around the future application of hard covers to large dams in Queensland, Maroon Dam was selected as a model on which to base this investigation. The investigation included undertaking a desk top wind and wave analysis for Maroon Dam as well as compiling a qualitative type risk register to identify the possible incremental risk associated with installation of a hard cover.

The wind and wave analysis identified that in the South East Queensland (SEQ) region, high wind velocities can be encountered and associated wave heights can be in the order of 1 metre or more, depending on fetch distances. Whilst the manufactured covers examined as part of this investigation have undergone wind testing or analysis, they have not been subjected to the combined wind and wave loading.

The qualitative risk assessment identified a number of risks for the existing dam as the base case and then extended this to a dam which includes a hard cover to determine incremental risks. The investigation identified that the installation of hard covers (and associated containment systems) increases the risk profile associated with the ownership and operation of a dam fitted with a hard cover. Further investigation and design is required to determine if these risks can be mitigated back to an acceptable level (through either design or other measures).

The installation of hard covers in Queensland is also an issue of much interest to the Dam Safety Regulator, part of the Office of the Water Supply Regulator, Department of Environment and Resource Management (DERM). Consultation with the Dam Safety Regulator will be necessary including undertaking a quantitative risk assessment for any dam being considered for a cover and ultimately obtaining formal approval for the works.

As a result of this investigation, a number of additional studies have been identified to gain a better understanding of specific design and operational issues and the performance of hard covers in situations likely to be encountered on large dams. The investigation was also to provide a generic approach methodology for undertaking further studies on how a hard cover can be placed on a dam. The approach developed has been divided into two parts as follows:

1. This part lists a series of questions that need to be considered (if applicable) to the dam being considered. These are considered a precursor and will provide much of the background information required; and
2. A series of steps leading from the initial investigation through to tendering for the supply of a hard cover.

Overall, this investigation has identified that hard covers have been developed but to date have only been applied to smaller dams. The installation of hard covers to large dams is still in its infancy in terms of development. Further work is required to address a number of risks that are applicable to large dams.

1. INTRODUCTION

Large reservoirs or dams are the primary method of storing water in Australia, particularly for meeting urban and industrial demand. One of the issues associated with the operation of large reservoirs is their water surface is exposed to the elements and high rates of evaporation can occur, reducing the yield from the dam.

In recent years, Australia has been experiencing ongoing drought conditions. During these periods, the loss of any water from storages has had a large influence on the yield and sustainability of water supply dams.

SMEC was commissioned by Griffith University to undertake a study of floating covers that would be suitable for installation on large dams and to develop a "generic approach" for organisations considering applying this technology to their water storages. The "generic approach" is a guide only to the issues to be resolved and the steps required; which may lead to the installation of a hard cover.

2. INVESTIGATION

This investigation is a desk-top study, except for the site visits as outlined below.

The study does not make any judgement between the different hard cover systems available in terms of their suitability, durability and the performance claims made by the manufacturers. It is intended to outline the issues associated with installation of a cover of this nature onto a dam or reservoir with a large surface area (say > 10 ha).

The investigation is limited to "hard covers" only. Hard covers are defined as those which are made up of a series of units that float on the water surface and, when linked together, form a large raft which covers a high percentage of the water surface.

Covers such as those comprised of large areas of synthetic cloth attached from the shoreline or suspended from cables are excluded from this investigation.

For the purposes of this investigation and risk assessment, it has been assumed that, if applied to a large dam in Queensland, the covers would only cover part of the available surface area for the following reasons:

- Complete coverage of a dam would be costly (refer to the note below);
- Covering the complete dam surface would incur additional operational issues associated with the possible placement or removal of cover units as the water level rises and falls; and
- The majority of dams in Queensland permit public access for a range of recreation uses, varying from limited boating access to full access and fishing. Loss of access is likely to be received unfavourably by the public and dam managers.

Note – Current indicative costs for the supply of hard cover units range from $22 to $30 per unit. Approximately 8,000 units would be required to cover 1 hectare of water surface. The cost to supply and install a hard cover for an area of 1 hectare would be of the order of $176,000 (@ $22 per hard cover unit), excluding the cost of containment booms and anchoring systems. Taking into account the works required for a complete system could see costs in excess of $200,000 per hectare being incurred (plus ongoing annual costs). Maroon Dam has a water surface area at fully supply level of 310 hectares. To cover the complete dam at the above costings would amount to over $54m.

2.1. Internet Search

In addition to the products being offered by Superior Pak (previously called Nylex) and the Aqua Guardian Group, there are a number of references that can be found in the public domain on the internet. The references found in a search included:

"Agfloat" which consists of recycled car and truck tyres which have been filled with recycled polystyrene. The system was used as a cover on Blyth Dam in South Australia. The amount of technical detail in the article was minimal, apart from a comment that approximately 2500 tyres were to be placed on the dam's surface.

(Reference - http://www.northernargus.com.au/news/local/news/general/blyth-on-a-roll-with-evaporation-reduction)

F Cubed Australia has developed a large floating cover (Raftex) using a frame covered with a synthetic material. The covers are relatively light (16 kg per module) for the area that they cover (16 m^2), but due to their perceived height it would appear that they could move around easily in windy conditions. The durability of the material cover and its ability to act as a "sail" when torn would be concerns with this product if applied to large open water surfaces.

It is noted that the majority of the hard covers have, to date, only been installed on relatively small and confined dams such as service basins and other agricultural dams. No references were found to actual placement of covers on existing large reservoirs or dams where a confinement system or barrier is required to contain the hard cover elements in a defined area.

2.2. Site Visits

As part of this investigation, a number of site visits were undertaken to hold discussions directly with product manufacturers and to inspect a possible site for the application of a cover of this nature. The site visits were also undertaken to gain an appreciation of the physical size of the covers and to discern the market application that the different manufacturers were targeting. The details of the site inspections are outlined below.

2.2.1. Manufacturers

The record of the discussions with the manufacturers and notes regarding each product are contained in the Appendices B and C attached to this report.

The manufacturers visited were:

- Superior Pak; and
- Aqua Guardian Group.

The summary of the resulting discussions are outline in the following sections.

2.2.1.1. Superior Pak

Superior Pak (previously Nylex) market a product called AquaCap™. This product is readily transported and easily placed on a water surface. Previous application of this product has included installation on a mining project dam.

The cover is similar in shape to a large circular lid and can be installed only with the rounded surface facing upwards (Figure 1).

Figure 1: **AquaCapTM by Superior Pak.**

Superior Pak has not developed a boom or similar system that would be required to contain the covers on a large water surface. The mining dam was a relatively small area and the cover is contained within the embankments of the dam.

2.2.1.2. Aqua Guardian Group

Aquaguardian Group has developed a double sided disc type cover marketed as AquaArmour™. The octagonal shaped cover has internal flotation cells and, when installed, it partly fills with water, which acts as ballast. The octagonal shape cover can be installed with either side facing up (Figure 2).

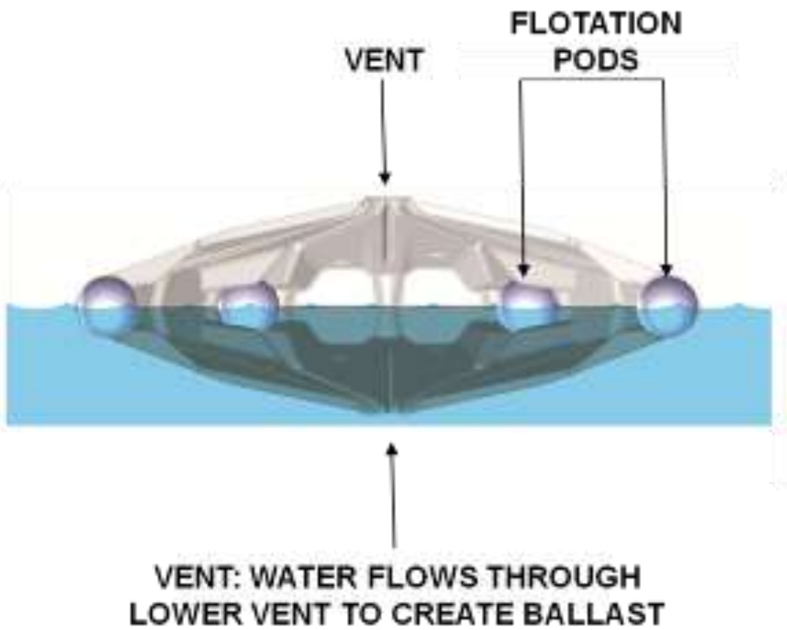

Figure 2: **Section1 through AquaArmourTM Unit.**

Due to the bulk (thickness) of this cover in its final format (approximately 350 mm thick), the manufacturers propose that covers be manufactured and assembled on site using equipment housed in a shipping container, with the covers being immediately placed on the water after the 2 halves have been welded together. In addition to on-site manufacturing, modules can also be produced in factories.

2.2.2. Maroon Dam

Maroon Dam was selected by Griffith University as the site on which to model the installation of a hard cover in order to identify the issues associated with its application.

Maroon Dam is located south of Boonah in SEQ and has a catchment that extends in a south west direction into the McPherson Ranges on the border between Queensland and New South Wales. The dam is owned and operated by Queensland Bulk Water Supply Authority trading as Seqwater.

Figure 3: View of Downstream Embankment of Maroon Dam.

The dam wall is an earth and rockfill structure with extended upstream and downstream weighting berms (Figure 3). A gravel access road crosses the crest of the dam. The spillway is a located to the right of the main embankment and consists of a wide chute cut through the ridge of the hill. A low concrete sill in the chute provides a control structure (see Figure 4). The water level in the dam is normally regulated such that water is unlikely to spill through the spillway chute except under extreme flood conditions.

Figure 4: Maroon Dam Spillway.

The dam has a submerged single level off-take structure located at the base of the rockfill embankment (Figure 5), which discharges water directly into Burnett Creek (a tributary of the Logan River). This off-take/release structure only permits water to be drawn from the base of the dam.

Figure 5: Maroon Dam Outlet – Discharge to Burnett Creek.

Full recreational use is permitted on this dam, including power boating, fishing, water skiing and other power craft. A number of recreational facilities have been established on the shores of the water body including picnicking, camping and other group facilities. The dam (and its associated water body) is considered an important recreation facility in this area (see Figure 6).

Figure 6: View of Lake from Spillway Entrance (looking south).

Water is released from Maroon Dam for downstream use in the Logan River catchment, including irrigation and urban consumption. Water from the dam is also extracted and treated on the site for use by the resident reservoir keeper, picnic areas and adjacent conference facility (small volumes only).

2.3. Maroon Dam Wind and Wave Action

As part of this study, SMEC has undertaken a desk top analysis of the possible wind and wave action that could be encountered on Maroon Dam. This analysis is based on the maximum fetch distance and prevailing wind direction across Maroon Dam and has been undertaken to gain an appreciation of the magnitude of possible wave heights, its likelihood of occurrence and the period between consecutive waves.

The study indicates that wind speeds (1 in 100 ARI) of 32 m/sec (115 km/h) can be encountered with short duration wind gust speeds of 48 m/sec (170 km/h) for the region, with the predominant wind direction being from the south-west. Taking into account the fetch distance across Maroon Dam, significant wave heights in the order of 1.1 metres and maximum wave heights ($H_{1/10}$) in the order of 1.2 metres can be expected under the above conditions. It is noted that the above short duration wind gusts exceed the test wind velocities for the two systems examined as part of this exercise.

Maroon Dam is located some distance inland from the coast and in a region that is not normally subjected to cyclonic conditions. For dams located further north (particularly in the sub tropical and tropical regions) and closer to the coastline, higher wind velocities (> 270 km/h = Category 5 Cyclone) can be expected (together with an increased level of wave action). The performance of hard covers in these regions under cyclonic conditions is uncertain.

The full desk top study on wind and wave action is attached to this report in Appendix A.

It is noted that in practice the selected site for a hard cover may be in a protected reach of a dam. Each site will need to be individually assessed. Alternatively, the installation of hard covers may be restricted to certain areas of dams where maximum wave action is below a selected design threshold.

3. RISK ASSESSMENT

A simple qualitative type risk register has been developed as part of this project, partly based on Maroon Dam, in order to deduce the differences in risk factors both with and without application of a hard cover. This risk register has been developed from a desk top review only and may not reflect the actual position of the dam owner (Seqwater). The risk register has been developed in order to gain an appreciation of the impact of installing a hard cover on a large dam such as Maroon Dam and whether the installation of a hard cover shifts the dam's existing risk profile.

The risk register developed does not include any change in risk that may occur as a result of any future dam upgrade work being undertaken (ie spillway improvements).

As noted above, Maroon Dam does not have a formal outlet tower or structure and the spillway arrangement is a wide side chute. In order to consider the issues that may be encountered on other dams where multi-level off-take towers or gated type spillways exist, the risk register includes items for these types of structures even though they do not exist at Maroon Dam. These items are highlighted with a colour coding in the risk register.

The risk register developed has highlighted that installation of a hard cover on a dam increases the total number of risks for dam owners. The additional risks occur mainly as operational risks particularly associated with: the spillway gates, gate operating systems, outlets and operation and maintenance of the hard covers containment systems; and the impact on recreation use or public access.

The risk register developed for this study was a *qualitative* type analysis to identify the range of additional risks only applicable to the placement of a hard cover on a dam. For the implementation of an actual project, this register should be used as a guide to the development of a *Quantitative* Risk Register in accordance with ANCOLD[1] guidelines and the *Guidelines on Acceptable Flood Capacity for Dams*[2]. The quantitative risk register will assign numerical values to both consequence and likelihood, which enables the magnitude and ranking of the risks to be more accurately gauged. The development of a quantitative risk register needs to be undertaken with the participation of the dam owner and the Queensland Dam Safety Regulator (refer to further comments in Section 4).

The critical issue that needs to be identified in the risk assessment is the comparison of the base case (no hard cover) against the situation where a hard cover is installed. This will identify the incremental consequences and risk. Similarly the risk matrix used for the desk top risk register (description of risk consequences and likelihood), is a guide only and needs to be tailored to suit the individual dam being examined.

4. DAM SAFETY REGULATOR

In Queensland, the Department of Environment and Resource Management (DERM) includes Dam Safety as a business unit within the Office of the Water Supply Regulator. This Department has the responsibility to overview all large dams in Queensland, ensure that they have in place dam safety programs and that the integrity of the dam is not being compromised, including increasing the risk of dam failure or the risk to the downstream population.

As the installation of a hard cover on a dam is likely to have an impact on the operation of the dam and its risk profile, the Dam Safety Regulator will need to be consulted and may place a number of conditions on installing a hard cover. The Dam Safety Regulator will need to feel assured that the dam and its operation are not being compromised by the installation of the hard cover and that all identified risks have been addressed and there is no increase in the Population at Risk (PAR).

It is recommended that before progressing with the detail design of a hard cover or seeking tenders for the installation of a cover, the Dam Safety Regulator is consulted regarding:

- Development of a Quantitative Risk Register;
- The matrix used to describe and assign numerical values to consequence and likelihood;
- The detail design of the hard cover and containment system; and
- Any other dam safety issues that need to be considered.

Prior to the installation of a hard cover, the Dam Safety Regulator will need to provide approval for the works.

5. WATER QUALITY

The installation of a hard cover and containment booms will have some impact on water quality, including:

- Providing surfaces for algal growth to develop;
- Restricting the contact and penetration of sunlight into the water body; and
- Possible change in temperature of the water under the cover compared to the uncovered sections of the dam.

[1] Guidelines on Risk Assessment, October 2003, Australian National Committee on Large Dams Inc, ISBN 0 731 027 620.
[2] Guidelines on Acceptable Flood Capacity for Dams, February 2007, Queensland Government, Department of Environment and Resource Management (DERM).

Any floating structure in a dam will develop a growth of algae on its surface. This is expected to have minimal impact on the overall algal mass in the dam as it will primarily be fixed to the cover and containment booms. It is expected that it will provide a source of food for fish and to some degree will be controlled in this manner.

The covers will reduce the contact and penetration of sunlight into the water in the area where they are installed in the order of 90% (depending on how the cover units raft together). In this area the overall algal mass in the water is likely to be less due to the lower incidence of sunlight.

It is noted that floating covers or roof systems are a common method of enclosing “treated water” storages. These significantly reduce the penetration of light into the water body. There does not appear to be any detrimental affects due to the covers in these applications, however in many instances the water in these storages is “turned over” on a frequent basis and may not be in storage for extended periods. Water in these storages is often chlorinated, which assists in controlling biological growths.

The covers are also likely to provide a means of insulating the water surface thermally. The covers either provide a hard surface or trap a layer of air at the water surface which will insulate the water from the air. Overall it is expected that the surface water temperature beneath the cover will be lower than the surrounding open water temperature (noting that dams often stratify with low temperature water existing below the thermocline. Maroon Dam has this issue).

This temperature variation is not expected to be detrimental to surface water quality and the degree of temperature variation will be impacted on by any sub-surface currents (inflows to the dam) as well as wind and wave action causing mixing.

6. DEVELOPMENT OF GENERIC APPROACH

There is a large variation in the type and layout of water supply dams across Queensland and Australia. The conditions under which the dams operate also vary depending on the end use of the water, catchment climatic conditions and runoff.

Varying degrees of recreational use are permitted on dams, ranging from no public access or no recreational use of the water body to nearly unrestricted use of the water body, including general boating and water skiing. All of this has an impact on how and where a hard cover can be applied.

The generic approach provided as a separate document (refer to Appendices) is not intended to provide any direct answers, but is intended to raise a series of questions that may need to be investigated and answered before making a decision to install a hard cover or undertake a design or seek quotations/tenders, followed by a systematic approach to implementing a hard cover system. This approach will need to be modified to suit individual applications.

7. ADDITIONAL STUDIES

The placement of a hard cover on large reservoirs or dams, is a practice continually being developed here in Australia. The completed examples that have been seen to date all relate to small dams where the surface area covered was relatively small and the dam embankments provide the method of containment (ie turkey’s nest type dams).

The manufacturers that were contacted had indicated that a limited amount of study had been conducted in respect to durability and the wind resistance of their units, and that the work was restricted to a combination of desk top study and experiments carried out in small tanks under controlled conditions.

It is evident that in order for hard covers to be seriously considered for installation, additional work is required to investigate a number of other issues, as noted below, which could be encountered when covers are deployed on large areas.

7.1. Combination Wind and Wave Action Study

Tests carried out to date on some of the hard covers have been either wind tunnel or desk top evaluations in regard to wind resistance and overturning resistance.

When placed on a large water surface which may include a reasonable fetch distance (greater than that examined at Maroon Dam), the covers may be subject to a significant wave action under high wind conditions. This combination needs to be studied to determine the impact on the various covers.

As noted in section 2.2.2 the wind speeds expected on Maroon Dam (particularly short duration wind gusts) and wave action are significant. However, it is not clear whether the testing carried out to date on existing hard covers included a combination of wind and wave action. It is understood that the testing has been carried out under laboratory conditions and is therefore unlikely to include wave action.

It is unclear from the information obtained to date whether the combination of wind and wave action will have an impact on the stability of individual cover units which could result in them being blown (turned) over or possibly being blown along the water surface by the wind once contact with the water is lost. It is noted that this will depend to a large degree on whether the units are ballasted.

If hard cover systems are to be considered for dams in sub-tropical and tropical regions, higher wind velocity combined with wave action testing is required. Consideration should be given to producing a design envelope for each cover type under various combinations of wind and wave action.

7.2. Likelihood of Cover Units Stacking Vertically Study

It is anticipated that when placed in large numbers and subject to both wind and wave action, hard covers may tend to pack together similar to ice flows (where slabs ride up on top of each other and a large pile is created).

The action described above effectively reduces the area covered and may lead to an increased degree of operator input if manual breakup of the combined mass is required.

Investigation is required into whether the covers will:

- Under a sustained wind and wave action loading stack together in a vertical fashion; and
- Whether they remain stacked together or return to a regular spread over time without any intervention.

7.3. Blocking of Spillway Gates Study

A high risk is that the hard covers will congregate at the upstream side of spillway gates. It is unclear how the different covers will react to the variations that can be encountered in respect to spillway gates. Whilst a system will need to be deployed to keep the hard covers away from any gates, the contingency around failure of any hard cover constraining system and the movement of the covers into the spillway area needs to be examined.

The collection of floating hard cover units in a spillway may also reduce the capacity of the spillway through partial blockage of the spillway. Any blocking of spillways (even partially) is seen as a high risk for dams as it could ultimately lead to overtopping of the dam.

The possible reduction in spillway capacity in this event needs to be quantified (noting that it will depend on a number of factors). Further study is required in respect to:

- How the hard cover units will react when they are forced into a spillway area;
- Whether they have the ability to jam the various types of gate operating systems (lifting cables, hydraulic rams etc); and
- The impact on different types of gates (stoplogs, vertical lifting gates, radial gates, undershot or overshot gates etc).

7.4. Wear Against Dam Structures Study

The majority of dams will have some internal structures, which may include spillway chutes, outlet towers and walkway supports. These structures are generally constructed from "hard" materials including concrete and steel.

Further investigation is required into how the various hard covers wear when subjected to movement against these types of surfaces. As for spillways, it is anticipated that a hard cover will need to be kept some distance away from these structures, but in the event that the cover restraining system fails, the covers may easily congregate against the structures. Ideally there needs to be some ability for the hard cover to physically withstand any impact against the structure for a short period, until the dam operator can move the covers back to their normal location.

7.5. Resistance against Vortex Action Study

Vortices are often observed in the proximity of spillway gates and other dam structures. Whilst this is not a desirable feature, it does occur and any floating cover will need to have some resistance against being drawn down and possibly blocking the flow path.

Further investigation is required into the ability of the various types of hard covers to withstand vortex action and the tendency for hard covers to block or restrict discharges through outlets or gates.

7.6. Containment Boom Design Study

The placement of a hard cover on a large dam or reservoir where the coverage is only over the partial area of the water surface, will require the use of a containment boom to keep the cover together in one area and to prevent it floating towards any spillway or outlet works. Any boom or other cover containment system will need to cater for:

- Wind and wave action;
- Variation in dam water levels including flood conditions where water levels several metres higher than full supply may occur;
- Durability of the containment boom;
- Ease of installation, handling and retrieval;
- How the boom is anchored or fixed; and
- Facilities within the boom for permitting entry of boats (or barges).

The containment boom, anchorages and fixing cables/chain systems will need to be flexible enough to cater for the full variation in water levels expected at the location of the hard cover together with the expected loads (including an allowance for safety factors and wear and tear) and how the anchoring system is fixed in place (sufficient mass to restrain the applied loads or fixed into the floor of the dam). Particular issues around anchoring and fixing systems include:

- Variations in the level of the floor of the reservoir;

- How to accurately place the anchors (may require the use of divers);
- The systems and equipment required to inspect, retrieve and maintain anchor systems;
- Preventing mooring cables or chains from becoming tangled as the water level in the dam falls;
- Whether the anchoring and mooring system provides a hazard to recreation users of the dam;
- The size and weight of mooring chains or cables to resist the applied loads under extreme loads (wind and wave) may incur handling and maintenance issues; and
- Providing capability in the mooring cables or chains to cater for sudden changes in water levels from flood inflows (and rising above the dam's full supply level).

The desk top wind and wave action study on Maroon Dam carried out for this study identified that wave heights in the order of 1.1 metres high could be expected. The impact of a containment boom on reducing wave heights is unknown. The design of containment booms (and their anchorage/restraint systems) should also include features which assist in reducing wave heights within the impounded hard cover area.

Further investigation or study is required into the above issues to identify options for the containment booms and the design parameters for this component. This will also need to consider any ongoing operation or maintenance issues.

7.7. Moving a Large Floating Cover Study

It is likely that a hard cover on a large dam or reservoir will need to be moved to maintain it over the water body (move away from the bank when water levels recede). Further investigation is required to identify the issues in moving or retrieving a large mass floating on the surface of a dam. This may include what systems need to be deployed to move a large mass and how much energy is required (size of boat/motor). This issue also impacts on any anchoring system.

Further investigation is required to determine the issues around trying to move or retrieve a large expanse of cover and how this can be achieved using readily available equipment.

7.8. Recreational Hazard Study

It has been identified that a significant risk with the installation of a hard cover relates to recreation use of the dam's water body. Installation of a hard cover will create an area where boating and recreation use is not permitted. Further investigation is required in respect to whether the hard cover could be considered a hazard to maritime safety and may need to marked with appropriate navigation marks and lights.

Risks associated with unauthorised access to the hard cover or wilful damage to the cover needs to be assessed by the dam owner as part of the risk assessment.

Further investigation is required to fully identify all of the issues where a hard cover is installed on a dam which permits recreation use.

7.9. Environmental

The placement of any cover on the surface of the water body will have an impact on the underlying water as noted below:

- Determine the impact of the reduction of solar radiation into the water column beneath the hard cover. The hard covers will block a substantial proportion of solar radiation required for photosynthesis and other biological processes within the water column. This may impact on the entire ecosystem in the water body.

- Examine and quantify any impact on the transfer of oxygen to or from the water and the impact that this may have on the biological profile of the water body under the hard cover.
- The shading / insulating effect of the hard cover may reduce the temperature of the water body beneath the hard cover. This may impact on the temperature profile of the water body including the depth of the thermocline. Investigation is required to study this issue.

7.10. Life Cycle Costs

The installation of a hard cover will be a long term installation in order to realise the savings associated with reducing evaporation. The total costs associated with the installation, maintenance and operation of the hard cover need to be defined to enable a full economic evaluation to be made. In addition to the manufacture, supply, delivery and installation costs, additional costs that need to be identified include:

- Maintenance activities, including ongoing inspections (and the cost of accessing the cover for inspections);
- Recovering and replacing damaged cover units;
- Site storage of spare units (most likely under cover); and
- Retrieval and disposal of covers at the end of their useful life.

8. CONCLUSION

This investigation has confirmed that there are a number of systems currently available in Australia in various states of development that could be utilised to reduce the evaporation from the water surface of dams.

To date, the systems identified have only been utilised for small dams where the dam embankment has fully contained the floating hard cover.

The application of hard covers on large dams where only a portion of the total water surface area will be covered raises a number of issues, including the design of containment booms and the overall change to the risk profile of the dam and the impact on both the operation of the dam and to the public.

This investigation has identified that the design of containment booms required to contain hard cover units in one area is still in the development phase. A number of issues are to be resolved around containment booms, including suitable anchorages, format of the link system between the anchors and the booms, providing flexibility to cater for the large variations in water levels that can occur as well as addressing maintenance issues.

The investigation around the issue of risk and impact on the dam operator and the public has raised a number of issues. These are highlighted in the attached qualitative risk assessment. Whether the change in risk (incremental risk) associated with the installation of a hard cover is acceptable is an issue for the dam owner to consider. However, any change in risk to the dam will also need to be approved by the Dam Safety Regulator, especially if there is an impact on the integrity or safety of the dam or other impacts. The change in a dam's risk profile and the mitigation measures required is a major issue in respect to installation of hard covers on large dams.

The Appendices attached to this report include a guide on the types of issues that need to be considered and addressed, together with a stepped approach to the installation of a cover system.

Appendix 1 - WIND AND WAVE CLIMATE STUDY

Introduction

Maroon Lake is located in South East Queensland (SEQ) around 80km south of Brisbane and 90km west of Coolangatta. The Maroon Dam wall is located at the north eastern end of the lake. Wind and wave conditions likely to occur within the reservoir are detailed in this report. Wind and wave climates were determined using wind data from the Bureau of Meteorology and the Australian Standard Wind Code (AS/NZS 1170.2:2002).

Wind Climate

Wind climate was assessed using wind data from the Bureau of Meteorology. Several wind stations from the Bureau were located within 60 km around Maroon Lake. The location of the study area is illustrated in Figure 1. These stations recorded hourly data over different time periods. The various wind stations taken into account for the wind climate assessment are shown in Figure 7. More details about the different wind stations used for the wind climate analysis are provided in Table 1.

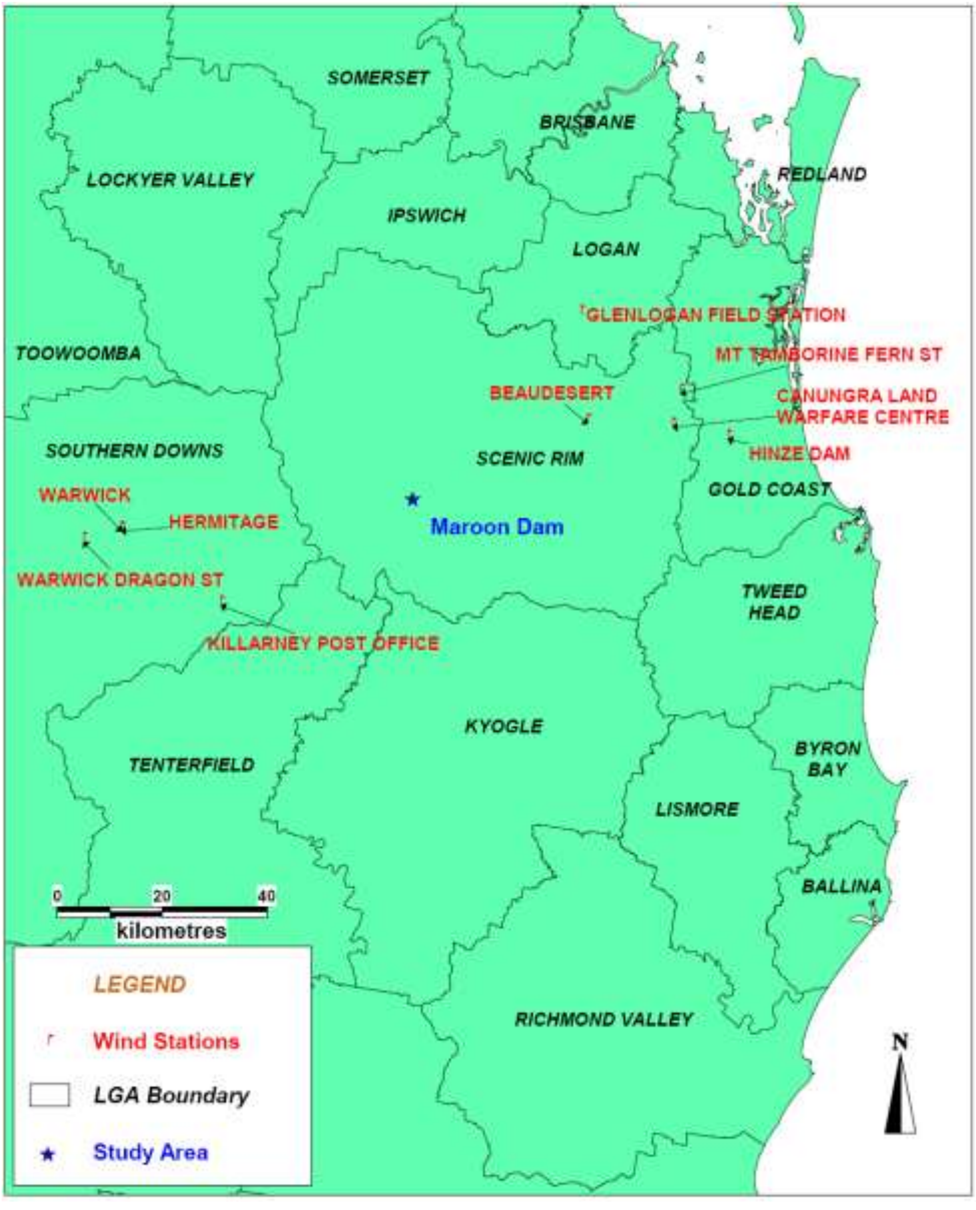

Figure 7: Study Area and Wind Station Location.

Table 1: Location of the Wind Stations used for the Wind Climate Analysis Relative to the Study Area and Range of the Data Records.

Wind Station Location	Distance from Study Area	Recording Start Date	Recording End Date
Beaudesert	37 km	1967	1979
Killarney Post Office	42 km	1965	1992
Hermitage	56 km	1965	2000
Warwick	56 km	1994	2007

The wind rose of the average 9am wind speed at Beaudesert in illustrated in Figure 8. It is noticeable that the main wind direction is the direction along which Lake Maroon has the longest fetch (i.e. length of water over which a given wind has blown). This direction was selected for the wind-generated wave climate analysis.

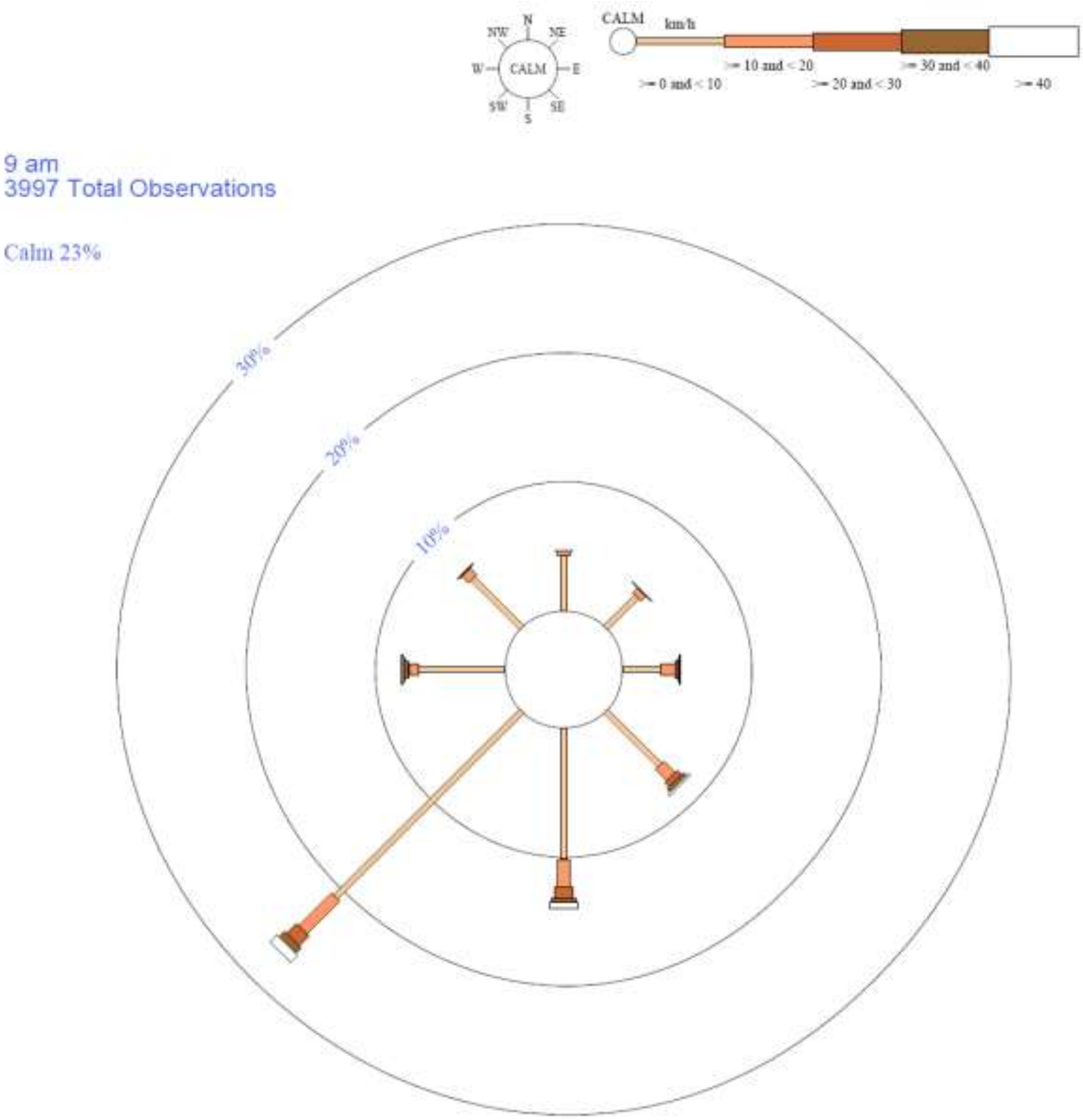

Figure 8: Average 9am Wind Speed at Beaudesert Wind Station (source: BOM).

Wind data from the *Australian/New Zealand Standard AS/NZS 1170.2:2002* were also used to determine the wind distribution. Wind regions defined by the Australian Standard are illustrated in Figure 9. The study area is located within Region B and the three-second gust wind data for this region are provided by the *Australian Standard*. The three-second gust wind data were converted into hourly data using the following formula (ACES manual):

$$\frac{U_i}{U_{3600}} = 1.277 + 0.296 \tanh\left(0.9 \log \frac{45}{t_i}\right)$$

Where: U_i is the i-second wind speed (here i = 3)

U_{3600} is the hourly wind speed

t_i is the wind gust length (here 3s)

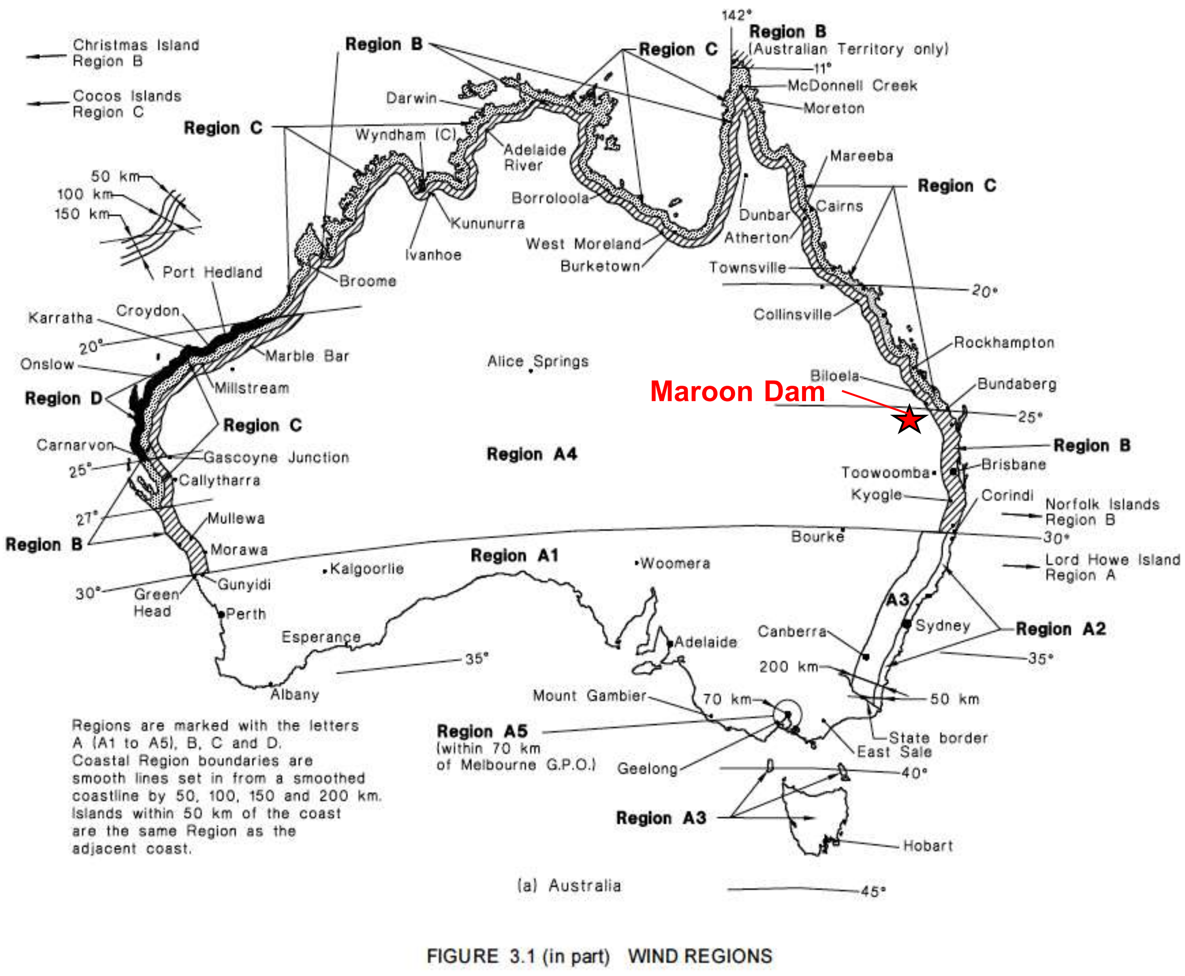

Figure 9: Wind Region (Australian Standard AS/NZS 1170.2:2002).

The 3-second gust wind speed and the hourly wind speed for region B for different Average Recurrence Interval (ARI) as described in the Australian Standard are shown in Table 2. From these data, a graph of the wind distribution has been created and is illustrated in Figure 10.

Table 2: Wind Speed for Region B for different Average Recurrence Interval (ARI) from the Australian Standard AS/NZS 1170.2:2002.

Average Recurrence Interval (year)	3-second Gust Wind Speed (m/s)	Hourly Wind Speed (m/s)
5	28	18.6
10	33	21.9
20	38	25.2
25	39	25.8
50	44	29.2
100	48	31.8
200	52	34.5
500	57	37.8
1000	60	39.8
2000	63	41.7
R	$106 - 92R^{-0.1}$	$\frac{1.277 + 0.296\tanh(0.9\log 15)}{106 - 92R^{-0.1}}$

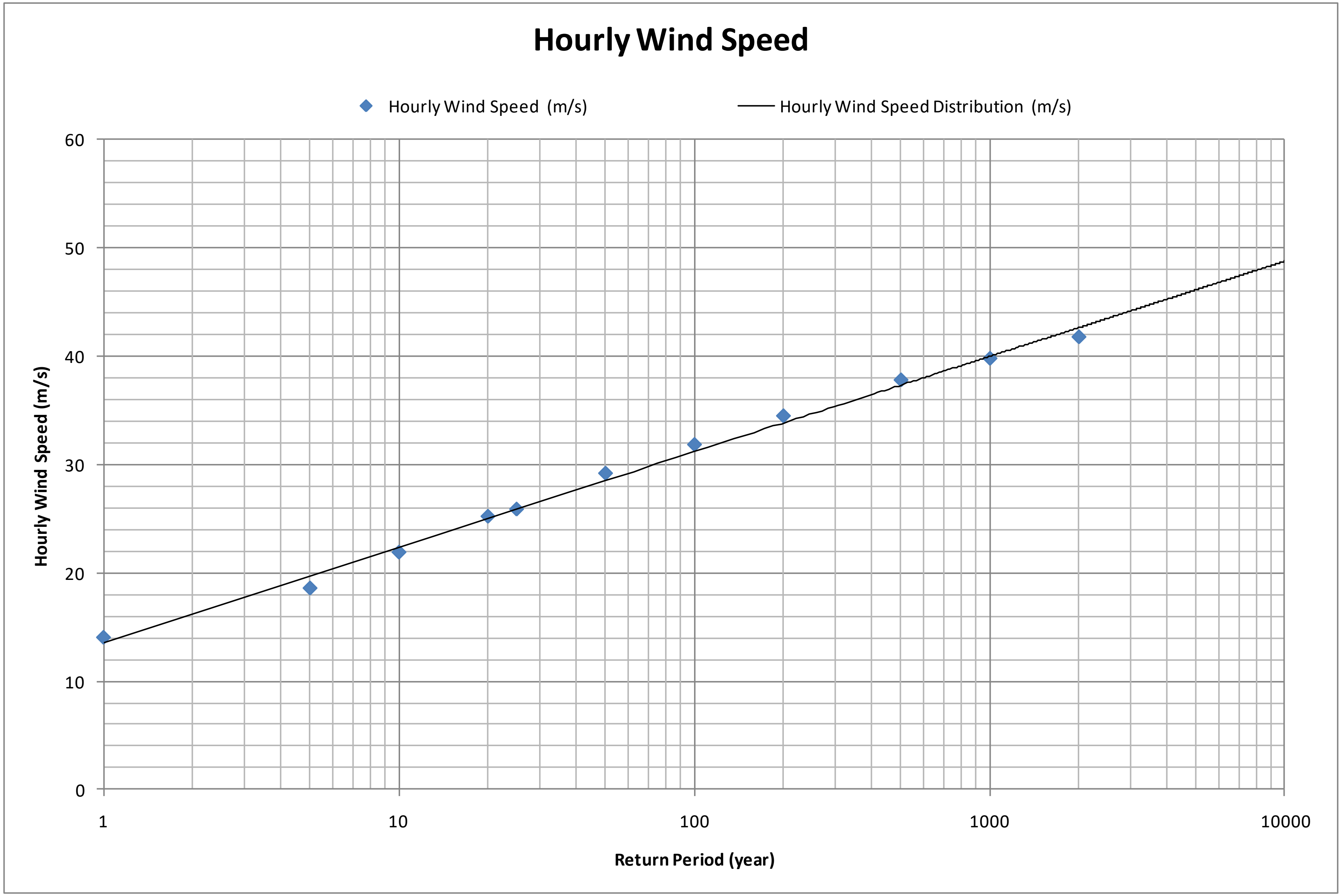

Figure 10: Hourly Wind Sped Distribution Graph.

Wave Climate

Wave climate analysis was undertaken using the previous wind data and the algorithms of the Automated Coastal Engineering Software (ACES). Maroon Dam is sheltered on its southern end by a rocky headland (Figure 11). Hence, wind-generated waves with the longest fetch would not directly impact the southern half of the dam but only the northern end of it.

The reference location was chosen directly north-west of the rocky headland (around 250m west of the dam) as it is the most exposed area for the selected wind direction. Fetches were measured from aerial photographs in direction ranging from 180°TN to 10°TN at 5° intervals (see Figure 11). The measurement of the fetches using aerial photography is reasonable given the fact that the shoreline of Maroon Lake is very steep (Figure 12) and the Maroon Reservoir is relatively full (Figure 13). Hence, the maximum fetches would not be significantly longer than the ones observed on the aerial photography. The measured fetch lengths are provided in Table 3.

Using these fetches and the previously determined wind speeds as input in ACES wave prediction algorithms, wind-generated waves were assessed for several return periods. The *significant* wave heights (average of the highest third of the wave heights), $H_{1/10}$ (average of the highest tenth of the wave heights) and wave period generated by a south-westerly wind (i.e. the direction which has the most significant impact on the study area) for different wind conditions are shown in Table 4. The distributions of both *significant* and $H_{1/10}$ wave heights have been determined from these data and are illustrated in Figure 14.

Waves reach up to 1.13m *significant* wave height and 3.49s wave period for a 1 in 100 year wind speed. The design wave height (i.e. the 1-in-100 year $H_{1/10}$) is around 1.21m.

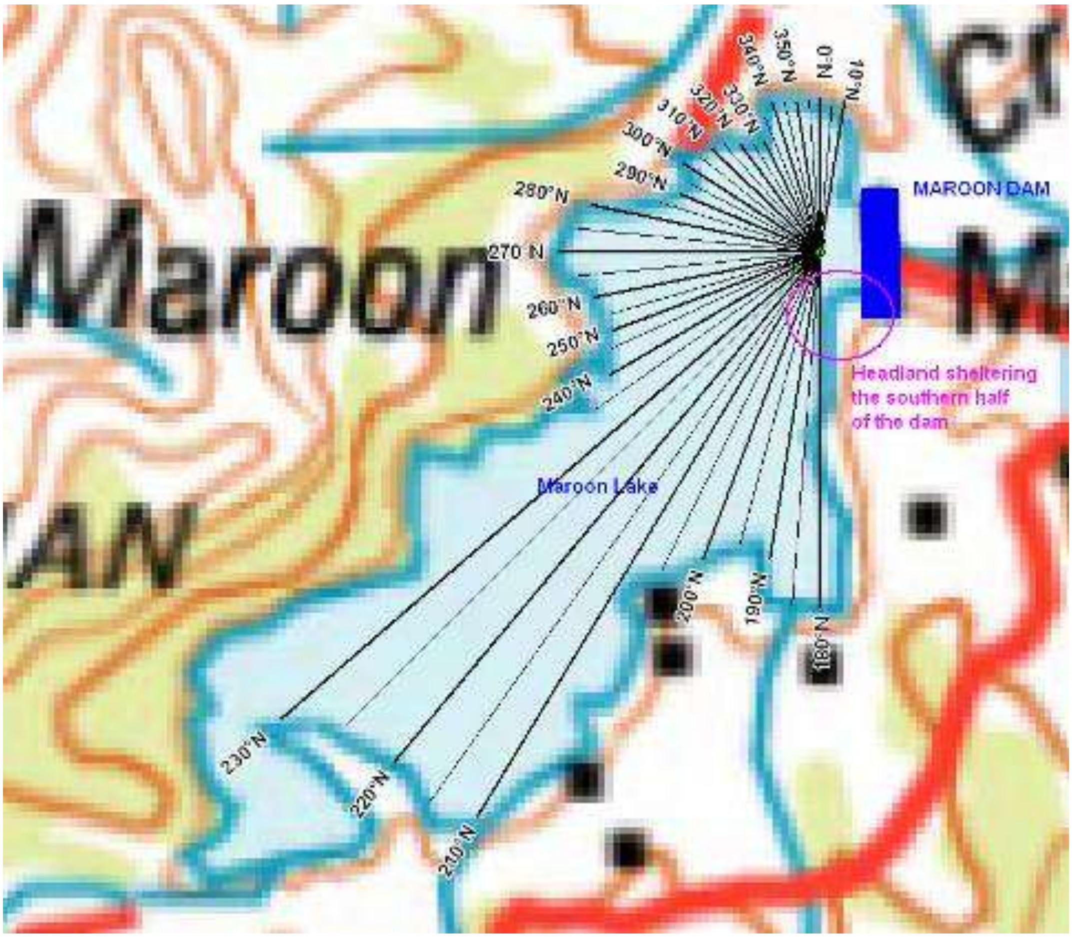

Figure 11: Fetches Measured for Maroon Lake Wave Climate Analysis.

Figure 12: Lake Maroon Lookout Highlighting the Steepness of the Surrounding Topography.

Figure 13: Vegetation Covered by Water showing that Maroon Reservoir is Relatively Full.

Table 3: Fetch Lengths from the Dam in Different Directions.

Direction (°TN)	Fetches (km)	Direction (°TN)	Fetches (km)	Direction (°TN)	Fetches (km)
180	1.46	245	0.81	310	0.49
185	1.60	250	0.76	315	0.44
190	1.28	255	0.75	320	0.43
195	1.32	260	0.88	325	0.40
200	1.39	265	0.94	330	0.36
205	1.43	270	0.93	335	0.35
210	2.54	275	0.99	340	0.33
215	2.53	280	0.69	345	0.33
220	2.47	285	0.61	350	0.54
225	2.57	290	0.57	355	0.53
230	2.67	295	0.56	0	0.53
235	1.07	300	0.54	5	0.56
240	0.86	305	0.51	10	0.54

Table 4: Wave Characteristics Results from ACES for a South-Westerly Wind.

Wind Speed Condition	3-second Gust Wind Speed* (m/s)	Hourly Wind Speed* (m/s)	Wave Characteristics Results		
			Significant Wave Height (m)	$H_{1/10}$ (m)	Wave Period (s)
Usual (Strong)	-	15	0.42	0.45	2.20
5 year ARI	28	18.6	0.55	0.59	2.55
10 year ARI	33	21.9	0.69	0.74	2.80
20 year ARI	38	25.2	0.83	0.89	3.04
25 year ARI	39	25.8	0.85	0.91	3.09
50 year ARI	44	29.2	1.01	1.08	3.32
100 year ARI	48	31.8	1.13	1.21	3.49

**Wind Speed determined from the Australian Standard and the Wind Stations Records*

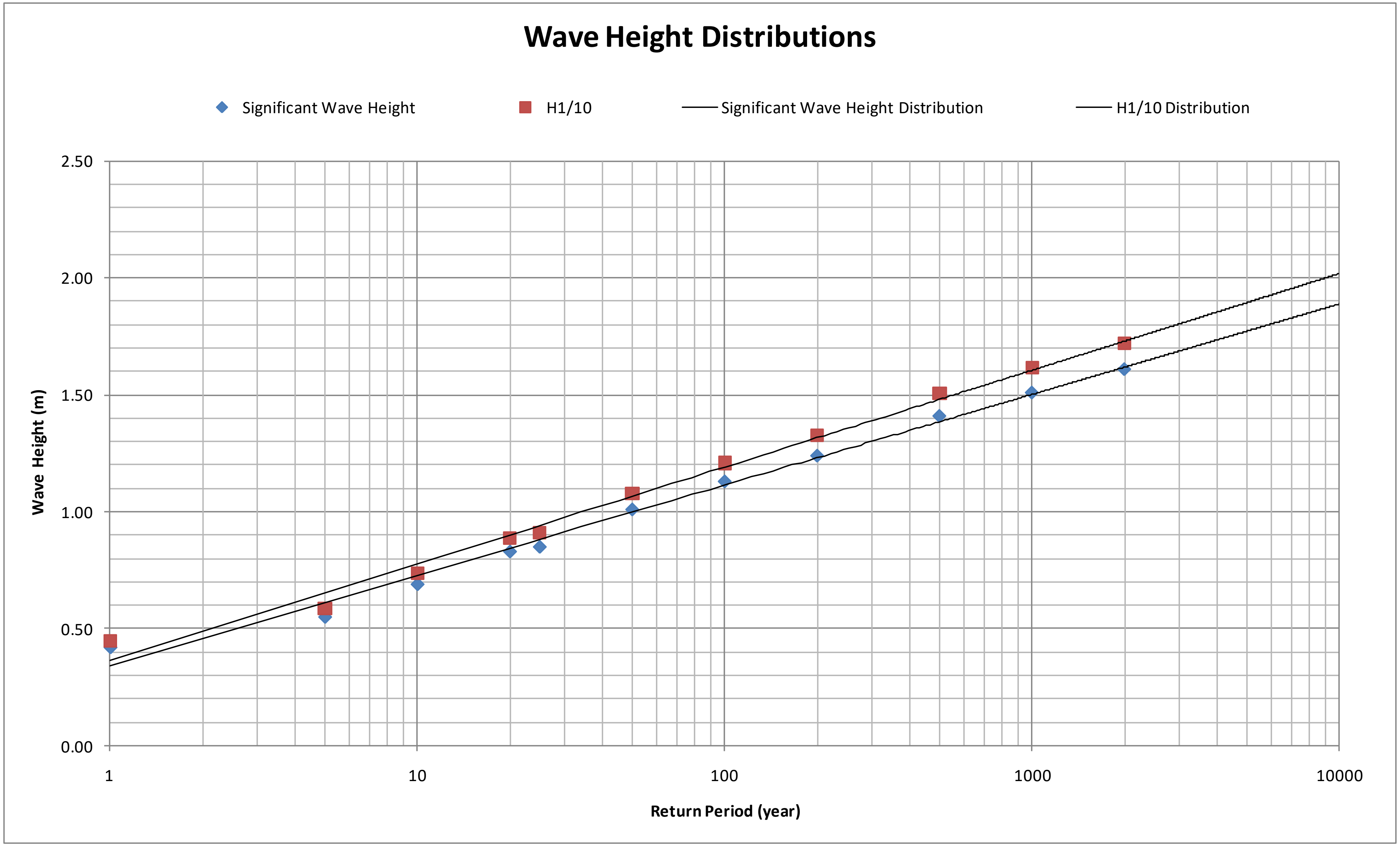

Figure 14: Wave Height Distribution at Maroon Dam.

Conclusion

Study of the wind and wave climate within the Maroon Reservoir shows that hourly winds can reach a speed of up to around 32 m/s in a 1-in-100-year event. This 100 year ARI speed could generate waves of up to around 1.1m wave height and 3.5s wave period. However, these wave parameters would only occur in case of strong wind in a south-westerly direction and would mostly impact the northern half of the dam wall as the southern half is relatively well protected by a headland from the main wind-generated wave.

Appendix 2 - HARD COVER INVESTIGATION - AQUACAP

Visit to Manufacturer – **Nylex (Superior Pak)**

Meeting with – **Shaun McInnes**

Location – **Melbourne**

Product

The product was originally produced by Nylex under the name AquaCap. This division of Nylex has changed its name to Superior Pak. The material of construction is polypropylene. This is a food grade material.

Product Description

The Aquacap is a best described as a lid under which there is a series of 6 separate flotation chambers around the inside edge (Figure 15).

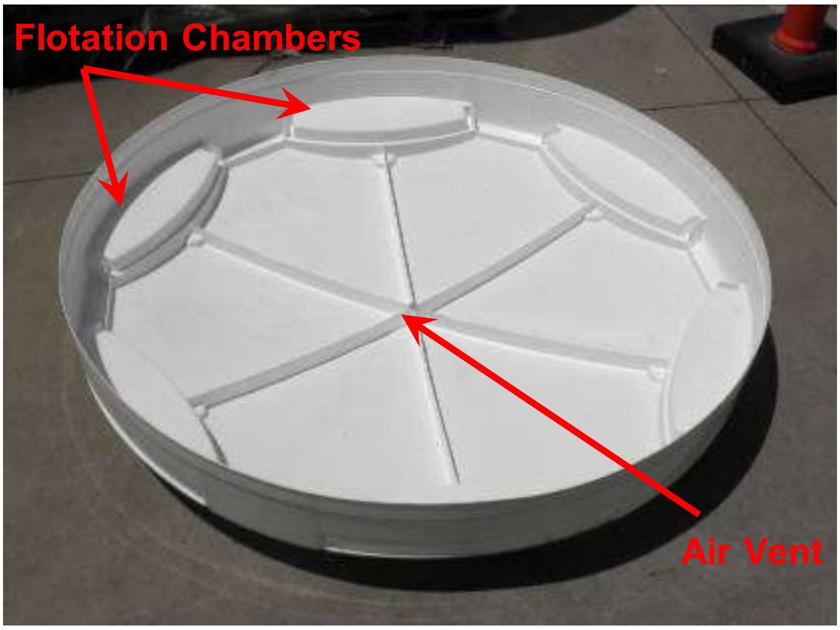

Figure 15: View of underside of AquaCap.

A single hole (approximately 10 mm diameter) in the centre of the cover provides for pressure equalisation and for air to be expelled when the cover is placed on the water.

The covers are circular in shape which would effectively prevent any interlocking and permits a small amount of sunlight to penetrate between the discs.

Product Manufacture

The product is manufactured from polypropylene using an injection moulding process. The covers over the flotation cells are welded in place to form a watertight chamber (Figure 16).

The caps are manufactured in Melbourne (Victoria). After manufacture, no further processing is required and as a result the caps can be placed directly onto the water surface off the transport pallet.

Figure 16: Top side view of AquaCap.

Product Development

Minimal information was provided regarding the development of the product. It would appear to be primarily aimed at the small dam market where a containment boom is not required. A lot of marketing was carried out in the mining sector.

Previous Applications

To date the product has only been installed on a single dam (as shown on the brochure). The dam is associated with a mining development in central NSW (near Parkes). There are currently no orders or further inquiries for the product.

Testing of Product

Testing of the AquaCap has included:

- Conformance of the material of construction (polypropylene) to food grade standards; and
- Laboratory wind testing of the stability of the cap.

The laboratory wind testing has indicated that the cap does blow over in wind speeds up to 130 km/h. The existing installation is reported to have successfully withstood wind speeds up to 100 km/h without the loss of any caps.

Coverage

The number of AquaCaps required to cover an area of 1 hectare (10,000 m^2) is approximately 8,500.

Approximate Cost

The approximate cost (Jan 2010) is $22 per cap, excluding GST and transport - a cost of approximately $187,000 per hectare.

Features of the Product

Features of the AquaCap include:

- Lightweight (easily handled);
- Stackable (for storage and transport) – 50 caps stacked on a single pallet (Figure 17);
- Easy to transport a large number (lightweight and stackable); and
- No need to orient the cap to form a large raft (totally circular in shape).

Figure 17: AquaCap Stacked on Pallets.

Application to a Large Reservoir

To date the AquaCap has not been used to cover a large reservoir. Superior Pak advise that they have access to a boom arrangement that could be utilised to contain the caps on a large reservoir. No details were available of this boom arrangement.

Other Comments

The AquaCap is easily transported and stored. A large number of spare caps can be stacked in a single pile (see Figure 17).

Placement and retrieval of the AquaCap does not require any special equipment and could be easily undertaken using a boat.

If the covers are inverted, they will continue to float (due to the internal buoyancy chambers), but this will expose a water surface. In the inverted state, there is the possibility that the water in the cover will heat up and evaporate at a rate equal to or higher than the uncovered reservoir.

Placement of the cover on a large dam could be undertaken from a boat or work barge, placing the covers directly within a containment boom. The only limitations will be safe working practices and a large enough boat or barge to minimise the numbers of trips required and sufficient safe working area for operators to place the covers. It is anticipated that there will be more issues to be resolved and work required in designing and placing a containment boom, than with the installation of the hard cover units.

Manufacture of the covers is under controlled factory conditions (implying that quality control measures are applied to this product).

Appendix 3 - HARD COVER INVESTIGATION – AQUA ARMOUR

Visit to Manufacturer – **Aqua Guardian Group**

Meeting with – **Ian Woodfield**

Location – **Melbourne**

Product

The product is a licensed unit which can be manufactured by anyone with the equipment using moulds supplied by Aqua Guardian Group. This group has developed and is marketing their idea. The product is marketed as "AquaArmour™"

Product Description

AquaArmour™ consists of two identical moulded covers which are welded together to form a disc. Prior to welding together, six flotation cylinders are placed inside the disc (completely sealed). As the discs are made from two identical covers, the unit can be placed on the water with either side facing up (Figure 18).

Vent holes permit water to enter each side of the disc. When floating on the water surface, the discs hold approximately 80 L of water, which act as ballast by holding the disc on the water, in turn minimising the potential for it to blow over.

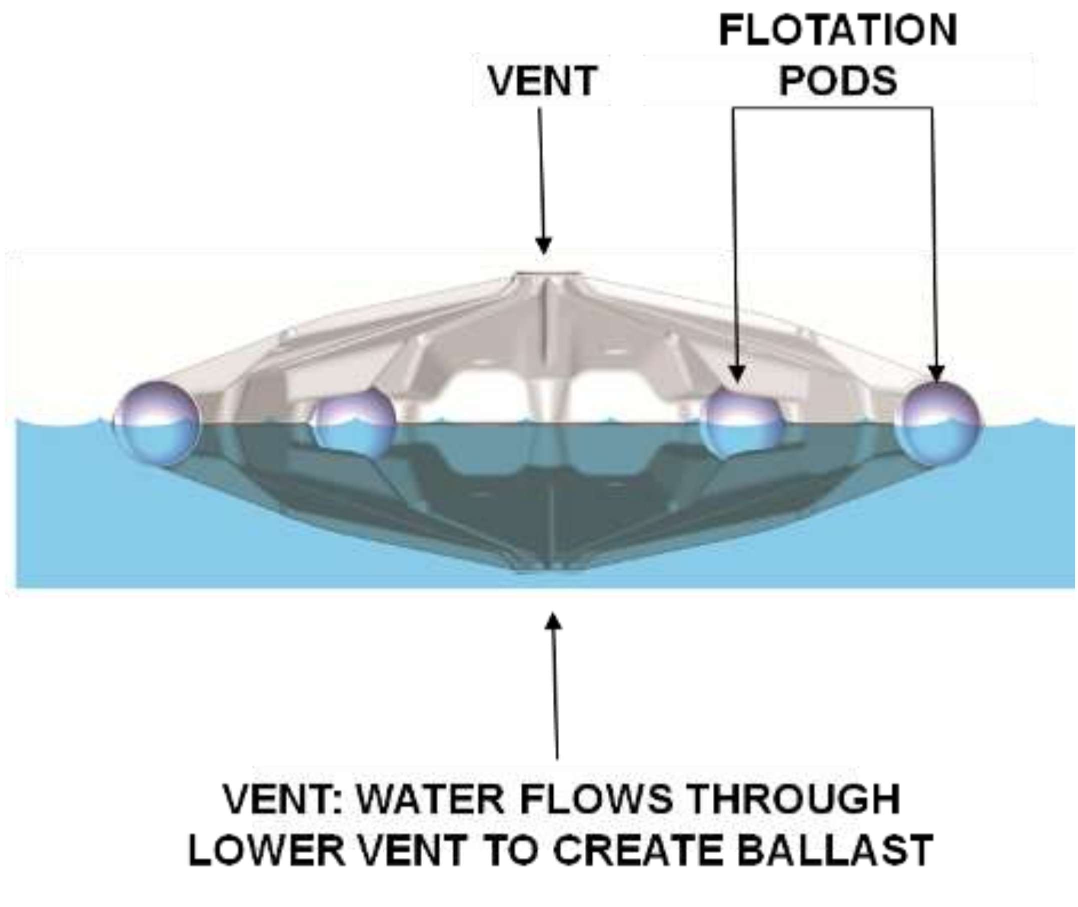

Figure 18: **Section through AquaArmour™ Unit.**

The covers are hexagonal in plan area, which enables them to raft closely together and provide a high percentage of cover (Figure 19).

Figure 19: Illustration Depicting Modules Arranging and Packing on the Water Surface.

Product Manufacture

The product is manufactured on the site of installation from high density polyethylene using an injection moulding process. In addition to on-site manufacturing, modules will also be produced at Venture Industries (Australia) in Campbellfield, Victoria, as well as Srithai Superware (Thailand).

Aqua Guardian Group has a signed agreement with both of these companies for manufacturing AquaArmour™ modules.

The discs are assembled on site before placing directly on the water body. The manufacture, assembly and welding process takes approximately 1.5 minutes per unit. The units are placed directly onto the water off the assembly line.

It is possible to manufacture the covers at an offsite facility and then move the stacked covers to the deployment site for final assembly and welding as the covers are capable of stacking closely for transport purposes.

The product is guaranteed to have a minimum life of 10 years (design minimum). Life expectancies of up to 20 years are anticipated in practice. The modules are also recyclable, providing “cradle to grave” sustainability.

Product Development

Discussions indicated that AquaArmour™ was still undergoing a degree of development but that the basic shape and concept that has been developed will be retained. Changes are likely in the manufacture process where containerisation of the equipment is being examined.

To date, there has been no requirement to contain the cover using a boom (the product has not been used to date on large open reservoirs). However, Aqua Guardian Group have started to develop some boom designs.

Applications

AquaArmour™ will be installed on an urban water supply dam located at Ouyen, north-west Victoria, in November 2010, in collaboration with GWMWater. There are two dams, each of four ha in surface area. Fifty percent of one dam will be covered with AquaArmour™ modules, the other dam will remain uncovered, and act as a control. An intensive testing regime around evaporation savings and water quality is currently being implemented for both dams.

Material Type

As noted above, the material of construction is high density polyethylene. This is a food grade material. A small amount of UV stabilising material has been added.

Testing of Product

Testing of the AquaArmour™ has included:

- Conformance of the material of construction (polypropylene) to food grade standards; and
- Analysis of the cover under wind loading conditions.

The wind loading analysis has indicated that the cover does flip over in wind speeds up to 200 km/h. No wind tunnel testing or on site trials have been undertaken.

Features of the Product

Features of the AquaArmour include:

- Lightweight (easily handled) – 3.5 kg when empty (no ballast water);
- No need to orient the covers to form a large raft (will automatically align themselves out as they are deployed);
- Can be rotated over to expose the underside (extends the life of the cover);
- Makes no difference which side is placed on the water;
- Even if flipped over the cover will remain functional; and
- The water ballast inside the cover increases its stability.

Coverage

The number of AquaArmour™ required to cover an area of 1 hectare (10,000 m^2) is approximately 9,000. Aqua Guardian Group calculates actual coverage is between 85% and 90% when the units are rafted together. On this basis they estimate that covers will achieve a reduction in evaporation of approximately 80%.

Approximate Cost

The approximate cost (Jan 2010) is $30 per module, fully installed, excluding GST – a cost of approximately $270,000 per hectare.

Application to a Large Reservoir

To date the AquaArmour™ has not been used to cover a large reservoir. Aqua Guardian Group advise that they are developing a number of boom arrangements that would enable the cover to be installed on large reservoirs. No details were available of this boom arrangement (still in commercial development).

Other Comments

It would be difficult to maintain a large stock of spare units due to the space that an assembled unit occupies. It may be possible to store the components (covers and flotation cylinders) but hand welding of the units would be needed. The material is relatively thin, so hand welding may not be feasible and there is likely to be a quality issue with the welds.

To remove the covers from the water will require the development of a lifting system. A water filled unit has a mass of over 80 kg and takes approximately 3.5 minutes to drain (it is noted that lifting or removal of the covers would be considered to be an infrequent event).

As noted above, manufacture of the cover is on-site due to its bulk when assembled. Manufacture is likely to take place at the edge of the water. The final location for the covers may be some distance away from the manufacture/launch site, which will require forming the covers into a raft and towing them into position.

The production and clean up of waste material at the manufacture location would need to be the subject of a managed and documented process.

Appendix 4 - GENERIC RISK ASSESSMENT OF A DAM

The risk assessment provided in the following spreadsheet is generic and qualitative, and has been undertaken as a desk top exercise only in order to compare a dam without a hard cover (ie dam in its current state) and the impact of installing a hard cover (ie identify possible incremental risk).

This risk assessment is to be used as a guide only to the type of risks that may be applicable.

- Part A of spreadsheet covers the base condition of a dam without a cover.
- Part B of the spreadsheet covers the condition with the installation of a hard cover.
- Part C provides details on the risk matrix adopted for this exercise.

Appendix 5 - GENERIC APPROACH TO PLACEMENT OF HARD COVERS ON LARGE DAMS

Introduction

This document is intended to provide a series of questions that anyone (dam owner) considering the installation of a hard cover on a large dam in Queensland will need to consider. In this instance a hard cover is defined as a floating cover made up of a series of units floating on the surface of the dam, which, when rafted together, form a large surface area on top of the water.

It is not possible to define an exact approach to the installation of hard covers as the location and shape of the dam's water surface as well as the type of outlet and spillway works all have an impact on how and where a hard cover may be installed.

A key part of any investigation will be the impact of the installation of a hard cover on the risk profile of the dam and the mitigation measures that may be required to maintain the dam at an acceptable risk level.

Type of Hard Cover

There are a number of hard cover systems that have been developed and installed, mainly on smaller "turkey's nest" type dams to date. This document provides an approach to the installation of hard covers on larger water bodies where the cover **may not** be restrained by the embankments of the dam. The approach outlined below is generic and is not based on any particular manufacture or type of cover.

Generic Approach

The approach outlined below is intended to act as a guide only as to the depth of the investigation required in respect to the installation of a hard cover on a large dam in Queensland. The following sections outline a series of questions that need to be considered, taking into account the context for the dam being considered. In some instances the questions may not be applicable (ie recreation use questions are not applicable if recreation use or public access to the dam is not allowed).

Dam owners will need to develop a position in relation to each question. Depending on the particular dam being examined for the installation of a hard cover, there may be additional issues that need to be investigated that relate to the particular site.

General

- Outline the purpose of the hard cover and the key project drivers (ie reduction of evaporation and the desired area of coverage).
- Is the benefit of the cover associated with dealing with a critical water shortage situation (required for political or social reasons) or is the benefit to be considered on a cost/benefit basis?
- Is there a good record of the profile of the bed of the dam (to identify the most appropriate location for a hard cover)?
- Update the dam's risk assessment (or undertake a risk assessment) to determine the change in risk profile and any mitigation measures required to keep the risk at an acceptable level. Seek guidance from the Dam Safety Regulator if there is an increase in the dam safety risk level.
- Consider the other risks identified (commercial, social, operational, safety etc) and the mitigation measures required. Does the risk profile change with the installation of the cover and how does this fit into the dam owner's risk appetite? Would the possible risk mitigation measures reduce the risk to an acceptable level?

- What impact will the change in risk profile have on insurance costs for the dam (including public liability and indemnity, cost of insuring the works and workers compensation)?
- Is the dam in a high wind area (ie coastal area subject to cyclones)?
- Undertake a wind and wave analysis of the dam.
- What is the range of rise and fall in the dam's water level, including peak flood conditions?
- Will the cover be installed abutting a shore (and therefore accessible from the shore) or will it be a free floating structure?
- Is the inflow into the dam likely to carry a high debris loading (which could hang up on the cover and containment booms)?
- Will the cover be installed by the system manufacturer or a sub-contractor?
- What is the involvement of the system manufacturer in the project?
- What guarantees will be provided with the hard cover (including warranty of the product)?
- Are there separate warranties and guarantees on different components (ie hard cover units versus the containment boom and mooring systems)?
- For large scale projects, what is the financial position of the contractor (or manufacturer) to guarantee delivery, installation and warranty?
- What is the history of the contractor or manufacturer in respect to the hard cover offered and similar products and projects?
- What is the location of manufacture for the hard cover (ie local, Australia, international)?
- Are references available for the proposed hard cover in respect to product testing and previous installations – if so, interrogate the references?
- If any hard cover segments were discharged through the spillway, what is the impact on the downstream environment and how would this be rectified (hard cover segments picked up)?
- Are there any permits or applications that will need to be submitted for the hard cover (ie local council, DERM etc)?

Current Dam Use

- For dams used for potable water supplies, do all materials proposed for the hard cover and any associated containment systems comply with current standards for materials used in potable water systems?
- Is recreation use of the dam permitted?
- What would the impact be on recreation use by installation of a hard cover (social and political impact).
- Would the preferred location for the hard cover impact on any other facilities or users (ie adjacent property or development owners, shore based recreation areas or commercial operations based on use of the lake (ie boat hire, education camps, camping grounds etc)? What is the impact and what are the mitigation measures that would need to be implemented?
- Identify the measures required to control recreation use in the vicinity of the hard cover (boating restriction zone).
- If installation of the cover requires clearing of trees or stumps left in the dam or re-contouring of structure in the base of the dam, how will this impact on the aquatic habitat and will this habitat need to be replaced?
- Will the hard cover have an impact on shore-based recreation areas (visual impact on picnic areas)?

- The proximity of the hard cover to publicly accessible areas (ie picnic or public viewing areas) where the public may be tempted to access the hard cover?
- Identify how the public would be informed about restrictions in respect to the hard cover (ie boating exclusion zones etc).

Dam Operator

- What are the perceptions of the dam operator(s) towards a hard cover (and what would need to be done to convince them of its merits if there are concerns)?
- What is the impact on the dam operator in terms of ongoing operation of the dam and maintenance? Define any additional workload, operating or safety procedures required.
- What facilities/equipment is the dam operator going to require to inspect and maintain the hard cover? Are these facilities or equipment included in the offer from the system supplier?
- Is special training required for the dam operator(s) in respect to the hard cover and containment booms?
- Identify any particular Occupational Health and Safety issues for inspecting and maintaining the cover (ie heavy weight, slippery, special lifting devices required).
- What will be the maintenance requirements for the hard cover and any containment system (ie containment booms and boom mooring arrangements) in order for the cover and booms to reach their design life?
- Is the design life for the cover different to the maintenance boom and will either component need to be replaced in order for the cover system to reach its design life?
- What is the frequency of inspection required for the cover?
- Does the installation include training of the dam operator(s) in inspection, maintenance and handling of the hard cover and containment booms?
- Does the project documentation include the supply of an operations & maintenance manual" for the whole system?
- What is the procedure, systems and equipment required to remove and store the cover units in the event of needing to remove the cover (ie low water levels stranding the cover on the bed of the dam)?

Hard Cover Design

- What is the proposed design life for the cover (and has the proposed cover been tested for this life)?
- Is the hard cover designed for the possible wind speeds (particularly if the dam location is subject to cyclonic wind conditions)?
- Determine the optimum location for the hard cover taking into account the variation in water level, dominant wind direction and exposure to long fetch distances (likely wave action).
- If the cover is to be installed over a partial area of the dam's water surface, how is it to be contained (ie a floating boom)?
- To make the large area of the hard cover more manageable, is it feasible to divide the cover into a number of cells?
- Design details for a floating boom including a mooring system that allows for variations in water levels.
- If a second containment boom is to be deployed (to act as a backup or physical barrier to keep boats away from the cover), how is this separation maintained?
- Has the containment boom been used on other projects – if so provide details of the location and references?

- Identify the long term durability of the hard cover under the likely operating conditions (wind and wave action) and will this meet the design life requirement?
- Is there good shore line access to the location where the cover is to be installed or will it need to be installed from a boat or barge?
- How can the cover be monitored in respect to durability and long term performance?
- If a cover unit or design boom unit is damaged, what is the likelihood of it sinking below the surface of the water? Is there an increased likelihood of this happening with time?

Dam Safety

- Could the cover reduce the capacity of the dam's spillway in any way?
- What would be the impact of the hard cover on the spillway in the event that the cover floated into the spillway approaches?
- Could the cover reduce the capacity of the dam's outlet works (block the flow of water to the outlet tower or block screens, valves or other outlet works)?
- For dams fitted with spillway gates, could the hard cover (or any segments) stop the gates being operated (ie jam the lifting mechanism)?
- Will special exclusion booms be required at critical locations including the outlet works and spillways. What form would these containment booms take?
- In a large flood event, could the floating cover build up on top of the dam embankment/wall and increase the pressure on the dam embankment/wall leading to failure of the dam?
- Has the Dam Safety Regulator been consulted in respect to the specific project?

Suggested Investigation and Design Steps

Following the investigation, compilation of data and answering of key questions (as noted above), the following are suggested steps if it is proposed to continue towards the installation of a hard cover. The following process may not reach an end if the risk level identified is too great, cost benefit ratio is unacceptable or the Dam Safety Regulator does not approve the proposal.

1. Compile all of the available data for the dam (Dam Data Book will be a good start).
2. Undertake a wind and wave action study for the dam.
3. Determine what will be the area of coverage (assuming that only part of the dam will be covered).
4. Carry out a survey of the base of the dam if this data is not already available (in the area proposed for the hard cover).
5. Identify the area(s) where installation of a hard cover may be feasible taking into account the bottom profile of the dam and dominant wind directions (and possible wave action).
6. Undertake a *Quantitative* Risk Assessment covering:
   (a) The existing dam without any cover (base case);
   (b) Installation of the hard cover;
   (c) Operation and maintenance of the hard cover; and
   (d) Change in risk profile for the dam (dam safety).
7. Assess the risks and possible risk mitigation measures required. Update the risk register for the dam to include risks identified for the cover.
8. Assess what impact the preferred cover will have on the overall operation of the dam, including proposed maintenance and operating regimes required to maintain the cover and the risk profile of the dam within acceptable limits.

9. Consider any impact on recreation users for the dam (if applicable) and any changes required.
10. Carry out a cost / benefit analysis (if applicable – not necessarily required where the hard cover is being installed in response to a severe drought). Costs to include any mitigation measures, as well the impact on recreation or other users.
11. Undertake discussions with the Dam Safety Regulator to examine the proposal and the change in risk profile (incremental risk) for the dam. Determine any requirements and conditions to be placed on the installation of a hard cover by the Dam Safety Regulator.
12. Seek tenders for the design and installation of a complete system from suitable contractors or suppliers.
13. Assess the tenders received including the technical aspects associated with:
    (a) Material of manufacture of the cover and containment booms;
    (b) Long term durability of all components (to withstand sunlight etc);
    (c) Design of the containment booms;
    (d) Ability to withstand high wind and wave action (including combination of both);
    (e) Operation and maintenance aspects;
    (f) Access arrangements through the containment booms;
    (g) How the system is to be installed (and any additional works required to provide access for installation);
    (h) Ongoing operation and maintenance costs;
    (i) Availability of spare covers (replace damaged units); and
    (j) Guarantees and warranties provided (and whether the contractor/supplier is established enough to support these).
14. Assess whether any additional works are required to satisfy dam safety requirements (ie additional containment booms at spillways and outlet towers.
15. What are the monitoring facilities that will be required to check the performance of the hard cover and its condition.

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