1. INTRODUCTION:

Bituminous geomembranes (BGMs) have been used extensively in a wide range of water management applications since they were initially developed in 1974. The applications for BGMs in water management applications include water supply dams, canals for irrigation, shipping canals, and canals for supplying water for production of electricity in power plants.
BGMs have a number of technical advantages over typical polymeric geomembranes as follows:

a) The high surface friction angle provides a higher level of safety to people and animals who may fall into the canal. The use of a BGM can in some case help avoid the costs of fences around canals.
b) A steeper slope face can be used if necessary (at least 10-15 degree steeper than with other type of liner).
c) The BGM can stay exposed due to its high UV resistance, and high mechanical resistance which is due to its thickness and its internal reinforcing geotextile.
d) Construction and maintenance vehicles with tyres can travel in the canal directly on the BGM which is not possible with most other membranes.
e) A BGM is considered self-healing (auto-seal) for small punctures due to the visco-elastic nature of the bitumen.
f) BGMs can be installed in high winds and harsh weather conditions and this helps prevent delays to the project schedule. BGMs are heavier than most common liners making it more resistant to wind uplift.
g) The attachment of a BGM to concrete is simple and is performed by sealing the geomembrane directly onto the primed concrete surface.
h) The coefficient of thermal expansion on a BGM is extremely low which means that BGMs do not experience wrinkles from expansion and contraction in high thermal
range environments. Wrinkles in canals increase the Manning’s coefficient and can have an adverse effect on water flow and long term durability.

i) The fact that the BGM can be installed by the irrigation company’s own workforce, after appropriate training from the BGM manufacturer, allows for a more flexible construction sequence on the canal.

j) BGMs are heavier than water and therefore do not float upwards like other polymeric membranes do, so there is no extra time and costs involved with ballasting requirements.

2. THE COMPONENTS OF A BGM – THE TECHNICAL ADVANTAGE

The multi-component structure of the BGM gives it a number of technical advantages over other polymeric membranes. A BGM is a geomembrane manufactured by impregnating a polyester geotextile with an elastomeric bitumen compound. The geotextile provides the mechanical resistance and the high puncture resistance. This elastomeric bitumen provides the waterproofing properties of the geomembrane and also ensures the longevity of the composite by totally impregnating the geotextile. The BGM composite also includes other components as illustrated in Figure 3 below.

![Figure 3: Schematic cross section of BGM](image)

The BGM composites contain internal non-woven polyester reinforcement from 200 g/m² up to 400 g/m² and overall thickness of the composites are from 3.5 mm up to 5.6 mm.

BGMs are by far the thickest and heaviest geomembranes on the market and combined with the inherent waterproofing properties of bitumen exhibit some unique qualities for irrigation canal projects as outlined below.

3. SPECIAL CHARACTERISTICS OF BGMS SUITED FOR IRRIGATION CANAL APPLICATIONS

The hybrid nature of a BGM leads to unique and specific mechanical properties and behavior which are ideally suited for irrigation canals and dams as follows.
3.1 Non-slip surface

The sand surface of the BGM provides a non-slip surface for construction workers during installation and also allowing easier exit from the canal for any human or animal that may accidentally fall into the canal.

![Kangaroo trapped on a slippery polymeric membrane](image)

Figure 4: Kangaroo trapped on a slippery polymeric membrane. The sand surface of a BGM allows animals to exit the irrigation canal or dam.

The high interface friction angle (34˚ to 39˚ depending on the material placed against the BGM) also facilitates steeper slope faces if required.

3.2 Ageing

The effect of ageing on the tensile strength of BGMs has been investigated by laboratory testing using a xenon lamp as per ASTM D 4355 and by testing of material exhumed after more than 30 years of service. The testing of BGMs has shown no significant reduction in tensile properties. For example, tests done on the ICOLD Ospédal dam in Corsica by the French Ministry of Agriculture after 30 years of service, showed that there was no variation in the mechanical properties of the Coletanche, and the Coletanche still had a very low permeability coefficient of $10^{-13}$ m/s. The tensile properties of BGMs are derived primarily from the polyester non-woven geotextile at its core and this geotextile is very well protected from ageing and degrading processes as it is totally impregnated with elastomeric bitumen.

In order to determine the long-term ageing and effectiveness of existing potential
covering membranes ANDRA (French National Agency for managing radioactive waste) developed a mathematical model and calibrated it with test results from samples from different existing sites where the materials had been installed for varying periods of time. ANDRA determined that the Coletanche BGM would have a resistance to bio-degradation in excess of 300 years (Convert, Coquille and Herment, 1993).

It is also worthwhile noting that bitumen has been used since antiquity to waterproof structures (Krishnan and Rajagopal, 2003).

### 3.3 Puncture resistance

BGMs have excellent puncture strength, due to the internal polyester reinforcement and the visco-elastic properties of the elastomeric bitumen. Larger stones can be tolerated in the subgrade (up to 25mm) and rocks in the cover soil (up to 150mm) without the need for a cushion geotextile. This often eliminates the cost and time required for installing a cushion geotextile. And it also gives the canal owner a greater deal of flexibility for maintenance in the future as the BGM can be trafficked on with light vehicles. This is shown on Figure 5 where a front end loader deploys the BGM on which it then drives. Note that there is no damage to the BGM.

![Figure 5: Construction equipment on a BGM without damage](image)

### 3.4 Wind uplift resistance

The BGMs typically used for irrigation canals and dams have a minimum mass per unit area of 4200 g/m² (for Coletanche ES1) up to 5800 g/m² (for ES3). This mass per square metre is more than three times that of a 2 mm thick polymeric geomembrane or more than four times that of the common 1.5 mm polymeric geomembrane. Combined with a higher tensile resistance (due to the presence of the internal reinforcing
geotextile), the BGM can sustain wind speeds 3 to 4 times higher than lighter polymeric geomembranes without damage or excessive straining. Consequently, on an irrigation canal or dam a BGM can be installed in stronger winds than other flexible geomembranes and will necessitate less ballast should large areas need to remain exposed for long periods of time. This is beneficial for helping maintain construction schedules in harsh climatic conditions.

3.5 Ability of the BGM to bond directly to a variety of materials

BGMs have a distinct practical and cost saving ability to connect directly to other materials such as concrete and steel that may form part of inlet and outlet structures, weirs etc. This results in considerable time and cost savings for the canal project. BGMs may be welded directly to steel and concrete structures in the canal by use of a bituminous primer applied to the pipe or structure, which is then heated and bonded directly to the melted surface of the BGM, forming a complete watertight seal. A batten strip (aluminum or stainless steel) may be fixed to increase the longevity of the weld. BGM's can also be effectively sealed to polymeric pipes by using Bitumseal adhesive mastic.

![Figure 6](image.jpg)

Figure 6. The BGM can be bonded directly to primed concrete inlet and outlet structures

3.6 Extreme temperature application

A bituminous geomembrane has a very low coefficient of thermal expansion compared to that of resin based polymeric geomembranes (2.2 x 10^{-3} mm/m/°C vs 1.0 to 2.5 x 10^{-1} mm/m/°C), and this gives the BGM a distinct advantage on canal or dam projects that are exposed to extremely hot or cold environmental conditions. This is particularly important in Australia where there are high temperature variations during the course of a day. A BGM does not expand and contract excessively under these temperature variations like a polymeric geomembrane does, with the associated problems of induced
wrinkles and contraction stresses. Figure 7a shows a BGM being laid in a pond in Guatemala during a sunny day with an ambient temperature of 39°C during installation. The BGM lays flat on the foundation soil with no wrinkles. Figure 4b shows a polymeric geomembrane installed in Vermont, USA under the same temperature. A large number of wrinkles can be observed on the polymeric geomembrane.

![Figure 7a & b: On the left a BGM installation without wrinkles and on the right a polymeric geomembrane installation with wrinkles under same temperature conditions](image)

### 3.7 BGM density heavier than water

A BGM has a specific gravity of 1.22 which is heavier than water and therefore the BGM will always remain submerged. This is in contrast to most polymeric membranes which are less dense than water (typically with an S.G. of 0.96) and so will tend to float upwards.
4. Examples of BGM applications in Irrigation Canals

4.1 Naches-Selah-Moxee Irrigation District, Washington State, USA

Figure 8. Irrigation canal in good condition after 5 years of service

Figure 9. The BGM is ideally suited to connect and adapt to complex shapes like this tunnel inlet
4.2 Ochoco Canal, Oregon State, USA

Figure 10. BGM connection to a drainage pipe in the irrigation canal wall

Figure 11. Preparation of the canal. Notice the rough subgrade.
Figure 12. Irrigation canal lined with BGM

Figure 13. The BGM irrigation canal after 6 years of service. (After 15 years of serve the canal is still in operation).
4.3 Lancaster Canal, United Kingdom

Figure 14. Installation of the BGM in the UK.

4.4 Nivernais Canal, France

Figure 15. Installation of the BGM in the canal using a hydraulically controlled spreader bar, which uses the hydraulics from the excavator to speed up deployment.
4.5 Sankt Dionysian Canal, Austria

Figure 16. A high velocity canal in the Austrian Alps using a BGM.

4.6 Chambly Canal, Quebec, Canada

Figure 17. Deployment of the BGM into the canal.
Figure 18. Construction workers fix a bar to the BGM to enable it to be pulled across the canal. The internal polyester reinforcing in the BGM prevents it from tearing.

Figure 19. The excavator pulls the BGM across the canal using the bar attached to the BGM.
Figure 20. The BGM anchor trench is backfilled.

Figure 21. The ease of flame bonding the BGM to primed concrete structures is shown.
Figure 22. Soil and rock cover being placed over the BGM

Figure 22. The final BGM canal.
CONCLUSIONS

In conclusion, we can say that BGMs offer canal designers a wide range of technical advantages and BGMs have been used successfully on many canal and irrigation projects around the world. These technical advantages help reduce the overall costs of canal construction by allowing less subgrade preparation, no soil cover, speeding up the construction programme, easy maintenance and the construction can be performed by local on-site labour.

REFERENCES
