

Long-Term Performance of Membrane–GAC Systems During Extreme Raw Water Conditions

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ABSTRACT

Across South Australia, ten water treatment plants (WTPs) incorporating coagulation/flocculation, membrane filtration and granular activated carbon (GAC) have operated for more than 15 years on highly variable River Murray source waters. These plants have experienced major raw-water disturbances including drought, blackwater events, elevated taste & odour (T&O) and dissolved organic carbon (DOC), algal blooms, and the extreme River Murray flooding event in 2002-2023.

This paper evaluates the long-term performance and resilience of the integrated membrane–GAC train across the ten WTPs, drawing on extensive operational datasets, historical taste and odour (T&O) challenges, and laboratory scale GAC performance assessments.

Full-scale results show consistent performance of MIB and geosmin removal even when inlet concentrations exceeded 700–1000 ng/L at several sites. Laboratory biological filtration potential testing confirms that the GAC across the treatment plants now operates primarily in biological mode for MIB and in mixed biological–physical mode for geosmin.

1.0 INTRODUCTION

The Country Water Quality Improvement Program – Phase 3 (CWQIP3) delivered a suite of ten water treatment plants (WTPs) across regional South Australia between 2007 and 2009, each designed around a common multi-barrier treatment train consisting of coagulation, flocculation, membrane filtration and granular activated carbon (GAC) contactors. These plants supply communities along the River Murray, a system well known for its extreme hydrological and water quality fluctuations, periodic drought and flood cycles, high natural organic matter (NOM), and seasonal cyanobacterial challenges. The consistent design of the CWQIP3 plants provides a unique opportunity to evaluate long-term operational performance across multiple treatment sites drawing from the same River Murray source, while still accounting for local raw-water quality differences due to offtake location.

Since commissioning, the CWQIP3 plants have been subjected to a wide range of raw-water challenges including elevated dissolved organic carbon (DOC), large algal blooms, and significant taste and odour (T&O) events driven by 2-methylisoborneol (MIB) and geosmin. Historical assessments performed on the GAC media has demonstrated that although the physical adsorption capacity of GAC declines with age, the media continued to remove T&O compounds at close to 100%, enabling sustained removal beyond the expected adsorption lifespan. Since 2015 routine evaluations across multiple sites showed that biological activity had become the dominant removal pathway for MIB, while geosmin continued to be removed through a combination of adsorption and biodegradation.

Over time, many CWQIP3 GAC beds have now exceeded 70,000 to more than 200,000 bed volumes, far beyond their nominal design expectation. Ongoing full-scale operational data and periodic laboratory-scale column tests are therefore essential for understanding the condition of the media, the stability of biofilm activity, and the risk of breakthrough during high-loading events. Recent GAC assessments such as a 2025 Blanchetown investigation confirm that biological removal remains robust, with active GAC achieving >98% removal of MIB and geosmin even at this advanced stage of media life. Autoclaved-sterilised GAC showed moderate physical removal of geosmin but very limited physical removal of MIB, reinforcing earlier findings that long-term performance depends on maintaining a healthy and undisturbed biofilm.

The resilience of the membrane–GAC treatment train was tested extensively during the 2022–23 River Murray flood event, which saw unprecedented concentrations of T&O compounds enter several

CWQIP3 plants. Inlet MIB reached 958 ng/L at Glossop and 1010 ng/L at Cadell, while geosmin levels peaked at 1120 ng/L at Blanchetown. Despite these extreme conditions, treated waters showed remarkable T&O removal potential with Blanchetown achieving ~85% removal of MIB and ~99% removal of geosmin during peak loading. These results highlight the critical role of biological GAC in maintaining water quality during challenging periods and demonstrate the system-wide resilience of the CWQIP3 treatment configuration.

This paper brings together long-term operational datasets, extreme-event performance, and laboratory GAC assessments from across all ten CWQIP3 plants to evaluate the ongoing effectiveness of the membrane–GAC treatment train. The objectives are to:

1. Assess T&O and DOC removal performance across the ten WTPs under both normal and extreme raw-water conditions.
2. Evaluate operational resilience during the 2022–23 flood event as a system-wide stress test.
3. Characterise the balance between physical and biological removal mechanisms as GAC ages.
4. Provide recommendations for asset-life planning and operational risk management into the future.

Together, these insights strengthen our understanding of the robustness of biological GAC performance and highlights the importance of ongoing proactive monitoring and operator understanding of system optimisation across diverse and challenging source-water conditions.

2.0 DISCUSSION

2.1 Historical Operational Performance of the ten CWIP3 WTPs

This analysis draws on the previous 10-years of operational datasets from all ten CWQIP3 membrane–GAC plants (2016–2026). In figure 2 there is a significant variance in the amount of treated water produced in bed volumes (BV) across the ten sites, with Woolpunda and Kanmantoo WTPs treating close to 200,000 BV since inception, whereas Cowirra WTP has treated 3 - 4 times less. Only Mypolonga has had a complete GAC media replacement (media replacement finalised in July 2025).

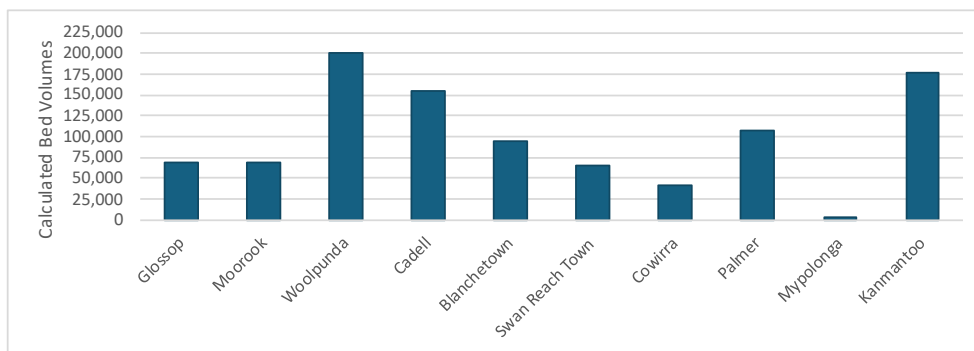


Figure 2: Calculated Bed Volumes for the Ten CWIP3 WTPs (as of December 2025). Note: GAC replacement at Cowirra WTP finalised July 2025.

Over the past 10-years, all ten WTPs have continued to have a particularly effective 2-methyl isoborneol (MIB) and geosmin removal capacity. Figure 3 shows the average inlet and outlet results from the weekly water quality monitoring program for a) MIB, and b) geosmin over this period. As can be seen even after 15 years GAC media age the removal of MIB and geosmin at all treatment plants is particularly effective over this period (except for the new GAC at Mypolonga WTP). DOC removal is less effective but still considerable considering the age of the GAC media.

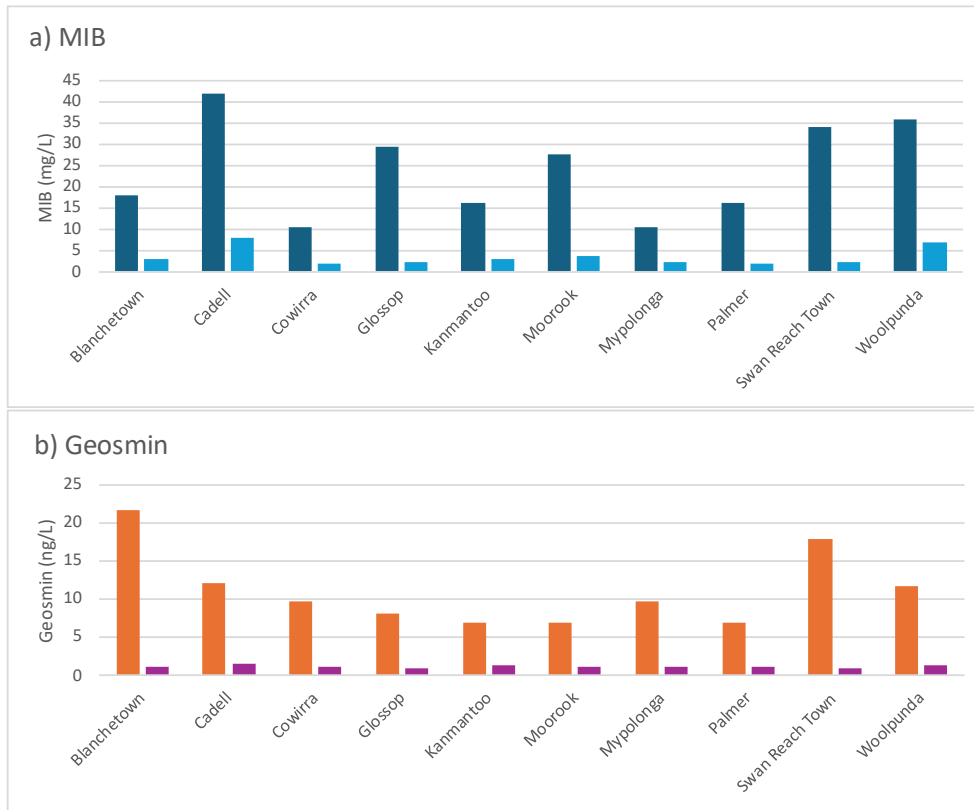


Figure 3: 10-year average Inlet vs Outlet T&O/DOC at 10 WTPs, a) MIB, b) Geosmin

2.2 Operational Resilience During the 2022-2023 River Murray Floods

T&O challenges and treatment resilience were observed during the River Murray Flood of 2022–2023, with several sites experiencing inlet MIB or geosmin above 700–1000 ng/L while maintaining low treated-water concentrations. All along the River Murray within South Australia, DOC levels increased to high levels reaching ~ 20 mg/L at the peak of the water challenge (highlighted in red in figure 4). It is worth noting that there were DOC challenges of 10 mg/L or more both pre and post the official flood period.

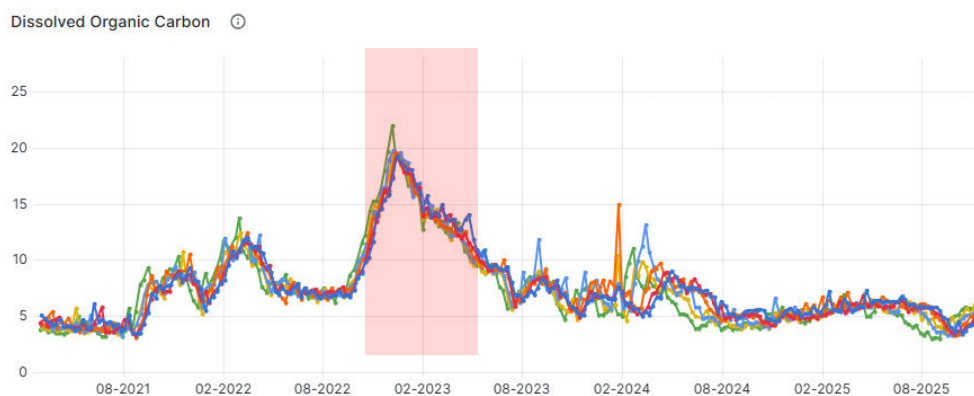


Figure 4: DOC source water challenges during 2022-2023 River Murray floods (red highlight). Sampled from 6 River Murray Sample pumps from Renmark to Tailem Bend.

During this extreme flooding and water quality event, the ten CQWIP3s plant performed admirably well. Across 2022 and 2023, raw-water MIB peaked at 1010 ng/L (Cadell), 958 ng/L (Glossop) and 767 ng/L (Woolpunda); geosmin peaked at 1120 ng/L (Blanchetown) and 690 ng/L (Swan Reach). Despite these extreme loads, treated-water maxima remained low; for example, Blanchetown recorded 30 ng/L MIB and 3 ng/L geosmin at peak conditions, demonstrating robust system-wide suppression of T&O.

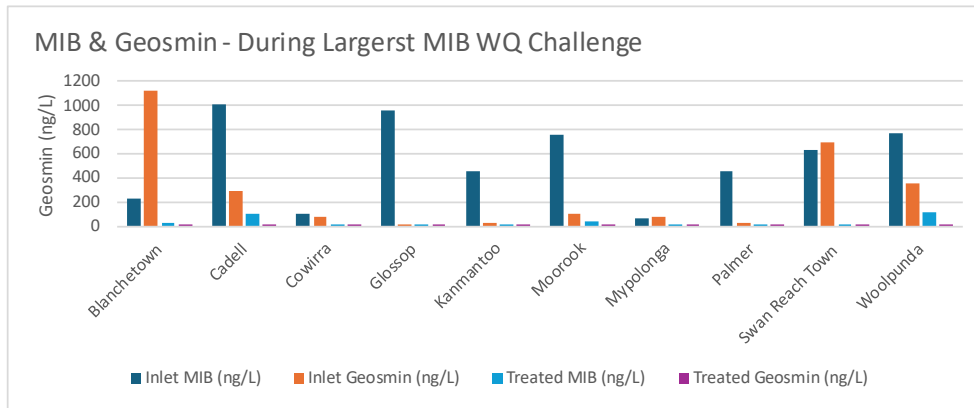


Figure 5: Maximum MIB & Geosmin inlet vs treated water results during the 2022-2023 River Murray flood event. This demonstrates the T&O removal ability of the ten WTPs during this extreme source water event.

A more detailed examination of inlet and treated waters at Blanchetown WTP demonstrates the ability of treatment to remove large proportions of extreme levels of MIB and geosmin well beyond normal operational parameters (figure 6). The removal efficiency during these events was largely unchanged when for calculated % removal of MIB and geosmin, demonstrating the combination membrane-GAC process can handle such extreme water quality events. During the 2022–23 flood, Blanchetown recorded MIB 224 ng/L → 30 ng/L (~85% removal) and geosmin 1120 ng/L → 3 ng/L (~99% removal), exemplifying performance under unprecedented inflows and WQ challenges.

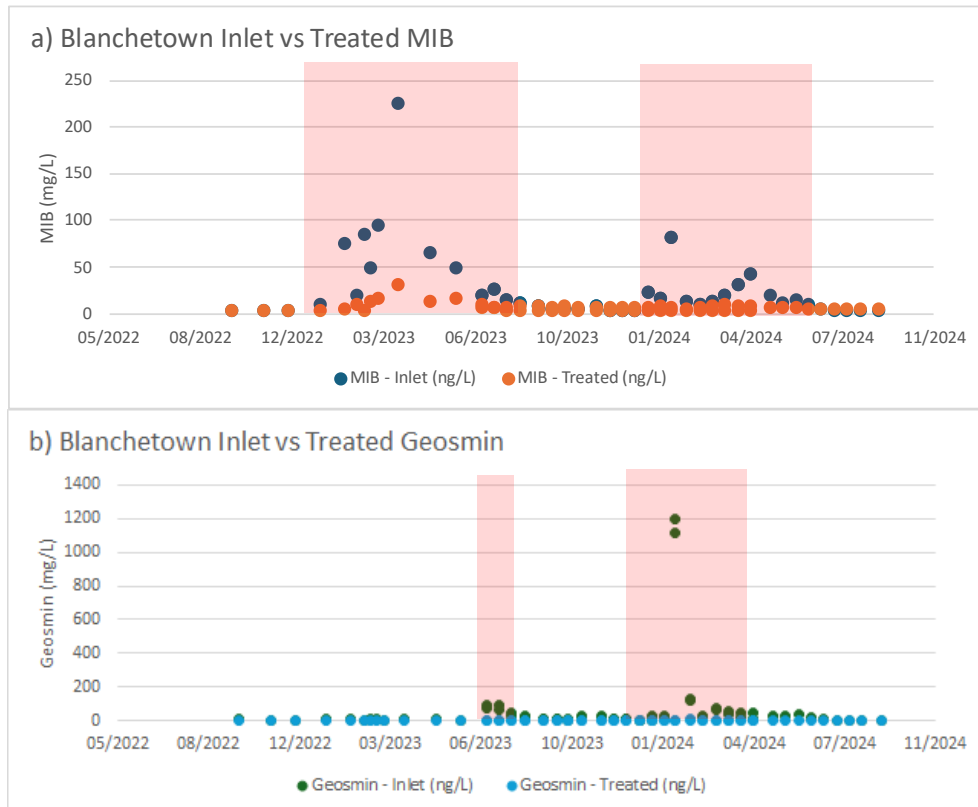


Figure 6: a) MIB & b) Geosmin inlet vs treated water results during the 2022-2023 River Murray flood event at Blanchetown WTP.

Across the ten CWIP3 WTPs, similarly elevated raw-water T&O levels were controlled to low treated-water outcomes, reinforcing the membrane-GAC train’s operational resilience (figure 7). The calculated % removal of both MIB and geosmin was very similar to normal operational efficiency during these extreme events with ~ 80-99% removal seen for MIB and ~ 90-99% removal for geosmin observed across the ten WTPs.

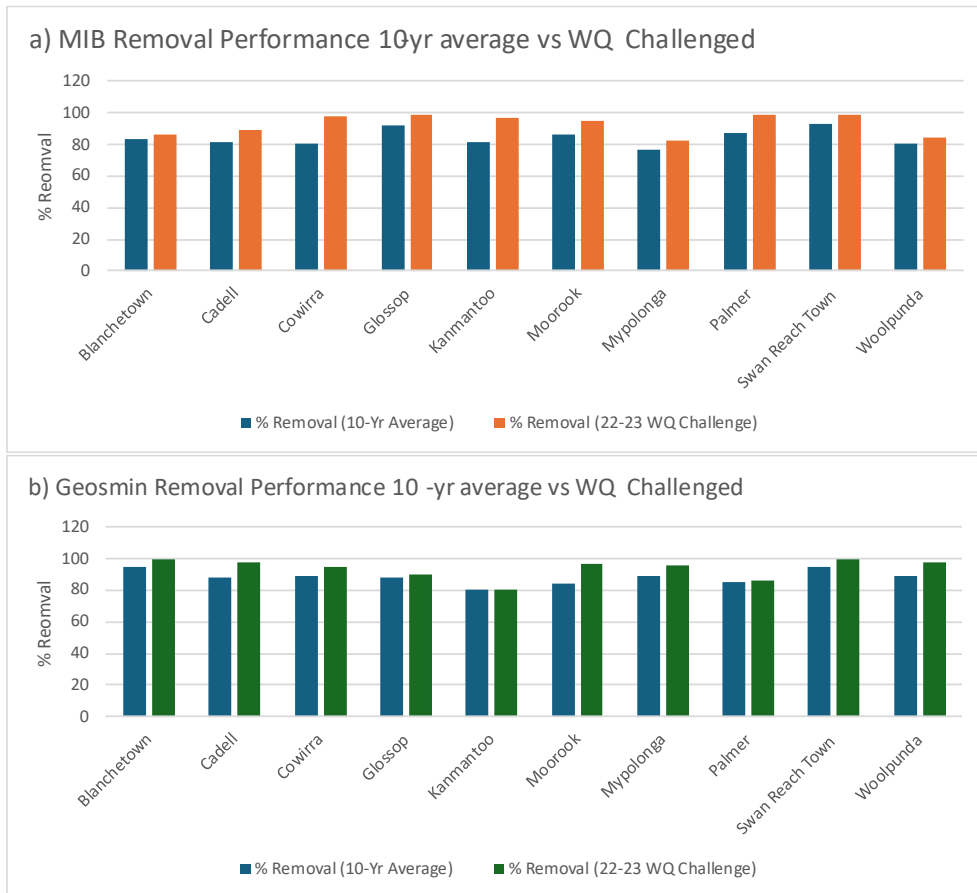


Figure 7: Treatment performance (% removal) of the ten WTPs comparing the 10-year average performance vs the maximum inlet values during the River Murray floods: a) MIB, b) Geosmin and c) DOC.

2.3 Biological vs Physical GAC Removal

Laboratory testing for Blanchetown GAC media showed that active GAC removed ~20% DOC and ~18–21% UVA254 (not shown), while autoclaved-sterilised media provided little to no DOC removal, confirming that DOC reduction is primarily biological. Comparatively, under full-plant flood conditions, DOC removal is ~67% at raw DOC levels of ~17.4 mg/L, highlighting the combined membrane-GAC train is particularly effective at DOC removal when used in combination. These observations are consistent with historical CWQIP3 findings showing that, as GAC ages, biological activity becomes the dominant mechanism for MIB removal, while geosmin continues to benefit from both biological and residual physical processes. Bench scale testing of Blanchetown GAC, biologically active GAC removed >98% of both T&O compounds, whereas autoclaved GAC removed on average ~25% MIB and ~69% geosmin, quantifying the present balance between biological and physical pathways. These results were derived using the established Biological Filtration Potential (BFP) method².

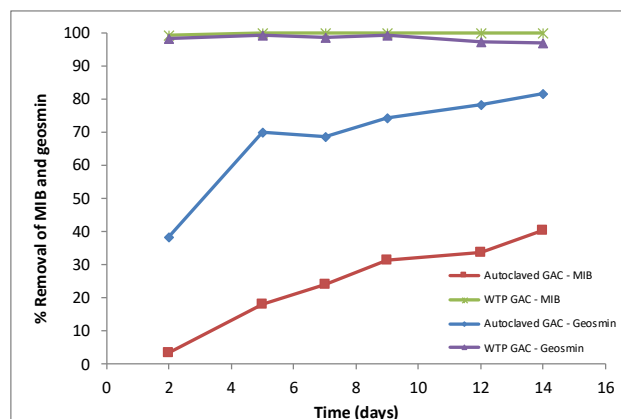


Figure 8: Percentage removal of MIB and Geosmin from Blanchetown WTP GAC in 2025

2.4 Integration with upstream membranes (why the train is resilient)

The resilience of the CWQIP3 membrane–GAC treatment train is strongly influenced by the stability provided by upstream ultrafiltration membranes, which deliver low-turbidity, consistent permeate to the GAC contactors -conditions that support biofilm health and sustained biological removal performance. This linkage is reflected in the BFP method itself, where columns are operated on membrane permeate to mimic full-scale conditions, and it explains why the system continues to perform reliably during high-load events. Routine laboratory BFP testing, when interpreted alongside long-term treated-water outcomes and bed-volume histories, has also enabled SA Water to safely defer GAC replacement without compromising aesthetic performance -an approach that has historically avoided a large capital expenditure. Going forward, preserving biological function and proactively managing breakthrough risks remain essential to maintaining both treatment resilience and asset-life efficiency.

3.0 CONCLUSION

The long-term assessment of the ten CWQIP3 membrane–GAC water treatment plants demonstrates that this treatment configuration continues to provide reliable and robust control of taste, odour and organic challenges across a wide range of River Murray water quality conditions. Despite GAC media now operating well beyond their original design life - often exceeding 150,000 to 200,000 bed volumes - the plants have consistently achieved high removal of MIB and geosmin, including during the unprecedented 2022–23 flood event where several sites recorded inlet concentrations above 700–1000 ng/L yet maintained treated water within aesthetic thresholds. Laboratory column testing (BFP method²) confirms that biological activity within the GAC is now the dominant removal mechanism for MIB, while geosmin benefits from both biological processes and residual adsorption, reinforcing the importance of maintaining stable, low-turbidity membrane permeate to support biofilm health. The strong alignment between laboratory findings and full-scale performance provides operators with confidence in the resilience of the membrane–GAC train under both typical and extreme conditions. Routine monitoring, BFP testing and careful operational management have enabled SA Water to safely extend GAC media life without compromising water quality, delivering both performance and asset-management benefits. Overall, the CWQIP3 treatment systems continue to demonstrate that a well-managed biological GAC stage, supported by upstream membranes, remains a highly effective and dependable barrier against T&O risks in a dynamic and challenging source-water environment.

4.0 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of SA Water Corporation, management and operators at the CWQIP3 WTPs, Water Science staff for laboratory and analytical support and Elizabeth Quarrell for her assistance with plant bed volume calculations.

5.0 REFERENCES

1. Sawade, E.; Cook, D.; Newcombe, G. (2017). *Evaluating 10 Years of GAC Filter Performance for Taste and Odours*. SA Water.
2. Sawade, E.; Ho, L.; Hoefel, D.; Newcombe, G. (2015). *Implementation of Biological Filtration for the Treatment of Cyanobacterial Metabolites*. Water Quality Research Australia – Project 1021.
3. Ho, L. & Newcombe, G. (2010). Granular activated carbon adsorption of 2-methylisoborneol (MIB): Pilot- and laboratory-scale evaluations. *Journal of Environmental Engineering* 136(9): 965-974.5.
4. Elhadi S.L.N., Huck P.M. & Slawson R.M. (2006). Factors affecting the removal of geosmin and MIB in drinking water biofilters. *Journal of the American Water Works Association* 98, 108-119.