Final Report

Effectively utilising water allocations for managing turfgrass in open spaces

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Summary

Southern Australia is expected to experience a significant decrease in water resources due to changing climate. Turfgrass managers are under continued pressure to restrict water use, while also maintaining high-quality surfaces. Understanding how to best manage water allocations to turfgrass in public open spaces is critical for maximising the community benefits of public open spaces. Consequently the aims of our four-year field-based project were to:

- Investigate if turfgrass can be maintained with a water allocation (7500 kL/ha per year), and the implications of further lowering the allocation on turfgrass quality;
- Evaluate how an annual water allocation is best distributed during the year; and
- Assess if using a soil wetting agent improved the effectiveness of a water allocation.

Turfgrass producers, businesses involved with the planting and maintenance of turfgrass, local government, managers of parks and gardens, contractors and other professionals associated with turfgrass management, water supply organisations, environmental regulators, plus government policy makers in Western Australia were our target audience.

Approaches for effectively utilising water allocations for turfgrass was investigated at The University of Western Australia (UWA) Turf Research Facility in Perth, Western Australia. Our field-based study compared how combinations of water allocation amounts, watering schedules, and soil wetting agent use, affected turfgrass growth and quality, for three years. Research findings and recommendations were communicated to the Turfgrass Industry via field days, industry magazine articles, presentations at industry workshops and national conferences, and the publication of a factsheet.

Warm-season turfgrasses, such as kikuyu, can be maintained on a water allocation of 7500 kL/ha per year in Perth in low wear situations. This amount is equivalent to replacing about 70% of Perth's net evaporation during the irrigation season (September–April) and is consistent with recommended irrigation requirements for warm-season turfgrasses. Lowering the water allocation below 7500 kL/ha per year will decrease turfgrass colour and growth, particularly in dry summers. For two water allocations (6250 kL/ha and 7500 kL/ha per year) applying a soil wetting agent markedly improved turfgrass colour during the summer months by decreasing water repellence and increasing soil water content.

There are a number of options for scheduling a water allocation during the irrigation season in southern Australia. Apportioning water each month based on historical monthly evaporation and rainfall data ('budget' scheduling) is a simple and effective approach to maintaining turfgrass on a water allocation. Refining the budget schedule approach by measuring net evaporation or soil water content to make adjustments to irrigation, may allow turfgrass managers to save small volumes of water for use later in the irrigation season.

Future research should focus on water allocation requirements for turfgrass in high-wear situations (e.g., high use recreational sports grounds), and develop software applications for remote scheduling of an annual water allocation during the irrigation season.

Keywords

Irrigation requirements; irrigation scheduling; kikuyu; net evaporation; public open space; soil moisture probe; soil water repellence; soil wetting agent; warm-season turfgrass; water-use efficiency.

Introduction

Southern Australia, like many other regions of the world, is expected to experience a significant decrease in water resources due to changing climate. Turfgrass managers are under continued pressure to restrict water use, while also maintaining high-quality surfaces. The importance of sports turfgrass for encouraging physical activity is well recognised within the community, however there is increasing evidence that well designed and maintained green spaces are also needed for mental health and well-being (Townsend and Weerasuriya, 2010). Urban planners are being challenged to retain and improve public open spaces (Hansmann et al., 2007), which will become increasingly difficult in a drying climate.

Water allocation is a key water planning method being utilised for irrigating public open spaces in southern Australia. For example, 6750 to 7500 kL/ha is commonly allocated each year to turfgrass managers utilising groundwater to irrigate public open spaces in Perth. The amount of water allocated to turfgrass managers is established by State and Territory Governments, however the most effective way to apportion the allocation during the irrigation season is left to the discretion of the turfgrass manager. It has been acknowledged that water planning is unlikely to be a one-off process due to the impact of climate change on water supplies, and that an adaptive approach to water supply and planning is required in Australia (Hamstead et al., 2008). Indeed, water allocations have been lowered from 7500 to 6750 kL/ha per year for some areas of metropolitan Perth since the approach was first implemented. Understanding how to best manage turfgrass on current, and possible lower future water allocations, is critical for managing these community areas.

The effectiveness of a water allocation applied to turfgrass grown in sandy soils is likely to be improved by overcoming the development of soil water repellency. Soil water repellence decreases water use efficiency by causing irrigation water to unevenly infiltrate the soil surface, bypassing a proportion of the turfgrass roots. In severe cases the applied water may run-off the soil surface before infiltration occurs. If left untreated, soil water repellence can lead to localised dry areas and turfgrass death. Patchy turfgrass cover in open space areas is unwelcome, as it may contribute to injuries, and encourage weed invasion. The development of soil water repellence may also invoke over-watering as the turfgrass manager attempts to overcome wilting turfgrass (Cisar et al., 2000). Our previous research demonstrated that applying an effective soil wetting agent decreased soil water repellence and maintained turfgrass quality without having to apply additional water (Barton and Colmer, 2011a; Barton and Colmer, 2011b). However, further research is needed to determine if applying a soil wetting agent improves the effectiveness of a water allocation.

The objective of our field-based project was to investigate approaches to best manage current and possible future water allocations to turfgrass in public open spaces. Consequently, the project:

- Investigated if turfgrass could be maintained with a water allocation (7500 kL/ha per year), and the implications of further lowering the allocation on turfgrass quality;
- Evaluated how an annual water allocation was best distributed during the year; and
- Assessed if using a soil wetting agent improved the effectiveness of a water allocation.

Methodology

Research Methodology

Study Site

Approaches for effectively utilising water allocations for turfgrass was investigated at the UWA Turf Research Facility in Perth, Western Australia. Perth has a Mediterranean-type climate, and in the last 22 years has had an annual rainfall of 732 mm, mainly (78%) falling from late autumn to early spring (May–September), a mean annual maximum temperature of 24.7 °C and a mean annual minimum temperature of 12.8 °C (Commonwealth Bureau of Meteorology, www.bom.gov.au). The soil at the site is known locally as Karrakatta Sand (McArthur and Bettenay, 1960). The site provided the infrastructure necessary for accurately assessing turfgrass management practices, including a variable-speed travelling irrigator that allowed water to be applied evenly and at known rates. Importantly for this project, the irrigator also recorded the volume of water applied to specified turfgrass areas so that researchers could confirm that the turfgrass plots were irrigated using the specified water allocation treatment. The site also included a weather station to measure climatic parameters, plus calculate the daily evaporative demand of the environment (also called reference ET).

Experimental plots (10 m^2) were planted in September 2011 utilising turfgrass harvested from a local government park that included a surface layer (25 mm) of mat with the potential to become water repellent. The three year experiment commenced the following July, which allowed time for the turfgrass to become established. Kikuyu turfgrass was selected as it is a warm-season turfgrass (warm-season turfgrasses are widely used throughout various parts of Australia), and is the dominate turfgrass type managed by local government in metropolitan Perth and many regional areas of Western Australia. Furthermore, the turfgrass was > 20 years old and was more representative of turfgrass managed by local government than newly planted turfgrass. The agronomic management (e.g., fertiliser and mowing regimes) of the turfgrass plots was consistent with industry practices (Appendix 1 Table 1).

Experimental Approach

To address the project objectives, a factorial experimental design was used, so that combinations of water allocation amounts, watering schedules, and soil wetting agent use, could be evaluated as to their ability to maintain kikuyu. Consequently, the experimental design was:

3 water allocations x 3 irrigation schedules x 3 soil wetting agent rates x 3 replicates

The three water allocations were 5000, 6250 or 7500 kL/ha per year. Currently, 6750 to 7500 kL/ha per year is allocated for many public open spaces in Perth. The three irrigation schedules were calculated using historical weather data ('Budget' schedule) from the Bureau of Meteorology, and were further refined using an onsite weather station ('Budget+Net Evaporation') or a soil moisture probe ('Net Evaporation+Probe' and 'Budget+Probe'; Appendix 1 Tables 2–4). A liquid soil wetting agent was applied at three rates: nil (control), at the manufacturer's recommended rate, or double the manufacturer's recommended rate. The soil wetting agent chosen was one of the commercially-available options currently used by the local Turfgrass Industry, and its effectiveness was demonstrated in independent studies prior to the current field project.

Measurements

Turfgrass growth and quality, as well as the development of soil water repellence, under the different water allocation treatments were assessed throughout the study. Turfgrass growth was determined by measuring the dry weight of clippings after each mowing event (Appendix 1 Table 1). In addition to good growth, turfgrass managers are required to produce a turfgrass surface with good colour. Consequently, turfgrass colour was measured using a Chroma Meter every four weeks and the concentration of total nitrogen (N) in the leaf tissue (clippings) was measured five times a year (i.e., every 3 months). Soil water repellence was measured in the surface soil (0–25 mm) every four weeks during the irrigation season using the molarity of ethanol droplet test (MED; King, 1981). Soil volumetric water content in the surface soil (0–25 mm) was also measured every four weeks during the irrigation season using a portable theta probe, and immediately prior to measuring turfgrass colour and collecting soil samples for measuring soil water repellence. Further measurement details are provided in Appendix 1.

Technology Transfer

Turfgrass producers, businesses involved with the planting and maintenance of turfgrass, local government, managers of parks and gardens, contractors and other professionals associated with turfgrass management, water supply organisations, environmental regulators, plus government policy makers in Western Australia, were our target audience. Our communication strategy used a number of approaches to inform our target audience of progress and final outcomes. Uptake of findings was most likely to be achieved by providing opportunities for research end-users to view experimental plots, as well as by presenting findings both orally and in written documents. Consequently, our communication strategy involved:

- Producing a *factsheet* at the completion of the study;
- Annual *field days* at the UWA Turf Research Facility;
- Presentation of research findings at local and national *industry conferences*, *seminars and workshops*;
- A final 'hands-on' *workshop* for industry partners summarising project outcomes and giving delegates an opportunity to apply the findings to their own situations;
- Regular *newsletters* to industry partners (distributed nationally as a pdf and on our website);
- Publication of research progress and findings in national *industry journals*;
- *Press release* statements; and
- Distribution of *progress and final reports* to HIA Ltd and Industry Partners.

The UWA Turf Industries Research Steering Committee oversaw and advised on the project's communication strategy. The Committee members represented: WA Turf Growers Association, Golf

Course Superintendents Association of Western Australia, Water Corporation, Department of Water, WA Local Government, Lawn Mowing Contractors Association, Irrigation Association of Australia (WA Region), Sports Turf Association of Australia (WA), WA Bowling Association, the fertiliser industry, private turfgrass consultants, and UWA research staff. Members of the UWA Turf Industries Research Steering Committee also assisted with disseminating information by reporting project progress and outcomes to their respective State and National Associations.

Project Evaluation

The project aims and experimental approach was evaluated annually by The UWA Turf Industries Research Steering Committee (see above for details of the Committee composition). The project leader presented results and any proposed modification to the experimental approach to the Committee at the end of each irrigation season, which were then discussed and agreed to before the next irrigation season commenced. The decisions were documented in the Committee minutes and also in HIA Ltd. Milestone Reports.

The outcomes and performance of the project were evaluated by the broader Industry towards the end of the project and following the presentation of key findings at the 2015 WA Turf Industry Seminar Day. Delegates were invited to complete a survey that sought feedback on the relevance of project findings to the Turfgrass Industry, its uptake and extension (Appendix 3 Table 1).

Outputs

Communication of our results and feedback from industry is important to the success of the UWA Turf Research Program. In collaboration with our Industry partners, we developed a communication strategy that included a website (http://www.plants.uwa.edu.au/research/turf-research-program), field days, publications in industry magazines, participation in industry workshops and national conferences, field days and the publication of a factsheet. The UWA Turf Research Staff were mainly responsible for disseminating research findings to industry groups; however, during the project we were also assisted by members of the UWA Turf Industries Research Steering Committee. The activities undertaken to facilitate adoption of our research findings during the life of the project are listed below. Those activities marked with an asterisk have delivered final outcomes to our target audience.

Factsheet

Guidelines for managing water allocations to turfgrass in open spaces in the form of an industry factsheet (Appendix 2) was distributed to the Turfgrass Industry and made available via the UWA Turf Research Program website (http://www.plants.uwa.edu.au/research/turf-research-program).

- *Barton L, K Johnston and T Colmer. 2015. Managing turfgrass on a water allocation. Published by The University of Western Australia.

Field Days

Field Days provided an opportunity for the Turfgrass Industry to view the experiment and for UWA research staff to get feedback from Industry. Representatives from all sectors of the Turfgrass Industry were invited including those from turfgrass management (e.g., local government, golf courses, schools), turfgrass production, businesses that service the Turfgrass Industry, water supply organisations, environmental regulators, plus government policy makers. Attendances were excellent, reflecting the project's relevance and interest to Industry.

- A 'Field Day' was held at the UWA Turf Research Facility (20 February 2013) to provide the Turfgrass Industry with an overview of the project, including aims, approach and outcomes, plus view treatment effects after one irrigation season. Approximately 110 people attended the day.

- A 'Field Day' was held at the UWA Turf Research Facility at Shenton Park (19 February 2014) to enable the Turfgrass Industry to view treatment effects in mid-summer after two irrigation seasons. Approximately 160 people attended the day.

- An 'Open Day' was held at the UWA Turf Research Facility (13 August 2014) to enable industry to view treatment effects in mid-winter. Over 50 people attended the day.

- *A 'Field Day' was held at the UWA Turf Research Facility (18 February 2015) to provide the Turfgrass Industry with a final opportunity to view irrigation treatment effects in mid-summer after three consecutive irrigation season. Approximately 105 people attended the day.

In addition, the UWA Turf Research Facility was visited by Industry representatives, students from TAFE, and staff of government departments during industry field days, on several occasions.

Industry Conferences, Seminars, and Workshops

Papers presenting research findings were given locally and nationally to the Turfgrass Industry. Presentations were given to turfgrass managers, turfgrass producers and staff from government regulatory bodies who liaise with the Turfgrass Industry.

- Barton L. 2012. UWA turf trials: Overview of project aims. *Local Government Water Efficiency Forum in Perth*, Mosman Park (Western Australia), 13 July 2012.
- Barton L. 2013. Effectively Utilising water allocations for managing turfgrass in open spaces. *2013 WA Turf Seminar Day*, Alfred Cove (Western Australia), 17 July.
- Barton L. 2014. Effectively utilising water allocations for managing turfgrass in open spaces. *Turf Australia National Conference*, Penrith (New South Wales), 28 August 2014.
- Barton L. 2015. The UWA Turf Research Program: Past, present, future. *Presentation to the "Perth Metro Parks Managers" group*, Claremont (Western Australia), 26 February 2015.
- *Barton L. 2015. Effectively utilising water allocations for managing turfgrass in open spaces. *2015 WA Turf Seminar Day*, Alfred Cove (Western Australia), 29 July.
- *Barton L and J Forrest. 2015. *Managing Turfgrass on a Water Allocation Workshop*, The University Club, Crawley (Western Australia), 30 September.

Newsletters

Our Industry partners were kept up-to-date with the project's progress via the UWA Turf Research Program Newsletter (distributed every 3 months) throughout the project. A total of 16 newsletters were produced during the project. Newsletters were distributed electronically in pdf format and were also made available from the UWA Turf Research Program website (http://www.plants.uwa.edu.au/research/turf-research-program). In addition, project updates and findings were presented in Association Newsletters via members of the UWA Turf Industries Research Steering Committee. Association Newsletters included 'Turfgrass Times' (Sports Turf Association WA and WA Turf Growers) and 'Overflow' (Irrigation Australia Ltd. WA).

Publications in Industry Journals

- Barton L, S Flottmann and T Colmer. 2012. Optimising water allocation usage. Australian Turfgrass Management Journal, Volume 14.5, pp 52–53.
- *Barton L, S Flottmann and T Colmer. 2015. Effectively utilising water allocations. Australian Turfgrass Management Journal, Volume 17.5, pp 56–57.

Scientific Conference

- *Barton L, S Flottmann and T Colmer. 2015. Effectively maintaining turfgrass on a water allocation in a Mediterranean-type climate. Accepted for presentation at the ASA, CSA and SSSA International Annual Meeting, Minneapolis (Minnesota), USA, 15–18 November.

Outcomes

The development of practical approaches to best manage current and possible future water allocations to turfgrass in public open space is the key outcome from this project. This was achieved by firstly designing and implementing a four year field-based research program in consultation with our target audience, and secondly presenting project findings to the Turfgrass Industry throughout the project. The Turfgrass Industry has an improved understanding of how to manage turfgrass using current water allocations, and the impact of lowering the water allocation on turfgrass quality in south-western Australia.

Warm-season turfgrasses, such as kikuyu (and presumably other species such as couch and buffalo), can be managed on water allocation of 7500 kL/ha per year in Perth in low wear situations. This amount of water can be easily distributed during the irrigation season (Figure 1) and is equivalent to replacing about 70% of Perth's net evaporation during the irrigation season (September–April); this value is consistent with the recommended irrigation requirements previously determined by a HIA Ltd-funded research investigating water requirements for warm-season turfgrasses in southern Australia (Colmer and Short, 2001). We found a water allocation of 7500 kL/ha per year generally maintained turfgrass colour to an acceptable standard throughout the irrigation season, and also encouraged growth (Figure 2; Plate 1). Lowering the water allocation below 7500 kL/ha per year decreased turfgrass colour and growth, particularly during dry summers such as in 2014 (Figure 2). A water allocation of 6250 kL/ha per year adequately maintained turfgrass colour and quality when there was summer rainfall (2013, 2015). Further lowering the water allocation to 5000 kL/ha per year produced unacceptable turfgrass colour each summer (Plate 1), unless it rained (2015). Interestingly turfgrass leaf N concentration in all water allocation treatments exceeded the minimum concentration (2.0%, Johnston, 1996) required to maintain kikuyu in the study region (Figure 2).

There are a number of options available for distributing, or scheduling, a water allocation during the irrigation season. The three approaches we investigated maintained turfgrass growth and quality to a similar extent for each water allocation, thus providing turfgrass managers with various options for irrigation scheduling depending on their resources. Apportioning water each month based on historical monthly evaporation and rainfall data ('Budget' schedule) proved to be a simple, but an effective approach to maintaining turfgrass when the water allocation was sufficient. Refining the 'Budget' scheduling approach by employing more sophisticated scheduling methods utilising soil moisture measurements and/or daily net evaporation values saved some water that was then able to be redistributed to later in the irrigation season. This was demonstrated in the 2013/14 irrigation season, where above average spring rainfall in September and October resulted in 14% (139 kL/ha) and 8% (77 kL/ha) less water being applied to the 'Budget+Net Evaporation' and 'Budget+Probe' schedules than the 'Budget' schedule, respectively (Figure 1D).

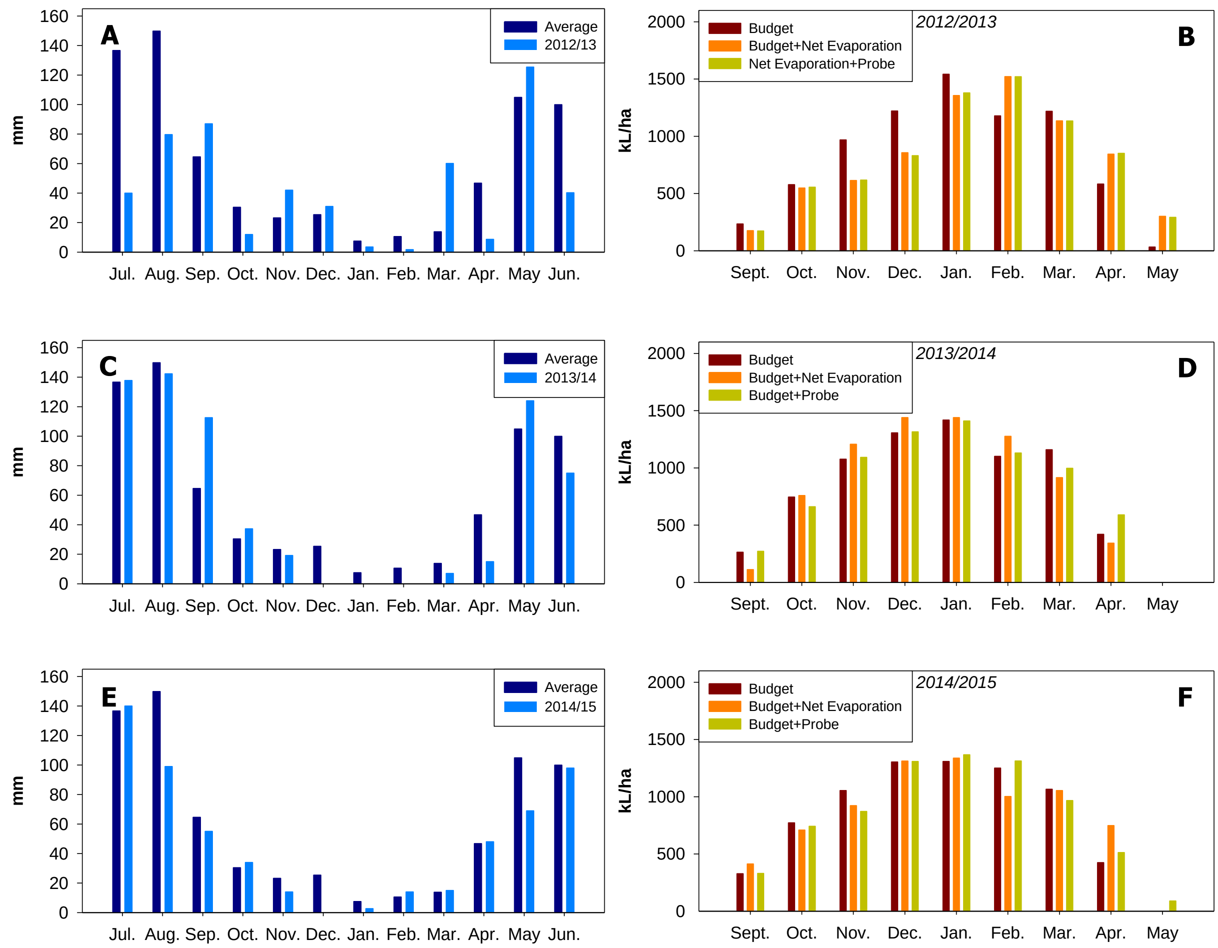

Figure 1. Monthly rainfall (A, C and E) and the monthly irrigation water distribution (B, D and F) for three irrigation schedule approaches for a water allocation of 7500 kL/ha per year in each year of study at the UWA Turf Research Facility in Shenton Park. In the 'Budget' schedule the water allocation for each month was calculated by multiplying the annual water allocation by the proportion of the annual net evaporation that historically occurred in that month. In the 'Budget+Net Evaporation' schedule the initial replacement value was the proportion of the water allocation to the net evaporation (historical, as in the 'Budget' schedule) at the start of the irrigation season, but irrigations were based on actual net evaporation for the current season and the allocation remaining was recalculated at the end of each month enabling re-budgeting for remaining months in the current season and with continued adjustments based on prevailing net evaporation. The 'Budget+Probe' schedule calculated the monthly water allocation as for the 'Budget' schedule, however irrigation only proceeded if the soil water content was below a critical value.

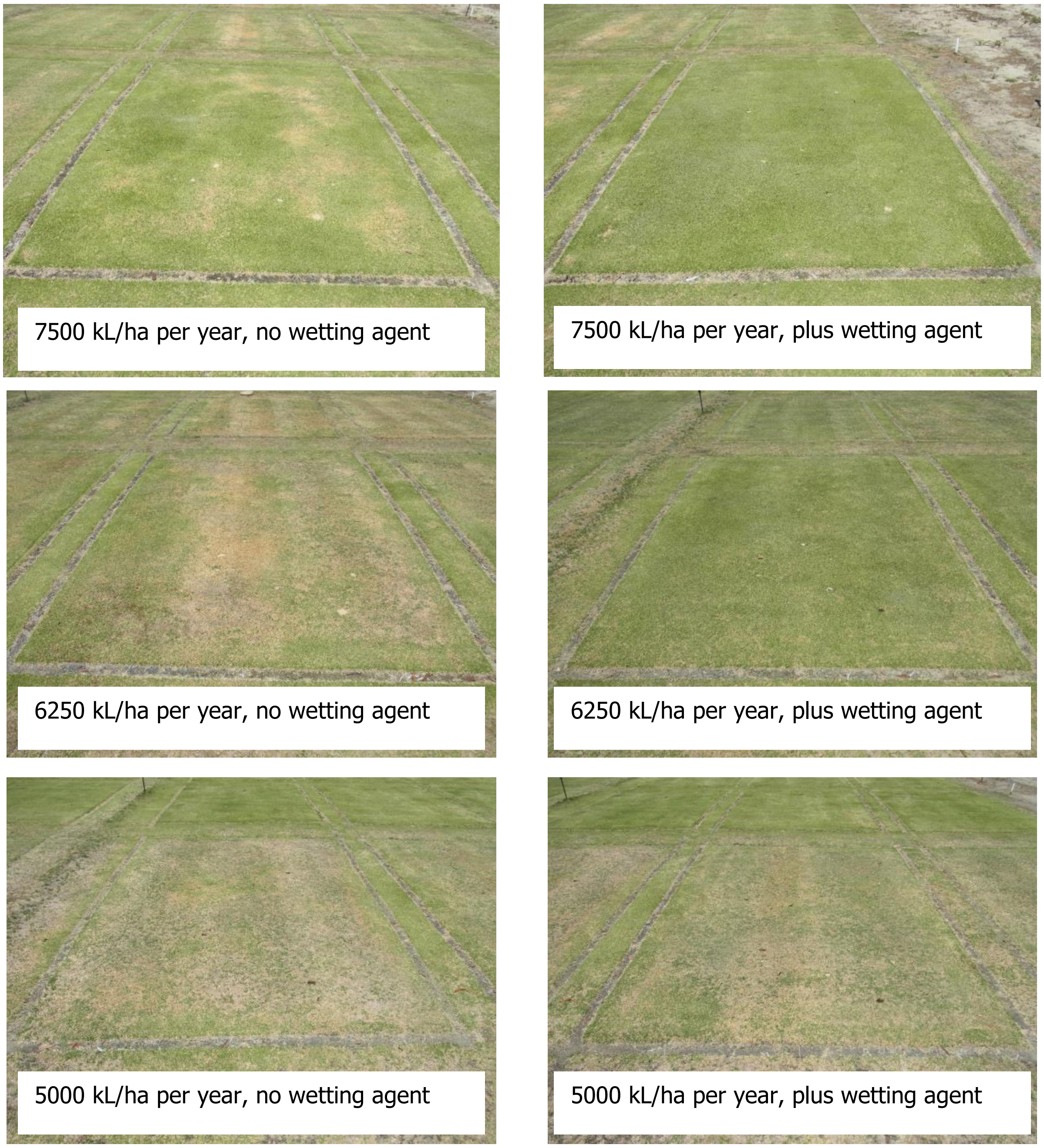

Plate 1. The effect of applying a soil wetting agent at the recommended rate on turfgrass colour in summer (January 2014) for each water allocation on a 'budget' irrigation schedule. Applying a soil wetting agent at twice the recommended rate also improved turfgrass colour, but often to the same extent as the recommended rate. Photo credit: S. Flottmann.

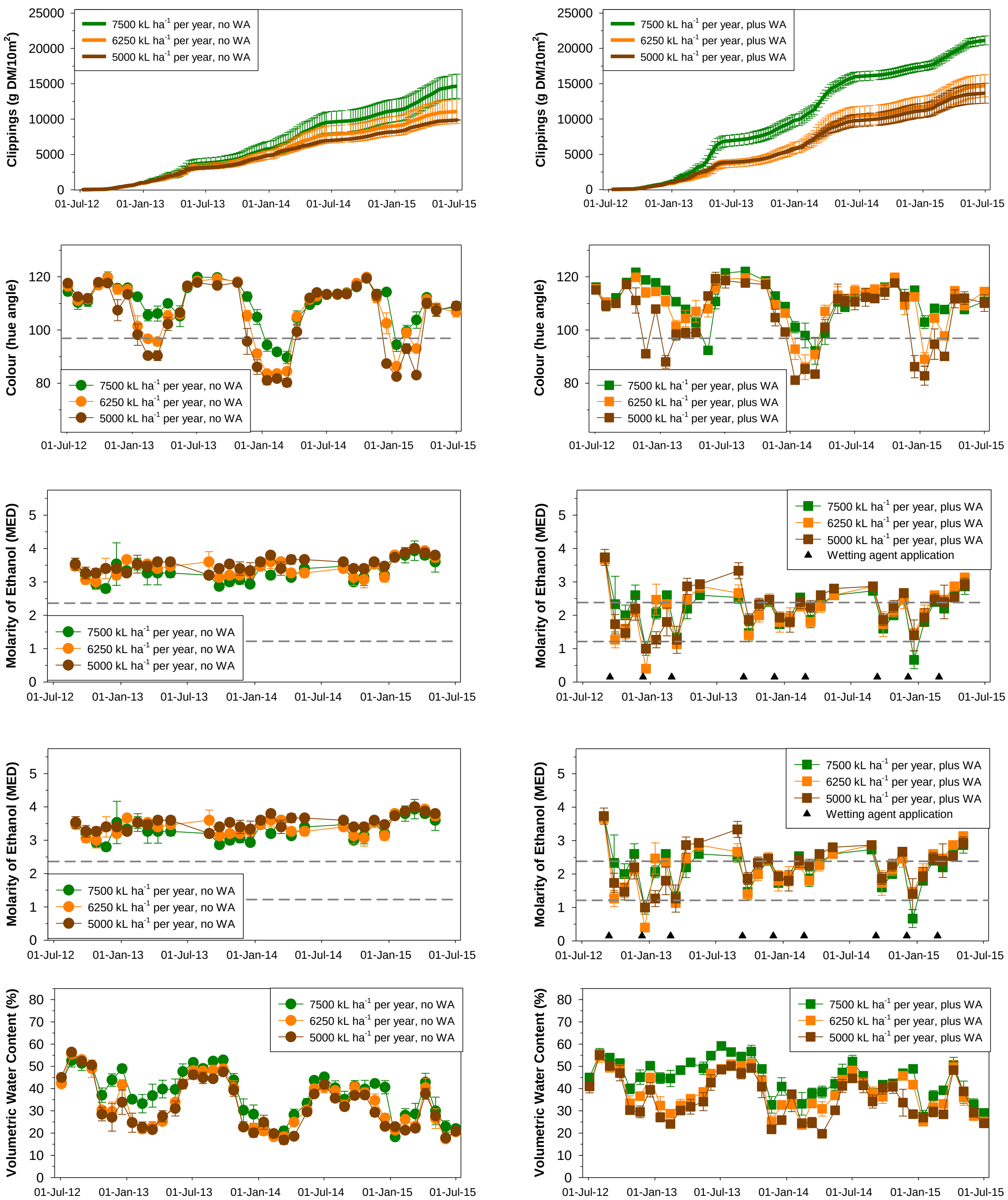

Figure 2. The effect of water allocation amount and the application of a soil wetting agent (abbreviated as WA) at the recommended rate on cumulative turfgrass growth, turfgrass colour, N concentration of clippings, soil water repellence (molarity of ethanol, MED; 0–25 mm), and soil volumetric water content (0–25 mm) with time (three years) for the ‘budget’ irrigation schedule. Turfgrass colour with a hue angle >97° and N concentration of clippings > 2% is considered adequate for kikuyu turfgrass. Soil with MED <1.2 and > 2.4 have low and severe water repellence, respectively.

Ultimately the ability of a turfgrass manager to maintain turfgrass on a water allocation will not only rely on the amount of water provided and the way it is distributed across the season, but also how effectively the water is applied (i.e. uniformity of distribution of the irrigation system) and utilised by the turfgrass. Applying a soil wetting agent improved the effectiveness of a water allocation in the present study where the soils were prone to becoming water repellent. For two water allocations (6250 kL/ha and 7500 kL/ha per year) applying a soil wetting agent at both the manufacture's recommended (Figure 2) and double the recommended application rate markedly improved turfgrass colour during the summer months (Plate 1). Applying a soil wetting agent alleviated water repellence and thus improved soil water content (Figure 2). Although applying a soil wetting agent decreased soil water repellence at the lowest water allocation (5000 kL/ha per year) it did not improve turfgrass colour; soil water content in this regime was still too low to maintain acceptable turfgrass colour (Plate 1, Figure 2). Soil wetting agents can assist turfgrass managers to maintain turfgrass on a sufficient water allocation.

The greatest impact of this project is that turfgrass managers responsible for maintaining public open spaces in metropolitan Perth are more knowledgeable about managing water allocations to turfgrass areas. Current turfgrass managers, and future managers (via our factsheet), are more aware of the opportunities and constraints to managing turfgrass on a particular water allocation, plus are aware of different approaches to distributing the water during the irrigation season. This will ultimately assist in maintenance of public open spaces, benefiting the physical and mental well-being of our communities, as well as efficient use of water resources in our drying climate. The project has also demonstrated that applying low water allocations risks decreasing turfgrass quality to the extent that the turfgrass is no longer adequate for all recreational purposes. Finally, the project has facilitated and encouraged industry to meet and discuss the application of the findings to turfgrass management. The outcomes from this project will continue to benefit industry in the long-term as water allocation is considered to be a key water planning method for achieving national sustainable use of water (www.environment.gov.au/topics/water/australian-government-water-leadership/national-water-initiative).

Evaluation and Discussion

Field-based research that included a study site made available for viewing by our target audience was an effective approach to achieving the project outcomes. Our field experiment was designed to specifically investigate questions raised by the local Industry regarding the management of turfgrass on a water allocation:

- Can the quality of my turfgrass be maintained on the current water allocation (7500 kL/ha per year)?
- What will happen to the quality of my turfgrass if the water allocation is lowered?
- How should my irrigation schedule apportion the annual water allocation during the year?
- Are there ways in which I can improve the effectiveness of the water allocation, such as by use of a soil wetting agent?

Annual field days during summer provided research end-users with an opportunity to view the answer to these questions, plus discuss with their peers and the research team the implications of their observations for turfgrass management in their situation (Plate 2). The success of the field days was evident by the number of attendees (see 'Output' section, page 9) and the positive correspondence received following the events. The research site was also frequented by members of the UWA Turf Industries Research Steering Committee following each meeting (at least four per year) and made available as part of local, national and international study tours. Targeting key Industry conferences and publications (see 'Outputs' section) further extended project outcomes to the Turfgrass Industry.

Involving members of the Turfgrass Industry at all stages of the project – conception, implementation and interpretation – ensured project activities and research outcomes were relevant to stakeholders. The UWA Turf Industries Research Steering Committee, and an associated project subcommittee, was involved in the development of the research proposal. These committees were subsequently engaged to ensure that the project activities selected, including the management of the field-based experiment and the nature of the outputs, would maximize the uptake of the project outcomes. Feedback on the field-based activities was sought from committee meetings at the end of each irrigation season, documented (committee minutes, HIA Ltd milestone reports, protocols), and then implemented the following irrigation season. The UWA Turf Industries Research Steering Committee members also provided advice on extension activities (industry articles, workshop presentations, factsheet) before they were presented to industry stakeholders. Consequently, feedback on the usefulness of the project activities and outputs was overwhelmingly positive. Indeed 88% of 90 respondents to a written survey at the end of the project (distributed at the 2015 WA Turf Seminar Day) believed that the field days, presentations and newsletters had effectively kept them informed of the project's progress (Appendix 3 Table 1).

Plate 2. Industry members and other research stakeholders visiting the "Water Allocation" field plots the UWA Turf Research Facility. Photo credits: N. Bell (top), UWA Institute of Agriculture (middle), E. Ricci (bottom).

Ensuring current turfgrass managers, and future managers, understand the opportunities and constraints to managing turfgrass on particular water allocations, and have the knowledge to best apportion a water allocation during the irrigation season, is the key outcome from this project. Anonymous responses to a written survey of 90 research stakeholders confirms that this outcome has been achieved. For example, 97% of respondents believed the findings from the 'Water Allocation Project' (this project) will benefit turfgrass management, while 79% of respondents agreed that project outputs would assist them to better manage their organisation's or clients' water allocation (Appendix 3 Table 1). Specific examples of how survey participants responded when asked in the written survey how they had benefited from the research included:

"Able to justify the time and effort we put into irrigation scheduling and increase the level of sophistication and efficiency of water delivery"

"Sets benchmark for water requirement for budgeting purposes"

"It has ensured that we allocate water efficiently"

"Possible to stick to 7500 kL/ha/year"

"Knowledge on the relationship between evaporation water use budgeting and benefits in use of wetting agent"

"Where we could spend or save money on wetting agents"

"With wetting agents and good scheduling water can be saved"

"Evidence based outputs are always useful for informing management"

"It has given me a goal to aim for. My system is not as efficient for delivery, but with wetting agent application we are getting close"

These learnings are impacting respondents now as they manage turfgrass on a water allocation, and will continue to do so in the future as our climate dries.

Finally, turfgrass managers responsible for maintaining turfgrass on a water allocation have improved confidence in their decision making as a result of viewing and participating in this 'Water Allocation Project'. As one participant in the survey stated: *"It helps us at a ground level to confirm real findings".* The project has facilitated discussions between key stakeholders across different organisations, from government regulators, through to local government and educational/sports facilities. These discussions have improved the understanding of the impact of water allocations amongst stakeholders, thereby leading to a better understanding between government regulators and those responsible for delivery of quality turfgrass surfaces to our communities.

Recommendations

Maintaining Turfgrass on a Water Allocation

- Warm-season turfgrasses, such as kikuyu, can be maintained on a water allocation of 7500 kL/ha per year in Perth in low-wear situations and when the irrigation system has a high distribution of uniformity.
- The implications of lowering the water allocation on turfgrass quality will vary depending on how much the water allocation is lowered, the amount of summer rainfall supplementing the irrigation, and the extent of wear.
    - Lowering the water allocation below 7500 kL/ha per year will decrease turfgrass colour and growth, particularly in dry summers.
    - A water allocation of 6250 kL/ha per year can maintain acceptable turfgrass when wear is limited, there is some summer rainfall and the irrigation system has a high distribution of uniformity; especially when a soil wetting agent is applied to water repellent soils.
    - A water allocation of 5000 kL/ha per year will result in unacceptable turfgrass colour during summer.
- The maintenance of turfgrass on water allocation in high-wear situations (e.g., high use recreational sports grounds) is not known. Further research should quantify water requirements for turfgrass surfaces in high-wear situations.

Distributing an Annual Water Allocation

- We recommend a number of options for scheduling a water allocation during the irrigation season.
    - In the first instance, a 'budget' approach that apportions water each month based on historical monthly evaporation and rainfall data is recommended for distributing the water allocation. It is relatively simple, and as effective as the other approaches investigated in this study, in maintaining turfgrass growth and quality.
    - Refining the 'budget' approach by measuring net evaporation or soil water content may allow turfgrass managers to save some water and use this later in the irrigation season, or to use less water that year than the maximum allocated. This approach of a budget refined by in-season data is recommended in those environments where unseasonably high rainfall can occur in spring and early summer. However, these approaches require either daily local net evaporation data or site specific monitoring of soil water contents and a decision system (e.g., irrigation events based on a site-specific threshold value for soil water content).

- Future research should investigate the development of software applications to assist turfgrass managers' schedule and monitor their irrigation based on local meteorological data. Ideally the application would also access real-time information on cumulative water consumption.

Role of Soil Wetting Agents

- Applying an effective soil wetting agent to turfgrass is recommended for soils prone to developing water repellence.
    - Applying a soil wetting agent improved the effectiveness of two water allocations (6250 kL/ha and 7500 kL/ha per year) in the present study. Applying a soil wetting agent markedly improved turfgrass colour during the summer months by decreasing soil water repellence.
    - Although applying a soil wetting agent decreased water repellence at the lowest water allocation (5000 kL/ha per year) in the present study, it did not improve turfgrass colour. This was because soil water content was still too low to maintain turfgrass.
- Soil wetting agents should be applied at the recommended application rate in early spring, or as an even split of the annual application rate between early spring and early summer.
    - This is because turfgrass grown in sandy soils in Mediterranean-type environments are susceptible to becoming water repellent early in the irrigation season.
    - Previous research has shown applying a soil wetting agent as a single application, or splitting the annual application, can be effective at preventing the development of soil water repellence (Barton and Colmer, 2011b).
- Readers are referred to Barton and Colmer (2011c) for further recommendations regarding the use of soil wetting agents on turfgrass grown in sandy soils.
- Additional research is needed to refine under what water allocation and soil types/environments soil wetting agents will not benefit turfgrass growth and quality.
- Future research on methods that can remotely assess if a soil is water repellent warrants further attention, and in combination with irrigation technology that can automatically apply a soil wetting agent.

Scientific Refereed Publications

None to report.

IP/Commercialisation

No commercial IP generated.

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Appendices

Appendix 1: Supplementary Methodology

Study Site

Agronomic management techniques (e.g., irrigation scheduling, fertiliser and mowing regimes) relevant to the Turfgrass Industry were applied to the turfgrass plots consultation with the UWA Turf Industries Research Steering Committee to ensure practices were consistent with Industry (Appendix 1 Table 1).

Appendix 1 Table 1. Summary of turfgrass (kikuyugrass) plot management

	Frequency	Other details
Irrigation	Sept: 2 times per week Oct: 3 times per week Nov–Mar: 5 times per week April: 3 times per week	See Appendix 1 Table 2
Mowing	Weekly from spring to autumn, otherwise fortnightly	Cylinder mower, cutting height 15 mm
Fertiliser	Four times a year (2 in spring, 2 in autumn)	Baileys 3.1.1. fertiliser, 234 kg/ha per application (i.e. 37.5 kg N/ha per application)
Soil wetting agent	September, December, February	Plots receive either nil, recommended, or twice the recommended rate on each application date

Measurements

Turfgrass growth of each plot (10 m^2) was assessed using the dry mass of mowing clippings. Plots were mown weekly, at a height of 15 mm, and the mass of the fresh clippings weighed. A sub-sample (20–25 g) of the fresh clippings was collected and weighed, and then dried (60 °C) for at least one week before reweighing to determine the fresh:dry mass ratio. After collecting the sub-sample, the remaining fresh clippings were immediately redistributed across the surface of the respective plot. The dry mass of clippings from the plot was calculated from the fresh:dry mass ratio.

Turfgrass colour was measured every four weeks, using a Chroma Meter; an instrument previously shown to enable quantitative assessments of turfgrass color (Landschoot and Mancino, 2000; Barton et al., 2006). Each turfgrass plot was divided into eight subplots (0.56 m^2), all more than 0.5 m from plot edges, which were then further divided into nine (0.0625 m^2) sampling squares using a sampling grid made from tensioned rope. On each sampling date, turfgrass color was measured in the corner of one randomly selected sampling square per subplot (eight measurements per turfgrass plot per sampling date). Colour was measured by pressing the measuring cylinder (50 mm in diameter) of the Chroma Meter onto the canopy surface to exclude external light. The Chroma Meter was calibrated before commencing measurements, and then after every 96 readings using a calibration plate. Turfgrass colour with a hue angle >97° is considered adequate for kikuyu turfgrass (Barton et al. 2006).

Total N in the dried clippings was measured at least five times a year (in July and then every three months), by fine grinding a subsample of clippings using a ball-mill, and analysing the tissue powder using a CHN analyser. Plant tissue N concentrations were validated against plant tissue standards analysed using the same procedures as described above. Plant tissue N concentration of clippings > 2% is considered adequate for kikuyu turfgrass (Johnston, 1996).

Soil VWC of the surface 25 mm was measured the day before applying the soil wetting agents, and then every four weeks, using a hand-held moisture probe. Measurements were taken on the same days and at the same positions as those of turfgrass colour. The probe was inserted into the ground and the mV output recorded. To calibrate the probe (i.e., convert mV to soil VWC), soil samples (surface 25 mm) were collected at selected times throughout the study, and the gravimetric water content and bulk density determined after drying the sample at 104 °C.

Soil water repellence was measured immediately prior to applying the soil wetting agent, and then every four weeks, using the MED test (King, 1981; Carter, 2002). Four intact cores (each core 52 mm in diameter, 25 mm in depth) per plot were collected using a soil corer, from the same positions that turfgrass colour and soil VWC were measured. Samples from each plot were combined, air-dried (40 °C) for at least one week, and then gently sieved (<2 mm) so as to remove rhizomes, but with minimal abrasion. To measure MED, droplets of ethanol ranging in concentration (0–5.4 M) were applied to each soil sample, and the lowest concentration that infiltrated the soil within 10 s recorded. Soil water repellence is ranked as follows: Low (MED<1.2), moderate (1.2<MED<2.4), severe (2.4<MED<3.2), very severe (MED>3.2) (King, 1981; Carter, 2002).

Appendix 1 Table 2**.** Description of irrigation schedules tested at the UWA Turf Research Facility

Description of irrigation schedules
Budget
• Water allocated based on historical monthly evaporation and rainfall data at the study site, whereby the allocation is divided into monthly quantities (September – April). • The allocation for each month is calculated by multiplying the annual water allocation by the proportion of the annual net evaporation that occurs in that month. For example, if 20% of total annual net evaporation occurs in January, then 0.2 x 7500 = 1500 kL/ha would be applied in January. • Monthly allocation then divided by the number of irrigation days per month to calculate a daily water application. • Water applied 2–5 days per week, depending on the time of year. • This approach enables water to be distributed throughout the year based on historical climatic data, but does not enable water to be saved for later in the irrigation season should there be below average evaporation or above average rainfall.
Budget+Net Evaporation
• The first monthly allocation for the irrigation season calculated as above, but expressed as a % replacement of net evaporation. For example, if annual net evaporation is 15000 kL/ha based on historical data, and the annual allocation is 7500 kL ha^{-1}, replacement is 50%. • Turfgrass irrigator programmed to replace the calculated replacement net evaporation during the month. • At the end of each month, the total amount of water applied since the start of the irrigation season is subtracted from the remaining annual allocation, and the % replacement value recalculated.
Budget+probe (2013–2015 only)
• A soil moisture probe is used to refine the 'budget' irrigation schedule described above. • The monthly allocation is calculated as above, however irrigation only proceeds if the soil water content is below a critical value. • At the end of each month, any water savings are redistributed across the remainder of the irrigation season. • This approach enables water to be distributed throughout the year based on historical climatic data, but also enables water to be saved for later in the irrigation season should there be above average rainfall in particular months. • This approach refines the 'Budget' schedule, with additional potential for water savings during times of low demand (i.e. lower net evaporation or with rainfall inputs
Net evaporation+probe (2012–2013 only)
• The first monthly allocation will be calculated as the 'Budget+Net Evaporation' schedule, however irrigation only proceeded if the soil water content is below a critical value. • At the end of each month, the total amount of water applied since the start of the irrigation season is subtracted from the remaining annual allocation, and the % replacement value recalculated. • This approach refines the 'Budget+Net Evaporation' schedule, with additional potential for water savings during times of low demand (i.e. lower net evaporation or with rainfall inputs).

Appendix 1 Table 3. An example of an irrigation schedule using a budget approach to distribute a water allocation of 7500 kL/ha per year.

Month	Expected net evaporation (mm) **A**	Expected net evaporation (kL/ha) **B =** A × 10	Proportion total expected net evaporation (%) **C** = (B ÷ 10670)*100	Monthly water allocation (kL/ha) **D** = (C x water allocation) ÷ 100
Sep.	39	390	3.7	274
Oct.	113	1130	10.6	794
Nov.	151	1510	14.2	1061
Dec.	183	1830	17.2	1286
Jan.	202	2020	18.9	1420
Feb.	173	1730	16.2	1216
Mar.	149	1490	14	1047
Apr.	57	570	5.3	401
Total	1067	10670	100	7500

Appendix 1 Table 4. An example of an irrigation schedule using a real-time net evaporation to distribute a water allocation of 7500 kL/ha per year.

Month	Expected net evaporation	Expected net evaporation remaining	Water allocation remaining	Replacement net evaporation	Actual amount of water applied
	(kL/ha)	(kL/ha)	(kL/ha)	(%)	(kL/ha)
	A	**B =** 10670[a] – sum previous months expected net evaporation in A	**C** = Water allocation at start of previous month – E from previous month	**D** = (C ÷ B) *100	**E**
Sep.	390	10670	7500	70	328
Oct.	1130	10280	7172	70	772
Nov.	1510	9150	6400	70	1054
Dec.	1830	7640	5346	70	1304
Jan.	2020	5810	4042	70	1309
Feb.	1730	3790	2733	72	1251
Mar.	1490	2060	1482	72	1066
Apr.	570	570	416	73	416
Total	10670				7500

[a]Total expected net evaporation for irrigation season = 10670 kL/ha

Appendix 2: "Managing turfgrass on a water allocation" Factsheet

Managing turfgrass on a water allocation

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TURF RESEARCH PROGRAMME

- Kikuyu turfgrass can be managed on a water allocation of 7500 kL/ha per year in Perth in low wear situations; less water will decrease turfgrass colour and growth, particularly during dry summers.
- Dividing an annual water allocation into monthly amounts based on historical monthly evaporation and rainfall data (budget scheduling) is a simple and effective approach to scheduling an annual water allocation.
- Applying an effective wetting agent to Perth's sandy soils improved turfgrass appearance when under two annual water allocations (6250 and 7500 kL/ha per year).

Background

Southern Australia is expected to experience a significant decrease in water resources due to changing climate. Turfgrass managers are under continued pressure to restrict water use, while also maintaining high-quality surfaces. Currently 6750 to 7500 kL/ha per year is allocated to turfgrass managers irrigating public open spaces with groundwater in the Perth metropolitan area. Understanding how to best manage turfgrass on current, and possibly lower future water allocations, is critical for maximising the community benefits of Perth's public open spaces.

Water allocation

Warm-season turfgrasses, such as kikuyu, can be maintained on a water allocation of 7500 kL/ha per year in Perth in low wear situations. This amount is equivalent to replacing about 70% of Perth's net evaporation during the irrigation season (September–April) and is consistent with recommended irrigation requirements for warm-season turfgrasses (Colmer and Short, 2001).

Lowering the water allocation below 7500 kL/ha per year will decrease turfgrass colour and growth, particularly in dry summers (Plate 1). A water allocation of 6250 kL/ha per year can maintain acceptable turfgrass in low wear situations and when there is some summer rainfall. A water allocation of 5000 kL/ha per year will result in unacceptable turfgrass colour and poor growth during summer.

Table 1. An example of scheduling a water allocation using a 'budget' approach using historical monthly evaporation and rainfall at the UWA Turf Research Facility, Shenton Park.

Month	Water allocation (%)
September	4
October	11
November	14
December	17
January	19
February	16
March	15
April	5

Irrigation scheduling

There are a number of options for scheduling a water allocation during the irrigation season. Apportioning water each month based on historical evaporation and rainfall data ('budget' scheduling) is a simple and effective approach to maintaining turfgrass on a water allocation (Table 1).

Refining the budget schedule approach by measuring net evaporation or soil water content may allow turfgrass managers to save small volumes of water to use later in the irrigation season (Figure 1). This can occur when net evaporation (and thus turfgrass evapotranspiration) is lower for some periods than anticipated from historical records.

Budget: water allocation for each month calculated by multiplying the annual water allocation by the proportion of the annual net evaporation that historically occurred in that month.

Budget refined by net evaporation: the initial replacement value was the proportion of the water allocation to the net evaporation (historical, as in the Budget schedule) at the start of the irrigation season, but irrigations were based on actual net evaporation for the current season and the allocation remaining was recalculated at the end of each month enabling re-budgeting for remaining months in the current season and with continued adjustments based on prevailing net evaporation.

Budget refined by soil moisture probe: same as Budget schedule, however irrigation only proceeded if the soil water content was below a critical value.

Figure 1. Monthly irrigation water distributions for the irrigation schedules tested for a water allocation of 7500 kL/ha per year in the 2013/14 irrigation season at the UWA Turf Research Facility.

Role of wetting agents

Applying a soil wetting agent can improve the effectiveness of a water allocation on soils prone to developing water repellencey. For two water allocations (6250 and 7500 kL/ha per year) applying a wetting agent markedly improved turfgrass colour during the summer months by decreasing water repellence and increasing soil water content (Plate 1). Although applying a wetting agent decreased water repellence at a water allocation of 5000 kL/ha per year, it did not improve turfgrass colour. This was because the soil water content was still too low to maintain acceptable turfgrass colour.

Plate 1. Turfgrass plots in summer (January 2014). Photos: S. Flottmann

Further reading and references

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Colmer, T.D., Short, D.C., 2001. Reducing water use by turf grasses in a Mediterranean environment: evaluation of diverse species. Final Report for Project TU96002, Horticulture Innovation Australia Ltd, Sydney. (online)

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Appendix 3: Supplementary Evaluation and Discussion

Appendix 3 Table 1. Water Allocation Project survey questions and answers (% of total) from 90 respondents.

Question	Answer
1. Do you believe the findings from the Water Allocation Project will benefit turfgrass management?	• Yes: 87 • No: 3
2. Have the findings and recommendations from the Water Allocation Project assisted you to better manage your organisation's or clients' water allocation?	• Yes: 71 • No: 5 • Not applicable as I/my organisation does not manage a water allocation: 14
3. In one sentence describe how findings from the Water Allocation Project has benefited your organisation or business.	*Sample of responses listed on page 18*
4. Do you believe presentations, field days and newsletters have effectively kept you informed of the project's progress?	• Yes: 88 • No: 0 • Did not state: 2
5. A factsheet summarising key recommendations will be produced and distributed to key end-users, plus made available online via the UWA Turf Research Program website. Will a factsheet be useful to you/your organisation?	• Yes: 86 • No: 1 • Not applicable as I/my organisation does not manage a water allocation: 2 • Did not state: 1
6. Which best describes you?	• Apprentice/student: 5 • Business aligned with the Turfgrass Industry (e.g., fertiliser, irrigation, mowing): 12 • Golf course superintendent: 2 • Grounds manager/staff in the Education sector (primary, secondary, tertiary): 19 • Local government employee: 34 • State government employee: 4 • Turfgrass/Irrigation consultant: 2 • Turfgrass producer: 4 • Researcher: 1 • Other: 5 • Did not state: 2