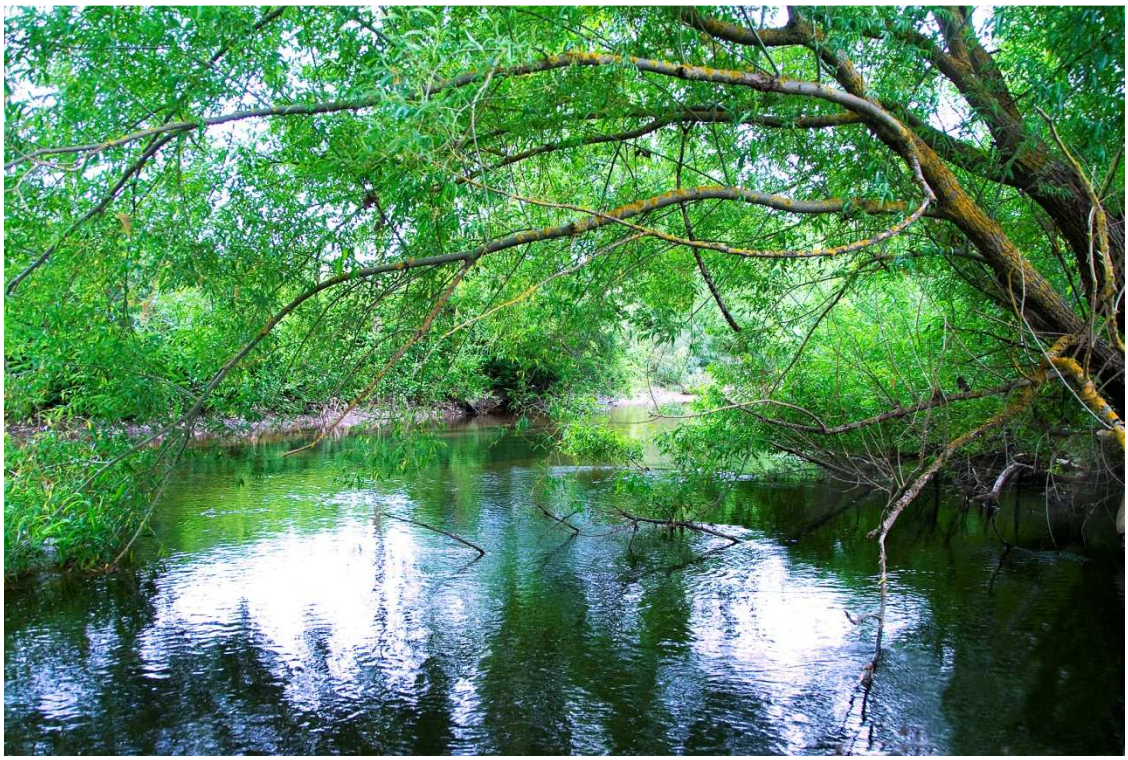
Quantifying water savings from willow removal in southeastern Australia

Tanya Marree Doody



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DECLARATION

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ABSTRACT

Abstract

Two global issues are brought together in this thesis to address a facet of both water resource and weed management in Australia. Water resource security is of global concern as human need for water increases and uncertainty in future water availability associated with climate change continues to evolve, particularly in arid and semi-arid regions. Furthermore, invasive species modify landscapes around the globe in response to anthropogenic ecosystem alterations, with significant impacts within aquatic systems. Water savings projects are under investigation in Australia in response to resource over-allocation and impacts of a prolonged drought from 1997 to 2009 ('The Millennium Drought'). An overarching aim of such investigations is to return water to the environment to meet future consumptive and environmental water requirements. In southeast Australia, invasive willows (Salicaceae: *Salix* spp.) have been identified as naturalized weeds which invade stream beds. In natural systems, stream beds are generally unoccupied and willow establishment increases total riparian leaf area and therefore total evaporative losses. Anecdotal evidence suggested water could be returned to creeks and streams if willows were removed, creating water saving. Strategies exist within State and Commonwealth agencies in Australia to monitor willow invasion, reduce environmental impacts and establish programs to reduce further spread. However, current methods to identify and monitor willow distribution are costly and time consuming.

In this dissertation, field investigations were undertaken to quantify water use of willows and to determine the potential water savings associated with removal of willows from creeks and streams within the Murray-Darling Basin. Methods are described which can potentially be applied across riparian zones worldwide, to aid water accounting and water resource management. Three years of sap flow and water balance measurements, undertaken to determine willow evapotranspiration, indicate that removal of *Salix babylonica* located within stream beds with permanent access to water ('in-stream' willows) in semi-arid areas will potentially return 5.5 ML ha^{-1} $year^{-1}$ of willow crown projected area to the stream when removed. A similar yearlong study undertaken in a cooler temperate region established potential water savings of 3.9 ML ha^{-1} $year^{-1}$ if *Salix fragilis* stands were removed from stream beds. Evapotranspiration of willow and endemic woody species were compared, establishing that removal of willows from water limited environments is unlikely to return a water saving. Two Penman-Monteith models (a model for *S. babylonica* and *S. fragilis*) were calibrated using field measurements of leaf area index and stomatal conductance. Each model was validated using field measured evapotranspiration and then run to calculate monthly pan coefficients (the ratio of evapotranspiration to pan evaporation) for each species across broad climatic ranges in Australia. Derived monthly pan coefficients and monthly pan evaporation predict evapotranspiration of willows across various climatic zones to assist accounting and management of water resources at broader scales. Furthermore, development of a simple open water evaporation model coupled with

evapotranspiration pan factors provides a means to estimate potential water savings from willow removal across broader climatic zones. The pan coefficient method presented has broader application across riparian systems worldwide providing a method to scale woody vegetation evapotranspiration across climatic zones using validated evapotranspiration models.

To further enhance and improve willow management practices, an economical remote sensing technique was developed to discriminate canopy area of willows located within stream beds from native vegetation and willows situated on banks which are generally water limited environments. A method is described using very high resolution WorldView-2 imagery (2x2 m) to identify and calculate total canopy area of both in-stream and water-limited willow infestations within a target region. Delineating willow canopy area provides a method to scale willow evapotranspiration and water savings predictions associated with removal of in-stream willows to catchment scale, to account for catchment evaporative losses, thus providing essential information to catchment managers.

As intensive and science-based resource management policies are required to address predicted future water scarcity in Australia, the knowledge delivered from this research addresses some important knowledge gaps. For example, current and future water availability is predicted within catchments using hydrological models, while vegetation evapotranspiration is predicted from remote sensing. Direct measurement of riparian evapotranspiration strengthens water availability estimates and addresses some 'unspecified losses' associated with Murray-Darling Basin water balance estimates. Estimates of potential water savings related to removal of willows also assists with catchment water accounting. Tools derived within this dissertation provide methods to scale willow and native riparian evaporative losses and water savings estimates from local to regional scales, further improving efforts to account for and manage water resources in Australia and worldwide.

This thesis provides evidence that water savings can potentially be achieved by removing willows located within stream beds which have permanent access to water and inhabit an otherwise unoccupied niche, increasing both total canopy leaf area and riparian evaporative losses. Methods are also provided to scale willow water use information from local to regional catchment scales.

Dedication

This thesis is dedicated to my amazing family. Firstly, to my husband Tom, for his unwavering support and patience throughout. There have been so many days when I thought I wouldn't make it through this PhD but thanks to the love and support of you Tom, I have. Secondly, to my daughter Madison (now 16) and my son Liam (now 14) for your love and patience and for allowing me the quiet periods I required when I required them! I hope, if nothing else during this time, you have learnt to chase your dreams no matter how high the mountain might seem or how impossible the situation might be. You will succeed, just hold onto to the passion in your heart and keep visualising the end result.

As well as creating this thesis I have maintained a full time position with CSIRO which overlapped an additional post graduate degree. I could never have been achieved any of this without the three of you. At various times you have all helped with the little and big things required in keeping a house running and a family together over 9 years of continuous study. I love all three of you dearly and cannot express my gratitude to your support which has allowed me to achieve a goal that is so meaningful to me. I dedicate my time from here to helping the three of you achieve your dreams and goals.

Every day I count my blessings to have such an amazing and loving family and this simple poem sums up the feeling in heart so beautifully.

I love my family so much

To be a part of a family like mine
is so divine
where love is shown
hurt is shared
our love for each other is never impaired

we talk
we laugh
we cry
but we are a family
and we do it all together
for as a family
we do it all as one

you hurt one
you hurt all
and as a family unit
we will all stand tall
for we are family
a family full of strength
a family full of love
a family no one can touch
that's why I love my family so much.

(Author unknown)

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Thank-you to Water for Rivers for funding the research presented within and daring to want to quantify how much water willows consume. Thank-you to the North-East Catchment Management Authority for funding the Victorian component of the research, with a special thank-you to Terry McCormack for his assistance and on-ground knowledge.

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More recently I have made international connections with scientists in the United States undertaking similar research. I would like to thank all of you for your valuable contribution to this thesis and for sharing different perspectives with respect to riparian weed research. Thank-you Dr Pamela Nagler (USGS), Professor Edward Glenn (The University of Arizona), Dr Kiyomi Morino (The University of Arizona), Assistant Research Professor Kevin Hultine (The University of Utah) and Associate

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