Remote imagery analysis improves condition monitoring and optimisation of management regimes of wetland assets.

Al Danger[1], Cat Gilbert[2], Katherine Williams[2] and David Carew.[1]

1. Melbourne Water, 990 Latrobe Street, Docklands, VIC 3008. Email: al.danger@melbournewater.com.au

2. GHD, 180 Lonsdale Street Melbourne 3000 Australia

Key Points

- Key business need to improve the rate and accuracy of collecting wetland condition data.
- Developed an award winning method to remotely assess emergent vegetation cover in wetlands.
- Results of analysis used to optimise capital and operational management programs reducing asset renewal forecast by $30M

Keywords

Stormwater wetlands, asset management, optimisation, investment, emergent vegetation, remote sensing

Introduction

Remote sensing of ecosystem condition enables large scale assessments as sophisticated analysis techniques become more readily available. Remote sensing is gaining popularity as the cost of accessing high resolution imagery falls (e.g. drone or satellite capture) and peripheral benefits, such as increased safety of field staff, are realized. Remote sensing also has clear advantage over field assessments when a large number of spatially separated features need to be assessed in a small timeframe.

Constructed wetlands (CWL) represent large capital and operational investment for Melbourne's taxpayers and substantially contribute to reducing pollutants such as nitrogen, phosphorus and sediment to Melbourne's sensitive marine bays (Melbourne Water Corporation 2011). This project contained two discrete parts: 1) application of a unique method of remotely assessing CWL vegetation cover as a proxy indication of stormwater treatment performance and 2) translating technical results to optimise management regimes of Melbourne Water's ~220 constructed stormwater wetland systems, comprised of 1099 wetland assets (wetlands and sediment ponds).

When functioning as designed, CWLs treat stormwater runoff by filtering and transforming nutrients and chemical contaminates bound to particles carried in stormwater. The primary design assumption for CWLs is an appropriate coverage of emergent vegetation (usually around 80% of surface area) that provides a high surface area for biofilms that drive transformation pathways (Payne *et al.* 2015). Hence, vegetation cover is used as indicator of wetland condition.

Melbourne Water previously utilised bank-side estimates of vegetation cover for condition assessments of CWL assets. This method of condition monitoring proved unsuitable for use across many disparate assets due to highly inconsistent survey results and the substantial time investment needed to adequately cover ~220 systems (Shuman and Ambrose 2003, Adam *et al.* 2010). Collecting robust data to make well informed management decisions was a key driver for this work.

Methods

Image capture

World View 2 imagery was tasked with restrictions for cloud cover, time after previous rainfall event, time of day and nadir angle. Assets on the fringe of the Melbourne Water region were not covered under the captured satellite image as the cost of increasing the image size to cover all assets would have greatly outweighed the benefits (Figure 1A). Imagery was captured between the 5th - 16th January 2014; this time of year was selected because plants are more easily identified in the red and near-infra red spectral bands while actively growing (Adam *et al.* 2010; GHD, 2013).

Object based image analysis was undertaken in order to interrogate both the spectral properties (including Normalised Differential Vegetation Index (NDVI) of the ortho-rectified image, and the spatial relationships of objects including additional vector data (i.e., the designed shape of each wetland system) and their interrelations. This developed measures of emergent vegetation cover for the 1099 individual waterbodies (90% of the asset base). Mapped data for each wetland system was also developed through this process.

Desktop and Object Based Image Analysis

To ensure analysis of emergent vegetation cover was accurate, we developed independent data for a random sample of 105 wetlands using high resolution (15 cm) aerial imagery desktop interpretation by ecologists. 20,775 individual 4 x 4 metre cells were categorized into 10% increments of vegetation cover using this high resolution aerial photography (Figure 1B). 50% of the classified cells were reserved for validation of the OBIA outputs, while the remaining 50% were used to analyse the satellite imagery, to iteratively 'train' the model to improve final outcomes. Figures 1C and 1D show the NIR satellite image in raw form compared to the final product with Object Based Image Analysis (OBIA) output.

OBIA is a type of analysis that groups pixels with similar values into a single object that becomes the basis for classification. Objects with similar spectral signals and spatial properties were then classified into dense (> 81%), moderate (80-41%), low density (40-10%) and open water (< 10%) vegetation and summed to form percent vegetation cover for individual CWL assets. This enabled robust and objective comparison of vegetation cover between CWLs.

Results

Figure 2A shows the vegetation cover classes for wetland assets. Designed vegetation cover varies considerably between wetlands cells so we conservatively estimate that approximately half of Melbourne Water wetland assets have less vegetation cover than designed. Importantly, we consider wetlands within ~10% of their designed cover to be functioning adequately.

Sediment ponds are designed with < 20% emergent vegetation. Asset failure occurs as the pond fills and shallows thereby increasing the amount of substrate suitable for plant growth. This can be identified through NIR analysis as vegetation cover exceeds a nominal threshold. We subjectively considered vegetation cover > 60% as indicating that ponds were full to the point they need scheduling for cleanout. Figure 2B shows ~50% of Melbourne Water's sediment ponds have > 60% vegetation cover, which suggests that these sediment ponds are not functioning as required.

Program optimisation

Wetlands

Wetland cells with abundant emergent vegetation provide the mechanism to treat aquatic pollutants found in stormwater. We therefore used emergent vegetation cover as a robust proxy for CWL condition (Payne *et al*. 2015). A priortised list of wetlands for capital renewal was developed based on the ranked cover of emergent vegetation. We constrained the program by focusing on CWLs with moderate vegetation cover, between 60% and 80% cover for minor renewals (< $500k) as it was expected these CWL would show the greatest cost/benefit return. Several major CWL projects (> $500k) were also identified where large assets were severely failing to meet designed performance standards and therefore substantially increase Melbourne Water's risk of failing to meet regulatory State Environmental Protection Policies (SEPP) targets. Conversely, several planed major capital projects were delayed because a wetland previously identified for works had a higher coverage of emergent vegetation than its peer and was therefore assumed to be performing better. Delayed capital investment formed a substantial proportion of the $30M savings, but additionally, a targeted programmed maintenance schedule was set based on the vegetation cover results – contributing additional savings.

Sediment ponds

Maintaining functional sediment ponds is critical to the performance of CWLs, as sediment ponds protect the downstream wetland from filling with coarse sediment, which if allowed to occur would reduce the water quality improvement service the wetland provides. Many ponds were identified for urgent desilting, some protecting major wetland assets in good condition. Proper asset maintenance extends asset life considerably and substantially delays the need for capital renewal costs if assets fail due to improper maintenance. This formed another substantial portion of the financial savings.

Discussion and conclusion

New and rigorous methods of collecting asset condition data for CWLs enabled direct comparison of CWL assets that could not have been reliably performed using previous bank-side methods. Inter-site comparison for making rapid management decisions provided a powerful tool to spatially priortise capital renewal works of CWLs and direct operational works programs (sediment pond desilts). With pre-NIR asset vegetation cover estimates and naïve asset management techniques, Melbourne Water estimated the capital investment needed for end of asset life renewals and to adequately rehabilitate prematurely failing CWL assets to be ~$90M. An up-front investment of < $250,000 to perform this study, ultimately allowed a projected saving of ~$30M in avoided and delayed costs over 5 years by allowing better optimisation of CWL management programs with the use of more sophisticated asset management techniques.

Capture of new high resolution satellite imagery in 2017 will add a temporal component to the analysis. Applying the method again will identify the trajectory of vegetation cover highlighting assets at risk of failure. This can direct the works program to intercept assets before they reach a vegetation loss tipping point and full asset failure. Coupling this with improved asset spatial data will further focus the remote sensing on the correct vegetation zones providing a more robust measure of asset condition.

Results of the vegetation cover assessment across Melbourne Water's CWL assets suggest better management regimes are required if regulatory requirements of SEPP are to be achieved. Optimising the capital and operational management programs with remotely captured data substantially improved the efficiency of delivering management programs that improve the CWL asset base that provides important environmental and community services.

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References

Adam, E., Mutanga, O. and Rugege, D. (2010). Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: A review. Wetlands Ecology and Management **18**(3): 281-296.

Report for Review of asset condition of constructed wetlands (2013). Report for Melbourne Water.

Melbourne Water Corporation (2011). Understanding the western port environment: A summary of current knowledge and priorities for future research, Melbourne Water Corporation.

Payne, E.G.I., Fletcher T.D., Danger A.R. and Carew D. (2015). Constructed stormwater wetlands literature review, music uncertainty assessment and study of melbourne water's guidelines and procedures.

Shuman, C.S. and R.F. Ambrose (2003). A comparison of remote sensing and ground-based methods for monitoring wetland restoration success. Restoration Ecology **11**(3): 325-333.

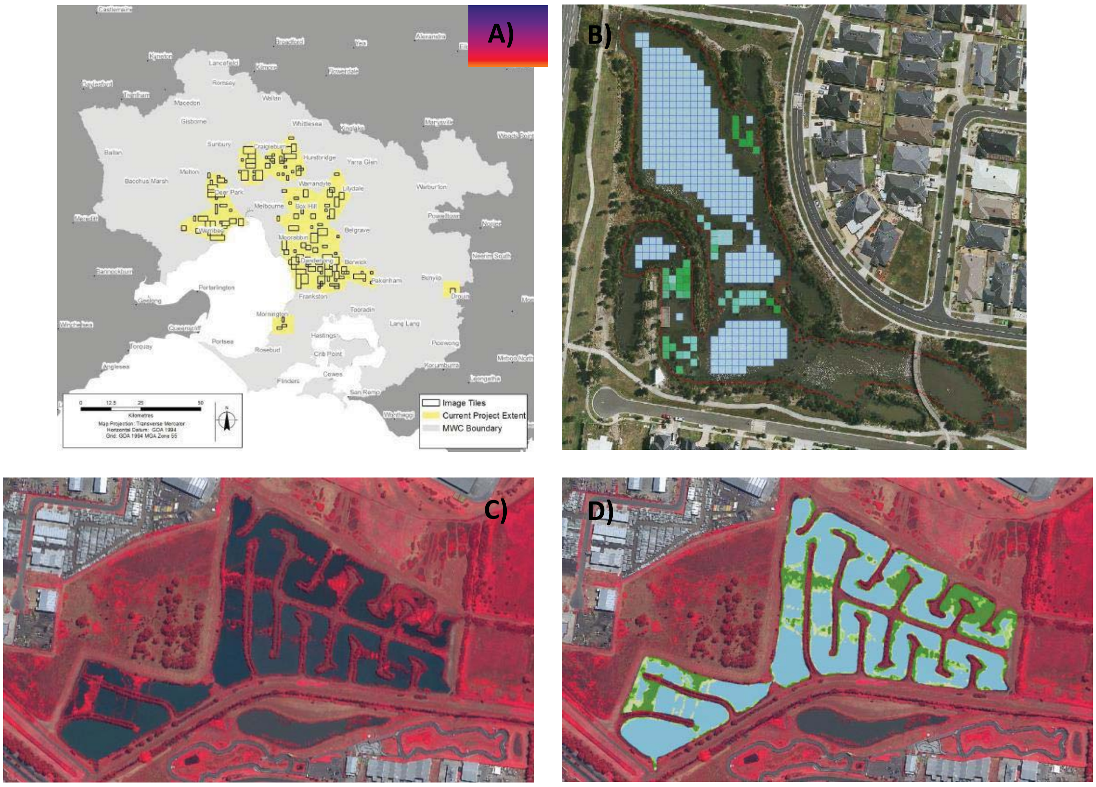

Figure 1. A) footprint of image capture, B) ground truth classification of 4x4 metre cells for model training and validation, C) raw ortho-rectified near infra-red satellite image, D) OBIA output – blue is open water and darker greens trend to denser vegetation.

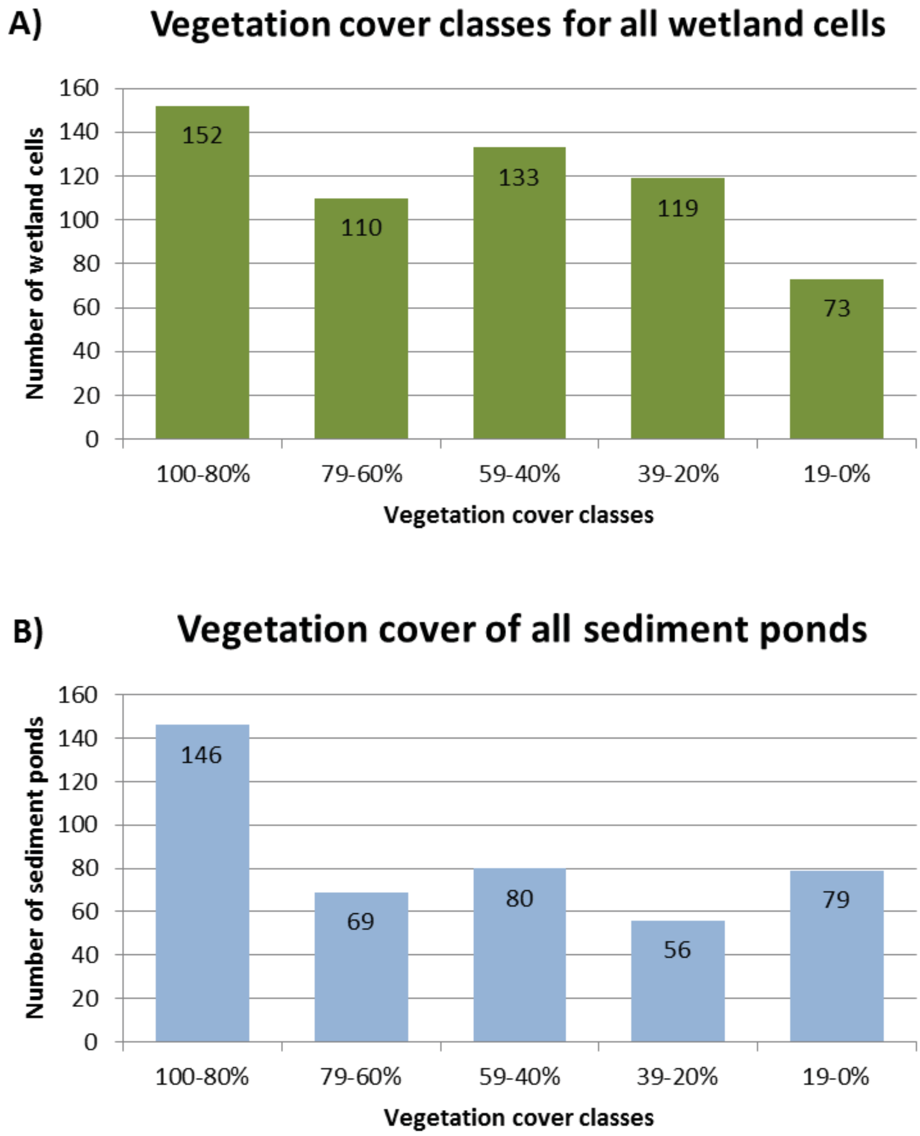

Figure 2. Number of CWLs in 5 vegetation cover classes.