

# Are Victoria's wetlands changing? The development of a method to systematically monitor the extent, water regime and vegetation characteristics of all mapped wetlands

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## Key Points

- The extent, condition and type of Victoria's wetlands are changing, but an absence of a state-wide monitoring method has constrained understanding of the scale and characteristics of change
- A Landsat Thematic Mapper optical remote sensing method has been developed to provide efficient and affordable method to monitor changes in the extent and type of wetlands in Victoria
- The method quantifies change in wetland extent, water regime and vegetation
- Results are provided at sub-wetland and sub-annual scale
- Results can be aggregated to report on change over eight years at a regional or state-wide scale

## Abstract

Victoria's geospatial wetland inventory maps the distribution and extent of approximately 35,500 wetlands. Many of these are naturally occurring wetlands that have been affected by anthropogenic activities which severely impacted their extent, condition and type. These anthropogenic influences, including climate change, will continue to affect wetlands in future. However no method was previously available to quantify such impacts.

In response, a method has been developed that provides an efficient and affordable method to monitor changes in the extent and type of wetlands in Victoria. This method has a specific focus on three indices: (a) extent i.e. the size and area occupied by wetlands, (b) water regime i.e. the pattern of inundation and drying in wetlands, and (c) vegetation i.e. the nature of vegetation occurring within wetlands.

The monitoring method uses Landsat Thematic Mapper optical imagery to assess changes in the maximum extent, frequency of inundation and vegetation cover index values in each wetland over time.

The method can substantially advance Victoria's understanding of the ongoing status of wetlands and provide major insights into the threatening processes that are contributing to loss of wetland habitat or changes in wetland type. This will allow more targeted and effective wetland management programs.

## Keywords

Wetland, Monitoring, Water regime, Extent, Vegetation, Remote sensing, Landsat, Victoria

## **Introduction**

Victoria's geospatial wetland inventory maps the distribution and extent of approximately 35,500 wetlands and identifies that 25,500 of these are naturally occurring (DELWP 2016a). Since European settlement anthropogenic activities have severely impacted the extent, condition and type of many naturally occurring wetlands. Anthropogenic influences, including climate change, will continue to affect wetlands in future. Data on long-term changes to wetland extent and type is required to understand the scale of these effects, to support policy development and on-ground interventions.

To date, the most reliable information on changes to wetland extent and type across Victoria is provided by comparisons of the "Wetland 1994" and "Wetland 1788" geospatial datasets (DELWP 2016b, c). These datasets were derived from interpretation of aerial imagery in the late 1960s, with accompanying field survey in the 1970s and digitization in the early 1990s (Corrick and Norman 1976; Ecosystems Management 2006). Therefore, while they may provide inferences on change since European settlement through to the 1960-70s, they do not quantify change during the last forty years.

Updates to the Victorian geospatial wetland inventory have been undertaken by catchment management authorities and the Department of Environment, Land, Water and Planning (DELWP) over the last 10 years and have provided new insights into the extent of wetlands (Alluvium 2011). However due to the progressive and varied nature of these updates, they do not provide a reliable indication of how the extent and type of wetlands has changed since the original 1968-1993 mapping.

DELWP, who are responsible for policy development regarding the management of wetlands in Victoria, commissioned this research to develop an efficient and affordable method to monitor changes in the extent and type of wetlands in Victoria. The method will allow DELWP to understand the ongoing status of different types of wetlands and identify processes contributing to loss of wetland habitat or changes in wetland type.

## **Selecting the most appropriate method**

Selection of the most appropriate monitoring method was undertaken by first specifying the monitoring requirements in detail, followed by a review of potential methods applied previously in Australia and internationally (in both research and management). This allowed a systematic evaluation of how well each potential method would achieve the specific monitoring requirements in Victoria. The selected method was then applied across a pilot area in northern Victoria.

The core monitoring requirements were to provide:

- **Indicators** that meaningfully represent the ecological changes of interest. The indicators of interest were (a) extent (the size and area occupied by wetlands), (b) water regime (the pattern of inundation and drying in wetlands) and (c) vegetation (the nature of vegetation occurring within wetlands).
- At a **spatial scale** allowing for assessments of wetlands greater than 1.0 ha across Victoria. Note that Victoria's mapped naturally occurring wetlands range vastly in size, with a median area of 3.7 ha and more than 80% of wetlands larger than 1.0 ha. This monitoring requirement therefore translates to addressing a very high portion of the mapped naturally occurring wetlands.
- At a **temporal scale** allowing an evaluation of state-wide wetland change every eight years, based upon observations made at least annually, and preferably more frequently.

Six essential criteria were devised from which to base the systematic evaluation of various potential methods:

- **Currently affordable** where data acquisition and processing can be implemented within the budget made available for the first assessment cycle.

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- **Cost certainty** to provide confidence that the monitoring cost will be stable or decrease over time.
- **Certainty of ongoing data supply** to ensure that compatible data will be available for the foreseeable future, enabling consistent metrics to be generated in future.
- **Frequency of data collection** that supports the eight-year temporal scale of reporting, and the annual (or more frequent) temporal scale of assessments.
- **Ability to monitor a large proportion of wetland types/sizes** through data streams of an appropriate spatial resolution and clarity.
- **Data available for a large proportion of wetlands** to provide coverage across the State and across a variety of wetland types.

Given the requirement to monitor changes across such a large number of wetlands and such a broad range of wetland types, with considerable cost constraints, the evaluation quickly identified that the wetland monitoring method needed to adopt a remote sensing, landscape scale assessment approach. The literature review confirmed that potential remote sensing approaches fell broadly into use of either Landsat satellite imagery, higher resolution satellite imagery, radar satellite imagery and/or digital aerial photography - each approach was at times coupled with other technology such as LiDAR.

The evaluation identified that utilising optical remote sensing data - in particular Landsat Thematic Mapper (TM) imagery - out-performed the alternative techniques and provided the only suitable and 'proven' option (Table 1). The use of Landsat TM supported both the classification of standing water (to inform the extent and water regime indicators) and assessment of vegetation cover and character (to inform the vegetation indicator). From a data continuity perspective, Landsat TM provides a level of robustness to technological and data supply changes that is unparalleled amongst other optical remote sensing options, given that:

- Landsat data is collected regularly, covers all of Victoria, it is archived since 1988.
- Landsat data is free and is available in consistently processed form from US and Australian archives.
- Landsat has a forward plan for ongoing acquisition.
- It is proven as the basis for operational vegetation and inundation monitoring systems in Australia.

## **Piloting the method**

As with any monitoring approach, the use of Landsat data is subject to a number of limitations. These were examined in a pilot application conducted in northern Victoria. This allowed the scope and influence of these limitations to be examined, while also demonstrating the practical utility of the method and its outputs.

In broad terms, the method facilitates monitoring of change in Victoria's wetlands over time through application of a simplified three-step process:

- Satellite remote sensing imagery (Landsat TM) is analysed to delineate the presence of water across the landscape, and examine vegetation cover over time.
- The water detection and vegetation cover data is then used to quantify the temporal and spatial distribution of water and vegetation in each wetland.
- This temporal trend data is then used to analyse the change in the maximum extent of inundation, the change in the frequency and duration of inundation and the change in vegetation cover over the reporting period.

Each of these steps and the outputs from the pilot application are discussed below.

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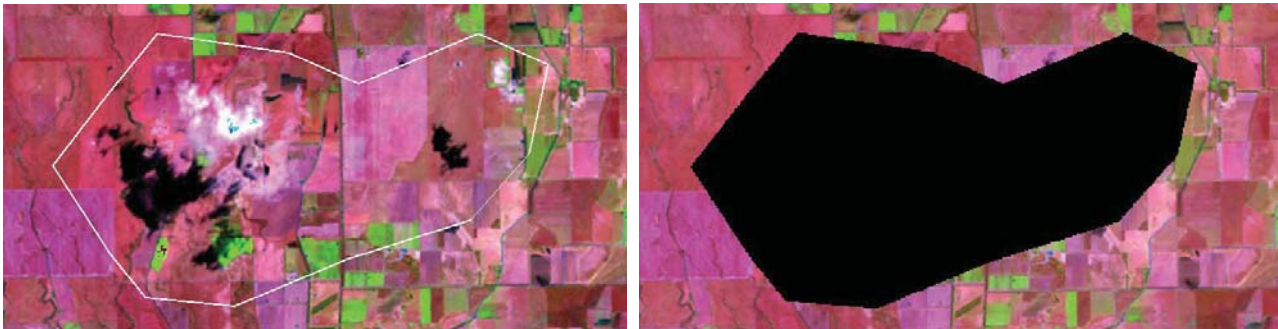
**Table 1. Evaluation of data sources and methods against the essential criteria**

Criteria	Landsat satellite imagery	Higher resolution satellite imagery	Radar satellite imagery	Aerial photography
Currently affordable (typically the cost of monitoring based on remotely-measured data decreases with time)	✓ Landsat data is free of charge.	✗ Currently costs \$1.50 - \$30 per km <sup>2</sup> (approx. \$350k to \$7.1m for all of Victoria).	✓ Sentinel-1 promises a free access data policy.	✗ Highly expensive program for state-wide acquisition.
Cost certainty	✓ refer above	✗ refer above	✓ refer above	? Future costs highly dependent on scale and extent of the DEWLP Coordinated Imagery Program
Certainty of ongoing data supply	✓ Landsat has a forward plan for ongoing acquisition. It is available in consistently processed form from US and Australian archives.	? New satellites are being launched and planned by different countries and commercial enterprises.	✗ Most current generation satellites require ordering in advance and lack an archive. ? Sentinel-1 promises forward continuity of data.	? Likely to be increasingly acquired into the future, but not across the entire state on routine basis.
Frequency of data collection	✓ Landsat systems acquire repeat coverage every 16 days on a regular basis. Landsat data is archived since 1988 (TM data).	? Most require ordering in advance, rather than archiving at set intervals.	✓ Sentinel-1 has a repeat cycle of 12 days	? Likely to be increasingly acquired into the future, but not multiple times per year for most areas.
Ability to monitor a large proportion of wetland types / sizes	? Resolution of 30m by 30m may affect detection and inundation area estimation for small and narrow wetlands.	✓ Pixel sizes of <5 m provides opportunity to improve mapping of smaller wetlands.	? Sentinel-1 is a 'C-band' system with a default mode resolution of 20 m.	✓ Very high resolution products
Data available for a large proportion of wetlands	✓ Landsat data covers all of Victoria	✗ Most require ordering in advance.	? Currently, in Australia, data access is limited.	? Likely to be acquired, but not necessarily across the entire State. Requires ordering in advance.

**Legend:** ✓ Likely to meet requirements of this criteria      ? Possible it could meet requirements of this criteria      ✗ Does not meet requirements of this criteria

### Satellite remote sensing imagery analysis

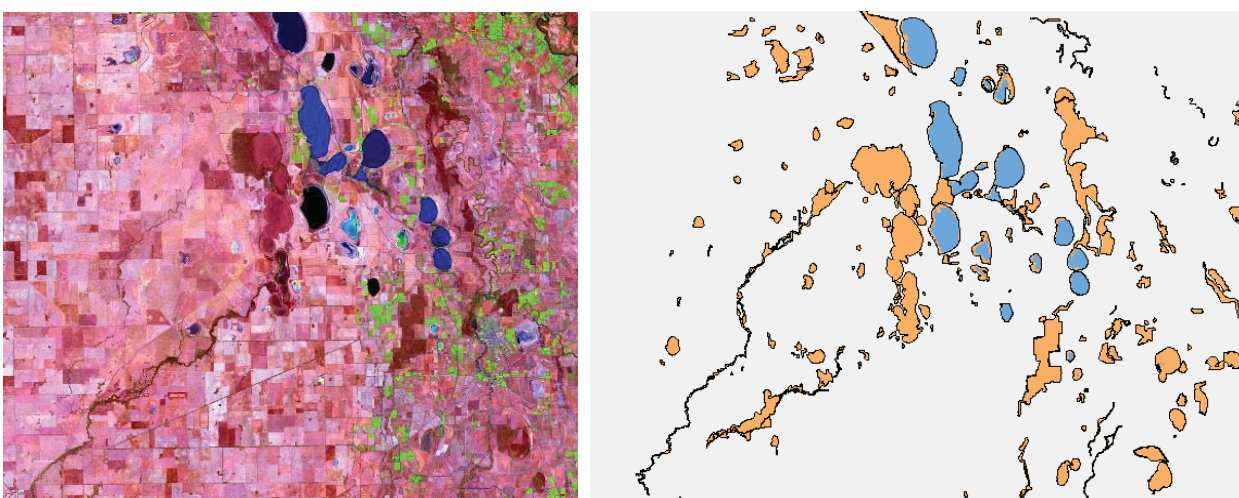
To examine change over time it is obviously important to have the highest possible frequency of images over a period. To achieve this, Landsat images from the United States Geological Survey archive were used when missing from the Australian Reflectance Grid (ARG25) archive – this occurred approximately 40% of the time in the pilot area. In addition, work was required to account for the presence of cloud in the imagery (through a manual cloud masking process as shown in Figure 1), and terrain illumination correction for hilly areas.



**Figure 1. Landsat 8 image data from 18/4/2014 showing cloud affected area (left) and corresponding resultant cloud masked image (right) where the black area represents the masked out area.**

Having pre-processed the imagery, an automated thresholding method on band 5 (i.e. mid – infrared) was used for each Landsat image, to delineate and map the presence of water in each wetland. First, a base classification at a chosen date was produced using a supervised approach to set the initial threshold values, with the thresholds for each scene then generated by matching it to the base classification. This automated matching enables an adaptive threshold to be selected for each date to produce a ‘wet/not-wet’ classification for each pixel. Supervised quality assurance was also employed to verify, validate and refine the classification, based on visual interpretation of the Landsat imagery.

Figure 2 shows an example of the classified output from January 2007 across a single Landsat 5 image. The image on the right shows the classification map (clipped to the mapped wetland boundaries), with wet areas as blue and dry areas as orange. This wet area mapping is consistent with visual interpretation of the image.



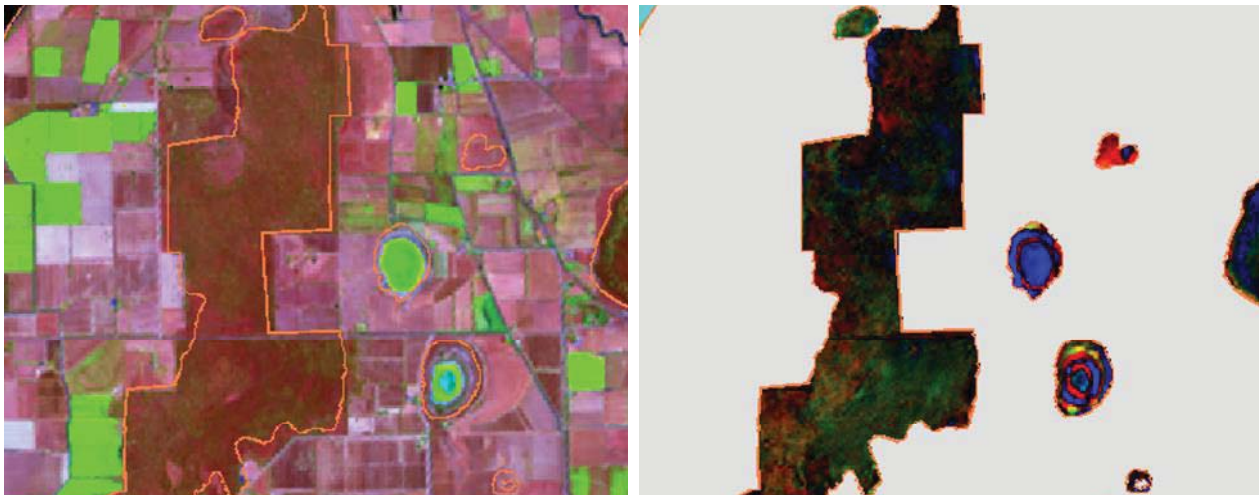
**Figure 2. Landsat 5 image data from 9/1/2007 (left) and corresponding classified map with blue areas representing ‘wet’, orange areas representing ‘non-wet’ and grey areas those beyond the mapped wetland boundaries (right).**

### *Quantify the temporal and spatial distribution of water and vegetation*

The process described above generated one of three inundation classifications (wet, dry, missing data) for every pixel in every Landsat image. Statistical analysis of these classifications enabled the development of two key products:

- Raster datasets / maps showing the proportion of times that each pixel was subject to inundation – example shown in Figure 4.
- Temporal plots and statistics for each wetland, describing the proportion of the wetland that was subject to inundation at each point in time – examples shown in Figure 5. The dynamics of inundation and sequencing of wet/dry periods can be visualised from these temporal plots.

To examine trends in wetland vegetation, a vegetation cover index was calculated from a sequence of images from the dry phases (to minimise dynamic short-lived changes from herbaceous components). The cover index approach used the methods of Lehmann et al. (2013) in their assessment of forest cover trends across the Australian continent, and calculated vegetation cover from a linear combination of Landsat bands 3 and 5. This process generated a cover index value for every pixel in every Landsat image. Figure 3 provides an example of the magnitude of change in cover index in a series of nearby wetlands over the eight year period from 1 January 2007 to 31 December 2014.



**Figure 3.** February 2015 image (left) and cover index trend image from 2007-2010 (right). The larger area of wetland vegetation shows some change patterns but is essentially stable. The colours in the two wetlands right of centre arise from vegetation changes following water level fluctuation – red represents a loss in vegetation, blue represents a gain, and yellow/greens represents limited change in vegetation. The small ‘red’ wetland above appears to have lost vegetation cover.

### *Analyse change in indicator values*

The temporal plots of inundation and vegetation cover index scores for each wetland enable the quantification of values for each of the three indicators of interest over the reporting period:

- **Extent index:** Calculated as the maximum inundated area over the assessment period, expressed relative to the historical maximum inundation extent.
- **Water regime index:** Calculated as the frequency of inundation (i.e. number of years in 10 that a wetland ‘holds water’) and duration of inundation (i.e. number of months that a wetland ‘holds water’ for before drying). Together these enable classification of the water regime category in accordance with Victorian wetland classification framework (DELWP 2016d).
- **Vegetation index:** Calculated as the change in vegetation ‘cover trends’.

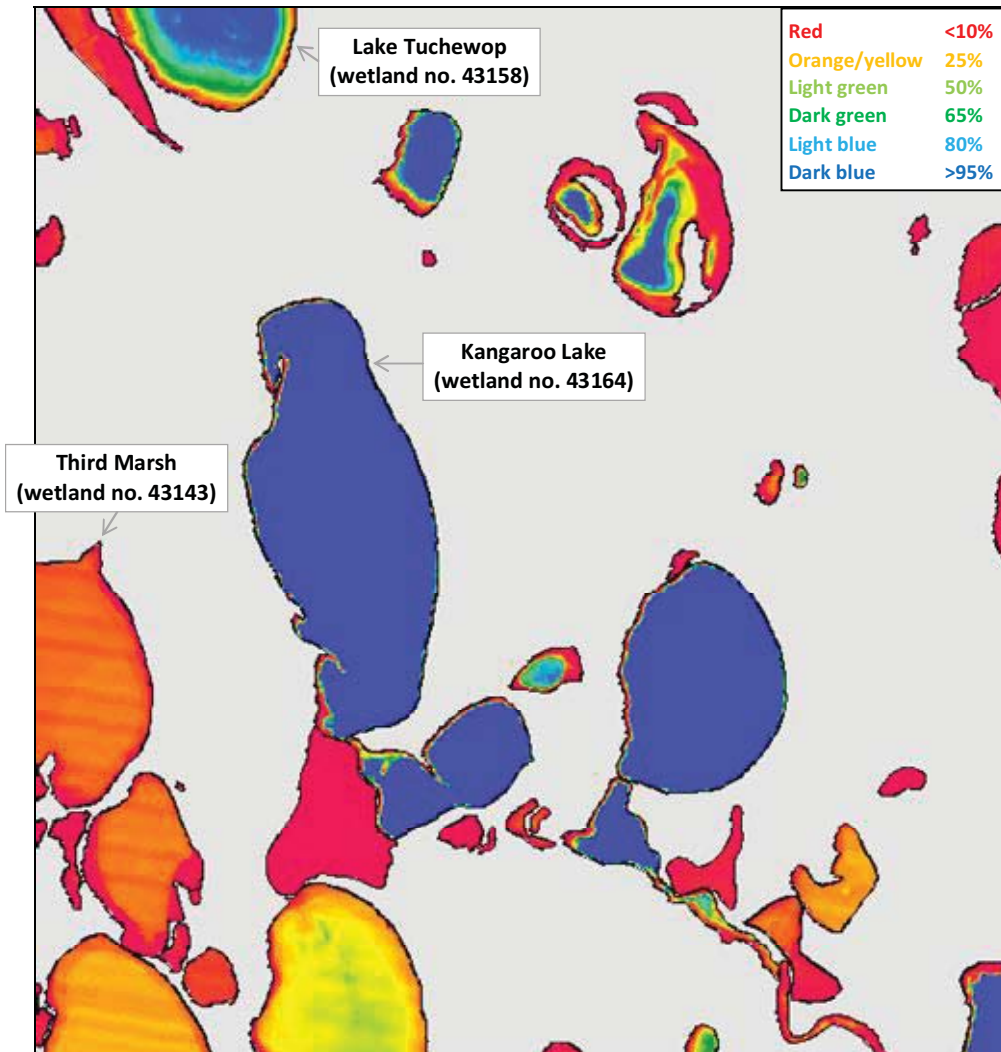


Figure 4. Percentage of wet observations summarised on a colour scale from red (low) to blue (high) from 2007 to 2014 in the pilot area.

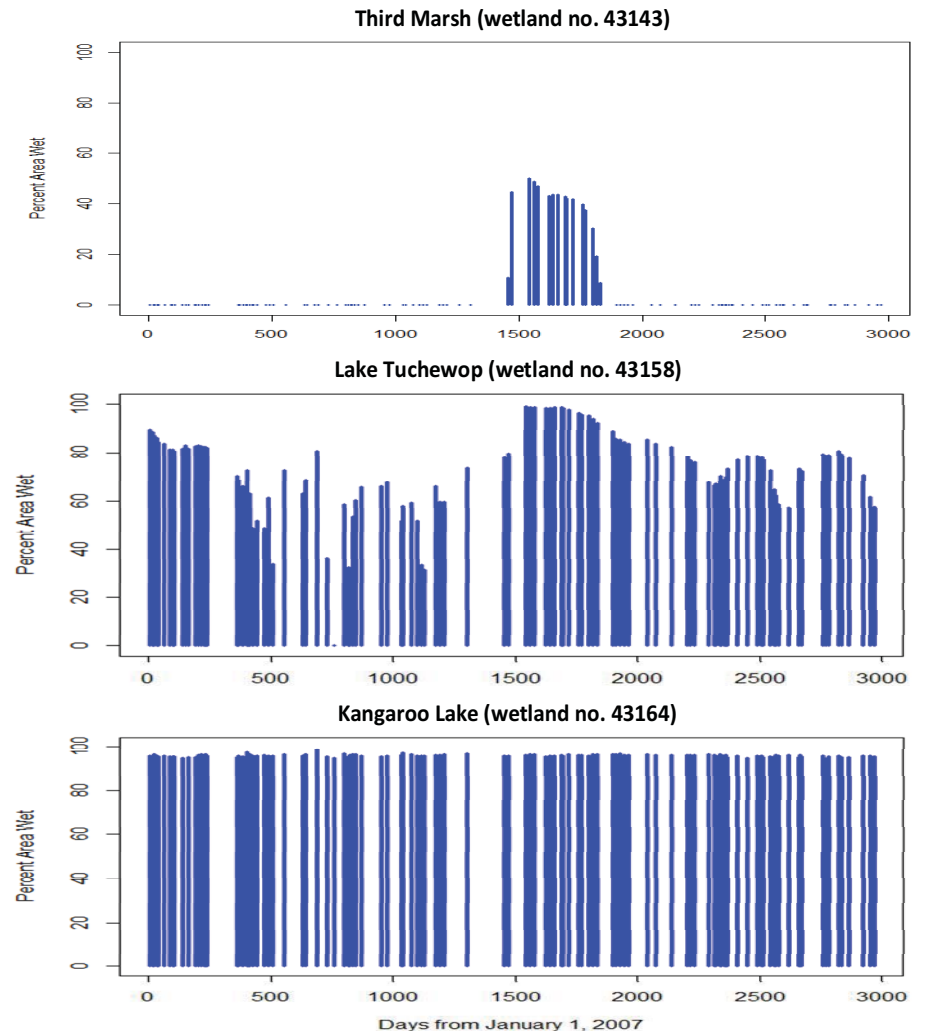


Figure 5. History of inundation percentage from 2007 to 2015 (116 images). Blue dots on X-axis indicate '100% dry', gaps on the X-axis indicate periods of missing or cloudy imagery.

## **Conclusions**

The Landsat TM monitoring method developed and piloted for this research enables three indicators of wetland character and function (extent, water regime and vegetation) to be routinely examined across Victoria's naturally occurring wetlands. This approach provides a robustness to technological and data supply changes that is unparalleled amongst other optical remote sensing options. However, like all methods there are limitations, which were confirmed in the pilot application, most notably:

- Vegetation cover over standing water can result in errors of omission, with the extent of inundation particularly difficult to identify beneath dense growths of Cumbungi, Common Reed or Swamp Paperbark and under dense patches of medium-sized graminoids (e.g. Sea Rush)
- It does not distinguish between different vegetation types and has no vertical metric of vegetation structure.
- It highlights change but does not attribute the cause of it.

These limitations are considered to be acceptable outcomes of the monitoring method, given the countering advantages of the monitoring approach:

- It builds upon freely available satellite imagery that is available across all of Victoria.
- Data extends back decades before present and has a forward plan for ongoing acquisition.
- It is cost effective – implementation and reporting is estimated to cost in the order of \$230,000 to \$400,000 for historical and current assessment of all metrics, depending on the intensity of the data collation and classification tasks. Future assessment cycles would involve relatively small costs (\$10,000 to \$40,000), while the task of data collation should reduce in the future as the Australian Geoscience Data Cube resources become more complete.
- It provides consistency in metrics temporally and geographically.
- It enables synoptic assessment at state and local scale.
- Although focused on naturally occurring wetlands, it could be developed to be equally applied to human-made wetlands.

In light of these advantages and limitations, the adopted method can substantially advance Victoria's understanding of the ongoing status of different types of wetlands. This will provide major insights into the threatening processes that are contributing to loss of wetland habitat or changes in wetland type, allowing more targeted and effective wetland management programs.

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