Challenges to scaling up site-based data for assessing environmental water outcomes in floodplain wetlands

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Key Points

- Monitoring and evaluation of ecological outcomes is critical to support effective and efficient use of environmental water.
- Hydrologic information of inundation extent and volume is essential for understanding the distribution of water throughout the environmental water delivery period.
- Linking responses of ecological indicators to hydrologic data will facilitate the scaling of ecological responses from site-based data to wetland- or asset-scale for improved scientific evaluation or communication.
- This paper reports on challenges and opportunities to scaling up ecological outcomes of environmental watering from developing inundation models, through to system scale carbon metabolism and density of biota.

Abstract

It is critical that the ecological outcomes of environmental watering events are detected, monitored and reported on for both the restoration of freshwater systems and auditing the use of water resources. Biomonitoring of river and wetland systems underpins most water resource management and has received significant funds and research effort during development. A shortcoming of many biomonitoring programs is that they are generally performed at spatial and temporal scales that are smaller and shorter than the systems and timeframes of interest. We use two case studies of large floodplain wetland systems in the lower Gwydir and Warrego Rivers to explore the challenges and sources of error inherent in collecting site-based hydrologic and ecological data to determine the condition of an entire wetland complex. Both systems are very flat (slopes >1:1000), have small elevation changes (0.1 m) and consists of a mosaic of small, incompetent channels, broader flow pathways and shallow (<1m) wetland depressions. This paper highlights the value of employing multiple sources of information when attempting to determine the inundation extent and volume to reduce the errors when scaling up site-based ecological data for assessing environmental water outcomes in floodplain wetlands.

Keywords

Environmental water, hydrology, biomonitoring, wetland, floodplain, restoration

Introduction

Monitoring and evaluation programs are designed to attempt to establish relationships between environmental water and ecological responses. One of the basic requirements for effective environmental water management is an understanding of the distribution of water throughout the system being managed. In systems with well-defined channels and wetlands, inundation can be monitored by networks of automated flow and water level gauges. In other systems, like many in the northern Murray Darling Basin, many river systems have poorly defined flow pathways that drain across very low gradient landscapes (Thoms *et al.*, 2004), quantifying relationships between flow and inundation, and therefore ecological responses, is more challenging (Chen *et al.*, 2014).

The lower Gwydir and Gingham wetlands in the Gwydir River system and the Western Floodplain in the Warrego River system are very flat (slopes >1:1000) systems that are near-terminal with only larger flood events flowing through them. As such, a number of complementary remote sensing, GIS and ground-truthing techniques are required to produce the best possible inundation maps for these systems (Frazier *et al.* 2012). This challenge is further complicated by the sources of error such as process uncertainty and observation uncertainty inherent in collecting site-based ecological data to determine the condition of an entire wetland complex (King *et al.,* 2005). Such challenges are part of the Long Term Intervention Monitoring project for the Commonwealth Environmental Water Office that seeks to assess the ecological outcomes across a range of biota for the Murray Darling Basin. This paper reports on efforts to understand the issues and challenges in developing inundation models in flat, densely vegetated wetlands where traditional approaches to inundation modelling are not successful, through to developing wetland-scale carbon metabolism and microinvertebrate density in these heterogeneous wetland systems.

Study areas

The Gwydir River in northern NSW drains the western side of the Great Dividing Range and terminates in the west at its confluence with the Barwon River, covering an area of 26,600 km^2 (Green *et al.,* 2011). In the lower Gwydir system, the river bifurcates into a series of channels, several of which feed the Lower Gwydir and Gingham wetlands (Figure 1a). These near terminal wetlands support a variety of wetland, semi-permanent and floodplain vegetation communities, which form important habitat for a number of endangered and threatened species (DECCW, 2011). The eastern extent of the Gwydir wetlands in the Old Dromana Ramsar wetland was chosen to test Digital Elevation Model (DEM) based modelling approaches for estimating inundation volumes and extents in the Gwydir system.

The Warrego River drains an arid catchment in Southern Queensland flowing south to its confluence with the Darling River in northern NSW. Near the junction of the Warrego and Darling Rivers, the Warrego River forms a large floodplain system called the Western Floodplain (Figure 1b). This large floodplain is heavily dissected by small flood runners from overflows at Boera Dam and drains to the Darling River under high flows. The Western Floodplain supports vast area of lignum, coolibah, river cooba and black box vegetation communities, and an array of wetland dependent biota (CEWO, 2014).

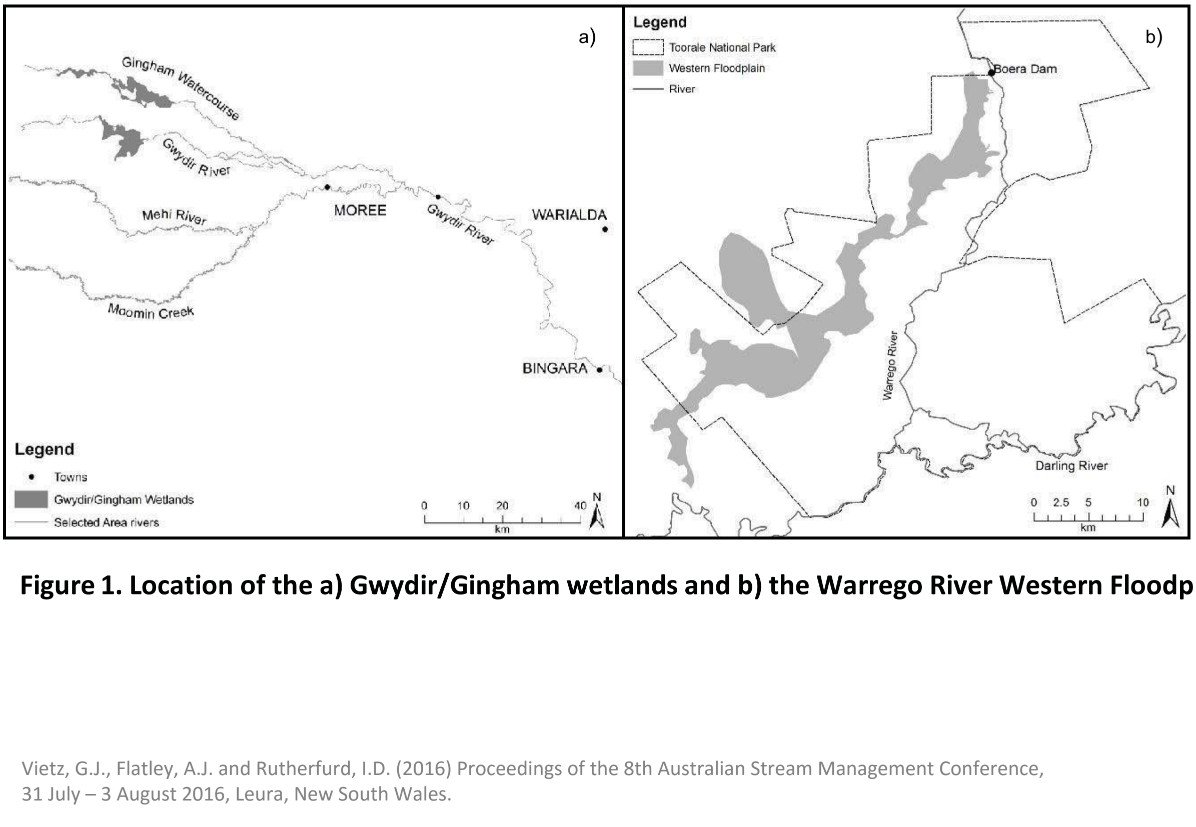

Figure 1. Location of the a) Gwydir/Gingham wetlands and b) the Warrego River Western Floodplain.

Methods

System scale inundation models

Five data sources were used to build a model of inundation extent and volume. Lidar imagery was obtained from the New South Wales Office of Environment and Heritage Spatial Imagery Services branch to create 5m DEMs. Landsat 8 scenes captured on multiple occasions throughout the inundation and contraction cycle were analysed to detect the presence of water in the landscape (Frazier & Page, 2000). The vegetation layer was derived from ground-based vegetation mapping (CEWO, 2014). Water level loggers were installed at various locations within each system to aid volume estimates. Field based observations of water depth (Total Station survey transects) and inundation extent (GPS-based wetted perimeter) were also used to inform the analysis. Volumes of inundation for each vegetation community were estimated for each of the Landsat image times.

Site-based biomonitoring

Biomonitoring sampling took place as part of the Long Term Intervention Monitoring in the northern Murray Darling Basin on four occasions in the Gwydir (8 sites) and two occasions in the Warrego (4 sites) from the commencement to the cessation of environmental water delivery (October 2014 through to March 2015). Sample events are planned to follow the inundation and contraction cycle, sampling immediately (days) after inundation, at peak area inundation, and at two times during the drying cycle.

Stream and wetland metabolism measures for temperature, dissolved oxygen and photosynthetic active radiation were logged for a minimum of 48 hours. Site-based gross primary production (GPP), ecosystem respiration (ER) and net primary productivity (NPP) in mg O_2/L/day were recorded and applied to the inundation models to determine wetland-scale rates. Monitoring of benthic and pelagic zooplankton were undertaken at each sample location. Benthic zooplankton were sampled by compositing five corers (250mL in <30cm depth) along a 100m transect at each site. Pelagic zooplankton were sampled by filtering 20L of the water column at each of five locations throughout the site. Each zooplankton sample was poured through a 63µm net. The volumes of the total samples were recorded and subsample totals were scaled up to each total sample volume and reported as density/L and applied to the inundation models to determine wetland-scale rates.

Results

Gwydir wetlands inundation model

The first step in developing the inundation model was to remove a significant regional east to west relief gradient evident in the wetlands by applying a tilt layer that produced an adjusted DEM representing a ‘closed’ system that could be virtually flooded to estimate inundation area and volume. Several cross sections obtained from the adjusted DEM were contrasted with field observations (Total Station survey transects) and vegetation community distribution as an indicator of water depth and permanence. The adjusted DEM created from Lidar data did not align with the true land surface within the wetlands from ground-based surveys due to dense vegetation coverage, creating large errors in DEM derived inundation volumes. Precision was improved by including site-based depth of discrete vegetation communities and water level logger data.

Inflows to the Gwydir wetlands in the 2014-15 water year were predominantly from environmental water deliveries. As environmental water arrived in the Lower Gwydir wetland inundated area increased to 1,779 ha in October 2014, peaking at 2,434 ha in February 2015, and receding to 443 ha in April 2015(Figure 2). A similar inundation pattern was evident in the Gingham wetlands with the peak at 3,909 ha in February 2015. Patterns in volume followed inundation extent, with the maximum recorded volume of 4,829 ML in the Lower Gwydir wetland and 8,977 ML in the Gingham wetland.

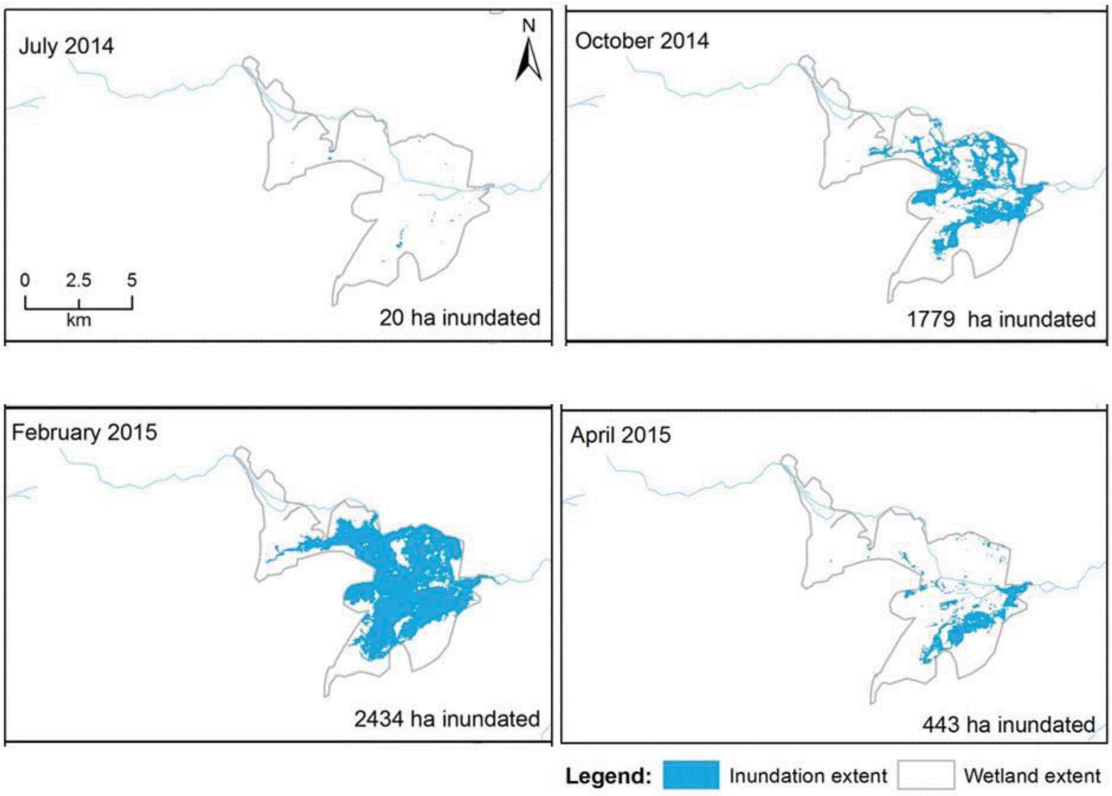

Figure 2. Inundation extents mapped in the Lower Gwydir wetland at four occasions throughout the 2014-15 water year.

Warrego Western floodplain inundation model

The DEM was the primary source of information used to model the relationship between inflows, and the extent and volume of inundation on the Western Floodplain. A regional north to south gradient was removed by applying a tilt layer to produce an adjusted DEM. A constraint layer was developed for modelled commence to fill water levels where inundated areas were predicted to connect to the upstream Boera Dam overflow point. The extent of inundation and volume were calculated for gauge heights between the estimated overflow height of the floodplain and the maximum height recorded at the Boera Dam gauging station. The maximum inundation extent was verified by comparison to an inundation extent derived from Landsat imagery at multiple points in the inundation period. Manipulation of the DEM was successful in estimating the extent and volume of inundation of the Western Floodplain, with good relationships observed between Landsat-derived inundation extent, water level data and field observations.

Inundation of the Western Floodplain was restricted to the northern sections of the floodplain in the 2014-15 water year. Inundation extent ranged from 0.5-36.9 ha when Boera Dam was above the estimated overflow level of the Western Floodplain (Figure 3). At lower gauge heights, inundation was restricted to a single flood channel at the northern section of the floodplain, until Boera Dam levels increased to 2.36 m (Figure 3). Volume estimates suggest that a maximum of 71 ML of water was stored in the floodplain during the peak of the flooding event.

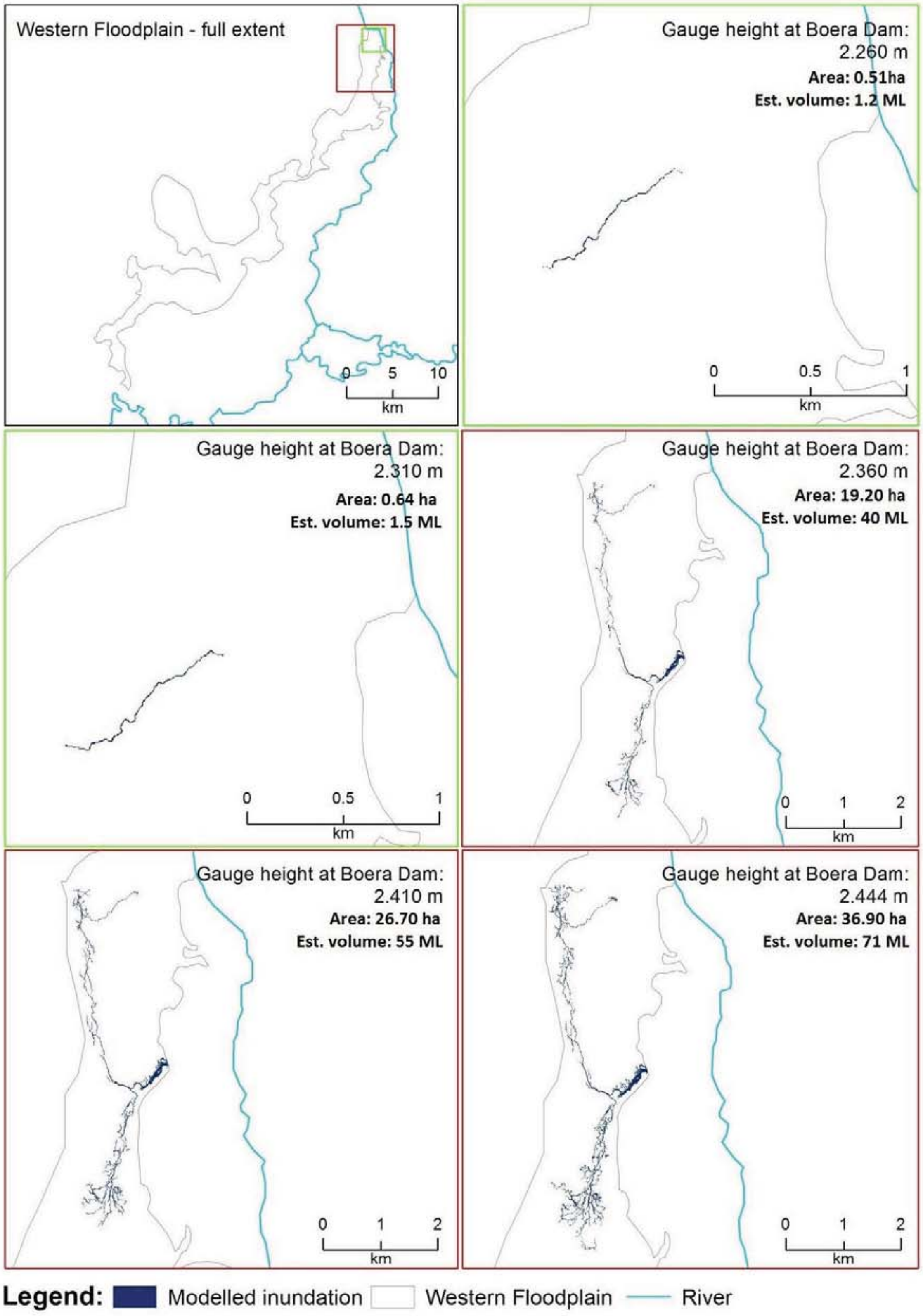

Figure 3. Inundation extents mapped on the Western Floodplain at five water levels measured with estimated inundated area and volume at Boera Dam during Feb–April 2015.

Site-based biomonitoring

The Gwydir Wetlands were net heterotrophic throughout the period of environmental flow delivery and inundation (Table 1). The Western Floodplain was only slightly net autotrophic (Table 1). All systems acted as carbon sinks throughout the period of inundation (Table 1).

Table 1. Rates of Net Primary Productivity (NPP) and amount of Carbon in the Gingham/Gwydir Wetlands and Western Floodplain. Vegetation habitat: WC=Watch Couch, OW=Open Water, EM=Emergent Macrophyte.

System	NPP by vegetation habitat (mg O_2/L/day)			NPP all vegetation habitats (mg O_2/L/day)		Carbon in whole system (Ton/C/m^3/day)	
	WC	OW	EM	Mean	s.d.	Mean	s.d.
Gingham Wetland Feb-15	-8.20	-3.89	-	-6.76	2.49	-18.97	6.99
Gingham Wetland Apr-15	-	-1.01	-	-1.01	-	-1.10	-
Gwydir Wetland Feb-15	-9.83	-	-4.12	-6.98	4.04	-10.52	6.09
Western Floodplain Feb-15		-0.92		-0.92	0.06	-0.020	0.001

The whole system scale abundance of total zooplankton followed a predictable cycle of maximum abundances when inundated area and volume were at a maximum. In the Gingham and Lower Gwydir Wetlands, whole system abundances of zooplankton were at a maximum of 1.6 x10^{14} in March and 6.9 x10^{14} in February respectively (Table 2). Peak whole system abundance of zooplankton in the Western Floodplain was at 2.4 x10^{9} in February (Table 2). Temporal shift in dominant zooplankton taxa in all systems indicated the succession of zooplankton communities during flow delivery and wetland inundation.

Table 2. Zooplankton site density, whole system abundance and whole system biomass in the Gingham/Gwydir Wetlands and Western Floodplain.

System	Site density (Number of individual/L)	Whole system abundance (Number of individual)	Whole system biomass (kg)
Gingham Dec-14	25027	4.9 x10^{12}	1.2 x10^{8}
Gingham Feb-15	11779	1.1 x10^{14}	2.5 x10^{9}
Gingham Mar-15	17907	1.6 x10^{14}	3.8 x10^{9}
Gingham Apr-15	62042	2.0 x10^{13}	4.7 x10^{8}
Lower Gwydir Dec-14	61457	1.5 x10^{13}	3.7 x10^{8}
Lower Gwydir Feb-15	149563	6.9 x10^{14}	1.7 x10^{10}
Lower Gwydir Mar-15	11232	2.5 x10^{13}	6.0 x10^{8}
Western Floodplain Feb-15	34	2.4 x10^{9}	5.8 x10^{4}
Western Floodplain May-15	26	3.2 x10^{7}	7.6 x10^{2}

Discussion

On the Western Floodplain of the Warrego River where vegetation density was far less, the Lidar-derived DEM was more accurate for inundation mapping, and was the primary source of information used with verification by water level loggers and satellite imagery. However, in the Gwydir, dense emergent wetland vegetation, standing water and an exceptionally flat landscape limited the value of Lidar data for DEM creation and inundation modelling. Dense reed mats present during Lidar capture mean that these areas appeared to stand above the surrounding landscape and hence significantly affected the accuracy of the resultant DEM. Similar inaccuracies have also been observed in other studies (Hopkinson *et al.* 2005). In this system we employed a multiple lines of evidence approach to link existing vegetation mapping (with known inundation tolerances), inundation information from Landsat imagery, on-ground Total Station and GPS-based wetted perimeter surveys, and on-ground depth loggers to develop an inundation model.

The estimation of ecosystem metabolism in terms of O_2 changes requires accurate calculation of multiples parameters (e.g. reaeration coefficients, PAR, temperature), data fitting and data filtering procedures. However, there is no *a priori* method to determine the accuracy of the metabolism rates as the 'true' values are never known (Grace & Imberger, 2006), and a reference condition for rates of metabolism are also unknown. With increasing use of ecosystem metabolism as biomonitoring indicator, developing techniques for the estimation of uncertainties in metabolic parameters is needed.

Zooplankton confidence limits can be introduced by natural spatial variation and sampling and operational errors. The study systems are spatially and temporally complex because the aquatic habitat expands and contracts during environmental delivery phases and changes in climate conditions. To minimise natural variation in these mosaics of landscape, we stratified zooplankton sampling within representative vegetation habitats.

The sources of error inherent in collecting site-based ecological data to determine the health of an entire wetland complex predominantly come from the assumption that the system behaves just like the small sample area (Downes *et al.*, 2002). Error ranges could appear quite small in site-based scale, they will have a profound effect on a whole system scale. Basic-scale evaluation has adopted a hierarchical approach to sample design in the LTIM projects (Gawne *et al.,* 2013). This approach of considering each watering area to be a nested hierarchy of zone are able to answer a question at a small-scale (unit, element or zone, <1year) and contribute to answering a question at a larger scale (area, Basin, 1-5 years). In recognition of the complex and nested nature of the system, evaluation process at multiple spatial and temporal scales must be undertaken.

Conclusion

This paper highlights the value of employing multiple sources of information when attempting to determine inundation extent and volume of wetlands within flat and densely vegetated landscapes. How the accuracy of these data holds with larger inundation events will be tested during the coming four years of this project. The sources of error inherent in collecting site-based ecological data to determine the health of an entire wetland complex should be defined and estimated for a successful monitoring and evaluating program.

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