Assessment of channel expansion and contraction using cross-section data from repeated LiDAR acquisitions in the Macquarie Marshes, NSW

Neda Yousefi, Timothy J. Ralph, William Farebrother, Hsing-Chung Chang and Paul P. Hesse

Department of Environmental Sciences, Macquarie University, NSW 2109, Australia. neda.yousefi@hdr.mq.edu.au

Key Points

- Channel change in floodplain wetlands can lead to alterations in inundation patterns.
- The Macquarie Marshes are a multi-channeled wetland system that is susceptible to change.
- Some trunk streams and return channels in the wetlands experience channel expansion due to erosion while some distributary channels experience channel contraction due to sedimentation.
- Cross-sections extracted from Digital Elevation Models (DEMs) and a DEM of Difference analysis could not resolve fine-scale channel adjustments over a short timeframe (i.e. 2008-2014).

Abstract

Floodplain wetlands have alluvial channels that change over time due to both erosion (sediment export) and sedimentation (sediment accumulation). Adjustments in channel capacity resulting from erosion and sedimentation influence the timing and extent of floodplain wetland inundation and alter in-channel and other habitats and their ecological processes, and are a key factor in river and floodplain management. Nineteen sites in the southern Macquarie Marshes were studied, some with multiple channels and others with a single channel, yielding 54 channel cross-sections in all. Two Light Detection And Ranging (LiDAR) Digital Elevation Model (DEM) datasets acquired in 2008 and 2014 were used to assess changes in channel size and shape due to erosion and sedimentation. Channel depth measurements could not resolve any changes in depth, and were not accurate when channels contained water. Comparisons of channel width measurements showed that 17% of channels experienced expansion over the 6 year period between LiDAR acquisitions, while 5% had a reduction in channel width, and 78% had no measureable change. The trunk streams of the Macquarie River and Bulgeraga Creek and a return channel of Buckiinguy expanded, suggesting erosion, whereas one reach of Bulgerara Creek and the distributary channel Monkey Creek contracted, suggesting sedimentation. Analysis of a DEM of Difference (DoD) for the whole area covered by the Macquarie Marshes LiDAR data was not able to produce reliable results for vertical level changes (deposition or degradation), particularly where water and dense vegetation were present. It is inferred from the DoD that any sedimentation or erosion in the system during this brief time window was beyond the limits of detection (±15 cm vertical; ±45 cm horizontal) and was not significant.

Keywords

Channel capacity, channel change, erosion, floodplain wetlands, DEM, sedimentation, wetland in drylands

Introduction

Floodplain wetlands provide unique habitat for water-dependent flora and fauna. Channels supply floodplain wetlands with water and play a critical role in maintaining ecological and geomorphological conditions, although, they are at the risk from natural disturbances and human impacts (Ralph et al., 2016). Channel change due to erosion and sedimentation is a concern in floodplain wetlands, especially where changes in channel capacity may affect the depth, extent and timing of floodplain or wetland inundation. Therefore, understanding channel behavior and the patterns of erosion and sedimentation in alluvial channels is helpful when manage managing wetlands.

Several methods have been introduced to assess channel expansion and contraction due to erosion and sedimentation in rivers and wetlands. For example, erosion pins (Palmer et al., 2014, Foucher et al., 2017), field plots (Smets et al., 2008, Smith and Vericat, 2015), cross-section surveys (Hupp et al., 2015), remote sensing and satellite imagery (Patro et al., 2009, Rowland et al., 2016), analysis of aerial photographs and historical maps (Ralph et al., 2016, Lallias-Tacon et al., 2017), Light Detection And Ranging (LiDAR) surveys (Croke et al., 2013, Huang et al., 2014), and Digital Elevation Models (DEMs) and DEMs of Difference (DoDs) (Bezak et al., 2015). Of these, LiDAR and DoD approaches are being widely applied due the growing availability of high resolution digital elevation data, for example, Croke et al., (2013 used LiDAR to assess basin-scale erosion and deposition in the Lockyer River valley in Queensland, Australia. Erosion and deposition patterns have also been quantified using LiDAR in Colorado (Brogan et al., 2015), while LiDAR and historical aerial photos have been used to reconstruct floodplain formations (Lallias-Tacon et al., 2017).

Although these techniques have been used worldwide, they have not been widely applied in multi-channeled floodplain wetland systems to help understand patterns of channel erosion and sedimentation. Therefore, the channel-dependent floodplain wetlands of the Macquarie Marshes were selected for this study, and cross-sections extracted from LiDAR-derived DEMs were used to calculate metrics and to assess channel changes over a 6 year period (2008-2014). A DoD analysis was also undertaken through the comparison of the repeated LiDAR-derived DEMs. The aim was to determine whether significant channel change could be detected, and if so, whether these changes signified hotspots of erosion and/or sedimentation that may be relevant for river and wetland management.

Study sites and methods

Study sites

The Macquarie Marshes are one of the largest semi-permanent inland floodplain wetlands in south-eastern Australia, spanning an area of >2,000 km^2 when in flood. The wetlands are located on the lower reaches of the Macquarie River in the Murray-Darling Basin, New South Wales, Australia (Fig. 1). Sediment erosion and deposition dynamics in the Macquarie Marshes lead to channel adjustment, channelization of wetlands, and avulsion, the relocation of channels from one part of the floodplain to another (Ralph et al., 2011, Ralph et al., 2016). The Macquarie Marshes have three core regions, the southern Macquarie Marshes, northern Macquarie Marshes and eastern Macquarie Marshes (Fig. 1C), and patterns of flow and flooding throughout the wetlands are variable and have changed over time (Thomas et al., 2011).

In the southern Macquarie Marshes, the trunk stream of the Macquarie River breaks down into a few major distributary channels including Oxley Break, Monkey Creek, Buckiinguy Creek, Monkeygar Creek and The Breakaway (Ralph and Hesse, 2010). Some of these distributaries break down again into smaller marsh channels and almost all discharge into significant wetlands, where, in many cases, return channels flow from the wetlands back into the trunk streams. Bulgeraga Creek is a major anabranch of the Macquarie River in this region and is also considered as a trunk stream. Nineteen key sites on ten major channels in the southern Macquarie Marshes were assessed in this study (Fig. 1D), all downstream of Marebone Weir. The hydrological record for the Macquarie River at Marebone Weir for the period of our study shows that drought conditions prevailed in 2008/09, before flood conditions occurred in 2010/11 and 2012/13 (Fig. 2).

Methods

Two LiDAR-derived DEMs acquired by the NSW Government Office of Environment and Heritage (OEH) in 2008 and 2014 were used for the morphometric analysis of the channels. The LiDAR-derived DEM data has

±15 cm vertical accuracy and ±45 cm horizontal accuracy. This translates to thresholds of change equivalent to 30 cm vertical and 90 cm horizontal when considering differences between cross-sections extracted from the DEMs. Channel cross-sections were extracted from the LiDAR-derived DEMs at 19 representative sites using ArcGIS. Analyses of the channel geometry including bankfull width, bankfull depth and width/depth ratio were undertaken using standard methods. Comparison of cross-section metrics from 2008 and 2014 were used to calculate changes in channel width and depth that occurred during the 6-year period.

A DoD was created by subtracting the LiDAR-derived elevations in 2014 from LiDAR-derived elevations in 2008 for the entire area covered by LiDAR data using the raster calculation tool in ArcMap 10.3. The potential vertical error for DoD values based on the two LiDAR acquisitions is up to ±30 cm vertical and 90 cm horizontal, and values less than these thresholds measured by DoD were categorized as no change.

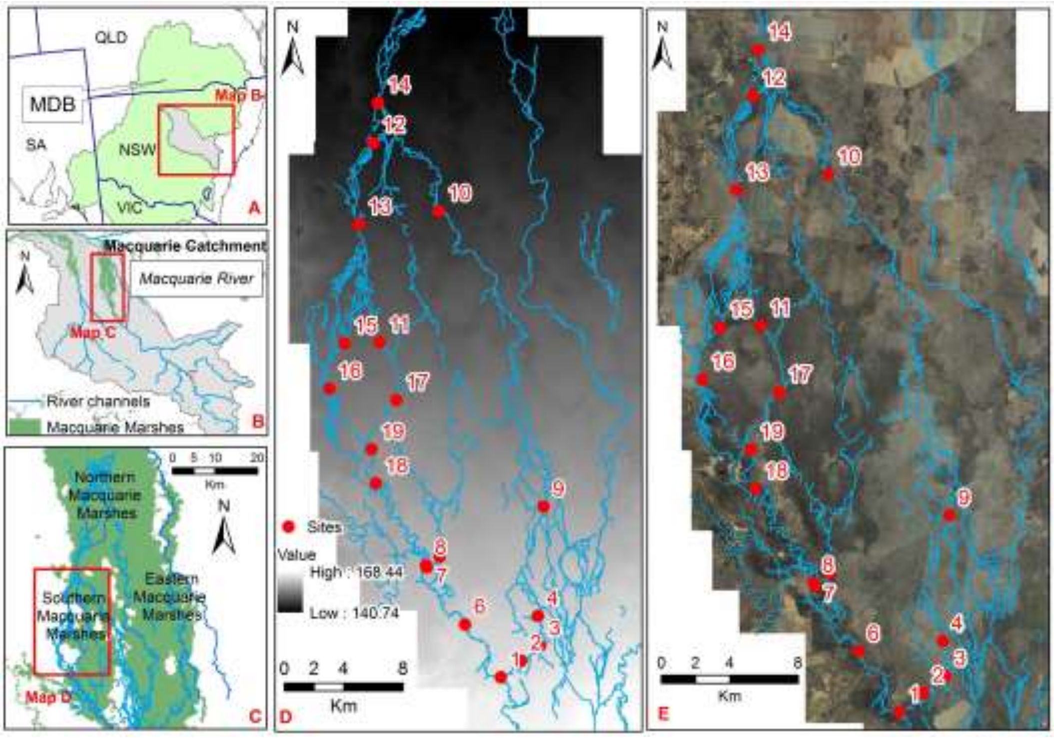

Fig. 1. Location of the Macquarie Marshes in the Murray-Darling Basin (A), in the Macquarie catchment (B), the southern Macquarie Marshes study area (C), nineteen study sites (D), and aerial imagery (E).

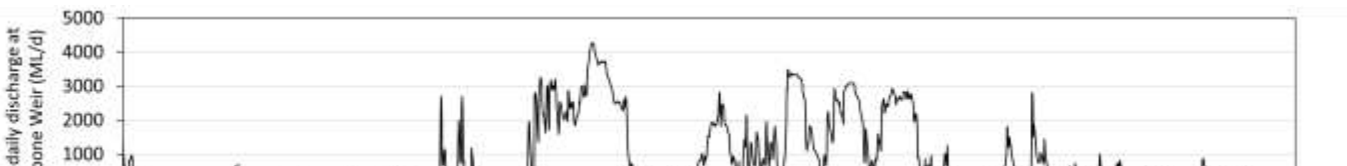

Fig. 2. Mean daily discharge entering the Macquarie Marshes (Marebone Weir) from 1/1/08 to 30/4/15.

Results and discussion

Cross-section morphology and change

Trunk streams in the study area (i.e. the Macquarie River, Bulgeraga Creek, Old Macquarie River) had channels with a mean width of ~39 m, mean depth of ~2 m and mean width/depth ratio (w/d) of ~21.

Distributary channels (i.e. upper and middle Oxley Break, Monkey Creek, Monkeygar Creek, Buckiinguy Creek) had a mean width of ~23.5 m, mean depth of ~2 m and mean w/d ratio of ~13. Return channels (i.e. Mole Marsh, Buckiinguy Return, lower Oxley Break) had a mean width of ~21 m, mean depth of ~1.6 m and a mean w/d ratio of 13.4 (Table 1). The channel width was therefore the main factor that could be used to differentiate channels in terms of their morphology.

Table 1. Common channel types and key metrics from the 2008 LiDAR-derived DEM.

Metrics from 2008 LiDAR-derived DEM	Trunk streams	Distributary channels	Return channels
Mean channel width (m)	38.9 *(4.4)*	23.5 *(2.5)*	21.2 *(1.9)*
Mean channel depth (m)	2.1 *(0.1)*	2.1 *(0.2)*	1.6 *(0.1)*
Mean width/depth ratio	20.7 *(2.6)*	12.9 *(2)*	13.4 *(1)*

Note: Values in parentheses represent standard error of the mean.

Three types of channel change were observed at the 19 sites between 2008 and 2014 (Table 2). The results showed an apparent contraction in channel width for just 5% of channels, possibly representing a dominance of sedimentation during the 6 year period. One reach of the trunk stream of Bulgerara Creek and the distributary channels of Monkey Creek and Buckiinguy Creek experienced channel contraction. Conversely, 17% of channels experienced channel expansion, including the trunk streams of the Macquarie River, Bulgeraga Creek and the Old Macquarie River, the major distributary channel Monkeygar Creek, and the return channel Buckiinguy Return, possibly due to erosion. However, the vast majority of sites (78%) had no detectable change during the 6 year period. This suggests that most of the channels in the southern Macquarie Marshes are either relatively stable over this short timeframe and/or that the methods used to detect change were not of sufficient resolution to detect fine-scale, subtle changes.

No channels exhibited measureable changes in depth using the LiDAR-derived DEM data. The results also show that depth measurements are unreliable when channels contain water, or when there is dense vegetation present in the channel or on the floodplain. For example, the cross-section extracted for site 9 shows a flat bottom which is due to water inside the channel, which is confirmed by imagery taken at the time of LiDAR acquisition (Figs. 3A and 3B). Therefore, the actual depth of the channel could not be measured at this site. At site 6, however, measurements were not affected by water, but by dense vegetation, again leading to poor channel detection (Figs. 3C and 3D).

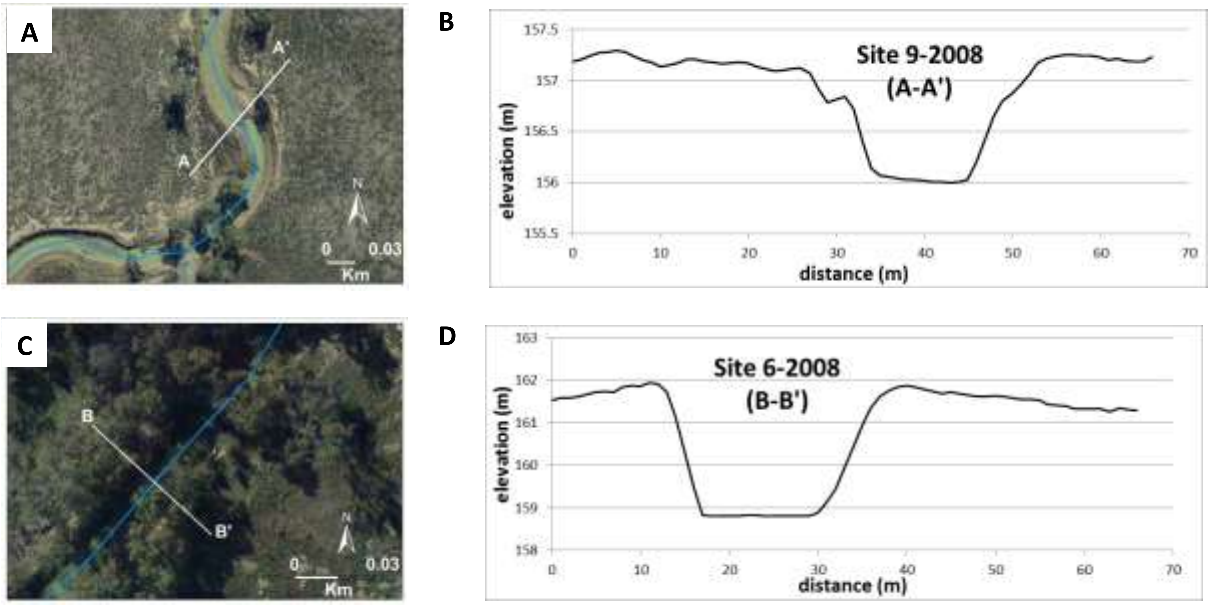

Fig 3. Imagery and cross-sections extracted from site 9 and site 6 showing the effects of water and vegetation on elevation data.

Table 2. Channel types and results of cross-section analysis from 2008 and 2014 LiDAR-derived DEMs.

Site number	Site name	Channel type	Cross section	Measured change in depth (m)	Change in depth >DEM threshold	Measured change in width (m)	Change in width >DEM threshold
1	Upper Oxley Break	Distributary	SMM001-1	0	-	0.08	-
			SMM001-2	0.001	-	0	-
			SMM001-3	0.031	-	-0.01	-
2	Middle Oxley Break	Distributary	SMM002-1	0.003	-	-0.12	-
			SMM002-2	-0.005	-	0.08	-
			SMM002-3	0	-	0	-
3	Lower Oxley Break	Return	SMM003-1	-0.001	-	0.01	-
			SMM003-2	0.008	-	0.14	-
			SMM003-3	-0.021	-	-0.68	-
4	Bulgeraga Creek downstream of Oxley Break	Trunk	SMM004-1	-0.006	-	-0.27	-
			SMM004-2	0.004	-	-0.86	-
			SMM004-3	-0.001	-	0.99	contraction
5	Monkey Creek	Distributary	SMM005-1	-0.001	-	1.49	contraction
			SMM005-2	0.003	-	0.06	-
			SMM005-3	0.016	-	1.03	contraction
6	Macquarie River downstream of Oxley Break and upstream of Monkey Creek	Trunk	SMM006-1	0.005	-	0	-
			SMM006-2	0	-	0.03	-
			SMM006-3	0.013	-	-0.13	-
7	Macquarie River downstream of Monkey Creek and upstream of Buckiinguy Creek	Trunk	SMM007-1	0.012	-	0.03	-
			SMM007-2	0.003	-	-0.04	-
			SMM007-3	0.012	-	-0.18	-
8	Buckiinguy Creek	Distributary	SMM008-1	-0.005	-	0	-
			SMM008-2	0	-	0.01	-
			SMM008-3	0.001	-	0.96	contraction
9	Bulgeraga Creek downstream of Oxley Break	Trunk	SMM009-1	-0.003	-	-1.15	expansion
			SMM009-2	-0.018	-	-0.86	-
			SMM009-3	0	-	-0.17	-
10	Bulgeraga Creek at Willancorah	Trunk	SMM010-1	0.005	-	0.18	-
			SMM010-2	-0.021	-	-1.05	expansion
			SMM010-3	-0.075	-	-4.02	expansion
11	The Breakaway	Distributary	SMM011-1	-0.006	-	-0.19	-
12	The Mole reed bed outflow channels	Return	SMM012-2	0.011	-	-0.04	-
			SMM012-3	-0.002	-	-0.04	-
13	Macquarie River at Maxwelton and the Mole	Trunk	SMM013-1	0	-	-0.79	-
			SMM013-2	-0.003	-	-0.07	-
			SMM013-3	-0.021	-	-0.65	-
14	Macquarie River at Pillicawarrina	Trunk	SMM014-1	-0.013	-	-1.95	expansion
			SMM014-2	0.003	-	0.04	-
			SMM014-3	-0.11	-	0.03	-
15	Old Macquarie River in Nature Reserve near Willie	Trunk	SMM015-1	-0.008	-	-0.85	-
			SMM015-2	0.001	-	-0.92	expansion
			SMM015-3	0.002	-	0.16	-
16	Old Macquarie River in Nature Reserve	Trunk	SMM016-1	0.006	-	0.04	-
			SMM016-2	0.014	-	-0.38	-
			SMM016-3	-0.007	-	-0.20	-
17	Monkeygar Creek upstream of The Breakaway	Distributary	SMM017-1	0	-	-0.05	-
			SMM017-2	0.012	-	-0.02	-
			SMM017-3	-0.003	-	-1.35	expansion
18	Buckiinguy Return and Buckiinguy Runner	Return	SMM018-1	0	-	-0.01	-
			SMM018-2	0.001	-	0.02	-
			SMM018-3	-0.006	-	-1.03	expansion
19	Macquarie River downstream of Monkey Creek and downstream of Buckiinguy Creek	Trunk	SMM019-1	-0.011	-	0.07	-
			SMM019-2	-0.083	-	-1.04	expansion
			SMM019-3	0.014	-	0.07	-

Note: '-' denotes no change.

DEM of Difference

The results of the DoD analysis for the whole Macquarie Marshes LiDAR acquisition area showed that the DoD could not accurately identify increases or decreases in elevation due to erosion or sedimentation because of the low resolution and detection limits of the data, in particular, where water or dense vegetation was present in either LiDAR acquisition. While reliable data was attainable in an ideal location (i.e. along a road that had not changed between 2008 and 2014; Fig. 4A), channels and wetlands with dense vegetation gave misleading results (Fig. 4B), as did areas with inundation at the time of acquisition (Fig. 4C).

A **B** **C**

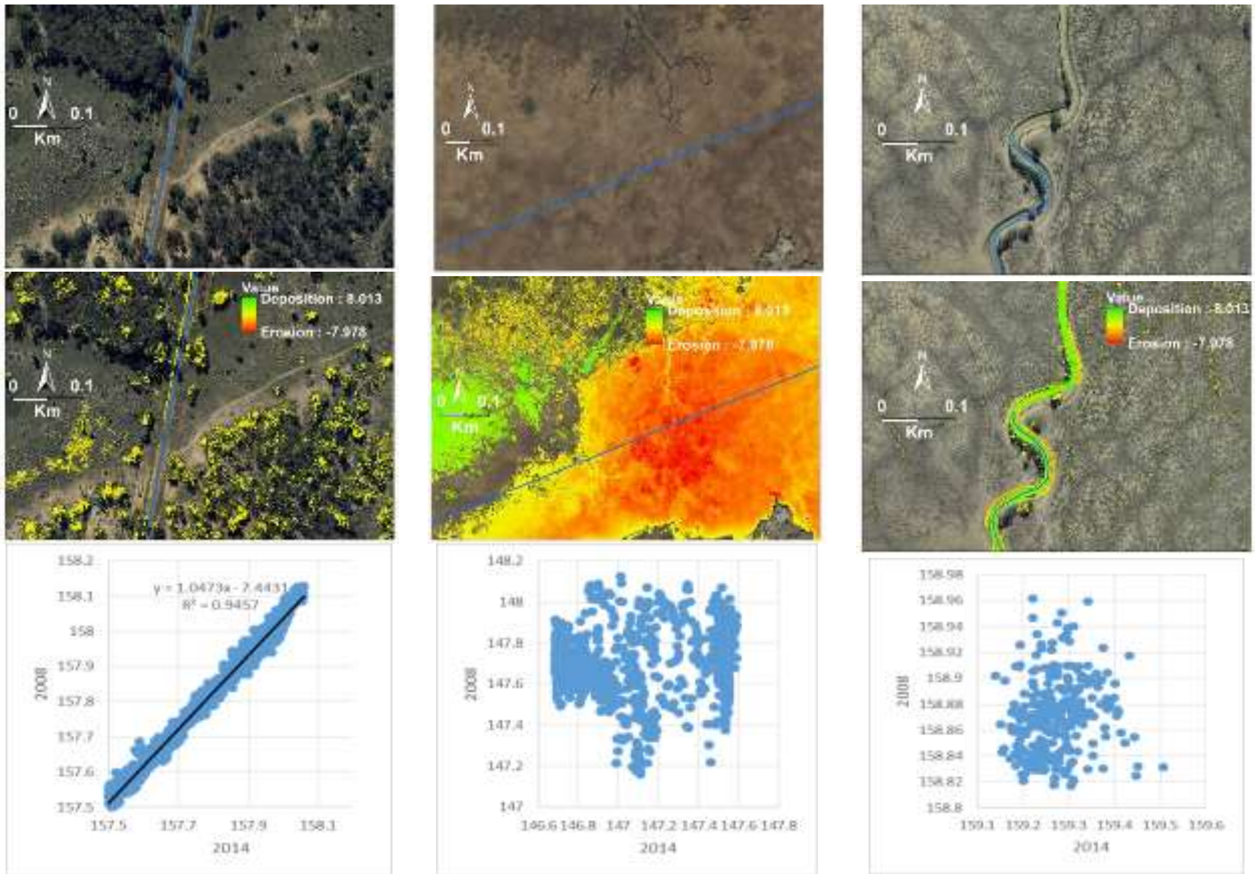

Fig.4. DoD results for a road (A), a densely vegetated area of wetland (B), and a channel with water (C).

Interpretations

In the six year period channel change in the Southern Macquarie Marshes was observed as minor adjustments in depth and width. The pattern of the channels in the southern Macquarie Marshes represents the dominant of the trunk stream channels in this area, where tributary and distributary junctions joined them. Regards the type of the channel, they could be eroded or deposited. Trunk stream channels and tributary channels which provide the majority of flow and incoming discharge exhibit channel erosion and expansion. Despite the findings of some eroded channels, distributary channels are more likely to exhibit deposition as the flow decreases because of channel branching. These results confirm a direct relation between flow and sediment transportation, increased flow leading channels towards higher risk of erosion.

LiDAR-derived DEMs could not provide precise data on floodplain and channel changes because of the limitation of the threshold accuracy. Based on this restriction the data suggest mostly unchanged cross-sections for the majority of sites.

Conclusions

Nineteen sites located in the southern Macquarie Marshes were studied to assess channel change in a six year period between 2008 and 2014. Although previous research has shown that channels in this system are highly dynamic (Ralph et al., 2016), results from two LiDAR-derived DEM surveys showed that the majority of channels did not change and of the changes that did occur, most suggested channel expansion. While LiDAR is a useful and important tool for understanding fluvial geomorphology and for measuring the size and shape of channels and other landforms, short-term repeated LiDAR acquisition and channel cross-section analysis yielded results that were not highly resolved, and in most cases potential changes in channel width and depth did not exceed the limits of detection. The DoD analysis was inconclusive during this short-term analysis of channel change likely due to the low-gradient nature of this environment. Further detailed research is required to apply high resolution LiDAR-derived DEMs in the Macquarie Marshes, and to test their validity for change detection over longer timescales.

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