Comparison of hydrologic dynamics in forested and agricultural sub-watersheds of a large mixed-use Prairie watershed

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1. RESEARCH OBJECTIVE AND STUDY SITE

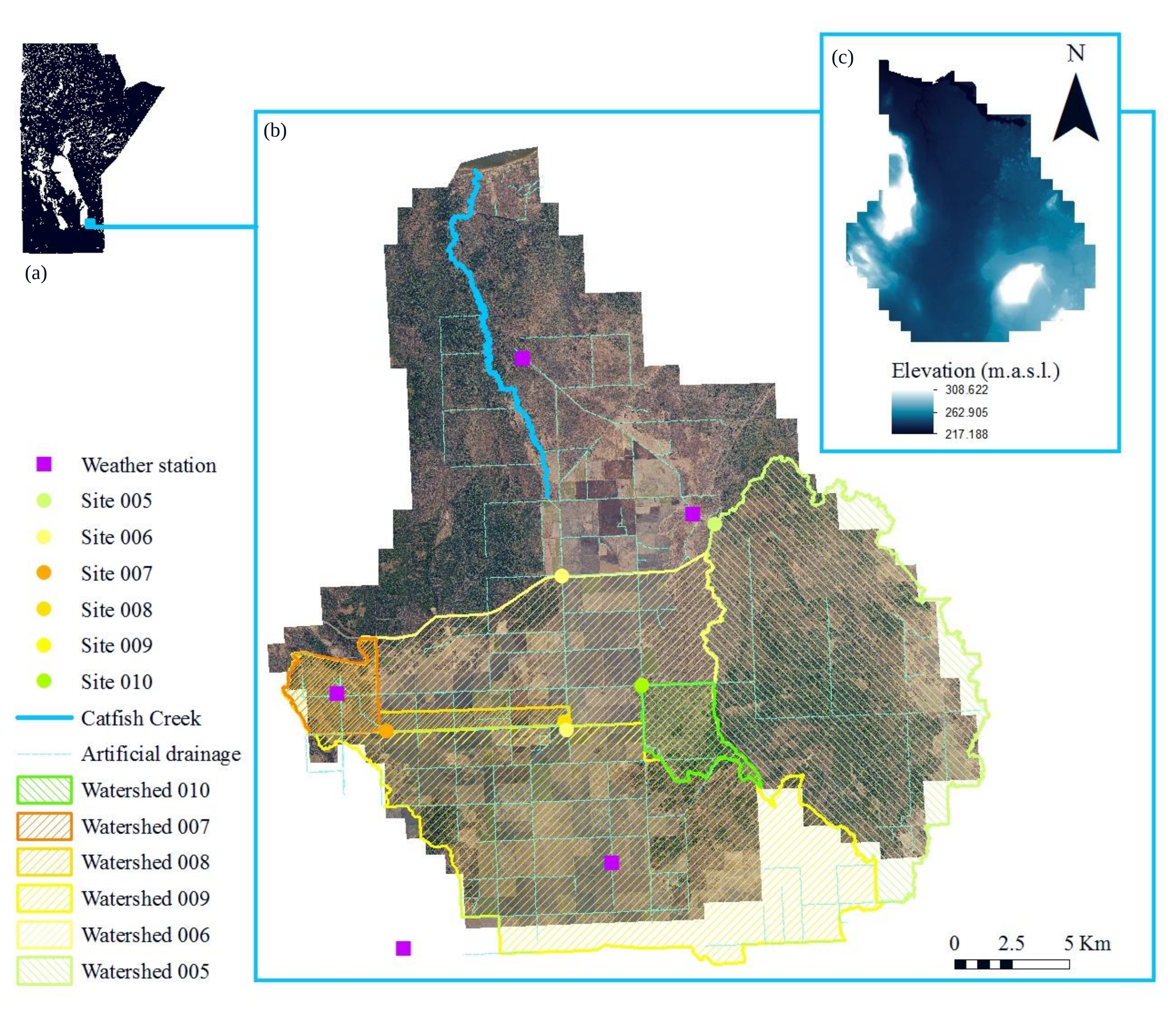
The natural history of the Prairies includes the large-scale human modification of landscape biology and hydrology from first settlement to present. Forested land has been and continues to be lost and runoff is increasingly artificially drained in this intensively managed region. The impact of such modifications on hydrological dynamics has yet to be understood in such a way that measurable landscape alterations (*i.e.*, area of forest lost, hydraulic capacity of artificial surface drains) can be linked to quantifiable alterations in event storm hydrographs or hydrological regimes. **Here we focused on a large mixed-used watershed to compare the temporal hydrological dynamics of forested sub-watersheds to those of neighbouring, deforested agricultural sub-watersheds within a similar geologic and pedologic setting.**

The Catfish Creek Watershed (CCW) drains a 600 km^2 area located approximately 90 km north-east of Winnipeg (Manitoba, Canada; see Fig. 1a) and has been extensively impacted by human activities including the continued clearing of forested land for cultivation. It is characterized as a low-relief, agro-forested watershed (~45% forest, ~40% crops, ~10% swamp, ~5% other, see Fig. 1b). Surface runoff is managed in part by a network of artificial drains in both the forested and cultivated portions of this watershed. The lower CCW is naturally-vegetated by parkland forest and swamp. The eastern edge of the upper watershed is also forested and of greater relative relief, while to the west the landscape is dominated by intensive, large-scale agricultural operations on a near-level landscape.

2. METHODS

Detailed topographic and landscape information was collected in a 1 m LiDAR and orthoimagery survey captured in spring 2012 (Fig. 1b and c). Through the spring of 2013, the CCW was instrumented with a network of 13 capacitance surface water level recorders (15-minute frequency, Fig. 2a,b) and 5 weather stations (1-minute frequency; Fig. 2c) to monitor the rainfall-runoff dynamics (see Fig. 3 for examples of a hydrograph and a hyetograph). Of the 13 gauging stations, 6 were identified as having upstream contributing areas classified as either agricultural (4 sites) or forested (2 sites) using spatial analysis tools and orthoimagery (i.e., >75% of watershed area is agricultural or forested; see Fig. 1b and Table 1). To isolate for the impacts of these land cover types on runoff behaviour, only these 6 watersheds dominated by a single land use were considered.

Rainfall events recorded in the CCW, and their associated runoff events at these 6 gauging stations, were manually identified and isolated for analysis for the period of 01 April 2013 to 01 September 2013. The timing of hydrograph response to these events was compared among the 6 sites. Specifically, the timing of the beginning and end of all rainfall events was determined; as well as the timing of and water depth at the beginning, peak and end of all runoff events. From these, 5 event parameters (Fig. 3) were calculated for every event at each site: (1) runoff event duration, (2) lag time from beginning of rainfall to initial hydrograph rise (hereafter referred to as lag to rise), (3) lag time from beginning of rainfall to hydrograph peak (hereafter referred to as lag to peak), and (4) time of concentration and (5) the difference of water depth at event runoff peak and immediately preceding the runoff event (divided by upstream contributing area to allow for inter-site comparison; hereafter referred to as maximum rise). Two statistical tests were used to compare event characteristics among sites. Firstly, all events characteristics associated with forested sub-watersheds were lumped into a single group while the events characteristics associated with agricultural sub-watersheds were lumped in another: the Kruskal-Wallis test was used to assess whether the two groups differed with statistical significance. Secondly, the Wilcoxon rank-sum test was used to consider site-to-site differences. In both cases, the null hypothesis (H_0) was that the event parameters came from the same statistical population.



▲ FIGURE 1: (a) Location of the CCW in Manitoba, Canada; (b) orthoimage of the CCW with gauging stations and extent of upstream contributing areas indicated; and (c) LiDAR image of the CCW

▼ TABLE 3: Summaries of site-by-site comparisons for each of the 5 events parameters (i.e. null hypothesis not rejected (H_0) versus rejected (H_1) at the 0.05 statistical significance level)

▨ → forested sub-watershed ▨ → agricultural sub-watershed

Table 3a:: Time of concentration - Wilcoxon rank sum test

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	H_1		H_0	H_0	H_0
Site 06	-	-	H_0	H_0	H_0	H_0
Site 07	-	-	-	H_0	H_0	H_0
Site 08	-	-	-	-	H_0	H_0
Site 09	-	-	-	-	-	H_0

Summary:		Percent of total possible combinations	
Accepted:	93.3%	Agriculture-to-forested:	87.5%
		Agriculture-to-agriculture, forested-to-forested:	100.0%
Rejected:	6.7%	Agriculture-to-forested	12.5%
		Agriculture-to-agriculture, forested-to-forested:	0.0%

Table 3b: Lag to rise - Wilcoxon rank sum test

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	H_0	H_0	H_0	H_0	H_0
Site 06	-	-	H_0	H_0	H_0	H_0
Site 07	-	-	-	H_0	H_0	H_0
Site 08	-	-	-	-	H_0	H_0
Site 09	-	-	-	-	-	H_0

Summary:		Percent of total possible combinations	
Accepted:	100.0 %	Agriculture-to-forested:	100.0%
		Agriculture-to-agriculture, forested-to-forested:	100.0%
Rejected:	0.0%	Agriculture-to-forested:	0.0%
		Agriculture-to-agriculture, forested-to-forested:	0.0%

Table 3c: Lag to peak - Wilcoxon rank sum test

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	H_1	H_0	H_0	H_0	H_0
Site 06	-	-	H_0	H_1	H_0	H_1
Site 07	-	-	-	H_0	H_0	H_0
Site 08	-	-	-	-	H_0	H_0
Site 09	-	-	-	-	-	H_0

Summary:		Percent of total possible combinations	
Accepted:	80.0%	Agriculture-to-forested:	75.0%
		Agriculture-to-agriculture, forested-to-forested:	85.7%
Rejected:	20.0%	Agriculture-to-forested:	25.0%
		Agriculture-to-agriculture, forested-to-forested:	14.3%

Table 3d: Runoff event duration - Wilcoxon rank sum test

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	H_1	H_0	H_0	H_0	H_0
Site 06	-	-	H_0	H_0	H_0	H_1
Site 07	-	-	-	H_0	H_0	H_0
Site 08	-	-	-	-	H_0	H_0
Site 09	-	-	-	-	-	H_0

Summary:		Percent of total possible combinations	
Accepted:	86.7%	Agriculture-to-forested:	75.0%
		Agriculture-to-agriculture, forested-to-forested:	100.0%
Rejected:	13.3%	Agriculture-to-forested:	25.0%
		Agriculture-to-agriculture, forested-to-forested:	0.0%

Table 3e: Maximum rise - Wilcoxon rank sum test

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	H_1	H_1	H_1	H_1	H_1
Site 06	-	-	H_1	H_1	H_1	H_1
Site 07	-	-	-	H_0	H_0	H_1
Site 08	-	-	-	-	H_1	H_1
Site 09		-	-	-	-	H_1

Summary:		Percent of total possible combinations	
Accepted:	13.3%	Agriculture-to-forested:	0.0%
		Agriculture-to-agriculture, forested-to-forested:	28.6%
Rejected:	86.7%	Agriculture-to-forested:	100.0%
		Agriculture-to-agriculture, forested-to-forested:	71.4%

Table 3f: Summary of all tests by site, null hypothesis rejected (%)

	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10
Site 05	-	80%	20%	20%	20%	20%
Site 06	-	-	20%	40%	20%	60%
Site 07	-	-	-	0%	0%	20%
Site 08	-	-	-	-	20%	20%
Site 09	-	-	-	-	-	20%

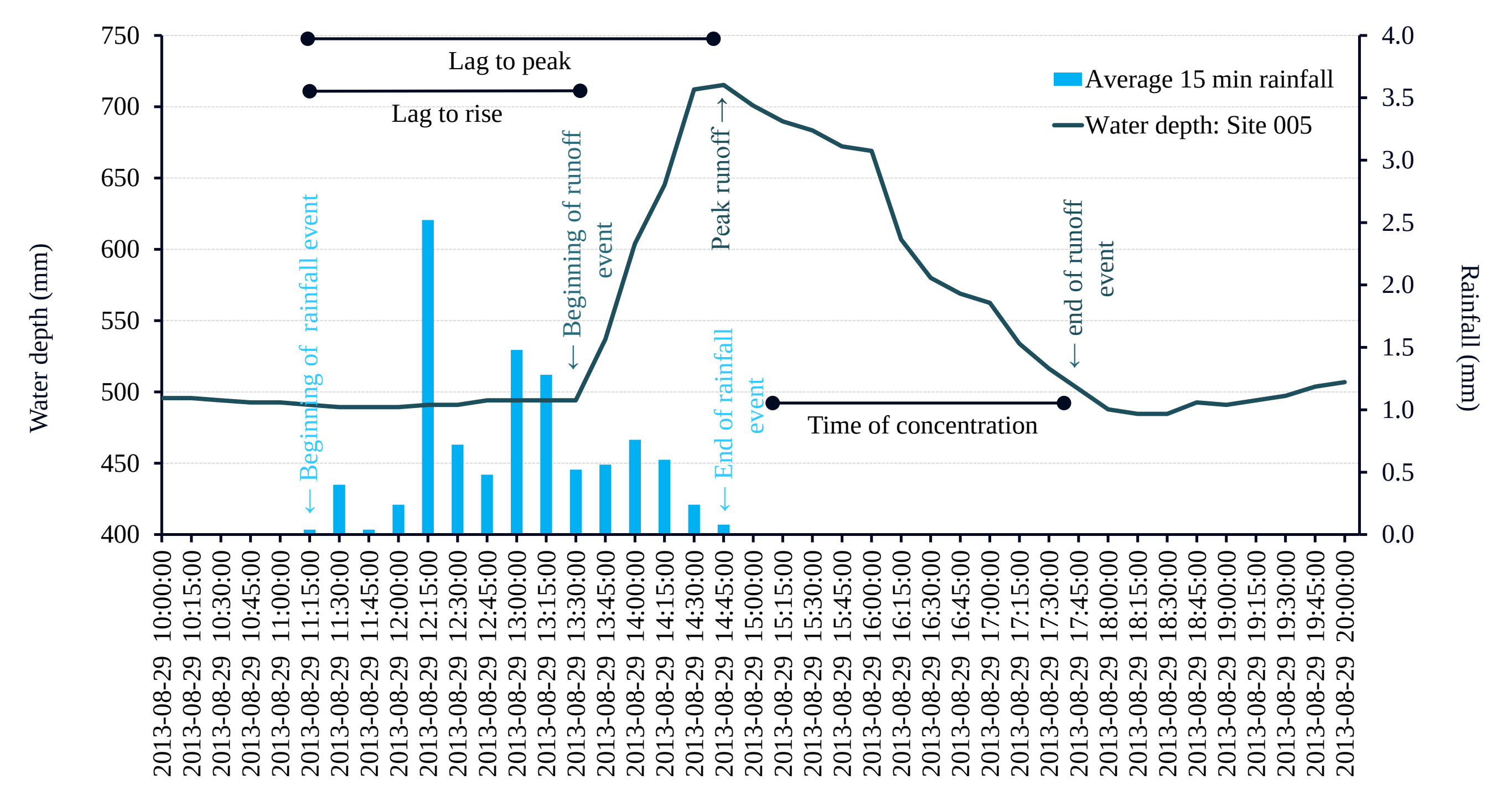
Total summary:		Percent of total possible combinations	
Accepted:	74.7%	Agriculture-to-forested:	67.5%
		Agriculture-to-agriculture, forested-to-forested:	82.9%
Rejected:	25.3%	Agriculture-to-forested:	32.5%
		Agriculture-to-agriculture, forested-to-forested:	17.1%

3. RESULTS AND DISCUSSION

In total, 65 rainfall events were defined from 01 April 2013 to 01 September 2013 in the CCW. These events range in duration from the 15 minutes to 14 hours. Not every rainfall event resulted in a runoff event at each gauging station.

"Regardless of the event parameter considered (i.e., runoff event duration, lag to rise, lag to peak, time of concentration or maximum rise), the Kruskal-Wallis tests revealed that differences between forested sub-watersheds and agricultural sub-watersheds were not statistically significant (null hypothesis not rejected; see Table 2 for results summary). However, when site-to-site comparisons were done using the Wilcoxon rank-sum test, some statistically significant differences in event parameters emerged between sites (Tables 3a-1f). When considered parameter by parameter, a full spectrum of results is apparent. For example, lag to rise is not found to significantly differ for any combination of sites while maximum rise differs significantly for almost every combination of sites. The number of site-to-site statistically significant differences vary depending on the event characteristic considered: differences are found only for 1 site-to-site pair for the time of concentration, but 2 site-to-site pairs for the runoff event duration, and 3 site-to-site pairs for the to lag to peak. The majority of the site-to-site differences are found in agricultural to forested comparisons (rather than in agricultural to agricultural or forested to forested comparisons). However, there was no strong, over-arching pattern of rejection of the null hypothesis in forested-to-agricultural site comparisons (or systematic acceptance of the alternate hypothesis when sites of the same landscape category were compared), thus indicating the temporal runoff characteristics and peak runoff depth are not dominantly controlled by land use/land cover.

While many studies have considered the long-term impacts of deforestation on runoff magnitude, few have considered the impacts of deforestation on the temporal characteristics of the storm hydrograph (Brown et al., 2013). The results presented here, i.e., forested and agricultural Prairie watersheds demonstrate similar temporal hydrograph characteristics, contradict previous findings that agricultural watersheds generally have shorter lag times (Jones & Grant, 1996; Lana-Renault et al., 2011; Sriwongsitanon & Taesombat, 2011).



▲ FIGURE 3: Example storm hydrograph and hyetograph from Site 005, 10:00 29 August 2013 to 20:00 29 August 2013. The five event parameters calculated for this study are indicated.

▼ TABLE 1: Drainage area and land cover type of study watersheds

	Site 005	Site 006	Site 007	Site 008	Site 009	Site 010
Total area (km^2)	145.32	264.36	12.51	19.44	158.9	13.12
Forested area (%)	99.95%	19.14	23.98%	15.53%	20.41%	100%
Agricultural area (%)	0.05%	80.86%	76.02%	84.47%	79.59%	0%

▼ TABLE 2: *p*-statistic results of the Kruskal-Wallis tests

	Runoff event duration	Lag to rise	Lag to peak	Time of concentration	Maximum rise
Forested sites to agricultural sites	0.1649	0.9478	0.3545	0.3545	0.9789

▲ FIGURE 2: (a) stilling well at Site 006; (b) Odyssey capacitance water level logger; and (c) HOBO U30 weather station;

4. CONCLUSIONS

Overall, the few differences in temporal runoff event characteristics found between our studied sub-watersheds cannot be attributed to land cover differences (forested versus agricultural) alone. This is contrary to previous findings that forests buffer or delay runoff response (Jones & Grant, 1996; Sriwongsitanon & Taesomabt, 2011); however, previous studies were carried out on naturally drained landscapes of greater relief. This suggests that near-level topography, engineered surface drainage, or the combination of the two, plays a more dominant role in runoff generation than agricultural or forest land cover. As few studies have considered the impact of deforestation on the event hydrograph, and even fewer have considered the impact of deforestation specifically on the temporal aspects of the event hydrograph, this topic warrants further future consideration in research, especially in the generally under-studied context of Prairie hydrology.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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