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Effects of Land Cover on Streamflow Variability in a Small Iowa Watershed: Assessing Future Vulnerabilities

[1]Keith Schilling, [1]Matthew Streeter, [2]Kasey Hutchinson,
[3]Christopher Wilson, [3]Ben Abban, [4]Kenneth Wacha and [3]Athanasios Papanicolaou

[1]*Iowa Geological Survey, University of Iowa, Iowa City, IA, United States*
[2]*Department of Public Works, City of Cedar Rapids, Iowa, United States*
[3]*Department of Civil and Environmental Engineering,*
Hydraulics and Sedimentation Laboratory, University of Tennessee, Knoxville, TN, United States
[4]*Department of Civil and Environmental Engineering, University of Iowa, Iowa City, IA, United States*

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Corresponding Author:
Keith Schilling
Iowa Geological Survey,
University of Iowa, Iowa City,
United States
Email: keith-schilling@uiowa.edu

Abstract: Agricultural expansion and urbanization, coupled with climate change represent major threats to the sustainability of river ecosystems and infrastructure. In this study, we evaluated how subbasins with different dominant land covers within the 27.5 km^2 Clear Creek, IA watershed affect key hydrologic indicators. Hydrologic output from two stream gages and a calibrated Soil Water Assessment Tool (SWAT) model were used as input to the Indicators of Hydrologic Alteration (IHA). Study results indicated that land cover plays a dominant role in controlling hydrologic variability at the subbasin level within a watershed. Subbasins dominated by urban development had nearly 30 more reversals than row crop or grass-dominated subbasins and the duration of small and large flood events were half as long. Row crop dominated subbasins had greater water yield and maximum flows and higher peak flows, whereas grass-dominated subbasins had lower rise and fall rates, fewer zero days and fewer reversals. Hydrologic variations from land cover differences were more prominently expressed at the subbasin level than at the watershed level, as the dominant land cover represented a greater percentage of the total land area. Study results suggest that future changes in LU/LC and climate will have significant effects on the hydrology of Clear Creek Watershed.

Keywords: LU/LC Change, SWAT, Indicators of Hydrologic Alteration, Urbanization, Row Crop

Introduction

Land Use/Land Cover (LU/LC) change, including both agricultural expansion and urbanization, coupled with climate change as seen through increased fluctuations between extreme events represent two major threats to the sustainability of river ecosystems and the incorporated infrastructure (Jeong *et al*., 2014; Pradhanang *et al*., 2013; Schilling *et al*., 2013). In agricultural regions, increased grazing pressure and expansion of cultivation have led to soil compaction, reduced infiltration and increased runoff (Fohrer *et al*., 2001; Hess *et al*., 2010; Holman *et al*., 2003; McIntyre and Marshall, 2010; Moussa *et al*., 2002; Papanicolaou *et al*., 2015; Tollan, 2002). It has been well documented in the literature that farm activities like tillage and the subsequently enhanced erosion, in addition to rainfall/runoff-induced erosion, not only affect the composition of surface soils but also their structure, such as the porous network and degree of compaction, thereby collectively affecting the spatial distribution of infiltration and saturated hydraulic conductivity within a field (Abaci and Papanicolaou, 2009; Papanicolaou *et al*., 2015). Additionally, urbanization leads to increased frequency of higher magnitude flows and flashier hydrographs as the proportion of impervious cover increases cutting off infiltration of rainfall into the soil (Hamel *et al*., 2013; Mejıa *et al*., 2014; Poff *et al*., 2006; Schoonover *et al*., 2006). Hydrologic alteration becomes noticeable when impervious cover exceeds 10% in the drainage area (Booth and Jackson, 1997; Wang *et al*., 2001). Further, urbanization affects low flows in streams as less water infiltrates into the soil and groundwater recharge is reduced beneath areas of impervious cover (Jeong *et al.*, 2014). Compounding the risks from LU/LC change, the increased variability in climate is predicted to have major impacts on streamflow patterns as extreme events are likely to occur more frequently (IPCC, 2007; Kim *et al.*, 2011; Markstrom *et al.*, 2011; Wilson *et al.*, 2012).

Evaluating the effects of anthropogenic change and climate variability on streamflow patterns is often conducted using measured data, watershed models (e.g., (Abaci and Papanicolaou, 2009; Gassman *et al.*, 2007) or hydrologic indicators (e.g., (Olden and Poff, 2003; Papanicolaou *et al.*, 2003). O'Connell *et al.* (2007) identified more than 100 rainfall-runoff models being used worldwide to evaluate watershed-scale effects of land management practices on streamflow. One such model used in watershed scale studies is the Soil and Water Assessment Tool (SWAT) (Arnold *et al.*, 1998; Gassman *et al.*, 2007; Neitsch *et al.*, 2004; 2005). SWAT has been used extensively to evaluate the effects of land use change on discharge and water quality (Babel *et al.*, 2011; Bharati and Jayakody, 2011; Jha *et al.*, 2010; Nie *et al.*, 2011; Palamuleni *et al.*, 2011; Schilling *et al.*, 2008; Wang *et al.*, 2012). Recently, Schilling *et al.* (2013) utilized SWAT to assess changes in flood risks from agricultural land use change in a large Iowa watershed. Large-scale models like SWAT perform channel routing, which allows for assessing the roles of specific sub-watersheds as major contributors to downstream flooding, as well as the downstream effect of any changes implemented in these critical sub-watersheds.

Hydrologic indicators, such as the seasonal patterns of flows, frequency, timing and duration of floods and rates of streamflow change, have been identified as critical factors affecting the ecological and hydrological functions of the streams and surrounding watersheds (Poff *et al.*, 1997; Pradhanang *et al.*, 2013). The Indicators of Hydrologic Alteration (IHA) tool (Richter *et al.*, 1996) incorporates many of the pertinent indicators for anthropogenically altered watersheds and has been widely used to examine flow alterations from in-stream perturbations such as dams (Mittal *et al.*, 2014; Richter *et al.*, 1996), as well as the combined effects of land use and climate change (Jeong *et al.*, 2014; Kim *et al.*, 2011; Pradhanang *et al.*, 2013). The IHA tool was developed by The Nature Conservancy in the 1990s to facilitate the evaluation of anthropogenic alterations to streamflow (Mathews and Richter, 2007) by quickly processing large quantities of daily hydrologic records to quantify the observed hydrologic variation (Richter *et al.*, 1998).

The objective of our study was to evaluate the effects of LU/LC change on streamflow in a small Iowa watershed, namely the Clear Creek, IA watershed, by inputting hydrologic output from SWAT into IHA to characterize hydrologic variability at the subbasin scale. Clear Creek is an intensively managed landscape and, like many areas of the U.S. Midwest, is facing expansion of row crop due to increased food and biofuels demand (Schilling *et al.*, 2010), as well as rapid urbanization in the areas bordering agricultural fields and grasslands. In this study, we assess how subbasins with different dominant land covers within the Clear Creek watershed affect key hydrologic indicators and identify future vulnerabilities to stream health and infrastructure as LU/LC and climate changes are projected to occur.

Materials and Methods

Study Site

The 27,520 hectare (68,000 acre) Clear Creek watershed is located in portions of Iowa and Johnson counties in east-central Iowa (Fig. 1). Clear Creek is representative of many U.S. Midwestern watersheds regarding land use (mixed urban-agricultural) and climate (humid-continental). Clear Creek has key hydrological and soil data (e.g., (Abaci and Papanicolaou, 2009; Papanicolaou *et al.*, 2015; Wilson *et al.*, 2012) available through its inclusion in the U.S. National Science Foundation's Intensively Managed Landscapes Critical Zone Observatory (IML-CZO).

Clear Creek is located in the Southern Iowa Drift Plain landform region of Iowa and is characterized by steeply rolling hills and a well-developed drainage network (Prior, 1991). Most of the soils are silty clay loams, silt loams or clay loams formed in loess and/or pre-Illinoisan glacial till. Soil orders include primarily Alfisols and Mollisols. The area has an average annual precipitation of approximately 890 mm, with the most rainfall connected to convective thunderstorms in May and June. The majority of streamflow occurs during spring and summer, with peak monthly streamflow following the rainfall patterns. Two United States Geological Survey (USGS) stream gages are located in the Clear Creek watershed at Oxford and near the watershed outlet in Coralville (Fig. 1). At the outlet, average water discharge is 2.05 m^3/s (daily or 64.6×10^6 m^3/yr) (Abaci and Papanicolaou, 2009).

Pre-settlement land cover in Clear Creek watershed consisted largely of tallgrass prairies and savannas but beginning in the mid-1800's, the landscape was rapidly transformed by Euro-American settlement to agriculture, pasture and homesteads (Rayburn and Schulte, 2009). As of 2002, the land cover in Clear Creek watershed predominantly consisted of cropland (61.6%), grass and pastures (20.1%), forest (10.8%) and urban or suburban development (7.6%) (Rayburn and Schulte, 2009). The headwaters contain the majority of the row crop agriculture in the watershed. Grassed and wooded areas become more abundant near the center of the watershed. A county park (Kent Park) that includes native habitat restoration is located in this part of the watershed. In the lower parts of Clear Creek, near the mouth, the municipalities of Coralville, Iowa City and North Liberty are partially contained within the eastern half of the watershed and these urban areas are expanding (Fig. 2). Rayburn and Schulte (2009) reported that the period of greatest change in urban cover was from 1980 to 2002 (+947 ha), with a similar rate of increase from 2002 to 2009 (Fig. 2).

SWAT Model

SWAT is a hydrologic and water quality model developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) (Arnold and Fohrer, 2005; Arnold *et al*., 1998; Gassman *et al*., 2005). It is a long-term, continuous, watershed-scale simulation model that operates on a daily time step and is designed to assess the impact of land use and different land management practices on water, nutrient and bacteria yields. The model is physically based and includes major components of weather, hydrology, soil temperature, crop growth, nutrients, bacteria and land management.

Basic data input required for the subbasins in the SWAT model include weather, topography, land use, soil and management data. Climate data for the model (including temperature, precipitation, solar radiation, wind speed, relative humidity) were obtained from the National Weather Service via the Iowa Environmental Mesonet (ISU, 2013) for two COOP stations located in the watershed at Marengo and Williamsburg. The baseline land use for the Clear Creek model was derived from the 2006 National Land Cover Dataset (NLCD) grid. Soil data obtained from the Soil Survey Geographic database (SSURGO) (WSS, 2013) were used to characterize soil properties in the watershed. Land use in the SWAT subbasins varied considerably with dominant land use fractions consisting of either row crop, grass or urban covers (Table 1).

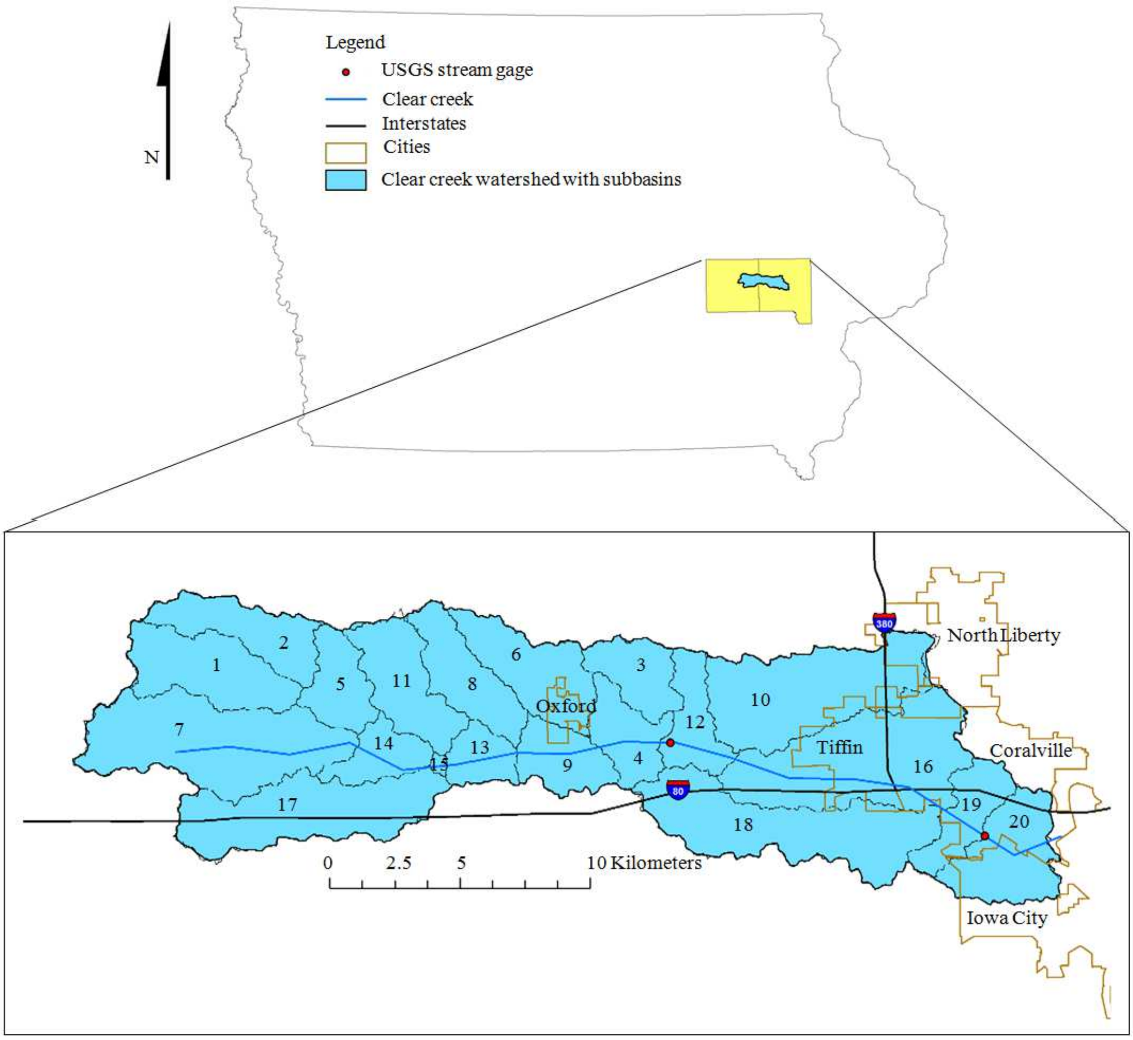

Fig. 1. Location of clear creek watershed in east-central Iowa

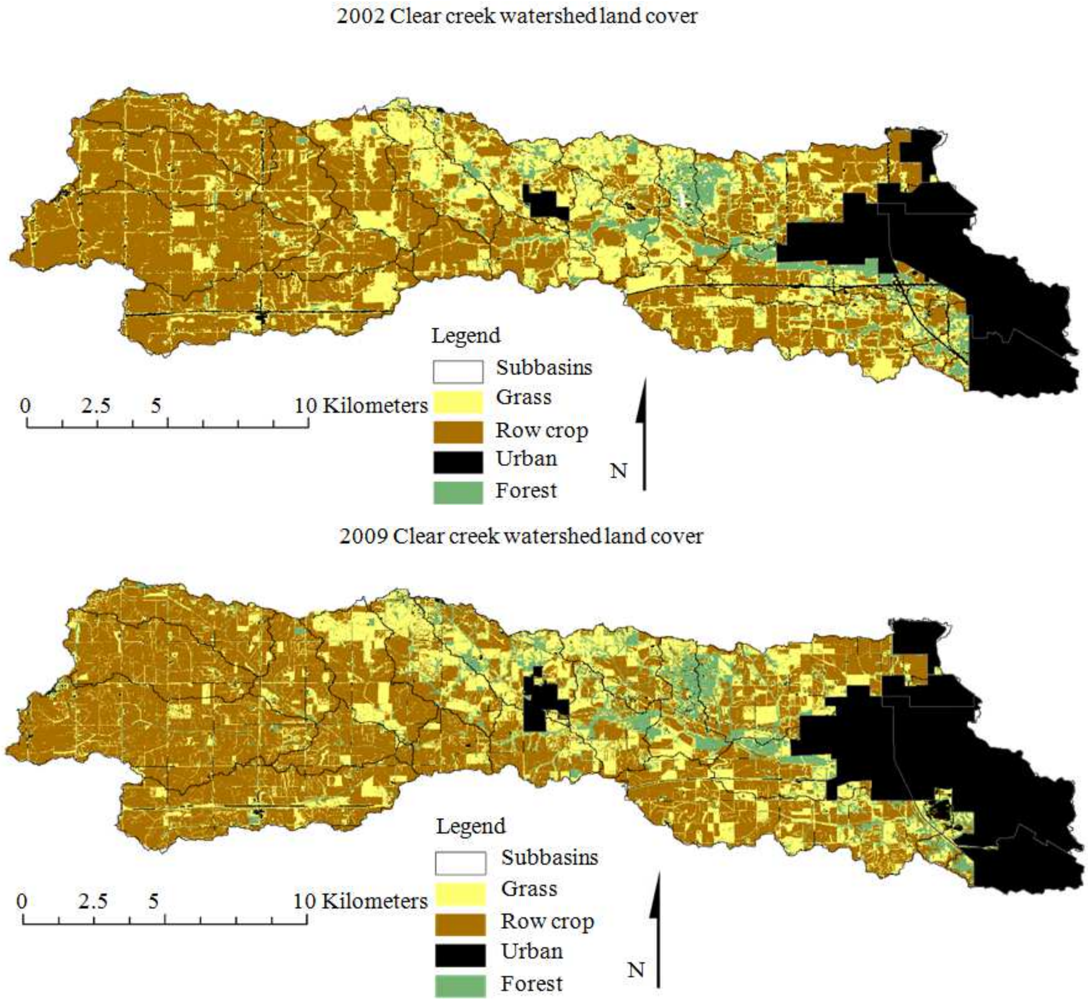

Fig. 2. Changes in LU/LC from 2002 to 2009 (land cover data from IDNR, 2013)

Table 1. Land cover fraction by subbasin area in clear creek watershed (shaded values denote dominant classification)

Subbasin	Row crop	Grass	Woods	Urban
1	0.82	0.1	0	0.08
2	0.79	0.12	0.01	0.07
3	0.26	0.55	0.09	0.10
4	0.30	0.48	0.14	0.08
5	0.72	0.19	0.02	0.07
6	0.19	0.57	0.07	0.17
7	0.86	0.07	0.00	0.07
8	0.31	0.56	0.05	0.08
9	0.54	0.34	0.05	0.07
10	0.46	0.35	0.10	0.09
11	0.56	0.36	0.01	0.07
12	0.19	0.47	0.29	0.05
13	0.79	0.14	0.01	0.07
14	0.82	0.10	0.01	0.08
15	0.80	0.15	0.01	0.04
16	0.32	0.29	0.15	0.24
17	0.68	0.18	0.00	0.14
18	0.51	0.36	0.04	0.09
19	0.07	0.20	0.23	0.50
20	0.03	0.13	0.19	0.65

A total of 20 subbasins and 1,786 Hydrologic Response Units (HRUs) were created for the Clear Creek watershed SWAT simulations (Fig. 1). One subbasin (no. 15) that encompassed a small area of the floodplain corridor was not included in the subbasin analysis. We utilized the SWAT daily hydrologic output from 19 subbasins for input into the IHA program.

The Clear Creek SWAT model was executed for a total simulation period of 13 years (2000-2012). Calibration was achieved by adjusting several hydrologic parameters, including the curve number, soil available water capacity, evaporation compensation coefficient and groundwater delay within their acceptable ranges (e.g., (Elhakeem and Papanicolaou, 2009; Schilling and Wolter, 2009). Model calibration was evaluated using the coefficient of determination (r^2) and the Nash-Sutcliffe coefficient (ENS), which are described by Krause *et al*. (2005) and are the most common statistics used to evaluate SWAT simulations (Douglas-Mankin *et al*., 2010; Gassman *et al*., 2007; Tuppad *et al*., 2011; Gassman *et al*., 2014). Moriasi *et al*.

(2007) present criteria for several different statistics and they propose that ENS values ≥ 0.5 are satisfactory for monthly comparisons between model output and corresponding measured data, with somewhat more stringent criteria used to judge annual comparisons and more relaxed criteria used for assessing daily comparisons. The same criteria were assumed for the r^2 statistics for the Raccoon River model, based on a similar extrapolation reported by Gassman *et al*. (2007).

IHA Analysis

The IHA software program (NC, 2015) was used to analyze observed daily streamflows from the two USGS gages present in Clear Creek Watershed and the SWAT simulated subbasin streamflows in order to characterize hydrologic variability in subbasins with different dominant land covers. We used the same 13-year data record for both analyses (2000-2012). The IHA program uses 33 hydrologic attributes to statistically characterize hydrologic variation, which in turn generates indicator statistics (Richter *et al*., 1996). Seventeen of the 33 IHA parameters focus on the magnitude, duration, timing and frequency of extreme events, whereas the other 16 parameters characterize the magnitude of flows or the rate of change in streamflow conditions (Richter *et al*., 1998; 1996). In this study, we focused on parameters that best reflected hydrologic variation among different LU/LC types in terms of timing, frequency and duration of high and low pulses, extreme events and rate and frequency of hydrologic changes (see list in Table 2).

Table 2. Mean values for IHA indices determined for subbasins

Land Use/Indices	Grass	Row crop	Urban
1-day minimum (m3/s)	0.0010	0.0016	0.0001
3-day minimum (m3/s)	0.0012	0.0019	0.0002
7-day minimum (m3/s)	0.0015	0.0024	0.0004
30-day minimum (m3/s)	0.0053	0.0068	0.0047
90-day minimum (m3/s)	0.0264	0.0396	0.0228
1-day maximum (m3/s)	2.1142	3.1559	2.7690
3-day maximum (m3/s)	1.1380	1.7427	1.3069
7-day maximum (m3/s)	0.6343	0.9580	0.6425
30-day maximum (m3/s)	0.3105	0.4369	0.2780
90-day maximum (m3/s)	0.1986	0.2784	0.1678
Number of zero days	14.9000	18.6000	48.2000
Date of minimum (Julian)	182.1000	140.7000	308.4000
Date of maximum (Julian)	149.0000	147.1000	103.6000
Low pulse count	10.1000	11.0000	17.3000
Low pulse duration (days)	9.7000	9.5000	4.6000
High pulse count	9.6000	9.1000	12.6000
High pulse duration (days)	1.9000	2.1000	1.3000
Low Pulse Threshold (m3/s)	0.0040	0.0042	0.0000
High Pulse Threshold (m3/s)	0.3180	0.4633	0.3400
Number of reversals	101.0000	108.5000	137.8000
Rise rate (m3/s/day)	0.1471	0.1907	0.1798
Fall rate (m3/s/day)	-0.0371	-0.0484	-0.0763
Extreme low peak (m3/s)	0.0008	0.0004	0.0000
Extreme low duration (days)	7.9000	14.1000	2.2000
Extreme low timing (Julian)	196.2000	179.5000	338.4000
Extreme low frequency	6.4000	7.2000	16.6000
High flow peak (m3/s)	0.4008	0.6190	0.3855
High flow duration (days)	4.8000	5.9000	3.0000
High flow timing (Julian)	162.8000	143.0000	185.3000
High flow frequency	12.6000	10.9000	26.0000
High flow rise rate (m3/s/day)	0.2795	0.4304	0.2963
High flow fall rate (m3/s/day)	-0.1381	-0.1879	-0.1498
Small Flood peak (m3/s)	2.5946	3.8850	2.9880
Small Flood duration (days)	35.9000	33.2000	15.1000
Small Flood timing (Julian)	150.2000	150.2000	151.2000
Small Flood frequency	0.8000	0.6000	0.8000
Small Flood rise rate (m3/s/day)	1.4476	2.2419	1.8965
Small Flood fall rate (m3/s/day)	-0.2368	-0.3624	-0.4123
Large flood peak (m3/s)	5.2360	8.6483	7.7000
Large flood duration (days)	20.0000	8.1000	11.0000
Large flood timing (Julian)	213.6000	223.5000	174.0000
Large flood frequency	0.1000	0.1000	0.1000
Large flood rise rate (m3/s/day)	3.4690	6.1241	7.6950
Large flood fall rate (m3/s/day)	-0.2662	-1.2202	-0.7502

We used the program to calculate indices over a continuous period of time rather than as a tool to compare hydrology from two different time periods for evidence of change. IHA output from subbasins with a dominant LU/LC greater than 50% of their total area were combined to produce mean subbasin IHA output per land cover type (grass, row crop and urban conditions).

Results

SWAT Model

The SWAT model for the Clear Creek Watershed was successfully calibrated at annual, monthly and daily time steps (Table 3). The r^2 and ENS statistics exceeded 0.85 for all of the annual and monthly streamflow comparisons, whereas the statistics were approximately 0.6 for the daily comparisons. These calibration statistics far exceed the standard statistical criteria (≥0.5) used to evaluate model performance that were previously described.

The average annual water balance for Clear Creek was evaluated using the SWAT model output. Of the 934 mm of average annual precipitation, the amount of evapotranspiration (ET) and stream discharge (Q) were estimated to be 641 and 292 mm, respectively. Baseflow was estimated to be 171 mm for the 13-year modeling period, which corresponds to a baseflow fraction of 60%. Discharge and baseflow represented approximately 31 and 18% of annual precipitation, respectively, which is consistent with other Iowa watersheds (Schilling and Libra, 2003). Greater average annual water yield occurred in subbasins with a higher percentage of row crop (Fig. 3), which is consistent with the hydrologic analysis in Papanicolaou *et al*. (2010).

IHA Analyses

The IHA indices calculated for the two USGS gages in the watershed indicated minor differences in hydrologic variability between locations considered mid-watershed (Oxford) and locations near the watershed outlet (Coralville) (Table 4). Most notable amongst the selected indices was the greater frequency of high flows and longer duration of large floods at the downstream gage location versus the mid-watershed gage (Fig. 4).

Greater differences in IHA indices were observed at the subbasin level (Table 2). Subbasins dominated by urban land cover had lower minimum flows across all time thresholds and were particularly evident in 7-day minimum low flows (Fig. 5). Urban-dominated subbasins also had a greater frequency of zero days and extreme low flows (Fig. 5). Hydrologic output from urban subbasins further showed evidence for increased flashiness, indicated by a greater frequency of reversals, high flow frequency, rapid rise and fall rates and short duration of high and low flood pulses (Table 2 and Fig. 5).

In contrast, row crop dominated subbasins had the highest maximum flows across the range of thresholds and greater peak streamflow values across small to large floods (Table 2). Grass-dominated subbasins had lower rise and fall rates compared to urban and row crop dominated subbasins, as well as fewer zero days and lower frequency of reversals.

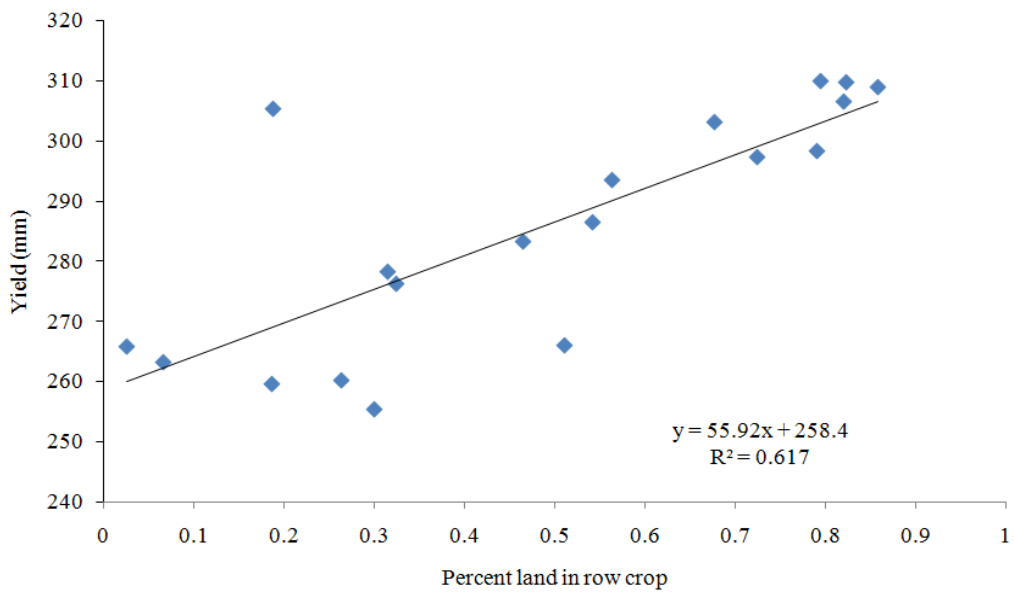

Fig. 3. Relation of row crop fraction to average annual water yield in 19 Clear Creek subbasins

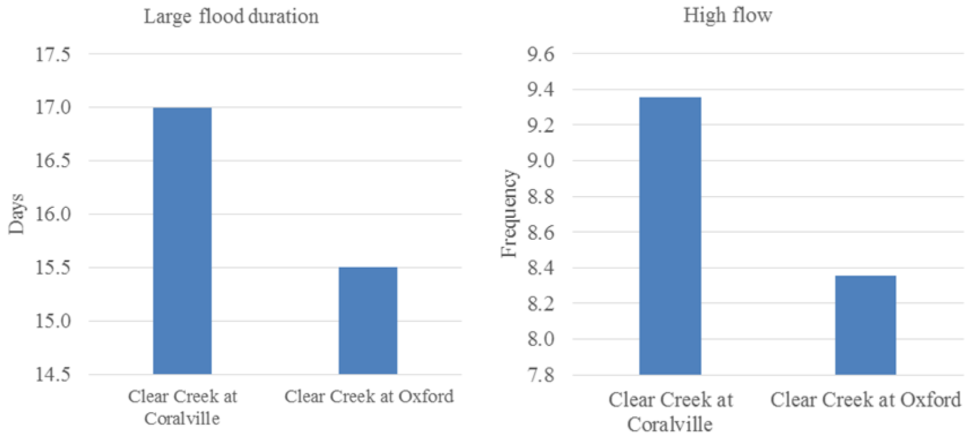

Fig. 4. Selected IHA indices from USGS stream gage sites at Oxford and Coralville

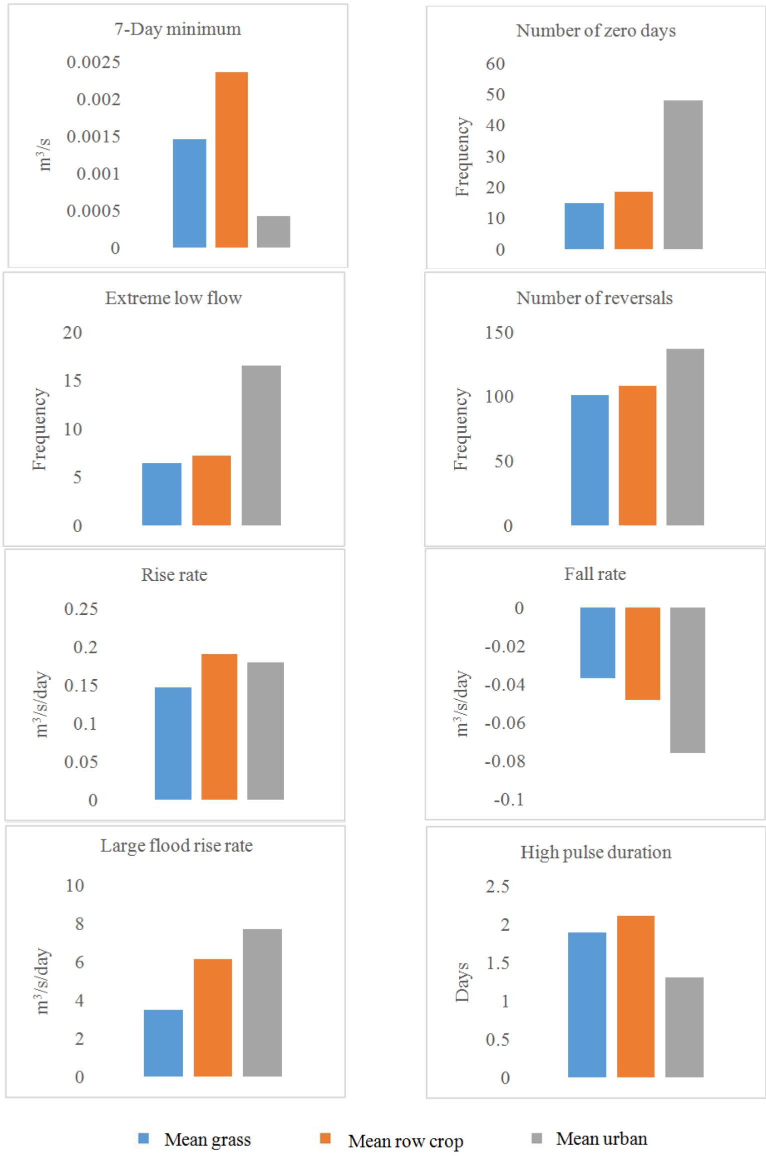

Fig. 5. Selected mean IHA indices derived from SWAT output for subbasins with dominant land cover type

Table 3. SWAT calibration statistics for two USGS stream gages in Clear Creek watershed

Location	Time step	Nash-Sutcliffe	Coefficient of determination
Oxford	Annual	0.97	0.96
	Monthly	0.85	0.85
	Daily	0.60	0.61
Coralville	Annual	0.90	0.94
	Monthly	0.86	0.85
	Daily	0.58	0.61

Table 4. Selected IHA indices for the mid-stream (Oxford) and downstream (Coralville) USGS stream gages in the Clear Creek Watershed

Gage/Indices	Clear Creek at Oxford	Clear Creek at Coralville
Number of zero days	0.0	0.0
Date of minimum (Julian)	226.9	305.9
Date of maximum (Julian)	181.6	170.2
Low pulse count	5.4	4.9
Low pulse duration (days)	26.9	22.1
High pulse count	6.5	7.3
High pulse duration (days)	2.2	2.4
Number of reversals	98.1	99.2
Extreme low duration (days)	14.2	15.7
Extreme low timing (Julian)	300.7	299.1
Extreme low frequency	3.1	2.1
High flow duration (days)	6.5	5.2
High flow timing (Julian)	125.4	130.2
High flow frequency	8.4	9.4
Small Flood duration (days)	32.7	36.2
Small Flood timing (Julian)	137.5	131.6
Small Flood frequency	0.9	0.9
Large flood duration (days)	15.5	17.0
Large flood timing (Julian)	154.5	241.0
Large flood frequency	0.1	0.1

Discussion

Effects of Land Cover on Streamflow Hydrology

Study results suggest that land cover plays a dominant role in controlling hydrologic variability at the subbasin level within a watershed. Although minor differences in IHA indices were observed at the mid-watershed and watershed outlet (Table 4), hydrologic differences were manifested more prominently at the subbasin level where land cover conditions were typically dominated by one land cover type. Larger watershed areas integrate and mix the hydrologic effects across land cover types so efforts to assess watershed-scale influences are often hampered. Results from a long-term paired watershed study in Iowa reported similar challenges (Schilling and Spooner, 2006). Greater differences in hydrology and water quality from prairie restoration were observed in smaller subbasins compared to the larger HUC12 watershed. Hence, results from our present study and others suggest that efforts to quantify hydrologic changes from LU/LC change should be focused on smaller subbasins where the changes represent a greater percentage of the total land area.

Subbasins dominated by urban land cover had lower minimum streamflows and showed evidence for greater flashiness as indicated by greater frequency of reversals, shorter duration of events and faster rise and fall rates. Lower minimum flows and greater number of zero flow days suggest that subbasins with a greater proportion of impervious surfaces have less groundwater recharge and provide less sustainable baseflow to streams. Moreover, impervious surfaces accelerate runoff and contribute to greater flashiness in streams (Jacobson, 2011; Walsh *et al*., 2005). During the 13-year period evaluated in this study, subbasins with dominant urban cover had nearly 30 more reversals than row crop or grass-dominated subbasins and the duration of small and large flood events were half as long. These results are consistent with typical hydrologic responses to urbanization (Jeong *et al*., 2014; Schoonover *et al*., 2006). Jeong *et al*. (2014) reported that baseflows were lower and mean monthly flows decreased with increasing urbanization, whereas Mejıa *et al*. (2014) used stochastic analysis to show that low flows (Q_{75} and Q_{90}) decreased with increasing urbanization.

Subbasins dominated by row crop land cover had greater water yield (Fig. 3) and maximum flows and higher peak flows. This was in part expected due to the higher curve numbers for agricultural areas, as well as compaction from intense farm activities (Papanicolaou *et al*., 2015). Greater water yield from row crop areas is consistent with patterns of increasing streamflow trends observed in watersheds with increasing amounts of row crop land cover (Tomer *et al*., 2005; Xu *et al*., 2013; Zhang and Schilling, 2006). Studies have shown that the area of annual crops (corn and soybean) is a good predictor of baseflow and streamflow (Papanicolaou *et al*., 2010; Schilling, 2005; Schilling and Wolter, 2005). Greater water yield from row crop areas is attributed, in part, to the short growing season of annual cropping systems of corn and soybeans that is poorly aligned with annual precipitation patterns (Abaci and Papanicolaou, 2009). Midwestern row crop landscapes are vulnerable to increased water loss during spring and fall periods when rainfall occurs on exposed, bare soils. Given the preponderance of row crop land cover in the Clear Creek Watershed (62%), we suspect that the greater frequency and longer duration of high flows at the watershed outlet (Fig. 4) is due to the influence of row crop land cover areas on watershed-scale hydrology. Schilling *et al*. (2013) reported that conversion of land use from row crops to switch grass or extended sod-based crop rotations in a highly agricultural Iowa watershed would reduce downstream flood frequency and severity.

Grass-dominated subbasins had lower rise and fall rates, fewer zero days and fewer reversals than subbasins dominated by urban or row crop land cover. Grasslands are known to increase infiltration and reduce flooding potential (Papanicolaou *et al*., 2010; Schilling and Drobney, 2014). In one study, grasslands were found to reduce peak runoff in 5- and 25-year 24-h rainfall events by 50-55% and 40-45%, respectively, compared to cropland (Gerla, 2007). Ecosystems dominated by grasslands rapidly infiltrate water, slowing runoff and lessening the kinetic energy of falling raindrops (Allen, 1993; Heimann, 2009; Knox, 2001). Lower rise and fall rates in grass dominated subbasins is consistent with hydrographs of prairie streams that have a relatively slow rise and fall with a high baseflow maintained by springs and groundwater (Menzel *et al*., 1984). Fewer days with zero flow and fewer flow reversals is indicative of greater baseflow and more stable flows in grass-dominated subbasins.

Additional results from previous studies in Clear Creek (e.g., (Abaci and Papanicolaou, 2009; Papanicolaou *et al*., 2010) provide further insight into the hydrologic condition of the watershed and support the above findings. In these studies saturated hydraulic conductivity was quantified in Clear Creek considering soil texture, seasonal changes in climate and land use activities. It is a reflection of how fast water infiltrates into the soil, which affects the availability of water for runoff. Faster rates of water infiltration into the soil correspond to less water available for runoff. The saturated hydraulic conductivity was highest in the central part of the watershed, which translated to less runoff due to the predominant grassed and forested land cover located here. The lowest values were observed in the western part of the watershed due to the abundance of agriculture. The eastern part of Clear Creek, which contained a mixture of urban areas and grasslands, had intermediate values. The type and quantity of a particular land cover (grass, crop, or pavement) becomes very important in controlling the relationship between infiltration and runoff (Papanicolaou *et al*., 2010).

Future Vulnerabilities from LU/LC and Climate Change

Study results suggest that future changes in LU/LC and climate may have significant effects on the hydrology of Clear Creek Watershed. Urban areas are expanding in the watershed from the metro areas of Coralville, North Liberty and Tiffin (Fig. 1). Expansion of urban areas will increase impervious surfaces in the watershed and results from this study suggest that subbasins with increasing urban areas will have lower flows and more flashy hydrographs. At the scale of the watershed, these effects may be masked by the influence of upstream row crop areas, but these hydrologic effects will be more noticeable within smaller subbasins. This may also relate to the location of the urban watersheds near the mouth, which will receive all the upstream water from the different subbasins, each with their own mixed distribution of land use. The ecological consequences associated with changing streamflow hydrology due to increasing urbanization are being increasingly recognized (Braud *et al*., 2013; Bressler *et al*., 2009; DeGasperi *et al*., 2009). Moreover, increases in stream flashiness from urbanization may result in greater stream bank instability which will threaten floodplain infrastructure such as roads, bridges and culverts (Sutarto *et al*., 2014). Incorporating new urban Best Management Practices (BMPs) such as bioretention cells, green roofs, permeable pavements and pervious concrete (e.g., Dietz (2007)) into urban planning and infrastructure will lessen the hydrologic impacts from increasing urbanization.

Expansion of row crop areas in the Clear Creek Watershed will likely come at the expense of grassland. Biofuel demands have resulted in higher commodity prices and economic pressures for converting perennial grasslands and pastures to corn and soybean rotations (Schilling *et al*., 2010; Secchi *et al*., 2011). Study results suggest that row crop expansion will increase peak flows and flood duration in the watershed. Agricultural BMPs are well established for reducing runoff from cropped fields (e.g., terraces, conservation tillage, grass waterways, ponds), so efforts should continue to incorporate these practices into new row crop areas. We echo the call of Schilling *et al*. (2013) for increased use of extended, sod-based rotations to reduce flood risks in agricultural watersheds.

Climate projections for the central U.S. suggest the region including south-central Iowa will experience increasing rainfall trends, with precipitation projected to increase 20% in the next 50 years (Villarini *et al*., 2011). The seasonality of precipitation in Iowa is also projected to change as most of the increase, on an annual basis, is expected to come in the first half of the year and lead to wetter springs and drier falls (Villarini *et al*., 2011). Greater precipitation occurring in the spring will increase the potential for LU/LC effects to become even more prominent in watershed-scale hydrology. Wetter climates will result in greater water yield from row crop areas and increase the flashiness of streams in urban areas. Combined, these conditions will increase the risk to the sustainability of the Clear Creek ecosystem and floodplain infrastructure. Effects of climate and LU/LC changes often combine to result in severe economic and ecological disasters. In Clear Creek, recent floods in 1993 and 2008 resulted in millions of dollars in flood-related damages in Tiffin and Coralville (Mutel, 2010). However, since the 2008 flood, awareness of the role of LU/LC on stream hydrology has increased and agricultural and urban interests have been working together around the common interest of reducing flood damages. Recognition is growing that reducing impacts from future climate change will require developing resilient landscapes designed to cope with the change.

Conclusion

In this study, hydrologic output from a calibrated SWAT model was used as input to IHA in order to evaluate the effects of land cover on streamflow in Clear Creek Watershed. Study results indicated that land cover plays a dominant role in controlling hydrologic variability at the subbasin level within a watershed. Subbasins dominated by urban development had lower minimum streamflows and showed evidence for greater flashiness as indicated by greater frequency of reversals, shorter duration of events and faster rise and fall rates. Row crop dominated subbasins had greater water yield and maximum flows and higher peak flows, whereas grass-dominated subbasins had lower rise and fall rates, fewer zero days and fewer reversals. Hydrologic variations from land cover differences were more prominently expressed at the subbasin level than at the watershed level, as the dominant land cover represented a greater percentage of the total land area. Study results suggest that future changes in LU/LC and climate will have significant effects on the hydrology of Clear Creek Watershed. Increasing awareness of potential consequence of LU/LC change in the context of a changing climate will lead to greater incorporation of urban and agricultural BMPs to develop more sustainable and resilient landscapes.

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Author's Contributions

Keith Schilling: Lead investigator and primary author.
Matthew Streeter: Responsible for IHA analysis.
Kasey Hutchinson: Responsible for SWAT modeling.
Chris Wilson: Development and hot spot identification.
Ben Abban: Map development.
Ken Wacha: Verification measurements.
Athanasios Papanicolaou: Overall supervision of the research.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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