FINAL REPORT

The University of Missouri Stormwater Monitoring Program

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TABLE OF CONTENTS

STUDY RESULTS IN BRIEF

- Turbidity is lower in stormwater runoff from the University of Missouri campus relative to the receiving water (Hinkson Creek)
- Suspended sediment is approximately 190% lower in University of Missouri campus stormwater runoff relative to Hinkson Creek.
- University of Missouri stormwater runoff temperature is, on average, approximately 13% lower than receiving water (Hinkson Creek) temperature.

ABSTRACT

The developed (or "built) environment is intricately linked to altered hydrologic regimes and water quality degradation. Land use changes accompanying development very often include vegetation removal, construction of impervious surfaces, and ditching and draining. These activities combine to reduce water infiltration into the soil and increase overland flow to receiving waterbodies. University campuses, often characterized by extensive impervious surface area (e.g. parking lots and buildings), have the potential to contribute disproportionately to receiving water body impairment. In recent years, many universities have undertaken focused scientific studies to determine the impact of campus land uses on receiving waters. In May 2013, in a precedence setting cooperative agreement between the University of Missouri (MU) Campus Facilities, the College of Agriculture, Food and Natural Resources Center for Watershed Management and Water Quality and the School of Natural Resources Interdisciplinary Hydrology Laboratory a long-term monitoring program was initiated to quantitatively characterize MU campus stormwater quality to more effectively manage the community's aquatic resources and better guide future campus development strategies. Seven monitoring stations were installed in campus drainages. Stations were equipped with pressure transducers to monitor water level and temperature, and optical back-scattering sensors to measure turbidity. 2015 monitoring season results show that average turbidity, level, and temperature of campus stormwater during eight runoff-causing precipitation events were 43.8 NTU, 35.3 cm, and 18.8 °C, respectively. Average turbidity, level, and temperature of streamwater at the two Hinkson Creek monitoring stations during the precipitation events were 107.3 NTU, 162.0 cm, and 21.4 °C, respectively. Results of this multi-year study suggest that campus stormwater is characterized by lower average turbidity and temperature, as compared to Hinkson Creek. In a complimentary study, gravimetric analysis of water samples collected during 2015 indicate that, on average, campus stormwater samples contained 186% less suspended sediment than Hinkson Creek samples. The University of Missouri Stormwater Monitoring Program (MU SMP) represents one of the first campus-wide, long-term, cooperative initiatives to address the impacts of university land uses on water quality and aquatic resources and represents a significant investment towards sustainability of aquatic and terrestrial ecosystem quality and human health.

PROJECT DESCRIPTION

Pollution of streams, lakes and other surface waters is a greater issue for society than ever before. To successfully restore water quality in impaired watersheds requires understanding the interconnections between hydrology, climate, land use, water quality, ecology, and socio-economics. Current understanding of these interactions is limited primarily by a lack of innovation, investment (in particular long-term), and interdisciplinary collaboration. Pollution from diffuse sources is most often driven by meteorological events (i.e. precipitation). It is understood that there is a correlation between pollutant loadings from a given watershed and rainfall volume, infiltration, runoff and storage characteristics (Novotny and Olem, 1994). Hydrologic modification resulting from development can increase or decrease diffuse pollution loads, illustrating the need to quantify the pollutant transporting mechanism(s), and consider the various pathways contaminants may travel from source areas to receiving water bodies. This is particularly important for the state of Missouri, which is one of nine central U.S. states that contribute more than 75% of upland nitrogen and phosphorus to the Gulf of Mexico, U.S. (Alexander et al. 2008).

Given the complexity of predicting climate and landscape interactions, it is not surprising that meeting water quality standards, particularly in rapidly urbanizing watersheds is challenging. In particular where jurisdictions must also meet the U.S. Environmental Protection Agency's (U.S. EPA) National Pollutant Discharge and Elimination System (NPDES) requirements. Often, information necessary to accurately estimate and model rainfall/runoff relationships, and calculate accurate stormwater flow paths is not available to make best management decisions. Given the inherent lack of information, and the scope of NPDES program requirements, stormwater managers struggle to predict the effect of local ordinances on water quality and receiving water bodies. This problem can be navigated by direct measurement monitoring. Direct measurement will almost always result in the most accurate pollutant loading estimates. However, while direct measurement is expensive in terms of instrumentation and labor, if a study is designed correctly (Clausen and Spooner, 1993; Hewlett and Pienaar, 1973; Hubbart et al. 2007), results are often scalable and transferrable. It is therefore critical to support properly designed local to regionally representative watershed studies, and avoid scattered investments in various landscapes (i.e. shotgun approach), that can cost millions of taxpayer dollars but never supply necessary data sets to resolve water quality problems.

The University of Missouri and the Hinkson Creek Watershed

The University of Missouri is located in the lower extents of the Hinkson Creek Watershed (HCW) within the Columbia city limits. The HCW is located within the Lower Missouri-Moreau River Basin (LMMRB) in central Missouri (Figure 1), and flows through a basin of approximately 231km^2, ultimately flowing into the Missouri River. Urban areas are primarily residential with progressive commercial expansion from the City of Columbia (population approximately 110,000). Land use in the watershed is approximately 34% forest, 38% pasture or crop land, and 25% urban area. The remaining land area is wetland, open or shrub/grassland areas (Table 1). Understanding the relative impacts of the MU campus on Hinkson Creek water quality is an ongoing Campus management question.

The Missouri Department of Natural Resources (MDNR) targeted a portion of the LMMRB as critical for controlling erosion and nonpoint source pollution in 1998 (MDNR 2006). Watershed restoration efforts in the LMMRB were accelerated by mandates of the Clean Water Act (CWA) and subsequent lawsuits. Hinkson Creek watershed is representative of the LMMRB with respect to hydrologic processes, water quality, climate and land use and was one of the first water bodies in Missouri to be placed on the CWA 303d list (1998). The impaired use for Hinkson Creek is "protection of warm water aquatic life" from *unknown pollutants* with the source attributed to urban runoff (MDNR 2006). Estimating a total maximum daily load (TMDL) for water quality is a reasonable goal in the HCW given the mode of listing. However, identifying specific pollutants, and translating pollutant loading to specific land uses is a difficult task without understanding water and pollutant transport and concentration processes at multiple locations throughout the watershed (Tim and Jolly, 1994; Frankenberger et al. 1999). Furthermore, relating aquatic biological health to pollutant loading adds an additional layer of complexity to resolving potential water quality impairment.

To generate data that address these uncertainties while providing a scientific basis for developing a TMDL, the watershed was equipped with state of the art nested-scale experimental watershed study design in the fall of 2008 and spring of 2009 including five fully-equipped hydroclimate stations (Figure 1). The project is designed to supply quantifiably validated scalable and transferrable results. Instrumentation is complemented by a United States Geological Survey (USGS-06910230) gauging station that has collected data intermittently since 1966. Each fully automated gauging station monitors water depth and a complete suite of climate variables. The study is encouraging cooperation, trust and innovation, between watershed stakeholders to reach a common goal to improve and sustain water quality. In this manner, the HCW serves as a model urban watershed for similar studies globally.

In order to assess the contribution of the University of Missouri campus to the current condition of Hinkson Creek, focused studies are needed that quantitatively characterize the quality and quantity of MU campus stormwater and the relative impact of campus land uses on Hinkson Creek. In a precedence setting cooperative effort between the University of Missouri (MU) Campus Facilities, the College of Agriculture, Food and Natural Resources Center for Watershed Management and Water Quality, and the School of Natural Resources Interdisciplinary Hydrology Laboratory, a study was initiated in the spring of 2013 to meet this need. Seven stormwater quality monitoring sites (Figure 2) were identified within campus drainage routes to comprehensively describe campus stormwater quality and quantity. Study results hold important implications for future development of the MU campus, the management of aquatic resources in Hinkson Creek, and sustainable University of Missouri campus development.

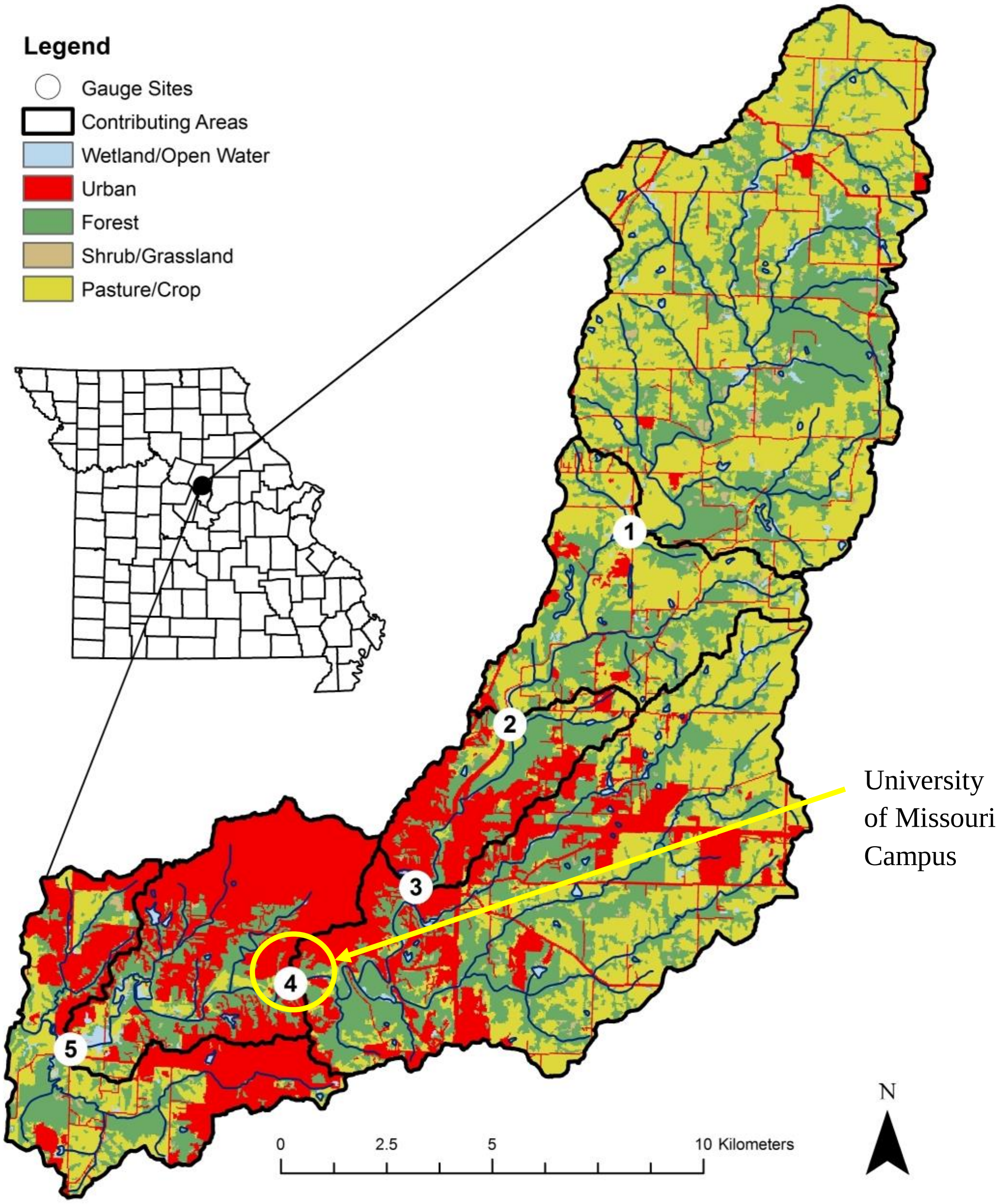

Figure 1. Locations of gauge sites (where #4 includes the USGS gauging station) in the Hinkson Creek Watershed (HCW), in Central Missouri, USA.

Table 1. Cumulative contributing and corresponding land use areas to each of five hydroclimate gauging sites located in the Hinkson Creek Watershed (HCW) in Central Missouri, USA.

Cumulative Contributing Area	Total Area (Km^2)	Wetland/Open Water (% Area)	Urban (% Area)	Forest (% Area)	Shrub/Grassland (% Area)	Pasture/Crop (% Area)
Site 1	77	2	5	36	2	55
Site 2	101	2	6	36	2	54
Site 3	114	2	11	36	2	49
Site 4	180	2	16	36	1	44
Site 5	206	2	23	34	1	39
Entire HCW	231	2	25	34	1	38

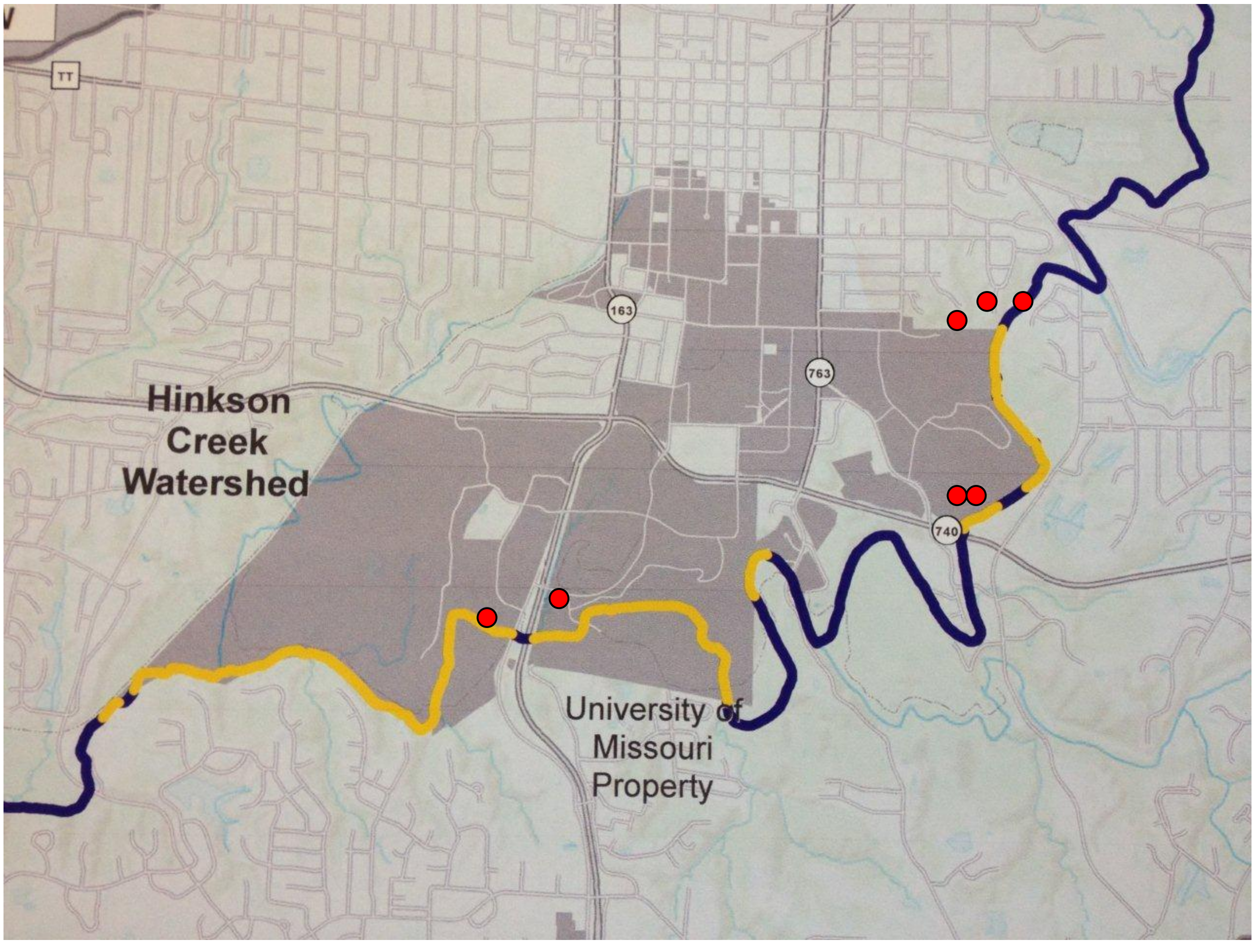

Figure 2. University of Missouri Campus (shaded area). Yellow designates University of Missouri, Hinkson Creek Frontage. Red dots designate locations of stormwater monitoring stations.

PROJECT GOALS AND OBJECTIVES

The objective of the Missouri University Stormwater Quality Monitoring Project was to quantitatively characterize campus stormwater quality using three water quality metrics including: turbidity (NTU), water depth (cm), and temperature (°C). These data provide researchers and MU decision-makers with useful information regarding the quality of campus stormwater and the impacts of campus land uses on the shared aquatic resources of the local community.

ACCOMPLISHMENTS

Background: Seven water quality monitoring stations were installed in May 2013 at the planned project sites (Figure 2). Campbell Scientific OBS-3+ optical backscattering sensors were selected to measure water turbidity (NTU). Campbell Scientific CS-451 submersible pressure transducers were selected to measure water level (cm) and temperature (°C). Instruments were set to record data at 5 minute time intervals. Custom housing units for the in-stream sensors were designed and constructed, thereby reducing the cost of project implementation.

Current reporting year: Monitoring stations were maintained and inspected approximately weekly over the course of the past year. Since project establishment in 2013, data were collected monthly and updated graphs were made publicly available via a freely accessible website (http://web.missouri.edu/~hubbartj/index_files/MUStormwater.htm) until September 2015. Preliminary data analysis is currently being used to improve understanding of pre-treatment water level, temperature, and turbidity regimes for the seven drainages. To avoid winter weather instrument issues encountered during 2014, sensors were removed from the field and stations were taken offline at the beginning of November, 2014. Sensors were returned to the field and stations brought back online in March, 2015. Thus results are presented from March – October 2015, which includes the historic wet season in mid-Missouri and summer months. Results from 2015 water turbidity, level, and temperature analyses are provided in Tables 2-4 and Figures 3-9. Figures show the uninterrupted data time series from the 2015 monitoring season. In order to provide a basis for future comparisons, tables present descriptive statistics of water turbidity, level, and temperature during the eight precipitation events selected for cross-section measurement (*see below*). Average turbidity, level, and temperature of campus stormwater during the precipitation events were 43.8 NTU, 35.3 cm, and 18.8 °C, respectively. Average turbidity, level, and temperature of streamwater at the two Hinkson Creek monitoring stations during the precipitation events were 107.3 NTU, 162.0 cm, and 21.4 °C, respectively. Results suggest that campus stormwater is characterized by lower average turbidity and temperature, as compared to Hinkson Creek. Results also indicate a reduction in average turbidity and increase in average level from Hinkson site 1 (located above campus) to Hinkson site 2 (located below campus). In October 2015, monitoring stations were decommissioned and all instruments were removed from the field.

In addition to automated stormwater monitoring, water grab sampling and stream cross-section measurement campaigns were conducted during the 2015 season. Stream cross-sections were measured during eight precipitation events (5/9, 5/14, 5/25, 5/30, 6/4, 7/6, 7/19, 7/20). Grab samples of stream water were collected from each site during fifteen runoff-causing precipitation events (3/10, 3/13, 4/2, 5/9, 5/14, 5/20, 5/25, 5/30, 6/4, 6/17, 6/26, 7/6, 7/19, 7/20, 8/22). Samples were analyzed using gravimetric methods. Preliminary results of gravimetric analyses are presented in Table 5 and Figure 10. Results indicate that average total suspended sediment (TSS) during the fifteen precipitation events was 19.09 and 374.43 mg/L in campus stormwater and Hinkson Creek samples, respectively, a difference of more than 186%. In contrast with turbidity results, gravimetric results showed an increase in average TSS from Hinkson site 1 (261.17 mg/L) to Hinkson site 2 (487.69 mg/L).

Table 2. Water turbidity (NTU) descriptive statistics from eight precipitation events during 2015 for seven stormwater monitoring stations, Columbia, MO.

	Avg.	Max.	Min.	Std. Dev.
East Campus 1	29.8	679.8	4.4	71.5
East Campus 2	65.9	1793.0	0.0	223.8
Trowbridge 1	52.5	771.8	3.3	89.3
Trowbridge 2	35.5	531.5	0.5	72.4
Mick Deaver	35.2	205.2	6.8	29.0
Hinkson 1	193.5	772.3	0.2	158.7
Hinkson 2	21.2	113.4	2.8	19.4

Avg. = Average
Max. = Maximum
Min. = Minimum
Std. Dev. = Standard Deviation

Table 3. Water level (cm) descriptive statistics from eight precipitation events during 2015 for seven stormwater monitoring stations, Columbia, MO.

	Avg.	Max.	Min.	Std. Dev.
East Campus 1	12.2	36.9	8.6	5.5
East Campus 2	7.4	44.2	0.0	7.4
Trowbridge 1	10.0	63.6	0.4	10.0
Trowbridge 2	39.4	122.7	8.2	16.8
Mick Deaver	107.3	244.0	90.8	32.2
Hinkson 1	117.1	255.3	43.0	43.9
Hinkson 2	206.9	486.8	113.5	84.4

Table 4. Water temperature (°C) descriptive statistics from eight precipitation events during 2015 for seven stormwater monitoring stations, Columbia, MO.

	Avg.	Max.	Min.	Std. Dev.
East Campus 1	18.3	24.5	14.5	2.8
East Campus 2	19.1	24.5	14.4	3.0
Trowbridge 1	19.3	24.4	13.6	3.0
Trowbridge 2	19.9	24.3	14.0	2.8
Mick Deaver	17.2	20.1	13.3	2.5
Hinkson 1	21.6	26.7	17.8	2.3
Hinkson 2	21.1	25.4	16.6	2.3

Table 5. Total suspended sediment (TSS) concentration (mg/L) descriptive statistics from fifteen precipitation events during 2015 for seven stormwater monitoring stations, Columbia, MO.

	Avg.	Max.	Min.	Std. Dev.
East Campus 1	12.06	62.29	0.48	18.72
East Campus 2	12.87	52.38	2.00	16.83
Trowbridge 1	28.03	160.55	1.52	39.50
Trowbridge 2	28.60	142.55	2.47	38.29
Mick Deaver	13.90	94.48	0.38	23.47
Hinkson 1	261.17	1175.85	3.73	294.68
Hinkson 2	487.69	2039.00	3.64	567.24

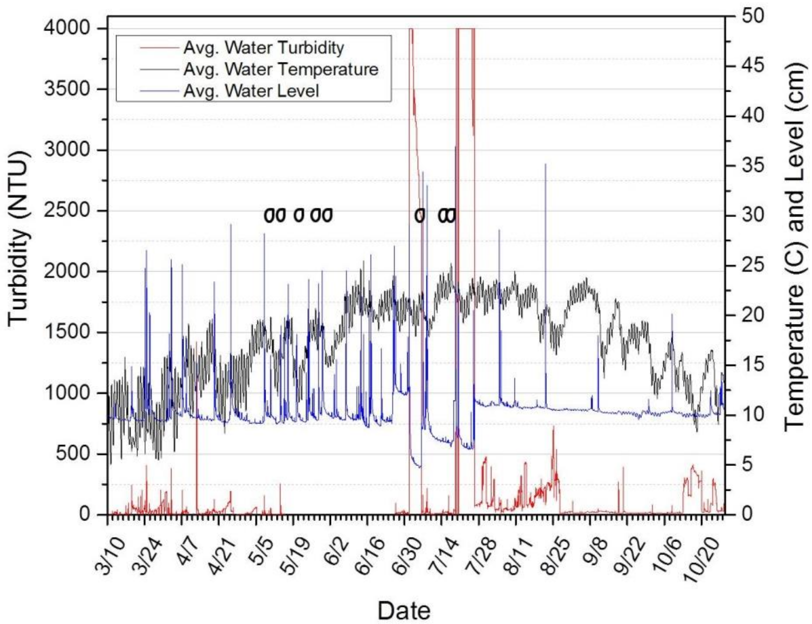

Figure 3. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at East Campus site #1. Raindrop indicates a precipitation event for which cross-sections were measured.

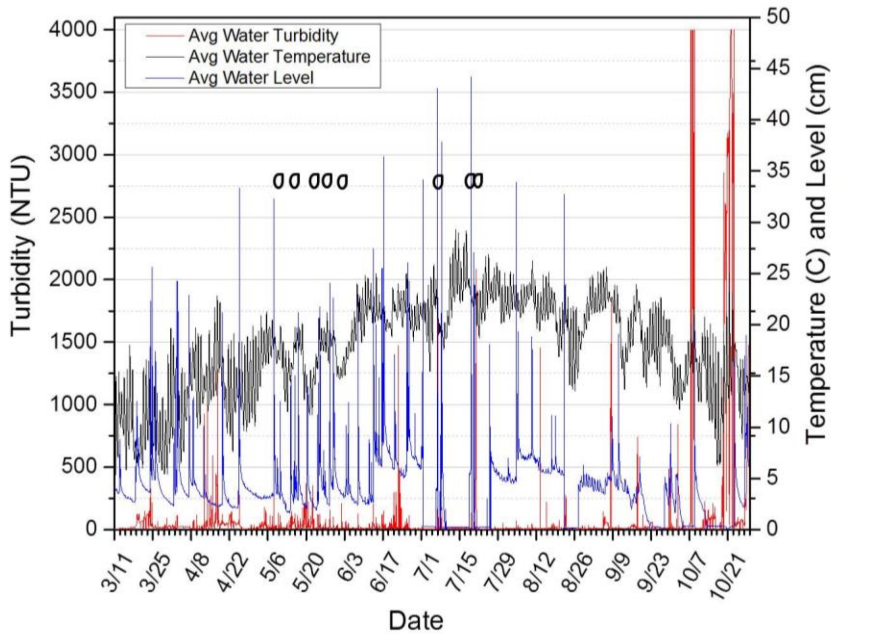

Figure 4. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at East Campus site #2. Raindrop indicates a precipitation event for which cross-sections were measured.

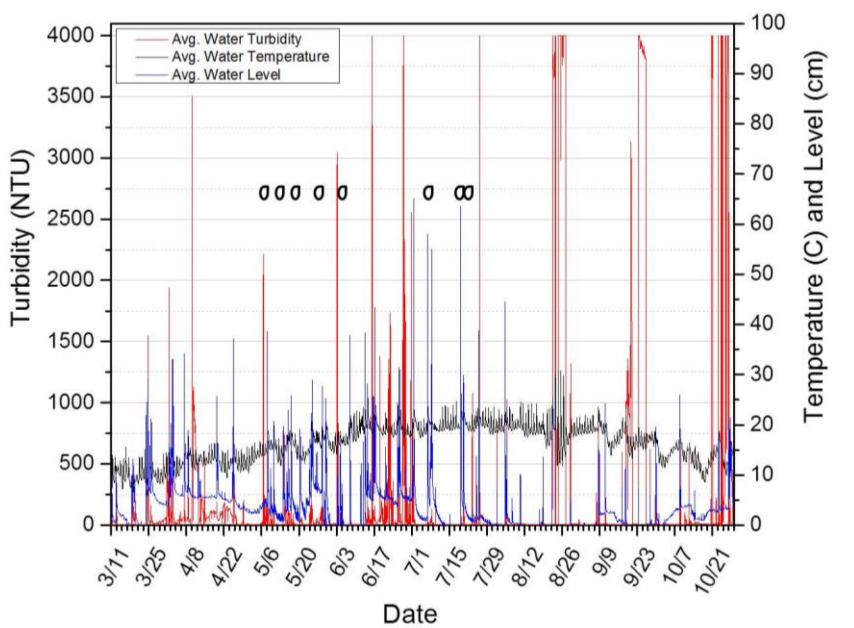

Figure 5. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at Trowbridge site #1. Raindrop indicates a precipitation event for which cross-sections were measured.

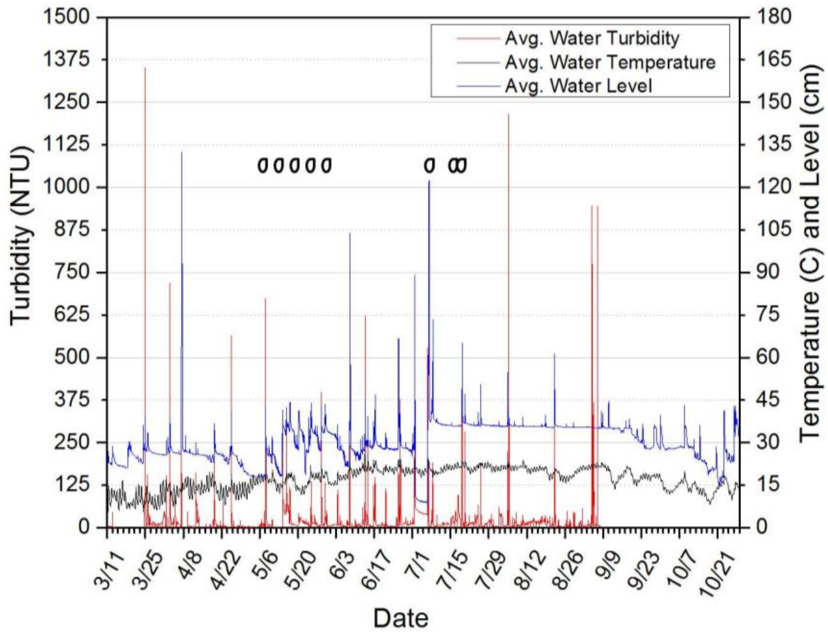

Figure 6. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at Trowbridge site #2. Raindrop indicates a precipitation event for which cross-sections were measured.

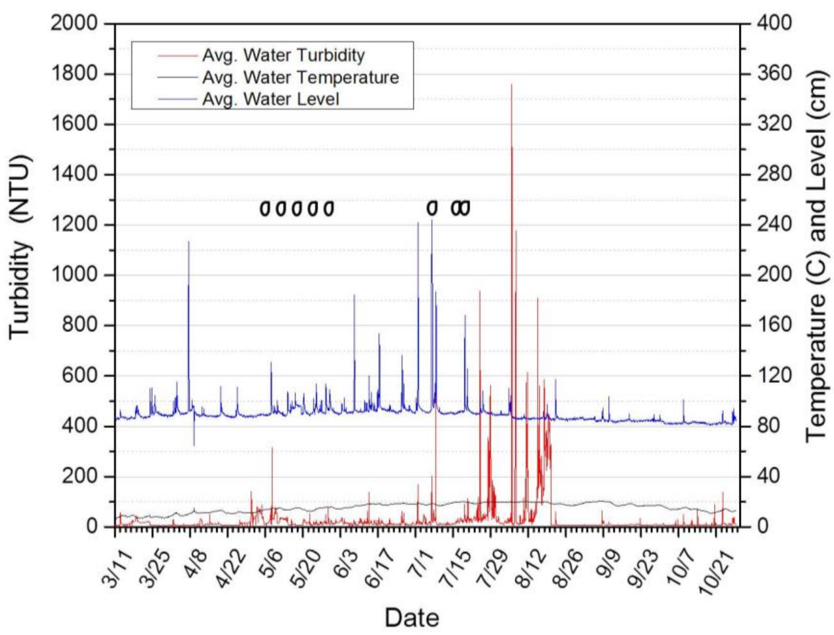

Figure 7. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at Mick Deaver site. Raindrop indicates a precipitation event for which cross-sections were measured.

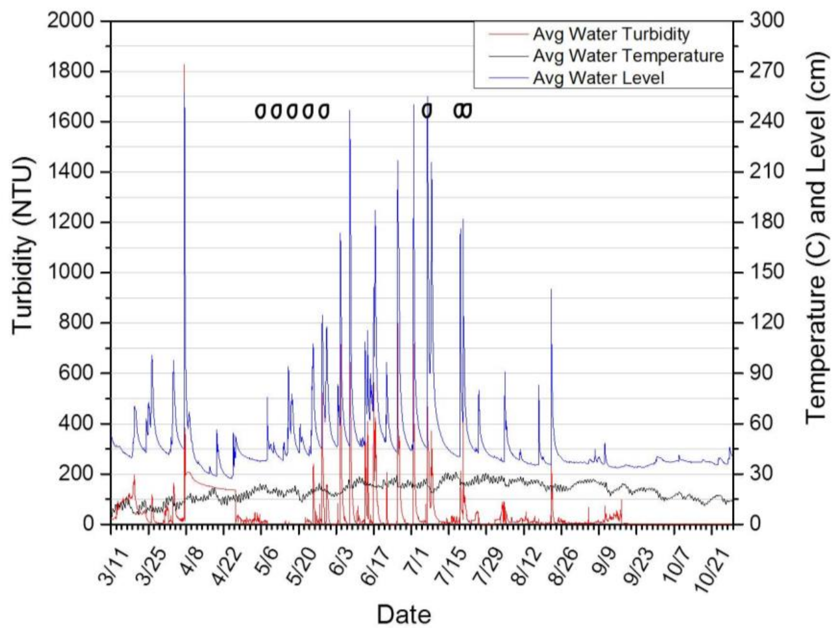

Figure 8. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at Hinkson site #1. Raindrop indicates a precipitation event for which cross-sections were measured.

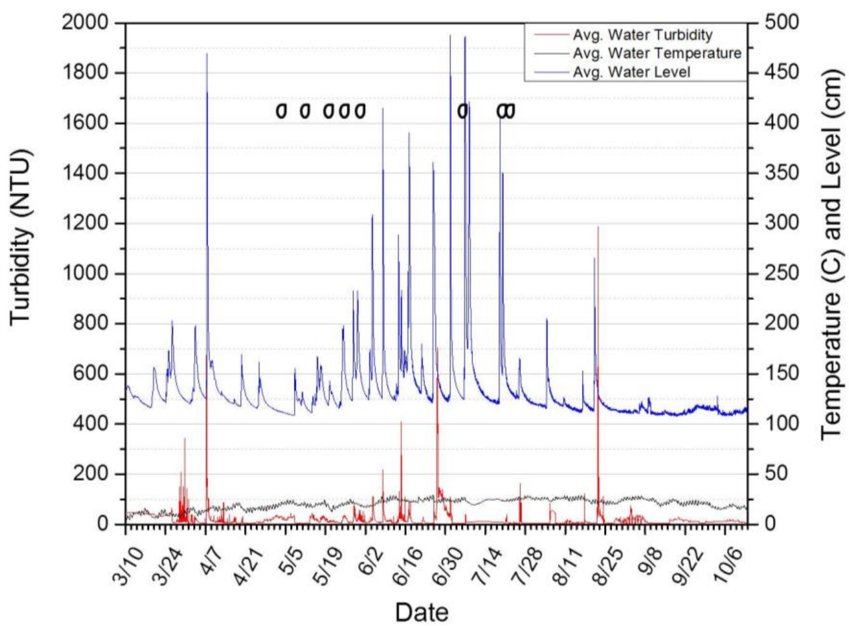

Figure 9. Water turbidity (NTU), level (cm), and temperature (°C) from June – October, 2014 at Hinkson site #2. Raindrop indicates a precipitation event for which cross-sections were measured.

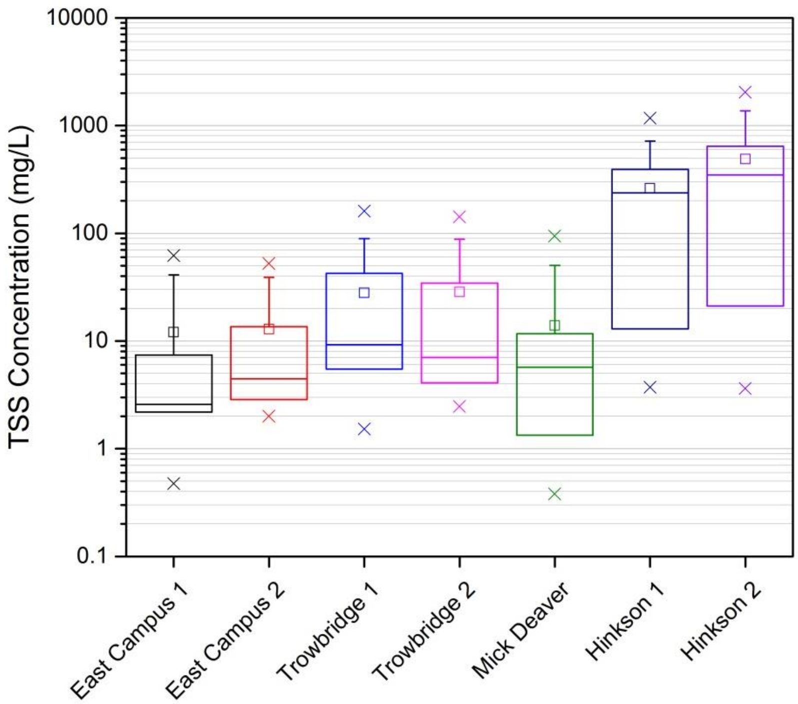

Figure 10. Box plot of total suspended sediment (TSS) concentration (mg/L) from fifteen precipitation events during 2015 for seven stormwater monitoring stations, Columbia, MO. Box represents 25-75 percentiles. Horizontal line denotes median. Small squares represent median. Whiskers show standard deviation. X represents maximum when above, minimum when below.

OBSTACLES AND REMEDIES

At certain sites (e.g. Hinkson 1) consistent siltation required regular cleaning of the turbidity sensor lens to preserve data quality. Additionally, during warm weather, certain sites (e.g. Trowbridge 1) were affected by algae growth on the instrument housing unit, including the turbidity sensor lens. However, as in the previous case, regular cleaning and maintenance was an effective solution. In early 2014, cold temperatures damaged several sensors. In cooperation with the sensor manufacturer (Campbell Scientific Inc., Logan, Utah), all damaged sensors were replaced or repaired at no cost, and returned to the field to continue data collection. However, turbidity sensor problems remained ongoing, with additional losses, mostly related to cold water temperature. Therefore, strategies for sensor deployment were summarily revised. When air temperatures began to drop in November of 2014, sensors were removed from the water, effectively taking the monitoring stations offline for the duration of the winter season to avoid destroying sensors. In March of 2015, sensors were redeployed and monitoring stations reactivated. This strategy successfully minimized maintenance costs. In June 2014, the lower Hinkson Creek monitoring station was moved in response to repeated stream bank failures. The new site was approximately 100 meters downstream in a more stable stream location, and operated reliably for the duration of the 2015 monitoring season. The turbidity sensors however, continued to pose a series of obstacles during the course of the project. In addition to the winter weather issues detailed above, there were data reliability issues associated with the sensors. As a function of the construction and programming of the turbidity sensors, site specific data comparisons indicate low sensor-to-sensor agreement. Instead, each sensor appeared to be characterized by a different low and high range, and sensitivity. Additionally, siltation and burial of sensors were consistent obstacles during the course of the project. Thus, it is advisable that future stormwater work should utilize a more reliable, rugged sensor with the ability to measure more informative water chemistry related parameters, including (but not limited to): electrical conductivity, chloride, and/or pH.

CHANGES IN PERSONNEL

The Graduate Research Assistant (GRA) hired in the spring of 2013 continued to assist with the instrument installations, ongoing field work, maintenance (i.e. weekly), data collection, post-processing and analysis (ongoing). The support of the GRA position will end December 31st, 2015.

In fall of 2014, an additional Master's level GRA was hired to assist with project data analysis and the production of a peer-reviewed journal publication. The GRA is currently funded by a Fulbright Scholarship and advised by PI Jason A. Hubbart, Ph.D. The GRA's duties have included assisting in the maintenance of field monitoring stations and collection of data. The project will serve as the GRA's Master's Thesis. In addition to water level, temperature, and turbidity data, the thesis project will include gravimetric analysis of stream samples collected at each monitoring site during fifteen precipitation events during the 2015 wet season (i.e. March-October). Results of suspended sediment analysis will be compared to turbidity data to produce information including the appropriateness of the turbidity metric. Stream cross-sections were measured during the spring and summer of 2015, and will be combined with observed water level data in order to determine streamflow at each monitoring site. Streamflow data and campus geographical data will be used to inform a computer-based predictive model, which is capable of producing estimates of both flow and solute/sediment loading on a precipitation event basis. This valuable information can be used to evaluate current and future campus stormwater mitigation practices and predict the response of the campus sub-catchment to storm events.

EQUIPMENT PURCHASED IN CURRENT QUARTER

By definition, "equipment" on the MU campus is instrumentation or other project infrastructure costing more than $5000. The initial investment in field instrumentation for this project consisted of NO item costing more than $5000, though there were multiple distinct parts/pieces resulting in a not-insignificant upfront investment. Since project establishment, no additional instrumentation purchase was necessary. Any other costs were absorbed by the Interdisciplinary Hydrology Laboratory.

UPCOMING ACTIVITIES

Analyses of stream cross-section and stage data will be paired with the results of gravimetric sediment analyses to produce information regarding sediment loading in the campus drainages and Hinkson Creek. The results of volumetric sediment analyses will be compared to streamflow results to determine the impact of campus land uses on sediment particle size class trends. Additionally, construction of a computer-based predictive model using geographical and streamflow data will continue in order to provide stakeholders with a management tool capable evaluating current and future campus stormwater mitigation practices and predicting the response of the campus sub-catchment to storm events. A peer reviewed publication is scheduled for submission in 2016.

PROJECT CONCLUSIONS

During each monitoring season (i.e. 2013, 2014, and 2015) results of water turbidity analyses showed lower average turbidity of campus stormwater relative to Hinkson Creek. Furthermore, results of grab sample analyses during the 2015 season indicate that, on average, campus stormwater samples contained 186% less suspended sediment than Hinkson Creek samples. Thus, study results indicate University of Missouri campus stormwater is characterized by lower turbidity/suspended sediment concentration relative to receiving waters. This trend is clearly visible in Figure 11, a picture taken at the confluence of the Mick Deaver drainage and Hinkson Creek during a precipitation event. In the picture, campus stormwater is visibly less turbid than that of Hinkson Creek. No information has been collected to date regarding the physiochemical composition of campus stormwater, a potentially important direction for future research.

Although, monitoring results showed decreased water turbidity from Hinkson site #1 (i.e. above campus) to Hinkson site #2 (i.e. below campus), the results of grab sample analysis indicated an increase in average TSS from Hinkson site 1 (261.17 mg/L) to Hinkson site 2 (487.69 mg/L). Such contrasting results could constitute additional evidence of the short-comings/limitations of turbidity sensors, and should be considered when selecting instrumentation for future research studies.

During each monitoring season (i.e. 2013, 2014, and 2015) results of water level analyses showed greater average level in Hinkson Creek, relative to campus stormwater drainages, and an increase in average level from Hinkson site #1 to Hinkson site #2. Granted, such trends are expected considering differences in contributing land area; specifically, greater contributing land area of Hinkson Creek than campus stormwater drainages, and increasing contributing land area with increasing stream distance. However, it is worth noting that increased streamflow, can result in bed scouring, bank erosion, and channel cutting, thereby altering the geomorphology of a water course and mobilizing sediment. Such processes could help explain greater average TSS of Hinkson 2 samples than Hinkson 1 samples, and geomorphological processes and trends in the lower Hinkson Creek Watershed.

Figure 11. Confluence of Mick Deaver drainage and Hinkson Creek during precipitation event (4/4/2014), showing contrasting water turbidity.

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