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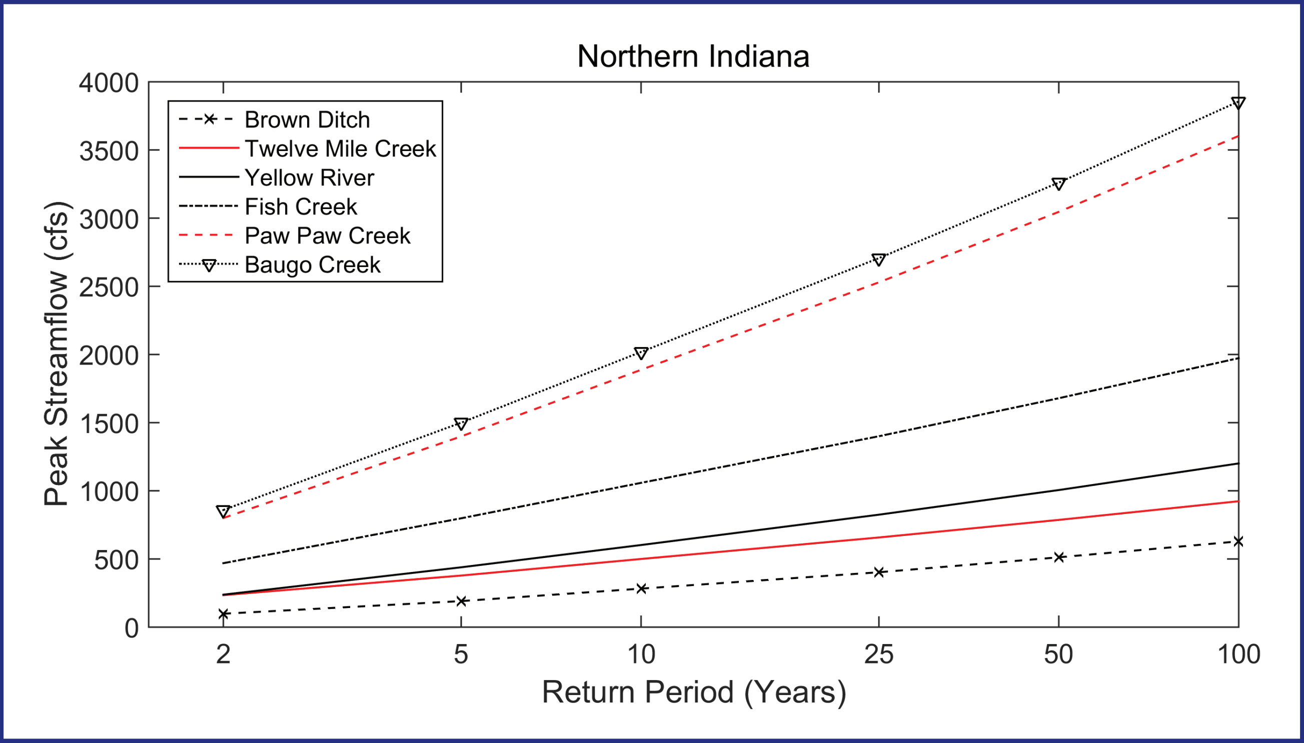
Relating Design Storm Events to Ordinary High Water Marks in Indiana



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16. Abstract

Hydraulic design and environmental permitting are heavily dependent upon Ordinary High Water Marks (OHWM) because they define the active river channel. The United States Army Corps of Engineers (USACE) use OHWM for regulation of the "Waters of the United States" as well as for flood and draught management. Current methods to determine OHWM are based on detailed on-site surveys to identify physical characteristics like scouring, deposition around the banks, absence of vegetation and water staining. These characteristics are site specific so there are fluctuations in measurements based on the water body, weather conditions, channel morphology, slope, fluvial patterns and size of the channel. A more reliable way to estimate this variable for hydraulic design is required that is based on storm recurrence intervals. Hydrologic and hydraulic modeling is used to relate OHWM to storm recurrence intervals by analyzing hydraulic and hydrologic parameters corresponding to design streamflow events for 26 watersheds (drainage area less than 200 square miles) in Indiana. The results show that the recurrence intervals of OHWM are actually smaller (less than 1 year) than the bank-full discharge intervals of 1.5-2 years which suggests that OHWM correspond to channel flows much smaller than bank-full discharge. Further analysis using the discharge-return period flow duration curves shows that the OHWM recurrence intervals have a fairly distributed range (0.73-1.12 years) and do not have a fixed recurrence interval. Trend analysis using Mann-Kendall test suggested that five hydrologic/hydraulic variables have a significant trend with OHWM discharges with drainage area, watershed slope and 2-year flow being the most significant. Regional equations are developed for Northern, Central and Southern Indiana to estimate OHWM discharges based on hydrologic/hydraulic parameter estimation using multiple and step-wise liner regression. Using these equations, it is possible to estimate OHWM occurrence discharges fairly accurately.

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EXECUTIVE SUMMARY

RELATING DESIGN STORM EVENTS TO ORDINARY HIGH WATER MARKS IN INDIANA

Introduction

Ordinary high water marks (OHWM) determine the lateral limits of federal jurisdiction over non-tidal waters in the absence of adjacent wetlands in the United States. Even though accurate estimation of OHWM has significant legal and economic implications, they are dependent on physical features of streams without any hydrologic definition. OHWM significantly impact hydraulic design and environmental permitting. For sites without an established OHWM, hydraulic structures are designed conservatively with higher construction costs. This conservative design is often carried out to reduce future maintenance costs, increase safety and reduce property owner complaints. Typically, bridges across a stream are most affected by the non-existence of precisely identified OHWM values. Having an objective way of identifying OHWM is desirable for increasing construction precision and economic sustainability of these structures. This project aims to relate OHWM with storm return periods to reduce the subjective nature of OHWM estimates. Accordingly, this project has the following objectives: (1) to establish and quantify the relationship between OHWM discharge and return periods for ungauged streams in Indiana; and (2) to relate OHWM discharges to the 100-year design discharges for Northern, Central and Southern Indiana.

Findings

- OHWM correspond to return periods of less than 2-years' duration.
- The average return period corresponding to OHWM from this study has a range between 0.73 and 1.12 years. This result suggests that the OHWM does not necessarily correspond to the bank-full depth with a return period of 1.5–2 years.
- OHWM discharges computed as a percentage of 100-year flows range from 2.5% to 5.7% for Indiana. However, on computing the 2-year flows as a percentage of 100-year flows for Indiana, the range is found to be from 20.7% to 23.8%. This range proves the hypothesis that 2-year flows are not accurate predictors of OHWM, and the current INDOT policy needs to incorporate a different range in estimating OHWM.
- For Indiana, it is found that ratio of OHWM discharge and 100-year discharge has an average value of 4.99% for the northern part, 3.60% for the central part, and 5.49% for the southern part.

Implementation

The findings and recommendations from this study are expected to be incorporated in the next update of the Indiana Design Manual. The revised policies will be used by the hydraulics division at INDOT for design projects and Federal Aid local projects.

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1. INTRODUCTION

According to Section 404 of the Clean Water Act (33 CFR Part 328.3) and the Indiana Department of Transportation's (INDOT) Indiana Design Manual, an ordinary high water mark (OHWM) is defined as "a line on the shore of a water body established by the fluctuations of water and indicated by physical characteristics such as clear, natural lines impressed on the bank, shelving, changes in the character of soil, natural destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas" (INDOT, 2013; Riley, 2005; U.S. Congress, 1986). One of the most important applications of OHWM is identifying the lateral limits of federal jurisdiction over non-tidal waters in the absence of adjacent wetlands for government organizations such as United States Army Corps of Engineers (USACE) and Environmental Protection Agency (USACE, 2001). They also define the regulatory boundaries between interstate waters, state-owned and public-owned properties (U.S. Congress, 1986). Thus, even though accurate estimation of OHWM has significant legal and economic implications, they are dependent on physical features of streams without any hydrologic definition. The current estimation techniques for OHWM rely on manual inspection using on-site signs like the presence of terrestrial versus aquatic vegetation, physical signs of scouring and soil erosion (Lichvar & Wakeley, 2004; Mersel, Lefebvre, & Lichvar, 2014; USACE, 2012a).

There are some common assumptions regarding the existence of OHWM such as (1) OHWM correspond to return periods of 1.5–2 years; (2) OHWM occur at bank-full discharges; (3) OHWM occur at the end of the vegetation scour line; and (iv) OHWM occur at the transition from riparian to upland vegetation (Lefebvre, Lichvar, & Curtis, 2013; Lichvar & McColley, 2008; Mersel, 2013a).

The issue with determination of OHWM at the end of vegetation scour line or at the transition from riparian to upland vegetation is that vegetation can vary temporally as well as spatially and the transition from riparian to upland vegetation is gradual and often hard to determine (Liu, Xia, Kuhn, Wright, & Arnold, 2013; Mersel, Lefebvre, et al., 2014; Mersel, 2013a). These field indicators are inconsistent across different regions, and thus it is essential to identify a generalized classification system applicable across all ungauged streams (Mersel, 2013b). OWHM field indicators such as climate, vegetation, soil characteristics and geology significantly impact OHWM distribution in streams (Curtis & Lichvar, 2010; Lichvar, Finnegan, Ericsson, & Ochs, 2006; Olson & Stockdale, 2010).

Studies in the past have tried to relate OHWM to bank-full discharges based on the assumption that bank-full discharges define the active channel and the physical indicators of bank-full discharge in natural channels are similar to OHWM indicators (Young, McEnroe, Gamarra, Luo, & Lurtz, 2014). Bank-full discharge of rivers occurs when the water surface elevation corresponding to the discharge is at the top of the banks and causes a change in the relationship between cross-sectional area and top width (Williams, 1978). Even though bank-full discharges are significant to flood-estimation and planning, these do not define the active channel discharge that occurs during most of the year (USACE, 2012a). Studies have also related bank-full discharge to return periods of 1.5–2 years, and hence the assumption that OHWM discharges should also correspond to return periods of 1.5–2 years is considered reasonable (Castro & Jackson, 2002; Young et al., 2014). Some studies have suggested that bank-full discharge are greater than OHWM for steeper channels with large sediment size while OHWM are greater for reaches with multiple side channels and mild slopes (Olson & Stockdale, 2010).

OHWM significantly impact hydraulic design and environmental permitting since they define the active channel (IDEM, 2008). A higher OHWM suggests a larger channel width and higher water surface elevation, and these can lead to the design of a larger hydraulic structure. For sites without an established OHWM, hydraulic structures are designed conservatively with higher construction costs (ODOT, 2007; USACE, 2012c). This conservative design is often carried out to reduce future maintenance costs, increase safety and reduce property owner complaints (ODOT, 2007; USACE, 2012b, 2012d). Typically, bridges across a stream are most affected by the non-existence of precisely identified OHWM values. Improper assessment of OHWM can cause excessive damages to both public and private properties during extreme flood events and can also cause significant scouring near the bridge piers and abutments (INDOT, 2009; Lee, 2010). It is clear that the current approach to determining OHWM is based on certain assumptions and visual interpretation of physical signs that have slightly different meaning for different individuals. As a result, the OHWM estimates are highly subjective, and can be sometime erroneous. The overall goal of this project is to establish a more concrete criterion for OHWM determination for Indiana watersheds by relating it to some watershed characteristics. Accordingly, specific objectives include (1) to establish and quantify the relationship between OHWM discharge and return periods for ungauged streams in Indiana; and (2) to relate OHWM discharges to the 100-year design discharges for Northern, Central and Southern Indiana.

2. SITE SELECTION AND DATA COMPILATION

In order to obtain a representative sample of all the sites in Indiana, 26 sites based on distinct topography and land use characteristics are chosen for this study. Using physiographical homogeneity for Indiana, three main regions are used for selecting watersheds: (1) Northern Moraine and Lake region; (2) Central Till Plain; and (3) Southern Hills and Lowland region (Robinson, 2013). Accordingly, 6 sites from Northern (Region 1), 13 sites from Central (Region 2) and 7 sites from Southern

(Region 3) are chosen for analysis as shown in Figure 2.1 and Table 2.1. The streams are chosen on the basis of availability of reliable observed OHWM data and watershed area for each region to obtain average discharge conditions throughout the year. Most of the smaller streams in Indiana are not perennial, and only carry discharge during storm events. The larger streams, on the other hand, have a predetermined OHWM which is fairly stable. Considering these factors, and the availability of observed OHWM for analysis, mid-sized streams with drainage areas ranging from a few square miles to about 150 square miles are selected.

This study required hydrologic and hydraulic modeling for the 26 sites in order to relate hydraulic outputs to OHWM. For hydrologic modeling, Digital Elevation Model (DEM), land use and soil data are compiled for each site. The 30 m resolution DEM is compiled for Indiana using the National Elevation Dataset (NED) provided by the United States Geological Survey (Gesch, 2007). The land use data for these sites is obtained from the National Land Cover Dataset (NLCD: http://nationalmap.gov/viewer.html) while the soil data is obtained using the Natural Resources Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO). Impervious cover data in the form of raster grid is downloaded from the Indiana Map Data Server (USGS, 2006). In addition, frequency storms of different rainfall durations are also compiled for each study site using the National Weather Service's (NWS) Precipitation Frequency Data Server (PFDS) which uses the partial duration series method for evaluating rainfall depth for different return periods (Bonnin et al., 2006). The design 100-year discharge values for all the sites and related OHWM widths and depths are also obtained from INDOT for model calibration.

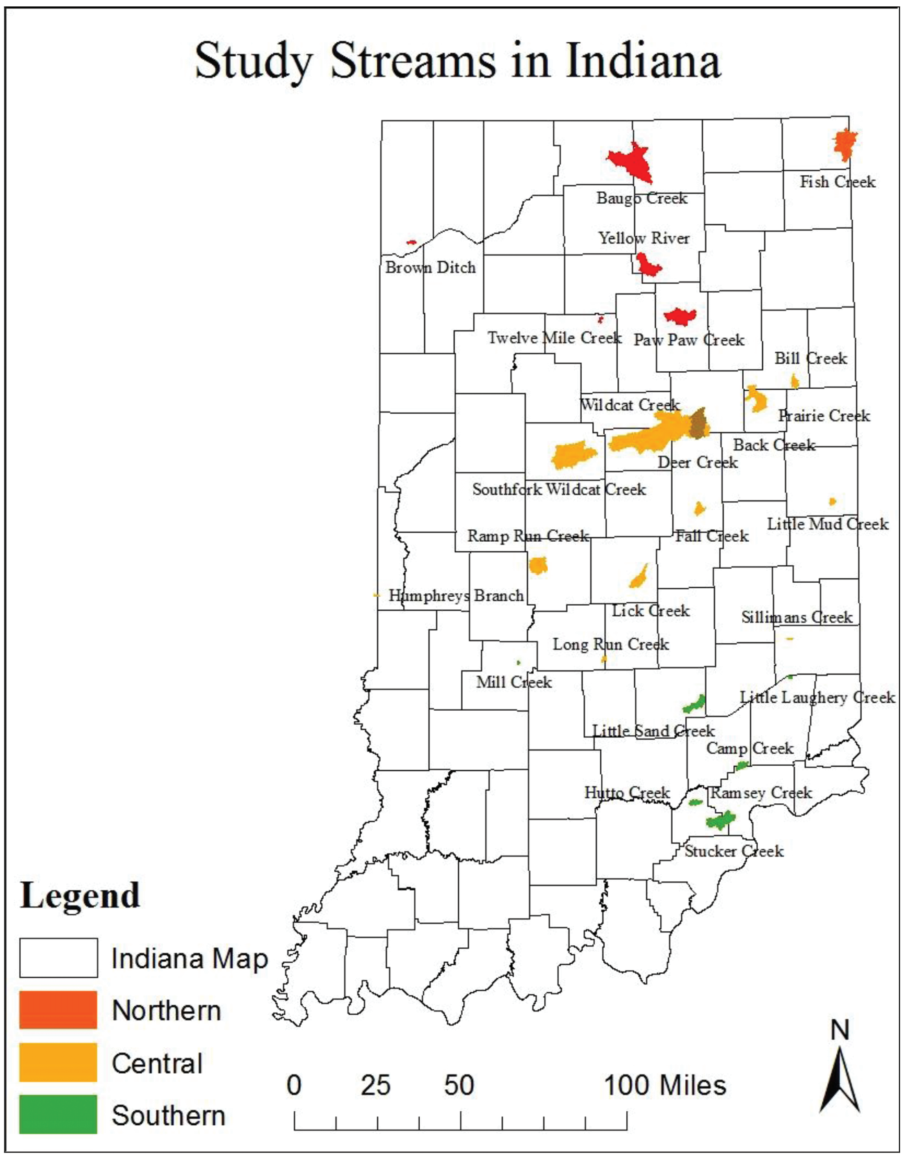

Figure 2.1 Watershed extents for identified streams in Indiana.

TABLE 2.1
Description of the sites chosen for this study.

Location	Name	Drainage Area (mi^2)	Location	Name	Drainage Area (mi^2)
Central	Humphreys Branch	0.97	North	Twelve Mile Creek	2.3
Central	Sillimans Creek	1.44	North	Brown Ditch	3.14
Central	Long Run Creek	2.62	North	Yellow River	27.28
Central	Little Mud Creek	3.64	North	Paw Paw Creek	32.3
Central	Back Creek	5.67	North	Fish Creek	41.4
Central	Bill Creek	6.97	North	Baugo Creek	78.75
Central	Fall Creek	7.93	South	Mill Creek	1.28
Central	Lick Creek	15.92	South	Little Laughery Creek	1.56
Central	Ramp Run Creek	23.58	South	Ramsey Creek	1.96
Central	Prairie Creek	27.78	South	Hutto Creek	6.00
Central	Deer Creek	35.42	South	Camp Creek	6.88
Central	Southfork Wildcat Creek	71.31	South	Little Sand Creek	16.14
Central	Wildcat Creek	165.0	South	Stucker Creek	27.27

3. METHODOLOGY

In order to accomplish the objective listed in the Introduction section, the methodology involves the following steps for all study sites: (1) data preprocessing and hydrologic modeling for obtaining peak streamflows; (2) 1D hydraulic modeling using peak streamflows for obtaining water surface elevations and top widths; (3) relating hydraulic model outputs to observed OHWM data; (4) establishing discharges corresponding to OHWM values; and (5) relating OHWM discharge values to 100-year discharge at the study sites.

3.1 Data Preprocessing and Hydrologic Modeling

Hydrologic modeling for all sites is conducted by using Hydrologic Engineering Center's Hydrology Modeling System (HEC-HMS; Feldman, 2000). HEC-HMS modeling for each site involved: (1) calibrating the model for 100-year discharge; (2) running the calibrated model for various design storm events to produce corresponding hydrographs; and (3) compilation of results for use in a hydraulic model. These steps require the identification of a loss method and a hydrograph transform method. The SCS Curve Number method was used as the loss method while the SCS Unit Hydrograph was used as the transform method.

Rainfall inputs for hydrologic modeling are obtained in the form of 24-hour duration frequency hyetographs using precipitation values corresponding to return periods of 2, 5, 10, 25, 50 and 100 years for all the sites. The drainage outlet for each watershed is set at the upstream cross-section station of the bridge at which the OHWM dimensions (width and depth) are measured. Each hydrologic model is calibrated for a 100-year design discharge which is provided by INDOT using the SCS Curve Number method that uses initial abstraction, curve number, lag-time and impervious cover percentage as model parameters for estimation of runoff. The curve number grid and lag-times for Indiana streams are extracted using the NED 30 m DEM, NLCD land use map for Indiana and SSURGO soil geodatabase in ArcGIS using the HEC-GeoHMS tool (Fleming & Doan, 2009). The initial abstraction for all the sites is set equal to 0.2 times the soil moisture retention potential.

Calibration is carried out by varying the lag-time for each sub-watershed in the basin and estimating the peak streamflow to match the 100-year design discharge for all the sites. The calibrated HEC-HMS model is run to produce peak streamflow values for 2, 5, 10, 25 and 50 year frequency storms.

3.2 Hydraulic Modeling

Hydraulic modeling is conducted for all study reaches to produce water surface extents and elevations corresponding to the hydrographs produced from HEC-HMS. Hydrologic Engineering Center's River Analysis System (HEC-RAS; Bruner, 2010) is used for hydraulic modeling with a steady state assumption by using peak streamflow values obtained from HEC-HMS as input discharge. Since the HEC-RAS models for all the reaches in the study were previously calibrated by INDOT for flood modeling purposes, the geometric data comprising of cross-sections, boundary conditions Manning's n values and bridge data are used without modifications. After running HEC-RAS simulations, the water surface extents and elevations upstream of the bridges are used to evaluate the widths and depths of flow corresponding to the different return periods.

3.3 Relating Observed OHWM to Hydraulic Model Outputs

The OHWM dimensions are measured at the upstream sections at the bridges located within the channel reach for all the sites. Outputs from HEC-RAS models for various storm events at the upstream cross-section station of the bridges are compared with available OHWM to relate the water levels to specific design storm events. In order to relate OHWM to return periods, the calibrated HEC-RAS models are used to obtain discharge values corresponding to OHWM depths and top widths using the method of trial and error. This method involves running the HEC-RAS models for different streamflow values and obtaining discharge-stage and discharge-width relationships at the bridge cross-sections where the OHWM measurements are made. These relationships are used to obtain the discharge values corresponding to OHWM width and depth for all the sites.

3.4 Relating OHWM Discharge to 100-Year Discharge

In order to get OHWM discharge for any site, regional ratios between OHWM and 100-year discharges are computed. These ratios are used to obtain the mean, standard deviation and 95% confidence intervals (CI) of % 100-year discharges for Northern, Central and Southern Indiana.

4. RESULTS

The results are presented in three parts: (1) hydrologic modeling results; (2) relationship of OHWM return periods with hydrologic/hydraulic modeling results; and (3) ratio of OHWM discharges with respect to 100-year discharges.

4.1 Hydrologic Modeling Results

Table 4.1 shows the HEC-HMS model calibration results using 100-year design discharge for all the sites. Figure 4.1 presents the peak streamflow values obtained from HEC-HMS using design storm events for different return periods for Northern and Southern Indiana on a semi-log axis. Results for Central Indiana are divided in two parts to clearly identify the sites with smaller and higher peak discharge rates as shown in Figure 4.2. The flood frequency curves for study areas in Southern Indiana have greater slope with respect to the return period.

4.2 Relationship between OHWM and Hydrologic/Hydraulic Outputs

Outputs from HEC-RAS models for various storm events at the upstream cross-section station at the bridges are compared with observed OHWM to relate the water levels to specific design storm events. Table 4.2 presents the HEC-RAS modeling results for a 2-year discharge and comparison with observed OHWM values for all the sites in increasing order of drainage area. The width of the 2-year discharge at the bridge cross-section is obtained by looking up HEC-RAS top width while the 2-year depth is calculated as the difference between the water surface elevation at the cross-section and the minimum channel elevation.

After obtaining the discharges corresponding to OHWM values, the results for all sites are compared with 2-year discharges. Using the flood-frequency curves, plot between peak streamflow and return periods, for all sites, rainfall return periods corresponding to OHWM

TABLE 4.1
HEC-HMS model calibration results for Indiana.

Location	Name	Drainage Area (mi^2)	Calibrated Peak Discharge (cfs)	Volume (inches)	100-yr Discharge (cfs)
Central	Humphreys Branch	1.0	390.6	4.64	391
South	Mill Creek	1.3	1161.1	4.01	1160
Central	Sillimans Creek	1.4	641.1	2.95	641
South	Little Laughery Creek	1.6	1500.9	4.26	1500
South	Ramsey Creek	2.0	999.6	4.46	1000
North	Branch-Twelve Mile	2.3	923.6	4.26	925
Central	Long Run Creek	2.6	1700.1	4.57	1700
North	Brown Ditch	3.1	629.2	4.49	630
Central	Little Mud Creek	3.6	1100.5	3.35	1100
Central	Back Creek	5.7	1231.5	2.52	1230
South	Hutto Creek	6.0	2599.0	4.37	2600
South	Camp Creek	6.9	2996.9	4.39	3000
Central	Bill Creek	7.0	661.1	2.22	660
Central	Fall Creek	7.9	2601.0	3.23	2600
Central	Lick Creek	15.9	6800.7	4.69	6800
South	Little Sand Creek	16.1	5111.3	4.44	5110
Central	Ramp Run Creek	23.6	6256.4	4.04	6260
South	Stucker Creek	27.3	7830.8	3.93	7830
North	Yellow River	27.3	1200.8	3.34	1200
Central	Prairie Creek	27.8	3301.5	4.64	3300
North	Paw Paw Creek	32.3	3602.9	3.92	3600
Central	Deer Creek	35.4	3700.0	3.99	3700
North	Fish Creek	41.4	1973.1	3.77	1975
Central	South Fork Wildcat Creek	71.3	9621.6	3.94	9620
North	Baugo Creek	78.8	3855.5	3.74	3860
Central	Wildcat Creek	165.0	9199.0	1.17	9200

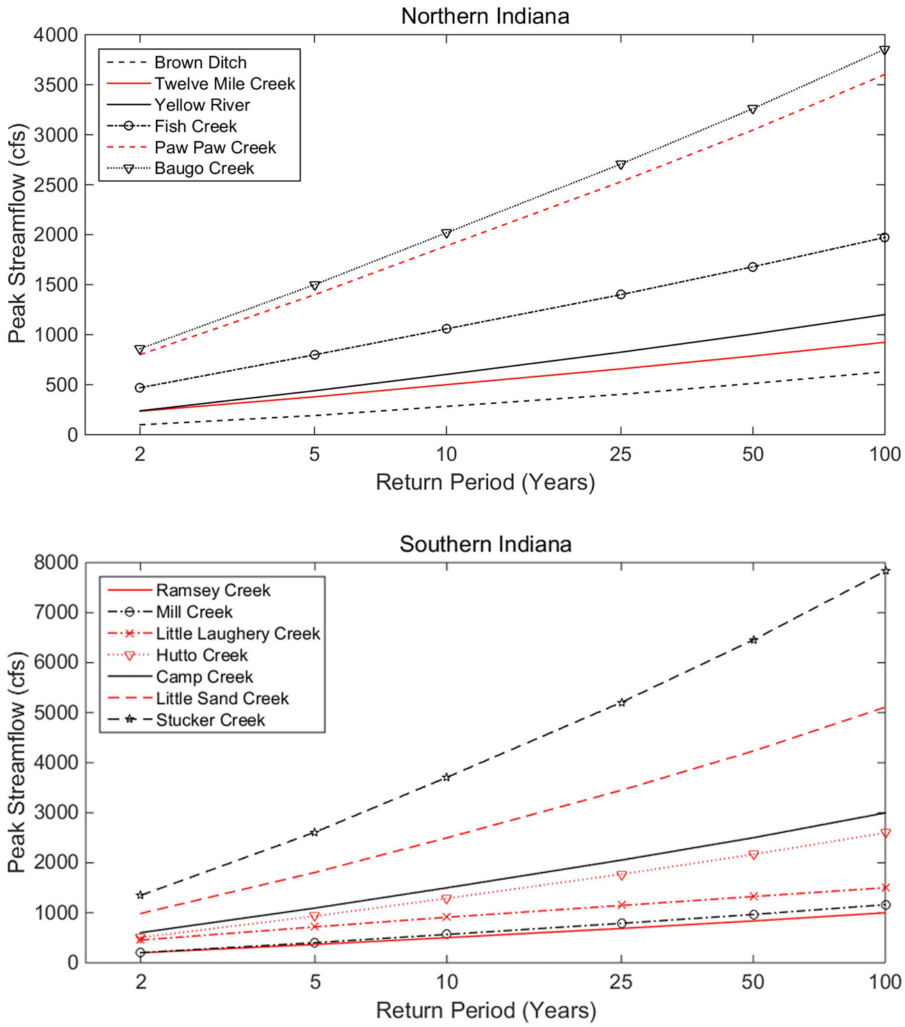

Figure 4.1 Peak streamflow versus return period using HEC-HMS for Northern Indiana (top) and Southern Indiana (bottom).

are estimated. The results suggest that OHWM correspond to return periods less than 2 years for 25 out of the 26 sites. In fact, the OHWM for 22 out of 26 sites have return periods less than or equal to 1 year. The average return period corresponding to OHWM is 0.92 years with a range between 0.73 and 1.12 years. This value suggests that the common assumption that OHWM correspond to bank-full dimensions with return periods of about 1.5–2 years does not hold ground for Indiana. Based on the results, the return period corresponding to OHWM is much smaller. Therefore, OHWM discharges should be modeled separately from bank-full discharges and even though there are similarities in the physical characteristics of bank-full and OHWM indicators, the active channel discharge is significantly lower than the bank-full discharge.

Table 4.3 provides detailed results for OHWM discharges and corresponding return periods in increasing order of return periods. It also presents a comparison between 2-year discharge, 100-year discharge and OHWM discharge for all the sites.

The results indicate a site-specific dependence of OHWM values, thus suggesting that OHWM are not related to any specific return period. However, these results can be applied to a variety of watersheds since OHWM correspond to return periods closer to 1 year for different drainage areas and different regions in Indiana. Even for sites with smaller drainage areas, the 2-year discharge values for Southern Indiana are higher than Northern and Central Indiana. This can be substantiated by the higher 2-year discharge to drainage area ratios for the sites in Southern Indiana when compared to Northern and Central Indiana. A possible explanation for this departure is the existence of steeper channel slopes for the sites in Southern Indiana which also explains why the OHWM values for Mill Creek and Stucker Creek are significantly higher than other watersheds with similar drainage area. Even though Humphreys Branch watershed is located

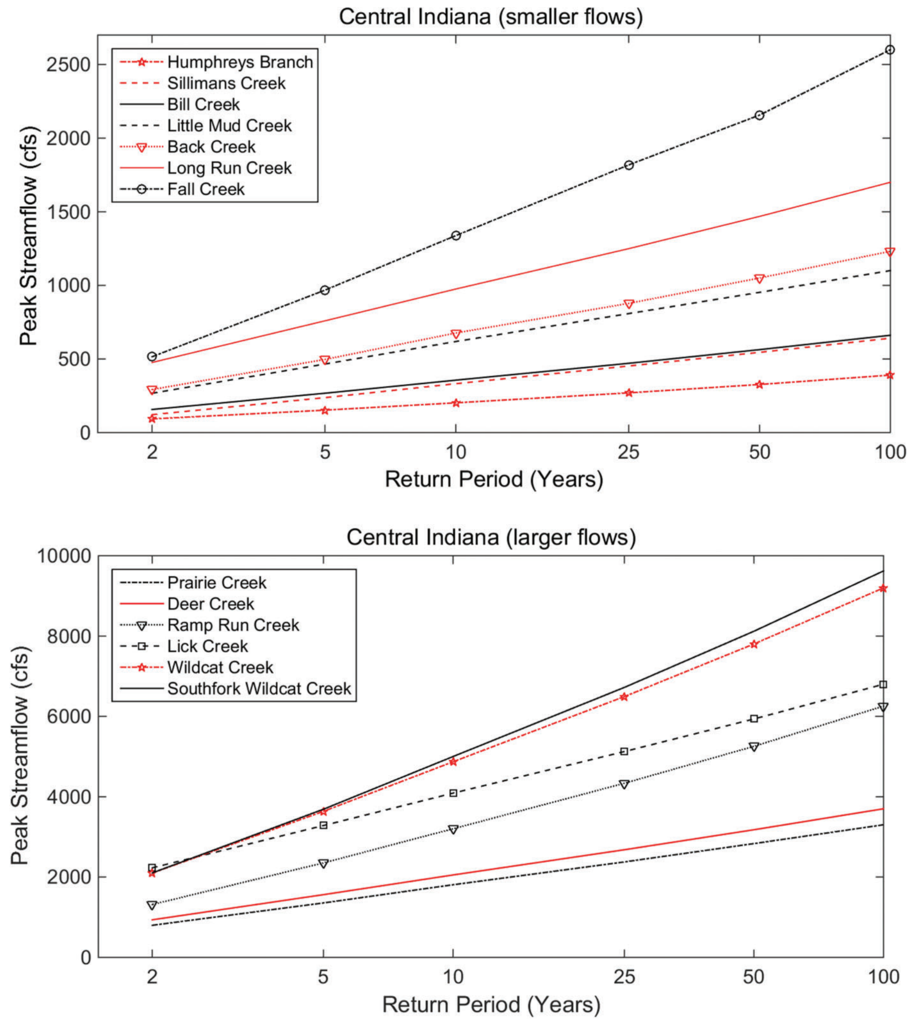

Figure 4.2 Peak streamflow versus return period using HEC-HMS for Central Indiana (top; lower peak discharge rates) and Central Indiana (bottom; higher peak discharge rates).

in Central Indiana, it is situated in Western Indiana which is a region with steeper slopes and therefore has a higher OHWM discharge. The dependence of OHWM return periods on average slope of the watersheds is clearly noticeable from the results.

For the sites with mild slopes, the OHWM correspond to return periods of less than 1-year. Southern Indiana is also characterized by a higher percentage of forest cover in comparison to Northern Indiana that has significant agricultural land use, and Central Indiana that has a higher percentage of urban land cover. This suggests that the slope of the watershed and vegetation characteristics of the watersheds play an important role in establishing the OHWM at these sites (Mersel, Lichvar, Gillrich, & Lefebvre, 2014). Even though the average slope of the watershed is a significant parameter in explaining the outliers, statistical analysis suggests that the slopes of the northern and central region are not significantly different from each other (Wilkerson & Merwade, 2010).

4.3 Range of OHWM Discharges

After obtaining a range of storm return periods, OWHM discharges are compared with 100-year discharge values for Northern, Central and Southern Indiana. Table 4.4 presents the statistical parameters of OHWM discharges and 2-year discharges as a percentage of 100-year discharge. This computation is carried out for 25 out of 26 sites after excluding Humphreys Branch results as this site is an outlier.

Table 4.4 shows that OHWM discharges computed as a percentage of 100-year discharges range from 2.5% to 5.7% for Indiana. However, on computing the 2-year discharges as a percentage of 100-year discharges for Indiana, the range is found to be from 20.7% to 23.8%. This range proves the hypothesis that 2-year discharges are not accurate predictors of OHWM and the current INDOT policy needs to incorporate a different range in estimating OHWM. This analysis also suggests that using the upper 95% CI value of OHWM discharge as a

TABLE 4.2
HEC-RAS outputs for 2-year discharge and OHWM geometry data for Indiana.

Location	Name	Drainage Area (mi^2)	2-year Depth (feet)	2-year Width (feet)	OHWM Depth (feet)	OHWM Width (feet)
Central	Humphreys Branch	1.0	2.2	16.5	2.5	18.0
South	Mill Creek	1.3	3.8	29.2	2.5	22.0
Central	Sillimans Creek	1.4	1.5	22.1	1.0	15.0
South	Little Laughery Creek	1.6	5.6	83.1	1.0	14.0
South	Ramsey Creek	2.0	3.5	71.2	1.0	10.0
North	Twelve Mile Creek	2.3	4.1	50.0	0.5	10.0
Central	Long Run Creek	2.6	5.1	41.4	1.3	20.0
North	Brown Ditch	3.1	4.5	37.2	3.0	32.0
Central	Little Mud Creek	3.6	4.3	36.9	1.3	22.0
Central	Back Creek	5.7	4.3	33.7	1.0	20.0
South	Hutto Creek	6.0	9.3	214.2	3.0	20.0
South	Camp Creek	6.9	4.4	74.2	0.9	12.0
Central	Bill Creek	7.0	4.6	22.2	3.1	13.0
Central	Fall Creek	7.9	5.6	247.0	3.0	20.0
Central	Lick Creek	15.9	9.7	100.9	1.1	30.0
South	Little Sand Creek	16.1	6.8	56.0	5.5	40.0
Central	Ramp Run Creek	23.6	6.9	83.1	2.5	32.0
South	Yellow River	27.3	3.8	29.6	3.0	22.0
North	Stucker Creek	27.3	5.4	62.7	5.0	48.0
Central	Prairie Creek	27.8	7.5	310.9	3.0	39.0
North	Paw Paw Creek	32.3	8.2	76.0	2.5	30.0
Central	Deer Creek	35.4	5.7	254.1	5.0	48.0
North	Fish Creek	41.4	3.9	47.0	2.0	34.4
Central	South Fork Wildcat Creek	71.3	9.5	451.0	2.8	61.0
North	Baugo Creek	78.8	6.3	85.7	3.0	50.5
Central	Wildcat Creek	165.0	8.8	204.0	4.5	108.0

TABLE 4.3
OHWM discharge data analysis and return periods*.

Name	Drainage Area (mi^2)	2-year Discharge (cfs)	100-year Discharge (cfs)	OHWM Discharge (cfs)	% 100-year	Return Period (years)
Lick Creek	15.92	2022	6800	30	0.44	0.29
Little Laughery Creek	1.56	454	1500	27	1.80	0.41
Long Run Creek	2.62	476	1700	48	2.82	0.49
Twelve Mile Creek	2.30	235	925	8	0.86	0.53
Little Mud Creek	3.64	267	1100	19	1.73	0.62
Prairie Creek	27.78	798	3300	120	3.64	0.68
Paw Paw Creek	32.30	800	3600	55	1.53	0.69
Southfork Wildcat Creek	71.31	2102	9620	130	1.35	0.70
Ramp Run Creek	23.58	1315	6260	80	1.28	0.73
Camp Creek	6.88	601	3000	20	0.67	0.75
Back Creek	5.67	292	1230	25	2.03	0.75
Wildcat Creek	165.00	2099	9200	430	4.67	0.78
Hutto Creek	6.00	506	2600	30	1.15	0.80
Ramsey Creek	1.96	200	1000	10	1.00	0.80
Fall Creek	7.93	515	2600	52	2.00	0.82
Baugo Creek	78.75	859	3860	160	4.15	0.85
Deer Creek	35.42	935	3700	350	9.46	0.86
Fish Creek	41.40	469	1975	180	9.11	0.92
Sillimans Creek	1.44	122	641	20	3.12	0.93
Bill Creek	6.97	157	660	70	10.61	1.01
Little Sand Creek	16.14	985	5110	300	5.87	1.03
Yellow River	27.28	238	1200	80	6.67	1.04
Brown Ditch	3.14	98	630	48	7.62	1.41
Mill Creek	1.28	203	1160	150	12.93	1.63
Stucker Creek	27.27	1345	7830	1175	15.01	1.86
Humphreys Branch	0.97	93	391	110	28.13	2.63

*The 2-year discharge value corresponds to the initial reference value for OHWM that was used by INDOT prior to this study. The %100-year column represents OHWM values as a percentage of 100-year discharges.

TABLE 4.4
OHWM and 2-year discharges as a percentage of 100-year discharges for Indiana*.

Location	Mean	Standard Deviation	Lower 95% CI	Upper 95% CI
OHWM Discharge Presented as %100-Year Discharge				
Statewide	4.11	3.82	2.53	5.69
Northern	4.99	3.36	1.46	8.52
Central	3.60	3.22	1.55	5.64
Southern	5.49	6.08	1.00	11.11
2-year Discharge Presented as %100-Year Discharge				
Statewide	22.26	3.71	20.73	23.79
Northern	21.51	3.42	17.93	25.10
Central	23.63	3.12	21.64	25.61
Southern	20.55	4.44	16.44	24.65

*All values represent %100-year discharges. The confidence intervals are calculated using a t-distribution.

percentage of 100-year discharge seems to be a conservative and reasonable estimate in determining the OHWM discharge. This upper 95% CI value can be used in hydraulic models to obtain width and elevation corresponding to OHWM which can be used as a reference for channel clearing purposes.

5. SUMMARY AND CONCLUSIONS

Using the results obtained in Table 4.4, it is possible to obtain an estimate of OHWM discharge corresponding to a specific region with a significance level of α=0.05. Following are the conclusions from this study:

1. OHWM depend on a variety of hydraulic and hydrologic parameters which include drainage area, 2-year discharge, average watershed slope and flood frequency estimates.
2. OHWM correspond to return periods of less than 2-year duration. This suggests that the reference value that was used by INDOT prior to this study needs to be modified.
3. In Indiana, average bank-full discharges correspond to return periods between 1.5 and 2 years. The average return period corresponding to OHWM from this study has a range between 0.73 and 1.12 years. This value suggests that the hypothesis that OHWM correspond to bank-full discharges is not true and is in fact much smaller than the previous assumption for Indiana.
4. The results based on comparison of OHWM discharge with 2-year discharges as a percentage of 100-year discharges clearly show that the mean OHWM discharge is about 4.1% while the mean 2-year discharge is about 22.6%. Even the upper limit of OHWM confidence interval is significantly less than 2-year discharges. This upper 95% CI value can be used determine maximum possible OHWM width and elevation for any site in Indiana.

The range of OHWM discharges developed in this study can be used as a guide for OHWM determination for ungauged sites that do not have physical indicators for OHWM. Prolonged floods or draught can also impact the location of OHWM which can reduce the accuracy of results since they do not account for change in discharge conditions over a long period of time. It should also be noted that the range of OHWM discharges developed in this study are based on the analysis of 26 watersheds in Indiana and increasing the number of sites in future studies can decrease the uncertainty associated with OHWM.

6. IMPLEMENTATION AND POTENTIAL SAVINGS

The findings and recommendations from this study are expected to be incorporated in the next update of the Indiana Design Manual. The revised policies will be used by the hydraulics division at INDOT for design projects and Federal Aid local projects. One of the primary uses of this study is to provide assistance in sizing bridge-waterway openings that rely heavily upon the estimation of OHWM. Based on previous projects, lowering the OHWM elevation by one foot reduces the bridge size by 650 square feet. Assuming an average bridge construction cost of $120 per square foot, this has the potential to reduce structure costs by $78,000. The cost savings will be greater for structures with higher profile grades, since the length of the structure is also affected by the rise of the structure. In addition to construction cost savings, an accurate estimation of OHWM can help reduce future maintenance costs by avoiding channel meandering, scouring and bridge or abutment repair. The existing INDOT channel clearing policy depends on estimation of OHWM based on 2-year discharge values and the results in this study suggest that modification is required. The regional OHWM ratios based on 100-year discharges developed in this study will be used to estimate OHWM discharges in existing hydraulic models. These hydraulic models will be further used to determine a range of OHWM widths and elevations. After estimating the OHWM attributes using the regional ratios obtained from this study, a comparison between existing OHWM attributes will be carried out and the changes will be adapted in future channel clearing policies.

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