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MEMORANDUM

TO: Mr. Bernard Lenz, PE

FROM: Brad Woznak, PE, PH, CFM
Riley Mondloch, EIT

DATE: December 4, 2017

RE: Ebner Coulee Modeling Phase 2 - Historic Rainfall Analysis

Background

During the first phase of this analysis, SEH estimated flow rates into Ebner Coulee using the USGS Regional Regression equations for Wisconsin and performed modeling to demonstrate that the FEMA effective flood maps may be overestimating floodplain extents due to an overestimation of peak flow rates. See Attachment 1 for the report from the first phase of this project. The results from the first phase of the report were presented to the City of La Crosse Floodplain Task Force Committee. The initial study indicated the potential for significantly lower discharge rates than those published in the effective FIS, which were based on a hydrologic analysis from the late 1970s. Because an overestimation of the flood risks can place an undue burden on the City's residents, the results of the first phase warranted additional analysis of the flow rates. The Wisconsin DNR and ultimately FEMA will require greater scientific justification and proof beyond a just utilization of the regional regression equations over that of the previous hydrologic methodology in order to concur with a letter of map revision based on revised flow rates.

This second phase of the project, discussed in this memo, involves utilizing a hydrologic model to develop peak flow rates, a methodology similar to that originally utilized for the effective FIS. SEH contacted the Wisconsin DNR for the effective hydrologic model and obtained a hardcopy output of the HEC-1 model dated September 1979. SEH performed an in-depth review of the effective HEC-1 model and it was determined that this model was only utilized to route hydrographs developed by other methods and does not perform any rainfall-runoff computations. Similar to the argument made by the USGS in September 1994, it does not appear that sufficient information is available in the FIS documentation to reproduce the design hydrographs from the original FIS. Given this reason, SEH developed a HEC-HMS model, with TR-55 methodology, to perform rainfall runoff-modeling for estimating peak discharge rates for Ebner Coulee. Once the HEC-HMS model was developed, calibration and verification was performed by analyzing historic rainfall events over the past 20 years to a hydrologic model that has been calibrated to first the 1430 cfs FIS discharge and then to peak flow rates developed utilizing the USGS regional regression equations.

The peak flow rates from the three most intense historic rainfalls were calculated with each of the models and results input into the 1D/2D HEC-RAS model developed during the first phase of the project. Floodplain mapping was generated for each of the models and overlaid on the same mapping in an effort to validate the model results to the inundation experienced in the field for each of the three events. Since major flooding has not been observed in this area with any storms over the last 20 years, if the model results indicate significant flooding for the three most intense historic events, it is likely that calculated peak runoff rates are being overestimated.

The ultimate goal of this study is to either verify that the FIS discharge rates are appropriate for the associated flood risk or if not, to develop a scientific methodology that can be moved forward for discussion with the Wisconsin DNR to obtain overview and concurrence in support of a Letter of Map Revision submittal to FEMA.

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Daily and Hourly Historic Rainfall Analysis
There are two rainfall gauging stations of interest for this study with available data for daily rainfall totals. The first station is the La Crosse Municipal Airport, station number USW00014920. The second station is the La Crosse Weather Forecast Office, station number USC00474373. The Weather Forecast Office is a newer station and does not appear to have data before 2000. The Municipal Airport station is approximately 5 miles away from Ebner Coulee, and the Weather Forecast Office station is about 1 mile away from Ebner Coulee. Given the closer distance, it would be ideal to use the Weather Forecast Office data only, however this station does not record hourly rainfall data, so it was necessary to include hourly data from the Municipal Airport station. See attached Figure 1 for a map showing the weather station locations.

Daily rainfall totals between 2001 and November 2017 were obtained for both stations and used to select the peak rainfall event for each year. Rainfall depths of the peak storm for each year at both stations are shown in Table 2. The values at the Weather Forecast Office were slightly higher for most years. The duration of the rainfall events typically varied between 12 and 36 hours.

Hourly rainfall depths were only available at the Municipal Airport station and were obtained from two sources. The NOAA NCDC has hourly rainfall reports from 2003 to 2012 that contain data for this station. WeatherUnderground.com was used to obtain hourly data for 2001, 2002, and 2013-2017. Neither of these sources had hourly rainfall data for 1997 to 2000. The project scope indicated performing the analysis on rainfall data back to 1997, but no data was available at the Weather Forecast Office before 2001 and no hourly data was available at the Municipal Airport station before 2001. We reviewed the yearly peak daily rainfall totals from 1997 to 2000 and it does not appear that any major storms occurred in this time period, so removing these four years from the analysis, will not impact the results.

The historic rainfall data was used to create hourly increment unit hyetographs for the peak storm of each year. These are plots of time versus cumulative rainfall depth for each storm normalized to 1 inch of depth. They are then multiplied by the total depth for each storm; this methodology allowed use of the closer Weather Forecast Office depths with the rainfall distributions from the Municipal Airport Location.

Available rainfall data from WeatherUnderground.com is reported in increments less than an hour, this more detailed data was used to create hyetographs with 10 minute increments for the three largest events. The hyetographs with a shorter time increment better capture short, intense periods of rainfall and may result in higher, more realistic runoff hydrographs. Since the data obtained from Weather Underground has inconsistent recording times at this location, ranging from 3 minutes to 1 hour, it was necessary to interpolate between some records to create the consistent 10 minute increment distribution for input into the HEC-HMS model.

HMS Model Calibration
HEC-HMS version 4.2.1 was used for the hydrologic analysis for this phase of the project.

From a review of available documentation, it appears that the effective FIS hydrologic analysis developed the flood hydrograph by scaling of the flood frequency information from Gilmore Creek in Winona, MN based on calculations utilizing the Bureau of Public Roads Method, also called the Cook Method. The USACE HEC-1 model was utilized to route the hydrograph through the Ebner Coulee System with UNET modeling utilized to develop water surface elevations.

During the first phase of this project, SEH estimated flow rates using the USGS Regional Regression Equations for Wisconsin; that analysis resulted in flow rates much lower than the 1430 cfs depicted in the effective FIS as the 1-percent discharge. See Table 1 for the Regression Equation results.

Table 1: Phase 1 Regression Equation Results

Source	Location	Drainage Area (SqMi)	Peak Flow (cfs)	ESE (%)	Minus 1 Standard Error (cfs)	Plus 1 Standard Error(cfs)
FEMA Effective	All Locations	0.9	1430.0			
Regression Eq.	Upstream Limit of Fema Model	0.61	360.8	44	202.0	519.5
Regression Eq.	Jackson Street	0.88	428.5	44	240.0	617.0
Regression Eq.	Farnman Street	1.13	494.7	44	277.0	712.3

During the first phase of the project, a HEC-HMS model using the SCS hydrologic method was also developed as another means to estimate peak flow rates; this methodology resulted in flow rates higher than the Regression Equations (100-year discharge of 601 cfs for the 0.61 square mile drainage area to the upstream end of the model), but still significantly lower than the 1430 cfs effective flow rate. SCS hydrology with HEC-HMS is being used again for this second phase of the project to create a hydrologic model calibrated to the 1430 cfs for the 100 year event.

An area of 0.9 square miles was used for the calibrated watershed model, this area corresponds to the larger watershed to the top of Jackson Street, not the top of the Ebner Coulee drainage ditch. It was determined that this was the only drainage area utilized in the original FIS to obtain the 1-percent flow rate of 1430 cfs. Based on the hydrologic characteristics, the Curve number (CN) and time of concentration of 58 and 67 minutes, respectively, were estimated.

Executing the hydrologic model with these original parameters results in a flow rate of 892 cfs, well below the 1430 cfs desired for calibration, so the CN was increased to 65 and time of concentration was lowered to 49. These values result in a 100 year peak flow rate of 1431 cfs, making this the HEC-HMS model calibrated to the FIS flow rate. Changing the CN and time of concentration to these values is reasonable for the following reasons: The original CN corresponded to B classified soils, because that is the majority soil classification in this area according the NRCS soils data. The new value of 65 corresponds to the same land cover distribution, but with half C classified soils and half B classified soils. The NRCS soils data is very approximate, and there are some C soils in the drainage area, so using a balanced value is very reasonable. Estimating the time of concentration is relatively approximate, so lowering it by 18 minutes is not unrealistic given the steep slopes of the watershed.

HEC-HMS Hydrologic Modeling with FIS Calibrated Model

A HEC-HMS model run was developed for each year utilizing the FIS calibrated hydrologic model and the historic unit hyetograph distributions from the Municipal Airport station with La Crosse Weather Forecast Office station total depths. These depths should be more appropriate for the Ebner Coulee watershed given the closer distance, the rainfall distribution was assumed to be similar to that of the Municipal Airport. Table 2 shows the peak flow rate results for each storm from the FIS calibrated HMS model. The approximate duration over which the majority of the rainfall total fell is also shown in Table 2, note that the rainfall distributions varied greatly, so for some storms the rainfall total may have fallen continuously while for others may have been made up of several separate periods of rainfall. The Atlas 14 rainfall depths for the 1-, 2-, 10-, 50-, and 100-year, 24-hour storm events with MSE3 distributions were also modeled in the FIS calibrated model for comparison and are shown in Table 3.

Table 2: Highest Total Storm Depth per Year and FIS calibrated HEC-HMS Peak Flow Results

	Total Storm Depth (in)			
	Municipal Airport	Weather Forecast Office		
Year	USW00014920	USC00474373	Peak Flow(cfs)	Duration (hours)
2001	3.12	4.19	318	32
2002	2.7	2.9	77	45
2003	1.05	1.39	3	28
2004	3.53	2.76	53	41
2005	3.15	2.96	171	28
2006	1.82	2.89	110	25
2007	6.76	7.59	**326**	40
2008	4.4	5.31	**527**	36
2009	3.33	3.36	317	23
2010	3.87	3.99	148	29
2011	0.98	2.58	153	36
2012	1.61	1.63	11	15
2013	2.77	2.42	74	29
2014	1.16	2.77	117	22
2015	1.49	2.32	40	14
2016	4.7	4.28	111	32
2017	5.15	6.26	**996**	12

Table 3: Atlas 14 Depths with MSE3 Distribution Peak Flow Results

Storm	Atlas 14 Depth	Q Peak (cfs)
MSE3 - 1 yr, 24 hr	2.61	95
MSE3 - 2 yr, 24 hr	3.01	159
MSE3 - 10 yr, 24 hr	4.47	490
MSE3 - 50 yr, 24 hr	6.53	1093
MSE3 - 100 yr, 24 hr	7.57	1431

HEC-RAS Hydraulic Modeling

The unsteady 1D-2D coupled HEC-RAS model from the first phase of the project was used for this analysis. HEC-RAS version 5.0.3 was used. This model uses 1D techniques to represent flow within the ditched portion of Ebner Coulee, and 2D techniques for the floodplain areas, when flow spills out of the channel. This model was chosen because it the best mix of preserving the original FIS modeling methodology while incorporating 2D modeling techniques for the complex overbank flows that cannot be properly represented with 1D flow methods. The three highest peak flow historic events were modeled, the years of these events are 2007, 2008, and 2017.

The HEC-HMS model was calibrated with a drainage area of 0.9 square miles to match the drainage area in the original FIS study; from a review of the watershed, this corresponds to the area draining to the top of Jackson

Street. The historic flow hydrographs obtained from this FIS calibrated HEC-HMS model were input at Jackson Street in the HEC-RAS model, which differs from the effective FIS HEC-RAS model which included the hydrograph from this drainage area at the top of the model/start of the Ebner Coulee. To estimate the discharge at the upstream end of the Coulee, the FIS calibrated HEC-HMS model was duplicated and the drainage area was modified to 0.61 square miles, the area draining to the top of the coulee system. This was used to obtain the flow hydrograph at the top of the coulee system for the historic storms. Table 4 shows the historic peak flows to Jackson Street and the historic peak flows to the top of the Ebner Coulee ditch for the three storms modeled. Note that the hydrograph applied to the HEC-RAS model at Jackson Street is actually the result of the total hydrograph with the top of model hydrograph subtracted from it, so the flows below Jackson Street will be summed correctly. Travel time between the two points is minimal and was neglected with this methodology.

Table 4: Peak Flows of Hydrographs used in HEC-RAS (FIS calibrated HEC-HMS model)

	Peak Flow(cfs)	
Year	0.9 Sq-mi	0.61 Sq-mi
2007	326	221
2008	527	357
2017	996	675

Figures 2, 3, and 4 depict the inundation of these three historic events as modeled with the unsteady 1D-2D HEC-RAS model using hydrographs developed with the FIS calibrated HEC-HMS model. The FEMA effective 1-percent floodplain is also shown for comparison.

Historic Storms Compared to Regional Regression Equations

For phase 1 of the project, a HEC-HMS model was developed using the MSE3 distribution with a 7.1 inch 100 year, 24 hour rainfall depth and calibrated to output flows matching the results from the USGS Regional Regression Equations (RRE). Similar to the modeling performed with phase 2, there was a version of this model with a drainage area of 0.61 square miles (to the top of the coulee/start of model) and a model with a drainage area of 0.9 square miles (to Jackson Street) matching the original FIS drainage area.

The three peak historic rainfall events were modeled with these RRE calibrated HEC-HMS models to obtain peak flows and hydrographs for the historic events calibrated to the Regional Regression Equation results. The 10, 50, and 100 year events with MSE3 distributions and Atlas 14 rainfall depths were also modeled with this calibrated model for comparison. The RRE calibrated HEC-HMS model peak flow rates for the historic events are shown in Table 5; this is a revised version of Table 4 showing the RRE calibrated HEC-HMS model peak flow rates compared to the FIS calibrated HEC-HMS model peak flow rates. Table 6 shows the MSE3 distribution peak flow rates from the RRE calibrated HEC-HMS model; the 100 year MSE3 peak flow is higher than the Regression Equation peak flow rates because Atlas 14 rainfall depths are slightly higher than the regression equation publication rainfall depths. The RRE calibrated peak flows are lower in 2008 than they are in 2007, opposite as seen with the FIS calibrated model; this is because the RRE calibrated HMS models have a different curve number and required much higher time of concentration/lag time and the lower rainfall depth and resulting runoff volume results in lower peak runoff rates.

Table 5: FIS Calibrated Peak Flow Rates versus RRE Calibrated Peak Flow Rates

	FIS Calibrated Historic Peak Flow (cfs)		RRE Calibrated Historic Peak Flow (cfs)	
Year	0.9 Sq-mi	0.61 Sq-mi	0.9 Sq-mi	0.61 Sq-mi
2007	326	221	241	172
2008	527	357	169	151
2017	996	675	441	317

Table 6: MSE3 Peak Flows from RRE Calibrated HEC-HMS Model

		RRE Calibrated Model MSE3 Peak Flow (cfs)	
Storm	Atlas 14 Depth	0.9 Sq-mi	0.61 Sq-mi
MSE3 - 10 yr, 24 hr	4.47	42	29
MSE3 - 50 yr, 24 hr	6.53	360	302
MSE3 - 100 yr, 24 hr	7.57	486	414

The runoff hydrographs developed from the RRE calibrated models were modeled in HEC-RAS and the resulting flood inundation areas are also depicted in Figures 2, 3, and 4.The purpose of this is to compare the observed historic flooding in the area to that of the inundation areas calculated from the various hydrologic methodologies. The method which most closely matches that of historic observations would be the most appropriate to utilize to represent the flood risk for the area.

Results Discussion

From a review of the available rainfall data from the past 20 years of record, it is apparent that none of the historic rainfall events reproduced the 100 year published flow rate, despite the August 2007 (40-hour duration) storm having rainfall totals near the 100 year Atlas 14 totals. The reason for this is that the real-world rainfall events do not always follow the MSE3 distribution which was used to calibrate the model. It's important to note that the original design hydrograph used in the effective modeling is unknown and not available for calibration against. The MSE3 distribution is conservative because it is developed utilizing the critical duration events and is typically used for design purposes. This means that the "true" 100 year rainfall distribution may be less intense than the MSE3 distribution, but the MSE3 is currently the most widely accepted rainfall distribution for this area.

2007 Peak Event

The 2007 event had the highest rainfall total depth. The rainfall depth over 40 hours is almost equal to the 100 year Atlas 14 depth at the Weather Forecast Office. Approximately 6.7 inches of this total fell in approximately 25 hours, which makes this portion of the storm initially appear to approximate a 50 year, 24 hour event. However, the calculated peak flow rate is nowhere near the 1093 cfs associated with the 2-percent event. Figure 5 shows the cumulative rainfall of the 2007 storm and the resulting runoff hydrograph from the FIS calibrated model. There are three periods of higher intensity rainfall that produce separate runoff peaks, this is part of the reason the peak flow rate is much lower than 1093 cfs. Figure 6 shows the 2007 storm cumulative rainfall and the MSE distribution cumulative rainfall for a 100 year, 24 hour storm. The MSE3 distribution has a very short intense period of rainfall where the majority of the rain falls within a 20 to 30 minute time period. The historic 2007 storm had slower steady rainfall spread over a longer time, which does not result in the same peak runoff even though the total reported storm totals are near the 100 year Atlas 14 depths.

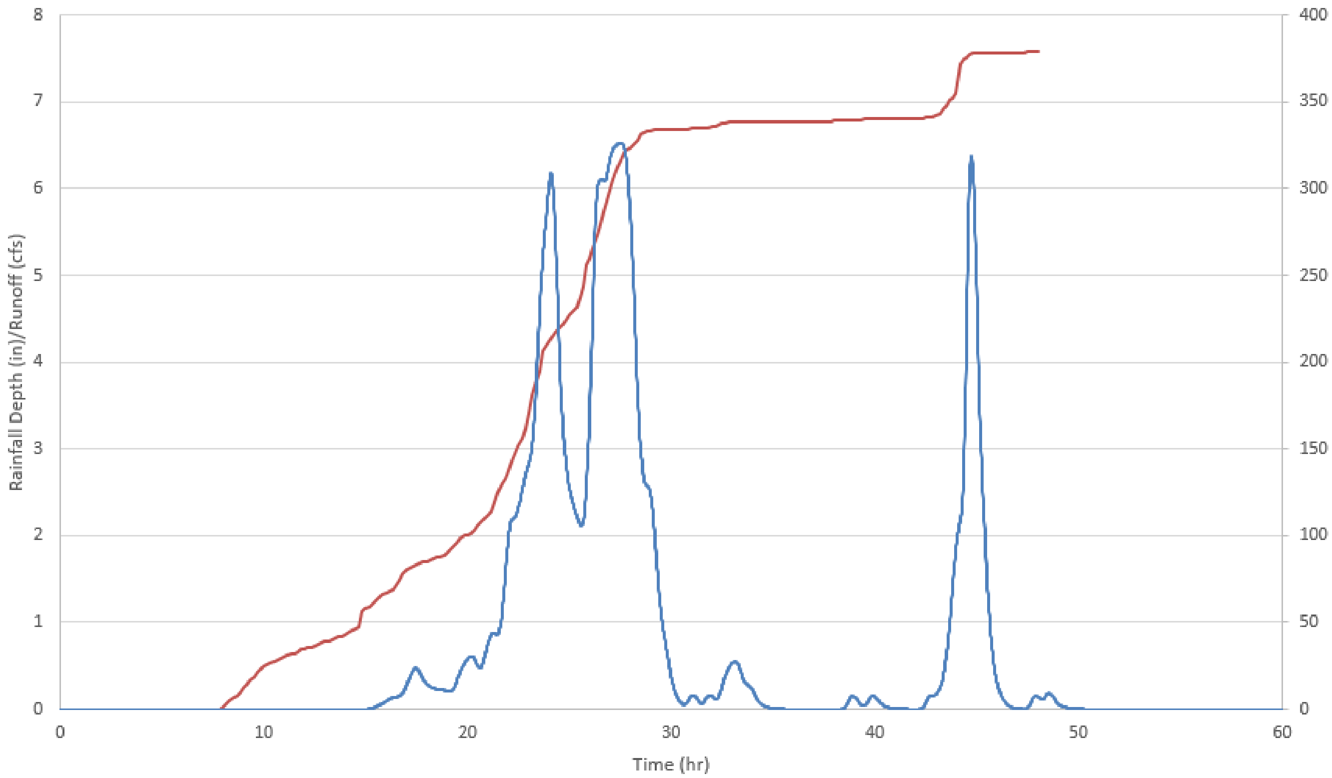

Figure 5: 2007 Historic Cumulative Rainfall and Resulting Runoff from FIS Calibrated HMS Model

See Figure 2 for the flooding inundation area results of the 2007 event from HEC-RAS. The inundation results from both the FIS calibration and RRE calibration are shown. The structures that would be at least partially inundated with the FIS calibration are also shown. For both calibrations, there is only very minimal flooding and only 2 structures that would appear to be inundated. For the FIS calibration, a small amount of flow would still break out from the Ebner Coulee ditch upstream from the 29th Street culvert, and flow would break out over the west bank between Jackson and Farnam Street. The RRE calibrated model is showing inundation to the west of the train tracks north of Farnam Street; flooding in this area is likely overestimated by the model because as previously discussed, not all of the runoff from the drainage area delineated to Jackson Street would actually get into the channel. Much of it would be picked up by storm sewer or stored in other depressions.

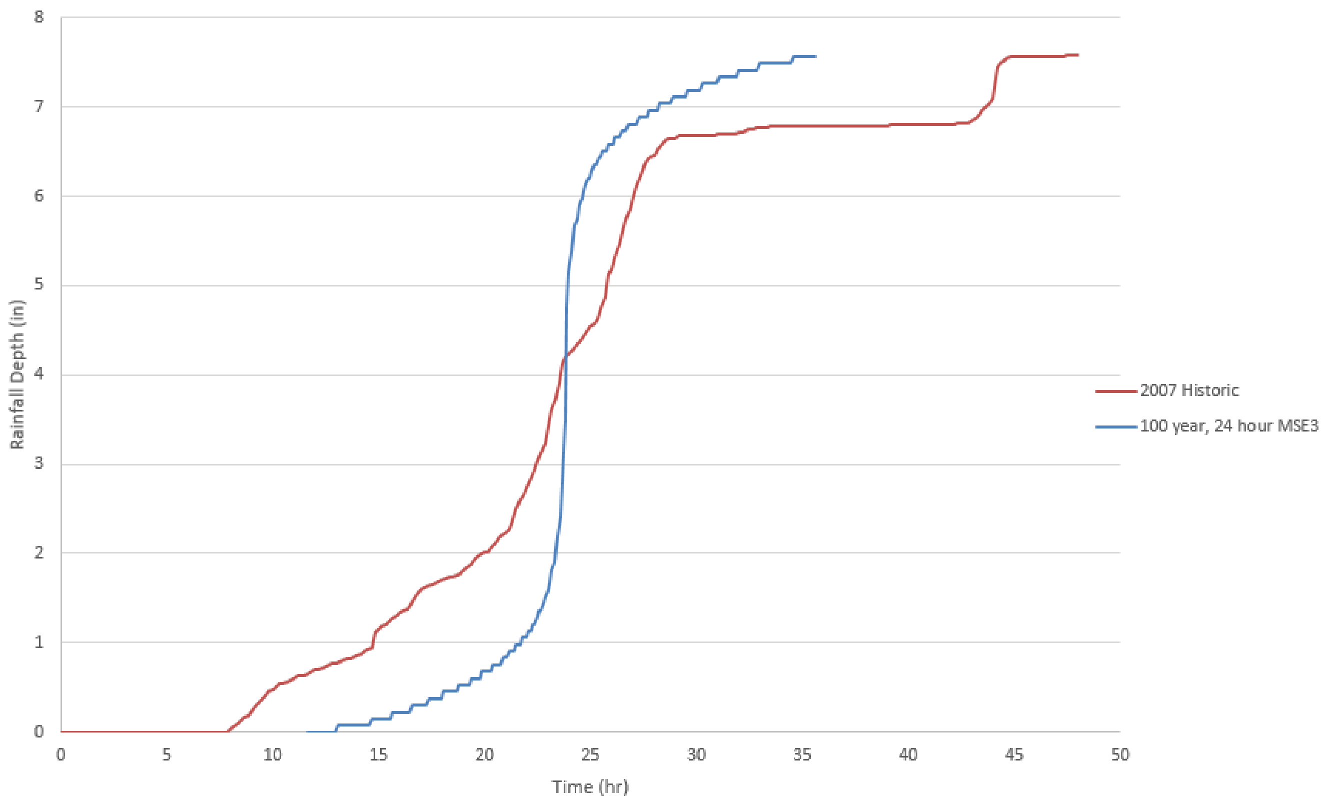

Figure 6: 2007 Historic Cumulative Depth and 100 year, 24 hour MSE3 Cumulative Depth

2008 Peak Event

As shown in Figure 7, the 2008 event has a similar cumulative rainfall distribution as the 2007 event, with slow, steady rain over a long time. However, the 2008 event had one period of high intensity where over an inch of rain fell in under an hour. This intense period resulted in a short but relatively high flow period of runoff.

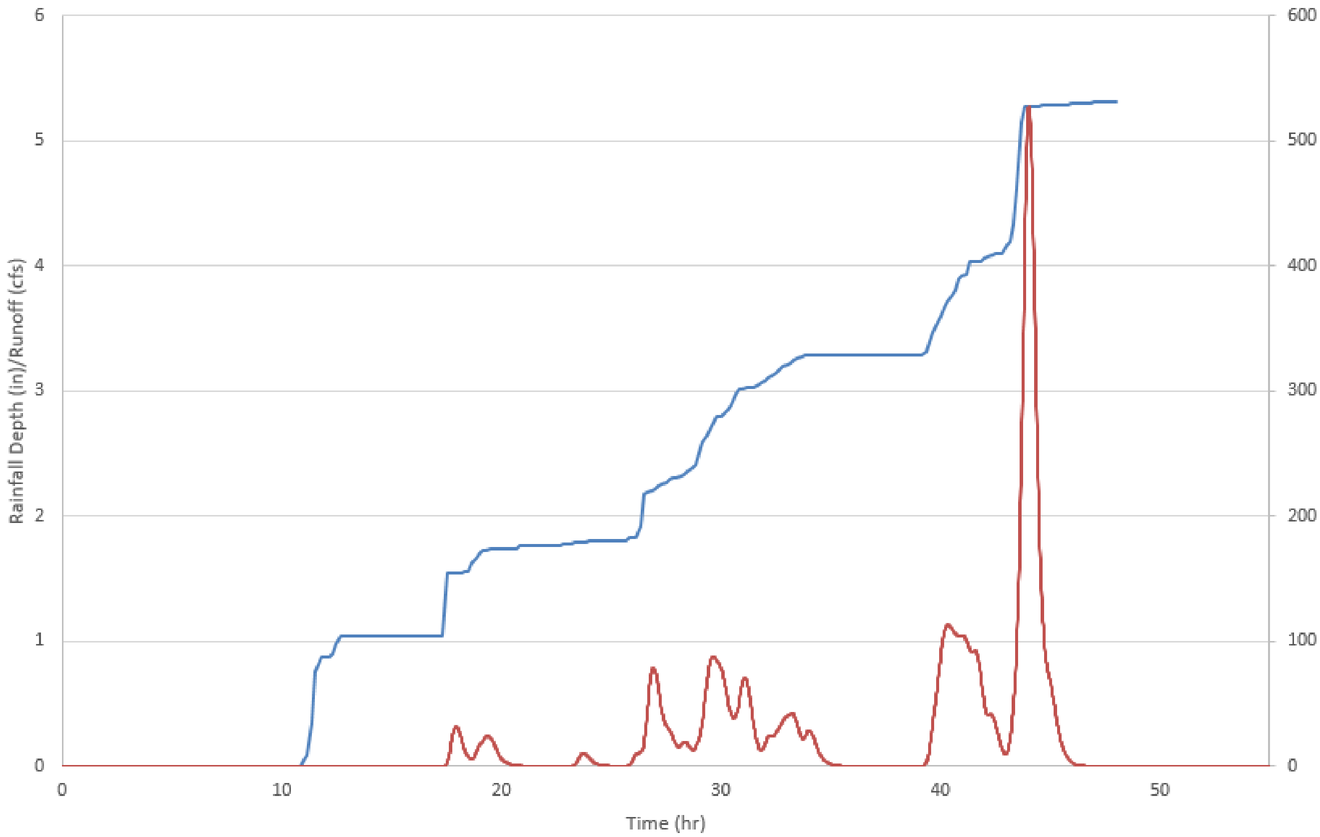

Figure 7: 2008 Historic Cumulative Rainfall and Resulting Runoff from FIS Calibrated HMS Model

For the 2008 event, more flow breaks out of the Ebner Coulee ditch upstream from the 29th Street culvert in the FIS calibrated model. This water then runs down the street and ponds up north of Farnam Street. Like with the first phase of modeling, the city storm sewer in this area was not modeled; this is consistent with the original FIS modeling technique. Approximately 24 homes appear to be at least partially inundated with this calibrated modeling. Based on feedback obtained during the City of La Crosse Floodplain Task Force Committee meeting, no homes were inundated during this event. The 2008 event results from the RRE calibrated model, shows only extremely minimal flooding to the west of the train tracks north of Farnam Street, which appears to be more in line with historic observations in the field.

2017 Peak Event

The 2017 event had the second highest total rainfall depths and produced the highest calculated runoff in the last 20 years. There are several periods of very high rainfall intensity, with the highest producing over an inch of rain in approximately 10 minutes. Aside from the period around hour 25 where the rainfall stopped temporarily, the rainfall distribution of this storm is much closer in shape and intensity to the MSE3 distribution than the storms of 2007 and 2008. The total rainfall depth at the Weather Forecast Office station is approximately a quarter of an inch less than the Atlas 14 50-year, 24 hour rainfall depth of 6.53 inches. The total storm length was approximately 12 hours, with most of the rain falling in just 5 to 6 hours. The Atlas 14 100 year, 12 hour rainfall total is 6.72 inches; this indicates that the July 2017 storm had a recurrence interval nearly that of a 50 year event.

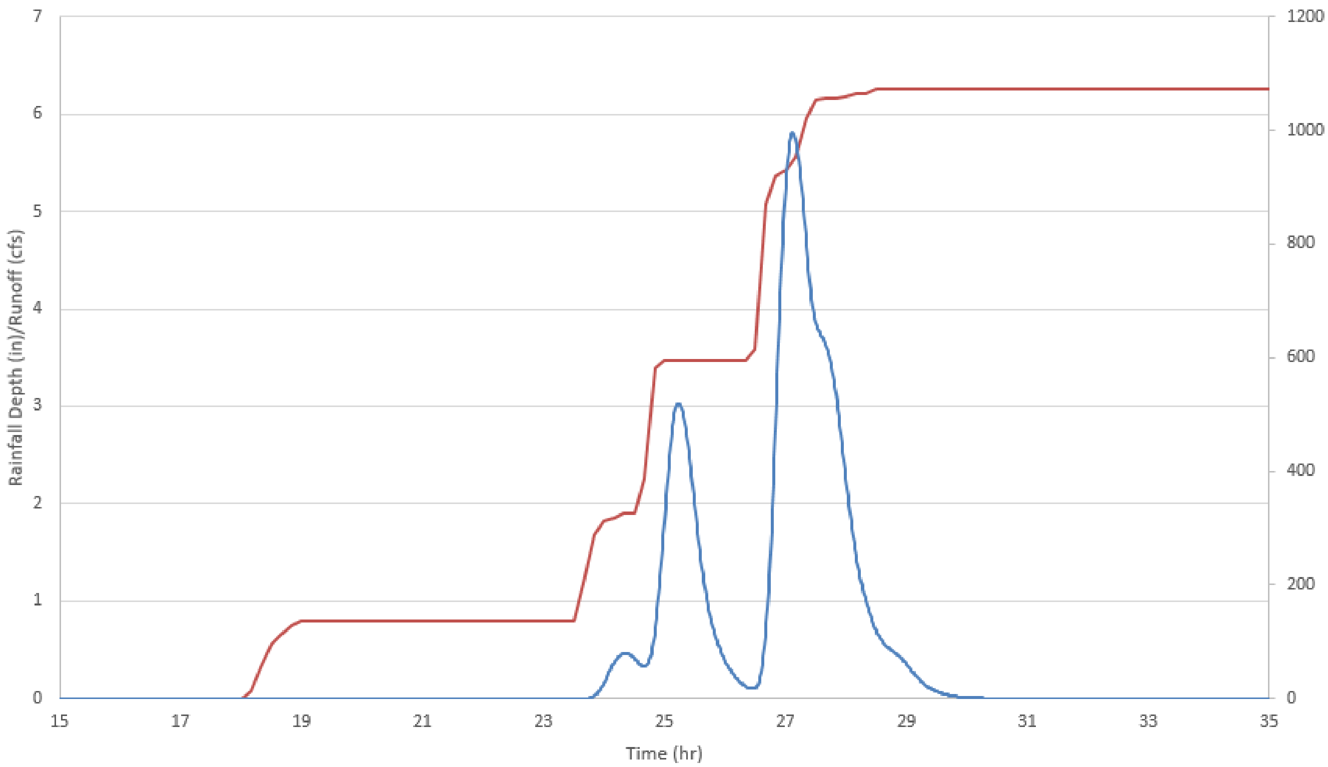

Figure 8: 2017 Historic Cumulative Rainfall and Resulting Runoff from Calibrated HMS Model

For the 2017 event FIS calibrated model, there is significant flow break out from the Ebner Coulee ditch upstream from the 29th Street culvert and flow break out from the right bank near the upstream end of the Ebner Coulee model. This results in additional inundation north of the drainage ditch, like what is seen in the effective FEMA inundation map. The flooding and ponding north of Farnam Street is major. Up to 88 homes appear to be at least partially inundated with this FIS calibrated modeling of the 2017 event, when no homes were reported to be inundated during this event.

For the 2017 event RRE calibrated model, there is still a significant amount of break out flow predicted from the left bank of the Ebner Coulee ditch upstream from the 29th Street culvert. This is similar to the amount of flooding seen with the model results associated with Regional Regression Equation developed 100 year event, from Phase 1 of the study. Based on input during the City's Flood Task Force Committee, even this inundation area is greater than that experienced in the field. This could suggest that even the Regional Regression Equation flow estimates over predict that experienced, but what may be more likely is that the 29th Street culvert or Ebner Coulee drainage ditch 1D geometry in the model is more restrictive than it is in reality, forcing more water out of the channel at this location. The 1D channel portion of the model has not been changed from the FIS effective model.

Summary

A 100-year (1-percent) event does not appear to have occurred in the Ebner Coulee watershed over the last 20 years; however, the 2017 storm was very close to that of a 50-year event. A 50-year flow rate is not reported in the Flood Insurance Study (FIS), but would be expected to be around 1100 cfs based on the FIS calibrated HMS model. The HEC-RAS modeling indicates that a 50-year event and the 2017 event would cause major flooding when using a model calibrated to the FIS 100-year flow. The fact that a nearly 50-year flood event and several other major events occurred in the last 20 years, and no major flooding was reported as the modeling would indicate strongly that the published 1-percent effective flow rate of 1430 cfs is too high and a Letter of Map Revision (LOMR) based on a hydrologic analysis with lower discharge rates predicated on a hydrologic model calibrated to the USGS Regional Regression equations would be warranted.

R.M.

Attachment 1: Technical Feasibility Report – Ebner Coulee Floodway FIRM Remapping
Attachment 2: Figure 1 – Weather Station Locations
Attachment 3: Figure 2 – 2007 Peak Event Calibrated Inundation
Attachment 4: Figure 3 – 2008 Peak Event Calibrated Inundation
Attachment 5: Figure 4 – 2017 Peak Event Calibrated Inundation

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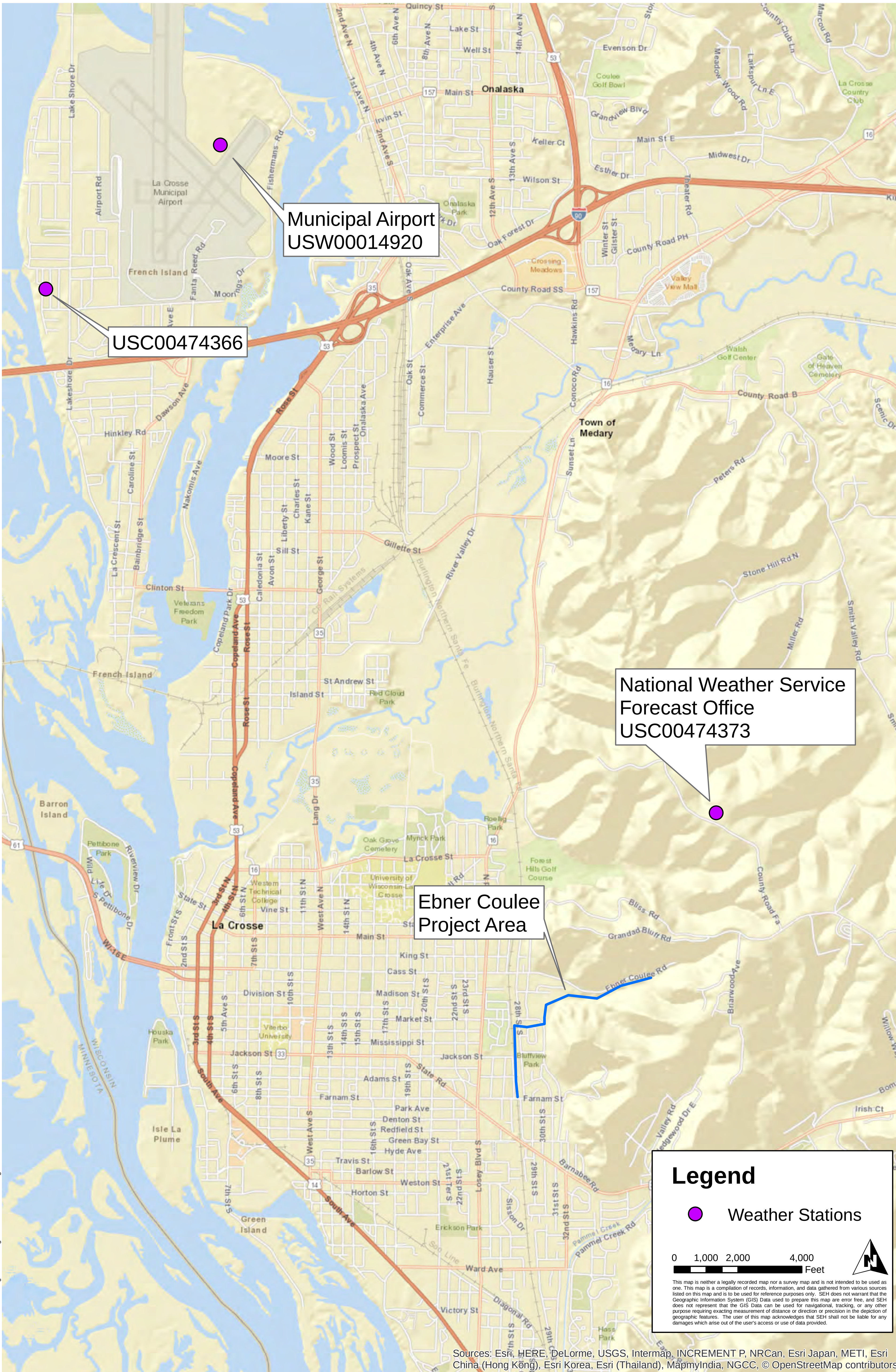

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SEH

Project Number: LACRS 142540
Print Date: 11/29/2017

Map by: rmondloch
Projection: NAD_1983_StatePlane_Wisconsin_South_FIPS_4803_Feet
Source: ESRI, FEMA & SEH

Ebner Coulee Floodway FIRM Remapping
La Crosse, WI

FIGURE 1
Weather Station Locations

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SEH

Project Number: LACRS 142540
Print Date: 12/1/2017

Map by: rmondloch
Projection: NAD_1983_StatePlane_Wisconsin_South_FIPS_4803_Feet
Source: ESRI, FEMA & SEH

Ebner Coulee Floodway FIRM Remapping
La Crosse, WI

FIGURE 2
2007 Peak Event
Calibrated Inundation

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Print Date: 12/4/2017

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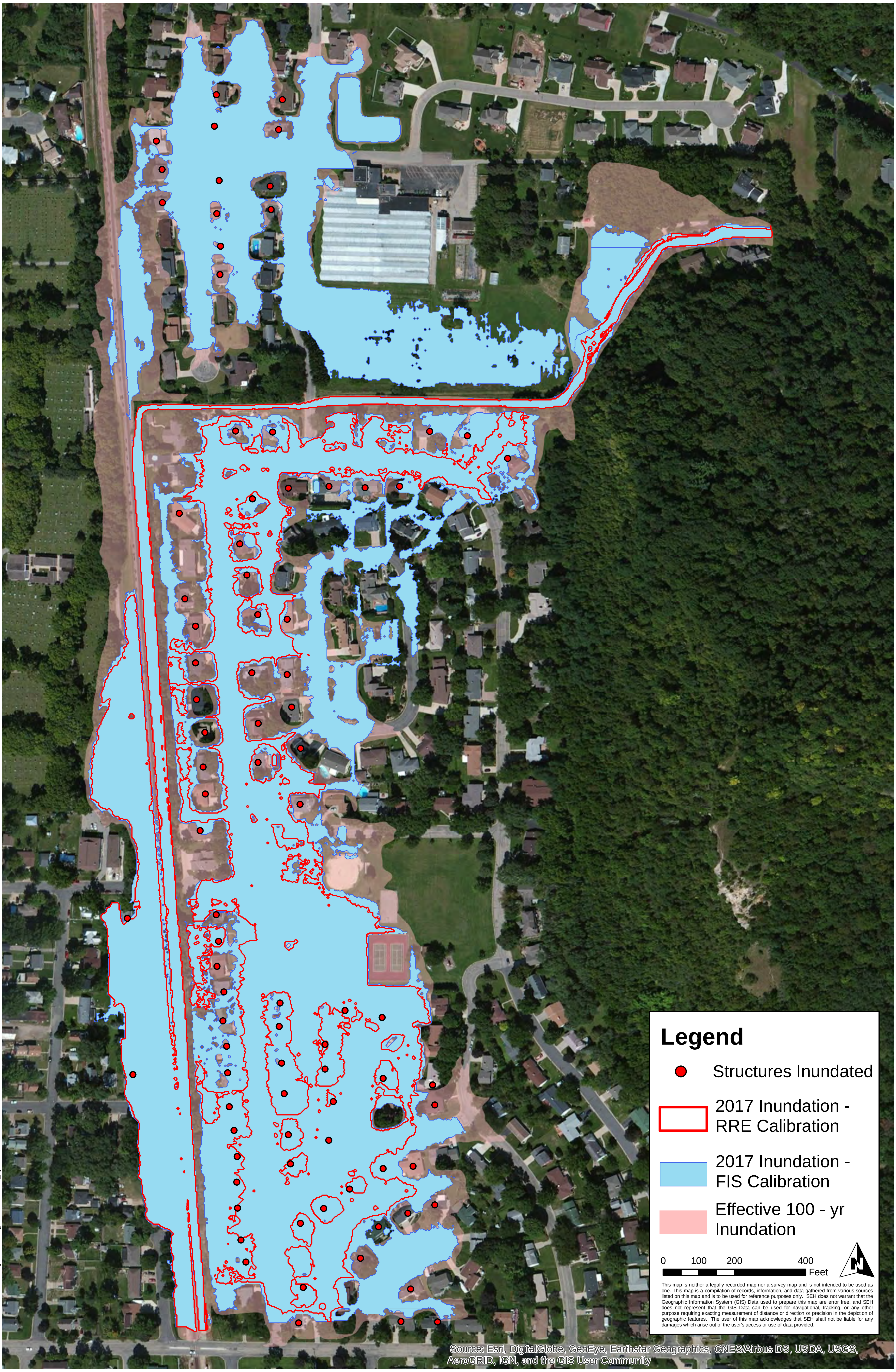
SEH

Ebner Coulee Floodway FIRM Remapping
La Crosse, WI

FIGURE 3
2008 Peak Event
Calibrated Inundation



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Project Number: LACRS 142540
Print Date: 12/4/2017

Map by: rmondloch
Projection: NAD_1983_StatePlane_Wisconsin_South_FIPS_4803_Feet
Source: ESRI, FEMA & SEH

Ebner Coulee Floodway FIRM Remapping
La Crosse, WI

FIGURE 4
2017 Peak Event
Calibrated Inundation