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TECHNICAL GUIDANCE and CASE STUDY for INEFFECTIVE FLOW and CONVEYANCE SHADOW AREAS

DATE: December 30, 2011

TO: Engineers, architects, land surveyors, and other floodplain management and development professionals

FROM: Brian K. Varrella, P.E., CFM
Floodplain Administrator, Civil Engineer III

RE: Case study and technical guidance for documenting flood risks within ineffective flow and conveyance shadows areas

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1.0 DOCUMENT

This document is provided as technical guidance on identifying ineffective flow areas and conveyance shadows in FEMA- and City-regulatory floodways and flood fringe areas, and for assessing their impact on proposed development within those areas. This guidance is further supported by an applied case study illustrating the principles offered herein.

2.0 TARGET AUDIENCE

Design professionals including engineers, architects, land surveyors, planners, and other parties assisting in development activities in floodway and flood fringe, together comprising the floodplain, as defined in Section 10-16 of the City of Fort Collins Municipal Code (Chapter 10, CoFC 2007).

3.0 BACKGROUND AND PURPOSE

City code allows some areas of floodways and flood fringes to be developed, with conditions, when standards have been satisfied or when flood hazards have been mitigated and documented to preserve and maintain public safety. One mitigation alternative involves the identification of specific areas within the floodplain that can be modified and developed without causing adverse flooding impacts to neighboring properties. Adverse impacts include raising water surface elevations on structures or property, diverting or redirecting flood flows to new locations or in increased volumes, and increasing velocity or erosion potential. Alternatives to mitigate such impacts include strategically placing new development in ineffective flow areas and conveyance shadows, both of which are the focus of this technical guidance. The technical methods of this mitigation strategy are currently being applied to projects in floodplains throughout the City.

It is the intent of this technical memorandum to assist in the definition and identification of ineffective areas and conveyance shadows and to apply the hydraulic utility of these features to create safe and economically viable development opportunities that meet the intent of Chapter 10. The careful application of development within ineffective flow areas may minimize the volume and extent of technical analysis required to preserve and document public safety in flood hazard areas.

Target audience members may, therefore, use this document as evidence that proposed development in ineffective flow areas and conveyance shadows will not increase flood hazards, and document these conclusions by reference in no-rise certifications and floodplain use permits delivered to Fort Collins Floodplain Administration.

4.0 TECHNICAL MITIGATION OF HYDRAULIC IMPACTS

4.1 Peak Flood Condition and Definitions

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) defines an area of ineffective flow as:

> ". . . areas of the cross section that will contain water that is not actively being conveyed. Ineffective flow areas are often used to describe portions of a cross section in which water will pond, but the velocity of that water, in the downstream direction, is close to zero. This water is included in the storage calculations and other wetted cross section parameters, but is not included as part of the active flow area. When using ineffective flow areas, no additional wetted perimeter is added to the active flow areas." *– Chapter, 3, Page 3-8, HEC 2010.*

Storage is a technical accounting of the reduction of peak flood discharge in the river lost to the natural filling and draining of overbank riparian areas during the time-variable course of a flood. Flood hydrology in City Master Plan Studies and FEMA Flood Insurance Studies (FISs) published for Fort Collins is documented using a snapshot in time, consistent with national standards of hydrologic practice. This snapshot is developed from a steady-state hydraulic analysis that removes all time-dependent variability of water surface elevations and flood volumes encountered during a natural riverine flood event by normalizing flood risk variables to a singular condition that is applied to all points in time.

The steady-state snapshot is known as the peak flood condition. It is nearly coincident with the peak discharge conditions where the maximum water surface elevations are encountered, where areas of flood inundation transverse to flow are widest, and where the outer limits of the floodplain boundary can be identified and mapped. The peak flood condition typically categorized for regulatory purposes and for flood hazard mapping in Fort Collins is the 1-percent annual chance storm event, also known as the 100-year storm. The 100-year peak discharge is known as the base flood, and the 100-year maximum water surface elevation is referred to as the base flood elevation or BFE.

Normalizing natural flood behaviors to a peak condition negates the storage function from hydraulic computations. The predominant function of ineffective flow areas is to store floodwaters, but when storage is negligible, these areas of near-zero flood conveyance serve only to reduce flow area in natural and man-made waterways.

Ineffective flow areas do not increase drag on flow or add any wetted perimeter to hydraulic calculations at a given cross section in a steady-state hydraulic analysis. Since ineffective flow does not actively convey water in the principal downstream direction in a steady-state hydraulic analysis, activities initiated in these areas will not cause any change to the BFE, peak discharge, or flood flow velocities in a hydraulic analysis. A project in an ineffective flow area can, therefore, be proposed with ground topography modifications, building pads, parking areas, fences, landscape and transportation features, and other flood flow obstructions without changing peak flood hazards on adjacent neighboring properties and infrastructure.

4.2 Ineffective Flow Area Identification

The HEC definition from Section 4.1 identifies ineffective flow areas as locations where water is present but does not move in the principal downstream flood flow direction. They are commonly referred to as eddies, slack water areas, stagnant or obstructed flow zones, or backwaters. The ground beneath ineffective flow areas is fully inundated but water does not travel contiguously in the principal direction of downstream conveyance. **Figure 4.1** shows where these ineffective flow areas are often located within a typical floodplain.

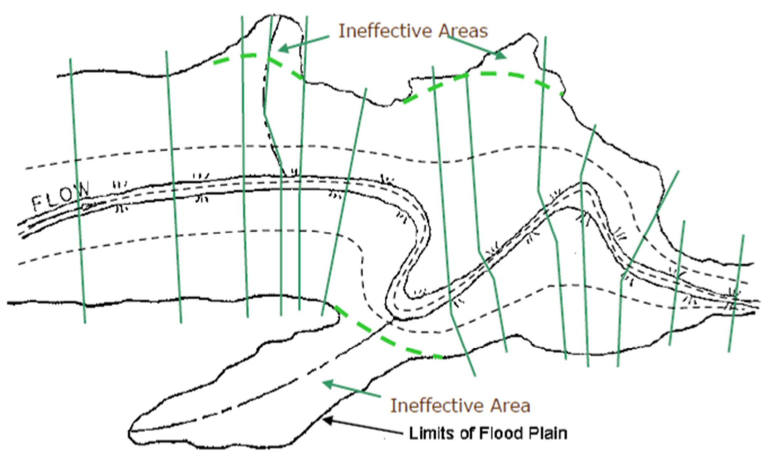

Figure 4.1. Example cross section layout with ineffective ares (HEC 2010).

Flood flows in topographically-isolated areas created by small tributaries or topographical features (as seen in Figure 4.1), behind man-made berms, and at bridge and culvert approaches are usually stagnant and ineffective prior to overtopping. Bridge approaches can be dry during flood events to allow safe passage of traffic across the bridge while flood flows pass beneath the structure. All flood flow must then contract through the bridge opening upstream, and expand to the full width of the natural floodplain somewhere downstream. HEC illustrates this common hydraulic behavior in **Figure 4.2**.

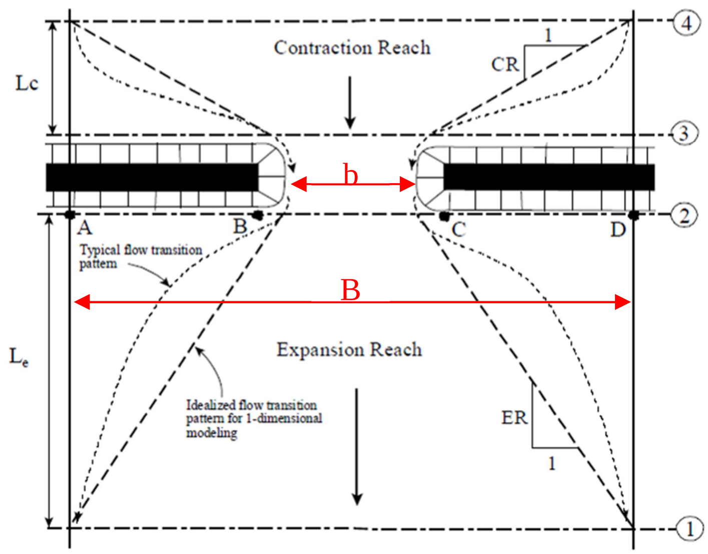

Figure 4.2. Cross section locations at a bridge (HEC 2010).

The boundary between ineffective flow and active conveyance is a smooth water-on-water boundary that generally tends to not provide additional resistance to flood flows. Identifying stagnant flow areas does, however, reduce available conveyance and flow area for floodwaters. The resulting hydraulic response is increased water surface elevations and wider mapped floodplains. After these natural river responses have been calculated and mapped in a peak flow conditions hydraulic analysis, flow encroachments and blockages can be constructed within the ineffective flow zone without obstructing conveyance, without changing the BFE, without changing flow velocities, and without changing floodplain or floodway boundaries at any given hydraulic model cross section.

4.3 Conveyance Shadow Identification

A conveyance shadow is hydraulically equivalent to an ineffective flow area, but differs in location. Unlike ineffective flow areas which tend to be located at the outside edges of floodplains, conveyance shadows are found in front of and behind mid-stream features. These often include natural features like large boulders or islands, or human-constructed features such as fill pads, buildings, boulders, vehicles, and other discrete blockages to flow that tend to occur within floodplains rather than at or near the edges. The obstructed or stagnant mid-stream flow area upstream of the blockage forces flood water to diverge and contract around the feature, then expand behind the obstruction at some location downstream. This phenomenon is illustrated in **Figure 4.3** from FEMA (2005).

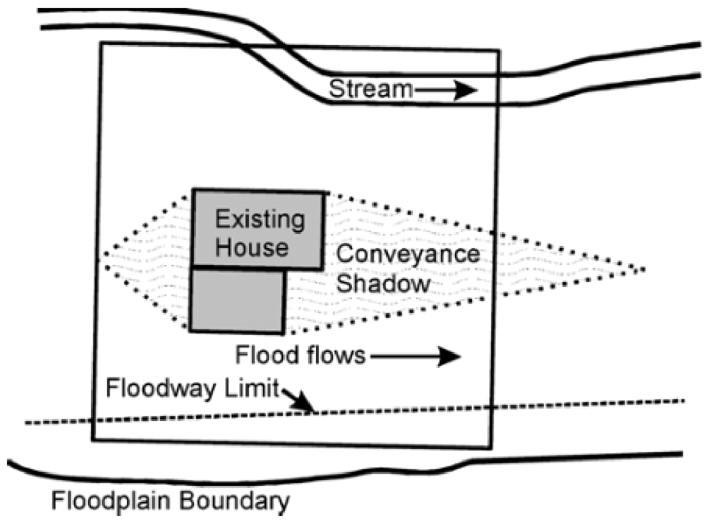

Figure 4.3. Determining the conveyance shadow (FEMA 2005).

The stagnant flow areas immediately upstream and downstream of the obstruction contain water that does not flow in the predominant downstream direction, and therefore may provide a very small amount of storage. The boundaries of conveyance shadows, as with ineffective flow areas, do not add significant drag to flow or wetted perimeter to a hydraulic analysis. Construction within conveyance shadows does not reduce active conveyance in the waterway, does not modify BFEs, and does not change flood hazards on adjacent neighboring property or infrastructure.

4.4 Ineffective Boundary Determination

The boundaries of ineffective flow areas and conveyance shadows can be calculated using rules of thumb and standard bridge contraction and expansion ratios published by HEC (2010). The contraction ratio at the upstream end of flow blockages is typically delineated on a 1:1 ratio off of perpendicular from the principal direction of flow. This is represented in Figure 4.2 as the dimension labeled “CR” upstream of the roadway approaches. On Figure 4.3 the 1:1 contraction ratio would be used to draw the triangle upstream of the featured labeled “Existing House.”

The expansion ratio downstream of a conveyance blockage is often determined using a 2:1 rule of thumb, formerly 4:1 in past practice by various departments of transportation across the nation. This ratio is measured with the larger dimension in the downstream direction parallel to flow, and the dimension of 1 in the lateral direction perpendicular to flow. This is represented in Figure 4.2 as the dimension labeled “ER” downstream of the roadway approach embankments and on Figure 4.3 as the triangle downstream of the feature labeled “Existing House.”

Flood waters tend to naturally contract more efficiently than they expand. This is reflected in typical torpedo profiles that are engineered to push water to contract over a short longitudinal distance at the nose and then expand over a long longitudinal distance at the tail, thereby minimizing resistance to flow and maintaining efficient underwater performance. Research initiated and published by HEC in the 1990’s indicates the expansion ratio of water is dependent on many variables that complicate this computation. A numerical method to determine an appropriate range of expansion ratio values was published by HEC (2010) and is reproduced herein as **Table 4.1**.

		nob / nc = 1	nob / nc = 2	nob / nc = 4
b/B = 0.10	S = 1 ft/mile	1.4 – 3.6	1.3 – 3.0	1.2 – 2.1
	5 ft/mile	1.0 – 2.5	0.8 – 2.0	0.8 – 2.0
	10 ft/mile	1.0 – 2.2	0.8 – 2.0	0.8 – 2.0
b/B = 0.25	S = 1 ft/mile	1.6 – 3.0	1.4 – 2.5	1.2 – 2.0
	5 ft/mile	1.5 – 2.5	1.3 – 2.0	1.3 – 2.0
	10 ft/mile	1.5 – 2.0	1.3 – 2.0	1.3 – 2.0
b/B = 0.50	S = 1 ft/mile	1.4 – 2.6	1.3 – 1.9	1.2 – 1.4
	5 ft/mile	1.3 – 2.1	1.2 – 1.6	1.0 – 1.4
	10 ft/mile	1.3 – 2.0	1.2 – 1.5	1.0 – 1.4

Table 4.1. Ranges of Expansion Ratios (HEC 2010).

It is recommended expansion ratios for hydraulic analyses be determined using the method outlined in Table 4.1 and supported by dimensions identified in Figure 4.2. If this dimension cannot be easily determined from these resources, a licensed professional engineer conducting a hydraulic analysis may certify a default 2:1 downstream expansion ratio to delineate the envelope of ineffective flow and conveyance shadowing in a given hydraulic study reach.

5.0 CASE STUDY – NORTH COLLEGE AVE. AT VINE DR.

The ineffective flow identification and analysis methods outlined in Section 4 were applied to a case study in north Fort Collins. The selected area is an obvious location where ineffective flow areas and conveyance shadows would be present. The flood fringe of the Poudre River east of College Avenue has a noticeable divergence or bulge to the north, away from the adjacent flood fringe alignment. This bulge in the fringe is a product of historically-low topography that draws water away from the north overbank of the Poudre River during a 1-percent annual chance flood event, and is a classic example of an area where ineffective flow will be present. Substantial development in this area occurred prior to the establishment of the National Flood Insurance Program (NFIP). Existing structures create multiple blockages to flood flow, resulting in upstream and downstream conveyance shadows. The unique combination of these features in the Poudre flood fringe makes the study area an ideal example of potential development that can be constructed without adversely impacting adjacent properties.

The study area is located north of Old Town near the intersection of College Avenue and Vine Drive, as shown in **Figure 5.1** below.

(continued, next page)

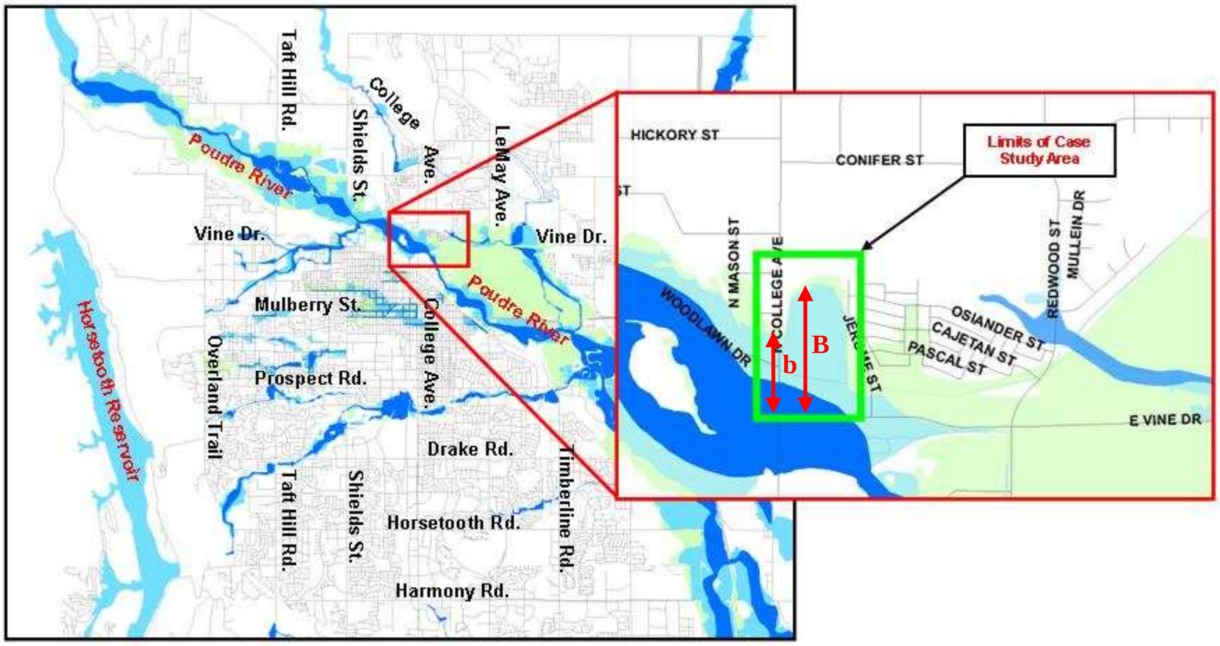

Figure 5.1. Vicinity map of the Fort Collins, CO case study area, indicated within the green box.

A technical determination of the location of ineffective flow and conveyance shadow boundaries begins with defining variables for downstream expansion ratios for entry into Table 4.1. Those variables are documented for this example as follows:

Identifiable Variables from Table 4.1:

b	=	900 ft	=	constriction opening (indicated on Fig. 5.1)
B	=	1,650 ft	=	full floodplain width (indicated on Fig. 5.1)
S	=	30 ft/mile	=	valley slope (approx from HEC model)
n_{ob}	=	0.083	=	overbank roughness (from HEC model)
n_c	=	0.035	=	channel roughness (from HEC model)

Data Entered Into Table 4.1:

b/B	=	0.55, use 0.5
n_{ob}/n_c	=	2.4, use 2
S	=	30 ft/mile, use 10 ft/mile (maximum)

Resulting Expansion Ratio for Mapping:

ER	=	1.2 to 1.5.

The final expansion ratio used to delineate ineffective flow and conveyance shadow boundaries was selected as 1.4:1 from the calculated range of values. This was deemed to be a reasonable value within the range on Table 4.1 based on the trend of decreasing expansion ratios with respect to channel slope. The contraction ratio (CR) of 1:1 was accepted from the standard rules of thumb identified in Appendix B of HEC (2010) and documented in Section 4.4.

The identifiable ineffective flow area and conveyance shadows in the study area are shown on **Attachment A**. This figure, developed using the above methodology, shows approximate 8 acres of land in the North College Avenue area can be encroached for development without causing adverse impacts to BFE, floodplain boundaries, or cross section average flow velocities. If constructed to the freeboard standards and other requirements of Chapter 10, new development in the area indicated in orange on Attachment A will be constructed to the letter and intent of the standards of Chapter 10.

6.0 CONCLUSIONS

Hydraulic obstructions constructed in ineffective flow areas and conveyance shadows do not impact BFEs, flow velocities, or floodplain and floodway boundary limits. New development and redevelopment can be constructed in these areas without causing adverse impacts to neighboring properties and adjacent public infrastructure. However, new construction in these areas must still meet all applicable standards of Chapter 10 to prevent adverse impacts to themselves, their friends and visitors, delivery personnel, customers, emergency services personnel, family members, and future owners of the property.

The principals and guidelines outlined in this memorandum can be carefully applied to all properties in floodplains across Fort Collins. They have historically been applied throughout the City for floodplain management and compliance purposes, and it is equitable to extend these options to applicants proposing future development in flood hazard areas. Other safety considerations outlined in Chapter 10 must be satisfied as applicable to each individual development case.

7.0 REFERENCES

City of Fort Collins (CoFC), *City of Fort Collins Municipal Code, Chapter 10; Flood Prevention and Protection.* (2007).
Available at: http://www.fcgov.com/utilities/img/site_specific/uploads/floodplain_Ch_10_Update_2010.pdf

Federal Emergency Management Agency (FEMA), *Flood Insurance Study for Larimer County, Colorado and Incorporated Areas.* Volumes 1-4, Flood Insurance Study Number 08029CV001B (2008).

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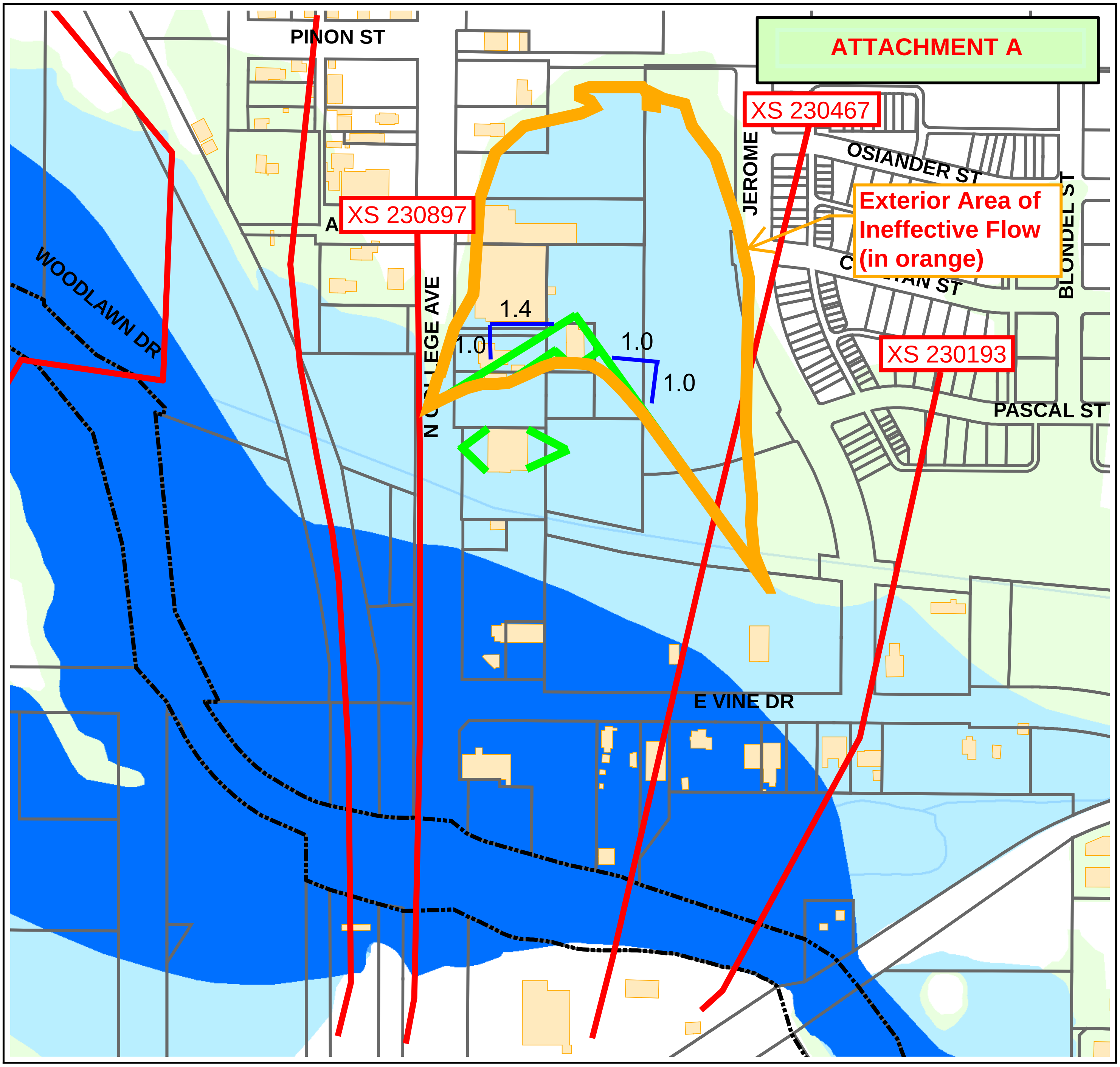
FEMA, *National Flood Insurance Program (NFIP) Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials.* FEMA 480 (2005).

Available at: http://www.floods.org/ace-files/documentlibrary/CFM-Exam/FEMA_480_Complete.pdf

Hydrologic Engineering Center (HEC), *HEC-RAS River Analysis System; Hydraulic Reference Manual*. Prepared for the U.S. Army Corps of Engineers, Version 4.1, CPD-69 (2010). Available at: http://www.hec.usace.army.mil/software/hec-ras/documents/HEC-RAS_4.1_Reference_Manual.pdf



FEMA Flood Risk Map

High Risk

FEMA Floodway - Area of 100-year floodplain with greatest depths and fastest velocities.

FEMA Flood Fringe - May Include:
- Areas of FEMA 100-year floodplain (FEMA Zones A, AE, AO, and AH)
- Areas of City 100-year floodplain including ponding areas and sheet flow areas with average depths of 1-3 feet.

There is a 1% annual chance that these areas will be flooded.

Moderate Risk

May include:
- Areas of FEMA 500-year floodplain (FEMA Zone X-shaded).
- Areas of FEMA or City 100-year floodplain (sheet flow) with average depths of less than 1 foot.
- Areas protected by levees from the 100-year flood.

Low Risk

Areas outside of FEMA and City mapped 100-year and 500-year floodplains. Local drainage problems may still exist.

This information is based on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) and the City of Fort Collins Master Drainageway Plans. This letter does not imply that the referenced property will or will not be free from flooding or damage. A property not in the Special Flood Hazard Area or in a City Designated Floodplain may be damaged by a flood greater than that predicted on the map or from a local drainage problem not shown on the map. This map does not create liability on the part of the City, or any officer or employee thereof, for any damage that results from reliance on this information.

All floodplain boundaries are approximate.

N W E S

0 90 180 360 Feet

City of Fort Collins GIS

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