FLOODPLAIN DEVELOPMENT REVIEW
FLOOD-RELATED HAZARD CALCULATIONS CHECKLIST
(FOR STRUCTURES OR OBSTRUCTIONS IN FLOOD PRONE AREAS)

Development Services Center
101 City Hall Plaza | Durham, NC 27701
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SECTION I. GUIDANCE DOCUMENTS
This checklist is a general guidance document that shows the minimum analysis that both the City of Durham and Durham County expect be conducted on structures and obstructions (objects) that are located in or are subject to flood water conditions.   *Note: FEMA provides additional resources, documentation, and recommendations beyond those highlighted herein.*
For More Information Contact: **DSCFloodplain@durhamnc.gov**

SECTION II. FLOOD-RELATED HAZARD CALCULATIONS REQUIREMENTS
☐ **SECTION II.1. Submittal Requirements**

1. Calculations shall be signed, sealed, and dated by a licensed Professional Engineer Register in NC.
2. Calculations shall accompany the permit application listed in the Floodplain Determination form.
3. Calculations listed in this checklist are required with any <u>Level 2 and 3 Floodplain Permit</u> that has structures or obstructions (objects) that are located in any of the areas that flood, such as: the Floodway, Floodplains (1%, 1%Future, 0.2%), non-encroachment areas, streams, wetlands, and all other potential flood sources located within the Limits of the City of Durham and/or within Durham County.

Note: The listed calculations maybe requested during the Building Permit-Floodplain Review or in an instance where concerns arise due to development conditions on any potential development site.

<u>Site conditions shall include</u>: boundaries, existing structures, water bodies, adjacent roads, lot dimensions, the surveyed location of Base Flood Elevations, and proposed development.

<u>Proposed Development shall include:</u> Any disturbance in the Floodways, Floodplains, and associated non-encroachment areas, such as additions or changes to existing structures, utilities, structures, surface and/or subsurface modifications (grading, fill, paving, etc.), etc.

☐ **SECTION II.2. Calculations Organization and Labeling Requirements**

1. Calculations should be organized per structure/obstruction.
2. Hazard calculations should be in the same order for each instance provided and labeled.
3. Provide a callout or bubble around each location that have Flood-Related Hazard Calculations for the proposed or existing structure/obstruction on the Floodplain Impact Plan.
4. A simple label should be provided that correlates to each callout/bubble on the Floodplain Impact Plan with the Flood-Related Hazard Calculations, i.e. A, B, C or 1,2,3, etc.

☐ **SECTION II.3. Provide a Soils Requirement**

<u>Backfill geotechnical considerations,</u> for site-specific soil properties, should include the following properties:

- 95% Standard Proctor,
- Suitable per NCDOTs Specifications,
- Required monitoring, and

Note: Soil Type Definitions Based on USDA Unified Soil Classification System.

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SECTION III. SITE BACKGROUND SUMMARY REQUIREMENTS

☐ SECTION III.1. Project Information & Regulations

Provide project information specific to the site:

- Floodplain Permit Application;
- Project Name Provided on Floodplain Permit Application;
- Floodplain Impact Plan;
- Identify the 1% ACF Base Flood Elevation (BFE);
- Flood zones (Floodway, 1%ACF, 1%ACF Future, 0.2%ACF, Non-Encroachment Areas);
- Site history (as it relates to development in or around the surface waters and flood zones);
- FEMA Regulations, Determination of Hazards ; and
- Minimum 2ft Freeboard Elevation Required, per the Unified Development Ordinance (UDO).

☐ SECTION III.2. Project Narrative

Provide a project narrative that describes:

- Project disturbance limits,
- Flood sources and associated zones of flooding,
- Proposed disturbance of both the flood sources and associated zones of flooding (including square feet),
- Potential for erosion due to proposed development in the proposed disturbance,
- Discussion of the site drainage (reference can be made to the SIA as long as it is provided),
- Discussion of each structure's/obstruction's set of flood hazard calculations and associated findings, and
- Discussion of additional items as seen fit to fully explain the site conditions and the potential flood impact and hazards.

Note: Guidance and information in this document was taken from multiple FEMA documents.

☐ SECTION III.3. Flood Hazard Summary Statements

After each calculation, for each structure/obstruction, provide a summary statement of the results with regard to:

- Concerns,
- Effects acceptability, and
- Mitigation measures (if required).

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SECTION IV. REQUIRED CALCULATIONS

☐ SECTION IV.1. Provide Flood Depth Calculations

Determine the <u>Design Flood Elevation</u>, computed as:

DFE=FE + ƒ

where:

DFE = design flood elevation (ft)

FE = flood elevation for a specific flood frequency (ft)

ƒ = factor of safety (freeboard), a minimum of 2.0 ft

Determine the <u>flood depth</u> associated with the flood protection, computed as:

H = DFE – GS

where:

H = flood depth (ft)

DFE = flood protection level or design flood elevation (ft)

GS = lowest eroded ground surface elevation adjacent to the building (ft)

   flood protection level should be equal to the BFE/DFE

☐ SECTION IV.2. Provide Hydrodynamic Load Calculations

For loads created on submerged elements by water flowing around them, such as a building, structural elements, and other submerged objects, the <u>hydrodynamic loads</u> are computed as F_{dyn}:

$$F_{dyn} = C_d * \rho * \frac{V^2}{2} * A$$

where:

F_{dyn} = horizontal drag force (lb)

C_d = drag coefficient (shown below, taken from: Shore Protection Manual, Volume 2 (USACE 1984))

ρ = mass density of fluid (1.94 slugs/ft3 for fresh water and 1.99 slugs/ft^3 for saltwater)

V = velocity of floodwater (ft/sec)

A = surface area of obstruction normal to flow (ft2) = (w)(H) if the object is completely immersed

Note: When an object is something other than a round, square, or rectangular pile, the coefficient is determined by one of the following ratios:

1. The ratio of the width of the object (w) to the height of the object (h) if the object is completely immersed in water, or
2. The ratio of the width of the object (w) to the flood depth of the water (H) if the object is not fully immersed.

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Width to Height Ratio (w/H or w/h)	Drag Coefficient (C_d)
1–12	1.25
13–20	1.3
21–32	1.4
33–40	1.5
41–80	1.75
81–120	1.8
>120	2.0

☐ **SECTION IV.3. Provide Hydrostatic Load Calculations:**

Calculations should show the sum of the pressures over the *surface under consideration* to represent the load acting on that surface. The analysis should provide hydrostatic forces defined to act:

   A. Buoyancy- Vertically upward on *horizontal surfaces*, the *underside of any submerged members,* such as floor slabs, walls, and footings, etc.
   B. Lateral Water Pressure-Laterally on *vertical surfaces* such as perimeter walls, posts, etc.
   C. Differential Water and Soil Pressure

☐ **SECTION IV.3.A. Buoyancy**

Vertical force equation, Buoyancy is, based on the assumption that foundation walls and slabs are substantially impermeable to the passage of water, computed as F_{buoy}:

$$F_{buoy} = \gamma_w * (Vol)$$

where:

   F_{buoy} = vertical hydrostatic force resulting from the displacement of a given volume of floodwater (lb)
   γ_w = specific weight of water (62.4 lb/ft^3 for *fresh water* and 64.0 lb/ft^3 for *saltwater*)
   Vol = volume of floodwater displaced by a submerged object (ft^3)

   Note: Sump Pumps may significantly increase buoyancy pressures.

☐ **SECTION IV.3.B. Lateral Water Pressure**

Lateral force equation for hydrostatic pressures from the flood depth to the lowest eroded ground surface elevation adjacent to the building:

$$f_{sta} = ½ * P_h * H = ½ * \gamma_w * H^2$$

where:

   f_{sta} = hydrostatic force from flood depth (lb/lf) acting at a distance H/3 above ground.
   P_h = hydrostatic pressure due to standing water at a depth of H (lb/ft^2), ($P_h = \gamma_w * H$)
   γ_w = specific weight of water (62.4 lb/ft^3 for *fresh water* and 64.0 lb/ft^3 for *saltwater*)
   H = flood depth (ft)

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☐ SECTION IV.3.C. Differential Water and Soil Pressure

For surfaces located below grade, saturated soil pressures must be included in the design load calculations, the resultant cumulative lateral force is computed as f_{dif}:

$$f_{dif} = \frac{1}{2} * (S - \gamma_w) D^2$$

where:

f_{dif} = differential soil/water force acting at a distance D/3 from the point under consideration (lb/lf)

S = equivalent fluid weight of submerged soil and water (lb/ft^3), see table below

D = depth of saturated soil from adjacent grade to the (bottom of the flooded or submerged surface ft)

γ_w = specific weight of water (62.4 lb/ft^3 for *fresh water* and 64.0 lb/ft^3 for *saltwater*)

Note: Expansive or swelling soils may significantly increase lateral earth pressures and foundation heave pressures, and need to be evaluated separately and added to these cumulative forces, evaluate these geotechnical behaviors.

Table for Effective Equivalent Fluid Weight of Submerged Soil and Water	
Soil Type (Based on USDA USCS)	Equivalent Fluid Weight of Submerged Soil & Water (lb/ft^3)
Clean sand & gravel (GW, GP, SW, SP)	75
Dirty sand & gravel of restricted permeability (GM, GM-GP, SM, SM-SP)	77
Stiff residual silts & clays, silty fine sands, clayey sands & gravels (CL, ML, CH, MH, SM, SC, GC)	82
Very soft to soft clay, silty clay, organic silt & clay (CL, ML, OL, CH, MH, OH)	106
Medium to stiff clay deposited in chunks & protected from infiltration (CL, CH)	142

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☐ SECTION IV.4.Provide Debris Impact Load Calculations

Flood-borne debris impact loads are imposed on structures/obstructions by objects carried by moving water. A reasonable allowance must be made for structures/obstructions that may suffer debris impact loads, therefore debris impact loads can be computed as F_i:

$$F_i = W*V* C_D* C_B* C_{Str}$$

where:

F_i = impact force acting at the BFE (lb)
W = weight of the object (lb)
V = velocity of water (ft/sec)
C_D = depth coefficient (see Table Below)
C_B = blockage coefficient (taken as 1.0 for no upstream screening, flow path greater than 30 ft; see Table below for more information)
C_{Str} = building structure coefficient
= 0.2 for timber pile and masonry column supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete) and reinforced masonry foundation walls

C_D (Depth Coefficient) Table		C_B (Blockage Coefficient) Table	
Floodway or Zone V	1.00	No upstream screening, flow path wider than 30ft	1.0
Zone A, Stillwater flood depth > 5ft	1.00	Limited upstream screening, flow path 20ft wide	0.6
Zone A, Stillwater flood depth = 4ft	0.75	Moderate upstream screening, flow path 10ft wide	0.2
Zone A, Stillwater flood depth =3ft	0.50	Dense upstream screening, flow path <5ft wide 0.0	
Zone A, Stillwater flood depth =2ft	0.25		
Zone A, Stillwater flood depth < 1ft	0.00		

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Reasonable considerations for calculating debris impact loads should to be given to the following:

Classification
- No impact (for areas of little or no velocity or potential source of debris),
- Normal impact,
- Special impact, and
- Extreme impact.

Conditions
- Immediately adjacent to or downstream from another building
- Downstream from large floatable objects (e.g., exposed or minimally covered storage tanks)
- Among closely spaced buildings

Factors
- Size,
- Shape,
- Weight of the waterborne object,
- Flood velocity,
- Velocity of the waterborne object compared to the flood velocity.
- Duration of the impact,
- Portion of the building to be struck.
- Depth of flooding, and
- Blockage upstream of structure.

Guidance
ASCE 7 Commentary, Section 4.1.2.9 in FEMA P-259 (FEMA 2012a), and Section 8.5.10 of FEMA P-55 (FEMA 2011c).

☐ SECTION IV.5.Provide a Scour Analysis

Analysis scour conditions and provide calculations include the following:

- Identify type(s) of expected scour,
- Calculate depth for each scour type,
- Account for cumulative effect, and
- Compare to known conditions (where tree roots and established vegetation are in relation to structure or object placement consider as part of the scour conditions and calculations)

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☐ SECTION IV.6.Provide Calculations per Scour Type (where appropriate)

Erosion and undermining under and around objects, scour, where the wearing or washing away of land and can occur in and around the object should be computed using the following factors:

Considerations

- Distance of the structure in question from the shoulder of the flood source,
- Shear strength of the soil,
- Frequency of rise and fall of the surface of the flood source, and
- Slope
    - Critical height,
    - Inclination,
    - Cohesive strength of the soil in the slope,
    - Level and variation of groundwater in the slope,
    - Degree of stabilization of the surface of the slope, and
    - Level and variation in level of water on the toe of the slope.

Scour types

- Local, flow patterns around objects or obstructions result in tight scallops along a drainage path (for obstructions, tailout/backwater bars, etc.)
- *Constriction*, occurs when objects or site features create a narrowing of the flood flow path (for Crossings, existing features, debris jam, etc.),
- Jet (for end of aprons, lateral bars, side channels, energy sinks, subchannels, etc.)
- Drop/Weir, result of roller formed by cascading flow (for Culverts-perched or under pressure flow, Spillways, Natural drops, etc.)

The scour at an embankment toe can be computed as S_{max}:

$$S_{max} = d*[1.1*(\frac{a}{d})^{0.4}*(\frac{V}{(gd)^{0.5}})^{0.33}]$$

where:

S_{max} = maximum potential depth of scour hole (ft)
d = depth of flow upstream of structure (ft)
a = diameter of pier, post, or pile or half the frontal length of the blockage (ft)
V = velocity of flow approaching the structure (ft/sec)
g = acceleration of gravity (equal to 32.2 ft/sec)

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The <u>localized scour at vertical pile or pole</u> can be computed as S_{max}:

$$S_{max} = 2.2a$$

where:

S_{max} = maximum potential depth of scour hole (ft)
a = diameter of a round foundation element, or the maximum diagonal cross section dimension for a rectangular element (ft)

The <u>localized scour around vertical enclosure</u> can be computed as S_{max}:

$$S_{max} = d_s * [2.2 * (\frac{a}{d})^{0.65} * (\frac{V}{(gd)^{0.5}})^{0.43}] * K$$

where:

S_{max} = maximum potential depth of scour hole (ft)
d_s = design stillwater flood depth upstream of the structure (ft)
a = diameter of a round foundation element, or the maximum diagonal cross section dimension for a rectangular element (ft)
V = velocity of flow approaching the structure (ft/sec)
g = acceleration of gravity (equal to 32.2 ft/sec2)
K = factor applied for flow angle of attack (see table below)

Table for Scour Factor for Flow Angle of Attack, K				
Angle of Attack	Length to Width Ratio of Structural Member in Flow			
	4	8	12	16
0	1	1	1	1
15	1.15	2	2.5	3
30	2	2.5	3.5	4.5
45	2.5	3.5	4.5	5
60	2.5	3.5	4.5	6