CHAPTER

8

FLOODPLAINS AND SINKHOLES

8.1 Introduction

Floodplain management is a decision making process that, when combined with appropriate land use regulations, is implemented in order to determine the most appropriate use(s) of local floodplains. The decision making process for floodplain management hinges on balance between these three concerns: 1) environmental quality, including preservation of natural and beneficial floodplain functions, minimizing stream modifications and protecting stream water quality; 2) economic development where necessary and appropriate; and 3) health and safety including minimizing risk to human life and risk of property damage.

Many natural floodplains have been affected by grading encroachments, bridges, box culverts and restricted channels. Historically, people settled near creeks and streams for uses such as transportation, water supply, agriculture, etc. Acceptable limits for flood risks were then determined mainly by trial and error and personal experience and judgment. Proper use or preservation of the natural floodplain can minimize the extent of flood damage, reduce stream flow velocities, reduce stream bank erosion, improve stormwater quality, provide for wildlife habitat, and provide recreational opportunities.

Knox County's floodplain management program is largely driven by two programs administered by the Federal Emergency Management Agency (FEMA): the National Flood Insurance Program (NFIP), and the Community Rating System (CRS) Program. These programs are described in detail in section 8.2. Knox County's regulations and policies for development in and around sinkholes are discussed in detail in section 8.5. It should be noted that Knox County's participation in the NFIP does not require regulation of stormwater in and around sinkholes.

Definitions for key terms utilized in this chapter (e.g., floodplain, floodway, flood fringe) are included in Volume 1, Appendix B of this manual.

8.2 Applicable Federal Regulations

8.2.1 National Flood Insurance Program

Congress created the NFIP through the National Flood Insurance Act of 1968 to respond to rising costs of taxpayer-funded flood disaster relief and increased flooding damages. The Flood Disaster Protection Act of 1973, the National Flood Insurance Reform Act (NFIRA) of 1994 and other legislation helped broaden the scope of the NFIP. The 1994 NFIRA provided mitigation insurance and a grant program for state and community flood mitigation project planning and established the Community Rating System (CRS), an incentive program for NFIP communities.

The NFIP uses two main mechanisms for achieving its cost-reduction objective: (1) transferring costs for flooding losses to floodplain occupants through insurance policy premiums; and (2) moving future development away from flood hazard areas as appropriate, or requiring flood-resistant design and construction in flood-prone areas. Before the NFIP was established, flood insurance was typically not available from private insurers and most communities did not regulate floodplain development.

Participation in the NFIP is voluntary. Approximately 20,000 communities in the United States and its territories participate in the program. Participation requires the adoption and enforcement of floodplain management ordinances that include minimum floodplain management standards, such

as designation of a 100-year floodplain and determination of flood elevations, which have been established by FEMA. Property owners that are located in communities that participate in the NFIP can purchase federally supported flood insurance. Communities that do not participate in the NFIP can be denied access to federal disaster funding, and property owners in such communities may be denied federal home loans, have relatively higher flood insurance rates, or may not even be able to obtain flood insurance.

In keeping with the objectives of the NFIP, Knox County's floodplain management program has the cornerstone objectives of ensuring that flood levels in local (NFIP regulated) streams are not increased, that public and private flood losses are minimized, and that natural and beneficial values of floodplains are preserved. This is accomplished through a combination of:

1. Restricting or prohibiting land uses in floodplains which are dangerous to health, safety and property due to water or erosion hazards, or which result in damaging increases in erosion or in flood heights or velocities;
2. Requiring that land uses vulnerable to floods, including facilities that serve such uses, be protected against flood damage at the time of initial construction;
3. Administering regulations with regards to controlling the alteration of natural floodplains, stream channels and natural protective barriers which are involved in the accommodation of flood waters;
4. Administering regulations with regards to controlling filling, grading, dredging and other development which may increase flood damage erosion;
5. Preventing or regulating the construction of flood barriers which will unnaturally divert flood waters or which may increase flood hazards to other lands; and
6. Seeking ways to reduce loss of natural floodplain areas and enhance natural benefits of floodplains in areas facing development.

Knox County's floodplain management program includes several types of activities undertaken by the County and others to manage floodplain areas. These activities are shown in Table 8-1.

The procedures outlined in this manual and mandated by the Knox County Stormwater Management Ordinance, Zoning Ordinance, and the Knox County Flood Damage Prevention Ordinance are in keeping with these key program goals. In fact, Knox County's floodplain management program performs to a higher standard than that required by FEMA of NFIP participant communities. This higher standard has enabled the County to also participate in the CRS Program.

8.2.2 Community Rating System

Over 1,000 NFIP communities receive flood insurance premium discounts through the CRS Program, a points-based incentive program where communities can receive credit for exceeding the minimum floodplain management methods required for NFIP participation. Each participating community has the opportunity to accrue points to qualify for reduced flood insurance rates for the local flood insurance policyholders. The CRS system is divided into classes, with larger discounts on flood insurance premium rates for communities with higher point totals. There are 18 creditable activities in four categories where communities can earn points within the CRS (shown in Table 8-2). Knox County participates in the CRS, and local flood insurance policyholders in unincorporated portions of the County receive discounted flood insurance premiums.

Table 8-1. Examples of Local Floodplain Management Program Activities

Type of Activity	Who Performs Activity	Activity Examples
Preventative activities	Knox County Engineering Knox County Commission Metropolitan Planning Commission Other agencies including TVA	Floodplain development and stormwater management permitting; stormwater drainage system maintenance; planning and zoning; floodplain regulations; buffer requirement regulations
Property protection	Property Owners (typically performed on a building-by-building or parcel basis)	Relocation; acquisition; building elevation; floodproofing; sewer backup protection; insurance
Natural resource protection	Knox County Engineering Knox County Parks & Recreation Other local agencies and utilities Special interest organizations Property owners and developers	Streambank restoration; wetlands protection; buffer zone implementation or restoration; erosion prevention and sediment control
Emergency services	Knox County Emergency Management Staff and other affiliated agencies	Flood warning; flood response; critical facilities protection; health and safety; maintenance
Structural projects	Knox County Engineering Other agencies including TVA Property owners and developers	Channel modifications; storm sewers; reservoirs; levees; detention ponds
Public information	Knox County Engineering Metropolitan Planning Commission	Outreach projects; technical assistance; environmental education; library

Table 8-2. Summary of CRS Program Credit Activities by Category

Category	Credit Activities
Public Information Activities	1) Maintain new construction elevation certificates 2) Provide and publicize map information service to identify property's FIRM zone 3) Outreach projects sending information to floodprone residents or all community residents 4) Hazard disclosure by real estate agents to potential purchaser of floodprone property 5) Maintaining flood protection information in public library 6) Provide and publicize service for property owner technical advice about protecting their buildings from flooding.

Category	Credit Activities
Mapping and Regulator Activities	1) Develop additional flood data 2) Open space preservation 3) Higher regulatory standards 4) Flood data maintenance 5) Stormwater management regulations to require new development to ensure that post-development runoff is no worse than pre-development runoff
Flood Damage Reduction Activities	1) Comprehensive plan and standard planning process for floodplain management 2) Acquire and/or relocate floodprone buildings to locations outside floodplain 3) Document flood protection (floodproofing or elevated) pre-FIRM buildings 4) Periodic inspections and maintenance as needed for channels and retention basins in drainage system
Flood Preparedness Activities	1) Provide early public flood warnings and have detailed flood response plan 2) Maintain levees not credited with providing base flood protection 3) Communities in a state with an approved dam safety program receive dam safety credit

8.3 Local Floodplain Management Tools

8.3.1 FEMA Flood Insurance Studies

The Knox County FIS and associated FBFMs and FIRMs show floodplain and floodway information for the streams in Knox County which have regulatory floodplains. The most recent FIS can be obtained for a nominal fee from FEMA (http://www.msc.fema.gov). The FIS can also be viewed and photocopied at the MPC Library in the City/County Building.

The FIS contains historical and background data on local streams, as well as a summary of technical data that was used to develop flood elevations, floodplain boundaries, and floodways. Two main features of the FIS that may be helpful to developers and site design engineers are Floodway Data Tables and Flood Profiles. For each stream in the FIS, the Floodway Data Tables present the distance along the stream at selected cross-sections, and the corresponding flood elevation, floodway width, mean velocity and section area. The Flood Profiles are graphs that present the water surface elevation along the studied portion of the stream for each flood event that was included in the FIS (the 100-year elevation at a minimum). The stream bed profile, cross-sections, road and other stream crossings, and stream confluences are also shown.

FIRMs depict the boundaries of SFHAs (i.e., 100-year floodplains), 500-year floodplains and approximate zones. FIRM maps typically have a zone designation associated with three areas, as designated by FEMA: 1) SFHAs; 2) other flood areas; and, 3) other areas. Zones within each area designation that are commonly shown on Knox County FIRMs are presented in Table 8-3, along with a general description of the information that is available for each zone. The developer or site designer should consult with the appropriate FIRM map for the exact definition of each zone.

The FBFM mapping presents the boundaries of the floodway, 100-year floodplain and 500-year floodplain. FBFMs also show the locations of selected hydraulic stream-cross sections that were used to develop the flood elevations and floodway widths.

8.3.1.1 FEMA Map Amendment and Revision Process

FEMA has established procedures for map amendments and map revisions for studied areas in which a property owner wishes to alter or encroach into a regulatory floodplain. Map amendments typically update the mapping by letter only; and therefore, a new FIS, FIRMs and FBFMs are not typically published. A list of the map amendments and revisions that are available through FEMA are presented in Table 8-4.

Table 8-3. Common Knox County Flood Insurance Rate Map Zones

FIRM Zone	General Description
Special Flood Hazard Areas (SFHA)	
AE, AH, AO, AR	Areas of the 100-year flood; BFEs and flood hazard factors determined.
A, A99	Areas of the 100-year flood; BFEs and flood hazard factors not determined.
Other Flood Areas	
X (shaded)	Areas of the 500-year flood. Areas of the 100-year flood with shallow flooding or other mitigating circumstances. BFEs and flood hazard factors determined.
Other Areas	
X (unshaded), D	Areas outside the 500-year floodplain. Flood hazards are undetermined.

Table 8-4. FEMA Map Amendments and Revisions

Letter Name	Letter Summary
Conditional Letter of Map Amendment (**CLOMA**)	A letter from FEMA stating that a proposed structure that is not to be elevated by fill (natural grade) would not be inundated by the base flood if built as proposed.
Letter of Map Amendment (**LOMA**)	A letter from FEMA stating that an existing structure or parcel of land that has not been elevated by fill (natural grade) would not be inundated by the base flood.
Conditional Letter of Map Revision Based on Fill (**CLOMR-F**)	A letter from FEMA stating that a parcel of land or proposed structure that will be elevated by fill would not be inundated by the base flood if fill is placed on the parcel as proposed or the structure is built as proposed.
Letter of Map Revision Based on Fill (**LOMR-F**)	A letter from FEMA stating that an existing structure or parcel of land that has been elevated by fill would not be inundated by the base flood.
Conditional Letter of Map Revision (**CLOMR**)	A letter from FEMA commenting on whether a proposed project, if built as proposed, would meet minimum NFIP standards.
Letter of Map Revision (**LOMR**)	A letter from FEMA officially revising the current NFIP map to show changes to floodplains, floodways, or flood elevations outlined in 44 CFR Part 65.

Map amendments and revisions are administered by FEMA. More information on this process and application forms for map amendments and revisions can be found at FEMA's website: www.fema.gov. The property owner or an agent of the owner is responsible for obtaining any required engineering or other services for a proposed map amendment or map revision.

Map amendments and map revisions require approvals from both FEMA and Knox County. Any encroachment or alteration of regulatory floodplains must be performed in accordance with the Knox County Stormwater Management Ordinance and Flood Damage Prevention Ordinance.

8.3.2 Knox County Engineering Floodplain Mapping

Knox County may have additional SFHA, floodplain and floodway information for streams in the FIS which were in need of improved flood management information, and for a number of streams that are not included in the FIS. This information may be used to regulate the development and redevelopment in floodplains in the unincorporated areas of Knox County in the same way that the FEMA-published data is regulated. Further, it should be noted the FIS, FBFMs and FIRMs **do not** include a depiction of the "no fill" boundaries. The location of no-fill boundaries is established by the Knox County Stormwater Management Ordinance, and has been mapped by Knox County Engineering for all studied streams. Floodplain, floodway, and no-fill boundary lines for all streams studied by Knox County are available from Knox County Engineering. Floodplain and floodway lines are available from the Knoxville, Knox County, Knoxville Utilities Board Geographic Information System (KGIS) (www.kgis.org).

It is the responsibility of the property owner or developer to obtain the appropriate regulatory floodplain management data for his/her property. When in doubt, Knox County Engineering should be consulted to determine if regulatory floodplain information is available. Data not included in the most recent FIS can be obtained from Knox County Engineering.

8.3.3 Stormwater Master Plans

A stormwater master plan is an engineering and planning study of a watershed and its stream network. Master plans can be used to regulate new development and redevelopment, address flooding (and sometimes water quality) problems, plan and prioritize stormwater capital improvements, and examine the potential stormwater flooding and quality impacts of future land use patterns and/or regulatory requirements. In some situations, the hydrologic and hydraulic models used to develop a stormwater master plan can be used to determine the stormwater impact of a single development.

Knox County has developed stormwater master plans for several County watersheds. The Director can utilize the information provided by a stormwater master plan for regulatory purposes to limit adverse impacts of a proposed development. Knox County Engineering should be consulted prior to development of a stormwater management plan to determine if a master plan will affect floodplain requirements.

8.4 Floodplain Management Regulations

This section summarizes the local regulations that are used to administer the local Floodplain Management Program, and provides additional policies and procedural guidance where necessary. Knox County ordinance language is presented in this section to the degree needed to allow an understanding of the supportive policy and technical guidance. The reader should consult the Knox County Stormwater Management Ordinance and the Flood Damage Prevention Ordinance for the complete floodplain management regulations. Both ordinances are provided in Volume 1, Appendix A and are discussed in more detail in Volume 1, Chapter 3 of this manual.

8.4.1 Summary of Ordinance Requirements for Development in Floodplains

Table 8-5 presents a summary of the floodplain development requirements stated in the Knox County Stormwater Management Ordinance. The requirements are separated into three categories, depending upon the location of the new development (or redevelopment).

8.4.2 Requirements for Land Use and Land Disturbance

The land use of areas located in floodway, no-fill, and floodplain areas are regulated by the Knox County Zoning Ordinance, as follows: uses permitted within the flood fringe shall be in accordance with Article 3.70, Flood Fringe Requirements; and uses permitted within the floodway shall be in accordance with Article 5.70, Floodway Zone. The reader should consult the Zoning Ordinance for specific requirements regarding zoning, structure placement, and land use planning for developments proposed in floodplain areas.

Table 8-5. Summary of Floodplain Development Requirements

Location of Development	Available Data	Summary of Requirements
AE, AH, AO, or AR, shaded X Zones	100-year floodplain elevations 500-year floodplain elevations (i.e., base flood elevations) Floodway widths No-fill boundaries	1. Floodplain Development Permit 2. FEMA Elevation Certificate for insurable structures 3. Floodway encroachments are prohibited. 4. Construction fill inside the no-fill boundary is prohibited. 5. An engineering study is required for exceptions to items 3 and 4 above. 6. A CLOMR and LOMR are required for modification of a floodway boundary.
A and A99 Zones	Approximate 100-year floodplain boundaries; no base flood elevations or floodway widths determined.	1. Floodplain Development Permit 2. FEMA Elevation Certificate for insurable structures 3. Developments greater than 40 lots or 10 acres require the determination of accurate floodplain, floodway, BFE and no-fill boundary data and conformance with requirements for AE zones. 4. For all other developments, encroachments are prohibited within a specified distance of the streambank. 5. An engineering study is required for an exception to item 4 above.
Unshaded X or D Zones adjacent to unstudied streams	No data available	1. Developments greater than 40 lots or 10 acres and adjacent to a stream that has an upstream drainage basin of $1mi^2$ or greater require the determination of accurate floodplain, floodway, BFE and no-fill boundary data, and conformance with requirements for AE zones. 2. For all other developments, encroachments are prohibited within a specified distance of the streambank.

Note: the Zoning Ordinance's definition for "floodway zone" encompasses the entire 500-year floodplain. It is important that the use by MPC of the term "floodway" for this zone not be confused with the regulatory definition for floodway that has been established by FEMA, is utilized by Knox County Engineering, and is defined in section 8.2 above. For purposes of floodplain regulation and management by Knox County Engineering, "floodway" specifically refers to a regulatory width across a stream that is calculated for the 100-year storm event. In Knox County, there is no regulatory 500-year floodway.

Knox County Engineering allows open space land uses and land disturbances within the no-fill boundary, so long as the land use does not alter, fill, or cause an encroachment. Further, land uses and disturbances must be in keeping with Knox County's requirements for water quality buffers where the regulated floodplain areas and water quality buffer areas overlap. Where water quality buffer and floodplain management requirements conflict or overlap, that provision which is more restrictive or imposes higher standards or requirements shall prevail. More information on water quality buffer requirements can be found in Volume 2, Chapter 6 of this manual.

8.4.3 Requirements for Engineering Studies

Engineering studies performed to develop floodplain, floodway, BFE and no-fill boundaries where required shall be performed by a registered professional engineer in the State of Tennessee, and shall be prepared and reported in accordance with FEMA standards. Such standards are documented in the FEMA publication *Guidelines and Specifications for Flood Hazard Mapping Partners*, which can be found at the following website: http://www.fema.gov.

Both hydrologic (i.e., peak discharge) and hydraulic (i.e., floodplain elevation and floodway width) computations shall be performed to develop the required floodplain data for a given stream. Requirements for hydrologic and hydraulic models are presented in the next two sections.

8.4.3.1 Hydrologic Modeling – Determining Peak Discharges

Peak discharges shall be determined for the 2-year, 10-year, 25-year, 100-year and 500-year storm events. The peak discharges shall be determined for pre-development and post-development land use conditions, and shall be utilized as input to the hydraulic model that is used to determine floodplain elevations and other floodplain data.

Four methods are considered acceptable for determining peak discharges for the purpose of floodplain data development, as follows:

1. gage analysis using statistical hydrologic methods;
2. Clark Unit Hydrograph;
3. the use of Tennessee Valley Authority (TVA) regression equations; and,
4. the use of a hydrologic model, such as USACE's HEC-1 or HEC-HMS.

The Director shall select the method that will be used on a case-by-case basis. The selection is based on the availability of existing hydrologic models and/or gage data in the same area as the proposed development, a history of flooding in the same area as, or downstream of, the proposed development, FEMA standards and requirements, and engineering judgment. Each method is discussed briefly below.

Where the Director requires gage analysis using statistical hydrologic methods, peak discharges shall be determined using methods that are widely known and accepted, such as Gumbel extreme values or Log-Pearson Type III distributions. Such methods are appropriate for flood flow frequency analysis when suitable gage data is available with many years of record. Longer gage data records improve the peak flow estimates.

Where the Director requires the use of regression equations, the Director shall specify the set of equations required for analysis. Regression equations appropriate for rural and urbanized areas in East Tennessee have been developed by TVA. Detailed information on the use of regression equations to determine peak discharges is presented in Volume 2, Chapter 3 of this manual.

In the event that the Director requires the use of a hydrologic model, the United States Army Corps of Engineers (USACE) HEC-1 or HEC-HMS software shall be used. Both models and manuals are available for download at the following website: http://www.hec.usace.army.mil. The use of these models requires the division of the upstream drainage basin(s) based on topographic drainage

divides, and/or an understanding of the basin organization and connectivity of a hydrologic model that may already exist for the area of proposed development. Knox County Engineering can provide input data and guidance for existing HEC-1 or HEC-HMS models.

For all HEC-1 and HEC-HMS models, Soil Conservation Service (SCS) curve numbers, the SCS time-of-concentration/lag time and Clark unit hydrograph methods shall be utilized to predict watershed response and generate design storm hydrographs and peak discharges. Channel routing shall be performed using Muskingum-Cunge routing techniques, and modified Puls routing shall be utilized to route flood storage areas, such as in-stream and off-line ponds and upstream of culverts and bridges.

8.4.3.2 Hydraulic Modeling – Determining Floodplain Elevations and Boundaries

The USACE HEC-RAS hydraulic modeling software shall be used for all hydraulic computations on streams where a HEC-RAS model, or no model, previously exists. On streams where the most current model is the older USACE HEC-2 hydraulic modeling software, the Director may allow the continued use of the HEC-2 model as long as FEMA modeling requirements are satisfied. Persons responsible for hydraulic analysis shall consult with Knox County Engineering to determine if an existing model will be utilized, or a new one must be created. Both programs are available from the Hydrologic Engineering Center's website: http://www.hec.usace.army.mil.

Flood Elevation

Flood elevations shall be determined for the 100-year and 500-year storm events. The Director may also require the determination of flood elevations for the 2-year, 10-year, 25-year, and/or 50-year storm events. FEMA requires the use of valid and accurate flood elevation, land survey, topographic and other pertinent information for the study area. It is important to understand that survey of stream cross-sections may be required upstream and downstream of the proposed development in order to adequately model the study area. Guidelines for stream cross-section surveys are presented in the next section.

Floodway

Regulatory floodway widths shall be developed for the 100-year storm event. For floodway development, the surcharges between the 100-year flood elevation profile and the floodway profile shall be no less than zero, and no greater than the maximum allowable surcharge of one (1) foot. Floodways shall initially be determined using equal conveyance reduction for the floodplain on opposite sides of the stream. The engineer can then optimize the floodway width to the narrowest width allowed within the surcharge limits, but without abrupt changes in width. Floodway boundaries that appear as a zig-zag or accordion-like will not be accepted unless the engineer can provide sufficient evidence to show that a more gradual and smooth boundary could not be obtained.

Floodway boundaries shall not be located outside of the 100-year floodplain boundary. For tributary streams, the regulatory floodway on the tributary shall be calculated without consideration of backwater flood elevations from the larger stream.

Base Flood Elevation

Base flood elevations shall be determined from the 500-year floodplain elevation, in accordance with the Knox County Stormwater Management Ordinance.

Flood Protection Elevation

Flood protection elevations shall be determined from the 500-year floodplain elevation. Where a higher backwater flood elevation (for the 500-year event) exists and at stream and tributary confluences, the backwater elevation shall prevail. If the future 100-yr floodplain elevation is higher than the current 500-yr elevation, then the future 100-yr elevation shall be used.

No-Fill Boundary

The "no fill' boundary shall be located at one-half the linear distance between the floodway boundary and the 100-year floodplain boundary. This measurement is relatively easy along most of the stream's length, where the floodway and floodplain are approximately parallel. In backwater areas (e.g., confluences with tributaries, ditches and channels) where these boundaries are not parallel, the method for delineating the no-fill boundary is as follows.

1. Delineate the incoming ditch or channel in the backwater area to the 100-year floodplain boundary.
2. Measure the distance along the ditch or channel from the floodway boundary to the 100-year floodplain boundary.
3. Mark the point that is halfway along the distance measured, and determine the topographic elevation at that point.
4. The no-fill boundary in the backwater area shall be drawn at (i.e., shall follow) the topographic elevation of the halfway point until the floodway and the 100-year floodplain boundary become approximately parallel to each other. At this point, the no-fill line shall be located at one-half the linear distance between the floodway boundary and the 100-year floodplain boundary.

8.4.3.3 Stream Cross-section Survey Guidelines

Determining floodplain and floodway data in accordance with FEMA standards often requires the collection of field survey data for stream cross-sections located along the stream reach, including cross-sections at bridge and culvert channel crossings. Field surveys shall be accomplished by differential leveling or differential GPS methods, with vertical error tolerances of 0.5 feet across the 100-year floodplain. Cross-section elevations and stations shall be determined at those points along the study reach that represent significant breaks in the ground slope, and at changes in the hydraulic characteristics of the floodplain. Stream cross-section survey data may be supplemented by KGIS topography in areas at least eight (8) feet vertically above the top of bank elevation.

Engineers responsible for the hydraulic analysis shall locate cross sections to accurately represent the stream reach. The cross-section through the stream channel shall be perpendicular to the channel from top-of-bank to top-of-bank. The cross-section shall be extended perpendicular to channel/floodplain slope to a point at least eight (8) feet vertically above the top-of-bank elevation. Where the channel is not aligned with the valley slope, these sections may be crooked (i.e., dog-legged) so that the flow direction is essentially perpendicular to the cross-section alignment. Elevation and location information shall be collected at each of the following locations on the cross-section: top of bank; toe of slope; stream invert; all edges of water; and all major changes of grade. Distance between survey points shall not exceed 100 feet.

For roadway and driveway crossings, the HEC-RAS and HEC-2 models require surveyed cross-sections for the roadway or driveway profile, as well as at the upstream face and downstream face of the structure. For level roadways, the roadway profile survey shall be collected down the middle of the road. If the roadway is super-elevated, the roadway profile survey shall be collected on the highest side (i.e., the side above which the road would be completely overtopped by a flood). If the crossing has a solid rail, also survey along the top-of-rail. For each face cross-section, the horizontal and vertical position of the following locations shall be surveyed:

- Tops of curb;
- Top of wingwalls at the junction with the upstream face and all changes in vertical or horizontal alignment (only required at upstream face);
- Low chord at the face of the abutments and at each substructure (e.g., culvert) where the depth to low chord varies;
- Ground at the face of the abutments (if footing is exposed, define shape of footing);

- Top of banks;
- Toe of slopes;
- All changes of grade;
- Edges of water;
- Stream invert; and
- Face of each substructure (if footing is exposed, define shape of footing).

For culverts, the survey shall obtain at a minimum: low chord (at top of each culvert), culvert invert, stream invert, culvert size and type (e.g., pipe arch, CMP, concrete box, etc.).

8.4.3.4 Reporting Requirements and Guidelines

Because the data provided in the engineering study may be submitted to FEMA, floodplain and floodway data shall be reported in accordance with FEMA standards. The Director may establish additional reporting requirements when deemed necessary to adequately document the flood study preparation and results. Typical items included with flood study reports include the following:

- Floodplain Study Report (see below);
- Digital copies of all models used;
- Scaled topographic maps that shows model cross-section locations, proposed structure locations and finished floor elevations;
- Stream profiles showing water surface elevations, stream bed, bridge and culvert crossings and selected cross-section locations;
- Support information for peak flow determination such as a map with watershed boundary and subareas or subbasins delineated;
- All input data used for computing water surface profiles in printed and electronic format (if applicable). Examples would be the HEC-2 and HEC-RAS input files;
- Summary output tables and charts showing computed water surface elevations, energy grade lines, velocities, cross-sectional flow areas, etc; and,
- Scaled flood elevation/boundary maps prepared in accordance with FEMA map standards.

At a minimum, flood elevation/boundary maps submitted to Knox County Engineering must include the following data for the study reach:

- pre-development topographic contours (2 to 4 ft intervals as available from KGIS);
- post-development topographic contours (1 to 2 ft intervals);
- the most current planimetric (e.g., roads, houses, streams etc.) information (field topography or KGIS planimetric information, if current);
- cross-section locations (labeled as named in hydraulic model) and river mile or distance;
- the 100-year floodplain boundary;
- base flood elevations;
- the 500-year floodplain boundary; and,
- the floodway boundary.

A second map (or set of maps) shall be prepared with all of the data described above and the no-fill boundary. FEMA does not regulate the no-fill boundary, therefore, two sets of maps are required (one with and one without the no-fill boundary).

Flood elevation/boundary maps can be submitted on the concept or site plan if desired, but must be "to scale" at least at 1"=200' or 1"=400', in Microstation (*.dgn) format, or other format suitable for use by KGIS. It is the responsibility of the person submitting the engineering study to consult with KGIS on a suitable format prior to submittal of the information to Knox County Engineering and/or KGIS.

Each engineering study shall include a Floodplain Study Report. At a minimum, the Floodplain Study Report shall be formatted and include the sections and information listed below. The Director may require information as necessary. Floodplain Study Reports shall be submitted with the Stormwater Management Plan for the proposed development.

I. General Description
   A. Site location
   B. Study limits
   C. Existing conditions
   D. Proposed conditions
   E. Boundary conditions
   F. Special considerations and assumptions
II. Hydrology (Peak Discharge Calculation)
   A. Description of methodology
   B. Peak discharge calculation locations
   C. Drainage basin delineation
   D. Assumptions
III. Hydraulics (Flood Data Calculation)
   A. Description of methodology
   B. Assumptions
IV. Results
   A. Summary output tables (as described above)
   B. Maps and profiles (as described below)
V. Supporting Data

8.4.4 Requirements for Construction in Floodplains

Construction requirements for structures located in floodplains are presented in the Knox County Stormwater Management Ordinance, Zoning Ordinance, and the Flood Damage Prevention Ordinance. Some construction requirements differ depending upon the type of construction (i.e., new residential, improved existing residential, manufactured homes, and non-residential); therefore, the person(s) responsible for construction should be sure to: 1) consult both ordinances; and 2) ensure conformance with the regulations that are appropriate with the type of construction being proposed. The Flood Damage Prevention Ordinance also contains provisions that address the construction of water supply and wastewater disposal systems (i.e., sanitary sewers and septic tanks) in floodplain areas.

It is important to note that conformance with Knox County's construction requirements for structures located in floodplains is required for all construction in floodplains, not just those that require submittal of a Stormwater Management Plan and/or approval of a building permit.

8.5 Regulations for Development in Sinkhole Areas

8.5.1 Background

In karst areas, such as Knox County, the surface drainage is significantly influenced by the hydrogeologic flow regime. Stormwater runoff is directed into the sinkholes, transmitted through the ground-water system through a network of interconnected conduits and finally discharged at resurgent locations (springs). If the stormwater runoff exceeds the capacity or rate of discharge of the sinkhole, flooding is probable.

Flooding in sinkhole areas can be caused by a number of factors. First, a lack of other surface drainage features in the area (e.g., streams) result in sinkholes and depressions serving as the primary drainage outlets for stormwater runoff. Developments that drain to these areas increase the volume of runoff that the sinkholes must handle, and often decrease the storage capacity of the sinkhole. Second, construction practices that may alter the karst terrain, such as sinkhole filling, blasting, and inadequate erosion and sediment control, can increase the potential for flooding. Partial or total filling of a sinkhole reduces the volume of surface storage available to contain stormwater runoff. Blasting can change the geometry of sinkhole throats and underground caves, blocking outflow pathways. Finally, a lack of adequate erosion and sediment control measures can increase the potential for silt and other debris to accumulate at sinkhole throats, effectively reducing the outflow efficiency. These factors, combined with seasonal hydrologic conditions such as saturated soils and periods of heavy rainfall, result in increased flooding potential in sinkhole areas and the propensity for geologic settlement (i.e., the appearance of previously unknown sinkholes) in sinkhole areas.

Knox County has significant areas that are characterized by karst geological formations, and therefore, have a high potential for the existence of sinkholes. In some areas, the presence of sinkholes is very evident. This is true in the Ten Mile Creek watershed near Cedar Bluff and Dutchtown Roads, where features such as rock outcrops, large enclosed depressions and rock-lined throats are numerous and easily seen. However, other sinkhole areas are not always so easily identified. Natural, gradual depressions can indicate the presence of sinkholes and the developer should be aware of regulations and policies that may apply to such depressions.

8.5.2 Regulations and Policies

The Knox County Stormwater Management Ordinance contains a number of stormwater and floodplain management requirements for developments that are located near and/or drain to sinkholes, which are summarized below. Persons responsible for development in or near sinkholes should consult the ordinance for a full detail of sinkhole development requirements.

8.5.2.1 General

- Developments in and around sinkholes require submittal of a stormwater management plan. A Floodplain Development Permit is required if structures are developed in or near a sinkhole floodplain.
- Minimum standards for flood management around sinkholes are based on the limits determined by the water surface elevation of the 100-year frequency, 4-day duration storm event (7.8 inches), assuming plugged conditions (0 cfs outflow).
- Where flood management provisions stated in the Knox County Stormwater Management Ordinance cannot be satisfied, or where development or redevelopment is proposed in critical sinkhole watersheds, stormwater master planning, or sound engineering judgment, calculations must be provided that show total retention of the difference between the pre-developed and

post-developed 100-year, 24-hour design storm. These calculations must include the entire contributing watershed area for all designed retention basins and sinkholes. Calculations must also be provided that show that the post-developed 100-year, 24-hour peak flow rate does not exceed the pre-developed 100-year, 24-hour peak flow rate. In basins or subbasins with a documented historical drawdown time, it may be acceptable to assume drawdown if the documented value is at least 1.5 times larger than the drawdown time for the region. In general, advanced subsurface testing must be performed and certified by a professional engineer registered in the State of Tennessee with a demonstrated expertise in hydrogeology. Subsurface testing shall reasonably determine the range of outflows under a variety of design conditions.

- The Director has authority to condition the approval of a permit upon the compliance with additional requirements, including but not limited to measures to avoid and/or protect the sinkhole throat, detention, conveyance facilities, or other stormwater management solutions required to reduce the adverse impact of the proposed development on other properties or on the subject development.

Additional policies pertaining to stormwater and floodplain management in and around sinkholes are as follows:

1. The minimum extent of a sinkhole area is determined by the sinkhole floodplain elevation using at a minimum, the limits determined by the water surface elevation of the 100-year frequency, 4-day duration storm event (7.8 inches), assuming plugged conditions (0 cfs outflow). For developments that drain to sinkholes, the pre- and post-condition runoff volumes shall be calculated using the CN procedure for wet or Antecedent Runoff Condition III (ARC III). The 100-year flood elevations for some sinkholes in Knox County (largely in the Dutchtown Road area in west Knox County) have been mapped by FEMA, and therefore are considered regulatory floodplains and shall be managed as such. The determination of the 100-year floodplain is presented in Example 8-1.
2. No person shall place or cause to be placed any substances or objects, other than stormwater runoff, in any sinkhole or sinkhole drainage area in such a way so as to allow such substances or objects to be washed into a sinkhole throat during storm events.
3. All persons draining stormwater runoff into sinkholes should coordinate with the State of Tennessee to insure appropriate compliance with the applicable provisions of the State of Tennessee Rules of the Tennessee Department of Environment and Conservation Chapter 1200-4-6 (Underground Injection Control) for Class V injection wells. Copies of approved permits and any pertinent site-specific provisions shall be submitted to the County prior to the issuance of a Grading Permit.
4. Disturbance of the immediate area around a sinkhole during construction activities shall be minimized to as little as possible. The use of mechanized equipment near the sinkhole throat should be avoided. All use of explosives shall be in compliance with the State Fire Marshall's Office. The underground system of caves and streams is dynamic and explosions in the vicinity can alter or block underground drainage passages. Sinkhole areas are known to be unstable for construction and structures placed on soil foundations in sink areas may be subject to both settling and collapse of the sink.
5. Knox County Engineering requires geotechnical studies for structures located within fifty (50) feet of the highest hachured contour (also called the "rim") of a sinkhole.
6. Uncontrolled fill placement may present additional settlement hazards when fill is placed in or near sinkholes. Knox County *requires* that appropriate geotechnical studies be done and measures taken to insure structure foundations are designed to take into account potential sinkhole locations and instability. Such studies should account for potential foundation problems for both undisturbed sink areas and those previously filled by others.
7. Drainage and flood calculations for sinkhole areas shall be performed by a professional engineer registered in the State of Tennessee.

8. The property owner shall contact TDEC to determine if any wells and/or springs are located on the proposed development site. Known wells shall be shown on the stormwater management plan for the site. In addition, the stormwater management plan shall include the name and phone number for the TDEC official that was contacted with regards to known wells and/or springs located on the site, and the date of the inquiry to TDEC. A copy of any written correspondence with TDEC may be included with the stormwater management plan.
9. The Director has the authority to require preparation of a sinkhole drainage study for developments that require a stormwater management plan that drain to sinkholes, are located adjacent to sinkholes, or are within a sinkhole drainage area. The purposes of the study and the minimum items that shall be included in the sinkhole drainage study are detailed in Section 8.5.3.2 and Section 8.5.4.3
10. Filling, altering or obstructing a throat or outlet to a sinkhole or system of sinkholes, or springs or system of springs is prohibited, without prior approval of a grading permit. Any excavation in a sinkhole must be approved by the Director prior to approval of a grading permit.
11. Developers and site contractors shall employ measures that will protect sinkhole throats and outlets. These may include, but are not limited to, including installation of erosion prevention and sediment control measures, limiting blasting activities or avoiding such activities altogether, avoid grading that causes an increase in area draining to the sinkhole after development, and locating structures and other proposed development away from the throat. No person shall fill or obstruct the outlet to a sinkhole or system of sinkholes, or fill over a spring.
12. When encroachment into a sinkhole has been approved, the Director may impose a no-fill zone requirement in sinkholes that have an obvious throat, a history of flooding, and/or where engineering judgment suggests that such a requirement is necessary for proper management of the local stormwater system. In such cases, a no-fill line shall be established by the contour line or interpolated contour line for the elevation that defines sixty (60) percent of the floodplain storage volume. The area encompassed by this line shall be defined as the no-fill zone for all development activities. No construction fill will be allowed in this zone. Any fill added in the floodplain but outside the no-fill lines must be compensated for by an equal volume cut below the sinkhole floodplain elevation. An example of the calculation of the no-fill zone is presented below in Example 8-2.
13. The Director may approve a reduction in the sinkhole storage volume if engineering calculations prepared by a professional engineer registered in the State of Tennessee document that the floodplain elevation resulting from the 100-year frequency, 24-hour duration storm, assuming post-development site conditions and a plugged sinkhole outlet (0 cfs) will not flood any structures. The calculation of the 100-year flood elevation for a sinkhole is presented in Example 8-1.
14. The finished floor elevation (FFE) of any habitable structure adjacent to a sinkhole must be at least one foot above the established floodplain elevation. No structure shall be located within the hachured contours of a sinkhole.
15. The County encourages site designers to limit the impervious area of the site as much as possible. Efficient use of parking areas can reduce the impervious area and reduce the post-development runoff volumes. Pervious surfaces can be used for overflow parking areas that will be used infrequently. Impervious area reduction techniques and other Better Site Design measures are discussed in detail in Volume 2, Chapter 5 of this manual.

8.5.2.2 Determining Sinkhole Floodplain and No-Fill Lines

The floodplain line for a sinkhole is defined by the sinkhole lip elevation or the flood elevation expected under extreme flood conditions. The storage volume beneath this elevation is the sinkhole floodplain storage volume. *The pre-development floodplain storage volume must be preserved under post development conditions.* If any fill is added in the floodplain outside the no-fill line this stipulation will require compensating excavation in the floodplain.

The no-fill line shall be established by the contour line or interpolated contour line for the elevation that defines *sixty (60) percent* of the floodplain storage volume. The area encompassed by this line shall be defined as a no-fill zone for all construction activities. No construction fill will be allowed in this zone.

The floodplain, no-fill line and dedicated easement shall be indicated on all preliminary and final plans.

The floodplain and no fill lines may be adjusted under following circumstances:

1. The floodplain line can be adjusted to equal the 100-year flood elevation (future conditions) determined from flood studies or Master Plans that consider future development in the watershed. The Director must approve the adjustment. The use of a flood study or Master Plan by the Director does not imply approval of the adjustment of the floodplain for the development.
2. If the contributing drainage area is less than 50 acres and there is documented evidence that resurgence is not a contributing factor to flood elevations, the floodplain elevation can be determined by the following procedure:
    A. Determine the volume of runoff for the 4-day, 100-year for the contributing drainage to the sinkhole for fully developed conditions. The volume of runoff will equal the drainage area multiplied by 7.8 inches of runoff.
    B. Based on the 4-day, 100-year volume of runoff, determine the predicted floodplain elevation in the sinkhole assuming no outflow from the sinkhole.
    C. If the predicted 4-day, 100-year floodplain elevation is less than the lip of the sinkhole this elevation can be used as the floodplain elevation.
3. The floodplain elevation can be reduced if the drainage directed to the sinkhole under current conditions can be safely redirected to a reliable surface drainage system. Calculations that quantify the pre- and post-development stormwater discharges to the surface drainage system must be provided in the Stormwater Management Plan.

Under all of the above scenarios, the no-fill line must be recalculated based on the revised floodplain elevation.

Example 8-1. Calculation of 100-year Flood Elevation for a Sinkhole

Assume: Sinkhole outflow is 0 cfs, all contributing watershed runoff outlets to the sinkhole and that all rainfall becomes runoff (no infiltration, evaporation, etc.).

Watershed Variable	Amount
Total area (ac)	10
100-year, 24-hour storm rainfall (in)	6.5
Total Watershed Runoff (ac-ft)	5.5

The incremental storage volume for the sinkhole is assumed to be calculated using a volume formula for the frustum of a cone. The frustum is the part of a right circular cone between the base and a plane parallel to the base whose distance from the base is less than the height of the cone. Let h be the height of the cone frustum, or for this case the difference between the elevations (2 feet here). The areas at the elevation increments are the areas at the top and bottom of the cone frustum, and are represented as A_1 and A_2, respectively. The incremental storage volume formula, including the conversion from cubic feet to ac-feet is:

$$\Delta V = \frac{(\frac{h}{3} \times (A_1 + A_2 + \sqrt{A_1 \times A_2}))}{43{,}560}$$

The calculated storage volume for receiving sinkhole is summarized in the table below:

Elevation (feet)	Area Inside Closed Contour (ft^2)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
938	0	NA	NA
940	225	0.00	0.00
942	2215	0.05	0.05
944	13250	0.32	0.37
946	69160	1.72	2.09
948	178000	5.48	7.57
950	260000	10.00	17.57
952	354000	14.04	31.61

To determine the 100-year floodplain elevation, the cumulative storage volume must be equal to, or exceed, the total watershed runoff of 5.5 ac-ft. This occurs between the 948 and 946 contours. Note that the sinkhole lip is located at elevation 952, so in this example, the 100-year, 24-hour flood is contained within the sinkhole without overflow.

Example 8-2. Calculation of Sinkhole No-Fill Line

The following elevation-storage table was developed for a sinkhole adjacent to a proposed development site:

Elevation (feet)	Cumulative Storage Volume (ac-ft)
900	0.0
904	3.5
906	5.0
908	8.0
910	11.0
912	15.0
914	19.0
916	25.0

The lip of the sinkhole is located at elevation 916, therefore the sinkhole floodplain line is defined by the 916 contour line. The sinkhole no-fill line is defined by the 912 contour line, as follows:

60% of 25 ac-ft = 15 ac-ft
The 912 elevation contour has the required 60% of total storage volume of 15 ac-ft.

Therefore, the development can encroach between the 916 and 912 contour lines but, the total storage volume below elevation 916 must be kept equal to 25 ac-ft. Note that the fill volume within the sinkhole but beyond the "no fill" line must be compensated for by excavating below the sinkhole floodplain elevation.

Example 8-3. Determining Runoff Volumes

Note: This example is for volume calculations only and does not include discharge calculations that would be required.

A five (5)-acre site that is currently 50% woods and 50% meadow is to be developed into a commercial shopping center. The proposed development will include 2.5 acres of impervious area, 1 acre of maintained lawn and 1.5 acres will remain wooded. The site drains to a sinkhole, which is located off the property, but inside the Dutchtown Road Drainage Basin.

All soils were determined to be in Hydrologic Soil Group C.

Determine the pre-development runoff volume (Q_v):

P = 6.6 inches
CN = 86 (woods and meadow good condition, AMC=III, soil group C, source TR-55)
S = 1000/CN-10 = 1.63 inches
$Q_v = (P-0.2S)^2/(P+0.8S)$ = 4.98 inches * 5 acres = 90,400 ft^3

Determine the post-development runoff volume (Q_v):

P = 6.6 inches
CN = (1.5 * 86 (woods) + 2.5 * 99 (imp. Area) + 1.0 * 88 (open space))/5 = 93
S = 1000/CN-10 = 0.75 inches
$Q_v = (P-0.2S)^2/(P+0.8S)$ = 5.78 inches * 5 acres = 104,900 ft^3

To meet Knox County requirements, the designer must reduce the post-development runoff volume by 14,500 ft^3 (104,900 ft^3 – 90,400 ft^3) to meet pre-development levels.

References

City of Knoxville. *Land Development Manual.* City of Knoxville Engineering Department, Stormwater Division, June 2006.