edcetera | engineering

Floodplain Engineering- Part II:

An Overview of Floodplain Management

by

David E. Fantina, PE

Course 304

4 PDH (4 Hours)

PO Box 449
Pewaukee, WI 53072
(888) 564 - 9098
eng-support@edcet.com

Introduction:
This course presents an overview of floodplain management including some of the state and national regulations affecting floodplain areas. It goes without saying that a knowledge of this material is imperative for engineers working in flood-prone areas. Not only is proper engineering required to prevent environmental damage to riparian areas, but it is also essential to protect human life and property during flood events. Flooding yearly causes massive loss of property and some loss of human life in many parts of the United States. In addition, flooding routinely closes roads, disrupts airports, and harbors, and damages utility lines. Therefore, it is a major hindrance to transportation and infrastructure. Understanding the dynamics of floodplains, what resources are available, and what regulatory agencies have jurisdiction over these areas can help engineers make informed decisions that can benefit public health and welfare.

This course also explains how engineers can analyze the anticipated forces that floodwaters place on structures within the flood zone. Knowledge of these processes can warn as to which structures at are high risk for damage during flood events.

The photograph below shows flooding over the route 377 bridge over the Washito River near Tishomingo, Oklahoma. Unfortunately, this is a common scene in many flood-prone areas. Seeing pictures like this make it easy to imagine the catastrophic effect on the communities involved. Understanding these events and being able to deal with them in a constructive manner is one of the main goals of this course.

Since prehistoric times people have settled in river valleys and along coastlines. These areas have provided abundant food resources and easy transportation. Even today, these areas are favored for their natural beauty and resources. This makes it ever more imperative that appropriate safeguards are in place in these locations. The Federal Emergency Management Agency (FEMA) will be referred to throughout this course, as it is the main regulatory floodplain agency in the country.

What is a Floodplain?

Quite simply a floodplain encompasses that area of land that is subject to flooding, either by a river or by the ocean. However simple as that definition might seem, there are actually different types of floodplains and floodplains, themselves, are divided into different regions.
Floodplains can be divided into several types:

1. Riverine floodplains.
2. Coastal floodplains.
3. Tidal floodplains.

In addition, floodplains can be divided by the frequency of inundation. Therefore, a piece of property can be within the 10 year, 100 year, or 500 year floodplain. This is explained in more detail later.

Floodplains associated with rivers can be further subdivided into floodway and flood fringe areas. Qualitatively, the floodway can be thought of as the inner part of the floodplain and is the part that carries most of the flood waters downstream. The flood fringe can be thought of as the outlying portion of the floodplain where floodwaters inundate the land but it does not contribute greatly to the downstream conveyance of the flood. However, these terms also have legal meanings as shown below.

FEMA's definition of a floodway;

"A regulatory floodway" means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations. For streams and other watercourses where FEMA has provided Base Flood Elevations (BFEs), but no floodway has been designated, the community must review floodplain development on a case-by-case basis to ensure that increases in water surface elevations do not occur, or identify the need to adopt a floodway if adequate information is available.

New York Department of Environmental Conservation Definition of a Floodway: According to the NYDEC the floodway is "that area that must be kept open to convey floodwaters downstream".

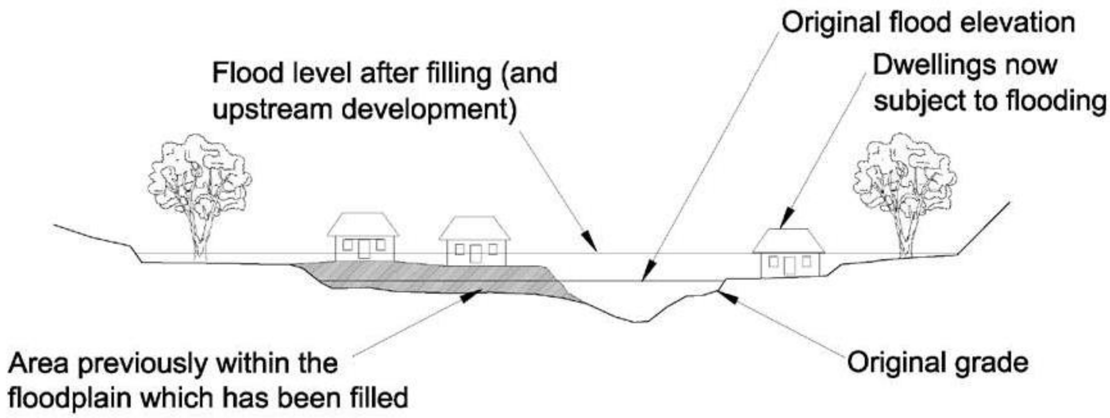
New York State has a two-tiered system of regulations within flood-prone areas. All development within the floodplain must meet the "no adverse effect" criteria, while development within the floodway must also meet the "no rise" criteria. These criteria are explained in slightly more detail below:

1. Adverse effect is defined as any physical damage to an adjoining or downstream property. One method for determining if an adverse effect will result from a particular project within the floodplain is to compare the BFE's (base flood elevations) of the project before and after implementation.
2. The no rise effect is similar to the no adverse effect criteria. It basically means that the NYDEC will not permit a project within the flood zone if it raises the flood levels at any point along the stream profile. To ensure that a project

complies with the no-rise criteria, the design engineer must model the stream, comparing pre-project flood levels to post project flood levels and prove that there will be no raising of the floodwaters caused by the project.

New York has Regional Floodplain Coordinators who are available (through the NYDEC) to provide advice and technical support for any specific floodplain development situations. However, in New York State it is the responsibility of the local Floodplain Administrator to determine what form of technical evaluation for a specific permit application.

Development within a floodplain can lessen the amount of volume provided for floodwaters and can, consequently, raise the level of the flood. This is shown schematically below:



Floodplain Schematic

FEMA Flood Maps:

FEMA regulates flood insurance on a national basis. According to FEMA: "Under federal law, the purchase of flood insurance is mandatory for all federal or federally related financial assistance for the acquisition and/or construction of buildings in high-risk flood areas (Special Flood Hazard Areas or SFHAs). The amount of flood insurance coverage required by the

Federal Disaster Protection Act of 1973, as amended by the National Flood Insurance Reform Act of 1994, is the lesser of the following:

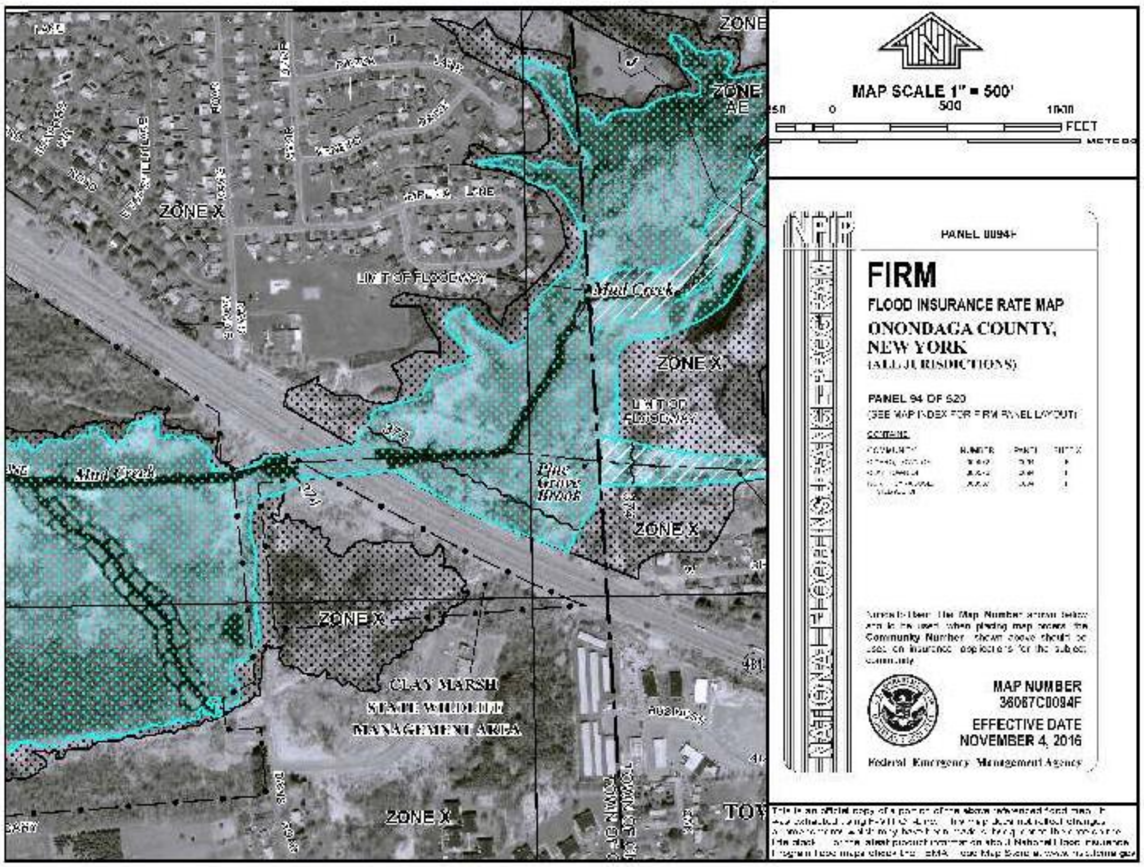
1. The maximum amount of NFIP coverage available for the particular property type, or
2. The outstanding principal balance on the loan, or
3. The insured value of the structure.

If the property is not in a high-risk area, but instead in a moderate-to-low risk area, federal law does not require flood insurance; however, a lender can still require it."

FEMA has prepared a series of Flood Insurance Rate Maps (FIRM) for areas throughout the United States. These maps are very useful for determining if a property is located within a flood-prone area and, in many cases, will specify the depth of flooding anticipated during a 100 year of 500 year flood event. However, there are some cautions to keep in mind when referring to these maps. For one thing, smaller streams are often not covered by the FIRMs and the maps are sometimes revised without the new information being readily available to the public. With these caveats in mind, however, we will look at the FEMA maps in general.

The FEMA flood map service center can be accessed at: https://msc.fema.gov/portal.
This website is relatively user-friendly and the particular flood map required can be viewed simply by inputting the property address.
FEMA actually produces two different types of maps for rating flood insurance: (i) the initial Flood Hazard Boundary Maps and (ii) the more detailed Flood Insurance Rate Maps.

A typical FEMA flood map is reproduced below. This map covers a portion of Onondaga County, including the outskirts of Syracuse, NY. The area shaded in blue represents the floodplain of the Oneida River.



This map was generated from the FEMA website and is called a "FIRMETTE" or a portion of a FIRM flood map.

FEMA uses a number of other terms, which are defined below:

The "100 Year Flood" is a common term used by FEMA, and its meaning is quite clear – it is a flood that occurs, on average, once every 100 years. Stated another way, it is the flood that has a 1% chance of occurring in any calendar year. In addition, an area within a 10 year floodplain has the chance of being flooded, on average, once every 10 years. Another way of saying this is that the area within a 10 year floodplain has a 10% annual chance of flooding. The area within a 500 year floodplain has a 0.2% annual chance of flooding, etc. A property that has only a 1% annual

chance of flooding sounds (at least at first glance) like an area that should not have too much chance of flooding. However, it should be obvious that over a period of years, the statistical chance of experiencing this flood grow. This is illustrated by the table below.
The chances of being flooded are shown in the table below:

Time Period	10 Year Flood	25 Year Flood	50 Year Flood	100 Year Flood
1 Year	10%	4%	2%	1%
10 Years	65%	34%	18%	10%
20 years	88%	56%	33%	18%
30 Years	96%	71%	45%	26%
50 years	99%	87%	64%	39%

Looking at the table above gives a more realistic (and more sobering) view of the chances of being flooded. For instance, a home in the SHFA with a 30 year mortgage has a 26% chance of experiencing flooding at least once during the life of the mortgage.

As shown on the map above, FEMA divides the floodplain into a number of "Flood Zones". Many of these deal with insurance issues and seem somewhat redundant. However, the major ones are described briefly below:

1. Special Flood Hazard Areas (i.e. areas within the 100 year flood) are labeled as follows: (Note that in all of these zones mandatory flood insurance requirements apply for communities that participate in the NFIP program).
    a. Zone A: The lowest floor elevation is required and the Base Flood Elevations (BFEs) are not provided.
    b. Zones A1-A30: The lowest floor elevation is required and the Base Flood Elevations (BFEs) are provided. (This is known as Zone AE on some maps.)
    c. Zone AO: These areas have shallow water depths (generally between 1 and 3 feet) and/or unpredictable flow paths. The BFEs are not provided.
    d. Zone AH: These areas have shallow water depths (generally between 1 and 3 feet) and/or unpredictable flow paths. The BFEs are provided.
    e. Zone A99: Enough progress has been made on protective systems such as dikes and levees to consider these areas out of the SFHA for insurance purposes. BFEs are not provided.
    f. Zone AR: These are areas with temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance requirements apply, but the rates will not exceed those for an unnumbered A zone, as long as the flood control

structure to be built is in compliance with Zone AR floodplain management regulations.

g. Zone AR/AE, Zone AR/AH, Zone Ar/Ao, Zone AR/A1-A30, Zone AR/A: These are dual zones that, because of flooding from other sources that the flood protection system does not contain, will continue to be subject to flooding after the flood protection system is adequately restored. For insurance purposes, all AR and A99 Zones are considered to be outside the SFHA.
h. Zone AR/A1-A30: These are numbered zones which specify a BFE.
i. Zone V: This is an areas that is inundated by tidal floods with velocity. BFEs are not provided.
j. Zones V1 though V 30: This is identical to the Zone V designation, except that BFEs are provided. (Note that this is known as Zone VE on some maps.)

2. Moderate or minimal hazard areas are labeled as follows:
    a. Zones B, C, & X: These are areas of moderate to minimal hazard subject to flooding from severe storm activity or local drainage problems.
    b. Zone D: This is an area where the flood hazard is undetermined and which is usually very sparsely populated. Zone D can also designate an area that is unmapped.

Based on the construction of flood control devices, or because of mapping errors, the FEMA maps must sometimes be revised or updated. Some valid reasons to update a flood study include the following:

1. To include more precise or updated ground elevation data within the floodplain or the channel.
2. To include the effects of a completed flood control project.
3. To revise the flood data based on new flood information. This may include newer information from stream gauging stations or other sources of data.

FEMA provides two different ways to enact a change to a flood map, as explained below:

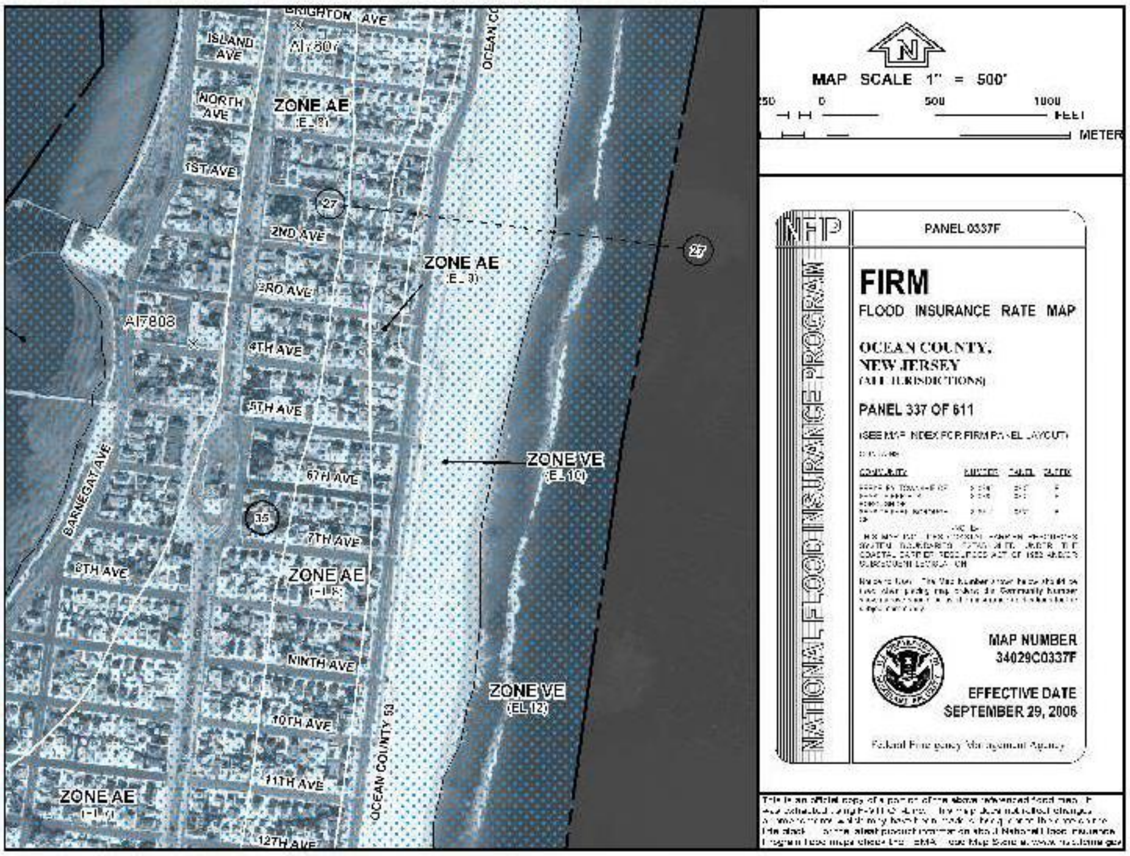
1. *Letter of Map Amendment (LOMA):* If a property owner believes that an area is incorrectly mapped within the SFHA, he or she may apply for an LOMA. FEMA will review the question and issue an LOMA if it found that the property is, indeed, outside the 100 year floodplain. This will obviate the need for the property owner to purchase flood insurance.
2. *Letter of Map Revision (LOMR):* A LOMR is issued by FEMA if there needs to be a change to the mapped SFHA. Often a revised flood study is required to

obtain a LOMR. The basic tool for preparing flood studies is the US Army Corps of Engineers software known as HEC-RAS (Hydraulic Engineering Center River Analysis Systems). To prepare a HEC-RAS analysis the engineer must first obtain survey data of the stream (including cross sections, and details on any bridges & culverts) and must obtain the discharge rate within the stream for the storm to be analyzed. On major streams this data is often available from the United States Geologic Survey, (USGS). Their streamflow data can be accessed at: https://water.usgs.gov/nsip/nasreport/es/NSIP_Executive_Summary.html If there is no streamflow data available, then the engineer must determine the flow in the stream using the Rational Method, the SCS Method, or some other approved of hydrologic analysis.

The photograph below shows part of a large flood control project built in the town of Bernardsville, NJ. This channel and culvert bypasses the portion of the town that has experienced significant flooding in the past. The flooding in Bernardsville has been substantially alleviated since the construction of this bypass. The construction of flood control structures, such as this one, are reasons to amend the FEMA flood maps.

A portion of another FEMA flood map is shown below. Unlike the one pictured above, this map depicts a coastal floodplain. The area covered is in the resort town of Seaside Heights, in New

Jersey. Note that this is a barrier island and is subject to flooding from both the Atlantic Ocean on the east and Barnegat Bay on the west.

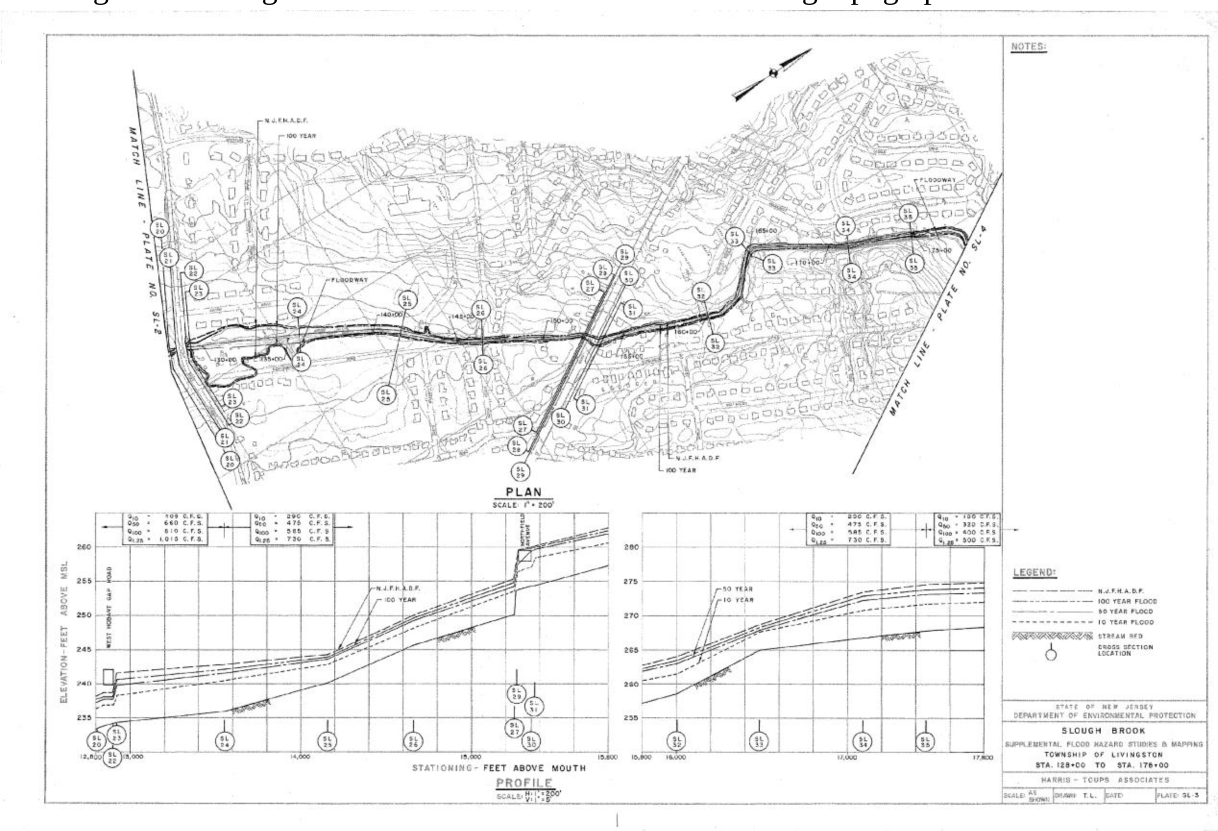


More than 22,000 Communities nation-wide participate in FEMA's National Flood Insurance Program (NFIP) by adopting and enforcing floodplain management ordinances to reduce flood damage. The NFIP offers federally-backed flood insurance to homeowners, renters, and business owners in these communities. In order for a community to participate they must adopt floodplain management ordinances that minimize damage to properties located within Special Flood Hazard Areas (SFHA), which, as stated above, is defined as the areas with a 1% annual chance of flooding. Specifically, the NFIP requires that all new or substantially improved residential and commercial structures in the SFHA to constructed at or above the level of the 100 year flood.

Other map sources:

Although FEMA is the major source for flood mapping, there are other governmental agencies that provide flood maps. These maps usually agree with the FEMA mapping, at least within reason.

Many states issue their own flood maps. The New Jersey Department of Environmental Protection (NJDEP) provides "State Adopted Flood Study" maps for many of the major streams in the state. Some of these maps (such as the one shown below) provide plan and profile information of the stream. This map is a portion of the flood study for the Slough Brook in Livingston Township. Note that a variety of different flood events are shown in profile. These include the 10 year, 50 year, and 100 year floods, as well as the "N.J.F.H.A.D.F". This stands for New Jersey Flood Hazard Area Design Flood and is equivalent to a 100 year storm plus 25%. It is the top profile shown on the map. The plan view shows the area inundated by the various flooding events along with reference cross sections and existing topographic information.



Coastal Floodplains and Beach Erosion:

Coastal floodplains are particularly dynamic systems. In many coastal areas beach erosion is a constant danger. A single coastal storm can cause widespread erosion and subsequent damage to property. The photograph below shows a house on the Outer Banks of North Carolina after a storm.

Coastal storms and the subsequent erosion they can cause can sometimes render entire neighborhoods or towns untenable. The town of South Cape May, New Jersey was incorporated in 1894. It included several houses and was connected to the city of Cape May by a railroad. However, a powerful hurricane in 1944 destroyed essentially the entire town and washed away the railroad line. What was left of the town was officially abandoned in 1945. The erosion was so severe that the famous Cape May Whale Watcher boat now travels along the coast about a half a mile off the shore over what was once the town of South Cape May.

These types of historic storms and catastrophic results are common in many coastal areas. Engineers working within these areas must be aware of the risks involved and also of the methods available to mitigate damage to properties.

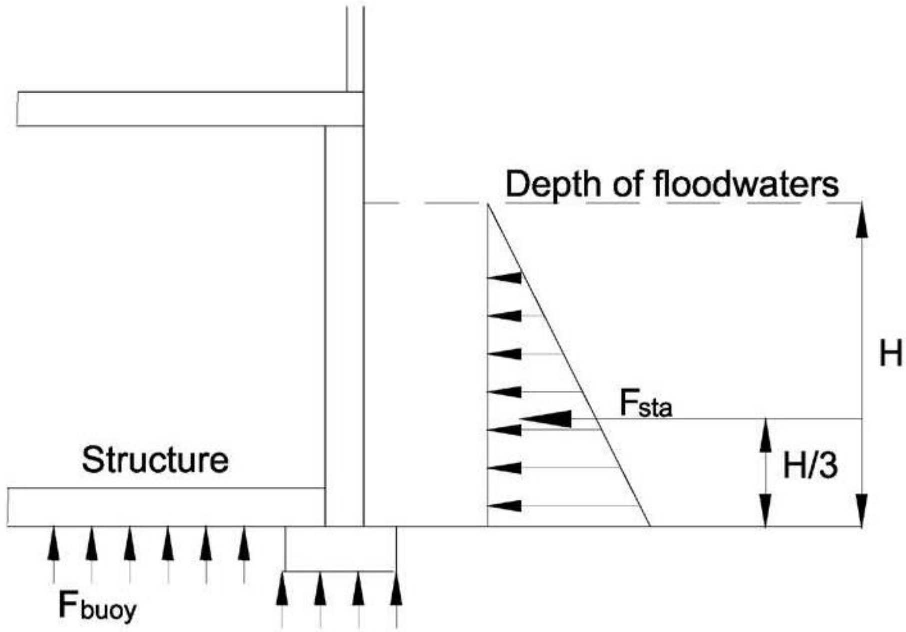
Specific Hazards Associated with Flooding:
Some of the hazards associated with flooding include those caused by:

1. Hydrostatic forces.
2. Saturated soil forces.
3. Combined saturated soil and water forces.
4. Hydrodynamic forces.
5. Buoyancy forces.

Each of these is discussed in some detail below:

Hydrostatic pressure is the pressure exerted by still and slow moving water. During floodwater contact with a structure, hydrostatic pressures are equal in all directions and always act perpendicular to the surface on which they are applied. The pressure increases linearly with the depth or "head" of the water above the point under consideration. The load acting on the surface is the summation of the pressures over the surface. When computing structural analysis of the hydrostatic pressures, they are defined to act in the following directions:

1. Vertically downward on structural elements such as flat roofs and similar overhead members having a depth of water above them.
2. Vertically upward from the underside of generally horizontal members such as slabs, floor diaphragms, and footings. (This upward force is also called uplift or buoyancy and is discussed in more detail later).
3. Laterally, in a horizontal direction on walls, piers, and similar vertical surfaces. For design purposes, the lateral pressure is generally assumed to act on the receiving structure at a point one third of the water depth above the base of the structure (or two thirds of the altitude from the water surface, which corresponds to the center of gravity for a triangular pressure distribution). This is shown in the illustration below:



Hydrostatic Force Schematic Diagram

The equation governing lateral hydrostatic forces is given as: $F_{sta} = (1/2)P_h H = (1/2)\gamma_w H^2$,
where:
F_{sta} is the hydrostatic force from standing water in (lbs per foot) acting a distance H/3 above the ground,
Ph is the hydrostatic pressure from standing water at a depth of H (lbs per foot). Note that $P_h = \gamma_w H^2$,
γ_w is the specific weight of water (62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for salt water), and
H is the flooding depth (feet)

Hydrostatic Force Analysis Example: An existing building in western Pennsylvania is located within the flood hazard zone of the Ohio River. The depth of the 100 year flood at the outside of the building is 42 inches. What is the resultant lateral hydrostatic pressure acting on the structure?

Solution: Use the equation for hydrostatic pressure, given above. Convert the depth of 42" to 3.5 feet and find: $F_{sta} = (1/2)\gamma_w H^2 = (1/2)(62.4)(3.5)^2 = 382.2 lbs$

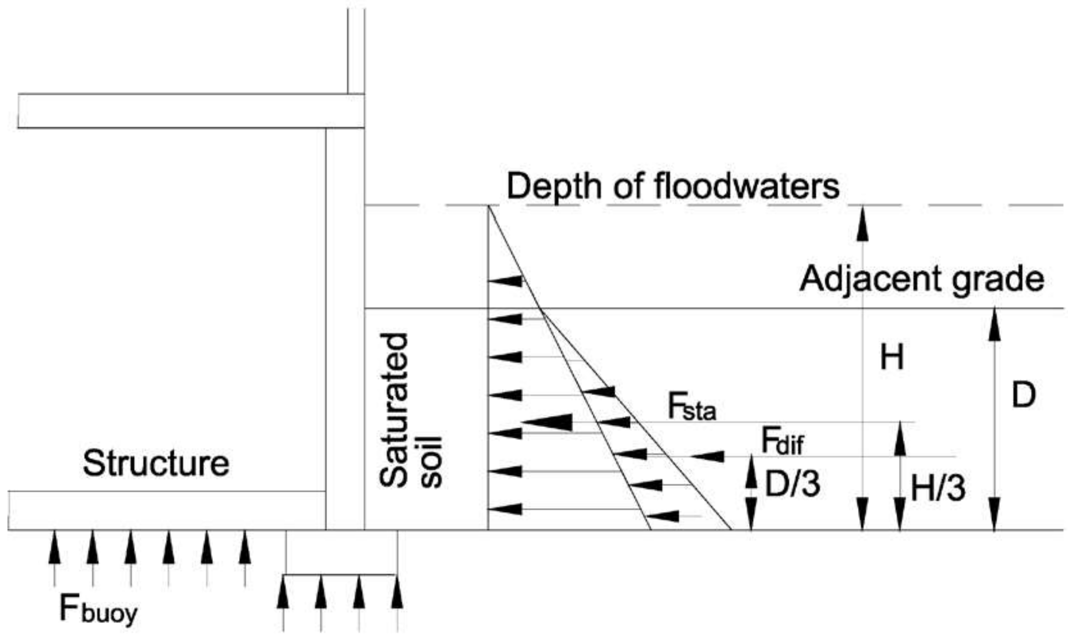
Note that 62.4 lbs/ft^3 is used for the specific weight of water because the Ohio River is a fresh water stream.

Saturated soil forces act on any portion of the structure which is below grade. Note that the equivalent fluid weight of saturated soil is different from the effective weight of saturated soil. The equivalent fluid weight of saturated soil is actually a combination of the unit weight of the water and the effective saturated weight of the soil.

The table below shows the effective fluid weight of submerged soil and water:

Soil Type	**Equivalent Fluid Weight of Submerged Soil and Water (lbs/ft^3)**
Clean sand and gravel	75
Dirty sand and gravel with restricted permeability	77
Stiff residual clays, silty fine sands, clayey sands and gravels	82
Very soft to soft clay, silty clay, organic silt and clay	106
Medium to stiff clay deposited in chunks and protected from infiltration	142

Combined saturated soil and water forces must be calculated whenever a structure is subject to hydrostatic forces from both of these elements. A structure subject to both of these forces is shown schematically below:



Combined Saturated Soil & Water Forces Schematic Diagram

The resultant combined lateral force of the water and saturated soil (F_{comb}) is the sum of the lateral hydrostatic force (F_{sta}, as calculated above) and the differential between the water and soil pressures (F_{dif}). The equation to calculate this differential is:

$F_{dif} = 1/2(S - \gamma_w)D^2$, where:

S is the equivalent fluid weight of submerged soil (as shown in the table above) in lbs/ft^3, and D is the depth of saturated soil from adjacent grade to the top of the footer in feet.

Combined Saturated Soil & Water Analysis Example: A concrete storage building is located within the floodplain of the Gulf of Mexico. The depth of the 100 year flood at the building is 5.5 feet. Three feet of the building is below grade. The soil surrounding the building is clean sand. Assuming that the soil is saturated during a flood, what is the resultant combined lateral force acting on the building?

Solution: As explained above, the resultant combined lateral force acting on the building is the sum of the lateral hydrostatic force and the difference between the soil and water pressures. First, calculate the hydrostatic lateral force as follows:

$F_{sta} == (1/2)\gamma_w H^2 = (1/2)(64.0)(5.5)^2 \ \ = 968 lbs$

Note that a value of 64.0 lbs/ft^3 is used for the specific weight of water because the water in the Gulf of Mexico is salt.

Now calculate the differential force as follows:

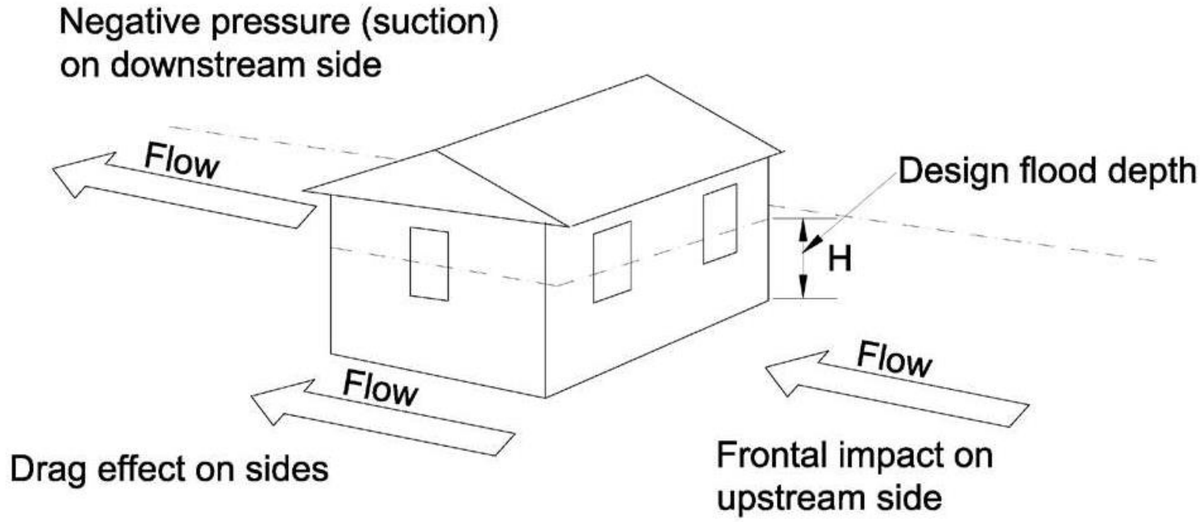
$F_{dif} = 1/2(S - \gamma_w)D^2$

Plug in a value of 75 lbs/ft^3 for S (representing clean sand from the table above) and a value off 3 feet for D (for the depth of the saturated soil). Therefore,

$F_{dif} = 1/2(75 - 64)(3)^2 \ = 54 lbs$

The resulting force acting on the structure is 968 + 54 = 1022 lbs.

Hydrodynamic forces occur when floodwater flow around a structure. These forces are shown schematically below and are a function of both the flow velocity and structural geometry.



Hydrodynamic Force Schematic

Hydrodynamic forces can be broken into two separate types: low velocity and high velocity hydrodynamic forces. Low velocity hydrodynamic forces (when the velocity of the floodwaters does not exceed 10 feet per second) can be converted to an equivalent hydrostatic force for calculation purposes. In order to do this it is necessary to calculate an equivalent head (dh) caused by the low velocity flows. The following equation accomplishes this:

$dh = C_d V^2 / 2g$, where:

C_d is the drag coefficient, which can be taken from the following table: (Note that the drag coefficient is a function of the width to height ratio of the building on which the force is acting.)

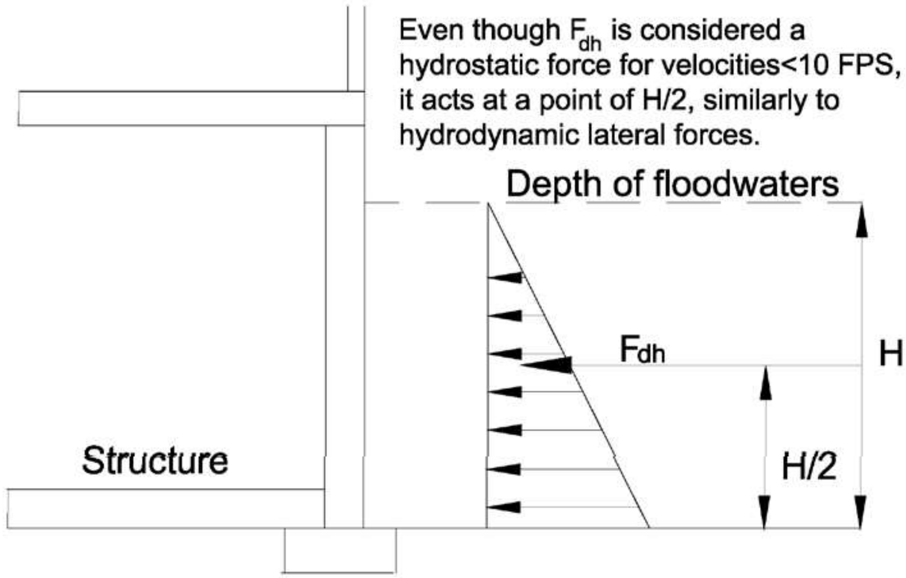
Width to Height Ratio (b/H)	**Drag Coefficient (C_d)**
1-12	1.25
13-20	1.3
21-32	1.4
33-40	1.5
41-80	1.75
81-120	1.8
>120	2.0

V is the velocity of the floodwaters (ft/sec), and
g is the acceleration due to gravity (32.2 ft/sec^2)

Once dh is calculated it can then be converted to an equivalent hydrostatic pressure using a modified version of the basic hydrostatic force equation shown above. The modified form of the equation is: $Fdh = \gamma_w (dh)H \; = P_{dh} H^2$ where,

F_{dh} is the equivalent hydrostatic force due to low velocity flood flows (lbs/ft)
γ_w is the specific weight of water (62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for salt water),
dh is the equivalent head calculated above,
H is the flood depth, and
P_{dh} is the hydrostatic pressure due to low velocity flood flows (lbs/ft). Note that P_{dh} is the specific weight of water times the equivalent head due to low velocity flood flows.

The diagram below shows how the equivalent head force acts on a structure:



Hydrodynamic Force Equivalent
Head Schematic Diagram

Example of Low Velocity Flood Flow Pressure: Calculate the hydrodynamic force caused by flood flows with a velocity of 4 feet per second acting on a 150 foot long structure with a flood depth of 3 feet.

Solution: First calculate the equivalent head due to the low velocity flows using the equation: $dh = C_d V^2 / 2g$.

The width to height (depth) ratio of the building is (150/3=50). Therefore, the drag coefficient is 1.75 (from the table above).

The velocity is 4 feet per second.

The equivalent velocity head is then: $dh = (1.75)(4)^2 / 2(32.2) = 0.435\, feet$

Now find the resultant force using the modified version of the equation:

$Fdh = \gamma_w (dh) H = (64.0)(0.435)(3) = 83.52 lbs.$

High velocity hydrodynamic forces (with velocity greater than 10 feet per second) require a more detailed analysis. The basic equation for these types of forces is:

$P_d = Cd\rho(V^2 / 2)$, where:

Pd is the hydrodynamic pressure in lbs/ft^2,

Cd is the drag coefficient (from the table above),

ρ is the mass density of fluid (1.94 slugs/ft^3 for freshwater and 1.9 slugs/ft^3 for saltwater), and

V is the velocity of the floodwater in ft/sec

(Note that a slug is a derived unit of mass and is defined as the mass that is accelerated by 1 ft/sec^2 when a force of 1 pound is exerted on it. In other words a slug has a mass of 32.2lbs).

Once the hydrodynamic pressure is calculated, the total force (F_d) acting on the structure can be computed by multiplying the pressure times the area (A) over which the floodwater is acting:

$F_d = P_d A$

Example of the calculation of hydrodynamic forces: A 60 foot long building is subject to high velocity floodwaters from a nearby river. The velocity of the floodwater has been estimated at 18 feet per second and the depth of the floodwater immediately outside the building is 24 inches. What is the total hydrodynamic force acting on the structure?

Solution:

First, identify the parameters:

- Width to height (depth) ratio is 60 feet divided by 24 inches (2 feet). This ratio is 30. Therefore, use a drag coefficient of 1.4.
- The river water would be anticipated to be fresh, so the mass density is 1.94 slugs/ft^2.
- The velocity is 18 feet per second

Plug in these values to find the hydrodynamic pressure:

$P_d = Cd\rho(V^2 / 2) = (1.4)(1.94)(18^2 / 2) = 439.99 lbs / ft^2$

The resulting total force is: $F_d = P_d A = (439.99)(2 X 60) = 52{,}799 lbs$

<u>Buoyancy forces</u> (or vertical hydrostatic forces) are governed by the following simple equation: $F_{buoy} = \gamma w(volume)$. Therefore, the buoyancy force (in lbs) is equal to the specific weight of water (lbs/ft^3) multiplied by the volume of the floodwater displaced by a submerged object (in ft^3). Note that buoyancy forces can also act on underground tanks in areas of high water table. Engineers working in these areas must calculate the buoyancy force that will act on septic tanks

or other underground structures to ensure that these structures will not float during times of high groundwater.

Buoyancy Force Analysis Example: A construction company stores its reinforced concrete septic tanks in a yard that is subject to coastal flooding. During a 10 year flood event, the floodwater depth in the yard is 18 inches. During a 100 year event, the floodwaters reach a depth of 4 feet. The tanks have outside dimensions of 108”(long) X 57”(wide) X 65”(high). The manufacturer’s brochure indicates that each of the tanks have a weight of 9250 lbs. Will the septic tanks float during a 10 year storm? Will they float during a 100 year storm?
Solution: First analyze a 10 year storm. The buoyancy force acting on a septic tank with the given dimensions is: $F_{buoy} = (64.0)(9X\,4.75X\,1.5) = 3192lbs$ (Note that the length and width of the tank are converted to feet and that the depth during a 10 year storm is 1.5 feet. Also note that the specific weight of water used is 64.0 lbs/ft^3, because the property is coastal and the water is presumably salt0. The resulting buoyancy force is less than the weight and the septic tank will not float during a 10 year storm.
Now analyze a 100 year storm. The buoyancy force during this storm is:
$F_{buoy} = (64.0)(9X\,4.75X\,4) = 10{,}944bs$. Note that in this case the buoyancy force is greater than the weight of the tank and, therefore, the tank would be expected to float during a 100 year storm.

Impact loads are forces acting on a structure by objects carried by floodwaters. It is very difficult to predict the magnitude of these forces, but reasonable assumptions may be made for them in the design of potentially impacted structures. A considerable amount of engineering judgment must be used in determining these forces. Impact loads are generally divided into the following classifications:

1. No impact (This applies to floodwaters with little or no velocity or areas with very limited potential source of debris).
2. Normal impact forces: These forces relate to isolated occurrences of typically sized debris or floating objects striking a structure. The process of analyzing these loads is discussed in some detail below.
3. Special impact forces: These forces occur when large floating objects (such as ice floes or an accumulation of debris) strike a structure. The analysis of these forces is beyond the scope of this course.
4. Extreme impact forces: These forces occur when huge, floating objects (such as runaway barges, collapsed buildings, etc.) strike a structure. These types of forces generally occur within the floodway or areas of the floodplain that

experience the highest velocity flows. The analysis of these forces is also beyond the scope of this course.

To analyze normal impact forces, the following equation can be used:

$F_i = WVC_D C_B C_{STR}$, where

F_i is the impact force acting at the BFE in lbs,
W is the weight of the object in lbs,
V is the velocity of the floodwater in feet per second,
C_D is the depth coefficient (which can be taken from the following table),

Flood Hazard Zone & Water Depth	**C_D**
Floodway or Zone V	1.0
Zone A, Stillwater flood depth > 5 feet	1.0
Zone A, Stillwater flood depth = 4 feet	0.75
Zone A, Stillwater flood depth = 3 feet	0.5
Zone A, Stillwater flood depth = 2 feet	0.25
Zone A, Stillwater flood depth < 1 feet	0.0

C_B is the blockage coefficient (which can be taken from the flowing table),

Degree of screening or sheltering within 100 feet upstream	**C_B**
No upstream screening, flow path wider than 30 feet	1.0
Limited upstream screening, flow path 20 feet wide	0.6
Moderate upstream screening, flow path 10 feet wide	0.2
Dense upstream screening, flow path <5 feet wide	0.0

C_{str} is the building structure coefficient (which can be taken from the following table),

Building Description	**C_{str}**
Timber pile & masonry construction – 3 stories or less above grade	0.2
Concrete pile or concrete or steel moment resisting frames – 3stoies or less above grade	0.4
Reinforced concrete and reinforced masonry walls	0.8

Impact Load Example: A warehouse building is located within the FEMA Zone A and the depth of flooding is expected to be 2 feet at the building. The building is constructed of reinforced concrete. The velocity of the floodwaters has been estimated at 8 feet per second. The building is located on a plain with no other buildings, walls, or other major obstructions within 100 feet of the building. For design purposes, the load force is being analyzed assuming an object weight of 500 lbs. What would be the impact force acting on the warehouse?

Solution: First determine the values of the parameters to be used in the equation above:

- W is 500 lbs. (given).

=

V is 8 feet/second (given).

- C_D is 0.25 (from the table above in Zone A, with a depth of 2 feet).
- C_B is 1.0. (There is no sheltering provided by adjoining buildings, etc.)
- C_{str} is 0.8 (This is because the building is constructed of reinforced concrete).

Plugging these values into the equation for impact forces, find:

$F_i = (500)(8)(0.25)(1.0)(0.8) = 800 lbs.$

The anticipated impact force is 800 lbs. Note, that the weight of the object is often just a guess as the engineer really has very little knowledge about what kind of object might break loose in a flood and become a battering ram.

Development within Floodplain Areas:

FEMA, as well as many other agencies, regulate development within floodplain areas. Some of the FEMA requirements (such as requiring all new or substantially improved buildings within the SFHA to be built at or above the flood elevation) have already been described. As stated earlier, in New Jersey, the NJDEP has jurisdiction over all floodplains. New development within flood plains is strictly regulated and a "Flood Hazard Area Permit" is required. The NJDEP divides these permits into the following four types:

1. Permits by Rule: There are 62 separate activities which qualify for a permit by rule. These are all minor disturbances to the floodplain and include such activities as "normal property maintenance", "construction of a dock, pier, or boathouse", and "reconstruction of a lawfully existing bridge superstructure".
2. General Permits by Certification: These also cover minor floodplain disturbances but they are slightly more involved that the above activities. The NJDEP includes 15 of these permits covering such topics as "construction of an agricultural roadway crossing" and "placement of water monitoring devices".
3. General Permits: The 12 activities covered under this heading include "mosquito control water management activities" and "construction of trails and boardwalks".
4. Individual Flood Hazard Area Permits: Any activity within a floodplain that is not covered by the relatively simple permits described above requires an individual flood hazard area permit. For this type of permit the NJDEP requires significantly more detailed plans and documentation and also a significantly larger review fee.

Some of the restrictions instituted by the NJDEP include the following:

1. No net fill within the flood area. (This is to prevent taking up flood storage areas on-site and increasing the flooding downstream).
2. Construction of residential structures within the flood hazard area are not permitted unless they meet specific requirements designed to prevent loss of life and damage to property.
3. Development within the riparian zone is restricted. The riparian zone is defined (by the NJDEP) as the land and vegetation located within and adjacent to a regulated water. In New Jersey, the width of the riparian zone is set at either at 50 feet or 150 feet depending on whether or not the stream is associated with trout production and whether or not there are endangered or threatened species associated with the stream.

Evacuation Plans:
In areas subject to major coastal or riverine flooding, effective evacuation plans are an absolute must. The development of a workable evacuation plan requires the involvement of a number of agencies and individuals including engineers, law enforcement personnel, first-responders, politicians and others.

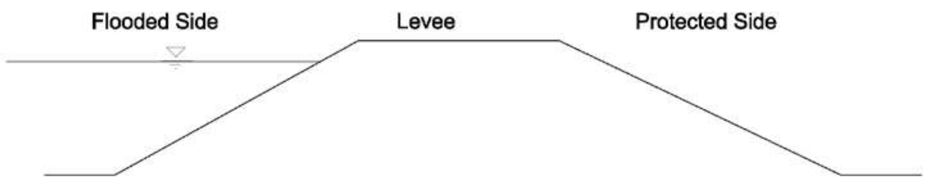
Signs are required to alert motorists to flood-prone areas. Typical signs are shown in the photograph below:

In addition to alerting motorists which roads to be avoided, an evacuation plan must also include signs delineating the path to higher ground. Flood evacuation routes must be clearly marked by signs like the one shown in the photograph below.

Floodproofing and Flood Control Devices:
Flood-prone areas can sometimes be retro-fitted with flood control devices that can minimize the flooding or move the floodwaters into less built up areas. Some of the measures used for flood control include:

1. Levees.
2. Flood gates.
3. Bypass channels.

FEMA describes a levee as "a man-made structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water so as to reduce risk from temporary flooding". Furthermore, the NFIP defines a levee system as "a flood protection system which consists of a levee, or levees, and associated structures, such as closure and drainage devices, which are constructed and operated in accordance with sound engineering practices." There are thousands of miles of levees located throughout the United States, which together protect millions of homes and business from the affects of floodwaters. Surprisingly, only a small percentage of the levees in this country are owned and operated by the US Army Corps of Engineers. In fact, nearly 85% of the levees are locally owned and maintained. Levees can be very effective barriers against flood waters. It is important to remember, however, that when a levee fails, the result can be more catastrophic than if the levee had never been constructed. A schematic view of a levee is shown below:



Levee Schematic

The photograph below shows a floodgate in Bound Brook, NJ. This gate can be moved across the road to complete a system of levees and walls that contain floodwaters from a nearby stream, known as the Green Brook. The house to the left of the gate will be protected from floodwaters when the gate is closed.

The photograph below shows the same flood gate from a different angle. The 'road closed' sign is probably not necessary as the gate forms an impenetrable barrier across the entire width of the roadway that is at least 8 feet high when it is closed. Before this flood gate was installed, this roadway was often covered by flood water during major storms.

The photograph below shows another part of the same levee system. On the left side of the stream is the channel of the Green Brook, which does not look like much of a watercourse during low flow conditions. This is deceiving, however, as this stream has contributed to massive flooding in this municipality. Across the levee is a ball field which is in the part of the town protected from flooding. (Note how the shape of this levee compares with the conceptual levee diagram shown above).

Emergency Preparation:
Obviously, being prepared in the case of a catastrophic flood can help an individual, family, or community, reduce their risk. The NFIP operates a web site (www.floodsmart.gov) that includes a checklist of preparedness for people living in flood-prone areas. While the components of this checklist are meant for the general public and not, specifically, for the engineering community, engineers working in areas subject to flooding should be familiar with these provisions. These include the following:

1. Keep flood insurance up to date.
2. Ensure that medical and financial records can be accessed during and after a flood.
3. Keep an emergency card in your wallet with names and phone numbers of family members.

4. Tune into radio or other local media to keep abreast of flooding issues.

Some Unusual Flood Hazard Areas:
There a many local situations that do not fit neatly into the typical designation of riverine and coastal floodplains. Some of these special areas are discussed below:

1. Closed basin lakes: There are two different types of closed lake systems.
   - Lakes with no outlets (such as the Great Salt Lake in Utah or the Salton Sea in California).
   - Lakes with inadequate, regulated, or elevated outlets (such as the Great Lakes and some glacial lakes).
2. Uncertain flow paths: In many most areas riverine erosion occurs gradually over a period of years. However, in some areas of the country, significant erosion and subsequent major change in river channels occur with virtually every flood. This often occurs in mountainous areas where high-velocity flood waters become laden with sediment and rock. In the valley where the slope flattens out, the floodwaters decrease in speed and the flood widens out into sheet flow spreading sediment and rock over a fan-shaped area, known as an alluvial fan. Alluvial fan flooding is less predictable than typical riverine flooding . Often it is impossible to predict where the floodwaters will spread out over the fan. Therefore, these types of floods pose the following separate hazards:
   - Velocity of floodwaters and the debris carried by the flood.
   - Sediment, rock, and other debris deposited by the floodwaters.
   - The portential for the channel to move across the fan during the flood.
3. Dam breaks: Needless to say a dam break can cause catastrophic flooding downstream. The actual dynamics of the flood caused by a dam break are quite complex but there are tools available for modeling these events. HEC-RAS has a dambreak analysis routine that can be used. Generally, dams break because of one of the following reasons:
   - The foundation fails (due to seepage, settling, or earthquake).
   - The design, construction, materials or operation of the dam are faulty.
   - Flooding exceeds the capacity of the dam's principle and emergency spillways.
4. Ice Jams: In northern climates, ice jams can form when warm weather and rain break up frozen rivers. They can also from whenever there is a rapid cycle of freezing and thawing. Ice jams can cause the following three separate flooding hazards:

Sudden flooding of areas upstream of the jam. (This can happen on clear days with little or no warning to residents upstream of the jam).

- Movement of ice floes that have the capability of doing significant downstream damage, including knocking over trees and destroying buildings.
- Sudden flooding of downstream areas when the jam breaks. The impact
- of a jam break-up can be as devastating downstream as that of a dambreak. The photograph below shows an ice jam on the Alleghany River in Oil City, Pennsylvania.

5. Mudflows: A mudflow is a type of landslide that occurs when runoff saturates the ground. During a mudflow soil that is generally dry turns into a liquid solution that slides downhill. This type of flooding is often more damaging than

a clear-water flood, due to the combination of debris and sediment and the force of the debris-filled water. The devastating effect of a mudflow on structures is shown in the photograph below.

Floodplain Management Strategies and Final Considerations:
In the introduction to this course it was noted that one of the course goals was to give the engineer some understanding of the flooding process, its regulatory effects, and how to mitigate against disasters. Riverine and coastal flooding causes millions of dollars in damage in the United States every year and disrupts the lives of countless people.

The photograph below shows a kayaker traveling down a street in Miami's South Beach area during a flood. This is, unfortunately, a not uncommon site in many coastal cities affected by frequent flooding.

Obviously, these types of floods cannot be eliminated. However, FEMA has guidelines for reducing the magnitude of the effects of such events. These can be divided into the relatively broad strategies and tactics shown below:

1. Strategy #1: Modify human susceptibility to flood damage.
    - Regulate floodplain use by using zoning ordinances to steer development away from flood-prone areas or other areas requiring protection.

- Establish development (and/or re-development) policies on the design and location of public services, utilities, and critical facilities.
- Acquiring land within in a floodplain to preserve open space and permanently relocate existing flood-prone buildings.
- Elevating or floodproofing new buildings and retro-fitting existing buildings.
- Providing warnings of flood events through forecasting, warning systems, and emergency planning.
- Restoring and preserving the natural resources and functions of floodplains.

2. Strategy #2 Modify the impact of flooding.
    - Providing information and education to assist self-help and protection measures.
    - Following flood-emergency measures during a flood event to protect people and property. (This includes mapping, signing, and keeping open potential evacuation routes).
    - Reducing the financial impact of flooding through disaster assistance, flood insurance, and tax adjustments.
    - Preparing post-flood recovery plans and programs to help people rebuild and implement mitigation measures to protect against future floods.
3. Strategy #3: Modify flooding, itself.
    - Building dams and reservoirs that store excess water upstream of developed areas.
    - Building dikes, levees, flood gates, and similar devices to keep water away from developed areas.
    - Altering stream channels to increase flow efficiency, and thereby reducing the frequebncy and magnitude of overbank flooding.
    - Diverting high flows around developed areas. (This can be done by installing emergency overflow channels or pipes).
    - Storing excess runoff within detention basins.
    - Controlling runoff from areas outside the floodplain.

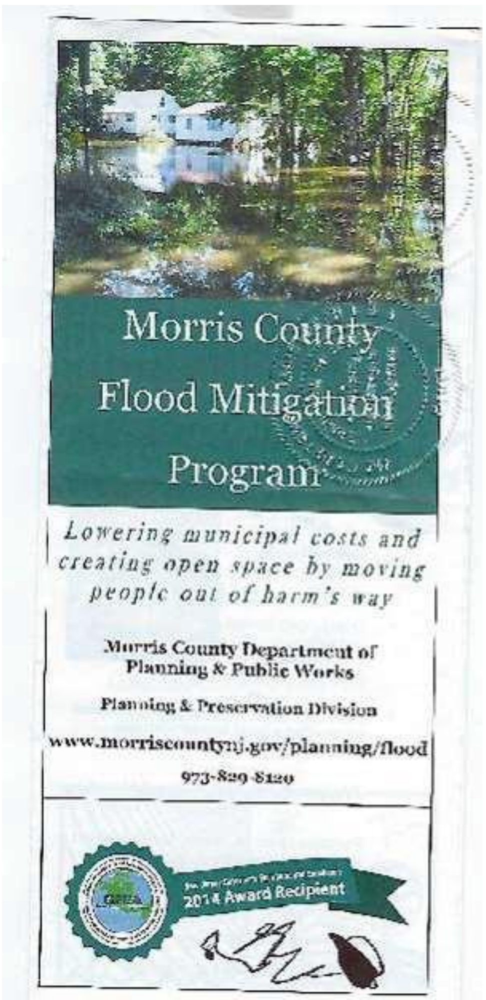
- Protecting inland development with shoreline protection measures that account for the natural movement of shoreline features.

4. Strategy #4: Preserve and restore natural resources.
    - Floodplain, wetland, and coastal barrier resources (including zoning) can be used to steer development away from sensitive or natural areas.
    - Land acquisition, open space preservation, permanent relocation of buildings, restoration of floodplains and wetlands, and the preservation of natural functions and habitats.
    - Information and education to make people aware of natural floodplain resources and functions and how to protect them.
    - Beach nourishment and dune building to protect inland development by maintaining natural flood protection features.

The list above is not exhaustive by any means. In addition, it is obvious that there is significant overlap between these strategies All of them however, have as their goal the protection of people from the myriad negative impacts of flooding.

As noted in this course, engineers have a variety of resources available to provide guidance on floodplain management. FEMA should be the engineer's first choice in understanding floodplain issues. However, most states also have agencies that have jurisdiction over these areas. Finally, many county and municipal agencies provide information on flood-prone area.

The brochure below is an example. This brochure describes the county project of purchasing flood-prone properties, demolishing the structures, and deeding the land as permanent open space. It describes who is eligible for the project and how to apply



By understanding the many issues that are involved in floodplain management and by knowing where to find helpful technical information, engineers can work to reduce the impacts of floods.