APPENDIX K

Emergency Flood Fighting and Flood Protection

K.1 Introduction.

K.1.1 Flood fighting is defined as measures taken before and during a flood to maintain existing flood risk management projects distressed by flood loading. Emergency flood protection is a feature constructed before or during a flood event that will provide flood risk reduction to an area that does not have an existing flood risk management project. Flood fighting and construction of emergency flood protection is extremely difficult to execute and the problems that arise during a flood fight are varied and innumerable. Levee performance issues during a flood will likely fall into one of the following general categories: overtopping, through-seepage, underseepage, erosion, or slope instability. This appendix will address each of these by presenting proven, accepted techniques for mitigating the risks posed by each based on documented experiences during historical flood fight events. It cannot be over emphasized that individual resourcefulness is a key element in a successful flood fight. A flood fight operation is an "art" that requires understanding and thought; as time, weather conditions, hours of darkness, and limited resources are formidable adversaries.

K.1.2 The organization of this appendix is somewhat chronological with respect to field activities during a flood: prior planning for surveillance and flood fighting, surveillance, and flood fighting measures in response to distress. Advance construction of emergency flood protection prior to a flood, although not common in all areas, is discussed next. The last section of the appendix discusses support to field activities that could be applicable to all phases of a flood fight, such as how to identify borrow areas, the availability of commercial materials, contracting, and haul road construction.

K.2 Planning.

K.2.1 Development of a Flood Fight Standard Operating Procedure (SOP) document is recommended for all organizations involved in flood surveillance and flood fighting, including USACE Districts, local levee sponsors, states, counties, municipalities, etc. Some USACE Districts have developed Flood Fight SOPs that are updated annually to reflect personnel and levee system changes. The information in this section is provided to assist in creating a Flood Fight SOP.

K.2.2 The Flood Fight SOP should outline roles, responsibilities, and duties for all participants, including field and office personnel, associated with the response during a flood event. A typical USACE Flood Fight SOP would cover Engineering, Operations, Construction, Real Estate, Contracting, Office of Counsel, Human Resources, Public Affairs, Resource Management, and any other functional areas within the USACE district that need to be engaged during a flood event. A Flood Fight SOP for a local levee sponsor or municipality should include information such as identification of flood-prone areas and previous high water marks, flood fighting plans, evacuation plans, delegation of responsibilities, lists of important suppliers of materials and special equipment, lists of local contractors, and establishment of earth borrow sites (locations where fill [dirt] can be taken from and transported, usually by dump trucks, to the flood fight or emergency construction location. The plan should further provide for the establishment of an emergency operation center and list various assistance programs available, either through the State or Federal government. Further assistance in developing local plans may be available to Local Sponsors by State or local emergency planners.

K.2.3 To ensure success and safety of the flood fight personnel, proper planning and preparation of the Flood Fight SOP is recommended prior to mobilizing the surveillance and flood fight teams. Although each flood is different, some aspects of the current flood will bear similarities to a previous event, and the SOP should be updated based on lessons learned.

K.2.3.1 Safety of personnel is paramount and nobody should be placed into a dangerous situation. Safety considerations should include safety briefings based on previously developed Activity Hazard Analyses. The “Buddy System” should be used when planning the flood fight effort, building flood fight teams in pairs, ensuring one member of the team is experienced in flood fighting.

K.2.3.2 The Flood Fight SOP should include information identifying hospitals, trauma centers, and/or local emergency medical services within the region. Phone numbers and addresses should be provided.

K.2.3.3 Each flood fight team should be outfitted with personnel protection equipment (PPE) including hard hat, eye and hearing protection, safety footwear and a personal flotation device (PFD). Field personnel should have current immunizations against Hepatitis A and B, and Tetanus.

K.2.3.4 The Flood Fight SOP must include: team assignments and work schedules that detail which levee district(s) the teams are assigned to, when they are scheduled to leave and how long will they stay, who they report to when they arrive in the levee district, what work they should anticipate doing and how are they going to do the work, and how often to report back to the District Office or the Emergency Operations Center (EOC). The Flood Fight SOP should detail increased activity as the flood progresses because higher flood levels imply more risk to the levee system. The Flood Fight SOP should establish a Battle Rhythm of local and upward reporting and the flood fight teams should schedule their reports so that their data can be made part of the upward reporting. An important detail to consider is the availability of phone service and internet service in the field. If limited communications capability exists in the levee district, the flood fight team must consider the time needed to drive to a location with communications capability.

K.2.3.5 The Flood Fight SOP should detail the office and administrative support needs of a major field operation. This may include handling details related to the use of government vehicles, making hotel reservations, preparing and maintaining time sheets and also travel vouchers if the flood fight teams are on travel status, and overtime requests.

K.2.3.6 The Flood Fight SOP should contain all of the necessary office and cellular phone numbers of all participants in the flood fight, including USACE and local levee sponsor personnel. It should also include phone numbers or websites where river gage information can be obtained.

K.2.3.7 The Flood Fight SOP should detail the standard equipment to be issued to all field personnel. A standard equipment kit may consist of the following item categories:

K.2.3.7.1 Data Recording. Waterproof notebook with pencils, pens, highlighters and permanent marker. All required blank data forms (inspection checklists, piezometer data form, relief well data form). A clipboard with a rain/wind cover is very helpful for keeping loose papers in place. Modern data recording methods include using a tablet and/or laptop computer to collect data.

K.2.3.7.2 Field Measuring and Marking Devices. Wired flags, aluminum tags, duct tape, fluorescent orange/pink ribbon, yellow high visibility marking spray paint. A 12-inch engineering scale plus a six-foot engineering folding ruler (an engineering scale has inches on one side and $1/10^{th}$ foot markings on the other). A 100-ft measuring tape.

K.2.3.7.3 Safety, Hygiene, Stinging Insect and Poisonous Plant Protection. Hand wipes, hand sanitizer, bag of rags, first aid kit, high visibility vest, lightweight leather gloves, bug spray or rub on insect repellent with high percentage of Deet (e.g., Deep Woods Off), bee/wasp/hornet spray with 20-foot range, sunscreen, poison-ivy and poison-oak antidote skin cleansers.

K.2.3.7.4 Weather Gear. Two piece rain suit, calf high rubber boots and hip waders. Chest waders should be considered too dangerous because of the additional depth of water that can be entered wearing chest waders.

K.2.3.7.5 Tools for Opening/Measuring Piezometers and Opening Relief Wells. Penetrating fluid, lubricants, 12-inch crescent wrench with one inch capability, pipe wrench with 18-inch handle, 3-lb sledge hammer, hand held mirror for reflecting sunlight into dark spaces (4-inch diameter or 4 by 6-inch), vegetation machete, snake chaps (where necessary), long handle shovel (round point). PVC Piezometer extensions (two 3-foot and one 1-foot extensions). A water level indicator for measuring piezometers.

K.2.3.7.6 Digital Support. GPS including a cable interface to the laptop to enable mapping-software location awareness. A 12-volt to 120-volt electrical inverter for use in a vehicle. Cellular phone or satellite phone for communications in remote areas. A “HotSpot” device to facilitate laptop internet connection via cellular signal. A digital camera, preferably one with GPS and compass capability that records location and direction of photographs.

K.2.3.7.7 A multi-cell, waterproof flashlight and a high power handheld searchlight. Extra batteries as required.

K.2.3.7.8 Levee Background Information. Record Drawings and Operation and Maintenance Manuals for the levees in the area of surveillance. Historical flood information including previous locations of all flood fight issues (excess seepage, slides, etc) and the previous flood fight techniques employed at those locations. USGS 10-foot contour maps. Digital georeferenced files or .kmz files that can be used in mapping software or with GPS to ascertain location on the levee.

K.3 Flood Fight Surveillance.

K.3.1 The collection, evaluation, interpretation, and dissemination of performance data is critical. Observations of levee performance during a flood event are extremely valuable to identify the early signs of levee distress and to verify levee design assumptions. These observations should be well documented during the flood event and formalized in an after action report when the flood event is over. The specific location, date, and river level when observations are made is important for levee performance projections for higher hydraulic loads and design of remediation for observed distress. For example, the river elevation when sand boils first appear at the levee toe is an important piece of information for back-analysis of the performance. Whenever possible, GPS coordinates should be obtained so that areas of specific observations may be positively identified after the flood event is over. Surveillance intervals will vary during a flood event. Less frequent intervals are appropriate during low loading or static river levels when there is no observed distress and more frequent intervals are appropriate during significant hydraulic loadings or after distress have been observed and a flood fight is underway.

K.3.2 Surveillance Methods. There are many methods of surveillance during a flood event. The most commonly used methods for surveillance of levee performance during a flood event include driving the levee crest in passenger vehicles, driving the levee slopes and toes in all-terrain vehicles (ATV), and walking various parts of the levee especially the landside slope, toe, and the landward area. The effectiveness of these surveillance methods is limited to what can be seen from the levee crest or accessed on foot or in vehicles in very wet ground. Minor levee distress oftentimes will not be observable from the levee crest more than 200 feet landward of the levee, especially if there is ponded water landward of the levee. Additional methods of surveillance are boat patrols to detect riverward scour, aerial surveillance using rotary winged aircraft, and aerial unmanned drone surveillance. These additional methods of surveillance, while often costly, can provide early detection and identification of levee distress than could not be observed from the ground until the distress is significant and levee failure is imminent. Regardless of the surveillance method used, high quality photographs should be taken, retained, and organized so that a record of performance can be documented after the flood event.

K.3.3 Surveillance Focus Areas. The entire levee system should be observed throughout a flood event, as any part can suffer flood distress that requires attention. However, experience has shown that some general locations should be more closely observed because they are likely areas for flood distress. The following sections provide general guidance on levee surveillance.

K.3.3.1 Levee slopes. The levee slopes should be observed to identify changed conditions during the flood event. Prior to the levee being loaded, an initial inspection should be performed to fill observed animal burrows that could cause through-seepage concerns. Throughout the flood event, as wildlife is displaced because of flooding, new animal burrows are likely to be created and filling burrows will be an ongoing endeavor throughout the flood event. As the levee begins to be significantly loaded, through-seepage may become evident as a saturation "horizon" moving higher in elevation on the landside slope. The observance of through-seepage will be a function of levee embankment materials, zoning, and flood duration. Homogeneous levees constructed with sandy materials will show signs of through-seepage relatively quickly while levees constructed with clay materials may not show signs of through-seepage except during long duration flooding lasting several months. Levees constructed of zoned embankments that include pervious filter drains may only show through-seepage exiting at the levee toe or drain exit. Through-seepage is not necessarily an indicator of poor performance, but generally most levee embankments have not been designed for theoretical steady-state through-seepage conditions with water at the levee crest. Likewise, the amount of through-seepage observed during an event can be an indicator of the potential for the development of embankment seepage and piping or levee instability failure modes during current and future flood events. Generally, the through-seepage conditions are worse just after the flood crest, but may increase under static river elevations during extended flood events. As the flood event continues and the landside slopes become saturated, the levee slopes will be more susceptible to slope instability. Evidence of longitudinal cracks near the upper slope and bulges near the lower slope indicate evidence of instability. When signs of instability are observed, the portion of the landside slope affected by the slide and the amount of visible through-seepage in the slide area are critical observations to document. Figure K-1 shows two photographs of a landside slope failure that occurred during a long duration flood event caused by embankment saturation.

Figure K-1. Landside Slope Instability.

K.3.3.2 Landside Toe and Landward 200 feet. A good understanding of the general foundation conditions for the levee will indicate the likelihood of observing underseepage. Levees on thick clay foundations with thin or non-existent sand stratums will generally have no or little underseepage. Levees on thin clay/silt blankets overlying thick sand stratums are much more susceptible to underseepage and are discussed further. When a levee is subjected to a differential hydrostatic head of water as a result of river stages being higher than the adjacent landside ground surface, seepage entering the pervious substratum through the bed of the river, riverside borrow pits, and/or the riverside top stratum, creates an artesian head and hydraulic gradient in the sand stratum under the levee. This gradient causes a flow of seepage beneath and landward of the levee and this seepage exerts an upward seepage pressure on the base of the blanket landside of the levee. This upward seepage pressure ultimately creates seepage through the blanket. The seepage emerging at or landward of the levee toe is termed underseepage. If the hydrostatic pressure in the pervious substratum landward of a levee becomes greater than the downward pressure of the submerged weight of the top stratum, the uplift pressure will heave the top blanket and it may rupture at weak spots with a resulting concentration of seepage flow in the form of sand boils. Active erosion of subsurface material as a result of substratum pressure and concentration of seepage in localized channels is termed piping. Where the foundation and top strata are heterogeneous, as is usually the case, seepage tends to localize instead of causing the entire top stratum to heave or become "quick." A combination of excess head and seepage can create sand boils and subsurface erosion that may culminate in formation of piping beneath the structure. The landside levee toe and the landward area for approximately 200 feet should be observed for signs of underseepage. Particular attention should be focused on landside ditches, low areas, landward buildings with basements, and other features that extend below the prevailing landside ground surface. Any unauthorized excavations near the levee should be backfilled prior to the flood. The entire levee system should be monitored for underseepage. Special attention should be paid to areas with levee alignment changes that are convex to the river, such as those at a mainstem-tieback alignment change, because they can be underseepage concentration points. Aerial surveillance is particularly useful for observing conditions beyond the landward levee toe, particularly if there is landward water ponding. Forested areas and areas with standing crops significantly limit the ability to make underseepage observations from the levee toe or crest. These areas generally must be patrolled on foot or utilizing an ATV to make observations. Pumping of underseepage to improve interior drainage should be held to a minimum, based on the maximum ponding elevation without damages (i.e., pond water surface elevation above which damages would begin to occur). Underseepage should be allowed to occur with no attempts to prevent or reduce the underseepage if no apparent ill-effects are observed, and if adequate pumping capacity is available to prevent interior ponding that would cause damages during precipitation events.

K.3.3.3 The magnitude of underseepage observed during a flood event is usually a good indicator of foundation seepage and the likelihood that a piping failure will initiate (i.e., development of sand boils) during current and future flood events. Generally, the underseepage conditions worsen as the river elevation rises, and often respond relatively quickly to changes in river elevation. Underseepage is generally estimated based on an estimated quantity of seepage water emerging from the ground from the landside toe and landward of the levee. The following definitions of underseepage are recommended for use in flood events so that consistent comparisons can be made between flood events and levee systems:

- Impounded water – Area covered in water but unable to determine source.
- No seepage – No evidence of saturated areas. (Figure K-2a)
- Very Light Underseepage – Saturated area only with no flow (Figure K-2a)
- Light Underseepage – Ground surface is saturated with seepage flowing slowly out of the ground surface such as a uniform thin sheet seepage flow. (Figure K-2b)
- Medium Underseepage – Seepage over large areas flowing into collecting streams on the surface (no sand boils). Small concentrated seeps may be observed that are not transporting foundation material. (Figure K-2c)

- Heavy Underseepage – Seepage over large areas flowing into collecting streams with sand boil activity. (Figure K-2d and Figure K-2e)

K.3.3.4 When sand boils are observed, they should be differentiated by size. The size of the sand boil should be measured both by the diameter of the sand boil throat and by the amount of material that is being deposited on the surface. The sand boil size and amount of material deposited at the surface are direct indicators for the likelihood of a foundation seepage and piping failure. Figure K-3 shows the typical geometry of a sand boil. The flow channel that extends through the foundation soils is termed the sand boil throat. Sand boils with larger throat diameters may have a higher potential to cause internal erosion of the foundation or represent a more matured state of failure mode development. The throat size of the boil may be consistently measured in the field by inserting part of all of a person's hand in the boil and comparing the diameter to how much of the hand that can be inserted, from one finger to more than a fist. The terms pin boil and descriptors like small, medium, and large refer to the throat diameter. The size of the sand cone formed by the sand boil (measured as the diameter of the sand boil foot print) is also an important characteristic and relates to how active the sand boil is in transporting foundation material. The activity descriptor should indicate how much material is moved from the boil. The terms low activity, moderate activity, high activity, and very high activity should be added to the size descriptor to indicate the amount of material moved. The below definitions are recommended for use to standardize sand boil descriptions. For example, a sand boil with throat size of 3 inches with more than 6 cubic feet of sand would be described as a "medium, high activity" sand boil. The sand boil size and activity descriptors in the subsequent paragraphs are recommended for use to standardize sand boil descriptions. Figure K-4 provides examples of sand boils of various size and activity.

K.3.3.5 Sand Boil Size Descriptors.

- Pin Boil – Throat size less than 1/2-inch in diameter (less than 1 finger width wide)
- Small – Throat size between 1/2-inch to 2-inches in diameter (up to 3 finger widths)
- Medium – Throat size between 2-inch to 4-inches in diameter (3 fingers to Fist)
- Large – Throat size between 4-inch to 6-inches in diameter (Fist and extended thumb)
- Very Large - Throat size greater than 6-inches in diameter (Larger than fist and extended thumb)

a: None or Very Light Underseepage

b: Light Underseepage

c: Medium Underseepage

d: Heavy Underseepage

e: Heavy underseepage with sandboil activity

Figure K-2. Examples of Underseepage Magnitude.

K.3.3.6 Sand Boil Activity Descriptors.

- Low Activity – No or very little sand observed around the throat of the sand boil and seepage discharge was clear.
- Moderate Activity – Cone of sand accumulated around the sand boil less than 6 cubic feet (6 cubic feet is roughly equivalent to one wheelbarrow full of material) or seepage discharge is slightly cloudy.
- High Activity – Cone of sand accumulated around the sand boil is greater than 6 cubic feet of material but less than 1 cubic yard, or seepage discharge is very cloudy.
- Very High Activity – Greater than one cubic yard (27 cubic feet) of material accumulated around the sand boil. (One cubic yard is roughly equivalent to the outside dimensions of a standard refrigerator/freezer), or seepage discharge is extremely cloudy.

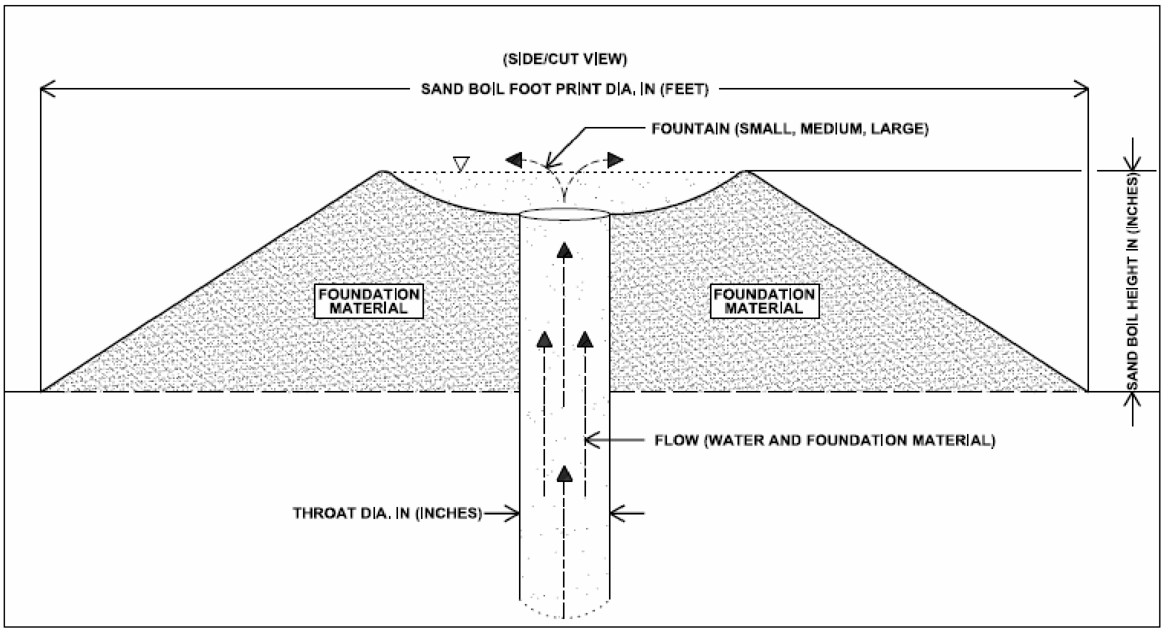


Figure K-3. Sand Boil Geometry.


a: Pin Boils


b: Small Boil, Moderate Activity


c: Med Boil, Moderate Activity


d: Very Large Boil, Very High Activity


e: Very Large, Very High Activity
Concentrated Leak under floodwall

f: Very Large Boil, Very High Activity

Figure K-4. Examples of Various Sand Boil Size and Activity.

K.3.3.7 Underseepage Control and Instrumentation Areas. Any location where underseepage control has been constructed, such as seepage berms, relief wells, buried collector systems, and levee and floodwall toe drains, should be carefully observed. Observations should be made for signs of distress, but also for signs of good performance that indicate the underseepage control is functioning as designed. Instrumentation such as piezometers, flow measuring devices, or movement monitoring devices may be installed to monitor the performance of underseepage control systems or to evaluate levee design assumptions. Underseepage berms are generally designed such that little seepage will exit the berm face but instead will be concentrated at the berm toe (Figure K-5). If sand boils or quick conditions are noted in the middle of an underseepage berm they could indicate a design or construction defect. It is common to observe sand boils at the toe of underseepage berms, particularly at very high levee loading. An understanding of the expected performance in this area should be obtained prior to expending significant flood fight resources in these locations, particularly for underseepage berms approaching 300 feet in width. Pressure relief systems, such as wells, collector systems, and toe drains should be observed for clear discharge and signs of unfiltered seepage exiting adjacent to the features. Figure K-6 shows a relief well that is transporting sand material in the discharge. This condition should be monitored and the relief well regularly sounded. All instrumentation should be read routinely. Levees are generally not exposed to frequent, high hydraulic loading so the expected performance during future flood events is generally based on evaluation of design assumptions and maintenance. Consequently, information obtained from instrumentation is extremely valuable and should be carefully recorded. All instrumentation data should be accompanied by readings on the nearest river gage, nearest freeboard gage, or measurements of the freeboard at the time of the reading. If piezometers begin to overflow (Figure K-7), they should have riser extensions added to allow for continued data collection. Flow measuring devices should be kept free of debris and accumulation of sediment or biofouling that can affect measurements. If there are no flow measuring devices, flow can be measured by a calibrated bucket with a stopwatch, the height of a discharge fountain, or by down-the-hole flow meters.

K.3.3.8 Riverside Scour and Flow Turbulence. Riverside scour is difficult to observe prior to significant levee distress occurring. The flow patterns near the riverside levee slope and up to 200 hundred feet riverward should be observed for signs of excessive turbulence or changes in flow patterns during high flows. Areas with abrupt changes in riverward features, such as tree lines, fence rows, riverside levee access ramps, roads, and areas with levee alignment changes can cause erosive forces during high flows. Figure K-8 shows turbulent flows between a tree line and levee that caused significant riverside scour during a flood event. Riverside scour can directly impact the levee embankment or change boundary conditions for underseepage. Aerial surveillance is useful for identifying areas of turbulence and priority areas for boat-borne sonar or weighted tapes/anchors that can provide direct information regarding erosion progression. If a previously stable area begins to show underseepage distress under sustained load, it could be an indication of riverside scour.

Figure K-5. Sand Boils Concentrated at Toe of Underseepage Berm.

Figure K-6. Sanding Relief Well.

Figure K-7. Overflowing Piezometer.

Figure K-8. Turbulent Flow Observed Adjacent to Levee that Caused Significant Riverside Scour. Note Trees Concentrating Flow Parallel to Levee.

K.3.3.9 Drainage Structures and Pump Stations. Any location of a pipe penetration within the levee embankment or foundation, such as drainage structure and pump station locations, should be routinely observed for signs of distress. Many different levee failure modes can occur at these locations. Failure of pipe closures, such as flap gates and sluice gates, can allow uncontrolled discharges into leveed areas through the pipe. Prior to the flood, all gates should be exercised and debris removed from gate slots and flap gates to ensure proper gate performance during the flood. A defect in a gravity pipe can serve as an unfiltered exit leading to failure by internal erosion into a conduit. Cloudy water observed exiting the pipe on the landside can be an indicator of internal erosion into the conduit. Seepage observed exiting around the conduit on the landside can be an indicator of internal erosion along a conduit. However, if the conduit has a filter on the landside, clear seepage exiting in this area is normal. Pump station pipes and wet wells should be observed for signs of settlement, sinkholes, and structural defects that could lead to removal of foundation material. If distress is observed, operation of the pump stations should be immediately halted (powered down). Other gravity-fed drainage systems and pressure utility systems that cross the levee, or are adjacent to it, should also be observed for signs of surface depressions, seepage, and sinkholes that could indicate distress that could impact the levee. Figure K-9 shows a sinkhole over a gravity-fed drainage structure that surface-expressed during a flood event.

Figure K-9. Sinkhole in Levee over Gravity-fed Drain Pipe.

K.3.3.10 Levee-to-Structure Transitions. Earthen embankments generally are more ductile structures with relatively large footprints, as opposed to structures that are generally rigid structures with relatively small footprints and may be pile founded. Locations where earthen levee to structure transitions occur at floodwalls, I-walls, pump stations, or closure structures are likely areas for distress to occur. Transition locations should be observed for signs of differential movement, embankment seepage, and foundation seepage. Failures at these transition locations can occur rapidly, and signs of distress should be quickly addressed.

K.3.3.11 Floodwall and I-wall Monolith Joints. Floodwalls are rigid structures that may be founded on pile or shallow foundations. I-walls are typically founded on sheetpile foundations. The joints between monoliths should be observed for signs of differential monolith movement (offsets between adjacent monoliths in 3-dimensions) that could indicate foundation distress. Because these structures are relatively rigid, failure can occur quickly and without significant indicators prior to failure. Monolith joints can also allow leakage. Generally, monolith joint leakage will be relatively small and will not cause significant issues. However, monolith joint leakage could be an indicator of differential movement that has torn a waterstop and could be enough to open a riverside crack and change loading on the structure. Figure K-10 shows differential movement at a floodwall monolith joint. If movement is occurring, temporary measurement points or survey locations should be established to monitor rate of movement.

Figure K-10. Floodwall Differential Movement and Concrete Damage on Stem.

K.4 Flood Fight Techniques.

K.4.1 Flood Fighting. Flood fighting is defined as emergency operations that are taken before and during a flood to prevent or minimize damages to public and private property. Flood fighting is extremely difficult to execute and there is no absolute method (or methods) that one can apply to guarantee success. Although each flood event is unique to itself, each event usually has some elements in common with previous flood events. Time, inclement weather conditions, working long shifts, working at night, lack of resources and trained personnel, plus lack of timely and accurate information all conspire to exert direct and ripple effects on every flood fighting effort. Only one thing is certain, failure to apply proven flood-fighting techniques in a timely manner will increase the probability of a failure and increase risk.

K.4.2 The most valuable asset available during a flood fight is the experience and common sense of field personnel. Many problems can be solved quickly and efficiently through the application of good common sense linked to technical experience. The collection, evaluation, interpretation, and dissemination of flood information are critical during flood fights, and whenever possible, only the best-trained and most capable personnel should be assigned to flood duty. However, it should be acknowledged that during long-duration and widespread flooding, it is likely that additional personnel, who may be inexperienced, will be assigned to the effort. In all cases, the flood-fight personnel will best serve the project by considering all of the possible solutions or techniques available for the particular problem and then constantly asking themselves “what if” concerning the consequences of the proposed action.

K.4.3 Regardless of the care taken during levee design, or the conservatism added to safety factors or input parameters, uncertainty will always remain regarding performance during hydraulic loading to the design flood level of sufficient duration to ensure complete saturation of the levee foundation and embankment. This uncertainty of performance is especially true for levees designed and constructed before the mid-1970s, prior to the emergence of the first USACE-wide levee design guidance. Long-duration and high-magnitude floods are likely to cause manifestation of weaknesses that were not apparent during the original design or construction and that will require flood-fighting. Even in modern levee systems designed by qualified individuals and constructed with close attention to detail, the benefit of closely spaced borings, geophysics, and relatively large design safety factors on critical failure modes, the levee system may have unexpected performance requiring emergency actions during a flood. Levee performance distress is often attributed to an unknown geotechnical flaw in the foundations, or some other unknown boundary condition, neither of which was identified during design. Providing emergency, temporary, or permanent levee strengthening via underseepage control, stability improvements, or erosion protection in response to flood distress caused by unknown conditions at the time of design should be considered necessary operations and maintenance of the levee to ensure it continues to provide the level of risk reduction intended by the original design and meets the authorized purposes. Operations and maintenance (O&M) manuals for levees should provide information regarding levee surveillance during floods, and temporary and interim risk mitigation measures to take in response to flooding distresses until permanent repairs can be implemented. It is nearly impossible to design and construct a levee that will require no flood fighting during significant loading. A proactive surveillance and flood fighting plan to lay out surveillance requirements and intervention techniques should be included in levee Operation and Maintenance Manuals and Flood Fight Standard Operating Procedures. It is a matter of fact that levees will continue to be strengthened in response to observed performance up to the historical record loading using the Observational Method and back analysis.

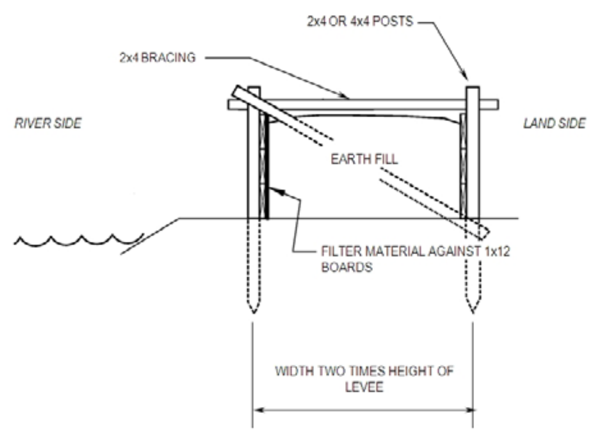
K.4.4 The flood fight measures described below are considered standard practice and should be followed as closely as practicable. For most situations, these procedures should govern and will yield acceptable results. However, emergency conditions will arise not covered by these standard practices. These atypical situations must be met by the individual and team initiative of flood fighters with prompt action using the resources (materials, labor, equipment, etc) on hand.

K.4.4.1 Supplemental Interior Drainage Provisions. For many levee sponsors and adjacent property owners, the pumping of interior drainage and underseepage during a flood event is desirable to prevent loss of crops and other property damage. However, the maximum allowable ponding should be allowed to remain because it can reduce the likelihood of underseepage distress. Supplemental interior drainage pumping should be performed with great caution. Discharge lines should be installed "up and over" the existing levee section to avoid reducing the level of protection. Additional material can be added to the levee crest to allow for vehicles to pass over the discharge-line pipes. Discharge lines should be extended a substantial distance riverward so that discharge does not erode the levee embankment. Alternatively, discharge lines can be placed in existing structures on the riverside of the levee. Intake pumps should be placed so they do not erode soil and reduce the thickness of the landward blanket. The maximum amount of water allowable should be allowed to remain in ditches and other localized depressions to provide underseepage resistance in these areas that are most prone to underseepage distress. If desired, supplemental pumping demand can be determined using the methods described under advanced construction of emergency flood barriers found in this appendix. However, in critical situations any amount of pumping ability that can be obtained is oftentimes used.

K.4.4.2 Overtopping Prevention. Levee overtopping is the flowing of flood waters over the levee crown. The necessity for raising the levee will be evident based on the height of the levee and the river stage predictions. Levee overtopping will erode the crown and landside slope of the levee, often leading to a levee breach. If the incipient overtopping location is located in the upstream portion or upper flank of the levee project, a breach at this location will allow a portion of the flood to flow through the entire protected area causing much more damage than if overtopping occurs on the downstream portion first. Consequently, a levee overtopping event should be prevented if at all possible, particularly in areas of high property value. When raising a levee the overall performance of the raised levee must be considered; increasing the levee height will increase the slope stability and underseepage demands on the levee and may require additional mitigation techniques elsewhere on the levee that may not become known until the raised portion of the levee is loaded. This will be particularly true for levees raised more than a few feet. Local past experience with this practice is extremely helpful in identifying areas of concern. The practice of temporarily increasing the levee height to prevent overtopping may locally be referred to as “capping” or “topping” the levee. The same techniques that can be used to construct emergency flood barriers can be used to raise levees, such as earthen raises, sandbag raises, earthen and lumber barriers, and modern barrier raises. It may be appear desirable to temporarily raise a levee by pushing up the landside slope to increase the height by steeping the landside slope. Unless a levee has an unusually flat landside slope (flatter than 1V:3H), this will generally not yield successful results. Temporary levee raises of a few feet or less have often been successful in the past, while the success rate of taller temporary raises is less certain because of stability and underseepage concerns. Some example levee crest raises are shown in Figure K-11.

K.4.4.3 Levee Armoring to Prevent Overtopping Damage. Sometimes there is no option to raise a levee, and overtopping is inevitable. Levees constructed of clays with good sod cover have historically been able to withstand short duration overtopping of up to a foot. But long duration overtopping, or overtopping of more than 1 foot is more likely to result in levee breach. In this case, the levee crown, landside slope, and landside toe can be made more resilient so the overtopping flows can pass without causing catastrophic damage to the levee section. To prevent overtopping breach, a 30 to 40 mil (thick) High Density Polyethylene (HDPE) sheet material has been used to prevent levee erosion leading to breach. One end of the HDPE should be anchored in a trench at the riverside edge of the levee crown. The trench should be 12-inches deep and about 8-inches wide. The HDPE should cover all three sides of the trench and be pinned into the trench in order to stay in place when the trench is backfilled. The HDPE sheet should be rolled down the landside slope and at least 15 feet beyond the landside toe. This end of the HDPE should also be anchored in a trench. The seams of the HDPE should be heat-seamed together and should be placed along and parallel to the fall line of the slope to prevent overtopping flows from getting under the HDPE. Alternatively, HDPE may be used only on the landside slope, not across the levee crown as well. Figure K-12 shows construction of landside HDPE erosion protection prior to overtopping, with ponded water visible in the landside area beyond the levee.

a: Mudbox Construction



b: Mudbox Schematic

c: Flashboard Raise

d: Hesco Levee Raise

e: Filled Isolated Low Spot

f: Clay Levee Raise

g. Sandbags used to raise levee crest to prevent overtopping

Figure K-11. Examples of Levee Crest Raises.

a: Deploying HDPE on Landside Slope

b: Deploying HDPE on Landside Slope

c: Anchoring HDPE in Anchor Trench

d: Completed HDPE Installation

Figure K-12. Construction of HDPE Erosion Protection on Landside Slope.

K.4.5 Underseepage. Distress to earthen embankments caused by underseepage is a common cause of failure. Sand boils are the earliest indicators of underseepage distress, and should be closely monitored, especially within 100 feet of the levee toe. Sand boils are most likely to occur near the landside toe or in low areas, such as ditches, landward of the levee. All boils should be conspicuously marked with flagging so that patrols can locate them without difficulty and observe changes in their condition.

K.4.5.1 Ringing Sand Boils. A sand boil which discharges clear water in a steady flow is usually not dangerous to the safety of the levee. However, if the flow of water increases and the sand boil begins to discharge material, corrective action should be undertaken immediately. The most widely accepted method of treating sand boils is to construct a ring of sandbags around the boil, building up a head of water within the ring sufficient to prevent further movement of sand and silt. Other methods such as attempting to plug the boil with soil material or placing large barrels over the boil are generally ill advised and are not likely to be successful. Examples of multiple sand bag rings are shown in Figure K-13, Figure K-14, and Figure K-15.

K.4.5.2 Actual conditions at each sand boil will determine the exact dimensions of the ring. The diameter and height of the ring depend on the size of the boil and the flow of water from it. Figure K-16 shows standard details for constructing a sand bag ring around a sand boil. In general, the following considerations should be followed when ringing a sand boil:

- The base width of the sandbag section should be no less than 1 1/2 times the contemplated height.
- The sandbag ring should encompass soft soils near the boil within the ring of sandbags to help prevent a boil from occurring adjacent to the ring.
- The ring should be of sufficient size to permit sacking operations to keep ahead of the flow of water.
- The height of the ring should only be that necessary to stop movement of soil, and not to a height that will completely stop the sand boil from flowing clear water. A good practice is to initially build the ring high enough to stop all flow and then remove sand bags to form an overflow that is the proper height to contain the boil. The outlet can then be adjusted as the river rises or lowers to maintain clear water flowing from the boil.
- The practice of carrying a sand bag ring around a sand boil to the river elevation is not necessary and may be dangerous in high stages. If seepage flow is completely stopped, a new boil will likely develop beyond the ring; this boil could then suddenly erupt and cause considerable damage. Where many boils are found to exist in a given area, a ring levee of sandbags should be constructed around the entire area (see example in Figure K-15) and, if necessary, water should be pumped into the area to provide sufficient weight to counterbalance the upward pressure.

Figure K-13. Multiple Sand Bag Rings.

Figure K-14. Multiple Sand Bag Rings Built Around Ineffective Initial Barrel Control.

Figure K-15. Multiple Sandbag Rings along Levee Toe with Larger Ring Around Entire Area Constructed Later.

K.4.5.3 Landside ditches. If sand boils initiate in the bottom of landside ditches, they can be effectively controlled by blocking the ditch downstream of the boil. Blocking the ditch will cause the ditch to fill with water and build up a head of water over the boil. The ditch may be blocked using a wooden bulkhead or a sandbag bulkhead. Generally this is sufficient to prevent further movement of sand and silt. If maintaining the ditch completely filled with water is not sufficient to prevent movement of material, a large sand bag ring will be required.

K.4.5.4 Intentional Ponding (water berms). If there is a large area of sand boil activity, an efficient way to control the movement of material is to allow intentional ponding of seepage and interior drainage to create a water berm. If the sand boil activity is in a low lying area, this can often be done by limiting interior drainage pumping or closing off small drainages away from the levee. If required, a short landside sub-levee can be constructed, similar to a temporary flood barrier, and used to control seepage by storing water over an area to provide a counterweight against excess head beneath the top stratum in that (sub-leveed) area. Sub-levees can be used to control seepage where the landside top stratum is relatively thin, and in low areas where seepage normally ponds. A disadvantage of sub-levees is that if sand boil activity worsens within the sub-leveed area, the ponded water makes observation and additional actions more difficult. Control of seepage by sub-levees still may require some manipulation of water levels in the sub-levee basins during high water. Controlling underseepage by means of tall sub-levees can be volatile because failure of the sub-levee when full of water would result in losing the control of sand boil activity at a critical time.

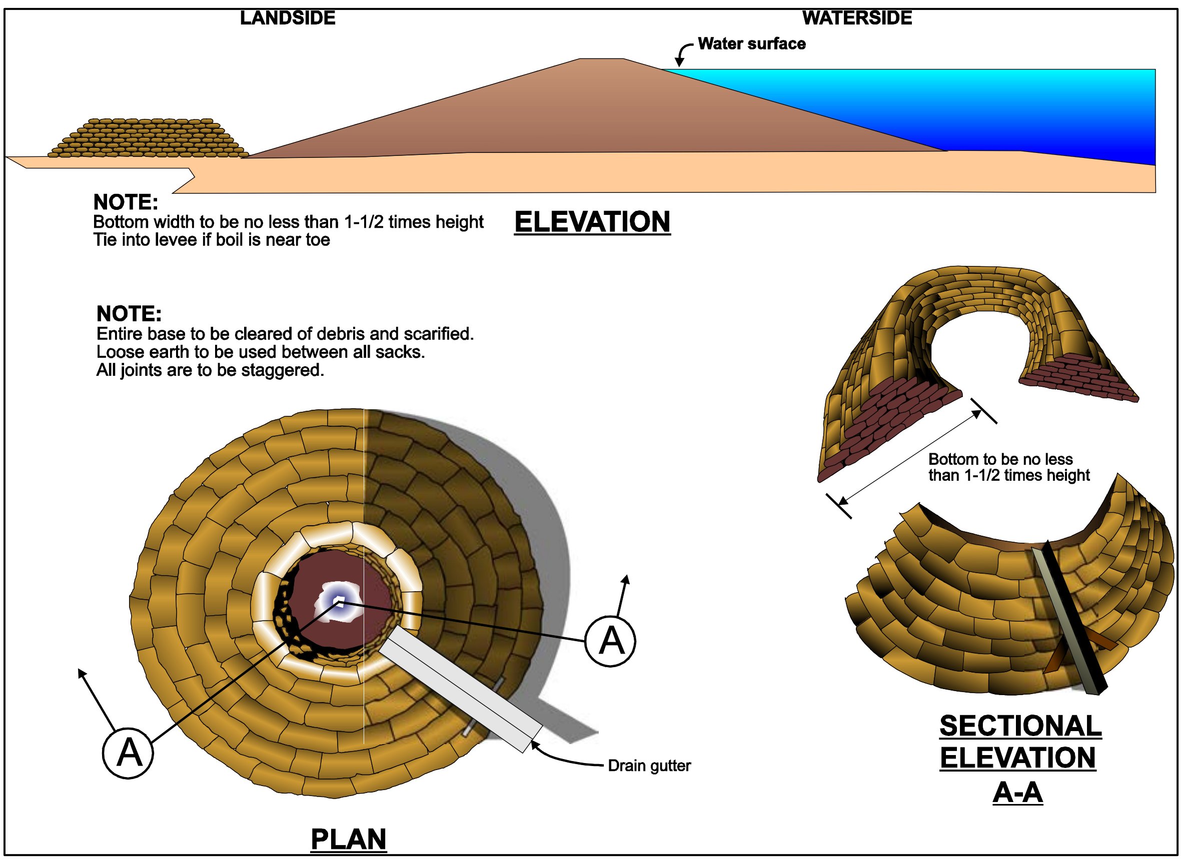


Figure K-16. Standard Details for Ringing Sand Boils.

K.4.5.5 Emergency underseepage berms. A landside berm can be used to control seepage by increasing the thickness of the top stratum immediately landward of the levee so that the weight of berm plus top stratum is sufficient to resist uplift pressures beneath the top stratum. A properly designed berm will be of such width that the excess head beneath the top stratum at the toe of berm is no longer critical, or the area of possible rupture of the top stratum is removed a sufficient distance from the levee as to no longer endanger it. A landside berm also affords protection against landside levee slope sloughing as a result of through-seepage. If subsurface information is available for the levee, it should be reviewed to estimate the size of the required berm. If no information is available, a minimum berm should be constructed with a width of 150 feet and a thickness at the landside levee toe of 3 feet. The minimum berm should be thickened, widened, or the size increased parallel to the levee as needed based on performance observations. Emergency underseepage berms should be constructed of material more pervious than the near surface soils landward of the levee. Sandy material is preferred and fat clays should not be used unless that is the only material available. Emergency berms constructed of fat clays should be carefully monitored as they generally have to be larger and thicker than berms constructed of more pervious material. Underseepage berms can also be constructed of clean crushed rock if a non-woven geotextile is used as a separator between the rock and the ground surface. Figure K-17 shows construction of an emergency underseepage berm adjacent to a levee; note the sand bag rings and standing seepage water. Figure K-18 shows an emergency seepage berm constructed to mitigate a concentrated leak under a floodwall; note the landward flood barrier constructed as a redundant flood fighting feature.

Figure K-17. Construction of an Emergency Underseepage Berm.

K.4.5.6 Emergency Relief Wells. Emergency relief wells can be used to control sand boil activity by reducing pressures in the foundation sands. Emergency wells are more difficult and expensive to construct that other types of sand boil control, but in areas with limited room landward of the levee or with no available borrow materials, they can be a good option. Generally, the benefit of relief well pilot holes to properly design blank intervals, filter pack gradation, and screen slot size will not be available and these must be estimated based on experience in the local area. Care must also be taken when drilling the relief wells to ensure that a flowing borehole does not develop. The hydrostatic pressure in the borehole must exceed the artesian pressure in the sand aquifer by the use of weighted mud and/or elevated drilling platforms.

Figure K-18. Emergency Seepage Berm Between Flood Wall and Adjacent Building with Full Height Flood Barrier Constructed Landside to Prevent Flood Waters from Entering the Leveed Area through a Concentrated Leak Under Floodwall.

K.4.5.7 Emergency pumping of existing relief wells. If the sand boils occur near existing relief wells, the wells can be pumped to increase the amount of pressure relief. Old relief wells or wells that have not been properly maintained may have lost substantial efficiency due to biological clogging and supplementary pumping can improve the well's effectiveness.

K.4.6 Through-Seepage. Seepage through an embankment, if the levee embankment is homogeneous, will first appear on the landside slope somewhere above the landside toe. If the levee embankment is made of impervious clays or silty clays, the flood event must be of a long duration for the through-seepage to appear. A seam or layer of more pervious material built into the levee will cause the through-seepage to appear higher on the landside slope, or appear sooner, than expected. If the seepage is clear, it should be carefully monitored. But if the through-seepage becomes cloudy, the seepage softens the landside levee slope, minor sloughs are observed at the landside toe, or the seepage is along a preferential path such as an animal burrow, emergency actions should be taken as described below.

K.4.6.1 Cover Riverside Slope with Polyethylene. Experience has shown that polyethylene (poly) and sandbags placed in the wet is an effective, expedient, and economic technique to seal the riverside slope and reduce embankment through-seepage. Wet placement may also be required to replace or maintain damaged existing poly. Figure K-19 shows the placement of riverside poly, prior to a flood event, in an area of slope distress to prevent through-seepage, and placement details are discussed in section K.5.2 on advance construction of emergency flood barriers.

Figure K-19. Poly Installed on Riverside Slope to Reduce Through-Seepage in Area of Slope Distress.

K.4.6.2 Landside Slope Weighted Filter Mattress. If the through-seepage has softened the landside slope, a free-draining, weighted filter mattress can be placed on the slope. The mattress will allow seepage to occur but will provide weight to the slope that resists the likelihood of slope failures. A non-woven filter fabric should be placed over the slope surface that is going to receive the filter mattress. There is no need to strip the slope. The mattress should be built of a clean crushed stone with a 6-inch maximum stone size and no more than 5% passing the #200 sieve, placed on the slope with a uniform thickness of 12 to 18 inches. If large quantities of sand are available, it can also be used as a weighted filter mattress but if the through-seepage quantity is substantial, perforated pipes (farm drain tile) should be buried in the sand mattress to ensure through-seepage is not limited by the less-pervious sand. If sloughing has initiated, the mattress should be constructed such that the finished slope of the mattress is slightly flatter than the original levee slope.

K.4.6.3 Emergency stability berm. If the through-seepage is occurring in the lower portions of the landside slope and causing sloughing of the toe, a small emergency stability berm can be constructed to stabilize the levee. Ideally, the berm would be constructed with the same materials that would be used for a weighted filter mattress to provide for filtered drainage. However, in an emergency situation, any materials will suffice if placed properly. The shape of the stability berm should be a minimum 5-foot thick and at least 15-feet wide. The top of the berm should be sloped to drain and the end slope should be no steeper than 1V:3H. The stability berm should extend beyond the visible limits of slope instability by at least 25 feet.

K.4.6.4 Figure K-20 shows construction of an emergency stability berm of sand material. Note extension beyond limits of originally planned berm due to additional slide areas and covering of berm with geotextile for surface erosion protection.

Figure K-20. Emergency Stability Berm, Under Construction and Completed. Large Sand Bags Were Used For a Toe Buttress to Reduce the Amount of Material Needed.

K.4.6.5 Shallow cutoff. If through-seepage is occurring along a localized preferential path, such as an animal burrow or similar defect, driven sheet-piles can be used to cut off the preferential path. The sheet-piles need to extend vertically and laterally some distance beyond the defect to prevent undermining of the cut-off. Sheet-piles can often be driven to the relatively shallow depths required for this action with small earthwork equipment that can be quickly mobilized to the site.

K.4.7 Riverside Scour. Erosion of the riverside embankment slope and foreshore can be one of the most severe problems encountered during a flood fight. Riverside scour can occur in the form of direct embankment scour and/or riverward scour. Riverward scour near the levee toe will often cause direct embankment scour and/or riverside slope failures. Emergency operations to control erosion prior to rising flood waters are discussed in section K.5.2 on advance measures, construction of emergency flood barriers. If riverside scour is anticipated, action should be taken prior to the flood. The advanced measures methods will generally be unsuccessful after scour has already started because of turbulent flow making construction difficult. After significant scour has occurred, large placements of riprap or quarry run rock are the best method to combat it. Placement of rock to restore or bolster the damaged levee section and/or construction of dike structures to deflect turbulent flow riverward of the levee are the recommended approaches. A successful operation will likely require significant quantities of material, trucks, and heavy mechanized equipment to place the rock. Figure K-21 shows significant riverside scour that severely impacted a levee embankment. Figure K-21a shows the initial observation, which was an apparent riverside slope failure. Figure K-21b shows emergency placement operations, and Figure K-21c shows the scour and emergency rock placement after the flood receded.

K.4.8 Drainage Structures and Conduits. Pipes that penetrate the levee embankment can have distress from seepage along the penetration, seepage into the penetration through a defect, or flood waters entering the penetration through a failed riverside closure.

K.4.8.1 Seepage along a conduit should be handled similarly to through-seepage. If the seepage is clear and not moving material, generally no actions are needed. If the seepage becomes cloudy or instability appears evident, the same flood fighting techniques as for embankment through-seepage should be employed.

K.4.8.2 Seepage into a penetration through a defect can cause a loss of embankment material that leads to a sinkhole, crest subsidence, or larger slope instability. Generally, flood fighting consists of attempts to slow or stop the seepage into the penetration and provide balancing hydrostatic head on the landside. Sinkholes that are observed on the landside should be filled with material to prevent larger stability issues. Sinkholes that are observed on the riverside should be filled with impervious material if available, and the area covered with poly to provide additional resistance to infiltration. If the sinkhole occurs below the water line and a whirlpool develops, emergency placement of large quarry run rock will usually slow the infiltration rate down to manageable levels. A sandbag ring, or other type of barrier, should be constructed around the pipe inlet to provide resisting hydrostatic head and limit the movement of material.

a: Initial observation of scour

b: Emergency placement operations

[Figure K-21]

c: Emergency rock placement after the flood receded

Figure K-21. Riverside Scour.

K.4.8.3 Flood waters entering a conduit through a failed riverside closure are often not a risk of levee embankment failure. However, even small penetrations can allow significant volumes of water into the leveed area and cause flood damages. If large quantities of water are entering the leveed area through a conduit because of a failed gate or substantial pipe failure on the riverside, typically emergency placement of large quarry run rock over the distress is successful at slowing the rate of inflow so that a barrier can be constructed on the landside to provide balancing hydrostatic head. If the riverside pipe or closure has been damaged, the landside barrier around the pipe inlet should be constructed the full height of the levee or to the predicted flood crest. If not constructed to the full levee height, provisions should be made to allow for a raise if the predicted crest is exceeded. The barrier can be constructed using the methods described in section K.5.2, advance construction of emergency flood barriers. Figure K-22 shows a landside barrier constructed to prevent floodwaters from entering a drainage structure through a failed flapgate. The barrier was constructed with sand using a poly cover to prevent embankment seepage. Figure K-23 shows a U-shaped barrier constructed of crushed rock to mitigate for a failed riverside closure structure. An alternative to barrier construction is installation of a pipe plug, or pig, in the pipe. Pipe plugs come in a variety of sizes and styles based on manufacturer.

Figure K-22. Full Height Flood Barrier Constructed to Prevent Flood Waters from Entering the Leveed Area through a Drainage Structure with a Failed Flapgate.

K.5 Advance Measures.

K.5.1 Advanced Measures. Advanced measures are those actions taken in advance of a pending flood to reduce risk in areas where there is no existing flood risk management project. Advanced measures consist of construction of large scale emergency flood barriers, local flood barriers for specific structures or infrastructure, and evacuations of areas where flood barriers cannot be constructed. It may not be feasible to protect entire communities with constructed flood risk management features based on economic or time and equipment considerations; therefore, evacuation of certain areas may be a necessary facet of an emergency operation. Evacuations are not specifically addressed in this appendix, but should be detailed in local Emergency Action Plans.

Figure K-23. Full Height U-Shaped Flood Barrier Constructed Landside to Prevent Flood Waters from Entering the Leveed Area through a Drainage Structure with a Failed Riverside Closure Structure.

K.5.2 Flood Barriers. In some areas where there is no existing levee system, construction of an emergency flood barrier can be used to reduce flooding risk. Flood barriers can be constructed of sand bags, earthen fill, or a combination of earth fill and lumber. Relatively recent advances in emergency flood barrier materials have been made, and “modern” flood barriers consisting of water filled membranes and frame supported waterproof membranes have been used with success. Interior drainage must also be considered when planning a flood barrier. ***The design and construction techniques described for emergency flood barriers are not intended for permanent structures.***

K.5.2.1 Flood Barrier Alignment. Prior to any flood barrier construction, a complete alignment for the proposed barrier should be established. The alignment should be the shortest practical route, provide the maximum practical protection, and take advantage of any high ground where practicable. The flood barrier should be kept as far landward of the river as possible in case of riverbank erosion and to reduce encroachment on the floodway by providing maximum space for overbank flows. This is especially important for smaller floodways where encroachment would directly impact the water surface profile. Sharp bends in the alignment should be avoided. Topographic, plat, or city street maps may be useful in selecting an alignment. Consideration should be given as to whether sufficient time remains to complete construction before the flood crest arrival. Keep as many trees and brush between the barrier and river as possible to help deflect current, ice, and debris. However, 5 to 10 feet should be allowed between the barrier toe and vertical obstructions such as trees for ease of construction and for monitoring during the flood. Consultation with City, County, State or other local floodplain management officials is recommended when establishing the alignment. In urban areas, many communities within a flood prone area already have some levees in-place. These communities typically fight the flood along this primary line of defense. Moving the alignment farther landward creates problems in determining methods to stop floodwater backup through storm and sanitary sewer lines. It could also leave storm and sanitary lift stations on the riverside of the flood barrier. Leaving some homes outside the line of protection also exposes the water mains to floodwater infiltration. Real estate and right-of-way considerations can influence the selected alignment. A professional survey is recommended or establishment of the alignment and barrier top elevations. However, if a professional surveyor is not available, a hand-level along with a known-elevation location can be used to lay out approximate grades. As soon as the alignment is firm, quantities of earthwork should be estimated for establishing construction equipment and borrow requirements depending on the type of barrier to be constructed. Barrier height should provide at least 2 feet of freeboard above the forecasted flood crest. In urban areas, the upstream end of the alignment should use a larger freeboard than the downstream end so that overtopping flows slowly fill up the area behind the barrier.

K.5.2.2 Flood Barrier Foundation Preparation. Regardless of the type of flood barrier used, proper foundation preparation is required. Because spring flooding is the only condition providing much advance warning prior to flooding, the first item of work in cold regions is likely snow removal along the barrier alignment. The snow should be pushed riverward so as to decrease landside ponding when the snow melts. Trees should be cut and the stumps removed. All obstructions above the ground surface should be removed, if possible. This will include brush, structures, snags, and similar debris. The foundation should then be stripped of topsoil and surface humus. Clearing and grubbing, structure removal, and stripping should be performed only if time permits. Stripping may be impossible if the ground is frozen. In this case, the foundation should be ripped or scarified, to provide a rough surface for bond with the embankment. Every effort should be made to remove all ice or soil containing ice lenses. Frost or frozen ground can give a false sense of security in the early stages of a flood fight. It can act as a rigid boundary and support the barrier; but on thawing, soil strength may be reduced sufficiently for cracks or slides to develop. It also forms an impervious barrier to prevent seepage. This may result in a considerable buildup in pressure under the soils landward of the barrier, and upon thawing pressure may be sufficient to cause sudden blowouts. If this condition exists it must be monitored, and one must be prepared to act quickly if sliding or sand boils develop. If stripping is possible, the material should be pushed landward of the barrier and windrowed.

K.5.2.3 Sand Bag Flood Barrier Construction. Sand bag barriers require access to tremendous labor resources, sand bags, and fill materials; and sand bag barriers are difficult to raise during a flood. However, constructing flood barriers from sand bags has been a historically successful method for low height barriers of short length. Sand bag flood barriers should be limited in maximum height based on construction requirements, cost, and performance. The maximum recommended height for a sand bag barrier is 5 feet, although taller sand bag barriers have been constructed and used successfully on some occasions. Based on the aforementioned resource constraints, sand bag barriers are often limited to 3 feet. Table K-1 shows the estimated number of sand bags needed for typical barrier heights and lengths.

Table K-1
Estimated Number of Sand Bags for Barrier Construction.

Barrier Height (ft)	Number of Sand Bags Required for Barrier Length					
	50 ft	100 ft	200 ft	300 ft	400 ft	500 ft
1	300	600	1,200	1,800	2,400	3,000
2	1,050	2,100	4,200	6,300	8,400	10,500
3	2,250	4,500	9,000	13,500	18,000	22,500
4	3,900	7,800	15,600	23,400	31,200	39,000
5	6,000	12,000	24,000	36,000	48,000	60,000

K.5.2.3.1 When constructing a sand bag barrier, care must be taken during filling, handling, and placement of bags. Sand is the easiest, and most common, material to use in a sand bag barrier. However, silt and clay can be used if that is the only material available. Sand bags must be properly filled and tied to construct a successful barrier. Bags should be filled 1/2 to 2/3 full and left untied or tied loosely near the top. Figure K-24 shows correct and incorrect sand bag preparation. Often sand bags are filled from sand stockpiles by workers using shovels. Consequently, sand bag filling typically requires a large number of workers, and this should be considered before planning a sand bag barrier. However, there are proprietary sand bag filling machines available that can significantly increase bag production rate with fewer workers. Figure K-25 shows one type of sand bag machine in use at a staging area where sand bags are prepared for transport to a location where they are needed. Other types of sand bag filling equipment could consist of crudely constructed hoppers and funnels.

K.5.2.3.2 Figure K-26 shows correct sand bag placement techniques for sand bag barrier construction. Sand bag barriers should be constructed with a base width that is at least 3 times the height to ensure stability. If a sand bag barrier greater in height than 3 feet will be constructed, a bonding trench that is 1 sand bag deep and 2 sand bags wide should be placed near the centerline of the barrier. If a short sand bag barrier is planned, but a future raise may be necessary, a bonding trench is recommended. Prior to placing a sand bag barrier, existing sod should be stripped. Sand bags should be placed lengthwise parallel to river flow and staggered and stair stepped. If sand bags are not tied, the open end should be overlapped with subsequent bags with the open end facing downstream. Sand bags should be thoroughly tamped into place to form a good bond between lifts.

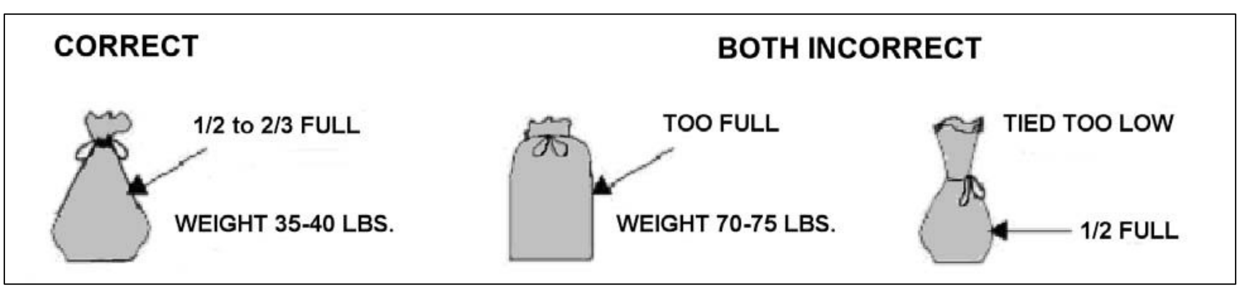


Figure K-24. Correct and Incorrect Sand Bag Preparation (MVP).

Figure K-25. Sand Bag Filling Machine in Use.

K.5.2.3.3 Sand bag barriers should be finished by sealing the riverside face with a polyethylene plastic (poly) to limit seepage through the barrier. The poly should be at least 6 mils thick. This material is generally available at farm stores, home improvement stores, and lumber yards in 20-foot wide by 100-foot long rolls. The poly should be placed with at least a 3-foot overlap, with subsequent sheets placed upstream of previous sheets to prevent river flow from uplifting the sheets. The poly should be anchored at the riverside barrier toe and at the barrier top as shown in Figure K-27 to prevent being washed away. Alternative methods of anchoring include burying the riverside poly edge in a 6-inch deep trench or placing a 1 to 2 feet riverside poly extension placed on a thin layer of loose soils and weighted down with sand bags. Excess poly should be left rolled at the top of the barrier in case the barrier needs to be raised.

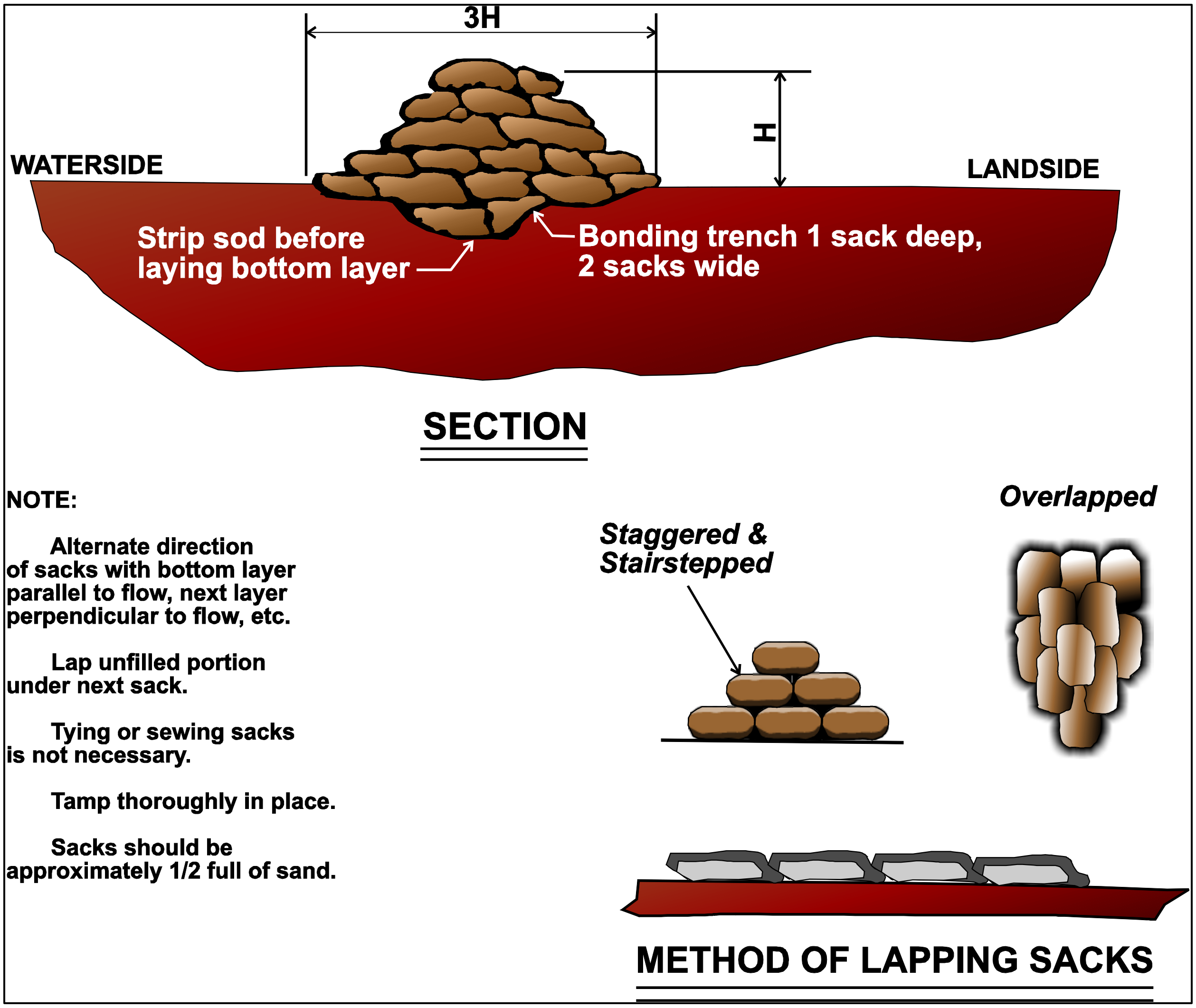


Figure K-26. Proper Sand Bag Barrier Construction Techniques.

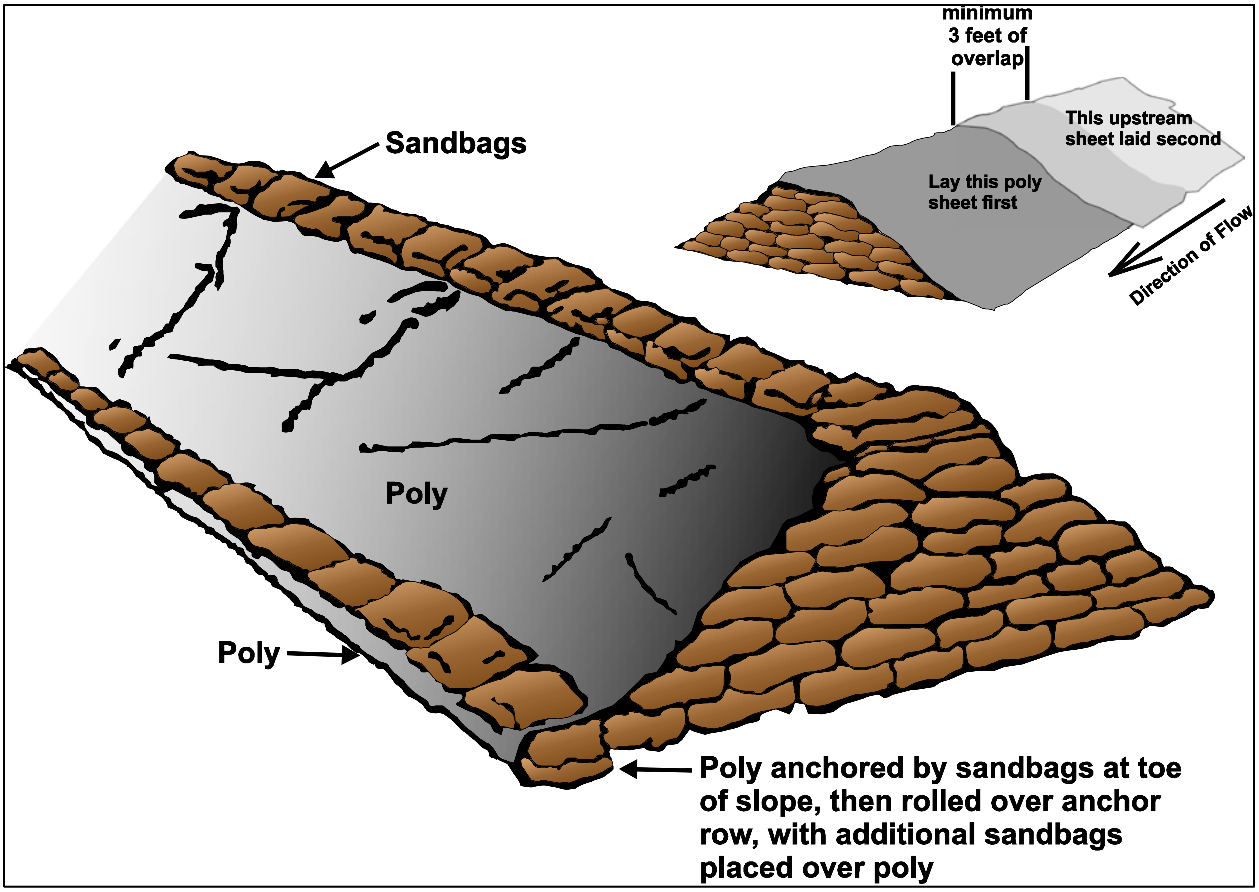


Figure K-27. Proper Placement of Poly on Riverside of Sand Bag Barrier.

K.5.2.4 Earthen Flood Barrier Construction.

K.5.2.4.1 Equipment. One of the important considerations in earthen flood barrier construction is the selection and availability of proper equipment to do the work. Under emergency conditions, obtaining normally specified earthwork equipment may be difficult and the work may have to be done with locally available equipment. Early planning and organization will help insure that proper and efficient equipment is available. If possible, compaction equipment should be used in flood-barrier construction. This may involve sheepsfoot, rubber-tired, or vibratory rollers, depending on the type of fill used. Scrapers are recommended for hauling from borrow areas on short hauls because of speed. However, truck haul has been the most widely used based on readily available equipment. A ripper will be necessary for opening borrow areas in the early spring if the ground is frozen. A bulldozer of some size is mandatory to help spread dumped fill. A bulldozer also provides at least some compaction during earth moving operations in the event no other equipment is available.

K.5.2.4.2 Fill Materials. Earth fill materials for emergency barriers will usually come from local borrow areas. An attempt should be made to utilize materials which are compatible with the foundation materials. Due to time limitations, however, any local materials may be used if reasonable construction procedures are followed. The material should be relatively clean (free of debris) and should not contain large frozen pieces of earth.

K.5.2.4.3 The majority of earthen flood barriers erected in recent floods consisted of clay or predominantly clayey materials. Clay is preferred because the cross-section width can be made smaller with steeper side slopes. Also, clay is relatively impervious and has relatively high resistance to erosion in a compacted state. A disadvantage in using clay is that adequate compaction is difficult to obtain without proper equipment. Another disadvantage is that if the clay is wet, subfreezing temperatures may cause the material to freeze in the borrow pit and in the hauling equipment. Cold and wet weather could cause delays and should definitely be considered in the overall construction effort.

K.5.2.4.4 When sand is used to construct an earthen flood barrier, the barrier cross-section requires flatter slopes and/or placement of poly on the riverside. Steep slopes without poly coverage on the riverside slope will result in seepage through the barrier that exits on the landward slope causing slumping of the slope and potential overall failure if it occurs over an extended period of time.

K.5.2.4.5 Silt materials should be avoided in construction of earthen flood barriers. If used, poly facing must be applied to the riverside slope. In addition to being very erodible, silt, upon wetting, tends to collapse if not properly compacted.

K.5.2.4.6 Cross-Sections. All earthen flood barriers should be constructed with an initial crest width of 10 feet to facilitate access and provisions for future raises, if necessary. The minimum stability cross-section for a clay earthen flood barrier is riverside and landside slopes of 1V:2.5H. Sand earthen flood barriers should have a riverside slope of 1V:3H and a landside slope of 1V:5H to maintain stability.

K.5.2.4.7 The final dimensions of the earthen barrier will be dictated by the foundation soils and underseepage considerations. Information on foundation soils should be requested, and considered if available, from local officials or engineers. If information is available, appropriate underseepage and stability berms can be quickly designed. In the absence of site-specific foundation information, geological mapping can be used to estimate the likely foundation conditions. If the foundation soils consist of substantial thickness of clay materials, at least 1.5 times the barrier height, then the minimum cross-sections above will likely be adequate. If the foundation soils consist of fine sand, or clay over fine sand, the minimum base of the earthen flood barrier should be 18 times the barrier height. If the foundation conditions consist of coarse sand, or clay over coarse sand, the minimum base should be 5 times the barrier height. To achieve the minimum base width that exceeds the minimum cross-section based on material type, landside berms can be constructed with a minimum thickness of 3 feet and a width required to achieve the minimum base.

K.5.2.4.8 Compaction. Proper compaction of the earthen barrier is critical to stability, and should be overseen by staff familiar with earth construction. The importance of compaction field oversight cannot be overstated. Use of standard compaction equipment, such as a sheepsfoot roller for clay soils and a vibratory roller for sand soils, should be used if possible. Loose lift thicknesses of 8 to 12 inches may be used, with 3 to 4 passes of compaction equipment to achieve compaction. However, proper compaction and construction may not be feasible during emergency operations because of time constraints or limited equipment availability. In most cases the only compaction available will be from hauling and spreading equipment, such as dump trucks and dozers. In those situations, thin lifts and more passes of the equipment should be used.

K.5.2.5 Poly for Scour Protection. Methods of protecting barrier slopes from current scour, wave wash, seepage, and debris damage are numerous and varied. However, during a flood emergency, time, availability of materials, cost, and construction capability preclude the use of all accepted methods of permanent slope protection. Field personnel must decide the type and extent of slope protection the emergency barrier will need. Several methods of levee slope protection have been established that prove highly effective in an emergency. Again, resourcefulness on the part of the field personnel may be necessary for success.

K.5.2.5.1 Experience has shown that a combination of polyethylene (poly) and sandbags is one of the most expedient, effective, and economical methods of combating slope attack in a flood situation. Poly and sandbags can be used in a variety of combinations, and time becomes the factor that may determine which combination to use. Ideally, poly and sandbag protection should be placed in the dry. However, many cases of unexpected slope attack will occur during high water, and a method for placement in the wet is covered below.

K.5.2.5.2 Anchoring the poly along the riverward toe is important. Any of the following three methods may be used: (1) After completion of the barrier, excavate a trench along the toe, place the poly in the trench, and backfill the trench; (2) place the poly flat-out away from the toe, and earth pushed over the flap; and (3) place the poly flat-out from the toe and place one or more rows of sandbags over the flap. The poly should then be unrolled up the slope and over the top (over the levee crest) enough to allow for anchoring with sandbags at the crest. Poly should be placed from downstream to upstream along the slopes and each sheet overlapped at least 2 feet over the previous (more downstream) sheet. Once it is rolled out, the poly is ready for the "hold-down" sandbags; it is mandatory that poly placed on the earthen barrier slopes be held down. An effective method of anchoring poly is a grid system of single sandbags, unless extremely high velocities, heavy debris, or a large amount of ice is anticipated. Then a solid blanket of bags covering the poly should be used. A grid system can be constructed faster and requires fewer bags and much less labor than a total covering. Various grid systems include vertical rows of lapped bags, two-by-four lumber held down by attached bags, and rows of bags held by one continuous that each bag is tied to. Poly can also be held down by a system using two bags tied with rope and the rope saddled over the barrier crown with a bag on each slope.

K.5.2.5.3 Figure K-28 shows suggested methods of laying and anchoring poly and sandbags. Since each flood fight project is unique (with respect to river, personnel available, materials, and other conditions), specific details of placement and materials handling will not be covered here. Personnel must be aware of resources available when using poly and sandbags.

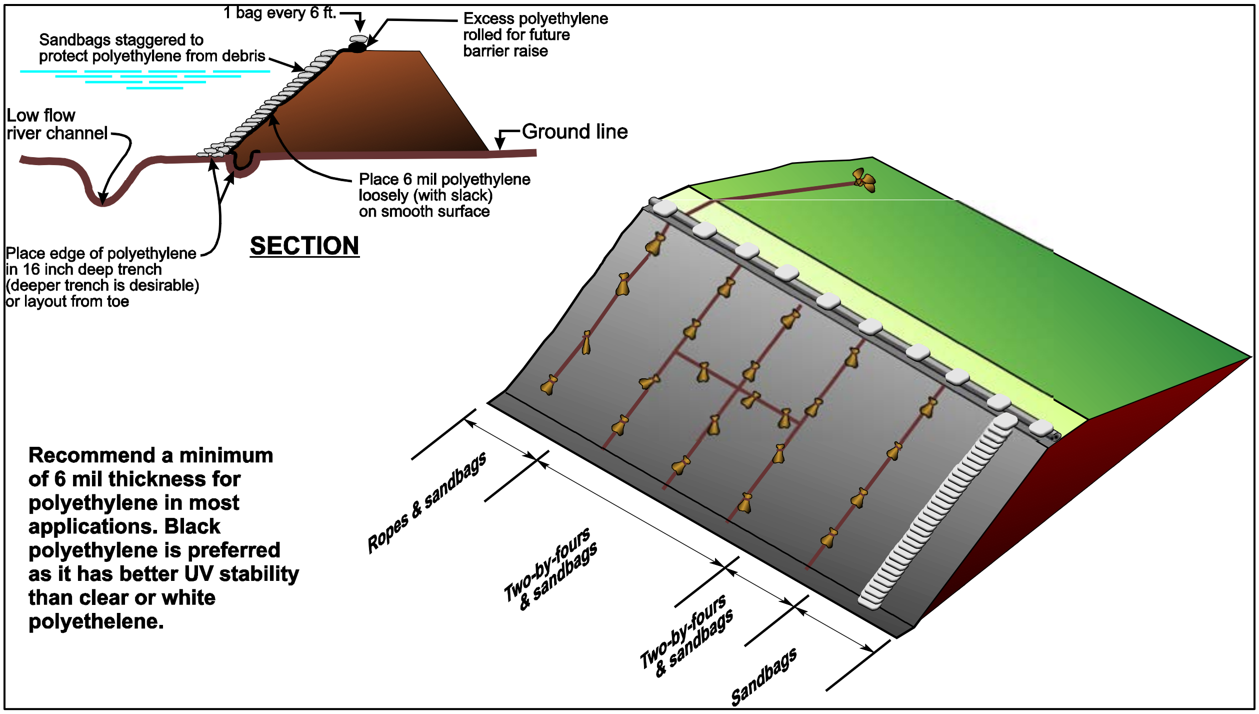


Figure K-28. Placement of Polyethylene Sheeting on a Temporary Barrier.

K.5.2.5.4 In many situations during high water, poly and to provide emergency protection must be placed in the wet. Wet placement may also be required to replace or maintain damaged poly or poly displaced by water-current action. Figure K-29 shows a typical section of barrier covered in the wet. Sandbag anchors are formed at the bottom edge and ends of the poly by bunching the poly around a fist or a handful of rock and tying the sandbags to this fist- sized ball of poly or poly/rock. Counterweights consisting of two or more sandbags connected by a length of 1/4-inch diameter rope are used to hold the center portion of the poly down. The number of counterweights needed will depend on the uniformity of the barrier slope and the water-current velocity. Placement of the poly consists of first casting out the poly sheet with the bottom weights attached and then adding counterweights to slowly sink the poly sheet into place. The poly, in most cases, will continue to move down slope until the bottom edge reaches the toe of the slope. Sufficient counterweights should be added to insure that no air voids exist between the poly and the barrier face and to keep the poly from flapping or being carried away in the current. For this reason, it is important to have enough counterweights prepared prior to the placement of the sheet.

K.5.2.5.5 In past floods there has been a tendency to overuse and in some cases misuse poly on slopes. For example, on well-compacted clay embankments, in areas of relatively low velocities, use of poly would be unnecessary. Also, placement of poly on landward slopes to prevent seepage and is generally never recommended because it may force seepage to another exit and/or increase seepage pressures in the embankment, and can prove detrimental. One limited use of poly on the landside slope of earthen barriers is to prevent rainwater from entering a crack where slope movement has occurred, particularly in fat clay soils. Keeping water out of the cracks resulting from slope movements is desirable to prevent additional hydrostatic pressure on the failure surface and strength softening.

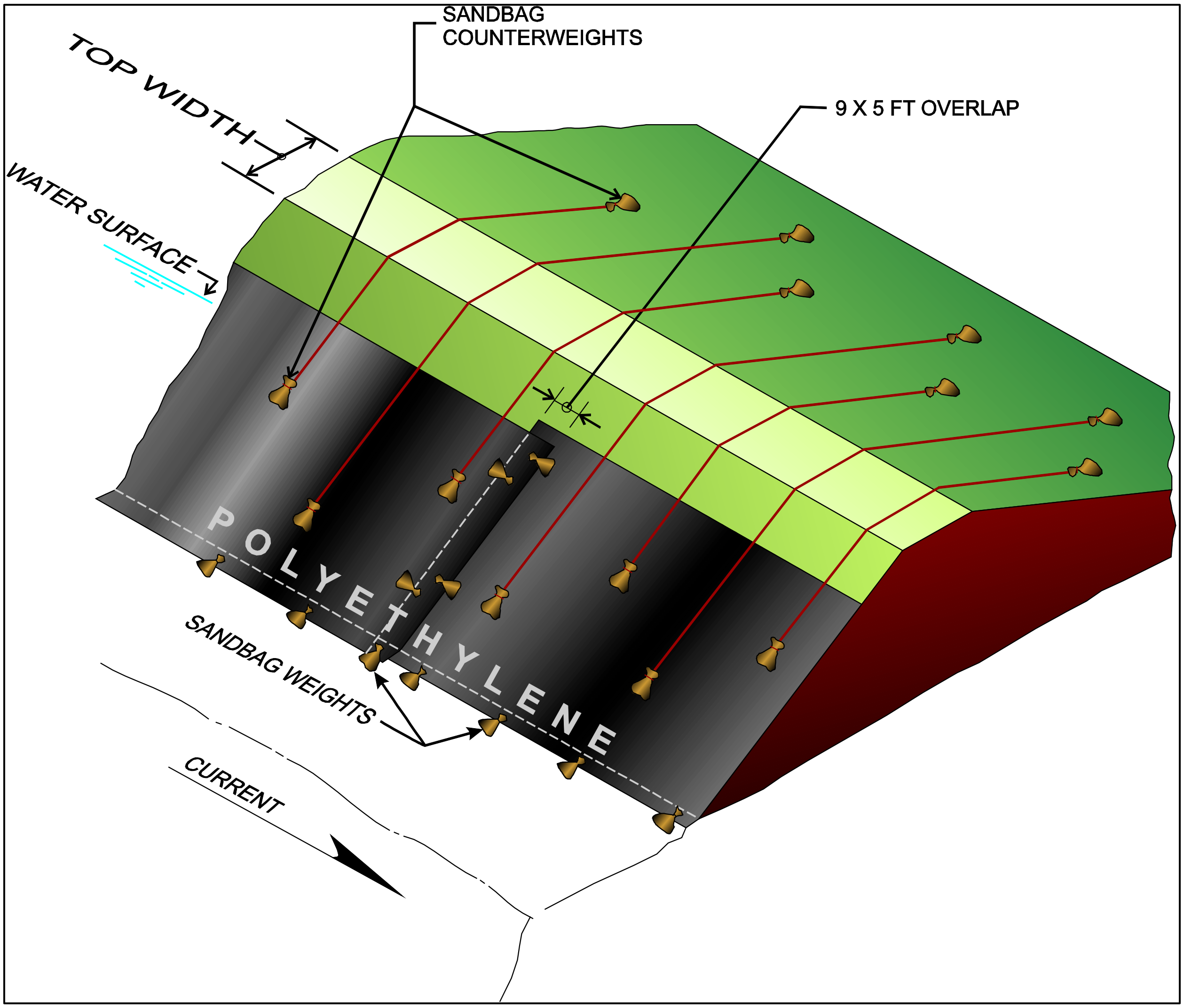


Figure K-29. Placement of Polyethylene Sheeting in the Wet.

K.5.2.6 Riprap for Scour Protection. Riprap is a very positive means of providing slope protection and has been used in a few cases where erosive forces were too large to effectively control by other means. Typically, riprap scour protection is only used in extreme situations because it is extremely costly, can be difficult to get to the site, and may require additional construction equipment to place.

K.5.2.7 Other Current and Debris Deflectors. In the past, small groins, extending 10 feet or more into the channel were effective in deflecting current away from the levees. Groins can be constructed by using sandbags, snow fence, rock, compacted earth, or any other substantial materials that are available. Preferably groins should be placed in the dry and at locations where severe scour is anticipated. Consideration of the hydraulic aspects of placing groins should be given, because haphazard placement may be detrimental. Technical assistance from personnel with hydraulic-expertise should be sought if doubts arise in the use of groins. Construction of groins during high water will be very difficult and results will generally be minimal. If something other than compacted fill is used, some form of anchorage or bonding should be provided (for example, snow fencing anchored to a tree beyond the toe of the levee.)

K.5.2.7.1 Log booms have been used to protect levee slopes from debris or ice attack. Logs are cabled together and anchored with a dead man in the levee. The boom will float out into the current and, depending on log size, can deflect floating objects.

K.5.2.7.2 Several other methods of slope protection have been used, such as straw bales pegged into the slope or straw spread on the slope and overlain with snow fence.

K.5.2.8 Earthen and Lumber Flood Barriers. Combination earth fill and lumber flood barriers, such as flashboard and box levees, are not commonly used primary flood barriers because the construction time is generally longer than other barrier types and the cost is usually higher. Typical flashboard and box levee construction is shown in Figure K-30. Combination barriers are best suited for raising, or capping, an existing levee or in highly constricted areas.

K.5.2.9 Modern Flood Barriers. Modern flood barriers have been developed in the last few decades that offer an alternative to traditional earthen and sandbag barriers. Modern barriers currently consist of large water filled bladders, frame supported waterproof membranes, and large sand bags and gabion style baskets. The primary advantages of modern flood barriers are reduced manpower and material requirements to install compared to earthen and sandbag barriers. Modern flood barriers can also generally be saved for reuse during future floods, and can often be rented instead of purchased. However, modern flood barriers are limited in height and generally cannot be raised during a flood if the forecasted peak increases. Water filled bladders are currently limited to 6 feet of water retention and frame supported waterproof membranes are limited to 10 feet of water retention. There is also a modern sand bag flood barrier that consists of large sized sand bags or gabion style baskets that can be filled with sand. They offer some manpower and fill material advantages compared to traditional sand bag and earthen barriers, but still require large amounts of fill materials and heavy construction equipment to move and place. The same foundation considerations and base width requirements for traditional sand bag and earthen barriers apply to modern flood barriers. Most modern flood barriers are proprietary in nature, and manufacturer specific installation instructions should be followed. Diagrams and photos of modern flood barriers are shown in Figure K-31, Figure K-32, Figure K-33.

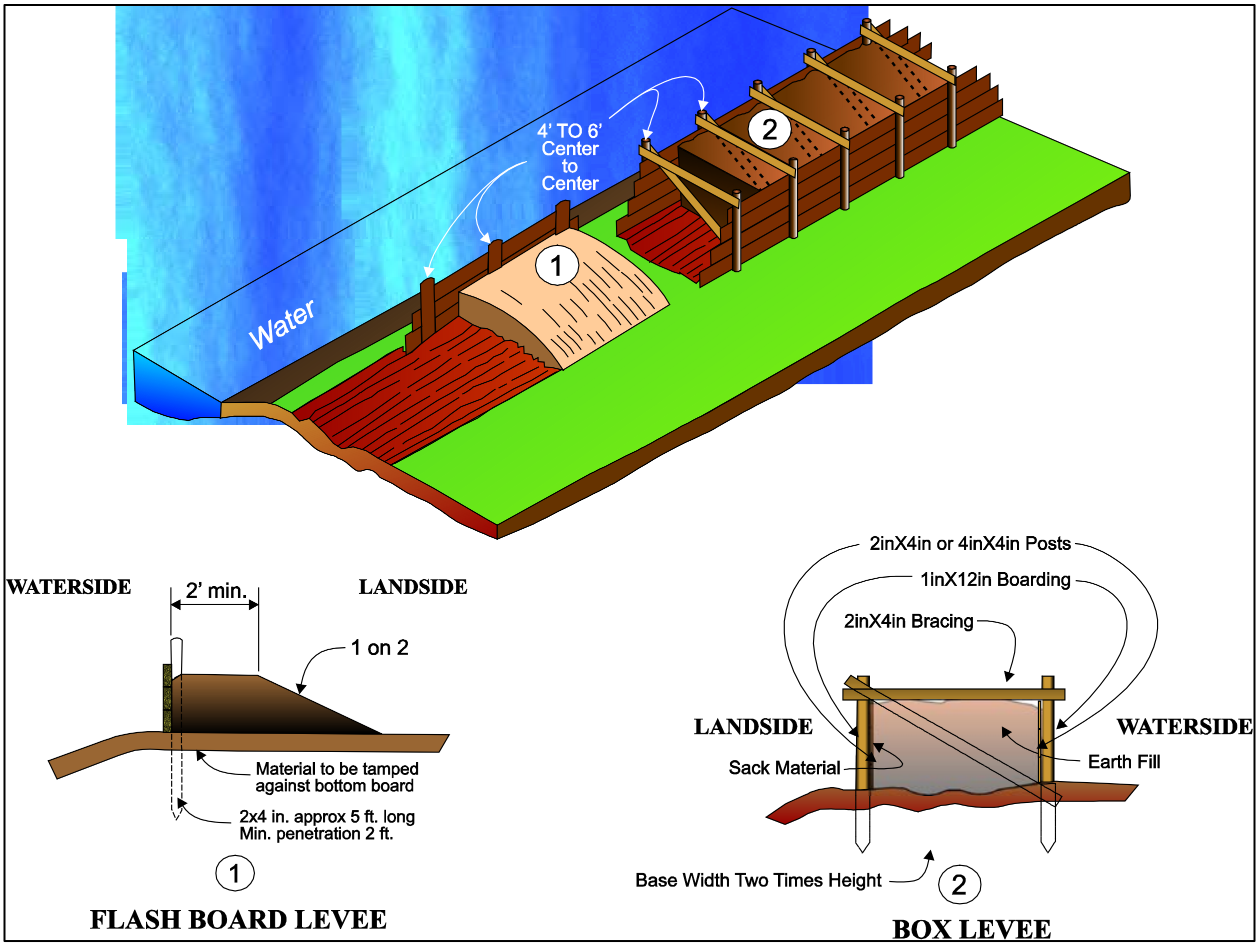


Figure K-30. Flash Board and Box Levee.

Figure K-31. Deployment of Water Filled Bladder Flood Barrier for Levee Raise.

Figure K-32. Deployment of Frame Supported Waterproof Membrane Flood Barrier.

Figure K-33. Deployment of Large Sand Bag Flood Barrier to Raise Levee.

K.5.3 Interior Drainage Considerations. In laying out a flood barrier, the problem of interior drainage from snowmelt, rain, or sewer backup should be considered. A certain amount of ponding, if valuable property will not be damaged, is not detrimental and may be allowed. The excess interior water can be pumped over the levee back into the river if pumps are available. In order to arrive at a reasonable plan for interior drainage treatment, several items of information must be obtained by field personnel. These are as follows:

- Size of drainage area.

- Pumping capacity and/or ponding required.
- Basic plan for treatment.
- Storm and sanitary sewer and water line maps, if available.
- Location of sewer outfalls (abandoned or in use).
- Inventory of available local pumping facilities.
- Probable location of pumping equipment.
- Whether additional ditching is necessary to drain surface runoff to ponding and/or pump locations.
- Location of septic tanks and drain fields (abandoned or in use).

K.5.3.1 Pumping of ponded water is usually preferable to draining the water through a culvert since the tailwater (drainage end) of a culvert could be raised (elevation increased) to a point higher than the inlet, allowing water to back up into the area being protected. Installation of a flapgate at the outlet end would prevent this, but would restrict interior drainage from leaving the leveed area. If a culvert is desired to pass water from a perennial stream through a levee, a delineation of the drainage basin and pipe size computations should be made by a professional engineer because the methods described in this appendix are not appropriate for that situation.

K.5.3.2 A method for estimating the interior drainage and seepage pumping requirements behind an emergency flood barrier is described below. The method ((Equation K-1)) is a simplified version of the storage-routing equation.

$$\mathrm{Q}_{pump,gpm} = \left(\mathrm{Q}_{rainfall\ inflows,cfs} + \mathrm{Q}_{seepage,cfs}\right) \times \left(\frac{448.83\ gpm}{1\ cfs}\right) - \frac{\mathrm{V}_{ponding,ac-ft} \times 5{,}431.21 \frac{\frac{gpm}{ac\text{-}ft}}{hour}}{T_{runoff,hrs}}$$

(K-1)

where:

$\mathrm{Q}_{pump,gpm}$	=	required pumping rate in gallons per minute (gpm)
$\mathrm{Q}_{rainfall\ inflow,cfs}$	=	inflows from rainfall in cubic feet per second (cfs)
$\mathrm{Q}_{seepage,cfs}$	=	seepage under the flood barrier in cubic feet per second (cfs)
$\mathrm{V}_{ponding,ac-ft}$	=	the volume of available ponding area in acre-feet (ac-ft)
$T_{runoff,hrs}$	=	the design runoff duration in hours (hrs)

K.5.3.3 The value of $\mathrm{Q}_{rainfall\ inflow,cfs}$ for drainage areas less than 1 square mile can be estimated using the Rational Method (Equation K-2), which is detailed in EM 1110-2-1417. This application of the Rational Method to estimate $\mathrm{Q}_{rainfall\ inflow,cfs}$ assumes the peak discharge during the event is constant throughout the rainfall duration. If local information regarding the intensity of the rainfall event is not available, a 6-hour rainfall event with an annual chance of exceedance (ACE) of 0.5 is considered appropriate to determine the pumping capacity for emergency flood barriers. A national map of the total rainfall depths for a 6-hour, 0.5 ACE rainfall event is shown in Figure K-34. For emergency flood barrier interior drainage applications, the duration of the storm can be adopted as the design rainfall duration, $T_{runoff,hrs}$.

$$Q_{rainfall\ inflow,cfs} = C \times (i)_{\frac{inches}{hour}} \times (A)_{acres}$$

(K-2)

where:

$Q_{rainfall\ inflow,cfs}$	=	peak runoff during the rainfall event in cfs
C	=	unitless runoff coefficient from Table K-2
$(i)_{inches/hour}$	=	design rainfall intensity with units of inches/hour
$(A)_{acres}$	=	drainage basin area in acres

K.5.3.4 It is recommended to conduct a more detailed rainfall-runoff analysis for drainage areas larger than 1 square mile because the estimate of $Q_{rainfall\ inflow,cfs}$ in this method (Equation K-2) assumes that the peak inflow is constant during the rainfall event, which may not be applicable for larger drainage basins. The Rational Method should not be used in drainage basins larger than 1 square mile because it does not produce accurate estimates of peak discharge in larger drainage areas. For estimating runoff in drainage basins larger than 1 square mile, other methods detailed in EM 1110-2-1417 are appropriate.

K.5.3.5 $Q_{seepage,cfs}$ should be assumed to be zero for emergency flood barriers on very thick clay foundations and 0.005-0.01 cfs per linear foot of emergency flood barriers on pervious foundations.

K.5.3.6 Example Problem.

K.5.3.6.1 A municipal water well field is located adjacent to a ponding area behind a levee. It is vital to ensure that ponding water does not flow into the well field and potentially contaminate the water well field. How many 5,000 gpm capacity pumps should be used to ensure the ponding area behind a 1,000-ft long flood barrier is not overwhelmed? The contributing drainage basin is 1-square mile in Northwestern Missouri and is mostly agricultural. The expected seepage rate through the flood barrier is 0.01 cfs per linear foot. The designated ponding area is 3 acres with an average depth of 6-feet.

K.5.3.6.2 Example Answer. The design depth of a 6-hour rainfall during a 0.5 ACE storm is about 2.5-inches (Figure K-34). Runoff to the ponding area is estimated with the Rational Method (Equation K-2). The unitless coefficient of 0.3 is chosen from Table K-2. The design inflow to the ponding area due to rainfall is calculated as:

$$Q_{peak} = 0.3 \times \frac{2.5\ inches}{6\ hours} \times 1\ mile^2 \times \frac{640\ acres}{mile^2} = 80\ cfs$$

Equation K-1 is then applied to estimate the pump size:

$$Q_{pump,gpm} = 80\ cfs + \left(0.01\frac{cfs}{lf} \times 1{,}000\text{ft}\right) \times \frac{448.83\ gpm}{cfs} - \frac{(3\ \text{acres} \times 6\text{ft}) \times 5{,}431.21\frac{gpm}{\frac{ac-ft}{hour}}}{6\ hours}$$

The required pumping discharge, $Q_{pump} = 24{,}101$ gpm

The number of pumps needed is

$$\text{No. of pumps} = \frac{Q_{pump}}{\text{Capacity of 1 pump}} = \frac{24{,}101}{5{,}000} = 4.82\ pumps \rightarrow 5\ pumps\ needed\ for\ design$$

Table K-2
Typical C coefficients (for 5-year to 10-year Frequency Design) (from EM 1110-2-1417, Table 11-1).

DESCRIPTION OF AREA	RUNOFF COEFFICIENT
Business	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential	
Single-family areas	0.30 - 0.50
Multiunits, detached	0.40 - 0.60
Multiunits, attached	0.60 - 0.75
Residential (suburban)	0.25 - 0.40
Apartment Dwelling Areas	0.50 - 0.70
Industrial	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.35
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Streets	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95
Brick	0.70 - 0.85
Drives and walks	0.75 - 0.85
Roofs	0.75 - 0.95
Lawns, Sandy soil	
Flat, 2%	0.05 - 0.10
Average, 2-7%	0.10 - 0.15
Steep, 7%	0.15 - 0.20
Lawns, Heavy soil	
Flat, 2%	0.13 - 0.17
Average, 2-7%	0.18 - 0.22
Steep, 7%	0.25 - 0.35

(from Viessman et al. 1977)

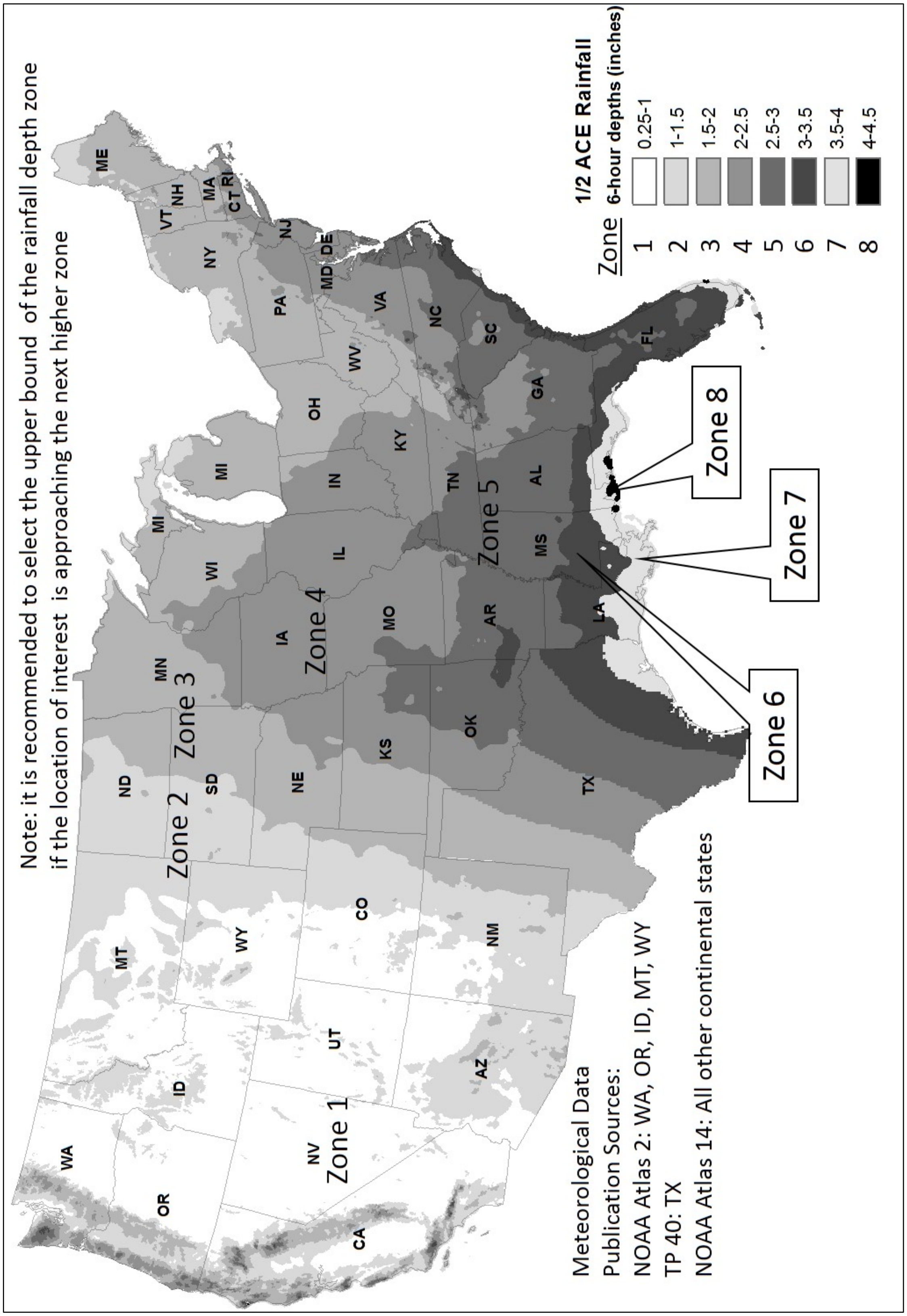


Figure K-34. Rainfall Depths During a 6-hour, 0.5 ACE Rainfall.

K.5.4 Local Flood Barriers. There are situations where it is not practical or feasible to construct an emergency flood barrier for large areas where there is no existing levee system, yet there may be critical or valuable infrastructure for which a flood barrier is desired. Nearly all the methods for constructing emergency flood barriers described in this appendix have been used to protect small areas or single structures. The same design and construction considerations apply for local flood barriers that apply to larger flood barriers.

K.6 Field Support.

K.6.1 Borrow Areas. The two prime requisites for a borrow area are that it has adequate material and the borrow accessible at all times. The quantity estimate plus an additional 50 percent should provide the basis for the area requirement. The area must be located so that it will not become isolated from the project by high water. The borrow area should also be located where the present water table if known, and the water table levels caused by high water, will not hinder or prevent its use. If possible, a borrow area should be selected that will provide suitable materials for construction. Local contractors and local officials are the best source of information on available borrow areas. If undeveloped, the area should be cleared of brush, trees, and debris, with topsoil and surface humus being stripped. In cold regions in early spring, it will probably be necessary to rip the area to remove frozen material. An effort should be made to borrow from the area in such a manner that the area will be relatively smooth and free-draining when the operation is complete.

K.6.2 Commercial Materials. During a flood fight it is possible that commercially purchased materials, such as rock and sand, may become necessary. Rock may be necessary to construct haul roads, stabilize levee slopes, construct stability berms, or armor scour areas. Sand is necessary to fill sand bags and can be used to create seepage berms or filtered exits. It is recommended practice to contact suppliers and producers of these commercial materials throughout the area of potential flooding in advance to know what materials could be available in emergency situations.

K.6.3 Haul Roads. A haul roads may be an existing road or street, or may have to be constructed. To mitigate damages it is highly desirable to use unpaved trails and roads, or to construct a road if the haul distance is short. In any case, the road should be maintained to avoid unnecessary traffic delays. If a haul road is constructed, the road should be wide enough for two way traffic to reduce the chances of collisions. The use of flaggers and warning signs is mandatory at major crossings such as highways, near schools, and at major pedestrian crossings. A borrow area, or source of sand for sandbags, should also be located promptly. This can become a critical item of supply in some areas due to long haul, project isolation, etc. It may become necessary to stockpile material near anticipated trouble areas.

K.6.4 Contracting. For construction of earthen flood barrier of any substantial length, or major flood fight operations involving large quantities of earth or rock fill, it is likely that a construction contract will be required. An emergency construction contract is very unique in that sole judgment as to the competence and capabilities of the contractor lies with field personnel. Close coordination with contracting staff is key to success. Field personnel must also be somewhat knowledgeable in construction operations. The initial contract is very important in that it delineates what equipment and procedures must be used and what materials are available for construction. During construction, if it becomes obvious that the equipment provided by the initial contract is inadequate to provide reasonably good construction or timely completion, a new or supplemental contract may be required. Procedures are the same as in the initial contract. Flexibility may be built into the original contract if it can be foreseen that additional pieces of equipment will ultimately be used. Some USACE districts maintain hired labor forces that may be used in some situations. Hired labor can offer significant flexibility in scope and schedule.

K.7 Data Collection.

K.7.1 Purpose. This section establishes the procedures for documenting levee performance during flood events. The purpose of data collection is to ensure that performance issues that occur during flood events are recorded accurately and timely. In addition, major levee system performance issues or levee system incidents causing inundation of the leveed area will follow event report procedures outlined in Chapter 13 of EC 1165-2-218 (Draft 2014 Nov 19), Incident and Evidence of Distress Reporting in Civil Works Structures. Levee performance observations during flood events are essential to identify inherent weaknesses of levees so remediation measures can be performed and to inform levee condition assessments such as levee inspections, levee risk assessments, levee screenings, and evaluation reports for the National Flood Insurance program (NFIP). Proper documentation will greatly assist future flood fight teams by providing them awareness of potentially poor performing areas of the levee system.

K.7.2 Composition and Qualifications of Data Collection Team. The Levee Safety Officer within the USACE district where the levee is located is responsible for ensuring that the required data is collected and documented as required herein. A licensed civil engineer with experience in levee design and remediation should lead the data collection team. Individuals collecting the data should be able to recognize conditions that may lead to levee failure and have knowledge of temporary and permanent remediation techniques.

K.7.3 Timing of Data Collection. Each segment of a levee system should have established criteria for data collection based on river gage readings or flood loading conditions. These criteria should be established by the Levee Safety Officer with input from the Levee Safety Program Manager, and other engineers within the district based on historical performance. Data collection should generally start in advance of river stages that historically produced performance issues. If no documentation exists for a levee segment, then the levee should be patrolled during loadings in excess of 25% of the levee height. It is important to have qualified personnel in the field before performance issues arise so it can be accurately determined when the levee started to show signs of distress.

K.7.4 Data Collection Procedures. Currently, no electronic data collection tools are adequate to perform the requirements listed. Existing tools such as MICA/Freeboard and the Levee Inspection System (LIS) are in use currently and could be modified to meet the criteria listed in Table K-3. Additionally, the National Levee Database (2007) (NLD) may also need to be amended in order to accommodate storage of the collected data. The tool or tools used for data collection should meet the following criteria:

- Has capability to collect the features and attributes identified in Table K-3
- Collects both line and point data
- Is an integrated tool that includes GPS/camera/video capability (ll photography, videos and notes data should be automatically referenced to the point or line data without transferring from a separate device)
- Has low cost (numerous units needed to support data collection)

- Is easy to carry (tablet or phone size)
- Can remotely connect to office using data network (wireless)
- Has user interface with dropdown menus to minimize typing
- Includes spell check feature
- Has ability to append data daily as features change
- Has capability for creating standardized reports

K.7.5 Performance Data Documentation. Although most levee deficiencies can be observed at any time during the year, some issues such as through-seepage and underseepage in levees and floodwalls, sand boils, overtopping observations, performance of closure structures, and culverts can be observed only during loading. The paragraphs outline all essential data and reports required during a flood.

K.7.6 Geospatial Data. Table K-3 lists essential features and attributes that should be collected during a flood event.

Table K-3
Features and Attributes to Collect During a Flood Event.

Feature Type	Feature Attribute	Description	Attribute in National Levee Database (NLD)?	Data supports Inspection Checklist items
All Features	Coordinate (Points or Lines)	Preferably automated during collection	Y	
	Date and time	Preferably automated during collection	Y	
	Name of person reporting	Preferably automated during collection	N	
	Photograph or video	Includes date stamp	N	
	Description	(Free Form) Other notes describing the feature	Y	
Sand Boils	Throat Size Description	(Standard Definitions - pin boil, Small, Medium Large)	N	4-1 & 5-1
	Activity Description	(Standard Definitions - Low Activity, Moderate Activity, High Activity, Very High Activity)	Y	
	Color of water	Clear, cloudy, muddy	Y	
	Contributing factors	Ditch at toe, culvert, blanket thickness, animal burrow, etc.	N	
	Remediation	Monitored, sand bag ring, barrel, water berm, temporary seepage berm	N	
Under-seepage	Quantity of seepage	Standard definitions - No seepage, Light, medium, heavy	N	4-1 & 5-1
	Contributing factors	Ditch at toe, culvert, blanket thickness, animal burrow, etc.	N	
Through-Seepage	Quantity of seepage	Standard definitions - No seepage, Light, medium, heavy	N	4-1 & 5-1
	Contributing factors	Ditch at toe, culvert, blanket thickness, animal burrow, etc.	N	

Feature Type	Feature Attribute	Description	Attribute in National Levee Database (NLD)?	Data supports Inspection Checklist items
Erosion (Rehab Line in NLD)	Severity	Standard definitions - ___	N	4-3 & 5-6
	Contributing factors	poor sod cover, high winds, concentrated flows, high velocity	N	
	Remediation	plastic sheeting, rock, stopping pumps, control of flows	Y/N	
Overtop-ping	Time of overtopping	Time and date that water started flowing over the top of the levee embankment	N	
	Depth of overtopping	Maximum depth of water flowing over the levee (above existing levee grade without erosion)	N	
	Time of breach	Time that the overtopping resulted in a rupture, break, or gap	Y	
	Breach width (After 15 min)	Approximate width of breach as observed 15 minutes after breach started	N	
	Breach width (After 30 min)	Approximate width of breach as observed 30 minutes after breach started	N	
	Breach width (After 1 hour)	Approximate width of breach as observed 1 hour after breach started	N	
	Breach width (After 2 hours)	Approximate width of breach as observed 2 hours after breach started	N	
	Breach width (After 4 hours)	Approximate width of breach as observed 4 hours after breach started	N	
	Breach width (After 8 hours)	Approximate width of breach as observed 8 hours after breach started	N	
	Breach width (After 24 hours)	Approximate width of breach as observed 24 hours after breach started	N	
	Remediation efforts	Levee cuts, levee raise, material used to stop breach	N	
Slides (Rehab Line in NLD)	Slide length	Measured by widest extent parallel to levee (ft)	Y/N	4-2
	Slide height	Approximate location of slide on slope	Y/N	
Flood-walls	Movement	Measurement of movement due to tilting, sliding or settlement during loading	N	5-2 & 5-7
	Waterstops	Description of flow and height of waterstop failure	N	
	Contributing factors		N	
Closures	Type	Stop log, swing gate, sliding gate, sand bag	Y	4-7, 7-2 & 7-3
	Date & time closure started	Start time for closure installation	N	
	Date & time closure complete	Finish time for closure installation	N	
	Operational issues	Missing parts during installation, broken components during operation, temporary fixes	N	
	Performance issues	Leaking stoplogs, leaking seals, misalignment	N	

Feature Type	Feature Attribute	Description	Attribute in National Levee Database (NLD)?	Data supports Inspection Checklist items
Gravity Drain	Effectiveness of closure	Indicate quantity of water leaking through gate	N	6-1 & 6-2
Gates	Quantity of seepage	Standard definitions - Light, medium, heavy seepage around pipe	N	
	Leakage	Estimate flow through culvert due to leakage	N	

K.7.7 Flood Summary Report. A report shall be prepared that summarizes the overall levee performance during the flood event. The report should include the following elements:

- River hydrograph with stage readings and frequencies
- Written observations of performance by levee station along with GPS coordinates where applicable
- Photographs of all major performance issues
- Maps showing all points collected
- Instrumentation readings
- Final breach dimensions if applicable
- Estimated number of houses/businesses flooded if applicable
- Estimated area and depth of inundation if applicable
- Any information regarding evacuation procedures

K.7.8 Reviews Approval and Distribution. A District quality control (DQC) review shall be performed on the data and Flood Summary Report prior to incorporation into the NLD. The review should be performed by a qualified team not involved in the data collection or report preparation. The purpose of the review is to confirm that the information provided is thorough enough to be used in subsequent levee inspections and assessments. The DQC review team will provide a summary of all comments and a signed report of the review completed. The Levee Safety Officer shall approve the flood summary report. Upon approval of the flood summary report, an electronic copy of the report will be posted in the NLD with report copies sent to the project sponsor and the USACE Major Subordinate Command.

K.7.9 Records Management. The NLD will be the repository for all performance data collected during flood events. All point and line performance data should be imported into the NLD Levee Inspection Tool prior to annual and periodic inspections.

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