

May 2019

# Clark Fork River Berm Surveillance & Contingency Plan

Former Smurfit-Stone/Frenchtown Mill
14755 Pulp Mill Road
Missoula County, Montana

*Prepared for:*
**M2Green Redevelopment, LLC**
**12 Willow Way**
**Alton, IL 62002**

**WestRock CP, LLC**
**P.O. Box 4098**
**Norcross, GA 30097**

**International Paper Company**
**6400 Poplar Avenue**
**Memphis, TN 38197**

NewFields

*Prepared by:*
**NewFields**
**700 SW Higgins Avenue, Suite 15**
**Missoula, Montana**

**DRAFT**

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# SURVEILLANCE AND CONTINGENCY PLAN

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NewFields

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| | |
|---|---|
| amsl | Above Mean Sea Level |
| AOC | Administrative Order on Consent |
| bgs | Below Ground Surface |
| BFE | Base Flood Elevation |
| CFR | Clark Fork River |
| DNRC | Montana Department of Natural Resources and Conservation |
| EPA | U.S. Environmental Protection Agency |
| FEMA | Federal Emergency Management Agency |
| FIRM | Flood Insurance Rate Map |
| HP | Holding Pond |
| H:V | horizontal:vertical |
| OU | Operable Unit |
| NFIP | National Flood Insurance Program |
| PRP | Potentially Responsible Party |
| RI/FS | Remedial Investigation/Feasibility Study |
| RIWP | Remedial Investigation Work Plan |
| STA | Station |
| USACE | U.S. Army Corps of Engineers |
| USGS | U.S. Geological Survey |

# 1.0 INTRODUCTION

## 1.1 Purpose

This Clark Fork River Berm Surveillance and Contingency Plan ("SCP" or the "Plan") proposes monitoring and potential response actions associated with the Clark Fork River (CFR) Berm at the Smurfit-Stone/Frenchtown Mill (hereafter referenced as the "Property"; **Figures 1** and **2**). The SCP identifies a plan for specific monitoring of the berm during CFR high flow events and identifies the actions that would be taken consistent with good engineering practices when issues are identified by the monitoring.

The primary objectives of this Plan include:

- Outlining procedures for monitoring and documenting CFR Berm stability during CFR high flow events;
- Promoting timely and efficient response to issues identified by the monitoring CFR Berm stability concerns; and;
- Effective communication with regulatory agencies, other stakeholders, and response teams during surveillance and response actions.

## 1.2 Limitations

The Plan was prepared in accordance with good engineering practices for levee surveillance and flood emergency action plan guidance, including:

- Monitoring Levees by the United States Society on Dams (USSD, 2016; included in **Appendix A**);
- The International Levee Handbook by the Construction Industry Research and Information Association (CIRIA, 2018; Chapter 6 included in **Appendix B**);
- The United States Army Corps of Engineers' (USACE) Policy Guidance Letter, Periodic Inspections Procedures for the Levee Safety Program, issued in 2008;
- The USACE Emergency Action Plan Guidebook, issued in 2015;
- The United States Department of Homeland Security's (USDHS) Emergency Preparedness Guidelines for Levees, A Guide for Owners and Operators, issued in 2012; and
- EPA's Interim Contingency Plan for the Smurfit Stone Mill Property, Prepared by the Emergency Response Unit, dated May 31, 2018.

This plan will be re-evaluated for content and applicability at the time of remedy selection.

# 2.0 BACKGROUND

## 2.1 Location and Setting

The Property is located approximately 11 miles northwest of Missoula, Montana and about three miles southeast of Frenchtown, Montana within the northwestern portion of the Missoula Valley (**Figure 1**). The street address of the Property is 14377 Pulp Mill Road, Missoula, Montana.

The Property (including three Operable Units; OUs) encompasses 3,150 acres. The CFR flows in a northerly direction along the Property's western property boundary. **Figure 2** depicts the Property's boundary, the location of the former Mill and wastewater treatment systems, the CFR, and the CFR Berm which is the focus of this plan.

## 2.2 Ownership and Regulatory Framework

The Property is currently owned and managed by M2Green Redevelopment LLC (M2Green). M2Green is a PRP for the investigation and cleanup of the Property. In addition, WestRock CP, LLC and International Paper Company are PRPs. These three PRPs have executed an Administrative Order on Consent (AOC) to perform a CERCLA Remedial Investigation under the oversight of the EPA. EPA requested the PRPs develop this Plan due to expressed concerns about the stability of the CFR Berm during high flow conditions.

## 2.3 Hydrology

The CFR is the largest river in Montana by volume; the upper CFR watershed has a drainage area upstream of the Property of approximately 9,000 square miles (FEMA, 1988). Flows in the CFR are dominated by snowmelt and precipitation, with seasonal high flows occurring during spring/early summer.

With the exception of a few areas as shown on **Figure 2**, the CFR forms the western boundary of the Property, flowing about 3.5 miles from south to north along the western boundary of the Property. A portion of the Property, including ponds that once held treated wastewater prior to discharge to the CFR, is located within the 100-year floodplain (**Figure 2**). The Flood Insurance Rate Map (NFIP, 2015) was updated by FEMA and adopted by Missoula County on July 6, 2015. The FEMA Floodplain Map is provided in **Appendix C**. The CFR Base Flood Elevations (BFEs), or modeled water surface elevations representative of a 100-year recurrence interval flood event, range between elevation 3,054 feet (upstream) and 3,037 feet (downstream) across the length of the Property, as shown in **Appendix C**.

# 3.0 BERM DESCRIPTION

There are numerous berms on the Property, initially constructed to manage waste and wastewaters during Mill operations. Two of these berms form continuous physical barriers to flooding events: the "CFR Berm" and the "Inner Berm" shown on **Figure 2**. The CFR Berm is a continuous earthen structure adjacent to the river. The Inner Berm forms a continuous earthen barrier between buried waste materials and the CFR and the 100-year floodplain to the west nearest the river. The surveillance/management of the Inner Berm is not addressed in this plan as recent flood evaluations indicate the CFR Berm would not be overtopped at CFR 100-year flows (NewFields 2018b). This Plan specifically addresses surveillance and contingency actions for the CFR Berm.

## 3.1 Clark Fork River Berm

The CFR Berm is an earthen berm located along the western edge of the Property (**Figure 2**). The CFR Berm is the longest berm on the property with a total length of approximately 23,443 feet (4.4 miles). The berm was constructed as a man-made barrier to contain treated wastewater . The CFR Berm begins at the southeast corner of holding pond HP1a (STA 0+00), extends westerly approximately 1,200 feet, then turns north (STA 12+00) and parallels the CFR for about 2.7 miles (STA 154+00) at which point it turns east and north until it terminates at an access road (STA 234+43).

The cross sectional dimensions and elevations vary along the length of the CFR Berm (NewFields, 2018b). In general, the berm ranges in height between 8 and 15 feet above the surrounding ground surface with a crest width between 15 and 25 feet on average. The riverside and landside slopes are generally inclined between 1.6:1 (horizontal:vertical; H:V) and 2.5:1, and vary along the entire length.

In 2010, representatives of the Montana Department of Natural Resources and Conservation (DNRC) visited the CFR Berm and stated that "the earthen embankments surrounding the reservoirs [ponds] are constructed of homogeneous materials that have been excavated from the interior floor portions of the reservoirs [ponds]" (DNRC, 2010). Field studies conducted by NewFields (2018b) of the CFR Berm support the DNRC's statement that the berm was constructed using native material. The berm is primarily underlain by alluvial sands and gravels; and a finer-grained layer at some locations.

## 3.2 Outfalls

Three outfalls, labeled as Outfall 1, 2, and 3 (Figure 2), were historically used to control permitted discharge of holding pond water to the CFR. Based on our review of available historical documentation, no as-built drawings for these outfall structures are available.

### 3.3 2018 Flood Event

The CFR experienced a 30-year flood event (NewFields, 2018a) during May and June 2018, as measured at U.S. Geological Survey (USGS) gauge station 12353000 located approximately seven miles upstream of the Property. Gauge station 12353000 recorded a stage measurement greater than 11.0 feet (flood stage) for approximately 5½ days during May and June 2018. The high water event of 2018 resulted in localized berm reinforcement to address potential stability issues. Boils were discovered in holding ponds HP-2 and HP-13a (**Figure 2**), and berm reinforcement activities were completed in holding pond HP-13a to address boils that appeared to be discharging sediment. There was no evidence that boils found in HP-2 were discharging sediment; therefore, berm reinforcement was not required in that location. More details about reinforcement of the CFR berm are documented in the Clark Fork River Berm Assessment and Reinforcement Report (NewFields, 2018a).

# 4.0 FACTORS AFFECTING BERM PERFORMANCE

## 4.1 Potential Berm Failure Modes

Potential berm failure modes can be grouped into three main categories:

- **External erosion**: failure resulting from berm undercutting or overtopping (including surface erosion, potentially leading to a breach);
- **Internal erosion**: failure resulting from under-seepage through the berm (including related subsurface erosion through either the berm foundation materials or placed embankment resulting in an erosional breach; and
- **Instability**: failure resulting from instability (including localized failures, or the development of tension cracks or other features that could alter berm topographic or hydrologic conditions and contribute to seepage or destabilization).

The occurrence of any of these potential failure modes can increase the risk of berm failure. Berm failure is often the result of a progression of compounding factors. A more detailed discussion of overtopping and stability-related risks for the CFR Berm is included below. Additional information about potential berm failure modes can be found in *Monitoring Levees* (USSD, 2016; **Appendix A**) as well as in the other references listed at the end of this document.

## 4.2 Overtopping Evaluation

In 2018, the PRPs completed an overtopping analysis of the CFR Berm. The analysis involved a comparison of LiDAR-surveyed CFR Berm crest elevations and CFR BFEs. The comparison along the entire length of the CFR Berm showed that at the CFR Berm's lowest point the available freeboard (vertical distance between BFE elevation and top of berm elevation) is at least four feet (approx. STA 76+00), as shown on **Figure 3.** Therefore, the study showed that the CFR Berm will not be overtopped during a 100-year flood event (NewFields, 2018b).

## 4.3 Berm Stability Evaluation

The PRPs also recently completed a geotechnical stability evaluation of the CFR Berm and a visual reconnaissance survey (NewFields, 2018b). The study found under high water conditions, similar to those seen in 2018, that there is a potential at some locations on the berm for under-seepage to occur, and that under-seepage has the potential to increase the instability of the berm via erosion of materials below the berm.

# 5.0 VISUAL BERM SURVEILLANCE PLAN

This section describes a visual surveillance program for the CFR Berm during high water events on the CFR.

## 5.1 POND AND RIVER GAUGES

As shown on **Figure 2**, graduated staff gauges will be installed in holding ponds and along the CFR to allow for a determination of approximate groundwater flow beneath the CFR Berm.

## 5.2 MONTHLY INSPECTIONS

Inspections of the entire length of CFR Berm will be performed in April of each year. Subsequent monthly inspections will occur at a frequency of one per month in May, June and July. The inspections will be conducted as described in **Section 5.5**. The results of all inspections will be documented as described in **Section 5.7.** Any necessary staff gauge installations or maintenance will be conducted during these inspections. The May, June, or July inspection may qualify as the Post-Event inspection described in **Section 5.6** depending on the timing of peak flow.

## 5.3 WEEKLY INSPECTIONS

Detailed weekly inspections will begin whenever the stage on the Clark Fork River below Missoula as determined by NOAA Gauge Station BELM8 (same as USGS Gauge Station 12353000) exceeds 10.5 feet for any part of that week. Detailed weekly inspections of the Inner Berm will be performed and recorded whenever the stage on the Clark Fork River below Missoula exceeds 12.5 feet for any part of that week as determined by NOAA Gage Station BELM8 (same as USGS Gauge Station 12353000). The results of all inspections, including any trends or changes noted over the course of the previous week, will be documented as described in **Section 5.7**.

## 5.4 DAILY INSPECTIONS

Daily inspections of the entire length of the CFR berm will be performed during each day that the NOAA Gage Station on the Clark Fork River below Missoula, Montana (BELM8) exceeds 11 feet (flood stage) for any part of that day. The results of all Daily Inspections will be documented as described in **Section 5.7.**

## 5.5 INSPECTION PROTOCOL

During high-water inspections, inspectors will complete and document the following:

- Survey the entire CFR Berm, paying particular attention to those areas which EPA has identified as Special Attention Areas. In 2018, EPA identified two Special Attention

Areas on the CFR Berm based on high water observations in 2018: one in the vicinity of narrow surface cracks on the CFR Berm adjacent to former holding pond (HP2) south of Outfall 1 (*HP2 Special Attention Area*; **Figure 2**), and one at the repaired boil area of former holding pond HP13A near Outfall 3 (*HP13 Special Attention Area*; **Figure 2**).

- Inspect critical areas of the CFR Berm as identified by the Geotechnical Stability Evaluation (NewFields, 2018b). These include areas near Stations 30+00, 76+00, 147+00 and 177+00.
- Record elevations of all river and pond staff gauges (**Figure 2)**.
- Boils or unusual hydraulic dynamics will be investigated in holding pond HP2 and HP13A, and for any portion of the Berm where river water is located within 50 feet of the riverside toe of the berm. ". Inspectors will look for evidence of seepage through the berm and for boils in ponds. If a boil is found, the inspector will determine if sediment appears to be discharging from the boil.
- Subsidence will be investigated, including low points, sinkholes/depressions, or other visible changes to the topography of the berm along the entire Berm.
- Joints or cracks, erosion, undermining, and scouring will be inspected along the entire Berm.
- Local sliding or sloughing of the berm materials, scarps, longitudinal cracking at the levee crest, and or bulging at the berm toes will be inspected along the entire Berm.
- Significant changes in color of river water or water in the ponds will be evaluated.
- Any and all other concerns that could impact the stability of the berm will be inspected for (including, but not limited to) unusual rodent or animal impacts, vehicular activity, and/or changes in vegetation or debris in the river.
- Photographs will be taken of any stability concern, all river and pond water elevations (at locations of gauges), and routine locations along the berm to help evaluate changes over time.

## 5.6 Post-Event Inspections

Within two weeks of the annual high water events, the CFR berm will be inspected to document conditions along the berm, as described in **Section 5.5**.

## 5.7 Inspection Documentation

All observations made during berm inspections will be recorded on inspection forms (**Appendix D**).

# 6.0 CFR BERM MANAGEMENT AND PREPAREDNESS

This section of the Plan identifies resources and procedures to mitigate and address a berm condition identified during any inspection. The PRPs' contractor or consultant will implement this Plan.

## 6.1 PRE-EVENT MONITORING

The potential for flood events that may impact the berm will be evaluated leading up to the CFR high water condition. Snow pack within the CFR watershed, USGS CFR gauge elevations, and meteorological conditions and forecasts will be monitored in anticipation of CFR high water flows. When such conditions indicate a potential for CFR high-water conditions, the inspections described in **Section 5.0** will be performed and the response personnel discussed in this section will be alerted in preparation for potential response measures that may be required.

## 6.2 RESPONSE ACTIONS TO IMPROVE BERM STABILITY

**Table 6-1** identifies potential berm stability issues that may arise during high water conditions and several actions that can be implemented to preserve the current stability and function of the CFR Berm. These mitigation measures are described in more detail in the *International Levee Handbook* (CIRIA, 2013; **Appendix B)**. Note that each intervention category or measure references a section of the Levee Handbook in which the recommended construction details, advantages, and disadvantages are discussed in more detail. The specific action taken at the Property would be dependent on Property conditions and based on consultation with the EPA and USACE.

The primary goal of any response action to address identified berm conditions will be to preserve the stability of the CFR Berm. Therefore, actions will be immediately taken when results of visual berm surveillance suggest potential stability issues with the CFR Berm. In order to initiate and execute response procedures in a timely manner, contact information for relevant parties must be readily accessible and pre-established communication procedures must be adhered to. The proper channels for communications and notifications are discussed in **Section 6.4**.

**Table 6-1. Response Intervention Techniques**

| Potential Stability or Flooding Issue | Applicable Intervention | Potential Mitigation Measures |
|---|---|---|
| Berm Overtopping | Raise the berm (Section 6.6.1) | Place and compact bulk fill material (Section 6.6.1.1) |
| | | Construct sandbag levee (Section 6.6.1.2) |
| | | Use novel material: lightweight concrete block, straw bales, tire bales (Section 6.6.1.3) |
| | | Drive piling (Section 6.6.1.4) |
| | | Construct a flashboard structure (Section 6.6.1.5) |
| | | Portable cofferdam structure (Section 6.6.1.10) |
| | | Portable dam system (Section 6.10) |
| | | Water inflated barrier (Section 6.10) |
| | | Water filled tubes (Section 6.10) |
| | | Open celled plastic grid wall (Section 6.10) |
| | | Filled permeable container (Section 6.10) |
| | | Demountable barriers (Section 6.10) |
| | Protect against overflowing/overtopping erosion (Section 6.6.3) | Construct an emergency spillway (Section 6.6.3.2) |
| External Erosion | Reduce Potential for Erosion (Section 6.6.2) | Construct rock/rip-rap berm (Section 6.6.2.1) |
| Internal erosion Via Seepage through or below Berm | Reduce infiltration to reduce through-seepage (Section 6.7.1) | Place plastic sheeting on the water side of berm (Section 6.7.1.1) |
| | Increase seepage path to reduce through-seepage (Section 6.7.2) | Expand berm on landside (Section 6.7.2.1) |
| | Reduce hydraulic gradient to reduce under-seepage (Section 6.7.3) | Ringing sand boils (Section 6.7.3.1) |
| | | Increase landside water level (Section 6.7.3.2) |
| Berm Instability | Reduce slope inclination and steepness (Section 6.8.1) | Reduce slopes to at least 1V:3H |
| | Reduce pressure underneath levee (Section 6.8.2) | Place landside berm |
| | Reduce saturation of levee (Section 6.8.3) | Lower groundwater levels below berm |

Note: The various document sections referenced in Table 6-1 are from CIRIA (2013).

## 6.3 Response Actions Should CFR Berm Breach

The potential for breaching or overtopping of the CFR Berm is low. The study completed by NewFields (2018b) showed that during a 100-year flood event there is an estimated minimum four feet of free board along the entire length of CFR Berm. In the event of a breaching or overtopping of the CFR Berm, the following actions would be taken:

1. EPA would be contacted immediately to inform and advise them of corrective measures being implemented. There is an estimated 800 acres of floodplain storage on the Property, lending to the potential altering of water movement in the floodplain ponds to control erosion.

2. If it could be done safely, actions would be taken to repair the CFR Berm breach or overtopping utilizing options identified in **Table 6.1**.

3. Daily monitoring (refer to **Section 5.4**) of the Inner Berm would commence to evaluate the potential erosion of the Inner Berm. To ensure that the stability of the Inner Berm is maintained and waste materials located behind the Inner Berm and outside of the 100-year floodplain are not released, the Inner Berm, where inundated with flood waters (**Figure 2**), would be inspected daily to identify erosion concerns.

4. Should a length of the Inner Berm show signs of erosion, rip-rap would be installed immediately to control the erosional forces on the inner berm at the point of concern.

5. Samples of flood waters on the site between the CFR and Inner Berms, and at the outflow back into the floodway of the river would be collected and analyzed for metals and dioxins/furans to evaluate whether contaminants may have been mobilized during a breach event. Sampling would be in accordance with the RIWP.

## 6.4 Notifications & Communications

Official notifications will be made by NewFields' berm inspector as shown in **Table 6-2,** dependent on the nature of identified berm condition or concern. There are three classes of notifications proposed: Level 1, Level 2 and Level 3, as described below.

- **Level 1 notifications** will be made after each berm inspection where no berm conditions implicating stability issues are identified. Level 1 notifications shall include an emailed report within 1 business day after completion of the inspection to the Agencies identified in **Table 6-2**.
- **Level 2 notifications** will be made when berm inspections identify a new condition that may be related to a stability concern, but such concern doesn't warrant an immediate

response action. Concerns that fit into this category include, but are not limited to, the rise of CFR up to the riverside toe of the CFR Berm, identification of debris in the river that may increase erosion of the CFR Berm, and identification of a boil flowing clear/clean water. Level 2 notifications shall include an immediate phone call to Allie Archer, or current RPM at EPA and Keith Large, or current coordinator for the Montana Department of Environmental Quality, and an emailed report within 12 hours after completion of the inspection to the others listed in **Table 6-2**.

- **Level 3 Notifications** shall be made when an identified condition raises a concern for imminent failure of the berm or when a berm failure actually occurred. Concerns that fit into this category outside of a berm failure include seepage of water through the berm, identification of a boil that is mobilizing sediment, visual identification of suspended sediment in a pond located adjacent to the CFR, visual identification of tannin-colored water seeping from the berm into the river, or any other observation where imminent potential failure is a concern. Level 3 Notifications shall be made immediately by phone and followed by an email to those individuals shown in **Table 6-2**.

**Table 6-2. Response Notification Matrix**

| Level I | Level II | Level III | Organization | Contact | Contact Information |
|---|---|---|---|---|---|
| X | X | X | Project Coordinator | David Tooke | 406-240-8360<br>dtooke@newfields.com |
| X | X | X | M2Green | Ray Stillwell | 618-910-2590<br>rstillwell@greeninvgroup.com |
| X | X | X | International Paper | Brent Sasser | 901-413-6890<br>Brent.Sasser@ipaper.com |
| X | X | X | WestRock CP, LLC | Steve Hamilton | 404-307-2865<br>steve.hamilton@westrock.com |
| X | X | X | USEPA | Allie Archer | 620-755-9388<br>Archer.Allie@epa.gov |
| X | X | X | Missoula County | Travis Ross | 406-543-3873<br>tross@missoulacounty.us |
| X | X | X | Montana DEQ | Keith Large | 406-444-6569<br>klarge@mt.gov |
| | | X | Missoula County EOC | Duty Officer | 911<br>406-830-0974 |
| | | X | USEPA EOC | Duty Officer | 303-312-6510 |
| | | X | Dick Lucier Excavating | Dick Lucier | 406-550-0855<br>lucierexcavating@gmail.com |

| | | | | | |
|---|---|---|---|---|---|
| | | X | Western Excavating | Riley Mytty | 406-728-1400<br>rmytty@westernexcavating.com |

## 6.5 ON-CALL CONTRACTORS

Contracts have been executed with two local earthwork contractors (Lucier Excavation and Western Excavating, Inc.) that can respond within hours to any stability concern. Contact information for these two firms is included in **Table 6-2**, and subcontract agreements with these contractors are included in **Appendix E**. On-call contractors can provide the following equipment (along with the necessary personnel for implementation):

- Heavy equipment (bulldozers, excavators, loaders, dump trucks compactors, etc.);
- Sandbags (including filling equipment and supplies);
- Borrow material;
- Riprap (for erosion issues);
- Pumps; and
- Emergency lighting.

## 6.6 APPROVED ONSITE BORROW MATERIAL

During emergency actions taken in 2018, the EPA and the USACE approved of an on-site borrow source as shown in **Figure 2** (NewFields, 2018a). Should a sandy gravel material be needed to address a berm stability concern, materials will be exhumed from this area and used.

# 7.0 REFERENCES

**Construction Industry Research and Information Association (CIRIA), 2013.** The International Levee Handbook. Joint research project of [CIRIA] (UK), French Ministry of Ecology (France), and the United States Army Corps of Engineers [USACE] (USA). ISBN-13: 978-0-86017-734-0. CIRIA C731, RP957; 1,343 pages. 26 November.

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**National Flood Insurance Program (NFIP), 2015.** Flood Insurance Rate Map, Missoula County, Montana and Incorporated Areas, Panel 1155E, Map Number 30063C1155E, Federal Emergency Management Agency (FEMA), Map Revised July 6, 2015.

**NewFields, 2015.** Remedial Investigation Work Plan, Smurfit Stone/Frenchtown Mill, Missoula County, Montana. Prepared for International Paper Company, M2Green Redevelopment, LLC, and WestRock CP, LLC. Missoula, MT.

**NewFields, 2018a.** Clark Fork River Berm Assessment and Reinforcement Report, Smurfit-Stone/Frenchtown Mill Site, Missoula County, Montana. Version 2. December 11 – Version 2.

**NewFields, 2018b.** Geotechnical Stability Evaluation of the Clark Fork River Berm, Former Smurfit-Stone/Frenchtown Mill, 14755 Pulp Mill Road, Missoula County, Montana. 28 November.

**United States Environmental Protection Agency (USEPA), 2018.** Interim Contingency Plan, Smurfit Stone Mill Site. Prepared by the Emergency Response Unit. May 31.

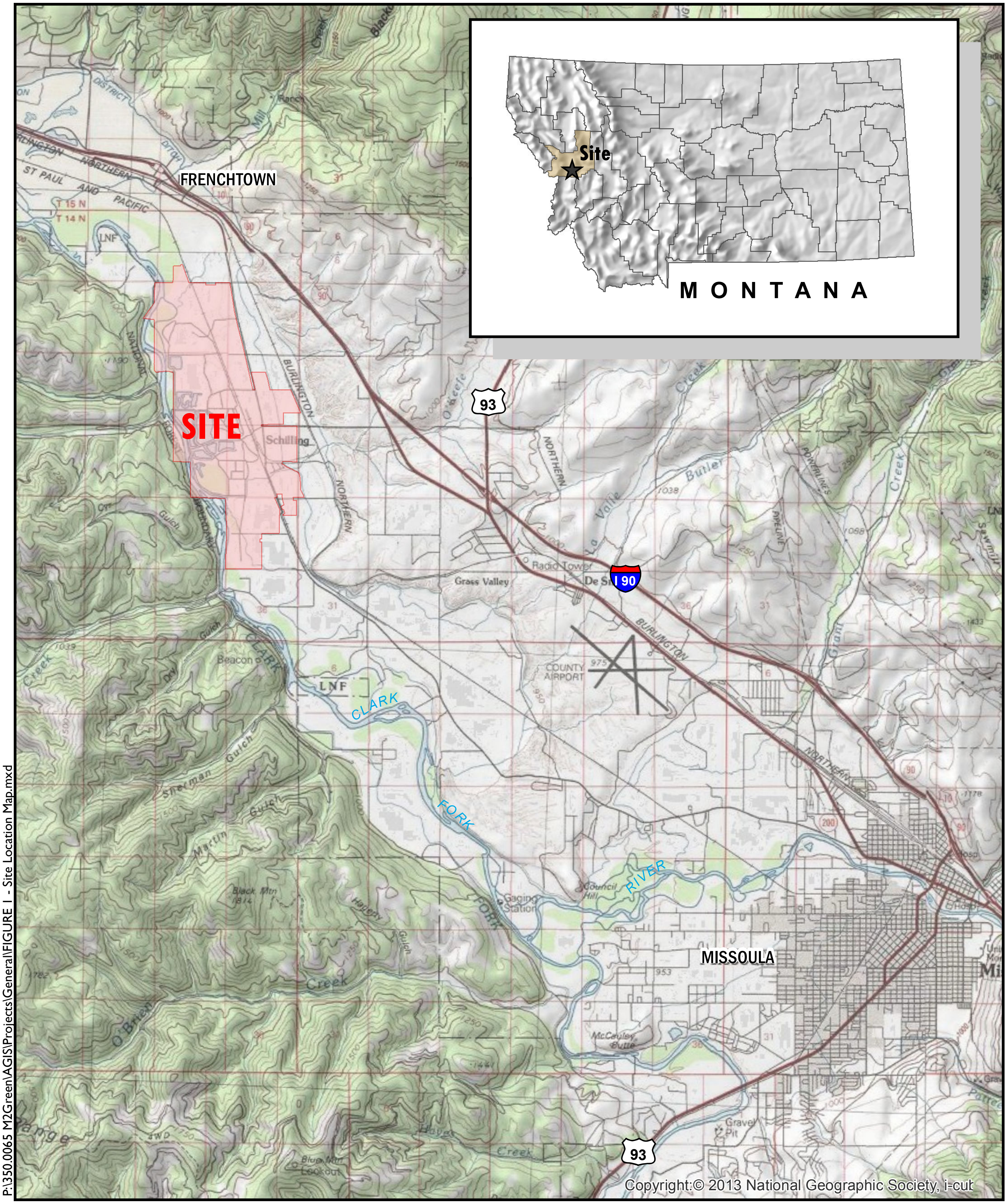
**United States Army Corps of Engineers (USACE), 2008.** Policy Guidance Letter, Periodic Inspections Procedures for the Levee Safety Program. December 17.

**United States Army Corps of Engineers (USACE), 2015.** Emergency Action Plan Guidebook. Version 1.1. January.

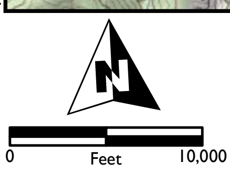
**United States Department of Homeland Security (USDHS), 2012.** Emergency Preparedness Guidelines for Levees, A Guide for Owners and Operators. January.

**United States Society on Dams (USSD), 2016.** Monitoring Levees. May. ISBN 978-1-884575.

# Figures




P:\350.0065 M2Green\AGIS\Projects\General\FIGURE 1 - Site Location Map.mxd

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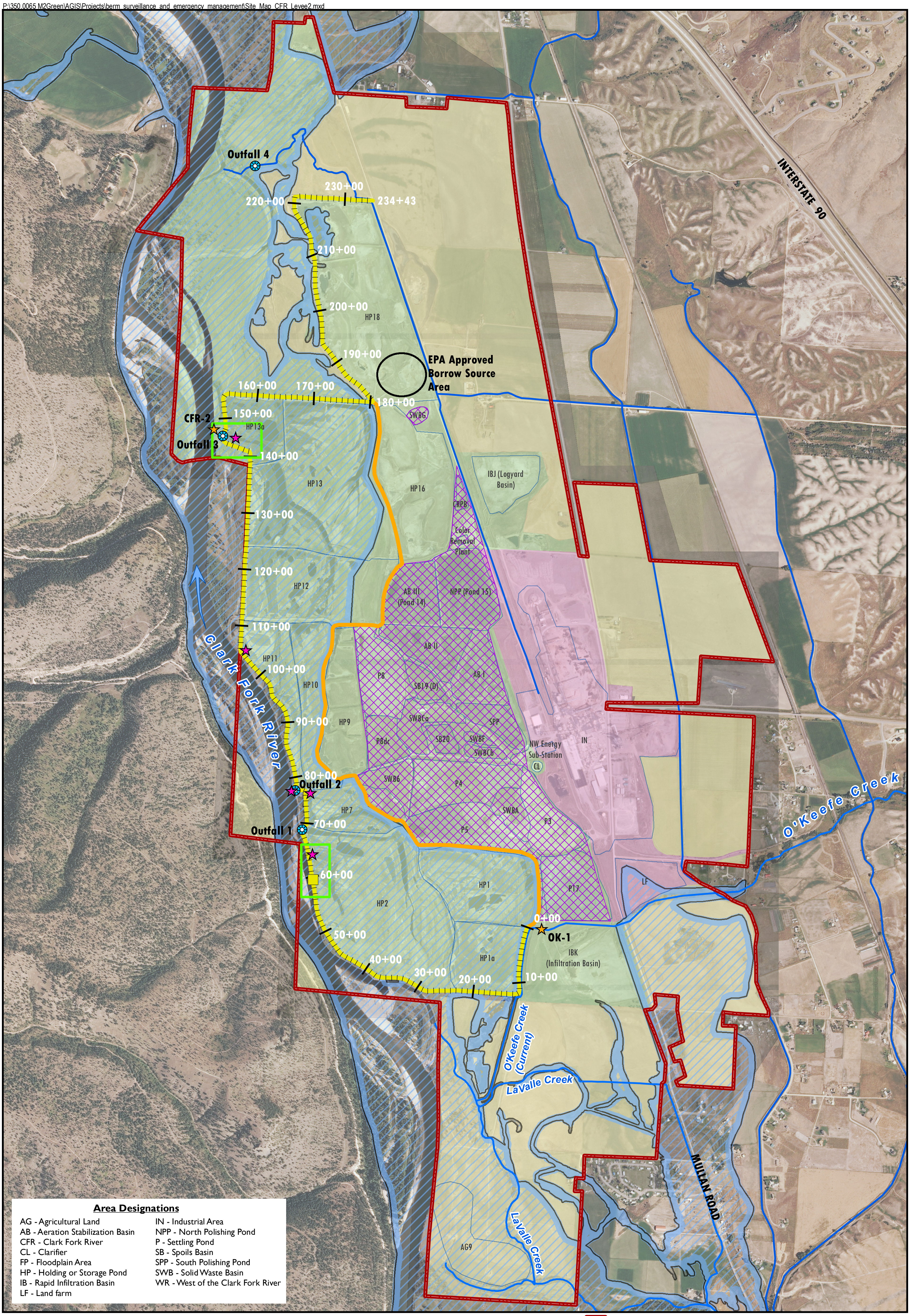
Location Map
Former Smurfit-Stone/Frenchtown Mill Site
Missoula County, Montana
FIGURE 1

P:\350.0065 M2Green\AGIS\Projects\berm_surveillance_and_emergency_management\Site_Map_CFR_Levee2.mxd




0 Feet 2,000

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*Floodplain Source: As defined by the Federal Emergency Management Agency (FEMA) 2013 Digital Flood Insurance Rate Map (DFIRM). (NFIP, 2015)

**Derived From 1937, 1940, and 1955 Aerial Imagery

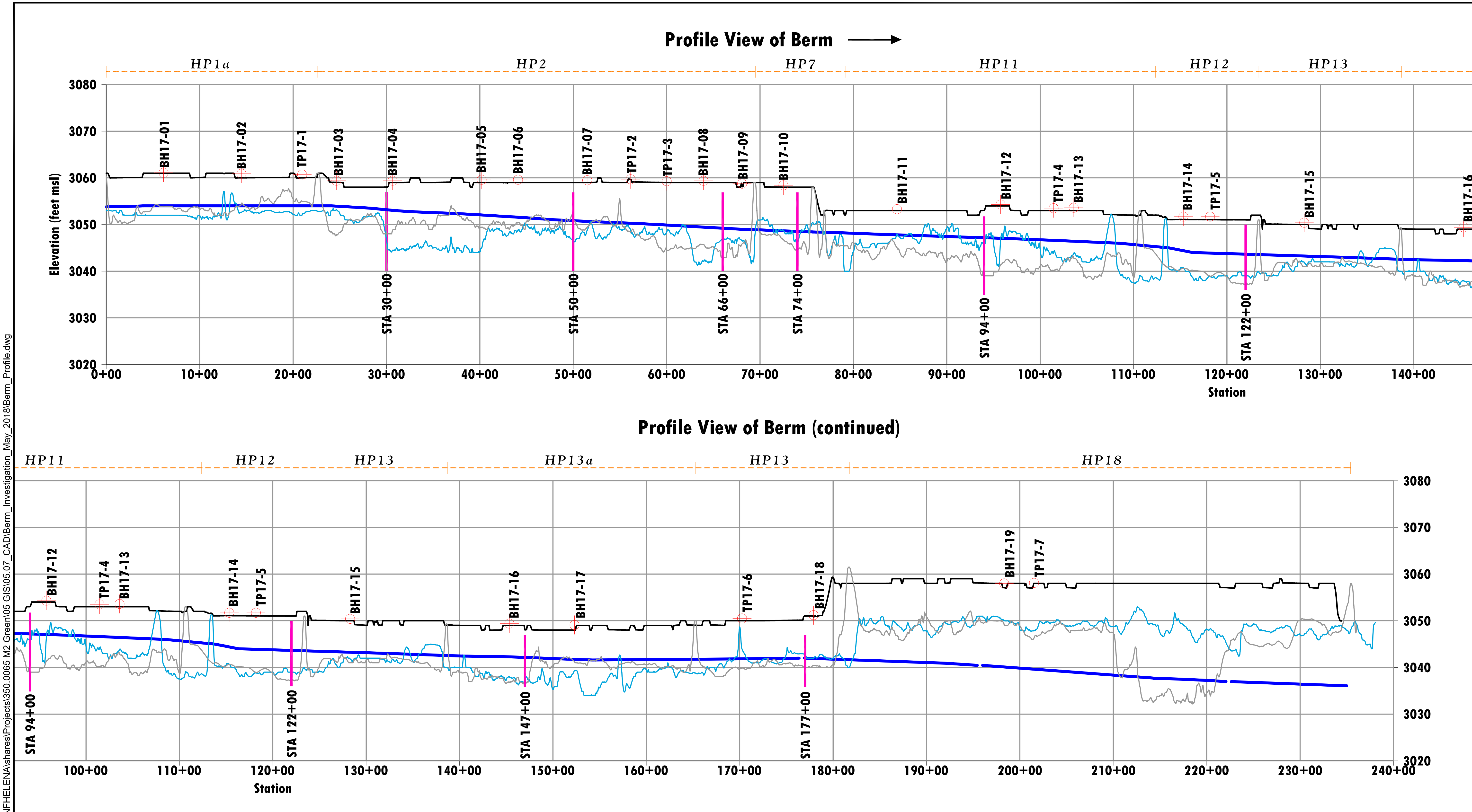
Aerial Photo Source: NAIP 2011 and NewFields 2016 (Within Site Boundary)

- Existing Staff Gage
- Proposed Staff Gauge
- Historic Tension Cracks
- Special Attention Areas
- Approximate Outfall Location
- 10+00 CFR Berm With 1,000-foot Stationing (100 foot intervals)
- Inner Berm
- Area of Waste Materials
- Ditch
- 100-Year Floodplain*
- Mill Site Boundary

**Operable Units (OU)**

- OU1 - Agricultural Lands
- OU2 - Industrial Area
- OU3 - Wastewater Treatment and Storage Areas

**Site Plan**
**Former Smurfit Stone/Frenchtown Mill**
**Missoula County, Montana**
**FIGURE 2**




Vertical Exaggeration 50x

0 Feet 1000

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Notes:

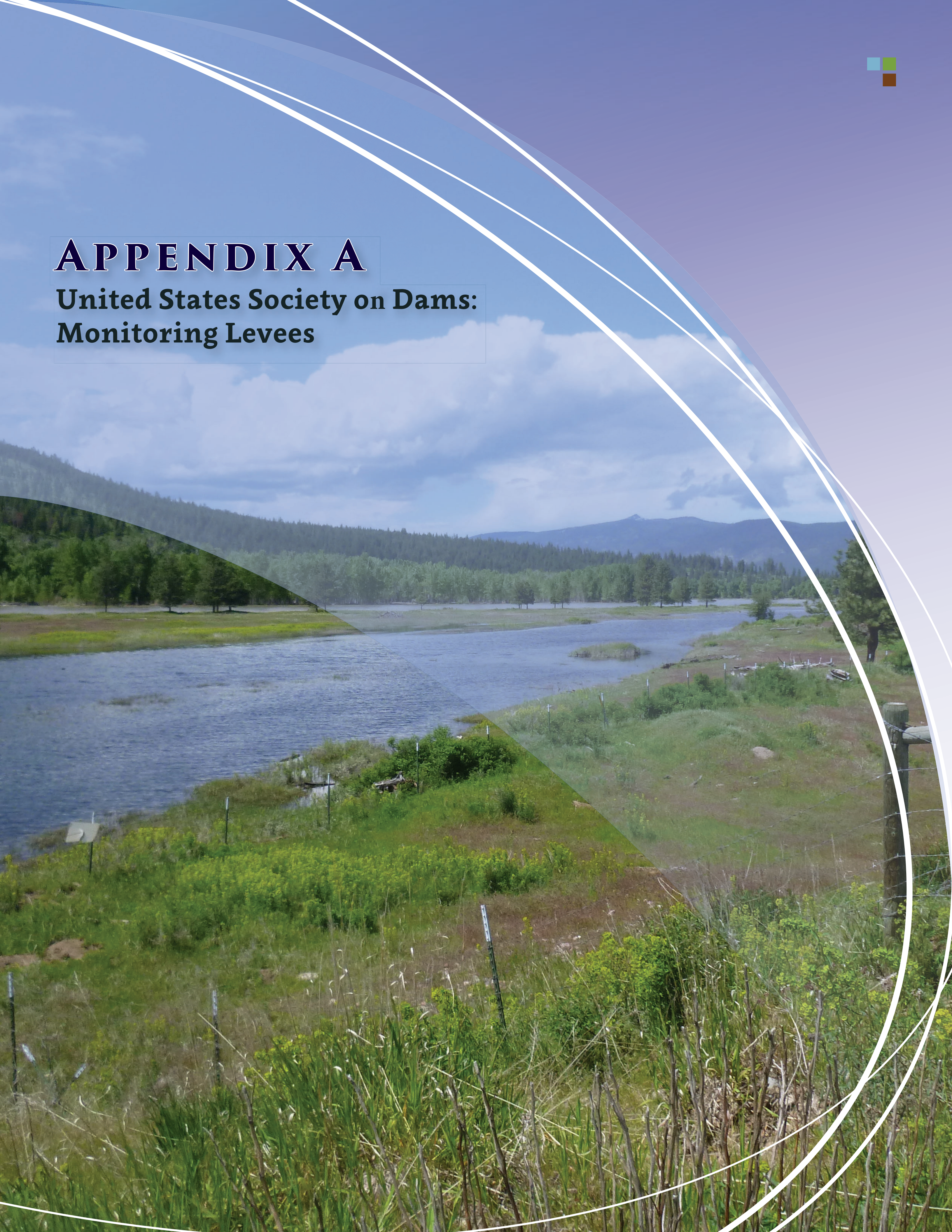
1. Base Flood Elevation Interpolated from Base Flood Contour Elevation: National Flood Insurance Program (NFIP), 2015, Flood Insurance Rate Map, Missoula County, Montana and Incorporated Areas, Panel 1155E, Map Number 30063C1155E, Map revised July 6, 2015.
2. Test Pit/Borehole locations: Survey Data, Territorial Landworks, 2018.
3. Lidar contour data: Flight Evolved, 2018.

TP17-1 Test Pit Location
BH17-01 Borehole Location
Base Flood Elevation (100-year flood event FEMA)
Berm Crest Elevation
Landside Berm Toe Elevation
Waterside Berm Toe Elevation
Holding Pond Locations (approximate)
Model Cross Section/Station

**Berm Crest Profile**
**Clark Fork River Berm**
**Former Smurfit/Stone Frenchtown Mill**
**Missoula County, Montana**
**FIGURE 3**

# Appendix A

## United States Society on Dams: Monitoring Levees



United States Society on Dams

# Monitoring Levees

**May 2016**

USSD Committee on Levees
and
USSD Committee on Monitoring of Dams and Their Foundations

# U.S. Society on Dams

***Vision***

A world class organization dedicated to advancing the role of dam and levee systems and building the community of practice.

***Mission***

USSD, as the United States member of the International Commission on Large Dams, is dedicated to:

*ADVOCATE*: Champion the role of dam and levee systems in society.

*EDUCATE*: Be the premier source for technical information about dam and levee systems.

*COLLABORATE*: Build networks and relationships to strengthen the community of practice.

*CULTIVATE*: Nurture the growth of the community of practice.



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# FOREWORD

The importance of monitoring programs for dams is widely accepted. There are many historical cases of dam failures where early warning signs of performance anomalies might have been detected if a good dam safety monitoring program had been in place, such that dam failure, and the catastrophic consequences associated with dam failure, could have been prevented. Historically, monitoring of levees has received less attention than monitoring of dams, except during intensive visual inspection efforts made during flood events ("flood fights"), when great efforts are made to locate and address levee problems before they become levee failures. The reasons for this lesser attention might include their generally have lower structural heights, when compared to dams, and their daunting lengths. However, the consequences of levee failures can be just as catastrophic as dam failures, so monitoring issues and discussions for levees should not be put off or avoided, just because the long lengths of levees can make the topic vexing. This White Paper addresses monitoring issues for levees, in an effort to provide information and perspective regarding this topic to professionals working in the fields of levees and levee performance monitoring.

This White Paper was prepared as a collaborative effort between the United States Society on Dams (USSD) Committee on Levees and the Committee on Monitoring of Dams and Their Foundations, and can be viewed as part of a series of White Papers by the USSD Committee on Monitoring of Dams and Their Foundations:

- Why Include Instrumentation in Dam Monitoring Programs?
- Routine Instrumented and Visual Monitoring of Dams Based on Potential Failure Modes Analysis
- Development of a Dam Safety Instrumentation Program
- Operation and Maintenance of an Instrumentation Program
- Instrumentation Data Collection, Management, and Analysis

While the above series of White Papers focuses on the monitoring of dams, many of the topics and issues discussed relate as well to the monitoring of levees. This series of White Papers primarily addresses the programmatic aspects of instrumentation for dam safety monitoring, rather than technological advances in instruments. These papers provide professionals working in the area of levee monitoring with some basic information to consider with respect to levee safety monitoring programs.

The Lead Author for this White Paper was Jay N. Stateler (Bureau of Reclamation, Denver, Colorado) of the Committee on Monitoring of Dams and Their Foundations. Co-authors from the Committee on Monitoring of Dams and Their Foundations were Pierre Choquet (RST Instruments, Coquitlam, British Columbia), John Lemke (Geodaq, Sacramento, California), Barry K. Myers (Engineered Monitoring Solutions, Newberg, Oregon), and Steven Z. Meyerholtz (Army Corps of Engineers, Seattle, Washington). Co-authors from the Committee on Levees were George L. Sills (Consultant, Vicksburg, Mississippi), Stephen L. McCaskie (Hanson Professional Services, St. Louis, Missouri), Graham Bradner (GEI Consultants, Rancho Cordova, California), and Scott A. Raschke (Schnabel Engineering, West Chester, Pennsylvania).

The Publication Review Committee (PRC) for this paper was headed by USSD Board Member Alex Grenoble (HDR, Inc.), with Committee members William Empson (Army Corps of Engineers), Andrew Verity (Terracon), Paul Booth (Arcadis), and Brett Cochran (Denver Water). The work of all these individuals, as well as the other members of the Committee on Levees and the Committee on Monitoring of Dams and Their Foundations who provided input regarding this paper, is acknowledged and appreciated.

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# INTRODUCTION

Levees are an important component of the civil infrastructure of the United States. They provide for the safe conveyance of water and reduce damage caused by floodwaters, so as to protect property and guard against potential loss of life. Due to the tremendous length of levee structures, totaling many thousands of miles, proper operation and maintenance of levees can be challenging. Events like Hurricane Katrina in 2005 have shown that levee failures can be catastrophic, and very costly. Historically, levees have been used to protect and/or reclaim land used for agricultural purposes. However, levees are increasingly providing protection for vast amounts of commercial and residential property as well. If levees fail, there is a potential for significant property damage, and in some cases, loss of life, as was experienced in New Orleans in 2005 relative to Hurricane Katrina. Because of this, levees need to be appropriately maintained and actively monitored so that they can be safely operated.

The failure of a number of dams in the 1970s, most prominently Teton Dam in 1976, led to a substantial and appropriate increase in the attention paid to dam safety and monitoring of dam performance, to look for early indications of developments that could conceivably result in dam failure. The 2005 levee failures in New Orleans led to a similar substantial and appropriate increase in the attention paid to levee safety, and the monitoring of levee performance, by the engineering profession. This White Paper is intended to support those efforts in the area of levee monitoring.

The goal of this White Paper is to provide an overview of the current state-of-the-practice in monitoring levees. This monitoring includes the use of visual observations and instrumentation for both regular, on-going monitoring work, as well as during flood events when “flood fighting” is taking place.

This White Paper begins with some sections that provide background discussion and information regarding topics that relate to the monitoring of levees:

- Types of levees, including some other types of long, linear structures that are similar to levees, such as flood walls and canals.
- Similarities and differences with respect to monitoring dams and monitoring levees, so that appropriate perspective allows proper use of pertinent methods and equipment used more commonly for dams
- Potential failure modes for levees, since understanding the potential failure modes is the first step in defining an appropriate monitoring program for a levee
- Risk considerations regarding levees and levee monitoring, since the fundamental purpose of levee monitoring is risk reduction
- Types of instruments that may be relevant to levee monitoring efforts
- Data collection, reduction, and storage relative to instrumentation used at levees, including the use of data acquisition systems

With this background in place, the discussion then moves to two central topics for this White Paper:

- Types of monitoring activities for levees, including methods employed
- Conclusions with respect to monitoring of levees

A separate section in this White Paper is devoted to each of the eight bulleted topics listed above, in the order indicated.

An appendix is included at the end of this White Paper that features a listing of publications that are relevant to the topics of levee monitoring and instrumentation, which will allow the reader to pursue topics raised and discussed in this White Paper in greater depth, as desired.

Note that common parlance used in this paper includes terminology such as "flood protection," and "flood damage prevention." This is mostly for convenience in simplifying the semantics used herein. While man-made structures have provided substantial benefits relative to mitigating potential damage due to naturally occurring flooding, it needs to be recognized that levees cannot protect against all possible levels of flooding. The impacts of man-made structural systems can have benefits in flood risk reduction, but other non-structural approaches can also be beneficial, and depending on the circumstances, may be more appropriate. When communicating with the general public, it is important to use care in selecting the words and phrases used, and make clear the distinction between "flood damage prevention/protection" (a virtually unachievable goal) and "flood risk reduction" (a desirable and achievable goal).

## TYPES OF LEVEES

Levees are generally long, linear, raised structures, commonly earth embankments, that are located and constructed to prevent the flooding of adjoining and other protected property. They can also be comprised of flood walls, particularly where land and right-of-way is confined, and closure structures, which are used to fill gaps where roadways, railways, etc. cross a levee.

The area protected by levees can range from undeveloped countryside, where the cost of levee failure would be relatively low, to densely developed urban areas, where the cost of levee failure could be very high. The nature of the protected property can be used as rationale or justification for allocating limited resources (construction funding and monitoring funding) to protect areas of greatest societal concern.

Levees typically have numerous penetrations for underground utilities, and may also have penetrations associated with storm discharge pipes, which may need to be equipped with gates, valves, etc. to allow closure to prevent backflow during flooding events. Levees often also include other features, such as pump stations that are used to remove landside storm water during flooding events, when the gravity drainage stormwater pipes are closed off to prevent backflow. Levees can also include seepage barriers (cutoffs) and relief wells/trenches. Levee designs and levee monitoring programs need to appropriately consider all these various factors and components, and the potential vulnerabilities that they may present, especially those that constitute a discontinuity in foundation soils and/or embankment materials.

Levees can be classified according to two distinguishing characteristics:

- The resources they protect – typically broadly classified as "rural" or "urban" levees
- Their geomorphic setting – typically classified as coastal and riverine. (However, at transitions between river and coastal environments, they are often also classified as estuarine.)

From an overall risk perspective, considerations regarding the first bullet above greatly impact the consequences of levee failure, and considerations regarding the second bullet impact the potential loads on the levee (that could impact the risks of levee failure).

Levees are a subset of a more general category of long, linear structures that also includes:

- Road and railroad embankments
- Flood walls (normally concrete or sheet pile, I-wall or T-wall)
- Canals (frequently concrete-lined)

The focus of this White Paper is on levees, but discussions in this White Paper also would apply to road and railroad embankments when they serve the same purpose as levees in a flood event (protecting property from floodwaters), since their earthfill composition and role during the flood event are the same. Flood protection levees often tie into road and railroad embankments instead of natural high ground. Also, they often intersect abutments for bridges that pass over the river that the levee provides protection against.

Flood walls are specifically constructed to reduce the risk of flooding, differing from levees only in terms of the composition of the structures themselves. Canals are a means of transporting and delivering water to farmlands and municipal users, and differ from levees in that they regularly operate to their normal capacity, while levees at some locations are more intermittently loaded, with potentially long periods of time between loading conditions that approach their design capacity.

For the purposes of this White Paper, much of the discussion will be devoted to monitoring of "intermittently" loaded levees, as opposed to "frequently" loaded levees. There are levees in certain environments, such as deltaic environments, which are loaded frequently or continuously at, or near, their design capacity. In these cases, the levees are essentially acting as a low-height dam, in which monitoring techniques recommended for dams would be largely applicable.

Note that some embankments are referred to as levees simply because they were constructed years ago and named "levees," when in reality such embankments are functioning as dams. This may be the case in certain reaches of an embankment, such as at a stream crossing where the surrounding landform is lower when compared to elsewhere along the embankment.

**Natural Levees**

In a riverine environment, the formation of a natural levee is caused by depositional and erosional processes, where sediment deposits eventually constrain the limits of "typically occurring" flood events. Natural escarpments develop at the margins of the "typically flooded area." If the river bed elevation increases, the natural levees on either side of the channel also naturally increase in height. Sediments picked up by the river in the flood event get deposited at the river bank areas, where flow velocities are lower, and therefore the water's sediment carrying capacity is less than in areas away from the river banks.

In a coastal environment, natural dunes may be present as well as ancillary offshore structures such as jetties and breakwaters, which mitigate wave impacts and encourage deposition of natural deposits. Man-made dunes are often used as coastal flood protection. Dunes (both artificial and man-made) are typically considered "sacrificial" features that are expected to degrade over time due to flood loading, wind, and other loads, and must be appropriately replenished through diligent management practices.

**Artificial Levees**

Artificial levees are intentionally constructed to protect adjacent property from flooding. Often times, artificial levees may have been built upon or may tie into natural levees. Artificial levees are located in many different environments, and for many different purposes, including the following:

- Along rivers (riverine)
- In deltas (coastal/estuarine)
- On lake shores (coastal), including structures that extend or supplement dunes along ocean shores or the shores of large bodies of water (coastal)
- Polders (water-impounding structures where there is no natural outflow)

Artificial levees can consist of permanent structures, or may be temporary, emergency structures that may be constructed using sandbags or rapidly placed earthfill.

**Riverine Levees**

The most common type of artificial levee is the riverine levee that is constructed along and typically parallel to a river channel. Riverine levees are the primary focus of this White Paper. However the topics addressed are, for the most part, readily adaptable to other types of levee systems.

The U. S. Army Corps of Engineers (USACE) has categorized riverine levees into five principal types:

- Mainline and Tributary Levees: Generally parallel to the main channel and/or its tributaries.
- Ring Levees: Completely encircle or "ring" the perimeter of a protected area.
- Setback Levees: Generally built as a backup to an existing levee that has become "endangered" due to such actions as river migration.
- Sublevees: Constructed for the purpose of underseepage control. Sublevees encircle areas landward of the main levee that are flooded, generally by capturing seepage water, during high-water stages, thus counterbalancing the hydrostatic pressures beneath the top soil stratum on the landward side.
- Spur Levees: Project from the main levee and provide protection to the levee by directing erosive river currents riverward.

(The information above is taken from the Memphis District website at http://www.mvm.usace.army.mil/Missions/FloodRiskManagement/Levees.aspx.)

**Levee Types Based on Ownership and Maintenance Responsibilities**

The National Committee on Levee Safety defines several levee categories, based on levee ownership and maintenance responsibilities:

- Owned by USACE, maintained by a local sponsor
- Owned and maintained by USACE
- Federally owned, but USACE is not the owner
- Not Federally owned (obtaining USACE assistance under Public Law 84-99 may be accomplished, as discussed below)

Levee Owned by USACE and Maintained by a Local Sponsor. The majority of the levees owned by the USACE fall into this category, where the local sponsor is required to perform essentially all operations and maintenance work. The sponsor furnishes assurances that it will maintain and operate the flood control works in accordance with regulations prescribed by the Secretary of the Army (i.e., USACE). The local sponsor is responsible for performing annual inspections of the levee, which are generally carried out immediately prior to the beginning of flood season.

Levee Owned by USACE and Maintained by USACE. A small portion of the levees owned by the USACE fall into this category. The local responsible agency is only required to perform minor maintenance work, such as cutting grass and repairing small erosion problems, and major maintenance work is the responsibility of USACE. Again, the local sponsor is responsible for performing annual inspections of the levee, which are generally carried out immediately prior to the beginning of flood season.

Federally-Owned Levee and USACE is Not the Owner. While the USACE owns a large portion of the federal levees, there are also other federal owners. For these levees, the bureau or agency that owns the levee would have full responsibility for all operations and maintenance regarding the levee, though assistance from the USACE could be requested through an interagency agreement, or services could be contracted for.

Levee that is Not Federally-Owned. The levee owner could be a state or local governmental entity, or a private entity. Again, the owner would have full responsibility for all operation and maintenance regarding the levee, though assistance from the USACE (or others) could be received via contract. Assistance can also be received from the USACE relative to flood situations under Public Law 84-99, as discussed below.

Public Law 84-99. When flood conditions exceed, or are predicted to exceed the response capability of levee and drainage districts, and local or state governments, the USACE has the authority under Public Law 84-99 (PL 84-99) to provide emergency flood response assistance, in the following categories (without further specific authorization of Congress):

- Emergency operations and “flood fight” assistance
- Rehabilitation of damaged “Flood Damage Reduction Projects”
- Advance measures

The assistance is intended to be supplemental to (and not a replacement for) local interests’ self-help and requires a Cooperation Agreement with USACE.

In the “advance measures” category, direct assistance or technical assistance can be provided. Direct assistance can take the form of supplies, equipment, and/or contracting for the construction of temporary and/or permanent flood control projects. Examples of technical assistance include having the USACE help with: (1) the performance of hydraulic, hydrologic, and/or geotechnical analysis efforts, (2) personnel to inspect levees to identify potential problems (and solutions to them), (3) evaluation work to determine the requirements for additional flood control protection, (4) recommendations regarding construction methods, and (5) the preparation of “flood fight” plans. Advance measures are designed with respect to a specific (impending) threat, and are to be temporary in nature, unless specifically excepted from this requirement.

The distinctions for the responsibility of a levee (ownership and maintenance) are important since it will likely define the type and frequency of inspections and other monitoring activities that occur, as well as other pertinent information, such as defined in Operation and Maintenance (O&M) manuals and other documents.

## SIMILARITIES AND DIFFERENCES — DAMS AND LEVEES

From a performance monitoring perspective, a great deal of information and many valuable references are available relative to instrumentation and monitoring of dams. Among these are:

- Guidelines for Instrumentation and Measurements for Monitoring Dam Performance (ASCE, 2000)

- Conference proceedings, publications, and White Papers from USSD
- Conference proceedings and guidance information from the Association of State Dam Safety Officials (ASDSO)
- Publications and guidance information from the Bureau of Reclamation (Reclamation) and the U. S. Army Corps of Engineers (USACE)

With respect to monitoring levees, the volume of available information is more limited, but rapidly growing. Some of the most recent innovative instrumentation applications (e.g., fiber optic sensors) were developed as a direct result of attempts to overcome one of the greatest challenges associated with levees, which is their substantial lengths (compared to dams). In addition, since the primary function of a dam and of a levee – to hold back water – is essentially the same, there are many similarities between the methods and equipment used for dams and what would be appropriate for levees, so information that is available regarding dam monitoring can have applicability regarding levees. Given this situation, it is useful to note the similarities and differences between monitoring dams and monitoring levees so that proper use of information regarding dams is made.

**Similarities**

Use of Potential Failure Modes Analysis (PFMA). An important similarity is that the PFMA method can and should be used to understand the risks and define the monitoring programs for both levees and dams. Additionally, where specific failure mechanisms/concerns are identified, monitoring (and evaluation) methods can be the same for dams and levees.

Some of the common potential failure modes for levees are the same as those for embankment dams:

1. Overtopping failure in a flood
2. Seepage erosion failure in a flood (through the embankment, through the foundation, and/or involving transportation of embankment materials into and through the foundation). Particular vulnerabilities exist where there are penetrations, which are often much more numerous for levees.
3. Slope instability in a flood, leading to overtopping failure
4. Slope instability in a flood, leading to embankment cracking and seepage-related failure
5. Blowout at the downstream toe in a flood, leading to one of the three previous potential failure modes
6. Slope instability leading to overtopping failure, due to coincident earthquake and flood loads
7. Slope instability leading to seepage-related failure, due to coincident earthquake and flood loads

Embankment dams can (and typically do) have additional potential failure modes, such as those associated with spillway performance, as well as others associated with normal (non-flood) operating conditions. However, in general, the potential failure modes that apply to levees align well with those that are applicable to dams.

Infrequently Wetted. Some flood-control dams are not frequently wetted, or may generally have low reservoir levels, except during flood situations. Such flood-control dams would be very similar to levees in terms of the potential failure modes that would be developed for them in the PFMA process. Considerations of the length of time a water load would be acting on the embankment, and how the embankment might respond, would be similar for flood control embankment dams and intermittently-loaded levees.

Ownership and Level of Regulation. Ownership issues and variations in the level of regulation is another area of similarity between dams and levees. Many times, entities responsible for levees do not have a source of revenue that is directly tied to levee operation and maintenance work, so funds available for this work may be very limited. Dam owners whose facilities do not generate much revenue, such as irrigation districts whose farmers do not make much profit on their cash crop, may be similarly strapped for funds for needed maintenance work. Regulatory oversight of levees may be limited or minimal in some instances. Similarly, when it comes to dams, state regulators are almost universally stretched very thin to oversee the large number of non-federal, non-FERC-regulated dams in their state.

**Differences**

Aerial Extent. The most obvious difference between dams and levees is that for dams, the area of concern is generally relatively limited in aerial extent. This makes studying and evaluating a damsite a more straightforward proposition than comparable efforts performed for levees. Consequently, the result can be a more manageable and implementable monitoring program. Visual inspections at dams can encompass the whole site on a relatively frequent schedule. For levees, their length creates many practical problems, including characterization for design and construction, and complications regarding operations, maintenance, and performance monitoring due to the length of levees.

Characterization of the Structure. Foundation geology unknowns and unknown variations in embankment composition and construction are much more likely to be present at a levee that at a dam, since a long levee structure cannot be explored as intensively as a damsite. For dams, site exploration work that produces a reasonable understanding of the characteristics of the site and structure can lead to a monitoring program that is fairly confidently defined. For levees, site and structure characterization is important, but it is not feasible for this characterization to be as complete as at dams. Foundation conditions for a levee can vary greatly since the levees are commonly constructed on fluvially deposited sediments, which can be complex and heterogeneous. Relic streambeds can incise the foundation below levees, perhaps at multiple locations. Effectively identifying all important geologic anomalies in levee foundations, either through direct subsurface exploration, geophysical methods, or review of historical data is highly desirable, but long levee lengths may make this challenging (at a minimum), or not realistically possible, in some cases. Another consideration is that the embankment materials used in a levee may vary greatly, since local materials are typically used and the local geologic environments can vary greatly along the length of a levee.

In light of this situation, paying attention to anomalous performance of a levee under load is often an important way to learn where to have special concerns and employ more intensive monitoring techniques. Even without high water loads, lush vegetation in an area can point to seepage concerns, which can lead to the area being a special attention area in a flood event. These considerations apply to dams as well, but given the special circumstances associated with levees, these considerations often take on even greater importance. Reaction to performance plays a greater role in the definition of the monitoring program at levees, than at dams, though the basic principle applies in both instances.

Additional Potential Failure Mode Consideration for Levees. As previously discussed, dams and levees share many similar potential failure modes, such as seepage and backward erosion of material due to piping. However, erosive forces occurring on the waterside of the levee can induce rapid loss of soil during a flood event. Such a condition is intrinsic to levees, where the flow of water is generally parallel (or sub-parallel) to the embankment, and high flow velocities are a regular occurrence during flood stages. A loss of waterside foundation or levee soil may exacerbate many of the common potential failure modes, in that waterside levee slopes may be destabilized, seepage paths through or beneath the levee may be shortened, and landside levee slopes may be destabilized due to higher pore pressures. For dams, while it is possible that similar erosion situations could develop near the inlet structures for spillways and/or outlet works, this situation is not nearly as prevalent.

Complicated Consequence Evaluations. For risk evaluation work, special considerations often exist for levees, not just relative to the potential failure modes, but for the potential consequences as well. It may be necessary to consider the impacts associated with failure of various system components. This may be more involved and complicated than comparable work performed for dams.

Heterogeneous Components. Levees are linear systems, often comprised of segments of heterogeneous components, including earth embankments, flood walls (of various types), and closure structures. There are often numerous major transitions along a levee's length, whereas a dam typically only has a limited number of major transition areas. Transition areas are particularly vulnerable to problem development due to the change in materials and configuration, and require special attention during design and construction, and subsequent monitoring.

Subsurface Penetrations. An acute vulnerability for dams and levees is subsurface penetrations. While dams and levees typically both have penetrations, levees frequently have a greater number and variety of them.

Practical Realities in Defining a Monitoring Program. For dams, there can be debates about the extent of the monitoring program, and the frequency that monitoring needs to be performed, but these debates may pale in comparison to the complexity of these debates regarding levees, where the area to be covered can be tremendously greater. Partitioning of levees, with respect to monitoring efforts, may be a necessity so that limited resources for monitoring efforts can be deployed as wisely and efficiently as possible. For example:

- **Special Attention Area** – Significant concerns exist. Monitoring program definition and execution can be much like that of a dam. Note that in some special attention areas associated with seepage, the vegetation may become so thick that the ability to effectively visually inspect the area is severely compromised, making the ability to quantitatively monitor actual seepage flow(s) in the area (if they exist) very valuable and beneficial.

- **Questionable Area** – Some elevated level of concern exists such that performance monitoring needs to be performed to an appropriate degree. However, if a significant amount of the structure is viewed to be in this category, then practical realities can limit, and perhaps severely limit, the monitoring effort that can realistically be carried out. Therefore, a challenging situation exists regarding the definition of questionable areas. Too much area designated as questionable means that the monitoring intensity may be diluted. However, too little area designated as questionable means that some areas may receive less monitoring than they should, and perhaps much less.

- **Seemingly Satisfactory Area** – Intensive monitoring efforts do not seem to be required, so the resources available for monitoring efforts are not deployed significantly in this area, but instead are diverted to areas of seemingly greater need. However, is enough really known about these areas to significantly scale back on monitoring efforts? Maybe so, but maybe not. Previously unknown problems may exist, or new problems may develop (e.g., new burrowing animal activity). What to do from a monitoring standpoint about long distances of seemingly satisfactory levees, particularly during a flood event, can be a difficult issue.

At dams, appropriate monitoring attention can be provided in most situations because of the much more limited aerial extent of the dam. It is often more evident for dams where special attention should be focused based on: (1) the location of the stream or river valley they are constructed across, (2) the location of certain geologic features that required special treatment, and (3) areas where critical loadings are present (e.g., the maximum section of the dam).

Magnitude of Water Pressure Loads. Another key difference is the magnitude of the water pressure loads on the structure. Dams and their foundations are typically subjected to significantly greater reservoir water pressures than levees. Therefore a flaw or weakness at a levee may not develop into a seepage incident, whereas at a dam, the same circumstance could develop into seepage-related failure of the structure.

Transitory Loading Condition. Some dams are operated with sustained high water level conditions, which is a more severe test regarding a seepage-related failure mode than transitory loading conditions associated with floods, which are more the norm for levees.

Length of Seepage Path. The length of the seepage paths at levees is typically significantly shorter than at dams. Therefore, any shortening of seepage paths due to animal burrowing activity, roots of vegetation, etc. may be more significant and consequential at levees than at dams.

## POTENTIAL FAILURE MODES FOR LEVEES

In one form or another, the concept of delineating potential failure modes for dams has been around for a number of years. The "Federal Guidelines for Dam Safety: Glossary of Terms (FEMA 148)," defines a potential failure mode as:

> "[a] physically plausible process for dam failure resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structures design, the construction, the materials incorporated, the operations and maintenance, or aging process, which can lead to an uncontrolled release of the reservoir." (FEMA, 2003).

It is believed that in the 1990s, the U. S. Bureau of Reclamation (Reclamation) was the first organization to make the concept of defining potential failure modes a fundamental element of their dam safety evaluation efforts. In 2002, the Federal Energy Regulatory Commission (FERC) initiated efforts that led to the development of the Potential Failure Modes Analysis (PFMA) program that was extended to all FERC-regulated dams within the following few years. Due to this, performing failure mode analyses for dams rapidly moved from "a new idea" to becoming more and more prevalent throughout the dam safety community.

The benefits of performing a PFMA include:

1. Identification of the most significant potential failure modes (threats) for the structure
2. Assessment, at least in a qualitative sense, of the level of risk associated with the various potential failure modes identified
3. Identification of actions that can be taken to reduce risks
4. Identification of immediate actions that can be taken in the event of intolerably high risks
5. Development of an appropriate monitoring program to address the various potential failure modes identified

While the PFMA process was developed for dams, clearly the same process can be carried out for levees, achieving the same benefits as noted above.

Steps associated with performing a PFMA for a levee include:

1. Gather the available records for the levee
    a. Geologic information
    b. Design information
    c. Construction information
    d. Historical aerial photographs
    e. Performance history, based on instrumentation data and visual observations
    f. Current design earthquake and flood loadings
    g. Analysis/evaluation work performed to date

2. Gather the people that have knowledge about the structure and/or have technical expertise to be drawn upon with respect to a discussion of potential failure modes, including:

    a. Facility operating and maintenance personnel
    b. Facility management personnel
    c. Geologist
    d. Geotechnical engineer
    e. Flood loading specialist
    f. Earthquake loading specialist, when appropriate
    g. People who have written performance reports, inspection reports, evaluation reports, etc. for the structure
    h. Other technical disciplines/personnel that have experience/information to share

3. Conduct a focused brainstorming session involving the above personnel to share information and experience about the structure so as to develop:

    a. Potential failure modes for the structure, and an understanding of the degree of threat they pose
    b. Actions that can be taken to reduce risks
    c. Additional information gathering, exploration work, etc. that might be appropriate in light of the unknowns encountered during the discussion
    d. An appropriate future monitoring program to address the potential failure modes identified

Synergy during the brainstorming session can lead to results superior to those that might otherwise be achieved.

The potential failure mode evaluation is site specific. The process searches for potential failure modes that are physically possible (or cannot reasonably be ruled out) given the information available. The potential failure mechanisms need to be described as precisely and specifically as possible, so that the remainder of the PFMA process can be effectively carried out. The most probable location(s) for development of each potential failure mode needs to be specifically identified, along with the manner in which the potential failure mode would likely initiate, progress, and eventually result in structure failure.

The identified potential failure modes are typically presented in order of apparent threat or likelihood (qualitative ranking), to help establish which modes deserve the most energy, effort, and attention in the monitoring efforts. (Quantitative risk analysis work, if subsequently performed, can refine this initial ranking effort.) It is important to understand that the identification of potential failure modes does not necessarily mean they are likely to occur. If the likelihood is viewed to be more probable than "fairly remote," then a "deficiency" may exist that most likely should be addressed in some manner. The concept of a potential failure mode being "physically possible, but of low likelihood" may be difficult to deal with in some instances, but the fundamental reality is that there is inherent risk associated with every levee, no matter how apparently well-designed and "safe" it may appear, and it is that reality that is typically being addressed by continued vigilant monitoring activities and periodic evaluation activities.

For dams, potential failure modes typically are developed for three loading categories: (1) normal operations, (2) flood loading conditions, and (3) earthquake loading conditions. Since levees are designed to address high water levels in flood events, and under normal conditions levees may have little or no water against them, the predominant potential failure mode category of interest for levees relates to flood loading conditions. Since it is very unlikely to have a major seismic event occur coincident with a major flood, often earthquake loading conditions end up being considered, but set aside, due to a low probability of coincident major earthquake and flood events. However, in highly seismic areas, consideration of this possibility may be appropriate.

For areas that are not highly seismic, the potential failure modes may include some or all of the following under flood loading conditions:

1. Overtopping, erosion of levee embankment materials due to overtopping flow, and failure by breaching.
2. Seepage-related failure due to backward erosion through the foundation, through the levee embankment, or through the foundation and then through the levee embankment, leading to failure by collapse of the overlying embankment and subsequent breaching. Penetrations through a levee, such as a conduit or pipeline, are particularly vulnerable locations for this potential failure mode, since compaction of materials against the penetrating structure may not have achieved densities comparable to other areas. Also, arching effects associated with the penetrating structure can provide "roof" support for a developing "pipe," and seepage flows can concentrate at the embankment/structure contact.
3. Slope instability, leading to embankment cracking and seepage-related failure.
4. Slope instability, leading to item 1 above.

5. Progressive slope failure, eventually leading to overtopping and failure by breaching, due to saturation and destabilization of the landside slope of the levee, followed by slope failure, repeated a number of times.
6. Blowout at the landside toe area, or further away from the levee, due to high pressures caused by underseepage beneath a confining layer, leading to items 2, 3, or 4 above.

For areas that are highly seismic, the potential failure modes may also include some or all of the following under coincident flood and earthquake loading conditions:

1. Overtopping, erosion due to overtopping, and failure by breaching, due to slumping that resulted from seismic shaking
2. Slope stability failure, leading to overtopping, erosion due to overtopping, and failure by breaching, due to liquefaction of foundation and/or levee embankment materials
3. Seepage-related failure due to flow though a seismic-induced crack or gap in the levee embankment that results in erosion of material and eventual failure by breaching

The above lists of potential failure modes for levees are by no means exhaustive and complete. Rather they are intended to give a sense of some of the more common potential failure modes for levees. PFMA work is site-specific, and many times some potential failure modes are developed that are unique for a particular structure. Participation by everyone associated with the levee, especially local operating personnel, is very important in the brainstorming discussions to uncover important information and develop potential failure modes unique to the particular circumstances of the levee being studied.

## RISK CONSIDERATIONS FOR LEVEES

Risk considerations in the context of levee monitoring and instrumentation include those factors that could reduce the risk to the protected areas. The factors to consider are:

- Potential risk reduction
- Residual risk to protected areas
- Benefit to Cost Ratio
- Instrumentation risk

### Potential Risk Reduction

The primary purpose of levee monitoring is to reduce the risk of levee failure and the associated consequences. Levee monitoring includes the possible use of instrumentation, so levee monitoring should be thought of as visual inspections, augmented by instrumented monitoring where appropriate.

Conventional levee monitoring programs rely primarily on observation of the levee system to identify potential problems that could lead to levee failure. Operation and monitoring plans include periodic inspections by trained personnel utilizing checklists and forms, or more sophisticated tablet tools, to identify areas of potential weakness that may require repair prior to flood season. Instrumentation is used to augment and enhance the visual monitoring efforts, particularly in areas where special concerns exist.

The strategy for monitoring levees with instrumentation, as opposed to visual monitoring, is different in that physical sensors are placed on, in, or below the levee and/or landside area to provide data regarding the actual performance of a levee at the point of measurement, which is compared to the expected performance of the levee for a specific loading condition. The reduction in risk based on the data from the instrumentation may be experienced by:

- Identifying levee components requiring repair due to instrumentation data that indicate that levee failure may occur when the day comes that the design loading conditions are experienced, or
- Reducing residual risk by removing people and moveable property from protected areas in anticipation of a levee failure, based on instrumentation data of concern.

**Residual Risk to Protected Areas**

The residual risk to protected areas has two components:

- Known risk - Levees only provide protection up to their design flood level (often the 100-year flood), so flood events exceeding the design flood level would be expected to overtop and fail the levee, and flood the protected area.
- Unknown risk – The potential for levee failure during a flood event less than the design flood event and for conditions not exceeding the design criteria.

Note that often the residual risk for different portions of a levee system may be quite different. For example, the approach of providing 3 feet of freeboard without evaluating the uncertainty associated with various flood events probably will not result in a uniform level of risk.

Managing the known risk is accomplished by communicating to the public in the protected areas what flood events the levee is designed to provide protection for and what flood events will fail the levee, and then working together on how to address this risk (e.g., additional flood protection measures, evacuation plans, etc.).

Managing the unknown risk is accomplished through monitoring activities, remediation efforts to address identified problems, and efforts to deal with emergency situations during a flood to prevent levee failure.

**Benefit to Cost Ratio**

There are insufficient funds to perform all the monitoring activities that would be desirable for all levees, and this situation is most prevalent and recognizable with respect to instrumenting levees. Given this situation, it is necessary to develop a strategy to allocate funds to those levee systems where the greatest benefit will occur. This is normally expressed as a benefit to cost ratio. Higher ratios are normally associated with urban areas. Since urban areas have a relatively high residual risk in the event of levee failure, it may be worthwhile to consider instrumenting these levee systems if it can be done at a reasonable cost and if it can be shown that the instrumentation: (a) can actually reduce the risk of failure, and/or (b) identify levee sections that may have a significant likelihood of failure in the event of a major flood event.

## Instrumentation Risk

There is a risk associated with the instruments themselves that could affect the instrument reliability. Instrument risk can include:

- Instruments may not have a satisfactory performance history
- Instruments may fail unexpectedly and unknowingly, which is particularly problematic if they are heavily relied upon for detecting early signs of distress
- Required maintenance of the instruments may not occur

Instrumentation may be incorporated in the original design and construction of a levee, but it is more likely that it will be provided at an existing levee. Unacceptably large disturbance of the existing levee may be associated with installation of some types of instrumentation (e.g., installing settlement cells in the foundation soil) which basically precludes their practical use.

One drawback to instrumentation programs is associated with the general funding mechanisms that are typically associated with both dams and levees. Instruments may be designed and installed as part of a capital improvement program; however, the operation and maintenance of the instruments will likely be the responsibility of the local sponsor. Local sponsors are generally funded through local assessments. Their budgets are generally small and operating and maintaining the instrumentation system may be an unsupportable burden. Even for a USACE levee, O&M funding will come from the "routine operations" budget, which must often be used for many different important and competing needs.

If reliance is placed on instrumentation for reduction of residual risk, and the instruments fail to provide data, the money has been wasted. However, a bigger concern is if the instrumentation is faulty and does not provide accurate data. In this case, it is possible that a real problem goes unrecognized, and instead the situation is viewed to be satisfactory, when in fact it is not. Potentially, a levee failure could occur in an area where the available instrumentation data says everything is satisfactory, which obviously would be a very bad situation. The other possibility is that the inaccurate instrumentation data indicates a problem where none truly exists. A lot of resources could potentially be misdirected to addressing this "non-problem" situation, which obviously would be another bad situation. Resources are scarce and need to achieve real benefits. Finally, if an instrument is installed incorrectly, the instrument installation work could compromise the integrity of the levee, increasing the risk of failure. If instrumentation installation work is improperly executed, a variety of problems could result. However, instrument installation work done in accordance with the current state-of-the-practice poses very little risk regarding collection of invalid data or damage to the levee. Nonetheless, as is the case with dams, each piece of instrumentation must have a specific purpose, as well as being installed using appropriate means and methods, because some limited risk (at least) does exist relative to each instrument installation.

## TYPES OF INSTRUMENTS FOR USE AT LEVEES

A number of different instruments and technologies can be used for levee monitoring. Some of them are the same as those used for monitoring embankment dams and for that reason they may provide an indication of conditions that are representative of a relatively small volume of the levee, while others may be more specific for levee monitoring in the sense that they attempt to provide an understanding of the condition of the levee on a broader scale. Instrumentation can broadly be classified according to the parameter it is used to detect and measure, which generally falls into one of the following three main categories:

- Hydraulic head (pore water pressure)
- Seepage
- Displacements (vertical and lateral)

The first consideration in selecting the type of instrumentation to be used is deciding what specific objective the instrumentation is to achieve (e.g., monitor pore water pressure in the foundation at the landward levee toe area). Specific monitoring locations and specific instrumentation types can then be chosen based on where and how the parameter is best measured, with consideration given to how the readings are to be taken, stored, and transmitted. Information from a risk-based evaluation of the potential failure modes to be addressed by the monitoring effort can be helpful relative to designing the instrumented monitoring program, which should supplement and augment visual monitoring efforts at the levee.

### Observation Wells and Piezometers for Water Pressure Monitoring

Observation wells are the simplest device for measuring water pressures in soils. Under unconfined conditions, the elevation of the water table can be determined. Observation wells generally consist of a slotted plastic pipe surrounded by sand in a borehole with an impervious bentonite seal provided at the top of the borehole to prevent impacts on the collected data from precipitation, snowmelt, surface runoff, etc. The elevation of the water table can be determined manually by inserting a water level indicator into the standpipe, or the readings can be automated by installing a pressure transducer (typically a vibrating-wire pressure transducer) in the standpipe.

Piezometers are used to measure the pore pressures (head) in levees and their foundations under both unconfined and confined conditions. Open-standpipe piezometers generally consist of a plastic standpipe that is installed in a borehole which has a porous element (typically plastic and having very small openings) attached at the bottom of the standpipe. Sand surrounds the porous element and a bentonite layer is used above the sand (and potentially below the sand as well) to isolate the “influence zone” for the instrument. The elevation of the water in the standpipe can be determined manually using a water level indicator, or the readings can be automated by installing a pressure transducer (typically a vibrating-wire pressure transducer) in the standpipe. More than one piezometer can be installed in a borehole (i.e., a “nested piezometer installation” with piezometers at different elevations) to measure the hydraulic gradient present. Alternatively, vibrating-wire piezometers can be installed directly in a borehole by placing them at the desired depths and backfilling around the instruments with sand and bentonite layers to isolate the desired “influence zones,” or by backfilling the borehole with a specially designed grout for the full height of the borehole. Other types of piezometers include twin-tube hydraulic piezometers and pneumatic piezometers, but their use in levees is very rare.

One consideration when installing water pressure monitoring instruments is the “lag time” or delay in instrument response associated with a change in pore pressure in the soil. In the case of an observation well or open-standpipe piezometer, a rapid change in soil pore pressure may not be immediately reflected in the water level in the standpipe. A sufficient volume of water must flow into the standpipe to achieve equilibrium with the pore water pressure of the surrounding soil. If the hydraulic conductivity of the soil is very low, it could take days, weeks, or months for this to occur. Where this is an important consideration, vibrating-wire piezometers should be installed directly in the borehole, as discussed above (eliminating the plastic standpipe).

Water pressure data are useful for understanding how the hydraulic head is dissipated as seepage water travels through and under the levee to the landside of the levee system. Anomalous seepage paths, high pressures in the landside foundation that could cause blowout, water pressures that could create instability, etc. can be identified and better understood. Baseline data can be collected and used to predict water pressures that might develop during a flood event, which then allows better assessment and evaluation of potential instability and seepage-related potential failure modes. Baseline data can be compared to data collected during a flood event to understand and better assess levee performance under flood loading conditions, and to calibrate and assess the validity of seepage models that have been used. Frequent readings often are desirable during flood events, which may point to the need for automation of instrument readings, and potentially real-time data transmittal as well.

## Seepage Flow

Direct measurement of seepage through a levee or its foundation can be a challenge if the seepage path is not known or if the seepage water cannot be collected and directed to a measurement location. When the opportunity exists to channel seepage water into a ditch or channel, weirs or flumes installed in the ditch or channel can be used to quantify the seepage flow. Small flows can be measured by timing how long it takes to fill a container of known volume (i.e., using the bucket and stopwatch method). In some instances, a velocity meter might be employed to develop the flow rate where the area of the flow is known and constant, such as a pipe that is flowing full. Water levels at weirs or flumes can be read visually using staff gages or using instruments. The instruments could be pressure transducers submerged in the flow, strain measurements associated with buoyancy changes of partially submerged weights, or non-contact type instruments such as ultrasonic or radar level sensors that sense the distance from a reference point to the water surface. The depth of water at the weir or flume is used to calculate the water flow rate using formulas that incorporate the weir or flume geometry.

## Soil Moisture Sensors

A change in moisture or water content in the levee embankment or foundation soils can be indicative of a change in the phreatic surface or ground water level, and rising pore pressures. Consequently, it is thought that this information could prove useful in monitoring relative to seepage-related issues.

Soil moisture content can be measured using soil moisture sensors or using suitable geophysical methods such as electromagnetic surveys which determine the electrical resistivity of soils along a continuous profile. Soil moisture sensors measure the dielectric properties of the soil-water system and provide an estimate of volumetric water content. Most commercial soil moisture sensors work on the principle of time domain reflectometry, frequency domain reflectometry, or capacitance, offering the possibility to be read with either portable readouts or automated data acquisition systems.

Soil moisture sensors measure volumetric water content immediately around the sensor. Measuring the soil water content along a continuous profile and being able to automate the measurements is interesting, but commercial products or methods currently available for this are not mainstream. Research work is ongoing. Alternatively, automated electrical resistivity arrays using geophysical equipment could also be considered as a method for continuously monitoring soil moisture content along a profile.

## Surface Settlement and Vertical Displacements

Areas of significant settlement are obviously important with respect to possible levee overtopping in a flood event. Settlement is a naturally occurring phenomenon, due to the consolidation of the levee embankment material and its foundation over time, but anomalous or excessive settlement may be an indication of internal erosion due to seepage taking place in the levee embankment or foundation.

A number of methods and types of instrumentation are available to measure settlement and vertical displacements. The methods vary depending on what type of displacement is to be measured, and what sort of measurement methods is feasible. The simplest form of displacement measurement (apart from just a qualitative visual observation) is the total displacement at the ground surface of a fixed location or marker, determined by surveying. This method provides the total vertical displacement, compared to an initial

baseline reading. Obviously lateral displacements can also be monitored coincident with this effort.
Other "traditional" methods can be used to provide the relative displacement of a location compared to a specific reference point, but these methods generally require installation of instrumentation within the body of the levee. Examples include "Borros" anchors, spiral or fixed-foot anchors, settlement cells, and extensometers. These might be appropriate during construction of a new levee, or major reconstruction of an existing levee, but their use at existing levees typically is very limited.

In addition to "traditional" surveying methods, newer technologies, including Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (InSAR), have become available which can be very cost-effective when used regarding long levee systems. These are discussed below.

Interferometric Synthetic Aperture Radar (InSAR). InSAR is a radar technique used for remote sensing. It can be ground-based, low-level airborne (airplanes or helicopters), or satellite-based, with commercially available sources for each. The technique uses two or more synthetic aperture radar (SAR) images of the ground surface to generate maps of surface deformations by using the difference in phase of the radar waves returning to the emitting source. InSAR holds the potential to provide centimeter-scale accuracy over timespans of days to years. Some ground-based InSAR systems even claim millimeter-scale resolution.

SAR systems that are under development include multi-frequency radar that allows fine resolution of surface features as well as penetration into the ground to detect buried anomalies.

Light Detection and Ranging (LiDAR). LiDAR is also a radar technique. It has been commercially available for a longer time than InSAR. LiDAR measures the distance to a target by robotically rotating a laser and measuring the time delay between the emitted and reflected signal. Ground based LiDAR is also called Terrestrial Laser Scanning or 3D Laser Scanning. Airborne and satellite LiDAR are also available.

## Lateral Displacements

Besides surveying monuments to determine lateral displacements, inclinometers are the primary method to monitor for lateral displacements at levees. Inclinometers can monitor for lateral displacements or offsets (perhaps associated with a slide plane) within the body of a levee embankment and/or within its foundation. Measurements are taken on two orthogonal planes along the alignment of inclinometer casing that is installed in a borehole. Displacement surveys are typically conducted using an inclinometer probe which is pulled through the inclinometer casing at 2-foot intervals to develop a complete alignment profile of the casing at that point in time. The profile can then be compared to previous profiles to look for offsets and changes. The inclinometer casing usually is installed vertically in a borehole to monitor horizontal displacements. However, it is also possible to install the casing horizontally to measure vertical displacements (settlements) along the alignment of the casing. An alternative to using a portable readout unit to develop a complete profile of the inclinometer casing is to use one or more in-place inclinometers in the casing. Each in-place inclinometer consists of a rod which can vary from one foot to 10 feet or more in length. The rod has a tilt sensor, can freely rotate at each end, spans a section of the casing of interest with respect to possible casing movement, and is left in place in the inclinometer casing. These in-place installations can be either read periodically using portable readout units, or automated, in order to provide continuous, real-time monitoring of changes in tilt sensor inclination.

For structures such as flood walls, inclinometer casings can be installed in the backfill adjacent to the structure, or within the concrete flood wall itself. Also, tiltmeters can be installed on flood walls to infer the lateral displacement from rotation of the face (assuming the flood wall is a rigid structure).

In some instances, it may be preferable to use shear strips or employ time-domain reflectometry (TDR) in lieu of installing inclinometer casing in a borehole. These instruments can be installed at less cost and can be rapidly read, but a full deflection profile is not obtained (which can be obtained when inclinometer casing is used). Rather, indications that shearing movements are occurring, and approximately where they are occurring, is the only information that is obtained. Often, this is all the information that is really needed. If desired, the reading and transmittal of data from shear strips can be automated, if desired.

## Temperature Sensors

Temperature measurements within the body of a levee, the foundation of a levee, or along the landside toe of a levee may help identify locations of concentrated seepage flows or locations of changed seepage flow (increased or decrease flow). The underlying principle is that if there is seepage, the seepage will cause a change of temperature along and near the seepage path. For example, relatively low temperatures may indicate the presence of significant seepage flow in an area if the water in the river is colder than the temperature in the levee embankment or foundation.

Temperature sensors, such as thermistors, resistance temperature detectors (RTDs), or thermocouples can be installed in boreholes or trenches in the levee soil or its foundation. Temperature sensors measure temperature locally (immediately around the sensor). Measuring temperatures along a line (perhaps at the landside toe of a levee) can be done using strings of temperature sensors, often called thermistor strings, where the spacing of sensors along an electrical cable linking the sensors can be as close as every 12 inches. Readings of thermistor strings or other strings of temperature sensosrs are often automated using data acquisition systems. Another way of obtaining a continuous temperature profile (perhaps along the landside toe of a levee) is to embed a suitable fiber-optic cable in the levee or in its foundation soil, as discussed in the section below.

## Distributed Temperature and Strain Sensing Using Fiber Optics

Fiber optic cables can be used for distributed sensing of temperature and strain. The fiber optic cable is the sensor, and temperature and/or strain can be measured along its full length using an optoelectronic readout apparatus. Most commercially available systems currently measure only temperature and are based on Raman scattering, which is a wavelength shift in the light that is sent through the fiber-optic cable using a laser. Typically, Distributed Temperature Sensing (DTS) systems can locate the temperature to a spatial resolution of 1 meter, with an accuracy to within ±1°C at a resolution of 0.01°C. Measurement distances can reach approximately 30 kilometers, and some specialized systems can provide even tighter spatial resolutions.

Other types of fiber optic monitoring systems, called Distributed Temperature and Strain Sensing (DTSS), analyze scattering in the injected light using the Brillouin approach, which has much less intensity than the Raman scattering and is based on the change in refractive qualities of the light carrier. DTSS systems are more expensive and less common than DTS systems. Their temperature measurement specifications are similar to the DTS systems and their strain measurement specifications are typically in the range of an accuracy of 10 microstrains and a resolution of 1 microstrain, with measurement distances that can be several kilometers to tens of kilometers. Specifications vary with the length of fiber optic cable that is monitored.

For both types of systems, the fiber optic cable needs to be strong enough to be embedded permanently in levee embankment or foundation materials, and must also be able to accommodate stretching. This is achieved by using custom-manufactured fiber optic cables which have a thicker protective jacket than the standard PVC jacket used for typical indoor fiber optic cables. For reference, some manufacturers of geosynthetic materials have incorporated fiber optic cable in these materials, so if they are incorporated in levee construction or modification work, a fiber optic monitoring capability would be built into the installed geosynthetic material.

## Microelectromechanical Systems (MEMS)

MEMS is a general descriptor used for a class of discrete multi-sensor systems that can be deployed in various types of arrays and patterns to improve spatial monitoring coverage. These devices take advantage of advances in miniaturization and reduced costs with new technological advances to produce sensors that can measure multiple types of responses (e.g., temperature, tilt, pressure, and strain). These devices often include on-board circuitry to process data directly into a digital format with no need for traditional analog to digital conversion.

## Conclusions Regarding Instrument Types Used for Monitoring Levees

Traditional instruments used at dams have one primary drawback that is particularly problematic when it comes to levees. They only measure a single type of response at a single instrument location (at a discrete point, or in the case of an inclinometer, along a discrete axis). New sensors are being developed that can measure multiple types of responses. New technologies (such as fiber optics) are being adapted to help overcome the challenges of instrumenting levees, but their adoption is likely to be slow due to the fact that the costs currently are relatively high and installation without significant disturbance is relatively difficult. At this time, this basically precludes their use for anything but new levees or major levee modification work. Geophysical methods, such as resistivity surveys, can provide information regarding levee seepage performance over fairly large areas, but typically such methods are used in studies being conducted for a limited period of time, as opposed to be part of a long-term monitoring program for a levee.

**Caution**. Care should be used when drilling and installing instrumentation within levee embankments. The use of a drilling fluid (water or air), which is circulated under pressure, might result in hydraulic fracturing of the levee embankment. Consequently, the current state-of-the-art is that drilling fluids should not be allowed to come in contact with levee embankment material (for the same reason it is not allowed regarding embankment dams). Hollow-stem augers, sonic drilling, or other forms of "dry" drilling should be used to advance the boring through the levee embankment. Then, if the use of drilling methods using drilling fluids is desired in the levee foundation, casing can be installed through the embankment, so that the drilling fluid does not contact the levee embankment material.

## DATA COLLECTION, REDUCTION AND STORAGE

Manual collection of data from instruments at levees is common. Typically, data are recorded in a field book for later entry into a computer to "reduce" the data to the desired engineering units, and to store the data. Printouts and plots of the data can then be produced. Plots can be prepared that are a function of time (e.g., water pressures at an instrument over time) or that compare the data from independent and dependent variables (e.g., water pressures at an instrument versus river level).

During a flood event, resources may be stretched thin and manually collecting the desired frequent readings from instruments may not be realistically possible. Automated means for collection and transmittal of instrumentation data may be highly desirable in this situation, which could then allow essentially real-time evaluation of levee instrumented performance. The automation system software could be written so that more frequent readings are obtained during flood events, compared to non-flood monitoring.

Automated data acquisition systems relevant to levee monitoring typically include battery-powered electronic hardware capable of collecting, storing, and transmitting digital readings from multiple sensors and multiple sensor types deployed at levee systems. The data acquisition system software conditions the raw sensor signal by applying anti-aliasing filters, offsets, and signal gain before converting the signal to digital values. The basic components of the levee data acquisition system include: sensors, signal conditioning circuitry, analog-to-digital conversion circuitry, data storage hardware, data communication hardware, and a power source. The power source for a

remote data acquisition system typically includes a rechargeable battery with solar panels and charge controllers. For remote applications like levee monitoring, the data communications hardware usually includes some form of wireless transmission (cellular, radio, or satellite) to a PC computer or web-server computer.
The data acquisition system typically collects readings from a large number of sensors, and this can be accomplished using a multiplexer approach or a digital network approach. The multiplexer method typically includes connection of each sensor cable to a central data acquisition system, and sensor readings are collected by switching input channels one by one. Alternatively, multiple sensor cables can be replaced by digital network nodes. Each network node digitizes the sensor signal as close as possible to the sensor and transmits the result digitally to a central data acquisition system via a single network cable or a wireless transceiver. All sensors can be sampled simultaneously in a network system.

Automated instrumentation systems used at levees have challenges that include: (a) the costs associated with the hardware, sensors, and installation work covering significant distances, (b) the costs of ongoing maintenance of the automated systems, which can be considerable, (c) survivability of sensors and data collection equipment exposed to harsh environmental conditions, including lightning strikes that can destroy even installations that employ state-of-the-art lightning protection, (d) potential vandalism or disturbance of equipment, sensors, or survey targets located in rural or populated areas with no security, and (e) exposure to damage from rodent or animal activity. Although challenges exist, equipment exists that can be successfully used, and efforts are always underway in the instrumentation community to come up with improved equipment that better addresses the challenges noted. It is generally wise to focus automation efforts on the key instruments and areas of concern, rather than simply embarking upon a program that tries to automate every instrument.

## TYPES OF MONITORING ACTIVITIES

Many types and levels of monitoring activities can be relevant to levees:

- Investigations to determine levee areas where performance concerns are greatest
- Comprehensive evaluations
- Routine visual monitoring
- Routine instrumented monitoring
- Monitoring during a flood event

The above five activities will be discussed below.

### **Investigations to Determine Levee Areas Where Performance Concerns Are Greatest**

Considerations regarding monitoring of dams and monitoring of levees are significantly different with respect to this activity. Sorting out where more intensive monitoring is needed for levees is a major issue that greatly impacts instrumentation and monitoring plans. Providing instrumentation at a significant density along all portions of a levee is typically inefficient, uneconomical, and unrealistic. Providing extra visual monitoring for the most potentially troublesome areas during a flood event is very important. Investigation work needs to be carried out to identify areas that appear to warrant special monitoring efforts. As previously noted, levees can be categorized as follows (though obviously other categorization methods can also be used):

- Special Attention Area
- Questionable Area
- Seemingly Satisfactory Area

This categorization then allows instrumentation and monitoring efforts to be appropriately scaled to the circumstances that exist along different sections of the levee. In performing site characterization work, consideration of the potential failure modes of concern can guide the information and data gathering activities.

Site characterization almost always includes initial visual reconnaissance efforts and topographic mapping of levee geometry using optical surveying methods, Global Positioning System (GPS) surveying methods, and/or airborne topographic surveys using LiDAR or other methods. Early site characterization work may also include the use of one or more of the following geophysical approaches to broadly look for areas where seepage issues may be especially prevalent and to look for structures passing through the levee which may create preferential seepage paths:

- Electromagnetic surveys to assess electric conductivity/resistivity (ground-based or airborne)
- Ground-penetrating radar (ground-based or airborne)
- Self-potential surveys

Subsequent phases of the work may focus in on questionable or potentially troublesome areas of the levee system, and may involve sampled soil borings, cone penetration tests (CPTs), additional geophysical work, and other information gathering.

For seepage-related potential failure modes, indications of anomalously high amounts of water or moisture in an area are important and would be relevant. These observations would generally be apparent when there is sufficient river stage such that seepage through and/or under the levee would be occurring at the time the information and data are being gathered. Otherwise, potentially misleading information and data may be collected. Therefore the timing of these seepage-related data gathering efforts is important. Evidence of potentially seepage-related sinkholes, depressions, etc. also would be of interest. This evidence, along with indications of low spots on the crest that could lead to overtopping, and indications of slope instability (longitudinal cracks, scarps, bulges at the toe of a slope, etc.), can be observed at any time the levee can be effectively viewed and inspected. Typically visual inspections and topographic surveys are used in combination to gather this evidence and information.

The time when these investigations are being carried out, and information about the levee and its foundation is becoming available, represents an appropriate time to carefully evaluate instrumentation needs for the levee. Instruments can help define and better understand "Questionable Areas," and monitoring of some of these instruments may potentially only be needed for a limited time (until the uncertainties are better understood). Instruments can be installed for more permanent, long-term usage in areas viewed to be "Special Attention Areas." Drill holes performed during exploration efforts can be completed with instrument installations (piezometers, inclinometers, etc.) at relatively low cost. Ideally, at the same time the iterative site investigation efforts are being carried out, the PFMA would be iteratively updated, and efforts to determine (and provide) appropriate instrumentation for the levee would take place, also iteratively updated as new information and data become available.

**Comprehensive Evaluations**

The USACE requires comprehensive levee inspections, termed Periodic Inspections by the USACE, every five years for their levees. This is viewed to be an appropriate activity for all levees, federal and non-federal.

The USACE Periodic Inspection is conducted by a multidisciplinary team led by a professional engineer. Components of the Periodic Inspection include evaluating routine inspection items; verifying proper operation and maintenance; evaluating operational adequacy, structural stability, and safety of the system; and comparing current design and construction criteria with those in place when the levee was built. Local sponsors participate on the inspection teams and all final inspection results are provided to the local sponsor and FEMA.

The USACE has been performing periodic levee inspections for many years. The currently used USACE Periodic Levee Inspection Program was created in 2006 and the first set of inspections was completed in 2010.

If visual inspections are performed when water levels are low, the ability to effectively evaluate the potential adverse effects of seepage may be compromised. Having performance records during flood events, that can be studied and evaluated, is clearly very important.

It would be desirable that a PFMA effort would take place as part of a comprehensive evaluation, with the effort appropriately scaled to the issues and concerns associated with the levee. Portions of the levee viewed to be "Special Attention Areas" should receive PFMA evaluations comparable to those of dams. The PFMA approach should also be applied to "Questionable Areas" and "Seemingly Satisfactory Areas," with effort levels appropriate to those situations. An important product of the PFMA work would be a Surveillance and Monitoring Plan for the levee that is developed in light of the location-specific potential failure modes identified as concerns, and the perceived risks associated with them.

## Routine Visual Monitoring

Routine visual inspections of levees are typically performed at least annually, and are generally performed prior to the flood season. The USACE refers to these inspections as "Routine Inspections." These walking inspections are performed to ensure: (1) the levee systems are being properly operated and maintained, (2) that no new encroachments on the levee have occurred, and (3) that no new structures, facilities, pipelines, roads, etc. have been constructed that pass over, under, or through the levee. These inspections verify maintenance work is being carried out that: (1) promotes the growth of a good sod cover for all levee surfaces not otherwise protected, (2) exterminates burrowing animals, (3) appropriately addresses the growth of undesirable vegetation on levee surface, and (4) provides routine mowing of grasses so visual inspections of all levee surfaces can be effectively performed.

These inspections are to be performed by trained personnel, under the guidance and leadership of experienced geotechnical engineers, utilizing checklists and forms, or more sophisticated tablet tools (discussed below), to identify areas of potential weakness that may require repair prior to flood season. Problems and concerns revealed by the visual inspections need to be promptly and appropriately addressed. Recent technological advances that involve handheld tablet devices that (1) take photographs, (2) allow the location and view direction of the photographs to be automatically recorded, and (3) allow notes to be tagged with the photographs, are very beneficial in speeding up inspection efforts, allowing precise documentation of inspection efforts and promoting straightforward storing and future retrieval of the collected information in computerized databases. The USACE developed the automated Levee Inspection System (LIS) tool as part of the National Levee Database (NLD). It is a Geographic Information Systems (GIS)/Global Positioning System (GPS)-based inspection tool that incorporates the levee inspection checklist and links directly with the NLD. This technology and these devices are also valuable with respect to visual inspections performed as part of a periodic comprehensive evaluation, and monitoring work performed during a flood event.

It bears mention that the development of the capabilities and use of unmanned aircraft (drones) undoubtedly will lead to their increased use to aid and supplement routine visual monitoring efforts at levees, most particularly during major flood events when resources are stretched thin.

## Routine Instrumented Monitoring

Instrumented monitoring activities generally involve instruments, sensors, and other systems that are installed on a permanent basis within, on, or beneath levees. These instruments or sensors are read at various times, either manually using portable readout units, or by automated means.

More commonly used instruments for levee monitoring include observation wells, piezometers, inclinometers, surveyed monuments, and seepage monitoring installations (weirs, flumes, etc.). Other types of instrumentation can be incorporated into levee monitoring systems, including temperature sensors, fiber optic cables (measuring temperatures and possibly strains as well), soil moisture sensors, and remote sensing methods such as InSAR and LiDAR, to identify changes in the levee geometry over time. Instrumentation and monitoring considerations for some of the most prevalent potential failure modes for levees are discussed below.

Seepage Erosion-Related Potential Failure Modes. The only direct evidence of initiation or progression of a seepage-related potential failure mode is evidence of sediment transport by seepage flow. However, since sediment transport almost invariably is episodic, rather than continuous, "moment-in-time" monitoring of the suspended solids concentration in a seepage flow (using a portable turbidity monitoring unit, for instance, or chemically analyzing a flow sample) is not beneficial, and can be very misleading. (Permanent installation of turbidity monitoring units has been found to monitor the deposition of "film" on optical surfaces, as opposed to the clarity of the water, rendering this alternate approach ineffective as well.) Routinely inspecting sediment trap locations along a seepage flow path permits detection of sediment transport, regardless of when it occurred, and therefore provides the desired "continuous" monitoring. Weir boxes and stilling pools in front of weirs are examples of effective sediment trap locations that can be routinely checked for evidence of sediment transport. Sediment traps should be provided along all seepage flow paths so that "continuous" monitoring for evidence of sediment transport is provided. Care must to be taken to prevent wind-blown soils, soils carried by surface runoff, etc. from depositing in sediment trap locations and creating uncertainty about whether sediment transport by seepage flow is occurring. High walls, covers, or other means may need to be employed, as appropriate for the situation.

An indirect method of monitoring for evidence of sediment transport is to look for indications of higher seepage flow rates over time, correcting for changing river water levels. Seepage paths that are expanding in size, due to erosion of material along the seepage path "walls" (i.e., the flow is eroding and transporting sediments) will show increasing flow rates with time. It is often easier to detect seepage problems in this manner, since flow rates can be accurately measured, as opposed to looking for visual evidence of sediment transport. However, looking for visual evidence of sediment transport should always be done, regardless of how effectively flow rates are being monitored. There can be other reasons that seepage flows might be increasing with time, that are not related to initiation/progression of a seepage-related potential failure mode, such as deterioration over time of an engineered seepage barrier, dissolution of foundation limestone by seepage flow, etc. However, any evidence of increasing flows with time should be promptly investigated since there is a real and significant possibility that it could be related to initiation/progression of a seepage-related potential failure mode. Typical instruments used for monitoring seepage flow rates include weirs, flumes, and velocity meters. A bucket and stopwatch approach can also be used for small flows. A seepage monitoring installation that can both measure flow rates and trap sediments carried by the flow, such as a weir and weir box, or a weir along a flow path, is the best choice, when practical.

In addition to instrumented monitoring, routine visual monitoring is important relative to seepage-related potential failure modes. This monitoring includes looking for:

- New seepage areas and wet areas (and evidence of sediment transport at these areas),
- Transverse cracks that could provide open seepage paths when the river water level is high,
- Open joints, cracks, etc. in conduits and walls in contact with levee embankment materials that could provide seepage paths,
- Animal burrows and roots of vegetation that could present open seepage paths, and
- Sinkholes, depressions, etc. that could be indications of subsurface removal of material by seepage flow.

Piezometers typically are not particularly useful for detecting the initiation/progression of a seepage-related potential failure mode since it is unlikely that the location of "point" measurements will be coincident with the developing seepage path. However, these instruments can provide information to allow a better understanding of general seepage patterns in an area of a levee, allowing potential seepage-related potential failure modes to be appropriately defined and better understood. A note of caution is appropriate here. Sometimes in the past it has been viewed that low hydraulic gradients (developed from piezometer data, along with headwater and tailwater data) mean that a potential seepage path has no prospect of developing into a failure mode. However, experimental testing as well as case history performance of dams has shown that sediment transport and seepage-related potential failure modes can develop with gradients even less than 0.1.

If significant concerns exist about the possibility of concentrated seepage flow developing in an area, that might lead to seepage-related levee failure, a dense network of soil moisture sensors or temperature sensors could be installed in the area to provide an alert of developing adverse conditions. Real-time (automated) monitoring of these sensors probably would be appropriate in this situation. Seepage detection could be accomplished by placing a line of instruments near the area of concern, which would commonly be the at the landside toe of the levee, or vulnerable areas offset from the toe (ditches, low spots, etc.). One approach for carrying out this instrumented monitoring would be to install a fiber optic cable along the landside toe of the levee, which could monitor for temperature anomalies every meter along the length of the cable, in the area of concern, as has been noted previously.

<u>Blowout at the Downstream Toe due to High Water Pressures from Underseepage</u>. Piezometers can be used to gather information about water pressures associated with underseepage beneath a confining layer, and about water pressure gradients, to determine if an apparent problem exists. Preemptive remedial actions can be taken before the flood season to appropriately address concerns about this potential failure mode. If the situation is less certain, then water pressure monitoring during flood events, perhaps using automation equipment, can provide additional data to better assess the situation.

Calculations can be made to determine water pressures that could lead to instability, and then the automation systems could provide alarms if those pressures are exceeded.

In general, the discussion included in the "Seepage Erosion-Related Potential Failure Modes" subsection above also applies regarding this potential failure mode. Additionally, discussion included in the "Slope Stability Failure" subsection below may also apply, if the failure mechanism that will breach the levee potentially could be slope instability caused by the increased foundation pore pressures.

Overtopping in a Flood Event. It is important that levees be periodically surveyed to observe for any anomalously low areas where overtopping in a flood could occur, as well as to determine the basic level of flood protection provided (i.e., actual levee crest elevation present). Visual inspections may be able to identify suspicious areas, where follow-up using optical or GPS-based surveying methods could be used to investigate the situation. For periodic surveys of the entire length of longer stretches of levees, remote sensing approaches such as LiDAR and SAR imagery can be used. LiDAR surveys can be performed using either a ground or aerial platform and SAR would most likely be performed from an aerial platform (airplane, helicopter, or satellite). It is conceivable that in the next few years, drones may be used to routinely conduct these surveys.

Slope Stability Failure. In the typical situation, where elevated instability concerns do not exist, monitoring efforts typically consist of visual inspections, looking for bulging at the landside toe area, longitudinal cracking at the levee crest or at the slopes of the levee, or evidence of scarps, sloughs, slides, depressions, etc. on the slopes of the levee. Periodic surveying of monuments on the levee embankment, looking for unusual settlements or deformations, also can be a component of the monitoring program, where this is viewed to be appropriate and warranted.

If elevated instability concerns exist, instruments that could be deployed include one or more of the following: inclinometer casing read with a portable probe, in-place inclinometer, shear strip, time-domain reflectometry (TDR), and surveyed monuments on the levee slope. If the concerns are high, then real-time data collection may be warranted, along with real-time data transmittal and evaluation.

## Monitoring During a Flood Event

Phenomena related to all potential failure modes must be carefully monitored during a flood event. Structures are best monitored by visual inspection. Walking or using all-terrain vehicles, and traveling along the landside toe of the levee during high water events is recommended, as a minimum. Levee failures during floods are frequently associated with overtopping flows, through-seepage, underseepage, or blowout. Recently, more seepage-related failures and incidents are being documented associated with animal burrowing. Instruments need to be read at an appropriate frequency during the flood event to collect the needed information.

During flood events and immediately following each major high water period, levees need to be inspected to look for unusual settlements, sloughing, caving on either the landside or waterside, seepage, and sand boils. Immediate steps must be taken to correct any dangerous conditions disclosed by such inspections.

Flood fighting is an art, but it certainly benefits from routine monitoring efforts, evaluation work, and planning work done prior to the flood. Comprehensive evaluations, and routine visual and instrumented monitoring need to be regularly performed so that key baseline information is available at the time of the flood event. Appropriate routine maintenance needs to be performed so the levee is in suitable condition at the time of the flood. Before every flood season, preparation and training to respond to a potential flood should be performed. Following each flood event, levees should be closely inspected and the performance of the levee during the flood should be documented. This documentation should include, as a minimum, photos, accurate locations and degrees of seepage, and information about any other poor performance issues which may have occurred during the event. As future flood events approach, this documentation should be studied to help identify potential problem areas. Also, this documentation should be reviewed to determine necessary remedial work that should be performed prior to the next flood season.

# CONCLUSIONS

## Visual Inspections Are Central to Monitoring Efforts

Routine visual inspections of levees are the central element of levee monitoring programs. These inspections should be performed: (1) at least annually, preferably just before the start of the flood season, (2) at a frequency during a flood event appropriate to the level of concern and risk about each section of the levee (i.e., different sections can have different, risk-based, inspection frequencies), and (3) as a part of more comprehensive levee evaluations that are performed approximately once every five years. Problems and concerns revealed by the visual inspections need to be promptly addressed and rectified as appropriate. Recent technological advances that involve handheld devices that (1) take photographs, (2) allow the location and view direction of the photographs to be automatically recorded, and (3) allow notes to be tagged with the photographs are very beneficial in speeding up inspection efforts, allowing precise documentation of inspection efforts, and promoting straightforward storing and future retrieval of the collected information in computerized databases. Increased capabilities and use of drones undoubtably will lead to their increased use to aid and supplement routine visual monitoring efforts at levees, most particularly during major flood events when resources are stretched thin. Personnel that perform visual inspections should be trained with respect to the critical nature of the work, and the potential consequences associated with failure of a levee.

**Definition of Areas Warranting Close Attention is Important**

Defining sections of levees that need more monitoring attention is an important activity regarding monitoring efforts. Levees are often long structures, and efforts to focus monitoring efforts in the areas where close monitoring is most needed provides effective and efficient monitoring, using the limited available resources to the best advantage. A three-category system (Special Attention Area, Questionable Area, and Seemingly Satisfactory Area) is noted herein, as an example of how the levee system could be categorized. Categorization can occur (1) by performing investigations to determine levee areas where performance concerns are greatest, (2) as part of comprehensive levee evaluations that are performed approximately every five years, and/or (3) as a result of actual levee performance experienced, particularly during major flood events. Phased approaches may be appropriate for investigations, where rapid, lower-cost methods can be used initially to cover all areas (e.g LiDAR surveys, electromagnetic surveys, etc.), and subsequent phases can collect more detailed information regarding areas that are apparently or potentially troublesome (potentially including drill holes where instrumentation might be installed). Good data and records collected during flood events about problem areas are valuable in defining areas warranting close attention in future floods, as well as identifying areas where remedial construction work would be appropriate.

**Instrumentation Can Be Beneficial In Areas Warranting Special Attention**

With a good understanding of the potential failure modes and the performance history of a levee, instrumentation systems can be designed to appropriately supplement visual monitoring efforts. The instrumentation may be temporary in nature, to gather more data about a specific concern in a specific area. Alternatively, the instrumentation may be for long-term use, when heightened concerns exist in an area. Automated data collection and transmittal may be appropriate where the instrumentation is intended to give a real-time warning of anomalous, unexpected, or undesirable performance.

# APPENDIX A
## PUBLICATIONS RELATING TO LEVEE MONITORING AND INSTRUMENTATION

No national standards, guidelines, or minimum criteria have been established for levee monitoring and instrumentation. Various federal, state and local agencies have adopted or put forth design requirements and standards, guidelines, and/or minimum criteria for the design, construction, operation, and maintenance of levees. In turn these indirectly influence levee monitoring and instrumentation. Many of these design, construction, operation, and maintenance requirements are necessary for levee recognition under the National Flood Insurance Program, participation under the Flood Control and Coastal Emergency Act (PL 84-99), and USACE Inspections under the Levee Safety Program.

The International Levee Handbook was published 2013 by the Construction Industry Research and Information Association (CIRIA) and represents the result of a collaborative effort involving the United States, France, and the United Kingdom, with support from Ireland, the Netherlands, and Germany. This handbook is intended to be a compendium of good practice, offering comprehensive guidance on the design, construction, maintenance and improvement of levees. Three pages of this 1,350-page handbook discuss the topic of “instrumentation and monitoring for levees.”

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# Appendix B

## International Levee Handbook (Chapter 6: Emergency Management & Operations Guidance)

# 6 Emergency management and operations

*Courtesy Árpád Szentiványi*

# CHAPTER 6 CONTENTS

# 6 EMERGENCY MANAGEMENT AND OPERATIONS

**Chapter 6** explains the management of levees and the role of levee managers in flood emergencies.

Key inputs from other chapters:

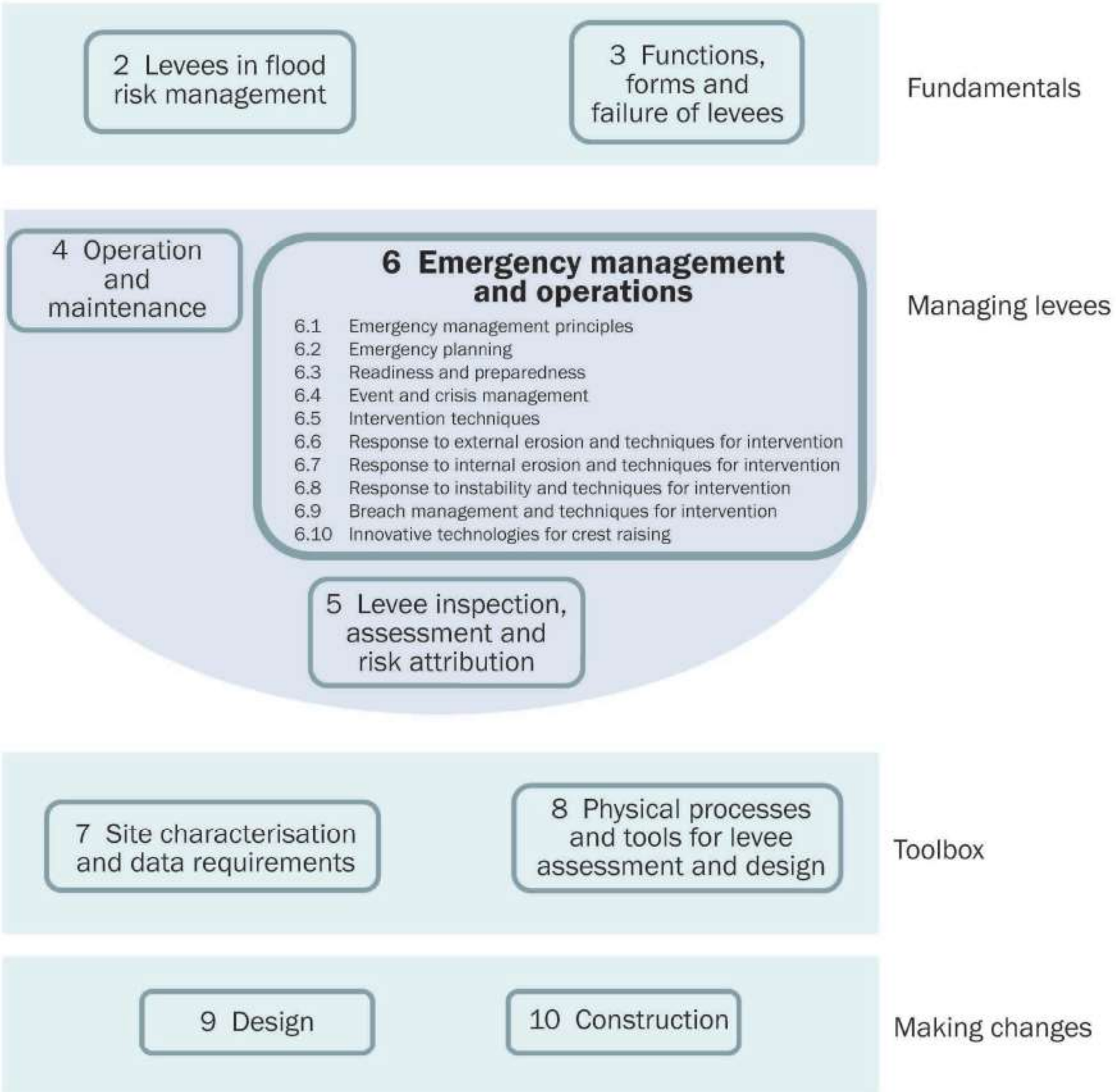
- Chapter 3 ⇨ **functions, forms and failure mechanisms**
- Chapter 4 ⇨ **integration with operations and maintenance**
- Chapter 5 ⇨ **levee performance assessments and flood risk analysis**
- Chapter 8 ⇨ **breach and inundation modelling**

Key outputs to other chapters:

- **post event data and analysis** ⇨ Chapters 4, 5, 9 and 10

**Note:** The reader should revisit Chapters 2 and 3 throughout the levee life cycle for a reminder of important issues.

This flow chart shows where to find information in the chapter and how it relates to other chapters. Use it in combination with the contents page to navigate the handbook.



# CHAPTER CONTENTS AND TARGET USERS

This chapter is divided into ten sections, providing an overview of the emergency management life cycle, which consists of preparedness, response, recovery and mitigation. The chapter focuses mostly on preparedness and response with minor information regarding recovery and mitigation, pointing the reader to other chapters of the handbook for more information on these two topics.

## Emergency management principles

Section 6.1 introduces the principles of emergency management and sets out the scope of the chapter. The emergency management life cycle is introduced with details given for the four phases of the cycle.

## Emergency planning

Section 6.2 presents the actions necessary to be undertaken prior to an event. Details are given related to required inputs for emergency planning, emergency action planning, flood response plans for levees, staff and security actions in planning, maintenance and update of plans, and data management and use in emergency operations.

## Readiness and preparedness

Section 6.3 describes those tasks and activities that are necessary to build, sustain, and improve operational capabilities. Details are given related to training and exercises as well as public awareness.

## Event and crisis management

Section 6.4 describes the varied role of levee managers, emergency managers, and responsible officials and their areas of responsibility. This section also details preliminary response activities, full response activities, and post response activities.

## Intervention techniques

Section 6.5 introduces the concepts of intervention techniques in light of potential failure mechanisms. Details are given related to flood response equipment, supplies, and activities.

## Response to external erosion and techniques for intervention

Section 6.6 presents techniques for intervention in response to external erosion. Details are given related to measures used for levee raising, external erosion protection, and protection from overtopping or overflow.

## Response to internal erosion and techniques for intervention

Section 6.7 presents techniques for intervention in response to internal erosion. Details are given related to measures used for reducing infiltration, increasing seepage path, and reducing hydraulic gradient.

## Response to instability and techniques for intervention

Section 6.8 presents techniques for intervention in response to instability. Details are given related to measures used for reducing steepness and inclination of slope, reducing uplift pressure, and reducing saturation of the levee.

## Breach management and technologies for intervention

Section 6.9 presents techniques for intervention in response to breaching. Details are given related to the stages of breach development and measures for management of each stage.

## Innovative technologies for flood crest raising

Section 6.10 presents innovative techniques useful for crest raising. Several representative methodologies are highlighted in this section.

# 6.1 EMERGENCY MANAGEMENT PRINCIPLES

An emergency is an incident, caused by natural or manmade hazards, that requires the levee manager (owner/operator) and other response partners to take action. A disaster is an event associated with severe property damage, deaths, and/or multiple injuries. Emergency management is the interdisciplinary field dealing with the strategic processes used to avoid or reduce the impacts from such events. The primary goals of emergency management are to save lives, prevent injuries, and reduce property damage. The main objectives for a levee manager, during a flood or storm, to attain these general primary goals are to avoid levee failure and to inform other response partners of the possibility of failure of the levee system or exceedance of the water level.

All risk management actors need to be prepared for emergencies in order to properly respond to such events. The actors are widespread and encompass the levee manager, emergency manager, response personnel, public safety and health organisations, utilities, government agencies and officials, private companies, and citizens. Although multiple actors should be involved in emergency management activities the level of involvement differs for each. Not every actor participates in every phase of an emergency event. However, every actor should apply the general principles of emergency management presented in this chapter as well as participating in communication between the actors during all phases of the event.

As demonstrated throughout history, breaching and overtopping of levees and subsequent flooding of adjacent areas always remain a threat, regardless of the height of a levee system and safety programmes. The burden for this flood risk mitigation is not borne solely by the levee manager, but is shared by all stakeholders for developing emergency management mechanisms to achieve and maintain an effective response. Levee managers play a key role in preventing flooding disasters by planning and preparing for emergency response and assisting in flood response activities.

Emergency preparedness and management is a process that is a necessary component of an effective risk reduction programme aimed at reducing the loss of human life and reducing property and critical infrastructure damage. Response activities during a flood event are intended to reduce the chances of levee failure, whereas planning and mitigation activities before and after a flood event are intended to reduce the consequences resulting from inundation. This chapter addresses basic principles and general guidelines that support effective emergency management practices.

### Scope

Figure 6.1 shows the emergency management life cycle, represented as a continuous process that can be grouped in four general areas: preparedness, response, recovery, and mitigation. Each phase of the life cycle is discussed as follows:

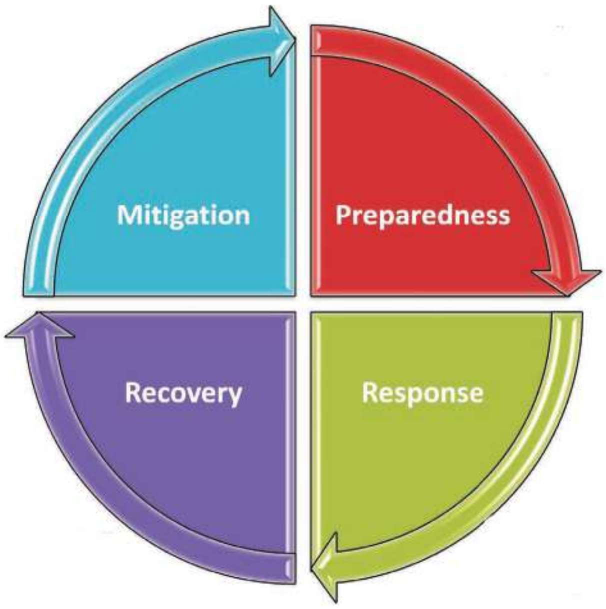



*Figure 6.1 Emergency management life cycle*

- **preparedness:** includes efforts focused on planning, organising, training, equipping, exercising, evaluating, and implementing corrective actions to ensure effective co-ordination during incident response and overall enhancement of all emergency management capabilities. Levee managers are generally responsible for assuring that the flood defence performs as intended, but co-ordination and planning with all affected stakeholders is essential to achieve the optimal risk reduction for the public. Preparedness activities and measures include the levee inspection process as well as development of communication plans, training of emergency response teams, development of emergency action plans, exercises, procurement and management of disaster preparedness supplies and equipment as well as levee inspection tools. Emergency preparedness plans are intended to provide a user-friendly protocol for managing emergencies in a co-ordinated and effective manner
- **response:** includes the mobilisation of emergency services and first responders to the disaster area and mobilising levee monitoring teams. Response activities include efforts conducted by core emergency services and first responders (eg firefighters, law enforcement, and emergency medical personnel), as well as special emergency operations (eg search and rescue, water rescue), emergency support teams, and emergency contract support. For the levee manager, the efforts range from actions taken to strengthen or raise (if not harmful to some other area) the levee as well as efforts (eg evacuation) by other emergency responders within the leveed area. Activities in the leveed area often involve co-ordinated action between the levee manager, flood risk management authorities and other stakeholders
- **recovery:** includes efforts aimed at returning the levee to full readiness and restoring the affected area to a normal state. Recovery activities are concerned with issues and decisions that should be made after immediate response needs have been addressed. Recovery typically begins after the emergency has subsided, but some recovery activities may be concurrent with response efforts. In this phase, permanent repairs to any damage to the levee or integral parts of the flood defence system would be made. In general, recovery involves individual, private sector, non-governmental, and public assistance programmes that focus on restoring economic activity, rebuilding community facilities and housing, addressing long-term relocation and care of the affected population, re-employment, repair of critical infrastructure, and other measures for community restoration and economic recovery
- **mitigation:** focuses on preventing hazards from developing into disasters in the future, as well as reducing the effects of disasters when they occur. Mitigation efforts are commonly associated with long-term measures for reducing or eliminating risks and/or improving the levee to a better performance level. Mitigation measures can be structural or non-structural. Structural measures involve technological solutions, such as levees or upstream flood discharge reduction. Non-structural measures include land-use planning, legislation, insurance, regulation, and risk communication to the public. Mitigation activities should be informed by risk assessment efforts. Mitigation measures can be influenced by lessons learnt from previous events. For example, areas of weakness identified during a prior flood event or during an inspection or assessment may be strengthened in preparation for the next event, thereby reducing the reliance on flood response efforts for defence. Measures may be implemented before, during, or after a flood or other incident. Several actions can be implemented to control or reduce existing risks. For example, measures dealing with improving the functionality of the levee by increasing the height, width, or bank protection, or curtailing new developments within the community (eg road construction, zoning or building code changes). Prevention measures can be very effective in areas that have not been developed or are in early phases of development. By implementing prevention measures, such as open space preservation and floodplain management, future development can be directed to minimise the risk from known hazards, while maintaining other community goals.

The emergency management life cycle applies to both general flood risk preparedness and management issues and also specific issues that can be useful to place the role of the levee manager in perspective. The emergency management life cycle is presented again in Figure 6.2 with specific information regarding the role of the levee manager and development of material in this chapter and the rest of the handbook.

The information presented for the rest of this chapter, detailing the role of the levee manager, is focused on the preparedness and response phases of the emergency management life cycle. Preparedness is detailed in Sections 6.3 while response is detailed in Sections 6.4 to 6.10.

1 2 3 4 5 6 7 8 9 10

This chapter does not include information about:

- **recovery activities:** these are mostly focused on final repairs of the flood response system and addressing consequences of the event, which involve the levee manager but to a lesser extent. These topics are covered in Chapters 9 and 10
- **mitigation activities:** these are mainly focused on improving the resilience of the flood response system or the community, which also involves the levee manager to a lesser extent. These topics are covered Chapters 4 and 5 with subsequent links to other chapters.

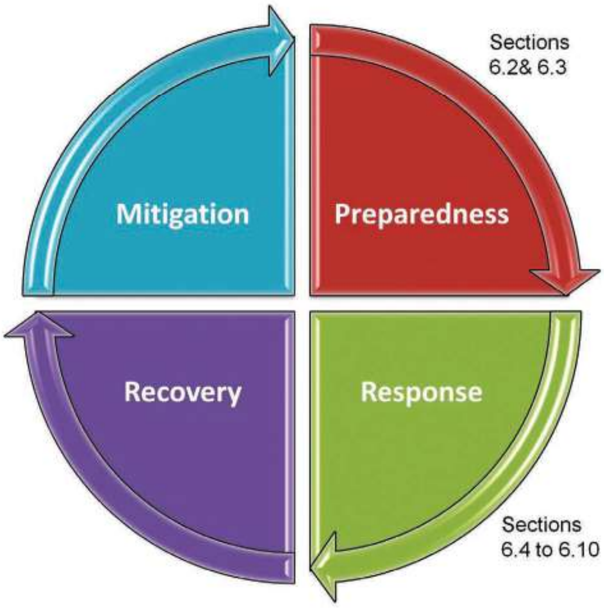



*Figure 6.2 Topics addressed in Chapter 6 and other chapters of the handbook on the emergency management life cycle*

## 6.2 EMERGENCY PLANNING

The actions taken in the initial stages of an emergency are critical to ensuring the function of the flood response system, saving lives, and reducing resulting consequences. Only through emergency planning in advance of an event can effective strategies for prevention/deterrence of risks be developed (FEMA, 2010).

### 6.2.1 Inputs for emergency planning

#### 6.2.1.1 Emergency management and levee failure

Understanding how levees fail is important in the development of emergency preparedness and planning efforts. These concepts are equally useful in the development of effective strategies to facilitate the implementation of potential repair solutions addressing levee failures. It is the levee managers responsibility to understand failure modes to better mitigate disasters. The most common modes of failure are seepage, overtopping, scour/erosion and slope instability.

Emergency preparedness planning for levees focuses on actions that may be considered before and during a flooding event that would supplement normal operating procedures undertaken by the levee manager (Chapter 4). Ideally, planning efforts should also address issues related to delegation of authority and responsibility, with updates incorporated as necessary to account for changes in personnel.

Emergency planning will cover other key aspects such as potential assembly or staging areas for flooding events, location of earth borrow sites, and procedures for maintaining records of equipment, manpower, and supplies. However, as no plan can guarantee that a levee system will not fail under all circumstances, levee managers are encouraged to work with local public safety officials and interact with them during their planning, for example, by providing information about the risk associated with levees. Emergency planning may also consider short-term situations that could arise during the life of the flood defence system. For example, if a culvert that runs through a levee is being replaced, a preparedness plan may be needed in case flooding arises during construction, when levee integrity is compromised.

Traditional failure mitigation strategies are discussed in more depth in Section 6.5. Chapter 3 contains detailed information regarding potential levee failure mechanisms.

#### 6.2.1.2 Risk identification

Levee managers should be aware of the risks associated with the functioning of the levee. Identifying where a levee is likely to overtop or where the levee is weak is key to planning how to employ resources during an event (details of approaches to levee performance assessment and flood risk analysis are given in Chapter 5). This will reduce, but not eliminate the risk to the leveed area. To further reduce the risk, the consequences of failure need to be analysed and minimised as well (discussion on risk analysis and risk attribution in Chapter 5). This risk reduction can be achieved through a variety of measures and instruments (Section 2.2). The levee manager can participate in these activities and assist local officials with reducing the consequences of inundation by understanding and operating the levee correctly.

If a threat to a levee is identified but a failure cannot be averted due to lack of resources, accessibility to expedient methods, or lack of time for their implementation, then the most likely action for the levee manager would be to co-ordinate with the appropriate individuals and organisations to evacuate the population at risk. If the levee manager is capable of addressing the vulnerability of the levee, the corresponding actions will be implemented to strengthen it and reduce the chances of failure. This may or may not be done in conjunction with the evacuations.

Understanding the flood risk, including inundation dynamics (Section 6.4) and the consequences of a levee failure or limitation is essential for decision making, particularly in time of a crisis. One of the most difficult decisions to make during an event includes intentionally flooding one area to save another area of higher consequence. Difficult decisions can be co-ordinated before the flood by designing levees with overflow sections or floodways, or pre-chosen levee segments to breach. Implementing them is still a complex decision, but can be made more acceptable by communicating and co-ordinating with all stakeholders involved before, during, and after flood events. See Box 6.12 for a case example, where the decision was made to intentionally breach a levee to activate a floodway as a measure to minimise flood risks. Deciding such measures during the actual flood without prior design and analysis is generally a bad idea, as consequences on other parts of the system can be worse than the locally avoided ones. The analysis of the flood (may include modelling) should be conducted at a larger scale than the local levee system, because of the influence of the levee system on a large part of the river, upstream, downstream and on the other bank or on the coast because of spatial variability in the wave and water level loadings.

#### 6.2.1.3 Flood inundation mapping

Flood inundation maps are a valuable resource primarily to emergency managers, however levee managers can also benefit from this information. For more information about how to develop flood inundation maps, see Chapter 8. The levee manager may or may not participate in the development of these maps, but may use them as a key resource during a flood event.

The following information describes how flood inundation maps are useful for each cycle:

**Preparedness**

- threat and type of risk
- population within risk area for evacuation or monitoring
- evacuation procedures (determine routes to be taken)
- shelters for evacuees

- population groups with special needs (eg schools, hospitals, nursing homes, jails, prisons, physical handicaps, senior citizens, foreign language speakers)
- agricultural areas with livestock
- facilities with hazardous materials and nuclear power facilities
- infrastructure within risk areas such as power, communication, transportation
- how the notification and warning process will be addressed
- community outreach and who will be responsible for public information
- command and control system used to co-ordinate response and location
- scope of damage, property destruction, deaths/injuries in an area.

#### Response

- serve as one of the primary documents to implement the plans
- determine actions to be taken based on current circumstances
- anticipate resources needed and stage them as appropriate.

#### Recovery

- compare inundation map with actual map post-flooding event
- incorporate inundation map in after action reports
- identify challenges and successes with information identified on inundation maps
- recommend any changes, additions or deletions to inundation maps for future planning and response.

#### Mitigation

- determine land use before the emergency
- identify areas of flooding risk during levee failure
- share with other entities that oversee land use issues.

So, inundation maps should present, for different scenarios, the sequence of inundation with the extent of the flooded area, water depth, water speed and raise rate. The choice for the inundation scenarios to be modelled and presented depends on a risk analysis of the levee system, presented in Section 5.2.

### 6.2.2 Emergency action planning

Levee managers are an essential participant in the emergency action planning process and may be responsible for both emergency management as well as levee operation and maintenance (O&M). Each actor involved in emergency response should have their own emergency action plan, which should be co-ordinated with the other actors. Emergency action planning and the resultant emergency action plan assists the levee manager in making decisions before an event (in contrast, 'flood response plans' are more focused on the activities of the levee manager on the levees than emergency action plans, which have a broader scope of activities).

Effective plans tell those with operational responsibilities what to do and why to do it, and they instruct those outside the jurisdiction how to provide support and what to expect. Emergency action plans should address a variety of issues, including:

- communication protocols/back-up plans with local emergency operations centres and the general public
- individual roles and responsibilities during an emergency
- supplies and materials that may be needed to support emergency operations
- co-ordination with evacuation plans.

It is important that the levee manager co-ordinates extensively with the appropriate emergency managers and other stakeholders to ensure a successful emergency response. There should be no ambiguity regarding who is responsible for major tasks. This enables personnel to operate as a productive team more effectively, reducing duplication of effort and enhancing the benefits of collaboration. Successful plans are simple, flexible, are frequently updated and exercised often.

Specific emergency action plans are derived from the aspects of the disaster life cycle: prepare, respond, recover, and mitigate. Integrating these key areas as part of a co-ordinated planning effort will lead to improved overall preparedness for the levee manager and other relevant parties.

- **prepare:** preparedness planning enhances the effectiveness of the flood defences beyond the normal operations and maintenance carried out by the levee manager. Routine operations and maintenance (Chapter 4) are needed for a flood defence to achieve a fully functional state. These routine actions are included in the operations and maintenance (O&M) manual, and do not need to be duplicated in an emergency action plan
- **respond:** response planning provides rapid and disciplined incident assessment to ensure a quickly scalable, adaptable, and flexible response to a threatened or damaged levee (Section 6.4 and Chapter 9). This assessment is based on observations made during event-related inspections (Section 6.4 and Chapter 4)
- **recover:** recovery planning (not discussed in detail in this Chapter) provides for a near-seamless transition from response activities to short-term recovery operations. This may include restoration of interrupted utility services, re-establishment of transportation routes, and the provision of food and shelter to displaced people as well as temporary and permanent levee repairs
- **mitigate:** mitigation planning (not discussed in detail in this Chapter) focuses on reducing disaster impacts through sustained actions that can reduce long-term risk. All mitigation planning efforts should be integrated into a co-ordinated strategy, linked to all of the other emergency planning aspects.

### 6.2.2.1 Emergency operations centre(s)

The severity of an incident (eg flood, levee failure) primarily determines the extent to which the response stays entirely under the purview of the levee manager or gets escalated to progressively higher levels. This escalation often results in some form of a centrally-led and controlled entity such as an emergency operations centre (EOC). The levee manager needs to be aware of this potential in order to provide or retain information, support and co-ordination.

An EOC serves as a central command and control facility with lead responsibility for carrying out the principles of emergency preparedness and emergency management – or disaster management functions – at a strategic level during a disaster. An EOC is responsible for the strategic overview of the disaster, and does not normally directly control field assets, instead making operational decisions and leaving tactical decisions to lower commands. A common function of all EOCs is to collect, gather and analyse data, make decisions that reduce life loss and property damage, maintain continuity of the organisation, within the scope of applicable laws, and disseminate those decisions to all concerned agencies and individuals. In large emergencies and disasters, the EOC also acts as a liaison between local responders and multiple government jurisdictions.

The key function of the EOC is to ensure that those who are responding at the scene have the resources (eg personnel, tools, and equipment) they need for their response efforts. EOCs may be organised by major functional disciplines (eg fire, law enforcement, medical services), by jurisdiction (eg federal, state, regional, city, county), or by some combination thereof. Boxes 6.1 and 6.2 show examples of typical emergency response command structure. The key feature is that the response is based on a tiered system (in this example three tiers: operational, tactical, and strategic). Note that the levee manager would be involved at the lowest tier (operational) but not necessarily with the other two tiers.

### *Box 6.1 Example response command structure in the UK*

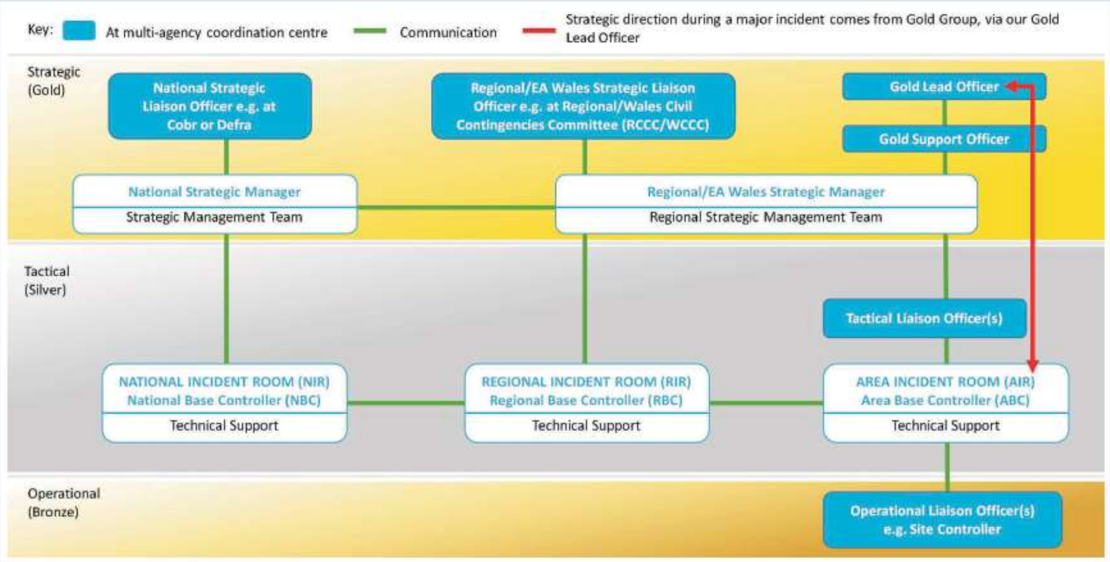



*Figure 6.3 Response command organisation in the UK*

### *Box 6.2 Example response command structure in France*

In France, management of protection structures against floods is regulated by several texts:

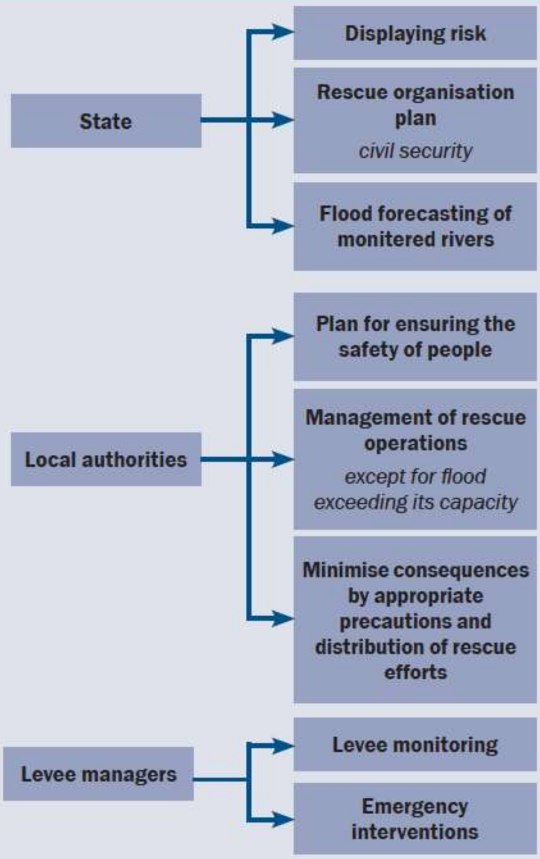
Decree No. 2005-1157 of 13 September 2005 made under the Act of August 13, 2004 for the modernisation of civil security, which provides that "any public or private person contributing to the general protection of populations, is able to ensure permanent missions assigned to it ... prepares its own management organisation of the event...." Furthermore the law prescribes the obligations of the mayor of a local authority (population safety plan) and prefects (rescue organisation plan, forecasting for monitored rivers...)

Decree No. 2007-1735 of 11 December 2007 on the safety of hydraulic structures, which requires managers of levees, the development "of the written instructions in which actions are set to monitor the levees in all circumstances and those relating to its operations during floods.... "

Art. L2212-2 of General Code for local authorities which gives police power to the mayor for:

- preventing by appropriate precautions, and for ceasing by the distribution of rescue needed, accidents and disastrous plagues and pollution of any kind, such as fires, floods, levee failures
- providing all emergency assistance measures, rescue and, if necessary, to cause the intervention of higher authority (prefect).

Sharing of responsibilities between State, local authorities and levees managers during flood periods is summarised in the flow chart.



### 6.2.2.2 Developing evacuation plans

While levee managers may or may not be directly responsible for developing an evacuation plan, they are encouraged to participate in the planning process and maintain close contact with appropriate governmental agencies during emergencies. They should provide timely and accurate information on levee conditions and the consequences of any failure, given previous studies of inundation and the associated mapping. This co-ordination will assist government agencies in making the appropriate decisions regarding evacuations (see the case study in Box 6.3).

Government agencies and local authorities are generally responsible for declaring the need to evacuate a given area and will, in many instances, already have evacuation plans in place. However, if levee managers are unsure about this, they should verify with local authorities whether a plan exists. Development of evacuation plans should be done in co-ordination with levee managers. This will ensure levee monitoring protocols during emergency conditions and notification procedures for communicating levee status to emergency response personnel are conducted effectively. A case example of how levee monitoring techniques can provide early warning in managing flood emergencies is provided in Box 6.4.

*Box 6.3* *A case study on the importance of evacuation planning, Storm Xynthia, France (2010)*

**Summary**

Having an evacuation plan with a clear command structure is essential to an effective response. Failure to communicate threats and quickly evacute people can be fatal. Political support and land use planning are also important to reduce flood damages and risk.

On 28 February 2010 at 02.00, the storm Xynthia hit the French Atlantic coast. The storm surge combined with the high tide and large waves caused flood defences to fail along the coastline from the Gironde (Bordeaux) to the Loire Estuary. A significant amount of land (>50 000 ha) was consequently flooded and 47 people died as a result of the storm. Most people died due to the flooding. A number of people died as a result of the storm itself (storm debris). The French departments of Vendée and Charente Maritime suffered the most. Some parts of the departments Gironde and Loire Atlantique were also flooded. The damage figure was about €2.5 bn (EUR). The estimated return period of this flood is around 100 years (based on historical records). It is impossible to give a precise return period for the storm. There is a lack of historical water level measurements available to give a more accurate estimation, furthermore the water level is not the only governing factor, which also includes wind direction.

**Disaster management**

The most important part of disaster management failed, the storm surge warning was not understood by the disaster management authorities and the public. Meteo France (French national weather service) had clearly provided a warning for the storm on all the TV networks and also given storm surge warnings. But the weather maps of Meteo France that were shown on TV provided no information on the risk for flooding. A small symbol may have been enough to alert the local population to the risk of flooding. Meteo France is not responsible for flood warnings. Local water levels have to be calculated by the local (department and municipal) authorities. Local authorities have to give the warning to the public. As the population prepared for high winds and not for flooding, this proved fatal. They closed windows and (electric) shutters. Electric shutters cannot be opened during a power blackout or flooding.

France has a number of laws restricting construction on the coastline (1985) and in areas prone to flooding (1995). However, since 1990 many houses were built along the coast in flood prone areas. These areas were protected by flood defences that are adequate for agricultural land but not for new housing areas. Maintenance costs for flood defences are covered by local organisations or private owners. A flood may hit a larger area than the parties concerned covering the maintenance costs. So maintenance costs and reconstruction costs are not covered by all beneficiaries.

A number of reasons contributed to the fatal aspects of the floods:

- building licenses for flood prone land were given by local government, elected officials (mayors), contrary to spatial planning laws
- buildings constructed since 1990 are usually only on the ground floor. Buildings from 1960 up till 1980 usually had the living quarters about two metres above soil level
- insurance companies often give a rebate (related to theft) if shutters or steel bars are installed on property owners' windows.

**Lessons learnt**

Flood warnings should be given in such a way that disaster management services and the general public can understand them and can evaluate which action they can take. This means a simple and explicit message (ie no technical jargon). It is important that both professionals and the public understand the same message. It has to be clear who gives which warning, who analyses flood risk and who is responsible for the communication with the public.

During storms some equipment can fail including water level gauges. Also communication links can fail. Contingency planning for failure of equipment is necessary. Redundancy in measuring devices is needed. Managing flood defences asks for strong, independent, local organisations with a very clear mandate for maintenance, new construction, financing and the inspection. All beneficiaries have to pay for the maintenance. Costs and benefits need to be proportional for all interested parties to reduce the risk of overdue maintenance.

*Box 6.4* ***A case study on the use of 'smart dikes' and visualisation surfaces as part of managing flood emergencies, UrbanFlood, European Union***

UrbanFlood, a European project funded under the EU seventh framework programme has investigated the use of sensors within levees to support online early warning systems and real time emergency management. Including such 'smart dikes', as part of early warning systems (EWS), can play a crucial role in mitigating flood risk by detecting potentially unsafe conditions and predicting the onset of a catastrophe before the event occurs. Also, it provides real time information on the behaviour and strength of a flood defence structure during an event.

UrbanFlood has investigated and demonstrated at pilot sites in Germany, the Netherlands and the UK the feasibility of remotely monitoring dikes and floods, whether from nearby offices or from other countries and continents through the secure use of internet-based technology. The systems that process and use the sensor data, such as models of the levee structure, failure mechanisms, breach development and the resulting flood inundation, along with the necessary visualisation software, have all been linked using internet technologies. Discussions and demonstrations of the visualisation of the results on multi-touch surfaces (Figure 6.5) has indicated that the approach, which allows co-ordination of all relevant information, may be particularly attractive to emergency management organisations.

*Figure 6.4* ***Fibre optic cable in geotextile fabric being laid in levee to measure ground strains at a pilot site (courtesy Victoria Bennett, RPI)***

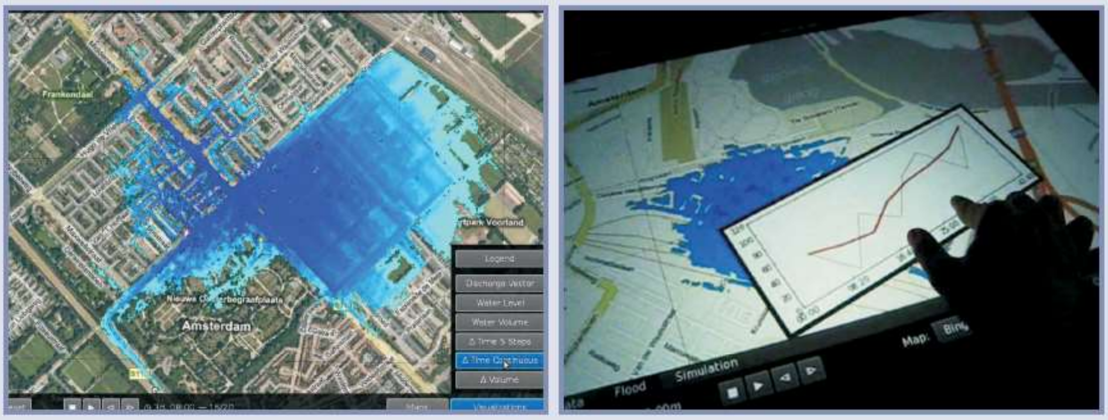



*Figure 6.5* ***Multi-touch surface in use to bring together levee sensor information and flood and emergency management simulations (courtesy UrbanFlood)***

## 6.2.3 Flood response plans for levees

As mentioned in Section 6.2.2, *flood response plans* are more focused on the activities of the levee manager on the levees than emergency action plans, which have a broader scope of activities. Flood response plans constitute a critical element to address necessary specific actions to be taken in order to help ensure that a levee provides the design height of a system during flood events. Flood response plans may encompass a variety of areas including not only emergency operations conducted on the levee, but also maintenance, engineering, and key support operations such as contracting, equipment, facilities, and communications, and the levee manager is advised to co-ordinate extensively with local and national authorities and other members of the community.

A key component of a flood response plan is the development of an emergency notification flow chart to establish who will be notified by whom and in what priority. The flow chart should include names and essential contact information (eg home, office, mobile). The flowc hart should also include emergency management agencies that need to be notified at various flood stages. Staffing of flood response is also an issue to be addressed in the plan and ensuring adequate personnel are available to operate 24 hours a day should be considered.

In order to get help from other actors and to inform them, it is strongly recommended that levee managers compile a directory including telephone numbers for the area's emergency operations centre, local contractors, flood response supply and equipment vendors, hospitals, railroad/highway departments, police and fire departments, and any other critical numbers.

As a basic planning recommendation, the flood response plan should include annotated drawings describing flood defence system features and potential areas of concern during a flood event. The list should clearly note:

- low areas
- areas subject to boils
- areas of known seepage
- areas of recent rodent activity
- alternate access points to the levee (should the primary become impassable)
- locations of drains that should be checked for closure
- available sources and locations of sandbags, pumps, and other supplies.

Along with this information, levee managers should include a detailed table of all of the locations of flood defence system features that may need to be closed such as floodgates, flap gates, and other closure structures and the organisation that is responsible for these closures. This table should denote the river level or other indicators that would signal that each of these flood defence system features needs to be closed. Also, the flood response plan should clearly describe protocols to notify the corresponding highway or railroad agencies responsible for closing roads or railroad tracks running through levees and flood walls.

Flood response plans should be published on paper and also can be published on the internet, or could be a communication of both for the widest distribution (see Box 6.5 for an example of a web-based flood response plan, and Figure 6.6 for a sample flood response plan outline).

**Box 6.5** ***Example of web-based communication of flood response plan to the public***


*Figure 6.6* *Example of web-based flood response plan (courtesy City of Coquitlam, Canada)*

## 6.2.4 Including staff and levee security in planning

Security issues should be addressed in the context of the overall threats facing the levee.

To ensure all personnel are aware of established security measures and protocols, including proper procedures for reporting suspicious activities, levee managers may choose to develop a security plan. The availability of a security plan can contribute greatly to the improvement of security as it details roles and responsibilities, physical and cyber security requirements, co-ordination with law enforcement officials, and procedures for reporting suspicious activities.

The scope and content of a security plan should be commensurate with the size and complexity of the levee system. The plan should clearly outline employee responsibilities as they relate to security, and should also address co-ordination mechanisms with the corresponding law enforcement jurisdictions.

Basic elements of the security plan may include:

- co-ordination with law enforcement agencies
- reporting and managing security incidents
- physical security
- communications and cyber-security
- employee and contractor identification
- security contracting
- co-ordination with emergency/operational plans.

In addition, the plan could address any security issues associated with visitor access, recreation areas, tours or other routine activities. The plan should also address the linkage between security activities and the levee's overall emergency preparedness plan.

## 6.2.5 Maintenance and update of plans

Emergency preparedness plans should be reviewed periodically, and after actual events or exercises, levee personnel should closely examine actions taken to determine whether they were effective and efficient. It is also beneficial to review the plans after events triggering its activation, after unusual or unexpected incidents, or after review of the plan by another actor.

Periodic plan updates should include verification that sources of emergency equipment and supplies, contact names, and telephone numbers are current. Updates should also incorporate a review of evacuation routes and emeregency shelter locations since these may change over time.

Given that floods may occur decades apart, it is important that any pertinent information be recorded for use in future planning efforts. Debriefing sessions should include all participants, to allow valuable feedback on lessons learnt, bearing in mind that the organisational arrangements and division of tasks between actors may change before the next flood. Information obtained during these sessions may include actions that worked well, areas for improvement, and recommendations to resolve any outstanding issues or concerns.

## 6.2.6 Data management and use in emergency operations

Information about a levee system is gathered over time to support the objectives of asset management. Managing data and keeping organised records about points where emergency action, previous breaches have occurred is important because these may indicate points of weakness in the levee.

These weak points will need to be more closely monitored during routine inspections and subsequent high water events. This information may also be used to inform decisions about permitting encroachments on the levee and for prioritising corrective actions on the levee.

*Box 6.6* *Example flood response plan template, Ireland*

**Flood emergency plan structure**

Cover page

Plan revision list

Executive summary

Table of contents

1) Introduction to the flood emergency plan.
2) Area of operation and flood history – risk assessment.
3) Roles and responsibilities.
4) Flood warning stages and action plan.
5) Information management and the media.

6) Appendices.
   - a List of contacts.
   - b Maps.
   - c Field Equipment, facility resource list, main buildings.
   - d Sandbag/Flood proofing policy and procedures.
   - e Evacuation and vulnerability registers.
   - f Incident report form and flood records.
   - g Traffic management.
   - h Recovery and clean-up operations.
   - i Flood forecasting and warning (system details).
   - j Safety, health, and welfare considerations.
   - k Training and testing of flood emergency plans.
   - l Flood emergency plan distribution list.
   - m List of definitions.
   - n Public information.
   - o Mutual aid agreements with other local authorities.
   - p Details of instructions for temporary flood defences.

7) Agency specific procedures.
   - a Gardai.
   - b Local authority (fire, civil defence, engineering).
   - c Permanent defence forces.
   - d HSE.
   - e Support services.

*Figure 6.7* *Example flood response plan template from Ireland*

Design of emergency repairs should take into consideration the levee composition and history (see Chapter 3 and, for data management, Section 5.6).

Table 6.1 provides a sample of all the types of data that can be used during emergency operations as well as indicating links to other relevant portions of the handbook where more information can be found. See Chapter 5 for how data will be managed and accessed.

*Table 6.1 Data useful during emergency operations*

| Type of data | Description of data and use in emergency operations | Links |
|---|---|---|
| Operations records | Records may include, but are not limited to:<br>• dates and notes on operation of pump stations and gates<br>• dates and notes on trial installations of closure structures<br>• preparation for floods and other emergency events<br>• protocols for stockpiling materials and carrying out emergency drills.<br>Use:<br>• information to reference when patrolling the levee. | Chapter 4 |
| Past performance data | Past performance data (also called points of distress), loading at the time distress was noted, and any effect on the levee will be important information for the maintainer to be familiar with. Include points where the levee required emergency action to prevent breach, reinforcement, as well as documentation regarding any permanent fixes.<br>Use:<br>• information to reference when patrolling the levee. | Chapters 4 and 5 |
| Data/results from inspections, safety assessments, surveys | Information collected from previous work provides:<br>• levee and foundation stratigraphy<br>• geology and geomorphology<br>• material properties.<br>Use:<br>• knowledge of likely failure modes<br>• areas that do or do not need patrol/survey<br>• selection of emergency measure. | Chapter 5 |
| Flood response plans | Flood response plans include reference information for how to react during an emergency situation and contingency plans. Details on these plans can be found in Section 6.2.<br>Use:<br>• reference when completing trial closures of closure structures/ emergency preparedness drills<br>• reference when acting in emergency response capacity<br>• reference key points to be checked during flood related inspections<br>• reference solutions to be used when a problem is detected during a flood related inspection (Section 6.2). | Section 6.2, Chapter 4 |
| Contact information | The levee manager should have to hand contact information for:<br>• any contractors working on the levee, past or present<br>• flood response personnel<br>• personnel required for emergency drills or trial closures (including those with access to stockpiled materials or required to install closure)<br>• local authorities and emergency managers<br>• local news media<br>• stakeholders (particularly those affecting large populations like office buildings, hospitals, prisons etc) and community leaders affected by levee failure.<br>Use:<br>• manager knows who to contact if there is a problem<br>• manager knows who to contact to complete emergency preparedness exercises. | Section 6.2, Chapter 4 |

## 6.3 READINESS AND PREPAREDNESS

Emergency preparedness efforts that include the entire spectrum of stakeholders lead to more resilient communities. Flood risk preparedness responsibilities are usually shared in some way between national and local agencies, private sector stakeholders, and the general public. Although it is not possible to completely prevent or mitigate every hazard that poses a risk, emergency preparedness efforts can help to reduce potential impacts of disasters by taking certain actions before an event occurs (US Department of Homeland Security, 2012).

Preparedness includes undertaking the tasks and activities that are necessary to build, sustain, and improve operational capabilities to prevent, protect against, respond to, and recover from an incident. Preparedness is a continuous process that involves:

- development of emergency plans
- assigning and training staff who can assist in key areas of response operations
- identifying resources and supplies that may be required in an emergency
- designating facilities and equipment for emergency use.

Levee managers should develop the appropriate level of preparedness regarding potential security issues, and also general risk management, particularly under conditions that stress the system. Facility staff need to be fully trained in assessing, observing, and reporting potential security vulnerabilities and suspicious incidents. Flood events can increase the attractiveness of the levee system as a potential target for security incidents. This is also the case for levee managers to be aware of general risk management.

## 6.3.1 Training and exercises

Important practical considerations and physical limitations that could be easily overlooked in a plan should be identified during exercises in which staff of the levee management organisation are trained to operate, maintain, and patrol the levee system. Periodic training and/or exercises are necessary in order to demonstrate how to operate the closure structures, patrol and inspect the area during a flood, and respond to sand boils and other deterioration and damage processes. Training and exercises also inform staff how much time and resources are necessary to complete certain tasks.

As general guidance, basic training and exercise activities should include:

- physical operation of features specific to the protection system (eg sluice gates, pumping stations, closure structures)
- notification of emergency response personnel
- test of communications and back-up communications system
- mobilisation of monitoring teams and monitoring flood defence system features
- basic flood response techniques
- co-ordination and control (eg between volunteers, patrols, operators, nearby levee districts, highway department, state emergency operations centre)
- dissemination of information to the public.

### 6.3.1.1 Training

During an emergency or disaster response, it may be necessary to assign staff to jobs other than those that they normally perform, or use personnel or volunteers normally not working for the levee manager organisation. So, it is critical that adequate training be provided in order to enable them to respond effectively to a levee emergency. Some personnel may already be employed within the community, but others may be recruited specifically for service in emergencies. Regardless of employment status, they should be recruited, assigned, and trained for their levee related tasks before an emergency event occurs. When possible, they should be included in exercises that enable them to practice these tasks under simulated emergency conditions so that when an actual emergency occurs, they can seamlessly transition into their new role. Training of all personnel should also include building awareness of health and safety issues.

1 2 3 4 5 6 7 8 9 10

### 6.3.1.2 Exercises

Emergency response on a levee or levee system can be complex and challenging and may require exercises (see Box 6.7 for an example of a full-scale exercise) for personnel in order to mount an effective response. They are typically categorised in two main types: **discussion-based exercises**, and **operations-based exercises**.

**Discussion-based exercises** are normally used as a starting point in the building-block approach of escalating exercise complexity. These types of exercises typically highlight existing plans, interagency/inter-jurisdictional agreements, procedures, and assist in developing new ones. Discussion-based exercises are valuable tools for familiarising personnel with expected capabilities and responsibilities. Discussion-based exercises may include seminars, workshops, tabletop exercises, and games.

**Operations-based exercises** represent an elevated level of complexity. They are used to validate plans, policies, agreements, and procedures reviewed and/or developed through discussion-based exercises. They can clarify roles and responsibilities, identify gaps in resources needed to implement plans and procedures, and improve individual and team performance. Operations-based exercises are characterised by actual reaction to simulated events, response to emergency conditions, mobilisation of resources, and commitment of personnel, usually over an extended period of time. Operations-based exercises may include drills, functional exercises, and full-scale exercises.

Documentation of exercise activities is important to identify shortfalls that may exist in planning and co-ordination, training, personnel, equipment, and facilities. A structured review or de-brief process can provide valuable feedback on the effectiveness of policies and procedures, identify areas for improvement, and give suggestions to correct deficiencies. Lessons learnt during exercises should be incorporated into subsequent training sessions, the emergency preparedness plan, flood response plans, or security plans.

*Box 6.7 Full-scale exercise example, Exercise watermark, UK (2011)*

Exercise watermark (2011) was the largest and most successful civil defence preparedness event ever held within England and Wales. It was a flood exercise with live play, took place between 7–10 March 2011, and involved more than 20 000 individual players across the resilience community. It provided a solid test of the nation's flood readiness.

The exercise involved ministers at the Cabinet Office Briefing Room, the Welsh Government, more than 10 government departments, 14 local resilience forums, and over 40 separate playing locations while locally delivered exercises involved a futher 34 groups. It demonstrated the capability to manage the response to a national flooding emergency.

Managed by Defra, supported by the Welsh Government, and delivered through the Environment Agency, *Exercise watermark* set out to test new arrangements against a severe flood scenario within England and Wales. These included the national flood rescue arrangements, Multi-Agency Flood Plans, new flood warning codes, and the Flood Forecast Centre as part of a range of initiatives implemented since the severe floods of 2007. The scenario included surface water, fluvial, reservoir and coastal flooding with breaches of flood defences, and a reservoir dam as part of the exercise.

The interim report was produced in June 2011 and contains 28 recommendations for planning, delivery, and review, and 31 proposed recommendations for learning outcomes from the exercise. These were high level recommendations and were relevant to exercise planning, emergency preparedness and incident response. There were also recommendations for community, local, and national levels.

## 6.3.2 Public awareness

The best examples of well-supported levee systems are in jurisdictions where levee managers and emergency managers have ensured that local businesses and citizens understand the flood hazard and the importance of the flood control system. While the levee manager may not be required to carry out public awareness activities, they are an important part of the community involvement process. Levee managers may be able to promote a greater awareness of key issues through publications and planned public meetings, as described here:

- **provide public materials:** many individuals, especially those living within a leveed area, will benefit from reading brochures detailing local flood protection. Levee managers might also release annual newsletters or newspaper articles. Information should be presented on the following topics:
  - how the levee system functions to defend the leveed area and its limitations

    - consequences resulting from levee failure and exceedance of their limits
    - historical overview of past floods and experiences, emphasising that historic scenarios may not represent what will happen in the future
    - flood response plans and procedures – how the community can contribute
    - local flood evacuation plans.
- **schedule public meetings:** unless there is an actual flood, attendance at public meetings on flood control may be minimal, especially if the public is not properly informed on flood control. Levee managers may find it useful to combine such meetings with discussions on local industry or other issues, or to raise certain issues during community events, such as annual or special public awareness programs
- **awareness of adjacent systems:** levee managers need to understand and communicate to potentially affected stakeholders and the community how adjacent sections of levees or components on private property impact the larger system. Even though these components might not be situated within the area of responsibility, the community could still be flooded if adjacent systems do not operate properly.

See Box 6.8 and Box 6.9 for examples of stakeholder engagement and awareness.

*Box 6.8* *Example of flood mapping and stakeholder engagement, Risk MAP Program, USA*

The Federal Emergency Management Agency (FEMA), an agency within the United States Department of Homeland Security, co-ordinates the federal government's role in preparing for, preventing, mitigating the effects of, responding to, and recovering from all domestic disasters, whether natural or manmade, including acts of terror. FEMA has recognised that a critical element of reducing flood risk involves the identification of the flood hazard. However, hazard identification and hazard mapping alone does not necessarily reduce flood risks.

In an effort to fullfil its role and objectives, FEMA created the Risk Mapping, Assessment, and Planning (Risk MAP) program (FEMA, 2008). The vision of Risk MAP is to collaborate with state, local, and tribal entities to deliver quality data that increases public awareness and to lead actions to reduce risks to loss of life and property. To achieve this vision, FEMA will evolve its focus from traditional flood identification and mapping to a more integrated process of identifying, assessing, communicating, and mitigating flood-related risks.

This vision is being intensely applied in those communities with levees. FEMA has identified new procedures that are improving the USA's ability to map and mitigate flood hazards related to levees. This process is based on two primary hallmark principles – an interactive stakeholder engagement process, and more robust engineering and mapping approaches – that establish the framework for a more credible, technically sound, and cost-effective approach.


*Figure 6.8* *Vision for the Risk MAP life cycle (courtesy FEMA)*

**Interactive stakeholder engagement process:** the levee analysis and mapping procedures include a highly interactive co-ordination process with key stakeholders, including community officials and levee owners. This process may include the formation of a local levee working group, members of which will include community officials and levee owners. FEMA will work with stakeholders to select the appropriate engineering and mapping approach based on a variety of factors, such as available data, levee system and flooding characteristics, potential level of risk landward of levee, levee owner willingness to contribute data or analyses, and available FEMA funding for the study.

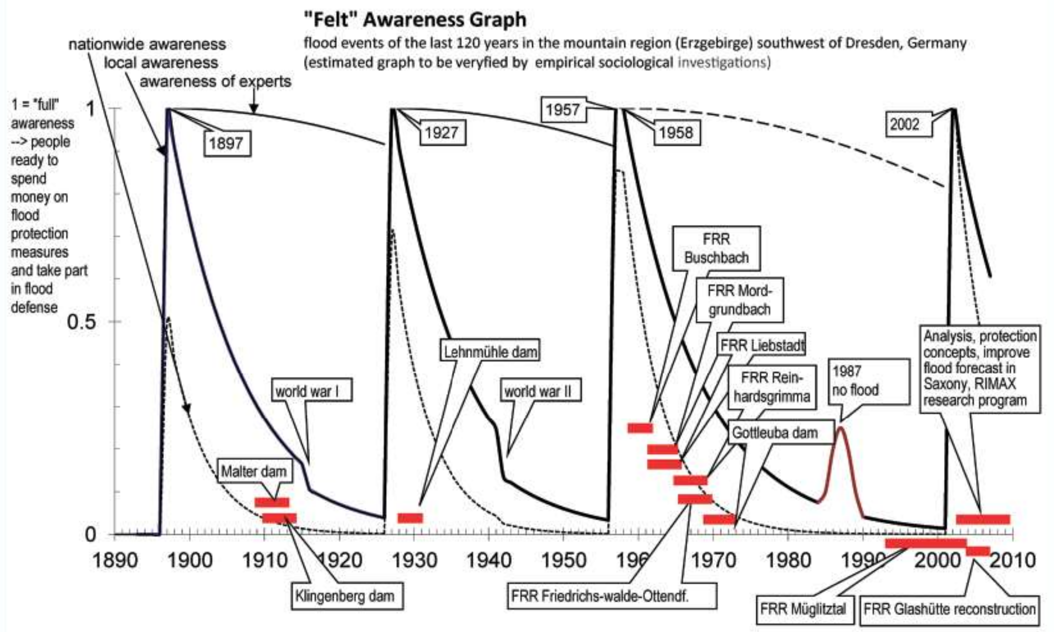
**More robust levee flood risk engineering and mapping approaches:** previously, FEMA used only one analysis and mapping approach to assess the flood risk associated with any levees that did not provide a minimum of flood protection for an event that had a 1 per cent chance of occurring in any given year. Currently, levee-impacted communities are able to apply a variety of analyses and mapping procedures that better reflect their unique circumstances and better characterise their flood risk. These include overtopping, breaching, and a natural valley (without levee) analysis.

*Box 6.9* *Public flood awareness over time – a study, Erzgebirge Region, Germany*

The interest of the public in flood prevention always depends on the level of awareness and the corresponding perception of the flood danger. After a flood event this public flood awareness peaks and unfortunately decreases relatively quickly as other events or problems develop over time.

Flood awareness curves corresponding to the regional awareness level, local awareness level, and technical expert community are shown in Figure 6.9. These curves, which correspond to a region near Dresden, are based on general assumptions and could be refined and quantified through empirical sociological investigations. However, some tendencies can be illustrated with this simplified representation:

- flood awareness at the regional and local level decreases relatively fast. The curves indicate that general regional flood awareness fell to half of its value in less than 10 years after the flood event
- the peak magnitude of the short-term regional perception increases over time, probably due to the expansion of the media and public communication mechanisms
- due to the apparent extreme flood recurrence period of 30 years (1897, 1927 and 1957) in the Erzgebirge region, many people expected a comparable extreme flood in 1987, which did not occur
- a number of planning, legislative, organisational and structural initiatives for flood protection were undertaken after each flood event, as shown in the figure (red bars). There is a time lag between the flood event and the corresponding flood protection initiatives, due to the associated planning, design, and construction efforts.




Pohl, R.: Historische Hochwasser aus dem Erzgebirge.- In: Dresdner Wasserbauliche Mitteilung 35/2007, TU Dresden, Institut für Wasserbau und Technische Hydromechanik, CD, ISSN 0949-5061, ISBN 978-3-86005-571-7 - FRR = flood retaining reservoir, red bars = post event response measures

*Figure 6.9* *Public awareness over time*

# 6.4 EVENT AND CRISIS MANAGEMENT

Levee managers, emergency managers, and responsible officials need to be aware of flood potential in their areas of responsibility. The use of available resources during a flood needs to be evaluated based on risks to personnel and equipment. Resources should be targeted to areas where levee performance concerns and/or potential failure consequences are the greatest.

Levee managers need to be aware of the following stages as the flood/storm event unfolds:

1. A meteorological forecast may predict the probability of high rainfall or a storm.
2. Based on the forecast the possibility of a flood may be predicted.
3. Based on this prediction a flood warning may be issued.
4. Levee managers move into **preliminary response activities**.
5. As the event unfolds, levee managers adopt **full response activities**.
6. **Post-response activities** after the peak of the event allow a return to more normal conditions.
7. Finally, after the event, recovery and mitigation may be implemented.

As the threat increases, the response needs to be adjusted accordingly. If the flood predictions allow time for emergency preparation or strengthening measures, then those measures should be implemented. On the coast, it is important to be aware that accessibility onto the levee for action may be limited by the severity of storm conditions (wind speed, wave overtopping etc). If the predictions are so severe that available resources or time constraints will not allow for adequate response, then evacuations may be undertaken. In some cases, emergency strengthening and evacuation might be used together.

As a storm approaches or as the flood potential increases, other responsible authorities may activate their emergency operation centres and their full emergency action plans in parallel with the activities of the levee manager.

## 6.4.1 Preliminary response activities

Upon receipt of official information forecasting potential high water or storm, levee managers should prepare for response activities. Levee managers are strongly encouraged to contact local emergency managers and activate their operations centre. Emergency managers and emergency operations centres should be informed of the condition of levee systems and given ongoing updates on the situation updates during a flood response.

As part of preliminary response activities, levee management staff should:

- divide the levee into geographic sections and assign the sectors to teams or individuals
- verify that staff have access to gate keys, current rosters, listings of flood defence system features and closures, plans, and other critical items
- co-ordinate efforts with communities upstream and downstream and eventually on the other bank of the river
- alert the community (leveed area) to the potential for flooding, giving it advance warning to take action and minimise potential damage to businesses and homes
- ensure local emergency operations centres are informed of the situation
- begin documenting the situation and send situation reports to the local emergency operations centre, as necessary
- provide safety briefing to response teams.

These activities should be part of the flood response plan (see Section 6.2).

As floodwaters approach the levee system, an initial high water/storm inspection should be carried out, in which the levee manager should ensure that special attention is given to the following items:

- water conditions, including waves, and any accumulation of trash, debris, ice etc
- condition of road, rail, and water access
- reconfirming the location, quantity, and conditions of all necessary tools and materials (eg sacks, sandbags, lumber, lights) and distribute and store them at points where maintenance is anticipated
- communication systems check
- inspection of drainage structures by the levee manager or other responsible authority (most drainage structures are situated to convey interior drainage from low points of the leveed area through the levee by gravity flow. Due to the location, drainage structures are generally subject to inundation at lower stages than most other flood defence system features, and special attention should be given to flap gates and other drainage structures that might not be accessible later)
- condition of any recent repairs to the levee system
- identification of any boil or seepage areas or other type of deterioration or damage, or water level getting close to the levee crest level.

Additional preliminary response activities could include:

- review assignments for patrols, closings etc

1 2 3 4 5 6 7 8 9 10

- obtain lists of all equipment, including motorboats, cars, construction and earthmoving equipment, and trucks that can be made available
- assess needed equipment support (vehicles, radios etc)
- verify serviceability of flood management equipment
- record guage readings and continue to monitor river stages
- close public access
- install levee or flood wall closures as necessary, all road closings should be co-ordinated with the corresponding transportation or railroad authorities before limiting access through the levee
- remove any hazardous materials from the vicinity of the levee system.

### 6.4.1.1 Patrols and inspections

A critical activity that occurs in an event response (in both preliminary and full response) is patrols, also called in other parts of this handbook as 'inspections'. To minimise damage and prevent levee system failure, problems need to be detected as early as possible and resolved accordingly.

Information presented in this section related to patrols is based on optimum conditions where there are no constraints in resources (personnel, equipment, funding, or time). Certainly, this will not always be the case and conditions dictate the level of patrol activity that can occur. If resources are a limiting factor then the levee manager should focus patrols on those sections that pose the highest risk (such as urban versus agricultural, areas with history of poor performance, areas with known susceptible material, areas with critical infrastructure, and other).

Ideally, the levee system should be patrolled at a frequent interval during preliminary and full response activities. During preliminary response a frequency of once per day is recommended, increasing that frequency as the event worsens. Patrols need to be conducted by teams rather than by individuals. Typical responsibilities of levee patrols are listed in the following:

- **general activities:**
  - record gauge readings
  - inspect fences on the waterside of the levee frequently to ensure they are free from debris (collected debris should be cleared immediately or the fence should be cut to free the debris and decrease the possibility of damage to the levee)
  - verify that all necessary access roads and ramps along the levee are usable or will be satisfactorily conditioned
  - take photographs of all significant issues (use date/time stamp and GPS co-ordinates, if available). Note gauge readings on photos if possible
- **specific levee activities** – look for the following signs of distress:
  - sand boils or unusual wet areas landward of the landside toe
  - slides or sloughs in levee embankment and signs of embankment instability (rotational or slip failures)
  - overtopping (predicted increases of water level exceeds observed freeboard)
  - seepage (water observed exiting the levee embankment or landside toe)
  - wave wash or scouring of the waterside (vertical scarps appearing along the embankment)
  - low areas in levee crown
  - check relief wells (flowing/non-flowing)
  - check flap/sluice gates for proper closure
  - check gap closures
- **specific flood wall activities** – look for the following:
  - saturated areas, seeps, or sand boils landward of the flood wall and sinkholes on both sides
  - settlement (vertical movement) of the flood wall
  - bank caving that may affect the structural stability of the flood wall

- inspect toe-drain risers (discharging/non-discharging)
- inspect the monolith joints for signs of failure or material deterioration
- check gap closures
- tilting of the structure (where water pressure forced the structure landward)
- overtopping (predicted increases of water level exceeds observed freeboard)
- concrete cracking and other deterioration

- **specific pump station activities:**
  - verify proper ventilation (eg fans, vents) of the pumping plant to prevent overheating of pump motors
  - look for sink holes or wet areas around the perimeter of the pumping plant and/or settlement of the pump house, all of which could potentially be the result of separation in the conduits. If this condition is suspected, pumps and motors should be shut down until an engineering review can be conducted to analyse the condition
  - verify that assigned operators are on duty 24 hours daily (24/7).

The patrol (or inspection) observations and actions should be described in a formal report that can be used, either as a way to pass information to management staff that can decide for emergency maintenance or repairs, or subsequently as a way to facilitate feedback and improvement of the plan. It can also help the management in difficult legal situations to justify its actions. See Section 5.6 for future use in any assessment or decision making.

#### 6.4.1.2 Safety and security precautions

To reduce the risk of injury to patrol team members, the best method for conducting a patrol is to have a three person team walk in a line across the levee with one person on the waterside of the levee near the water surface, one at the top of the levee, and one on the landside toe of the levee. The team should move slowly enough to enable the waterside member to probe below the surface with a rod in order to discover any erosion that may be taking place. All personnel need to have appropriate safety gear such as a safety line and flotation vest.

The waterside member also needs to be especially observant of floating objects. The limbs and roots of an uprooted, floating tree can strike anyone walking along the edge of the water. To increase the chance of identifying floating objects, walk in the upstream direction when patrolling the waterside of the levee. When patrolling flood walls, the patrol should not walk the top of the wall, but rather concentrate on potential problem areas on the landside of the wall.

Each person on the patrol should be thoroughly familiar with the community evacuation plan and signals. If evacuation is necessary, the patrolling organisation should move to a predetermined location and keep the team intact. If evacuated, when returning to the levee system, physical conditions may be considerably different from those observed before the evacuation, especially if the levee was overtopped. If overtopping occurs during nightfall, it is recommended that the patrols do not resume until daylight, although there may be cases where this recommendation cannot be followed.

Patrols need to look out for anyone that seems out of place, or any activity that seems suspicious. Individuals may try to take advantage of the already dangerous situations on levees or flood walls for their own purposes. Any suspicious activities should be reported immediately to law enforcement authorities.

#### 6.4.1.3 Emergency maintenance and repairs

Once an inspection has been completed, urgent maintenance issues should be addressed before the floodwaters rise further, a breach starts to develop, or a new flood occurs. Emergency maintenance activities are no substitute for normal annual maintenance (see Chapter 4), and owners/operators should not defer the activities listed as follows:

- immediate attention should be given to the crest level of each levee section or profile by comparison of existing crest levels with those shown in 'as-built' record drawings. Fill any settlement, holes, gullies, and washes in the levee crown, embankments, and landside berms with compacted fill material. Materials used to fill depressions should be obtained from distant sources (not adjacent to a levee system) unless it has been determined that borrowing in areas adjacent to the levee will not adversely affect its stability or the control of under seepage. Use adjacent material only under direct supervision of the section leader and with the advice of appropriate staff. The fill material should be compacted and protected from wave wash and other erosion as necessary. Use sandbags, if adequate fill is not available

- examine all drainage ditches on the landside of the levee and remove any obstructions. Be prepared to construct seepage drainage ditches, including appropriate filter arrangements, but not until actual seepage appears. Excavation of ditches near the levee, or in the long berm area, is hazardous and should not be undertaken except under direct supervision of appropriate staff
- drainage structures are generally subject to inundation at lower stages than most other features of the flood control flood defence system, and any maintenance problems should be corrected as quickly as possible. All flap and sluice gates that are in critical condition should be manually checked and repaired as needed before the outlet end of the structure becomes submerged. Remove debris or other potential obstructions. If the gate system on a drainage structure fails to operate and cannot be repaired, consider blocking the structure opening by other means.

#### 6.4.1.4 Interaction with the community

The patrol team may see observers on the levees or at flood walls. In densely populated areas, an additional person should be assigned to each patrol team to act as a safety officer, explaining the dangers that are present. Teams may distribute instruction cards describing the community evacuation plan. It is important for the members of the public to be warned of the danger in the vicinity of the levee itself and evacuated or kept away.

### 6.4.2 Full response activities

Depending on the predicted severity of the flood event, a levee manager and/or emergency manager will stage their responses, specifically inspection and intervention actions, according to the threat. The decisions about the level of response would generally be made in co-ordination with local authorities.

Some flood plans prescribe specific sets of actions at specific river stages (or floodwater levels), as described in Box 6.10. If the plans do not detail specific actions at defined water surface elevations, the level of response will depend on the decisions of the local authorities. At lower threat levels, less frequent patrols may be needed. At higher threat levels, however, additional teams will be called in and a higher degree of activity will be warranted. Boxes 6.11 and 6.12 present case examples of adjusting response level to changing flood conditions.

During full response activities, patrols are continuously conducted. In addition to preliminary response activities, levee staff should:

- keep a record/inventory of flood management equipment, materials and supplies as they are used
- keep the public informed of the current situation through the media, if warranted
- carry out any intervention actions (see Sections 6.5 to 6.10), including repairing any erosion, seepage, or stability problems
- keep pumping station operators on duty whenever it appears that operation is imminent during flood periods, even when station operation has been automated. Operators should thoroughly understand the manner in which the pumping station was designed to operate and be capable of manual operation should automated equipment or sensors fail
- use portable pumps to pump water over the levee if water ponds in undesirable areas or is rising too quickly in ponding areas
- patrol ponding areas
- monitor debris basins and trash racks for sediment and accumulated debris.

*Box 6.10* *Staged response to flood fighting example, France*

SYMADREM is a public institution responsible for monitoring, management and maintenance in all circumstances of levees located in the Delta of the Rhone. Its scope of management covers 210 km of river levees and 30 km of sea levees, which were erected during the 19th century. 115 000 people are protected by levees. SYMADREM has 24 permanent agents (eight engineers, eight levees guards and eight administrative staff). Main decisions are made by a board of 29 elected people.

During flood periods a graduated monitoring and emergency response is employed.

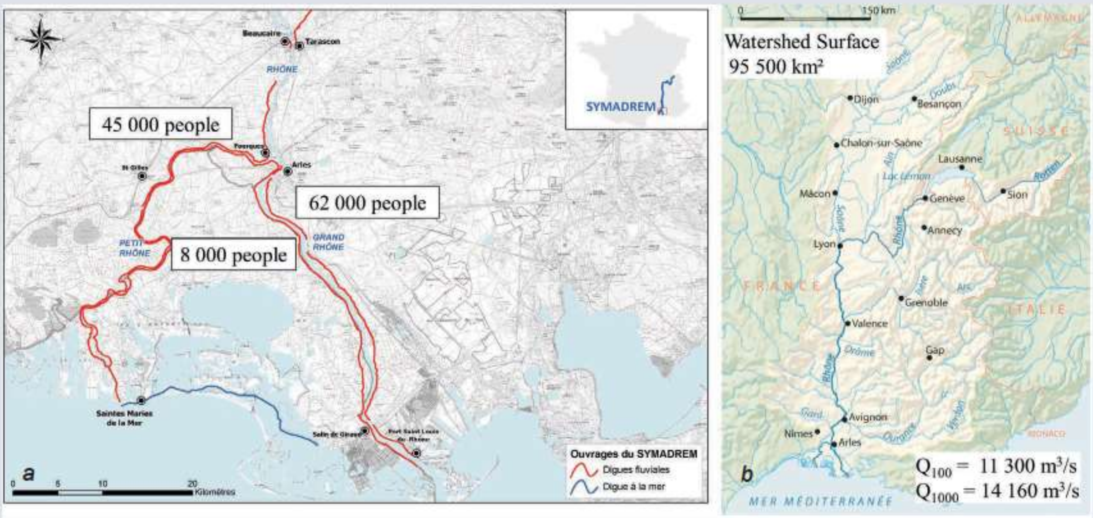



*Figure 6.10* ***Delta of the Rhone river (a) and watershed (b) (courtesy SYMADREM)***

**Issues during flood periods:** Camargue levees were built in the second half of the 19th century after the great floods of 1840 and 1856, whose return periods were respectively 400 and 250 years. The structures were erected on other older levees. Given their form of construction (compaction with manual tamping devices of 15 kg) and their heterogeneous composition (alternating silt/sand) due to successive stages of building, levees are very exposed to failures by internal erosion. The probability of structural damages exists from the early loading from the river and increases with the importance and duration of the flood. Floods of 1993, 1994, 2002 and 2003 showed that breaches can occur in levees before the water reaches the crest. Under these conditions, any early deterioration or damage that is not detected quickly and treated immediately, can worsen rapidly and lead to formation of a breach and the flooding of the leveed area.

**Principles of levees monitoring and emergency interventions plan:** given respective obligations of SYMADREM and local authority mayors (see French Policy of framework in Figures 6.11 and 6.12) and in response to the important length of levees to monitor and insufficient staff to implement effective monitoring, SYMADREM has set up a plan, based on the provision by municipalities of municipal officers and citizen volunteers.

Five alert thresholds are defined, according to the flow upstream of the delta, geometry of the structures and safety levels of levees:

| Alert threshold | Decisions | Discharge threshold per group | | |
|---|---|---|---|---|
| Pre-alert | Plan activation: monitoring of specific points | 4200 | | 7500 |
| Alert 1 | Reinforced monitoring (closing of crossing hydraulics works) | 5500 | | 8400 |
| Alert 2 | Linerar monitoring (day only) | 6750 | 7500 | 9000 |
| Alert 3 | Linear monitoring (day and night) | 8400 | 9000 | 10 500 |
| Alert 4 | Safety level – evacuation of monitoring team | XX | XX | XX |

For each alert threshold, an action plan corresponding to the risks caused by the flood, is defined. The stakeholders involved in this plan are:

- SYMADREM for levees management
- local authorities for ensuring safety of population and supply monitoring team
- companies of public works for emergency interventions
- flood forecasting governmental agency
- prefectures and civil security (army and rescue department) for crisis management and organisation of rescue.

Entities of levees monitoring and emergency interventions plan are:

- command post for levee monitoring, which is composed of engineers, levee guards and administrative staff

*Box 6.10 Staged response to flood fighting example, France (contd)*

- **44 monitoring teams:** municipal officers and volunteers from communal reserve of civil security (under direct authority of the mayor and functional authority of SYMADREM, when monitoring levees)
- **eight municipal correspondents (appointed by the mayor):** responsive for composition and management of monitoring teams (equipment, transport)
- companies (three) of public works for emergency works.

The command post for levee monitoring is based in the headquarters of SYMADREM. For the first two levels of warning (early warning and alert no. 1), levees are not directly influenced by the river, with the exception of specific areas of weakness such as lack of freeboard or presence of former breaches. Monitoring of levees is carried out by the levee guards. Repair of the disorders (burrows of badgers) are executed by the companies in charge of maintenance works. It is also during these stages that the floodgates of the hydraulic structure crossings are closed by owners and the gates closing the access at the levees opened. During these two phases, the command post for the levee monitoring is reduced (only directors). The synopsis of the organisation setup for these two stages is:

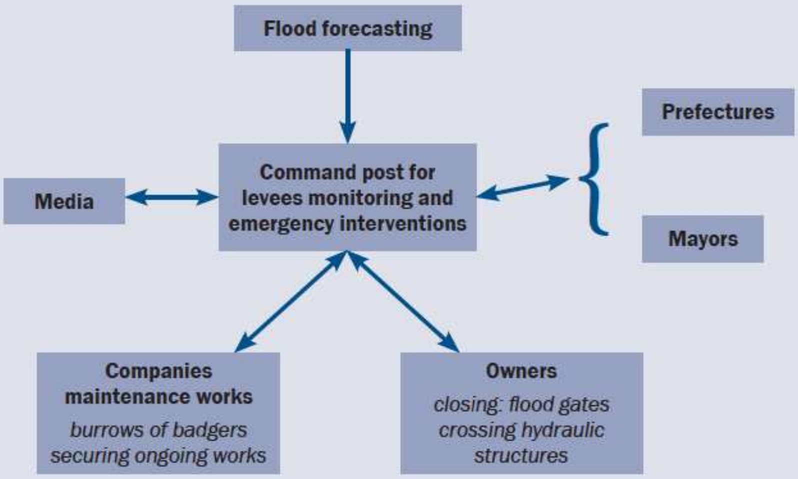



*Figure 6.11 Early alert and alert no.1 – SYMADREM management during flood, links with others*

For alerts no.2 and no.3, levees are influenced by the river. Linear monitoring is in place. On alert no.2, monitoring is performed during the day. On alert no.3, monitoring is performed 24 hours a day. The 44 linear monitoring teams, composed of municipal employees and volunteers from communal reserves of civil security, are under the direct authority of the mayor and functional authority of SYMADREM, as soon as they are on the levees. The command post for the levee monitoring is widened (all staff mobilised). The synopsis of the organisation setup for these two stages is:

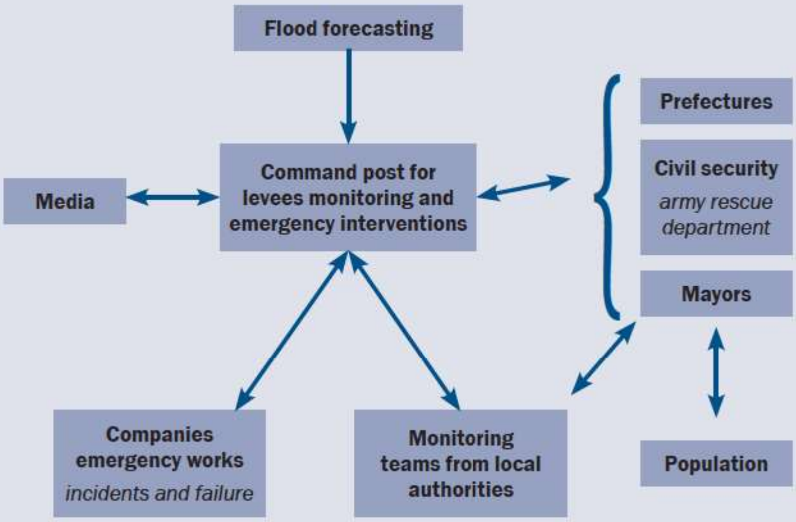



*Figure 6.12 Alert no.2 and alert no.3 – SYMADREM management plan during floods and links with others*

For alert no.4: safety or design level is reached.

Monitoring teams are evacuated. Information is made to mayor and prefect to organise the security setting of population. Beyond the level of safety, levee monitoring is limited to the vigilance of the levee guards. Monitoring by helicopter is requested to the representative of state (prefect).

*Box 6.10* ***Staged response to flood fighting example, France (contd)***

In addition, the management plan includes the following provisions:

- stopping, in case of danger, the monitoring of levees and interventions
- information from the authorities in case of imminent danger and levee failures
- assessment of post-event
- training and simulation exercises
- provision of monitoring equipment (life jackets, lamps)
- establishment of a system of benchmarks
- signage of access to levees.

The improvements planned in the three coming years are:

- additional storage areas for materials
- development of additional access points at the levees
- securing communications (digital radio)
- securing power supplies
- setting up an automatic phone call
- geolocation.

**Note**
Exercise on the SYMADREM levees, guard is equipped with a parka with life jacket integrated. Municipal officers are equipped with classic life jackets. Communications are made with a digital radio.

*Figure 6.13* ***Levee guard (a) and one monitoring team during a flood simulation exercise (b) (courtesy SYMADREM)***

*Box 6.11* *Flood response – early detection example, Gowdall Barrier Bank, UK (2000)*

**Summary**

Even if a failure cannot be prevented by emergency actions, the flooding might be delayed long enough to provide time for full evacuations.

In November 2000, flooding of 150 properties in Gowdall village, major roads, the East Coast railway line and the surrounding countryside occurred following the failure of a washland barrier bank at Heck Ings. However, due to emergency works undertaken by the local Environment Agency team and their professional partners, flooding of the village was delayed, giving the residents an additional three days to evacuate their homes and move their possessions to safety.

Controlled washlands (areas for flood storage) provide flood risk management in the area and are bounded by the riverbank, a higher level barrier bank to the landward side, and then subdivided into compartments by lower level cross banks. The upstream compartments fill then cascade, via the cross-banks, into the next compartment down. On the morning of 2 November, a site patrol noticed slips on the outer face (dry side) of a barrier bank in the Heck Ings compartment. An engineer visited the site, decided that a breach was inevitable and that it was too dangerous to carry out repairs.

The railway line providing the transport link into the Drax power station lies between the breach site and the village, and was identified as a potential secondary line of defence. Environment Agency staff worked closely with the railway authority, the power station, the Internal Drainage Board, highways authority, emergency services and the public to ensure this could be achieved. Where the local road passed beneath the railway a temporary dam was constructed to a height of three metres. A second minor access track crossing was blocked with locally found clay. Culverts were also plugged with clay. A fish farm, a house, and a residential caravan on the 'wrong' side of the secondary defence were evacuated.

The bank finally breached at 3.00 am on 3 November 2000. The temporary dams successfully held a two metre head of water, however once the water built up behind the new defence line some leakage occurred and some culverts blew. The floodwaters started to fill the fields towards Gowdall village. The villagers were warned by loud hailer vans and additional manpower started sandbagging all properties in the village. Once it became apparent that major flooding could not be prevented the village was evacuated, although some residents refused to leave their homes.


*Figure 6.14* ***Levee breach in Gowdall (a) and temporary dam under construction on roadway under Drax railway line (b) (courtesy Environment Agency)***

*Box 6.12 Flood response – risk-informed example, Birds Point Levee, USA (2011)*

**Summary**

Emergency managers may, at times, be faced with choices about flooding one sparsely populated area to protect a more densely populated area.

Deploying a flood-control tool it had not used in 74 years, the U S Army Corps of Engineers (USACE) detonated explosives to breach part of the Birds Point levee in Missouri's Bootheel region to ease the flooding in the town of Cairo, Illinois, and elsewhere in the region.

The decision to 'activate' the Birds Point–New Madrid Floodway was made by the president of the Mississippi River Commission (MRC). When the first segment of the two mile-long 'fuse plug' levee was breached, darkness prevented journalists from seeing how quickly the swollen Mississippi River rushed into the farmland of the floodway. Another segment of the frontline levee was to be breached by explosion later in the night and a third segment, the next morning.

The controversial decision to activate the floodway for the first time since 1937 set off a wave of complaints from Missouri officials who warned of the damage to fertile farmland on the 130 000 km2 floodway, but stirred praise from Illinois officials who wanted the USACE to use every tool available to ease record flood conditions at Cairo and elsewhere near the confluence of the swollen Ohio and Mississippi rivers.

Across the river, officials inspected sand boils and other evidence that floodwaters were undermining some levees around Cairo, most of whose 2800 residents had been evacuated. The National Weather Service said the Ohio River had crested above 18.9 m at Cairo – the level at which a master plan calls for activation of the Birds Point–New Madrid floodway.

Major General Michael Walsh, the MRC President commented about his decision:

> *"Making this decision is not easy or hard – it's simply grave – because the decision leads to loss of property and livelihood – either in a floodway – or in an area that was not designed to flood. The state of Missouri has done a superb job of helping people escape the ravages of water in the floodway. So, with the tool that has withstood many tests: the test of operation in 1937; decades of challenges that resulted in the 1986 Operation Plan; reviews and numerous unsuccessful court challenges – I have to use this tool. I have to activate this floodway to help capture a significant percentage of the flow. I don't have to like it, but we must use everything we have in our possession in the system to prevent a more catastrophic event. So, today, I give the order to operate the Floodway."*

The hours immediately following the detonation saw the Ohio River at Cairo fall more than 15 cm, to 18.7 m. That still surpassed the former record of 18.1 m, set in 1937.

The success of the comprehensive Mississippi River and Tributaries (MR&T) system to date is rooted in the lessons learnt. Perhaps the most important lesson was the necessity to accommodate the Mississippi River by not attempting to exclude it entirely from its natural floodplain. The floodway and backwater features of the MR&T system was implemented for this very purpose – to accommodate the natural tendencies of the river during times of flood, and to help relieve the enormous stress on the levee system and the danger to people, their homes, and the businesses that support the economy.

Damages prevented in the flood of 2011 are in the tens of billions of dollars to date. The levees, floodways, spillways, and backwater areas of the MR&T project are preserving lives, communities, and industry from the impacts of catastrophic flooding. Channel improvements on the Mississippi River are serving as a critical part of the flood control system in this historic event. Without river bend cut-offs, dikes and revetments, the flood would overwhelm the MR&T project and the communities it protects.

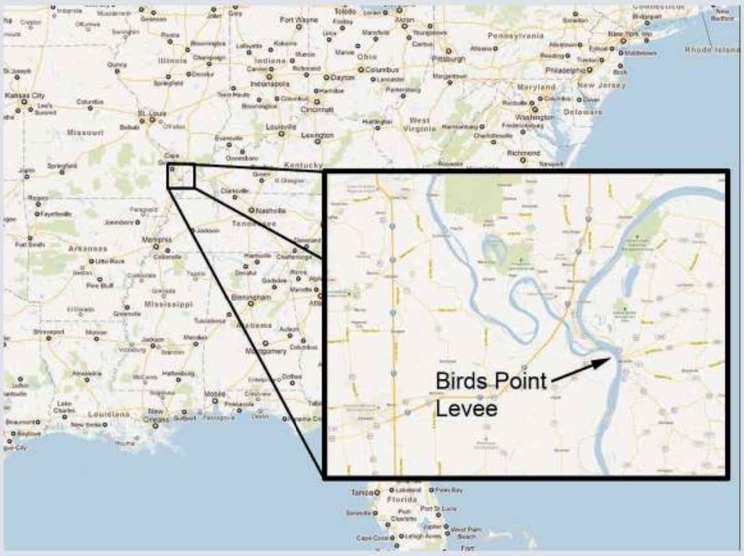



*Figure 6.15 Location map for Birds Point Levee (courtesy USACE)*

*Box 6.12* *Flood response – risk-informed example, Birds Point Levee, USA (2011) (contd)*

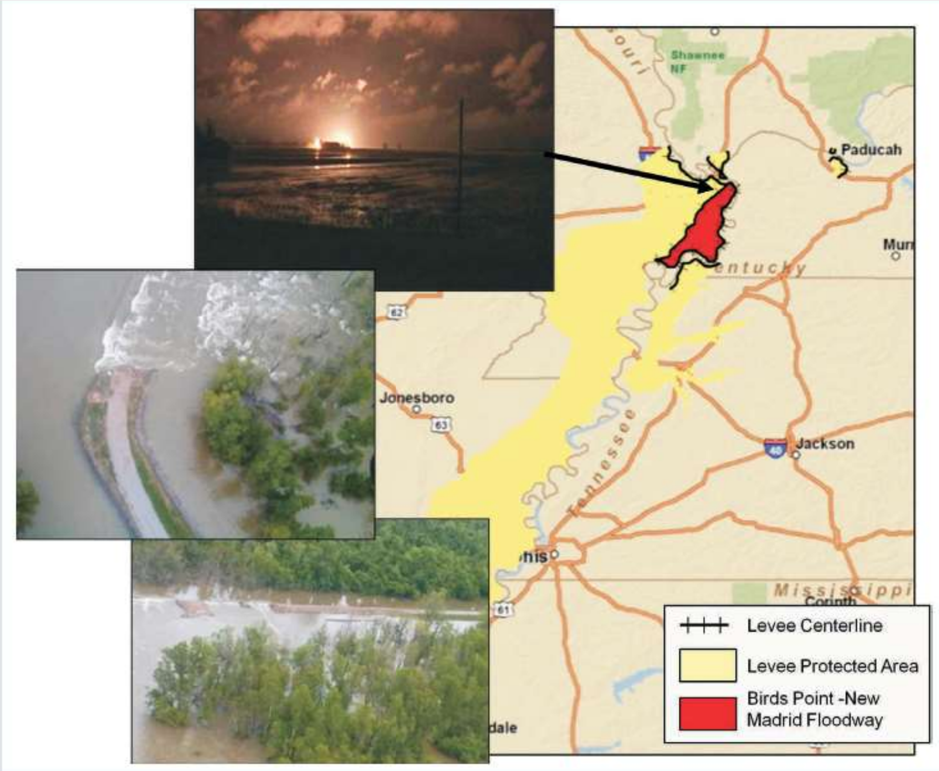



*Figure 6.16* *Birds Point Levee controlled breaching (courtesy USACE)*

## 6.4.2.1 Evacuation plan activation

At some point it may become necessary to initiate an evacuation of the threatened area. It is unlikely that the levee manager will have the authority or resources to perform this activity. An evacuation will most likely be ordered by the emergency manager (local, state or federal authority). The levee managers role in such a case will be to abide by instructions given by the proper authority. See Box 6.13 for an example of evacuation. Levee managers may also provide the necessary information to the emergency manager to be able to decide the evacuation.

*Box 6.13* *Evacuation issues in developing countries*

The levee system encroachment issues faced by developing countries, such as India, are significantly different from those faced by Europe and the USA. Figure 6.17 illustrates how one group of people living in an Indian floodplain responded to a levee breach by moving their community onto the embankment itself. Though this can be an obvious challenge to flood-fighting, these people simply had no other dry place to go.

*Figure 6.17* *India evacuees on a levee*

## 6.4.3 Post response activities

After the response activities are complete, the levee manager should take care to ensure that the pre-event level of protection provided by the levee is quickly restored.

### 6.4.3.1 Short-term operational activities

Review of the operations and maintenance (O&M) manual (see Chapter 4) will provide specific details about some of the needed actions post-flood event. Other actions that may be needed to return the flood defence system area to the pre-flood condition can be found in the emergency action plan. Among these are:

- immediate operational activities (which may not be the direct responsibility of the levee manager):
  - return sluice gates in the levees to the normal position
  - open all closure structures in the levees and properly clean and store all components.
- inspection and repair:
  - conduct a post-event inspection, noting high-water marks, locations and extent of damage
  - make repairs to the levee as soon as possible in preparation for the next flood event
  - all temporary protection measures (eg sandbags and material placed during temporary levee raises) should be removed and disposed of properly
  - restore any damaged access routes, staging areas and collateral damage to the pre-flood condition.
- equipment:
  - make an inventory of all remaining flood response equipment, sandbags, and other supplies
  - repair or replace damaged equipment, and restock supplies in preparation for the next flood event
  - salvage any reusable or recyclable materials and supplies (eg wood from flashboards).
- other meetings and activities:
  - meet with key personnel, volunteer representatives, and community partners to debrief, share remaining concerns, and discuss lessons learnt during the event
  - leverage community interest and success stories to increase community awareness about the importance of the levee system
  - revise local emergency preparedness plans to account for lessons learnt and changes to recommended procedures
  - beginning planning for any long-term needs, such as studies or improvements (including improvement of level of protection).

Deployment of temporary solutions during flood emergencies should not be considered to be a permanent solution. Alternative mitigation strategies should be considered after the flood event and, where necessary, appropriate actions should be initiated to install permanent structures.

### 6.4.3.2 After action report

Following an event, actions and results should be properly documented in a report. It is likely that the levee manager and emergency manager will both produce documentation related to the event (and indeed may also be possible/useful/necessary for a national scale analysis, incorporating all activities). The levee manager should co-ordinate any specific activities that were conducted into the larger report on the levee system to ensure complete and thorough reporting. After-action or feedback reports are generally made available to all interested public safety and emergency management organisations and serve the following important functions:

- a source for documentation of response activities
- identifies problems/successes during emergency operations
- analysis of the effectiveness of the components of the emergency action

- identify any potential needed improvements to the levee or the level of protection provided
- describes and defines a plan of action for implementing improvements
- captures key lessons learnt.

The key components of after-action reports are:

- overview
- goals and objectives
- analysis of the outcomes including levee performance and response actions
- analysis of the capacity to perform critical tasks
- summary
- recommendations (including specific improvements for each stakeholder).

If consideration is given to making an intervention (semi-) permanent, specific complete performance assessments of the applied intervention techniques (such as seepage berms) should be carried out.

### 6.4.3.3 Long-term mitigation

Lessons learnt can provide emergency management officials and levee managers valuable information about how to plan for the future and provide improved responses. This information can also be used to inform public officials and residents about flood risk and to assist in public policy discussions concerning land use and building codes. Other outcomes of an after-action review could produce either a more effective response during an emergency or improvements to the flood control defences to reduce the need for flood response. See Box 6.14 for example of lessons learnt from an after-action report.

*Box 6.14* *After-action items examples, Hurricane Agnes (1972) and Tropical Storm Lee (2011), USA*

In 1972, a large hurricane struck the USA eastern seaboard causing major flooding in the state of Pennsylvania. The levees protecting a major town were insufficient and losses were very large. As a result of this, the flood protection system around the town was improved and when another large storm hit the same area in September 2011, the levees held and protected the town.

A significant flooding event happened in June 1972, when a hurricane-turned-tropical storm struck Pennsylvania and stalled over the central part of the state for nearly 24 hours. Hurricane Agnes dropped a minimum of five, and in some areas as much as 18 inches of precipitation on Pennsylvania, inundating streams, rivers, and towns. On the evening of 23 June 1972, Agnes moved north across western New York and into Canada, dissipating along the way. In its wake, the storm left a persistent drizzle and one of the most devastating natural disasters in the history of the United States.

Federal flood control structures constructed by the USACE, Philadelphia District successfully accomplished their intended purpose during the storm. Elsewhere, however, floodwaters topped non-federal flood works and inundated towns, leading the Philadelphia District to mobilise in response. Starting around the clock, the Philadelphia District activated staff before the arrival of Hurricane Agnes for field monitoring, maintaining a watch on storm advance, river stages, readiness of reservoirs to store floodwaters, and availability of sandbags. On 23 June, as the storm hovered over Pennsylvania, Philadelphia District officials directed that an emergency operations center be activated. Shortly afterwards, the District staff deployed to Wilkes-Barre to assist in sandbagging, although their efforts were halted when floodwaters overflowed existing dikes and deluged the town. In other areas closer to Philadelphia, the District assisted in the removal of debris from the Schuylkill and Delaware rivers.

In the aftermath of Hurricane Agnes, Wilkes-Barre's levees were strengthened and improved to protect against future flooding. They were tested several times by substaintial flooding and tested to the extreme in 2011 by Tropical Storm Lee. The levee system had undergone a rehabilitation in the early 2000s and it was decided to construct a roadway flood closure on Market Street as opposed to relying on sandbagging for protection at that location.

Wilkes-Barre's $175m upgraded system of dikes and flood walls prevented tens of millions of dollars in property damage from Tropical Storm Lee in 2011.

When a flood event causes extensive damage, the lessons learnt from that event should be used to plan for future events. Hurricane Agnes demonstrated where flood defences were weak and the response was to strengthen and improve those defences. As shown by the storm in 2011, the efforts were successful and well executed.

# 6.5 INTERVENTION TECHNIQUES

Even though there are many types of failure modes and origins, the emergency responses to these signs of distress can be similar (Environment Agency, 2009, Ogunyoye *et al*, 2011, and State of California 2010). There is no absolute method that can be applied to guarantee successful operation of every levee system. However, failure to react in a timely manner and apply proven flood response techniques greatly increases the risk of failure. Although each flood is unique, there are many common elements from one flood to the next, and proper planning will improve response time and chances of success.

Levee managers and owners are responsible for their levee systems O&M, and are also key stakeholders in flood response activities during high water/storm events. To be ready for these tasks, they are responsible for establishing flood response plans (Section 6.2.3), conducting training, stockpiling needed materials, and for other flood preparations (Section 6.5.1). This section outlines some basic activities that will help ensure that flood responses will be timely and effective.

The choice of intervention techniques will depend on the threat posed by the flood. River systems vary greatly in the flood duration, size of river and velocity of flows. Coastal flooding is significantly different in that the wave action and tidal influence make intervention during a storm very difficult, so the best response for a coastal levee is to make preparations before the storm and take action once a storm is predicted.

Typical circumstances during a flood may differ strongly among levees along different types of water systems, as will the required flood response activities. So, the requirements for intervention techniques differs to a certain extent among levees. Table 6.2 presents some differences. The consequent impact on flood response and techniques is that levees along the coast, estuaries, lakes and some rivers:

- are hard to access during the flood, especially the waterside slope and crest
- need focus for patrolling to detect signs of distress or external erosion, eg the waterside slope (wave attack) and crest (overtopping)
- requires a fast response.

*Table 6.2 Differences in flooding characteristics*

| Feature | Wind driven events<br>*Levees along coast, estuary, lake* | High water driven events<br>*Levees along river, canals* |
|---|---|---|
| Weather condition | Storm, high wind speeds and high waves are likely | Can be any, but high wind speed (and waves) are not likely |
| Response/ preparedness | Forecast approximately days/weeks | Forecast likely in terms of weeks (although in small catchment areas also days, sometimes hours): flash floods |
| Duration of the event | Short: approximately one day (peak: hours) | Long (likely): varies from days to weeks |
| Repair | Hours/days: depending on the damage, before the next tide or at least before the next storm (which may be a matter of days) | Weeks: most likely a second flood will next follow soon, time repair may be in terms of weeks/months (except small catchments) |
| Failure mode | Focus on external erosion | All failure modes equally likely |

## 6.5.1 Flood response equipment and supplies

Levee managers should maintain a stockpile of necessary supplies and equipment used to respond to typical high water/storm events. In a flood, stockpiled materials will provide the capability to quickly initiate a preliminary response while additional materials and equipment are being delivered. The specific requirement for supplies varies depending on the size of the levee system and on past flood events. The best way to determine the necessary quantities for the current stockpile is to inventory the type and quantity of supplies that were used during previous floods if such information is available.

Flood risk management materials and equipment may include (in no particular order):

- **sandbags:** levee managers should maintain an adequate supply of sandbags that can be used for a levee raise or sandboil ring diking. Burlap sandbags have a limited shelf life (usually about eight years if stored in a humidity controlled environment) and should be inspected annually and replaced when necessary. The stockpile of sandbags should be stored in a dry, secure location that does not expose the sandbags to sunlight (Figure 6.18). Continued sunlight and weather will rapidly deteriorate the sandbag material

*Figure 6.18 Sandbag storage at a levee pumping station (courtesy USACE)*

- **plastic sheeting:** there are many applications for plastic sheeting during flood responses. If it is one of the items that typically gets used in a community during a flood response and there is any doubt about its availability during an emergency, it should be stockpiled in preparation for a high water event
- **shovels/sandbag filling machines:** if the levee system contains areas where large quantities of sandbags will be needed, a reliable method for filling them is also needed. Levee managers may want to consider investing in equipment that will assist in completing this process more quickly
- **emergency lighting:** it is strongly recommended that levee managers maintain emergency lighting, permanent or movable, that would be readily available for use during flood responses
- **communication systems:** reliable communications are extremely important for co-ordinating flood response efforts and for calling for assistance when needed. Mobile telephones work very well, but are limited in their capacity for communicating with multiple people at one time. Cellular networks may become inoperable or overloaded during an emergency. Two-way radios may be preferable as they are extremely reliable for short distances and have the capability to broadcast to several people at once. Without a reliable communication system, any flood management effort will be more difficult and may require additional manpower. Advances in communication technology now enable various communication systems to speak with one another without requiring separate radio systems. Many public safety organisations are replacing legacy communication systems with these newer systems. A wide range of facilities, such as nuclear power plants and prisons have incorporated these upgrades. Levee owners may consider updating their systems to help consolidate communications
- **sources of borrow material:** sources of landside borrow material should be located prior to a flood event. Several borrow areas should be identified in advance as wet weather or muddy conditions could unexpectedly limit access to some sites. Careful consideration should be given to access points of the levee when selecting sites for the borrow material
- **rip-rap (rock armour) for erosion:** while it might not always be necessary to stockpile rip-rap, it is important to know the location and telephone numbers of local quarries capable of supplying rip-rap during an emergency. Some levee systems maintain a supply of gravel on site to ensure levee access routes during an emergency
- **flotation vests:** the health, safety and welfare of workers and volunteers should always be the highest priority during a flood response. Flotation coats or vests should be worn at all times when

working near the waterside of the levee or near fast moving water. Floodwaters can quickly sweep a person downstream, and hypothermia can set in quickly in cold water conditions

- **pumps:** pumps are a critical part of any flood management effort. Pumps are used to control interior drainage and seepage through the levee. Levee managers or local authorities that experience frequent flooding should consider purchasing one or more high capacity pumps
- **temporary flood wall systems:** temporary flood wall systems can be installed to provide a flood defence barrier in areas where the predicted height of the rising river is higher than the height of the levee system or in areas where no flood defence system exists. Several products of this type are available and discussed in Section 6.10.

## 6.5.2 Flood response activities

It is critical for levee managers to understand the impacts of flood response activities. Where and how to employ flood response efforts involves:

- knowledge of the local area
- the condition of the flood defences
- the state of preparedness of the locals
- the predicted storm severity.

Special considerations should be given to the nature of the flood threat (ie whether the flood is due to river flooding, a large rain storm, or coastal flooding associated with large waves or storm surge). As in the example in Box 6.15, thought should be given to unintended consequences of a temporary measure.

**Caution**

**Many of the intervention techniques in this section may appear to represent a good course of action as a predicted flood approaches, but doing so may have unintended hydraulic and structural consequences such as:**

- **more rapid inundation of the leveed area in the event of overtopping or breach**
- **damage to another jurisdiction downstream or across the river**
- **damage to the levee itself.**

**An overall flood management effort should address these types of issues and co-ordinate the impacts of all activities.**

*Box 6.15* *Coastal flood response options, USA*


*Figure 6.19* *Consideration of unintended consequences (courtesy USACE)*

A large storm was predicted to affect the west coast of the State of Washington (USA) in 2010 when emergency planners determined the existing levee system was inadequate to provide the necessary protection. The map (Figure 6.19) shows where the storm surge was expected to flow into the populated area (red arrows). Access to these areas was not possible, so an alternate location was proposed. However, after further evaluation, the setback berm was determined to be in such a location as to hold water in that made it through the first line of defence and was not constructed. Although the berm would have prevented flooding from a direct assault, the negative impact of the structure preventing water on the landward side from returning to the sea made this solution impractical. Careful consideration of the whole flood response effort should be given so as to avoid unintended consequences.

### 6.5.2.1 Response activities and levee failure mechanisms

A well-designed and constructed levee, that is properly maintained, and does not experience overflow/overtopping should be able to hold throughout a flood event or a flood event up to its design level. However, it is important to recognise that whenever there is water holding against the levee, the potential for an emergency condition to develop exists. The danger increases with the height of water, the duration of the flood stage, the intensity of the current, and the wave action against the levee face. See Box 6.16 for an example of a typical flood response. There are three main categories that can be identified associated with mechanisms that could potentially lead to a levee failure:

- **external erosion** – includes erosion triggers such as overflowing, overtopping, wave wash conditions, and scour
- **internal erosion** – includes erosion triggers such as seepage and sand boils
- **instability** – includes soil movement and landslides.

Potential levee failures may be prevented if prompt action is taken and proper response methods are employed. The following sections describe some of the general actions that should be taken to raise the crown of a levee or to respond to sand boils, seepage problems, or wave wash if these problems are identified during a patrol. Table 6.3 gives an overview of the response measures that can be used as intervention for the three categories of levee failure mechanism previously discussed. This list is by no means exhaustive but represents either a response measure that is predominantly used or a response measure that is representative of a class of measures. Each of these measures will be discussed in some detail in the remainder of this section. It is important to note that all the measures presented in Table 6.3 are meant to be used as a means to prevent the levee from progressing from deterioration to damage to breach. In the event that a breach is initiated or fully developed, then response activities are unique and will be detailed later in Section 6.9.

The methods described here represent good practices developed because of many years of experience in dealing with problems resulting from high water/storm events. There is a wide range of intervention techniques that can be implemented depending on the conditions of the flood event. A levee manager should evaluate the event situation and identify the requirements in order to respond given available materials, equipment, staff, and time.

*Table 6.3 Measures to be used as intervention in an emergency response*

| Failure mechanism | Applicable intervention | Measures |
|---|---|---|
| External erosion | Raise the crest (Section 6.6.1) (locally only, or if carefully planned at a larger scale) | Place and compact bulk fill (earth, clay, ash etc) (Section 6.6.1.1) |
| | | Construct sandbag levee (Section 6.6.1.2) |
| | | Use novel material: lightweight concrete blocks, straw bales, tyre bales (Section 6.6.1.3) |
| | | Drive piling (Section 6.6.1.4) |
| | | Construct a flashboard structure (Section 6.6.1.5) |
| | | Portable cofferdam structure (Section 6.10) |
| | | Portable dam system (Section 6.10) |
| | | Water inflated barrier (Section 6.10) |
| | | Water filled tubes (Section 6.10) |
| | | Open celled plastic grid wall (Section 6.10) |
| | | Filled permeable container (Section 6.10) |
| | | Demountable barriers (Section 6.10) |
| | Provide erosion protection (Section 6.6.2) | Construct rock/rip-rap berm (Section 6.6.2.1) |
| | | Place asphalt/bitumen layer (Section 6.6.2.2) |
| | | Construct small groyne (Section 6.6.2.3) |
| | Provide protection against overflowing/overtopping erosion (Section 6.6.3) | Place plastic sheeting on the land side and the crest (Section 6.6.3.1) |
| | | Construct an emergency spillway (Section 6.6.3.2) |
| Internal erosion | Reduce infiltration to reduce through-seepage (Section 6.7.1) | Place plastic sheeting on the water side (Section 6.7.1.1) |
| | Increase seepage path to reduce through-seepage (Section 6.7.2) | Construct seepage berm (Section 6.7.2.1) |
| | Reduce hydraulic gradient to reduce under-seepage (Section 6.7.3) | Ringing sand boils (Section 6.7.3.1) |
| | | Increase landside water level (Section 6.7.3.2) |
| Instability | Reduce slope inclination and steepness (Section 6.8.1) | |
| | Reduce pressure underneath levee (Section 6.8.2) | |
| | Reduce saturation of levee (Section 6.8.3) | |

*Box 6.16* *Flood response example in the Netherlands*

The combination of heavy rainfall and high water levels at sea (due to two large north-western storms) resulted in unusual situations in the Northern Provinces of the Netherlands in January 2012. Water from the inland water transport system could no longer be discharged at sea and many levees were overflowing and risking instability due to saturation.

Several precautionary measures were taken by the water boards Noorderzijlvest and Fryslân:

- opened special flooding areas to reduce water levels in other parts of the system or to prevent the water from rising further
- stopped draining water to the main water system (causing shallow inundation in the polders)
- set water pumps to full capacity to drain water to the sea
- placed sandbags on landside slope and toe of levee to prevent micro and macro instability and piping
- placed impermeable geotextiles on the waterside slope of the levee
- placed sandbags and bare soil on top of the levee to prevent from overtopping
- the village of Woltersum was evacuated, including the cattle of dairy farms
- extra inspections executed to detect cracks, deformations, water and sand coming through the levee.

During normal situations the water boards lead and are responsible for operations and maintenance of the levees. During critical situations the Regional Policy Team and Regional Operational Team are responsible and make decisions. The central government is then in charge instead of the water boards, because integral decisions need to be made. The role of the water board is solely to give advice. During evacuations the mayor of the regarding village is in charge.

Stakeholders that are involved during emergency preparedness are mainly employees of the water boards, boroughs and provinces, constructors, medical aid organisations, fire department, police departments and the army. Engineering companies, Directorate-General for Public Works and Water Management and volunteers are hardly involved in these situations.

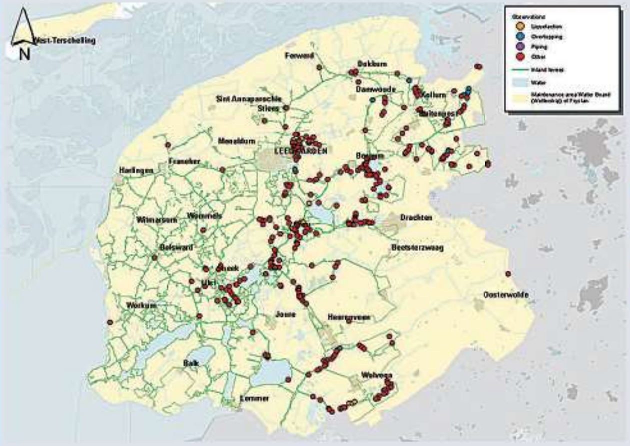



*Figure 6.20* *Flooding in the Netherlands, January 2012 (courtesy Wetterskip Fryslân)*

Difficulties that were faced during flooding in January 2012, and lessons learnt:

- massive media attention (water board at Fryslân gave 15 interviews a day with five employees working 15 hours a day to answer press questions)
- changes of roles and responsibilities need to be clear and communicated with people in the field
- lack of capacity to make the calculations and write decision papers
- large effort was required for registration of the movements of the cattle (as required by rules regarding animal diseases), and thorough decontamination of the trucks after each visit of a farm.

# 6.6 RESPONSE TO EXTERNAL EROSION AND TECHNIQUES FOR INTERVENTION

External erosion is the wearing away of a surface (bank, streambed, embankment, or other surface) by floods, waves, wind, or any other natural process. See Chapter 3 for a detailed description of the external erosion process.

There are three main conditions that can trigger external deterioration and potential failure mechanisms on levees. These are:

- **overflowing** refers to the steady flow of water over the levee crest
- **overtopping** refers to the intermittent water flow over the levee crest, including wave action
- **wave wash** refers to the erosion of the levee slope on the water side as a result of wave action.

It is important to note that wave action effects can be triggered by passing boats, onshore winds, or storms. In either case, wave action may seriously damage a levee, particularly if the water surface is near the levee crown, if the levee is newly constructed, or if the levee is constructed of sandy soil. In many cases, the necessity for wave wash protection cannot be foreseen, and construction often becomes an emergency operation. The fluctuation of river stages as well as the uncertainty of weather conditions often make it impracticable to anticipate wave wash damage, except for the assembling of necessary materials and supplies at convenient supply bases. A severe storm of a general nature may cause serious damage to the levee line. As it is impossible to predict the severity and duration of such storms, it is the duty of field forces to recommend the construction of protective works that can be reasonably justified and to hold themselves in constant readiness to support emergency response as they ensue.

Techniques to mitigate external erosion generally focus on:

- raising the crest elevation
- providing erosion protection on the levee slopes.

## 6.6.1 Levee raising measures

The impacts of raising a levee should be considered when formulating a plan of action. Co-ordination of the levee manager with the local authorities should be ongoing during the flood event and plans for raising a levee need to include the impacts to other flood districts or communities within the flood basin. When a flood is predicted far enough in advance that it allows for construction of temporary levees in areas of high consequence, the appropriate equipment and material should be located and mobilised immediately. Flood forecasts can be used to determine how high to build a temporary levee or to raise an existing one. The alignment for a temporary levee is generally determined by practical considerations about land use and ownership, as well as physical constraints related to the logistics of construction.

There are a number of ways that the levee crown can be raised (Table 6.3). Care should be given to ensure that the levee raise does not jeopardise the stability of the existing levee by adding excessive weight and flood loading to the levee. Excess weight could cause slope failure. Heavy equipment should not be used on a levee whenever the water surface level is near the top of the crown, as the vibration may cause a failure. In no case should such equipment be allowed on an earthen levee after the levee has started to seep. It should also be checked that raising the levee does not flood previously leveed areas, without properly informing the local authorities and considering possible evacuation of the local population.

### 6.6.1.1 Place bulk fill

Provided the work is carried out well in advance of the high water event, in areas where there is sufficient space for construction and with the proper equipment, the most efficient means of raising low stretches of the levee is to use bulk fill (see Figure 6.21). The fill material could be soil (local or hauled), gravel fill, ash from coal fired stations, black furnace slag, or other suitable material. This measure can be used under these conditions:

- there is good access to the embankment and slope
- embankment can withstand heavy equipment.

This measure should be avoided if there are substantial flows over the crest that can wash away the material being placed or if there are safety concerns for personnel and equipment.

Before placement of the fill material the existing embankment surface should be scarified and clear of any debris. The material should be placed on the crest in lifts, ideally with each lift properly compacted. This may not always be possible depending on the situation. Figure 6.22 shows an increase in levee height by simply placing bare soil (clay) in the crest. The height is determined by predicted levels of water/wave.

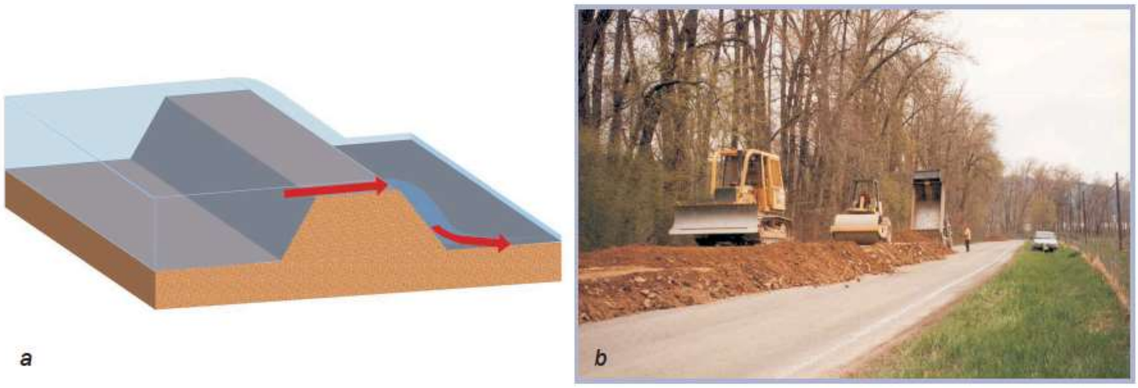



*Figure 6.21* *Levee overflow (a) and levee raise with earthfill (b) (courtesy ASCE)*

*Figure 6.22* *Increase crest height with bare soil (clay) (courtesy Wetterskip Fryslân)*

### 6.6.1.2 Construct sandbag levee

Sandbags (or alternatively big bags) can be used to raise the height of an existing levee (Figure 6.23), or they can be used over open ground to protect an area with no levee at all. Any time a sandbag levee will be constructed over one layer high, the bags should be stacked in a pyramid structure to ensure stability. The basic rules of thumb in constructing these structures is that they should be approximately three times as wide as they are high, and the sandbags should be staggered within each layer just as they are staggered from one layer to the next. The directions of the bags (transverse or longitudinal) may be alternated, as long as no loose ends are left exposed. The base area available limits the height of a sandbag capping, so a levee can usually be raised only a few feet by this method. The measure can be used under these conditions:

- good access to embankment crest and slope
- embankment can withstand heavy loads and equipment
- ample supply of sandbags, sand, and staging area.

This measure should be avoided if there are substantial flows over the crest that can wash away the sandbags being placed or if there are safety concerns for personnel and equipment.

The following is a description of the proper steps required to construct a sandbag levee:

- clear the foundation where sandbags are to be placed. This will provide for a good boundary between the ground surface and the sandbags, and reduce the amount of seepage that could occur along the boundary
  - sandbags should be filled one-half to two-thirds full

- refrain from tying bags if they are filled at the site of placement. If the bags are to be filled off site and transported to the placement site, then tying the bags will prevent losses due to spillage
- place the filled bags length-wise and parallel to the direction of flow
  - lay the unfilled portion of the bag flat on the ground
  - place the succeeding bags on the unfilled or tied portion of the previously laid bag and stamp into place to eliminate voids and form a tight seal
  - stagger the joint connections when multiple layers are necessary and stack the sandbags in pyramid fashion.

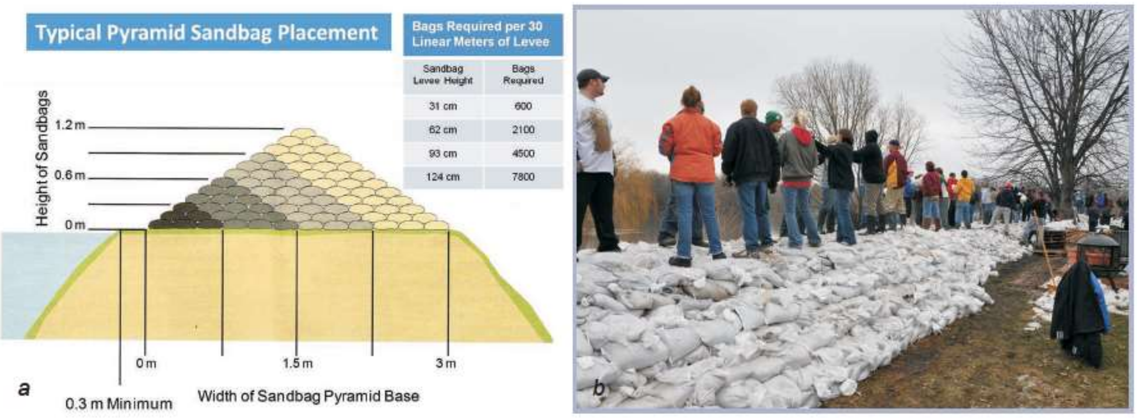



*Figure 6.23 Typical sandbag levee (a) and levee raise with sandbags (b) (courtesy USACE)*

### 6.6.1.3 Use novel materials

Although bulk fill and sandbags are the most common material used to effect a levee raise, other novel materials can be used under certain conditions. These materials include lightweight concrete blocks, straw bales and tyre bales (Figure 6.24). The benefit of using this material is in situations where the levee can not support any heavy material or the crest width is too narrow to facilitate use of fill or sandbags.


*Figure 6.24 Lightweight concrete block (a), straw bales (b), and tyre bales (c) (courtesy Environment Agency)*

All three material types require the use of plastic sheeting or geotextile to cover and act as an impermeable layer. Also, these materials will require stabilising with wire, ropes, or some type of ballast.

### 6.6.1.4 Sheet piling

Where river flood levels will be elevated for a considerable period of time, installing sheet piles is a good option to consider if there is a need to raise the levee (Figure 6.25). Piling can be driven either waterside of the levee (near toe, toe, midslope) or through the levee crest. If the piling is driven on the waterside, depending on the height above grade and expected water levels, then support may need to be provided by filling between the piling and levee with some type of fill material.

If permitted, consideration can be given to extracting the piles after the event and returning the levee to its original condition. This can be done where:

- there is good access to embankment crest and slope
- the levee can withstand large heavy equipment
- necessary repairs are made to any damage to the levee by the activity.

This measure should be avoided if water levels are high (generally placed at low water levels) or if there are safety concerns for personnel and equipment.

Piling would generally be placed when water flows are low or subsided. The piles are driven into the embankment to a depth determined for proper stability and/or cut-off of flow. Any fill material that is used should be of sufficient size or compaction to not be affected by erosion.

*Figure 6.25 Use of piling for levee raise (courtesy Environment Agency)*

### 6.6.1.5 Flashboard structures

This type of levee raise can be very useful in certain conditions, Figure 6.26. Generally, this measure takes time to construct and is material/labour intensive. The measure is straight forward to construct and can accommodate additional raises to a certain extent. The primary materials used in this measure are wooden stakes and panels, and sandbags or other suitable fill material. The measure can be used under these conditions:

- good access to embankment crest and slope
- embankment can withstand large heavy equipment.

This measure should be avoided if there is limited time available for placement or there are safety concerns for personnel and equipment.

To construct a flashboard, wooden panels are driven vertically into the crest on the waterside. The panels are supported with sandbags or fill material on the landside. Also, wooden stakes are used to prop the panels. An impermeable material (plastic sheeting or geomembrane) can be placed over the structure.

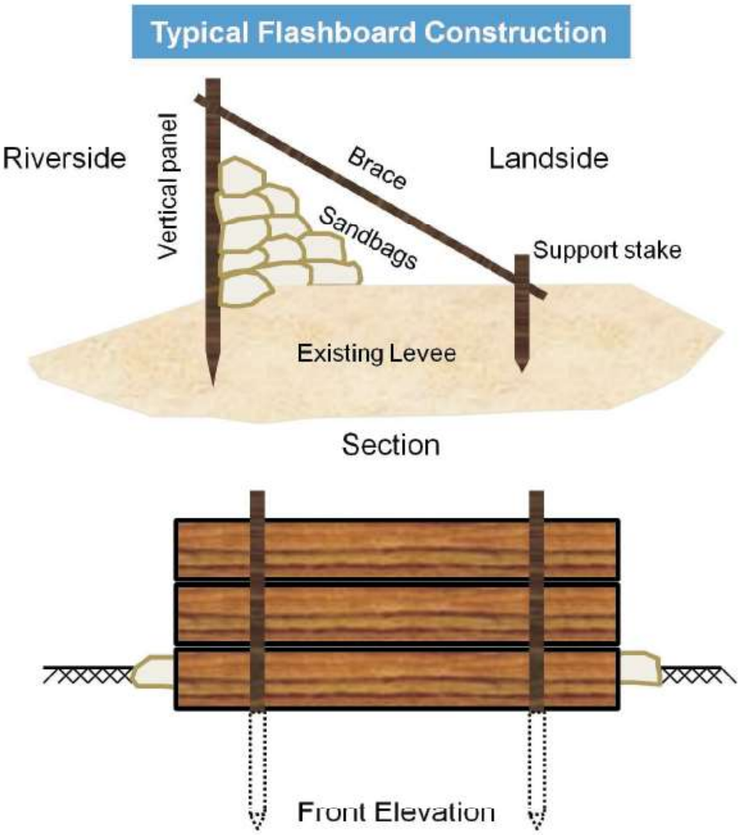



*Figure 6.26 Use of flashboard for levee raise*

## 6.6.2 External erosion protection measures

Scour is the erosion of the riverside slope of the levee by abnormally high water velocities or wave action, Figure 6.27. Physical conditions that cause scour are outside angles in the levee, waterway gaps that have been cut through abandoned levees, secondary levees, and topographical features that may create relatively deep channels adjacent to the levee during high water/storm event. Levees constructed across points of land are often subject to current scour as a result of the concentration of flow. Scours are particularly dangerous due to the treacherous manner in which they develop and the difficulty of detection until almost irreparable damage has been done. However, the chief danger, is that the scour will work into the levee slope. This type of scour resembles the caving bank of a river in action and appearance, in that it erodes under water and has a vertical caving face. When the water is near the top of the levee, and by the time the vertical caving face appears above the water surface, a large portion of the levee is gone. Flood response personnel should make careful observations of the riverside of the levee in all reaches where an unusually fast current is apparent. For flood protection projects that have been designed using a hydraulic model, careful observations of the riverside of the levee should be made where the profiles show a steep high water slope. Turbulence in areas where the water is shallow is a good sign of no scour, but should be monitored. If the turbulence unexpectedly becomes still, scour may be suspected and soundings should be made immediately. Conversely, in deep water, scour may be indicated by turbulence and eddies. Field personnel should be particularly watchful for such conditions. If erosion is evident, immediate steps should be taken to protect the levee.

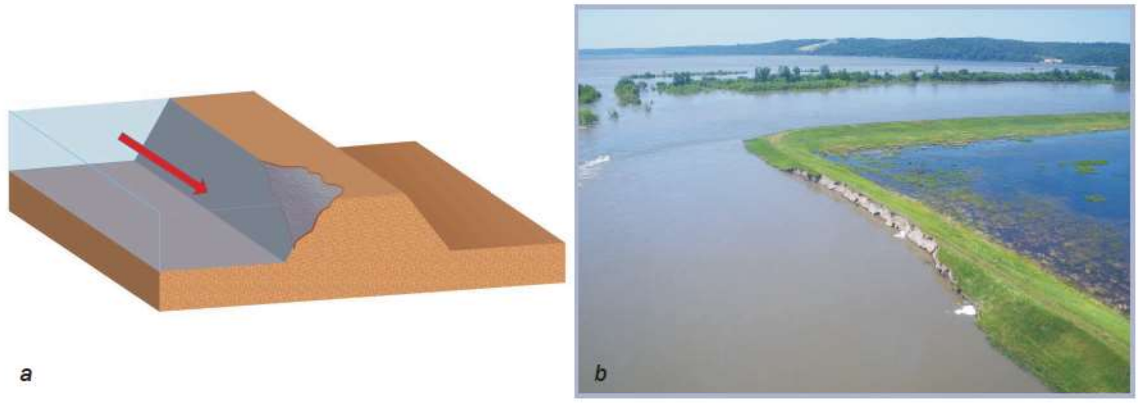



*Figure 6.27 Scour on a levee graphic (a) and field image (b) (courtesy ASCE)*

The methods used in protecting a levee against current scour depend entirely upon local conditions. In some cases, the current attack is so severe, and the scour is of such serious nature, that it requires specially designed structures that cannot be constructed with the ordinary high water response equipment and personnel. Usually, however, current scour can be prevented or stopped by relatively simple techniques. In cases where minor current attacks are evident on the levee slopes, especially on newly constructed levees, the riverside slope should be protected from current action. The current protection work should extend as far under water as practicable in an attempt to restore the original levee cross-section.

#### 6.6.2.1 Rock berm

Construction of a rock berm is a positive means of providing slope protection and has been used in instances where erosive forces (carried by current, waves, or debris) were too large to efficiently be controlled by other means (see Figure 6.28). The rock can be from any source but should be sufficiently large and angular to resist movement once placed. This method has the advantage that it can be placed under adverse conditions where other measures could not, such as high water, strong currents or waves. The disadvantage of this measure is that the material is usually high in cost and not local to the needed area, requiring potentially long haul times. This measure can be used under these conditions:

- there is good access to the embankment and slope
- embankment can withstand heavy equipment
- adequate supply of rock.

This measure should be avoided if there are safety concerns for personnel and equipment.

For construction of a rock berm the material is first placed at the bottom of the levee waterside toe or bottom of the scour hole, then continued up the waterside levee face (some locations prefer to construct the berm on the landside slope of the levee, see Box 6.17). The width of the berm is primarily determined by the nature of the scour and water forces. Material is placed until the berm is stable and will sustain an additional lift. The length of the berm should be sufficient to fully cover the scour area and overlap the undamaged levee on both sides. Where possible, consideration should be given to first placing a geotextile or other filter to limit wash out of fine material, but it should be appreciated that this may be impractical under the prevailing conditions.

*Figure 6.28 Construction of a rock revetment (courtesy USACE)*

### 6.6.2.2 Asphalt/bitumen surface

Many levees particularly in coastal settings are covered with a layer of asphalt, concrete blocks or stones (see Figure 6.29). This revetment material may be damaged during a storm in the form of cracks, fissures, or missing material (Pullen *et al*, 2007). In these cases the levee manager should try to make an emergency repair as soon as possible to minimise the damage. There are basically two options for making these repairs. One would be to replace missing material with stones that are held in place with asphalt that has been mixed and heated such that it can be 'poured' into the material. The second option related to cracks and fissures is to fill those damaged areas with the same pourable asphalt. The asphalt will harden as it cools down. The additional use of a geotextile can be considered if the wave and wind conditions allow. Care should be given to the use of geotextile to prevent the material from interfering with the penetration of asphalt between and around the repair material.


*Figure 6.29 Examples of levee with asphalt (a) and stone revetment (b) (courtesy STOWA)*

### 6.6.2.3 Construct small groyne

This measure consists of constructing a small groyne from the levee extending a short distance into the channel or sea to deflect the current away from the levee or add protection from wave attacks to the levee. Groynes of this type are known as deflecting groynes since they change the direction of flow without repelling it. They are generally short and used for limited, local protection.

This emergency groyne can be constructed of several types of material including rock, sandbags, earthfill, timber, or any other available substantial material. Preferably, groynes would be placed in the dry at locations where severe scour may be anticipated. However, they can be constructed in the water (using suitable material) under certain current and wave conditions. Consideration should be given to the resulting hydraulics since haphazard placement of a groyne may have detrimental consequences. Some examples of groynes are given in Figure 6.30.


*Figure 6.30 Examples of rock groyne (a), timber groyne (b), and earthfill groyne (c) (courtesy Wikimedia Commons)*

*Box 6.17 Levee scour intervention example, France*

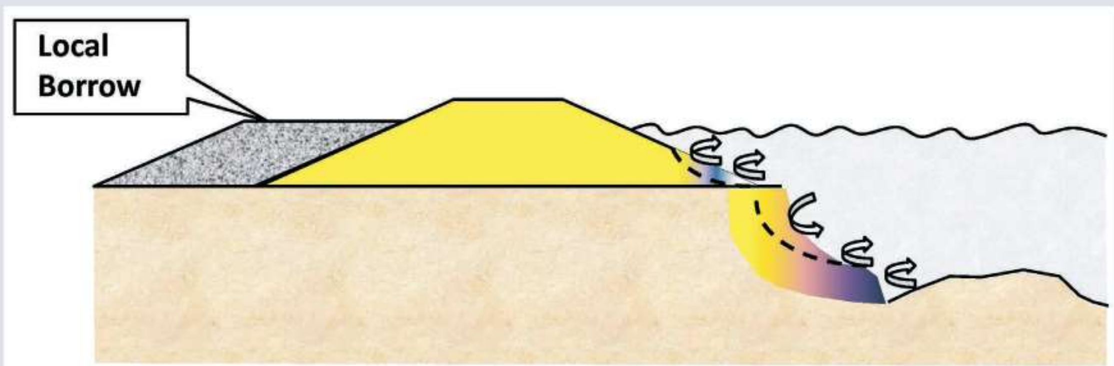



*Figure 6.31 Scour intervention example, France (courtesy SYMADREM after Irstea)*

In France preference is given to landward interventions for delaying external erosion consequences. As shown in Figure 6.31 local borrow is placed on the landward side of the levee in response to toe erosion on the riverward side.

## 6.6.3 Protection from overtopping/overflow erosion

### 6.6.3.1 Plastic sheeting

The use of an impermeable sheeting (plastic or geotextile) that is properly anchored can be an efficient measure to protect a levee from erosion as a result of overtopping or overflow (see Figure 6.32). The material needed consists of impermeable sheeting, sandbags and rope, all of which are normally in ample supply. The amount of equipment is minimal and may consist of a tractor or bulldozer to assist in unrolling the sheeting. This measure can be placed both in the dry as well as in high water/storm events, although it is most commonly placed before the event. This measure is used under these conditions:

- access to the embankment and slope
- adequate supply of sheeting, sandbags, sand, and rope.

This measure should be avoided if there are safety concerns for personnel and equipment.

The following procedures should be followed depending upon whether installation is being done before or during the event.

- placement in the dry (during low tide or before water levels rise)
  - dig a trench parallel with the embankment at the toe
  - place the leading edge of the geotextile inside the trench and backfill
  - unroll the geotextile up the waterside slope
  - ensure there is ~1m overlap between sheets and anchor down with sandbags
  - drive stakes into the ground just above the area to be protected (the stakes are 1.3 m apart with a 0.3 m stagger)
  - secure the tarp to the stakes with tie-down buttons
  - use a criss-cross method to place the sandbags on all the edges of the tarp
  - ensure that the landside termination of the material is properly secured inside a trench and backfilled or anchored with sandbags
- placement in flood/storm
  - using sandbags as bottom weights, anchor the geotextile at the waterside toe
  - using sandbags, counter-weight the textile against the embankment slope. When impermeable geotextile is used, this will prevent air from being trapped between the embankment slope and the geotextile.

*Figure 6.32 Use of plastic sheeting to prevent overtopping/overflow erosion, placing plastic sheeting on levee waterside (a) and finished placement (b) (courtesy USACE)*

### 6.6.3.2 Emergency spillway

In the event that one of the temporary levee raise measures detailed previously cannot be implemented or have been unsuccessful then consideration should be given to construction of an emergency spillway, Figure 6.33. This method can be used to accommodate water flowing over the levee while preventing erosion or potential breach of the levee. This measure could also be used if only a short segment of the levee is not at required grade or there is a need to reduce the water level. The materials needed for this measure are sandbags and plastic sheeting. The measure can be used under these conditions:

- good access to embankment crest and slope
- good supply of sandbags, sand, plastic sheeting.

This measure should be avoided if there are substantial flows over the crest that can wash away the sandbags being placed or if there are safety concerns for personnel and equipment.

To construct an emergency spillway, remove the landside slope of all material or debris that would impede placement of the plastic sheeting. Place the plastic sheeting up the landside slope over the crest onto the waterside slope. Link all sides of the sheeting with at least one row of sandbags. Further sandbags may be required to accommodate level of flowing water or to provide additional weight. Sandbags placed on the crest should tie into high ground or other levee raise measures.

*Figure 6.33 Use of emergency spillway (State of California, 2010)*

## 6.7 RESPONSE TO INTERNAL EROSION AND TECHNIQUES FOR INTERVENTION

As a river, stream, lake, canal, or sea rises, the hydrostatic pressure against a levee slope increases significantly and can force water into the levee embankment and its foundation (see Figure 6.34). This seepage will generally follow paths of least resistance. According to the geotechnical properties of the soil, internal erosion may then happen. Internal erosion (as seen in Section 3.5.2.2) is indeed a family of different mechanisms:

- **backward erosion:** detachment of soil particles when the seepage exits to an unfiltered surface leading to retrogressively growing pipes and sand boils
- **concentrated leak erosion:** detachment of soil particles through a pre-existing path in the embankment or foundation
- **suffusion:** selective erosion of the fine particles from the matrix of coarse particles
- **contact erosion:** selective erosion of the fine particles from the contact with a coarser layer.

**Note**

The term 'piping' can be confusing because it is often used to describe either of these internal erosion mechanisms or a combination of these. Internal erosion, once it has started, may lead to a breach in the levee, either alone, or in combination with other mechanisms (instability, settlement and overtopping).

Seepage is generally not a problem unless:

- the landward levee slope becomes unstable due to saturation
- internal erosion happens as a consequence of seepage
- pumping capacity or runoff limit for the levied area is exceeded.

Techniques to mitigate internal erosion generally focus on:

- reducing the seepage flow by:
  - reducing the infiltration of floodwater in or under the levee
  - increasing the seepage path
  - reducing the hydraulic gradient
- accommodate the seepage, but prevent internal erosion from developing, by improving filtration (see also Figure 6.41 in Box 6.18).

**Warning**

**Fighting seepage in an improper manner can cause internal erosion. Pumping of seepage should be held to a minimum, and ponding should be allowed during high water to the extent that it does not cause damage. Levees have been endangered during past floods by attempts to keep low areas pumped dry, and additional time and effort were expended in controlling sand boils caused by pumping.So, seepage should be permitted if no apparent ill effects are observed and if adequate pumping capacity or tolerance for runoff is available in the levied area.**

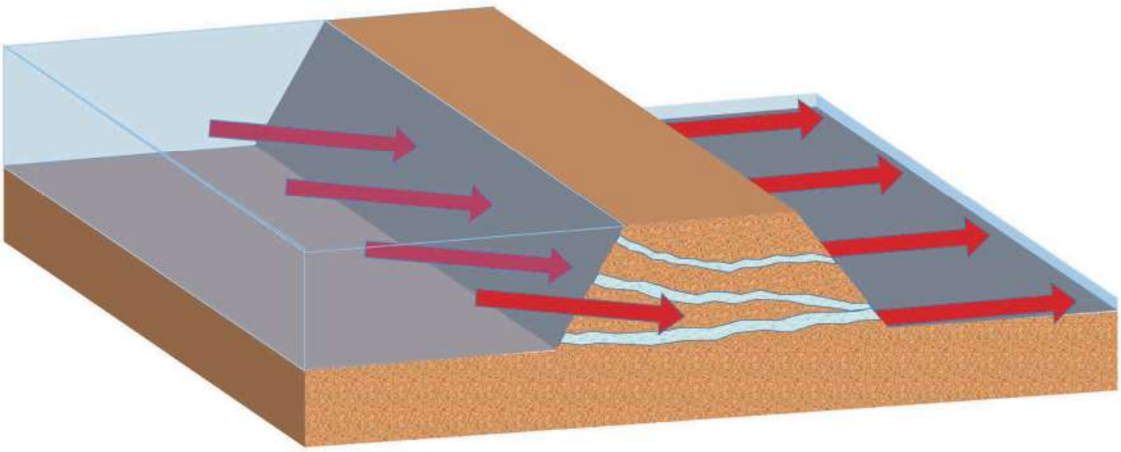


*Figure 6.34 Internal erosion process (courtesy ASCE)*

## 6.7.1 Reduce infiltration measures

If a section of levee is known or suspected to be susceptible to damage induced from seepage then measures can be taken to reduce the amount of water that is flowing through the levee. These measures provide a means to lessen the movement of water into the soil thereby reducing the hydrostatic pressures and reducing the potential for internal erosion. These measures can be implemented under wet or dry conditions and are generally straightforward.

### 6.7.1.1 Impermeable sheeting

The use of an impermeable sheeting (plastic or geotextile) that is properly anchored can be an efficient measure to reduce infiltration (see Figure 6.35). This measure can be used to reduce infiltration over very long stretches of the levee or it may be used at discrete points where a waterside boil inlet has been detected (see Figure 6.36). This measure has been previously detailed in Section 6.6.3.1.

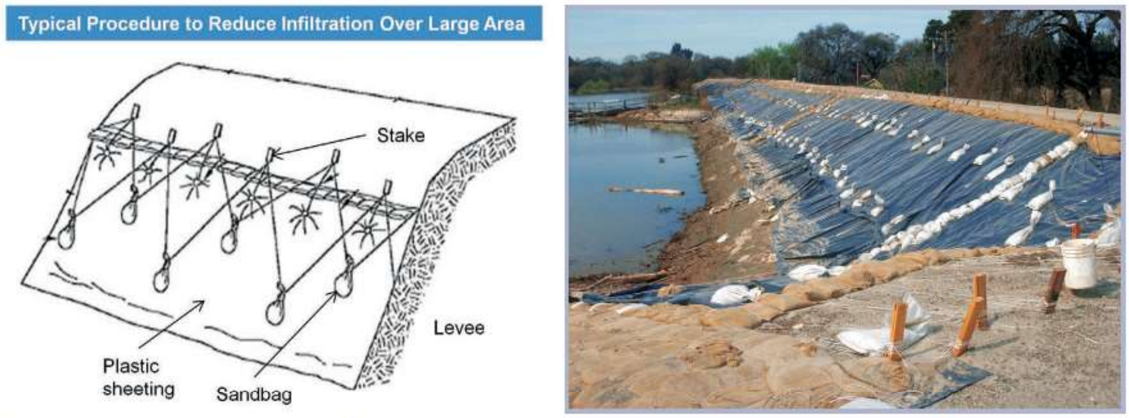



*Figure 6.35* *Use of impermeable sheeting to reduce infiltration over large area (a) and field application (b) (from DWR, 2010 and courtesy USACE)*

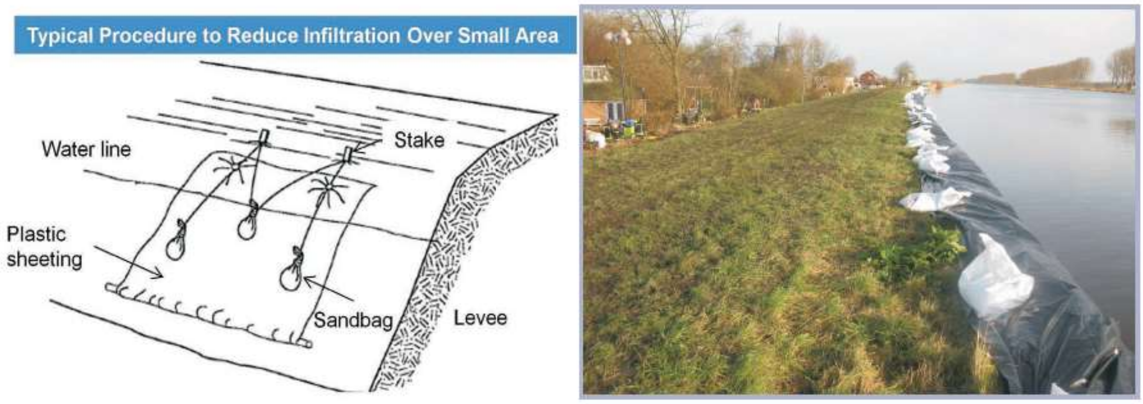



*Figure 6.36* *Use of impermeable sheeting to reduce infiltration (from DWR, 2010, and courtesy Henk van Hemert)*

## 6.7.2 Increase seepage path measures

If a levee has continuous seepage or under-seepage problems then one of the most common solutions is to construct a riverside blanket of relatively fine-grained impervious to semipervious soils. If these blankets are continuous and extend riverward for a considerable distance, they can effectively reduce seepage flow and seepage pressures landside of the levee. The effectiveness of the blanket depends on its thickness, length, distance to the levee riverside toe, and permeability. However, these measures need to be implemented in dry conditions and so might be most appropriate for preliminary measures. In a high water/storm event when seepage flow and seepage pressures are a concern then the only alternative is to construct a seepage berm on the landside of the levee (see Figures 6.37 and 6.40).

### 6.7.2.1 Seepage berm

If uplift pressures landward of a levee become greater than the effective stress of the foundation top stratum, heaving and rupturing of the top stratum may occur, resulting in sand boils. The construction of landside berms can eliminate this hazard by providing additional length required to reduce uplift pressures at the toe of the berm to tolerable values and additional weight needed to counteract these upward seepage forces. This measure can be used effectively under these conditions:

- adequate space on the landside for construction
- ample supply of material (soil, rock etc)
- consideration has been given to requirements for any necessary filter layers or geotextiles, given practical installation constraints (time, operating environment etc).

Four types of seepage berms have been used, with selection based on available fill materials, space landside, and relative costs:

1 **Impervious berms:** a berm constructed of impervious soils restricts the pressure relief that would otherwise occur from seepage flow through the top stratum and consequently increases uplift pressures beneath the top stratum. However, the berm can be constructed to the thickness necessary to provide an adequate safety margin against uplift.

2 **Semipervious berms:** semipervious material used in constructing this type of berm should have an in-place permeability equal to or greater than that of the top stratum. In this type of berm, some seepage will pass through the berm and emerge on its surface. However, since the presence of this berm creates more resistance to flow, subsurface pressures at the levee toe will be increased.

3 **Sand berms:** while a sand berm will offer less resistance to flow than a semipervious berm, it may also cause an increase in substratum pressures at the levee toe if it does not have the capacity to conduct seepage flow landward without excessive internal head losses. Material used in a sand berm should be as pervious as possible, with a minimum permeability of $100 \times 10^{-4}$ cm per sec. Sand berms require less material and occupy less space than impervious or semipervious berms providing the same degree of protection.

4 **Free-draining berms:** a free-draining berm is one composed of random fill overlying horizontal sand and gravel drainage layers (with a terminal perforated collector pipe system), designed by the same methods used for drainage layers. Although the free-draining berm can afford protection against under-seepage pressures with less length and thickness than the other of seepage berms, its cost is generally much greater than the other types, and so it is rarely specified.

Response personnel should start by dumping material against the back of the levee. The material should be shaped with a bulldozer (if possible), being extremely careful not to nick the levee itself. Any gashes in the levee could allow water to start flowing. These berms can be constructed rapidly and be used to great advantage if the materials and personnel are available to implement them.

*Figure 6.37 Seepage berm constructed landside of levee (courtesy USACE)*

### 6.7.3 Reduce hydraulic gradient measures

Technically, hydraulic gradient is the difference in head measurements over the length of the flow path. Practically, this means that as the water level increases on a levee due to a high water/storm event the difference in elevation of water from the waterside to landside of the levee produces a pressure on the levee and foundation. This pressure is an uplift pressure that can either reduce the weight of the overlying soils or puncture the foundation in the form of sand boils. Both of these conditions are hazardous to the levee and can lead to failure if not properly addressed. There are three measures that are generally used to address these two concerns:

- landside berm
- ringing of sand boils with sandbags or other suitable means
- increasing landside water level to lessen hydraulic head difference across the levee.

Landside berms will not be discussed in this section since the previous discussion presented on seepage berms is directly applicable. As stated, seepage berms serve to increase the seepage path and reduce hydraulic gradient. Some general considerations for construction of a berm to reduce hydraulic gradients include the permeability of the berm material and the size of the berm. Generally a pervious or semi-pervious material would be used in this case as opposed to an impervious material.

### 6.7.3.1 Ringing sand boils

Water that issues from sand boils flows through pervious strata under the levee and then breaks through the surface cover, washing with it material from beneath the levee base. A sand boil may gradually undermine a levee and result in a failure by causing sudden subsidence of the levee. It is difficult to evaluate the seriousness of sand boils. Consequently, all sand boils should be watched closely. Any boil that enlarges and increases its discharge of material, especially if located within 60 m of the levee toe, is considered to be a threat to the levee and should be controlled. Treatment of boils, however, is not limited to those within 60 m of the levee toe. Incipient boils should be marked conspicuously so that patrols can locate them without difficulty and observe changes in their conditions. A boil, which discharges clear water in a steady flow, is usually not a serious menace to the safety of the levee. However, as the hydraulic head is increased to stem soil particle movement, the pore pressures within the levee are also increased and slope stability may be affected. The only action necessary in this case is to make careful and frequent observations of the boil and to drain the excess water to prevent its impoundment near the levee. However, if the flow increases and also then carries a material load of sand and silt, corrective action should be taken immediately to prevent levee failure. This measure can be used under these conditions:

- there is a visible sign of sand boil
- the sand boil is of a size to warrant concern
- the sand boil is transporting fines.

This measure should be avoided if there are safety concerns for personnel and equipment.

An accepted method of ringing or sacking a sand boil is shown in Figures 6.38 and 6.39. The base of the sack ring is prepared by clearing the adjacent ground of debris, vegetation or other objectionable material, to a width sufficient for the base of the ring. The base should then be thoroughly scarified to provide a watertight bond between the natural ground and the sack ring (a very important step). The sacks are laid in a general ring around the boil, with joints staggered and with loose earth as mortar between all sacks. In general, it has been found that the best results can be obtained by starting construction of the sack ring at its outer edge and working toward the centre. The ring is carried to a sufficient height to stop the flow of soil from the boil. Work is stopped when clear water only is being discharged. A v-shaped drain constructed of two boards or a piece of sheet metal should be inserted near the top of the ring to carry off the water. A spillway made of sandbags can also be used to discharge water from the sandbag ring.

It is impossible to establish exact dimensions for a sack ring because varying field conditions will govern each specific situation. The diameter of the ring, as well as its height, depends upon the size of the boil and the flow of water from it. Response personnel should determine the size of the ring upon consideration of the following:

- the sack ring should have sufficient base width to prevent side failure
- the width should be determined by the contemplated height of the ring, and should be no less than 1.5 times the height
- the enclosed basin should be of sufficient size to permit the sacking operations to keep ahead of the flow of water. If there are any weak areas close to the sand boil, it is recommended to include them within the ring, and so avoiding the possibility of a subsequent breakthrough.

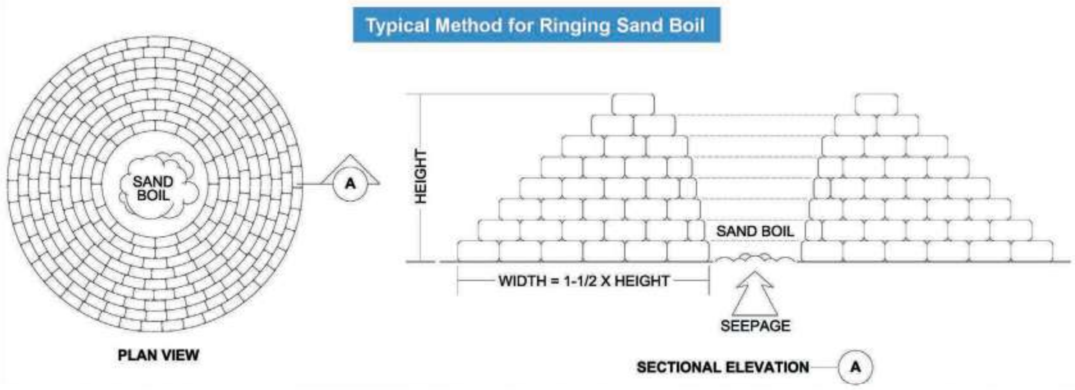



*Figure 6.38 Recommended method for ringing sand boils (courtesy USACE)*

### 6.7.3.2 Increase landside water level

Another method to reduce the hydraulic gradient through the levee is to raise the water level in landside ditches (if present) or creating small dams on the landside close behind the levee in which the seepage water may be caught, creating ponds on the landside. For this measure it should be ensured that stability will not be threatened by saturation of the levee.

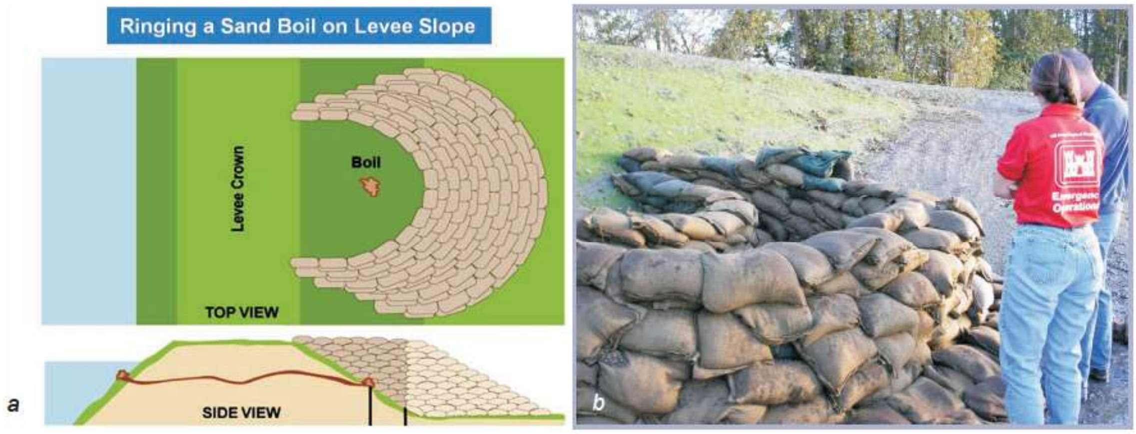



*Figure 6.39 Schematic of ringing a sand boil on levee slope (a) and field implementation (b) (courtesy USACE)*

## 6.8 RESPONSE TO INSTABILITY AND TECHNIQUES FOR INTERVENTION

Previous discussions related to internal erosion have highlighted many of the concerns related to instability. As the water level on the levee increases the uplift pressures reduce the weight of the soil producing a potentially unstable levee. Also, as the saturation of the levee increases this can reduce the strength of the levee material and create local slope failure on either the landside or waterside. Normally, the local slope failures are small and isolated, which can be relatively quick and easy to repair. These generally do not threaten the overall stability of the levee however they do represent a loss of material that creates a shorter flow path and exposes material subject to erosion or scour. In any event, these local slope failures should either be repaired by placing and compacting soil or covered with plastic/geotextile and monitored until repair can be completed. The techniques that will be presented will address those concerns that are likely to lead to breach of the levee if not addressed. Techniques to mitigate instability generally focus on:

1 Reducing the steepness and inclination of the slope.
2 Reducing water pressures underneath the levee.
3 Reducing groundwater table/saturation of the levee.

## 6.8.1 Reduce steepness and inclination of slope

Steep slopes, on the order of 1V:2H or steeper, have a higher potential of failure than gentle slopes, on the order of 1V:3H or more gentle. If the stability of the slope is a concern an effective intervention measure is to simply reduce the steepness of the slope. In an emergency response situation this is accomplished by the addition of a landside berm. How flat the resulting slope becomes is dependent mostly on amount of space for constructing the berm and amount of material. All of the previous discussion and examples related to a seepage berm apply for this case. Adding a landside berm serves to not only reduce the steepness of the slope but also adds additional weight to counter the uplift pressures. The use of a landside berm for both instability and internal erosion is presented in Box 6.18.

## 6.8.2 Reduce uplift pressure

The measures that can be used to reduce uplift pressures in the levee or landside foundation is placement of a landside berm, which has already been discussed in great detail.

## 6.8.3 Reduce saturation of levee

Since saturation can lead to instability in the levee, reducing the saturation is an intervention measure to improve stability of the levee. This topic has been detailed previously in the section discussing measures to reduce infiltration by use of an impermeable sheeting and sandbags.

*Box 6.18 Instability and internal erosion mitigation examples, France*

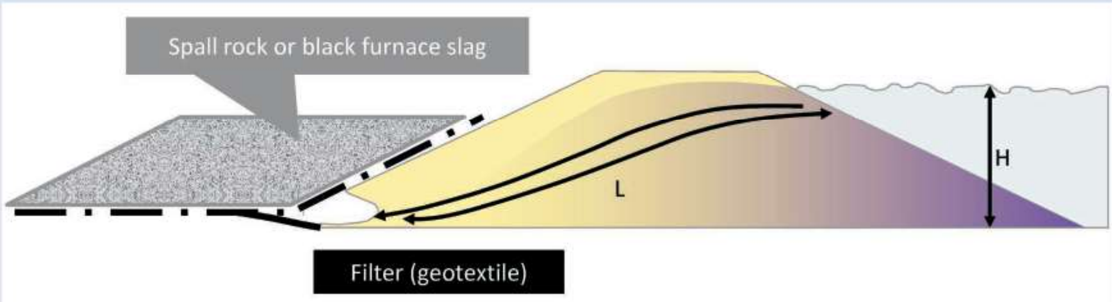



*Figure 6.40 Through seepage intervention (courtesy SYMADREM after Irstea)*

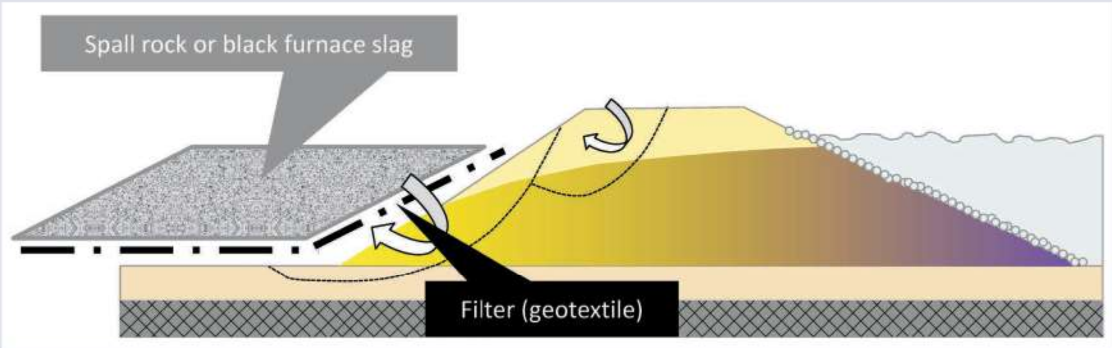



*Figure 6.41 Stability intervention (courtesy SYMADREM after Irstea)*

Placement of fill on the landward side of the levee along with a geotextile can improve both the resistance to internal erosion as well as global stability of the levee slope.

# 6.9 BREACH MANAGEMENT AND TECHNIQUES FOR INTERVENTION

Levees can breach before overflow/overtopping (see Figure 6.42) if there are structural issues with the levee making it unstable under a hydraulic load. Seepage, stability, and scour can all lead to a breach if not successfully mitigated during a flood response (see previous section).

Whatever the initiating mechanism, once the levee has breached, the velocities through the breach can be quite high and access to the breach to attempt a closure can be challenging. Appropriate materials to close a breach can be hard to procure and deliver to the site. Large rock is generally the best material, but many alternative materials have been tried in the past ranging from large sandbags (0.75 $m^3$), to large trees, to railroad cars. Generally, access to a breach will be using trucks along the top of the levee, or in some cases only possible via helicopter, since both the riverward and landward side of the levee will be inundated.

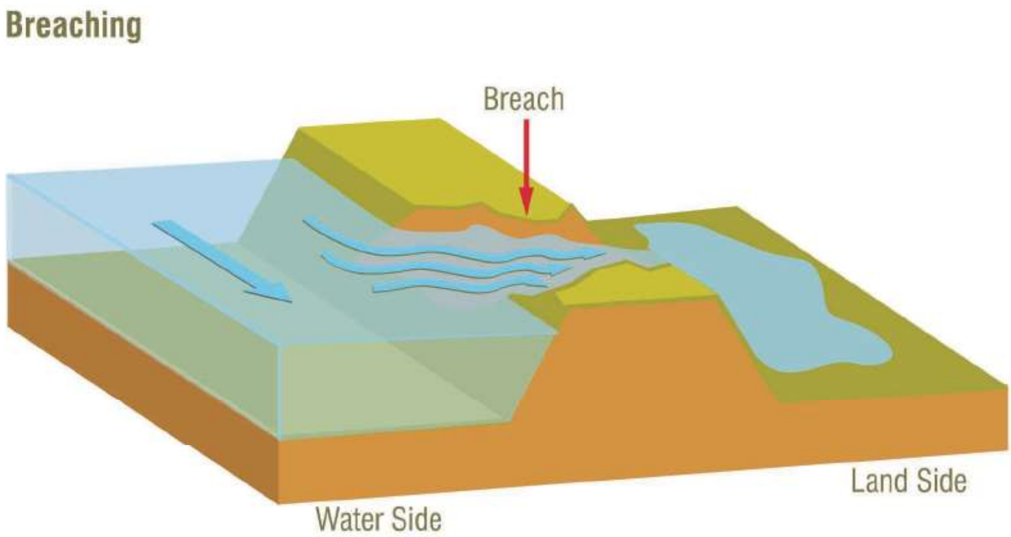



*Figure 6.42 Levee breach before overflowing (courtesy ASCE)*

Breach growth affects both the levee body and its foundation. There are several stages of a breach (Figure 6.43 presents one type of breach development), which will determine the type of emergency response that can be implemented. The response personnel should be familiar with these stages to assist in arranging for a proper response.

For each stage of breach, the following information provides guidance toward action that should be taken.

**Stage 1 and 2: intervention measures should be employed**

- use intervention measures as described under external erosion

**Stage 3 and 4: still a good chance to prevent full breach and limit breach growth**

- use intervention measures as described under external erosion and/or place material in the breach

**Stage 5: unlikely to prevent full breach, focus on limiting breach growth**

- place material in the breach

**Stage 6: repair during the event is only possible for small embankments or with major resources. Focus on limiting breach growth**

- if the breach is small and the flow is not dramatic then place material in breach.

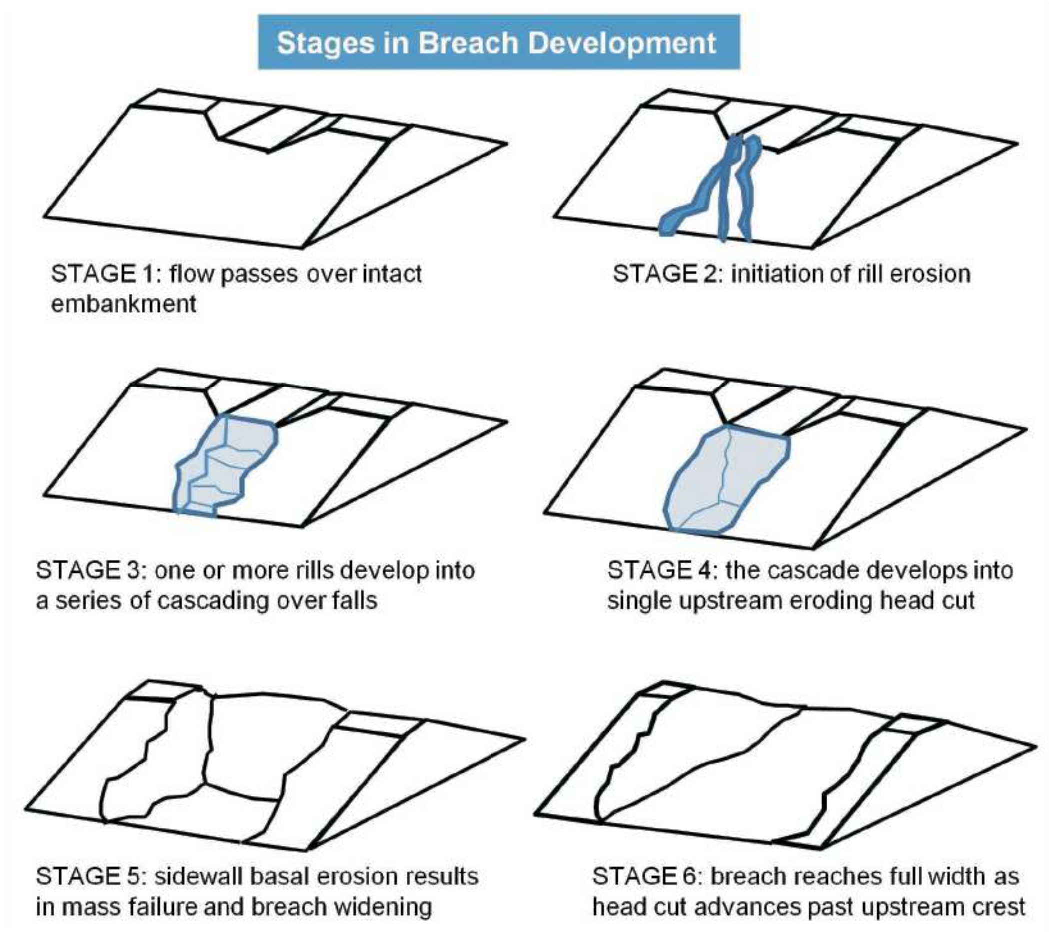



*Figure 6.43* *Stages of breach (Hahn et al, 2000)*

The material necessary for closing a breach with high velocities flowing through it will need to be large and heavy in order to stay in place against the flows (see Figure 6.44). Large rock is typically used for these efforts that will work well to stem the flow, but as a consequence, the closure berm will generally leak substantially. For this reason it is advisable to construct the closure berm either landward or riverward of the breach so that the porous material will not be in the final levee footprint (see Figure 6.46). Material selection should be given considerations such as presented in Table 6.4. Figure 6.45 shows the use of sandbags for closure of a levee breach.

*Table 6.4* ***Material considerations for filling large breaches or under high flow velocities***

| Considerations | Suggested solution method |
|---|---|
| • measures with small units (bulk, sandbags) are not likely to seal a large breach and such lighter elements will be washed away before flows are staunched<br>• placement by plant (non-manual) is faster and can be safer.<br>Check if it is safe to intervene in this case | Consider use of more stable larger elements placed inside the breach and placement by machine such as bulk fill, gabions, large sandbags (0.8 m³), concrete blocks, barge sinking, old cars or similar |


*Figure 6.44* ***Response to levee breach, limiting breach growth using big bags (a) and gabions (b) (courtesy Environment Agency)***

*Figure 6.45* ***Emergency repair of coastal levee Nam Dinh, Vietnam after Storm no.7 (2005) (courtesy VNICZM project, Nam Dinh pilot office)***

Also, consideration should be given to the alignment of a breach closure. It is important to remember that emergency responses to breach closure are temporary measures that may impede the activity of permanent repair once the crisis has passed. Table 6.5 presents three breach closure alignment options with advantages and disadvantages of each.

*Table 6.5* ***The following are breach closure alignment options (shown in Figure 6.46)***

| Option | Advantages | Disadvantages |
|---|---|---|
| A | • shallower water depths<br>• any lost material from closure will add to permanent fix or fill scour hole<br>• can be used as cofferdam for permanent fix. | • longer path and time<br>• more material<br>• trees or obstacles in the way. |
| B | • shallower water depths<br>• shortest closure path<br>• less time. | • higher velocities<br>• large rock under alignment could interfere with permanent fix. |
| C | • shielded from river currents<br>• lower velocities. | • longer path and time<br>• more material (could have large scour hole). |

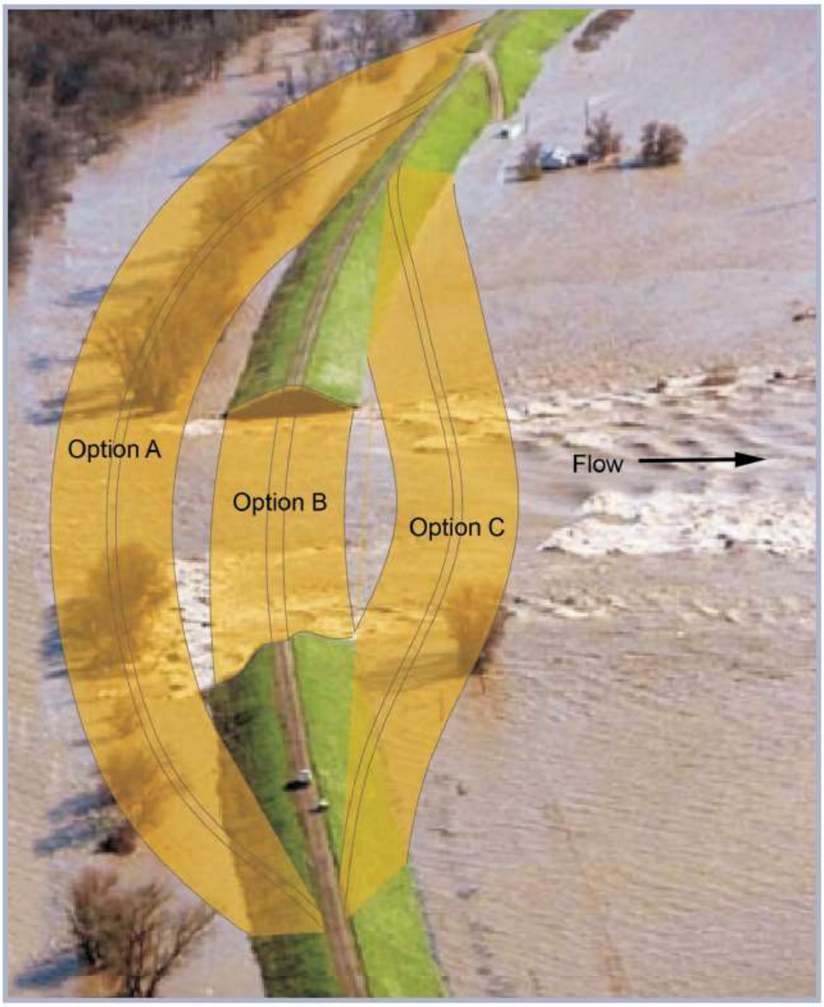



*Figure 6.46* *Solution: breach closure alignment options (courtesy USACE)*

# 6.10 INNOVATIVE TECHNOLOGIES FOR CREST RAISING

Sections 6.4.1 and 6.4.2 presented information concerning material and methodologies that are traditional common means of responding in a flood emergency. However, these are not the only materials and methods available. Boxes 6.19 to 6.25 highlight some common technologies that employ state-of-the art materials and innovative designs. The methodologies presented are not by any means an exhaustive list but those presented are meant to illustrate types of methodologies such as filled tubes, filled containers, freestanding barriers, frame barriers, and sectional barriers. Each methodology has additional features such as being rigid or flexible, air filled or water filled, permeable or impermeable, and automatic or manual. There are a wide variety of other commercial solutions based on the same principles.

Although all of the innovative systems shown can be deployed on a levee crest, each situation needs to be evaluated to ensure that the right solution is chosen for each application. However, the application of these technologies have proved to be successful and in some situations serve as the method of choice for response actitivity.

*Box 6.19* *Open-celled plastic grid flood wall*

**Details**

- collapsible plastic grid 20.3 cm high
- expands into 1.2 m × 1.2 m or 1.2 m × 0.6 m sections
- interlocks
- filled with sand from the top with a loader, excavator, bottom-dump, or other piece of earthmoving equipment
- light enough to be handled by two people
- small enough to be manageable in the wind
- fits into a pickup truck bed or helicopter
- requires no special tools
- small footprint and cross-section.

*Figure 6.47* *Plastic cell field setup (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Easy and quick to construct | Some breakage of grid if handled roughly |
| Very stable, even on soft soils | Added weight may decrease slope stability |
| 90 % reusable | Requires machinery to fill |
| 1.8 m wide footprint (1.2 m high structure) | Some difficulty in removing fill from cells after use |
| Very low seepage | |

*Box 6.20* *Portable cofferdam systems*

**Details**

- uses a steel supporting structure
- continuous reinforced vinyl liner membrane
- means of water diversion, retention, or impoundment
- the support structure is designed to transfer hydraulic loading to a near vertical load, thereby creating a free-standing structure with no back brace to extend to work area
- the liner system is flexible, sealing most irregular contours
- this system can be installed almost anywhere, in any configuration, and to any length
- the equipment is offered as rental item in heights of 1 m, 1.5 m, 2 m and 3 m.

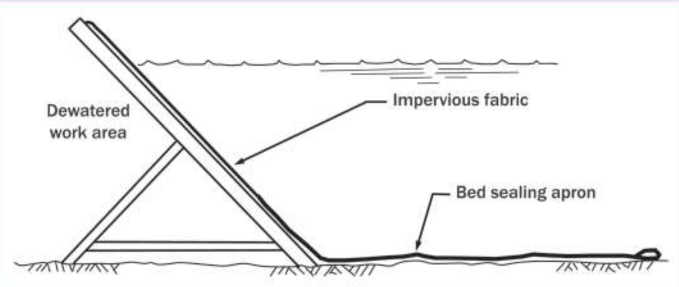



*Figure 6.48* *Portable cofferdam diagram (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Easy and quick to construct and remove | Height cannot be increased if flood worsens |
| Low seepage once bed seal established | Requires wide levee topwidth to be set up on levee crest |
| 100 % reusable | May be damaged by floating debris |
| Stable, except on soft soils | Access to levee top limited when installed |

*Box 6.21 Portable dam system*

**Details**

- rapidly deployed and removed
- assembled along pre-installed anchor line and seepage barrier
- a standard element is 2.1 m long
- 0.75 m to 1.2 m level of protection
- custom elements available
- 1.2 m wide foot print (1.2 m high structure)
- 100 per cent reusable and repairable.

*Figure 6.49 AquaFence implementation (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Easy and quick to construct and remove | Should have pre-installed anchor line and barrier |
| Low seepage | Height cannot be increased if flood worsens |
| 100 % reusable | Requires a large levee crest to setup |

*Box 6.22 Water-inflated barrier*

**Details**

- water inflated property protector – uses any water source
- industrial-grade, vinyl-coated polyester membrane material
- internal baffle system provides role over stability
- 0.3 m to 2.5 m high tubes provide protection to 75 per cent or 0.2 m to 1.8 m high
- rapidly deployed and removed
- 3.8 m wide foot print (1.5 m high protection)
- stores compactly.

*Figure 6.50 Water inflated barrier field setup (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Uses readily available water as fill material | Height cannot be increased if flood worsens |
| Can be positioned very quickly | Requires wide levee topwidth to setup on levee crest |
| Very stable, even on soft soils | Added weight may decrease levee stability |
| 100 % reusable | Access to levee top limited when installed |
| | Can be punctured by equipment or vandals |

*Box 6.23* *Water-filled tubes*

**Details**

- uses any water source
- flexible interlocking tubes
- single tube 0.5 m diameter, 15.25 m long
- stack like a pyramid up to 6 m held together by straps
- rapidly deployed: 1.5 minutes from fire hydrant or three minutes by pump
- height easily added by strapping next row to current structure
- easily removed, using water for washing
- three tubes high: 1.5 m wide foot print (1.2 m high protection)
- stores compactly, 15.25 m delivered in 200 litre drum
- can be filled with concrete.

*Figure 6.51* *Tiger dam system implementation (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Easy and quick to construct and remove | Can be punctured by equipment or vandals |
| Can adapt installation to situation | Requires wide levee topwidth to setup on levee crest |
| 100 % reusable | May be damaged by floating debris |
| Height of protection can be increased if flood worsens | Access to levee top limited when installed |
| Very stable even on soft soils | |

*Box 6.24* *Filled permeable container*

**Details**

- cellular barriers of permeable material
- lined with geotextile or geosynthetic fabrics
- filled with aggregates to form barrier
- containers strengthened and held in place by wire meshes, pins, frames
- impermeability controlled by fill material
- stackable, flexible, conform to foundation.

*Figure 6.52* *Example of filled permeable container (courtesy USACE)*

| Advantages | Disadvantages |
|---|---|
| Height of some systems can be increased by stacking | Clogging of material/effluents within the fabric can make cleaning difficult or impossible |
| Can be installed by relatively unskilled labour | Stacked defences require significant width, which may not always be available |
| Small storage space required | Some steel supports and pins may buckle or deform beyond reuse under stacking and service loading |
| Adapts to uneven terrain | Need to dispose of large volumes of probably contaminated material after flood event |
| Can use readily available fill material | Seepage can be a problem, but this can be minimised by using a suitable choice of geotextiles and fill |
| | High bearing pressure on bedding surface when stacked |
| | Some can be reused, but only a limited number of times |

*Box 6.25* *Demountable barriers*

**Details**

- rigid panels placed horizontally between stanchions
- permanent foundation with stanchion guides
- lined with seals to ensure water tightness
- stanchions can be permanently installed or attached to installed connections.

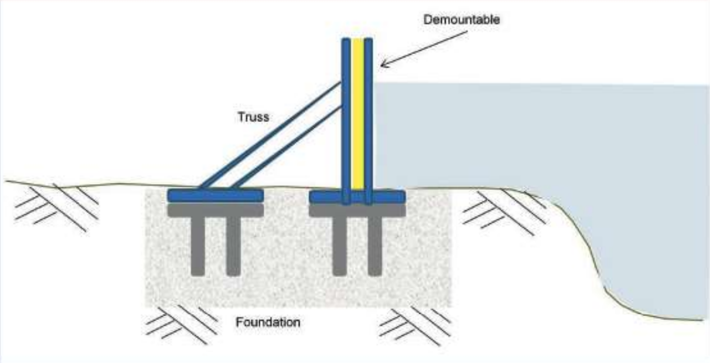



*Figure 6.53* ***Schematic of demountable barrier (see Chapter 4, Table 4.3 for field application)***

| Advantages | Disadvantages |
|---|---|
| Generally robust and well engineered | Large storage area required |
| Good resistance to loading and impact | Heavy transportation and lifting requirements |
| Very durable | Long installation and mobilisation period |
| Can be increased in height by adding panels up to the height of the frame | Permanent parts susceptible to damage and vandalism |
| Very low seepage through and under the structure | |

# 6.11 REFERENCES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# Appendix C

## FEMA Flood Insurance Rate Map (FIRM) for CFR Berm Area

# NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

**Accredited Levee Notes to Users:** Check with your local community to obtain more information, such as the estimated level of protection provided (which may exceed the 1-percent-annual-chance level) and the Emergency Action Plan, on the levee system(s) shown as providing protection for areas on this panel. To mitigate flood risk in residual risk areas, property owners and residents are encouraged to consider flood insurance and floodproofing or other protective measures. For more information on flood insurance, interested parties should visit the FEMA Website at http://www.fema.gov/business/nfip/index.shtm.

**Coastal Base Flood Elevations** shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 11. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

**Base map** information shown on this FIRM was derived from U.S. Geological Survey Digital Orthophoto Quadrangles produced at a scale of 1:12,000 from photography dated 1990 or later.

Based on updated topographic information, this map reflects more detailed and up-to-date **stream channel configurations and floodplain delineations** than those shown on the previous FIRM for this jurisdiction. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on the map. Also, the road to floodplain relationships for unrevised streams may differ from what is shown on previous maps.

**Corporate limits** shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

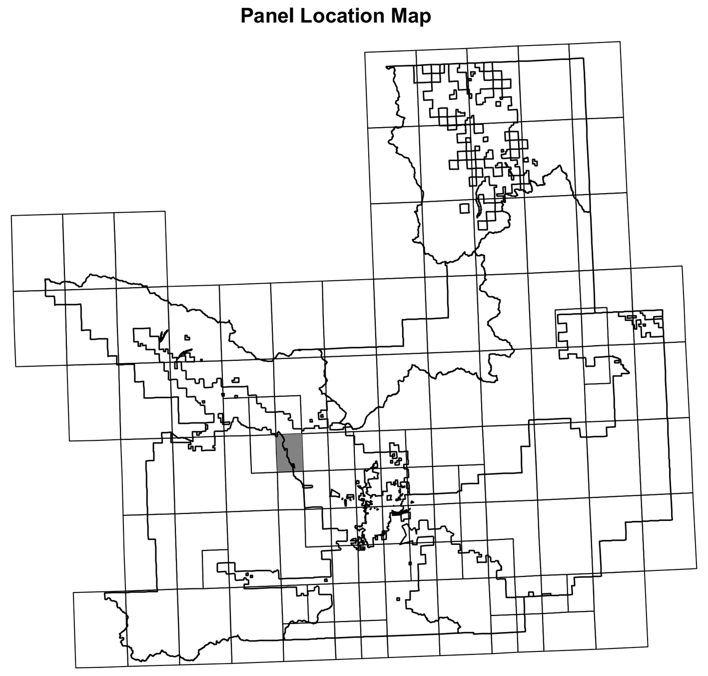
If you have **questions about this map,** how to order products, or the National Flood Insurance Program in general, please call the **FEMA MAP Information eXchange (FMIX)** at **1-877-FEMA-MAP**(1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip/.

**Missoula County Vertical Datum Offset Table**

| Flooding Source | Vertical Datum Offset (ft) | Flooding Source | Vertical Datum Offset (ft) |
|---|---|---|---|
| Clark Fork | 3.6 | | |

Example: To convert Clark Fork elevations to NAVD 88, 3.6 feet were added to the NGVD 29 elevations.

**Panel Location Map**



As per the Administrative Rules of Montana (ARM) 36.15.501(6), "The designated floodplain boundary is based on base flood elevations. The mapped floodplain boundary may be used as a guide for determining whether property is within the designated floodplain, but the exact boundary shall be determined according to the base flood elevation. If the local administrator determines it is unclear whether property is in or out of the floodplain, the local administrator shall require the applicant to provide additional information which may include elevations obtained through a level survey performed by a professional engineer or registered land surveyor."


NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 14 NORTH, RANGE 21 WEST.

# LEGEND

**SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD**

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

| | |
|---|---|
| **ZONE A** | No Base Flood Elevations determined. |
| **ZONE AE** | Base Flood Elevations determined. |
| **ZONE AH** | Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined. |
| **ZONE AO** | Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined. |
| **ZONE AR** | Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood. |
| **ZONE A99** | Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined. |
| **ZONE V** | Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined. |
| **ZONE VE** | Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined. |

**FLOODWAY AREAS IN ZONE AE**

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

**OTHER FLOOD AREAS**

| | |
|---|---|
| **ZONE X** | Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood. |

**OTHER AREAS**

| | |
|---|---|
| **ZONE X** | Areas determined to be outside the 0.2% annual chance floodplain. |
| **ZONE D** | Areas in which flood hazards are undetermined, but possible. |

**COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS**

**OTHERWISE PROTECTED AREAS (OPAs)**

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% annual chance floodplain boundary
0.2% annual chance floodplain boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

| | |
|---|---|
| 513 | Base Flood Elevation line and value; elevation in feet* |
| (EL 987) | Base Flood Elevation value where uniform within zone; elevation in feet* |

*Referenced to the North American Vertical Datum of 1988

| | |
|---|---|
| A — A | Cross section line |
| 23 - - - - - 23 | Transect line |
| 45° 02' 08", 93° 02' 12" | Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere |
| $^{49}89^{000m}$ N | 1000-meter Universal Transverse Mercator grid values, zone 11 |
| 4989000 FT | 5000-foot grid ticks: Montana State Plane coordinate system, (FIPS Zone 2500), Transverse Mercator |
| DX5510 × | Bench mark (see explanation in Notes to Users section of this FIRM panel) |
| • M1.5 | River Mile |

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
August 16, 1988

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

*(Date of Revision)* : to change Base Flood Elevations, to update corporate limits, to update roads and road names, to change Special Flood Hazard Areas, to incorporate previously issued Letters of Map Revision, and to reflect updated topographic information.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

**MAP SCALE 1" = 1000'**

500 0 1000 2000 FEET
300 0 300 600 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

**PANEL 1155E**

# FIRM

## FLOOD INSURANCE RATE MAP

## MISSOULA COUNTY, MONTANA AND INCORPORATED AREAS

**PANEL 1155 OF 1900**

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

| COMMUNITY | NUMBER | PANEL | SUFFIX |
|---|---|---|---|
| MISSOULA COUNTY | 300048 | 1155 | E |

REVISED
REVISED
PRELIMINARY

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

**MAP NUMBER 30063C1155E**

**MAP REVISED**

Federal Emergency Management Agency

# Appendix D

## Berm Special Inspection Form

NewFields

## PROJECT TITLE

| | | | |
|---|---|---|---|
| Former Smurfit-Stone/Frenchtown Mill<br>Berm Surveillance | | Date: | |
| | | Inspector Name: | |
| Project Number: | | Report Number: | |

## TASK COMPLETED/OBSERVATIONS

Date: ______________________

Type of Inspection: [Weekly/Daily/Post-Event] _________________________

Arrived at Site: [Time] ____________________; Departed Site: ________________________

Clark Fork River Staff (USGS Station 12353000 "Clark Fork below Missoula, MT"):_______ft.

Others on Site (Name and Affiliation):

Name: _________________________ Affiliation: __________________________________

Name: _________________________ Affiliation: __________________________________

Name: _________________________ Affiliation: __________________________________

Name: _________________________ Affiliation: __________________________________

## STAFF GAUGE MEASUREMENTS

Record the depths at all accessible staff gauges and photograph them.

| **Gauge Number/ Location** | **Date** | **Time** | **CFR Gauge Height (ft.)** | **CFR Flow Trend** | **Notes** |
|---|---|---|---|---|---|
| **Clark Fork River** | | | | | |
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| **Holding Ponds** | | | | | |
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| Berm Observations (Including Special Attention Areas) (Mark Y/N for each line) | | | |
|---|---|---|---|
| | **Y** | **N** | **Notes** |
| New or changed sediment transport? | | | |
| Low points, sink holes, or depressions? | | | |
| Tension cracks or open joints? | | | |
| Erosion, scour, or undermining of berm? | | | |
| Sliding, sloughing, or bulging? | | | |
| Visible plumes or changes in river color apparently emanating from the Site? | | | |
| Animal burrows or roots as potential seepage pathways? | | | |
| Other concerns (vehicular activity, trespassing, changes in vegetation, debris? | | | |

Discuss "yes" observations above:

## NOTIFICATIONS/COMMUNICATIONS

Level 1/2/ 3/ [circle one]

Justification for Notification Level:

If Leve1 2 or 3, list Contacts Made Immediately:

| Entity | Person | Date | Time | Contact Information |
|---|---|---|---|---|
| NewFields | Dave Tooke | | | 406-240-8360, dtooke@newfields.com |
| NewFields | Chris Cerquone | | | 406-830-6102, ccerquone@newfields.com |
| M2Green | Ray Stillwell | | | 618-910-2590, rstillwell@greeninvgroup.com |
| IP | Brent Sasser | | | 901-413-6890, Brent.Sasser@ipaper.com |
| WestRock | Steve Hamilton | | | 404-307-2865, steve.hamilton@westrock.com |
| EPA | Allie Archer | | | 620-755-9388, Archer.Allie@epa.gov |
| DEQ | Keith Large | | | 406-444-6569, klarge@mt.gov |
| Missoula County | Travis Ross | | | 406-543-3873, tross@missoulacounty.us |
| Western Exc. | Riley Mytty | | | 406-728-1400, rmytty@westernexcavating.com |
| Lucier Exc. | Dick Lucier | | | 406-550-0855, lucierexcavating@gmail.com |

Submitted Daily Field Report via e-mail to:

## MITIGATION DECISIONS/ACTIONS

1)

2)

3)

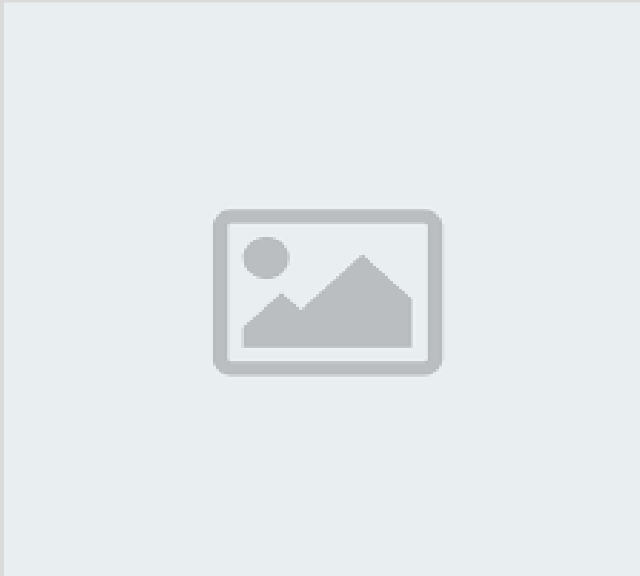
4)

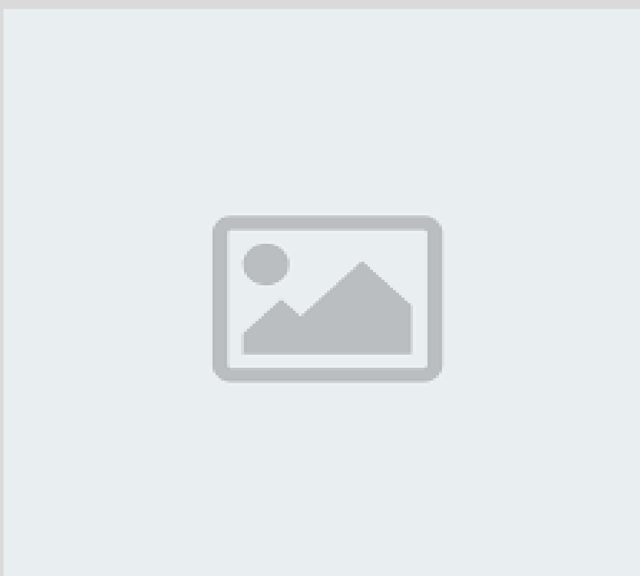
5)

6)

## OTHER COMMENTS

# PHOTOS





# PHOTOS