Temporary Flood Barriers
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We provide services to the transportation community through research, technology transfer and education. We create and participate in partnerships to promote safe and effective transportation systems.
Temporary Flood Barriers

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Kentucky Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U. S. Department of Transportation

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<td>16. Abstract</td>
<td>This report investigates the use and effectiveness of temporary flood barriers (TFBs) to mitigate the impacts of flood waters on Kentucky's roadways. TFBs are structures, usually filled with sand, which are constructed along the edges of roadways and thus serve as a buffer against rising waters. In doing so, they can protect the structural soundness of roads, and ensure that roads remain open to traffic during flood events. The report is divided into four main sections. The first chapter introduces the concept of TFBs and notes situations in which they have been effectively deployed. The second chapter surveys the different kinds of TFBs currently available on the market and advances recommendations regarding which types are the most efficient and cost effective options for Kentucky. After this, the report investigates 8 potential sites at which TFBs may be deployed, in Kentucky's Highway Districts 1 and 2. Two sites are recommended for further testing and potential implementation, and two alternative sites are suggested in case the preferred sites prove unworkable. The fourth chapter briefly explores the legal issues related to TFB usage. Because of the potential liability issues involved, to avoid legal action being taken against state employees in the case of TFBs failing and causing damage to adjacent property, the report recommends subcontracting the installation and maintenance of TFBs out to private entities. A final chapter summarizes all of the conclusions and recommendations of this report, and suggests that the Kentucky Transportation Cabinet move forward by a) inviting manufacturers to demonstrate their products onsite; and b) developing, in consultation with emergency managers and other officials at the local level, a comprehensive flood mitigation strategy that incorporates TFBs.</td>
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Ryan Tenges.................................................................FHWA
Executive Summary

The purpose of this research is to investigate the suitability of using temporary flood barriers to maintain critical transportation highway linkages in flood prone areas. Flooding is a natural hazard that poses a danger to Kentucky’s communities, businesses, and road infrastructure. For example, the Kentucky Transportation Cabinet (KYTC) estimated the June 2011 floods that impacted the state caused $30 million in damage to the state's roadways. Without putting into place mitigation plans to protect roadways, future flooding events will lead to further monetary costs and impair the operational structural integrity of the state’s roads. The loss of critical infrastructure produces negative effects over the short- and long-term; because individuals and businesses rely upon a sound roadway system, extensive damage incurred during flooding can produce a multiplier effect that ensures the consequences of flooding will be felt long after the waters have receded. Therefore, it is in the interest of Kentucky to develop plans to deal with risky flooding events, which a) minimize the amount of destruction that occurs as a result of flooding; and b) are able to keep roadways open and accessible to traffic as waters begin to rise. Preserving open roadways during flooding is critical during emergency situations that require individuals to evacuate from endangered areas.

This report investigates whether temporary flood barriers (TFBs) offer a practical and economical solution to prevent the worst effects of flooding on vulnerable roadways. TFBs are physical structures installed along the margins of roadways that prevent water from inundating them during flooding events. They assist in preventing damage to roads, and provide a means of keeping roads open even while flooding is ongoing. After briefly discussing cases where TFBs have been used with success, and then describing the different varieties of TFBs available on the market (along with their attendant drawbacks and positive features), the report provides a detailed situational analysis of 10 sites in western Kentucky identified as being especially susceptible to flooding. Each situational analysis examines the local geography and infrastructure features with an eye towards determining if individual sites are possible candidates for TFB evaluation and usage. Two main sites and two alternative sites have been chosen that meet all of the criteria laid out by the study committee. Following this, the legal implications of installing TFBs is explored. The potential exists for TFBs to redirect high waters onto adjacent, unprotected properties, which may cause damage. Because of potential state employee liability issues, the report suggests that private contractors should be employed to carry out the construction, maintenance, and disassembly of TFBs.

In sum, TFBs provide an attractive method for dampening the worst effects of flooding by ensuring roads remain open, safe, and protected as waters rise. It is the recommendation of this report that the KYTC move forward to develop a strategy for implementing TFBs. This involves two major steps. First, vendors of the recommended TFBs should be invited to demonstrate their products at the selected sites to choose which TFB is best suited for each one. As the report emphasizes, the choice of TFB is context sensitive. Secondly, the KYTC should move to formulate flood mitigation plans for roadways that actively incorporate TFBs. During this phase, emergency operations managers at the county and local levels should be consulted to create flood mitigation plans that synergistically combine structural remediation (i.e., the use of TFBs) with emergency evacuation procedures. TFBs alone cannot prevent all possible damage that roadways can suffer during floods. But they constitute an economical measure that can alleviate some of the worst effects.
Chapter 1: Introduction to Temporary Flood Barriers and Their Uses

1.1 Description of Temporary Flood Barriers

Temporary flood barriers (TFBs) are structures installed during periods of flooding to protect roadways and other vulnerable areas from potentially-damaging inundation. TFBs are typically located along one or both sides of a road corridor to preserve infrastructure functionality. Positioning depends on the source of water and the angle at which the water approaches a roadway. TFBs are beneficial in their capacity to suppress hazardous water flows, bolstering the safety of travelers, and ensuring traffic flows are not disrupted – which is key during floods that require evacuation. TFBs consequently improve evacuation efficiency while lowering the probability of stranding people in perilous situations where they are exposed to the dangers of rapidly rising flood waters. The main objective of using TFBs is to keep roadways in a safe and operable condition during hazardous flooding events. Using TFBs would assist the Kentucky Transportation Cabinet (KYTC) in keeping critical roads functional and safe during flooding events. Compared to permanent barriers, TFBs provide greater flexibility, allow for quick implementation, and are more cost effective. TFBs provide an attractive method for executing flood mitigation, significantly reducing the high cost of damage that would otherwise be incurred by unprotected roadways. While investing in barriers during major flooding events is a wise strategy, keeping a supply on-hand, which is readily available, and easily deployable, in the case of emergencies is an essential component of any flood mitigation strategy. If a stock of TFBs are not kept in store, the amount of time spent acquiring them, and then installing them, while a flood is unfolding could lead to unacceptably high levels of damage that could have been otherwise avoided by careful planning and the prior stocking of TFBs.

1.2 Road Closures and Flooding in Kentucky

Each year a portion of Kentucky’s roadways are damaged by flooding. Depending on the severity of the event, the consequences may range from entire roads being washed out to increased erosion and sedimentation, which can require costly, and prolonged cleanup efforts. Further, during high-magnitude events, unprotected roads may be forced to close, leading to adverse travel, traffic bottlenecks, and hampering the ability of motorists to move to safer ground. In the spring of 2011 serious flooding affected a number of Kentucky roads. The KYTC estimated these floods exacted $30 million in damage to Kentucky’s roads, with a great deal of that damage located in western Kentucky. For example, a portion of US 60 in western Kentucky was temporarily closed between mile markers 12 and 20 in Livingston County. Traffic entering Kentucky from Illinois via the Ohio River Bridge and Shawneetown was re-routed towards KY 56 and US 60, leading to substantial traffic congestion and delays (Dunn 2011). Table 1.1 below outlines roads that were either closed or impacted by high waters during this event:

Table 1.1 Kentucky Roads Affected By 2011 Flooding

<table>
<thead>
<tr>
<th>County Name</th>
<th>Road Name</th>
<th>Location</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullitt</td>
<td>Cedar Grove Rd.</td>
<td>Between MP 10-11</td>
<td>CL</td>
</tr>
<tr>
<td>Bullitt</td>
<td>Beach Grove Rd.</td>
<td>Between MP 3-4</td>
<td>CL</td>
</tr>
<tr>
<td>Bullitt</td>
<td>KY 44</td>
<td>Between Shepherdsville and Dixie Highway</td>
<td>HW</td>
</tr>
<tr>
<td>Daviess</td>
<td>KY 298</td>
<td>Between MP 2-3</td>
<td>HW</td>
</tr>
<tr>
<td>Daviess</td>
<td>KY 500</td>
<td>Between MP 0-1</td>
<td>HW</td>
</tr>
<tr>
<td>Henderson</td>
<td>KY 136</td>
<td>Between MP 0-10</td>
<td>HW</td>
</tr>
</tbody>
</table>

MP = Mile Points; CL = Closed; HW = High-Water Impacts
Road closures have direct impacts on the transportation budget given that KYTC is tasked with keeping critical routes open during flooding events. Finding a pragmatic and cost effective solution to offset the worst effects of flooding is thus a top priority. Applying TFBs on a more widespread basis is one fruitful way of reducing the costs of coping with unexpected flood events while carrying out the KYTC’s mission to maintain operable roadways during all conditions. The remainder of this research project, and a subsequent series of technical reports, investigates the most cost-effective manner of using TFBs.

1.3 Flooding Hotspots Designated for Investigation

Preliminary investigations have identified a number of flooding hotspots that are prone to high waters, particularly in Kentucky’s Highway District’s 1 and 2. These sites were chosen by the Study Advisory Committee based upon their experiences in the region. The following sites warrant further investigation:

<table>
<thead>
<tr>
<th>County Name</th>
<th>Road Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crittenden</td>
<td>US 60</td>
<td>At MM 23</td>
</tr>
<tr>
<td>Daviess</td>
<td>US 60</td>
<td>Between MM 2.6-5.7</td>
</tr>
<tr>
<td>Fulton</td>
<td>KY 94</td>
<td>Between MM 9.4-9.6</td>
</tr>
<tr>
<td>Henderson</td>
<td>US 60</td>
<td>Between MM 4-5</td>
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<td>Hickman</td>
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<tr>
<td>Hickman</td>
<td>US 51</td>
<td>Between MM 4.4-4.6</td>
</tr>
<tr>
<td>Hopkins</td>
<td>KY 502</td>
<td>Between MM 4-5</td>
</tr>
<tr>
<td>Ohio</td>
<td>KY 919</td>
<td>Between MM 3-4</td>
</tr>
</tbody>
</table>

MM = Mile Marker

Figure 1.1 (below) shows the location of each site.

Chapter 3 provides more detailed information on these sections and their characteristics.

1.4 TFBs Under Consideration

There is a wide range of TFBs to choose from. This study analyzed 6 distinct types of TFBs, including:

- Continuous Sand-Filled Tubes
- Concertainer and Floodline
- Defencell
- Rapid Deployment Flood Walls (RDFW)
- TrapBags
- MetalithH₂O

The second chapter discusses these various TFBs in greater detail. Briefly, these structures are made from a variety of different materials, including polypropylene geotextiles, welded mesh, Eastman plastic, and prefabricated corrugated aluminum panels. TFBs can be solid or inflatable and used as temporary structures, or where required as more permanent structures. Usually TFBs are made operable by filling them with materials, which establishes the support and structure needed to keep flood waters at bay. Depending on their construction, TFBs incorporate a range of fill types, including (but not limited to) water, sand, earth, gravel, crushed rock, and other granular materials. Barriers are available in a number of sizes. Length, width, and height of TFBs can be modified according to needs, as can their form, which
most often come in a rectangular, cellular, or pentagonal shape. The type of TFB chosen dictates what equipment is necessary to erect them upon deployment. Most barriers require a standard front-end loader, while others demand more specialized equipment to comply with specific deployment procedures. The number of workers and labor hours needed to properly set up a barrier varies according to TFB. Each TFB comes with its own unique features, and so not all TFBs are equally suited to all flooding situations. The choice of barrier should be context-dependent. Those charged with managing infrastructure should choose the barrier on a case-by-case basis by accounting for local variations in roadways, topography, and the kind of goals they wish to achieve with the barrier.

Figure 1.1 Map of Sites Chosen for Further Investigation

1.5 Use of TFBs in Flood Mitigation

Throughout the United States and England a number of states and municipalities have successfully used TFBs to deter the worst impacts of flooding. In Fargo, North Dakota, which frequently suffers dramatic floods due to seasonal snowmelt and rainfall, TFBs have been used to prevent road closures. In 2009, Fargo kept critical roadway infrastructure functional by quickly putting 30 miles of barriers into place (Hesco 2011). Similarly, in Minot, North Dakota, flood barriers were deployed quickly and successfully. In nine hours, 10 National Guard soldiers were able to establish a barrier that was 400 feet long, 4 feet wide, and 33 inches tall, protecting valuable infrastructure (Knudson 2009). This attests to the benefits of using TFBs in lieu of sand bags. Sand bags, while often effective, require more labor effort (and time)
to fill, which means less extensive areas of infrastructure can be protected on short notice. The Iowa Department of Transportation (DOT) has expanded its use of barriers in recent years, which has led to a reduction in the amount of damage inflicted by floods. Cedar Rapids, Iowa has incorporated the use of TFBs into its repertoire of flood mitigation practices. During the 2011 floods that impacted the state, the Iowa DOT installed TFBs along Interstate 29 (Iowa DOT 2011). In Jamestown, North Dakota, workers were able to install TFBs during the nighttime hours. This successful deployment was made possible by a unique feature of the TFB chosen that enabled workers’ head lights to illuminate the barrier they were working on (Geocell Systems 2011). During Hurricane Katrina Slidell, Louisiana successfully used TFBs to minimize damage. The insurance provider for a waterfront property in the town required a barrier elevation between the property and Lake Pontchartrain to be at 14 feet, 2.5 feet above the 11.5 foot elevation that was already in place (Hesco 2011). TFBs were assembled three weeks before Katrina made landfall, which added the 2.5 feet required for insurance purposes. The United States Army Corps of Engineers rely on TFBs when major flooding events occur. In April 2011, TFBs were rapidly installed during an emergency situation in Smithland, Kentucky. Within 3 hours of receiving a call, the barrier manufacture delivered 3 miles of TFB, which the National Guard installed to mitigate the worst effects of flooding.

1.6 Conclusion

TFBs can be a viable, economical, and time-saving option for mitigating the impact of flood waters on selected Kentucky roadways. On numerous occasions, in Kentucky and the rest of the United States, TFBs have proven very effective at keeping vital infrastructure open, safe, and functional for motorists during hazardous situations.

References


Chapter 2: Temporary Flood Barriers – Types, Characteristics, and Limitations

2.1 Introduction

This chapter surveys the characteristics of different TFBs. This appraisal was conducted with an eye towards those TFBs that efficiently and reliably keep critical infrastructure safe, and functional, during high-magnitude flood events. This chapter covers TFBs that could be feasibly implemented within Kentucky. A more concise summary of this investigation’s findings is contained in Table 2.1, at the end of this chapter. This consists of a matrix that displays the characteristics, benefits, and drawbacks of various TFB systems. The study advisory committee determined these analyses should be restricted to barriers that a) protects against water levels \textit{less than or equal to} 4 feet, and b) are no longer than one-quarter mile when implemented. With this in mind, the barriers discussed below include:

- Continuous Sand-Filled Tubes
- Concertainer/Floodline Units
- Defencell
- Rapid Deployment Flood Walls (RDFW)
- TrapBags
- MetalithH20

2.2 TFB 1: Continuous Sand-Filled Tubes (CAS)

![Figure 2.1 Application of Continuous Sand-Filled Tubes with CAS Off-Road Environmental Series Track Machine](image-url)
Continuous sand-filled tubes are comprised of woven polypropylene that are filled with sand using a CAS Off-Road Environmental Series Track Machine. As the machine moves along a desired track it lays down tubes and fills them with sand, establishing a buffer against flooding. Creating higher barriers requires the stacking of multiple tubes in a pyramid shape (Figure 1). Like the other products outlined in this section, this method is faster and more efficient than using sand bags while requiring fewer workers and less oversight; the machine fills the equivalent of 150 sandbags/minute. Individual tubes are 1,000 feet long with a diameter of 1 foot. For example, the barrier in Figure 1 represents a 3-foot-high structure, and is made up of 6 tubes (a barrier 4 feet high would require 10 tubes). Despite the stated advantages of sand-tube barriers, it is important to note the material used to construct the tubes is the same as what is used in regular sandbags. As such, sand tubes and sand bags are practically identical with respect to their respective containment, endurance, and strength (Whitley 2010). One advantage sand tubes offer over sand bags is their continuous, one-piece structure, which reduces the likelihood of seepage. However, in the case of failure sand tubes demand repair several options are available:

- Set down another tube to compensate for the failure
- A preformed segment can be laid down using a loader
- Conventional sand bags are used to patch things up

Although the use of sand tubes is cheaper than other methods described below, this ignores the cost of the equipment needed to place the tubes. The CAS Off-Road Environmental Track Machine is non-optional, which adds considerable expense to this form of flood mitigation. Depending on the situation, the cost of the machine may be prohibitive (the price of a new TR30 is $428,000). However, Whitley (2010) claims that the machine can be entirely paid for by the savings achieved in laying down 15,000 feet of tubing. The figures below estimate the cost of installing a one-quarter-mile-long barrier that is 4 feet high, the number of labor hours involved, and the amount of fill material needed.

<table>
<thead>
<tr>
<th>Barrier Price</th>
<th>CY of Fill Required</th>
<th>Estimated Fill Cost</th>
<th>Deployment Time</th>
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<tbody>
<tr>
<td>$79,200</td>
<td>682.57</td>
<td>$13,651.40</td>
<td>11.4 hours</td>
</tr>
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</table>

CY = Cubic Yards

*All estimated fill costs are based on an assumption of sand costs at $20 per cubic yard. Readers should bear in mind that sand expenses will be variable, based on the location and variety of sand chosen. For our purposes, what is most important is comparing expenses among the flood barriers using a fixed cost. The $20/cubic yard of sand applies for all calculations contained in this report,
2.3 TFB 2: Concertainer/Floodline Units (HESCO)

HESCO produces the Concertainer and Floodline units; the latter are specifically tailored to ameliorate the effects of flooding. Floodline units have a cellular structure. The outside of each cell is made of galvanized wire mesh and the interior is lined with polypropylene fabric. As sections are joined together via pins and plastic ties a wall is formed; each cell is open at the bottom and top. Materials used to fill the individual cells include earth, sand, and well-graded gravel. While they can be used for other purposes, Floodline units have been geared toward use in flooding defense and mitigation; to achieve this end, they are engineered to minimize permeability and leakages. HESCO touts that Floodline units are K12 certified, which means they are incredibly strong and durable. They have also been extensively tested by the US Army Corps of Engineers at their Flood-Testing facility. Even with the flood chamber filled to three-quarters of the units’ height and simulated wave overtopping occurring, the Floodline units were resilient and the wall remained intact and undisturbed. Individual barriers come in a number of sizes and can be reused up to 3 times. The principal difference between the Floodline units and Concertainer units is that the former units have dividers reinforced with welded wires, which enhances their impervious qualities. Concertainer units lack this welded wire, but are still usable for flood protection – although it is unclear to what extent this affects performance. One of the main benefits of these units is the time they save during emergency situations. For instance, a 30 foot section can be put up, joined, and filled with material by two workers with a standard bucket loader in approximately 20 minutes. The figures below estimate the cost of installing a one-quarter-mile long barrier that is 4 feet high, the number of labor hours involved, and the amount of fill material needed.
<table>
<thead>
<tr>
<th>Product</th>
<th>Barrier Price</th>
<th>CY of Fill Required</th>
<th>Estimated Fill Cost</th>
<th>Deployment Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concertainer</td>
<td>$36,298</td>
<td>587</td>
<td>$11,470</td>
<td>29 hours</td>
</tr>
<tr>
<td>Floodline</td>
<td>$39,988</td>
<td>587</td>
<td>$11,470</td>
<td>29 hours</td>
</tr>
</tbody>
</table>

CY = Cubic Yards

2.4 TFB 3: Defencell (FIBERWEB)

![Defencell Units Implemented for Flood Defense](image)

Figure 2.3 Defencell Units Implemented for Flood Defense

Fiberweb manufactures Defencell units. Originally designed for ballistic defense purposes in the military, these units have subsequently proven effective at flood protection. During the April 2011 floods, the US Army Corps of Engineers constructed a Defencell Flood Wall in Smithland, Kentucky. This project was unprecedented in its scale, qualifying as the largest emergency installation of a Defencell Flood Wall system in the United States (Defencell 2011). The main advantage of the Defencell system is its composition – it is made of lightweight, stackable materials and is 100% polypropylene geotextile. Defencell systems are highly portable and modifiable. After being situated, individual cells are filled with earth, sand, gravel, or other aggregates to provide the necessary reinforcement. Their flexible design means they are usable in a variety of topographic settings. Likewise, the porous textile material mitigates against throughflow and the build of water, which amplifies the rate at which materials are compacted, thereby improving performance. The use of Defencell systems require a front-end loader, one operator, two laborers, installation poles, and approximately 20 minutes per unit, irrespective of size. Units are not reusable, however, barriers can remain in place for up to three years. There are different models and sizes available. Instead of providing an exhaustive list of figures for detailing the specifications of each unit (as done in other sections), the numbers below constitute a representative range for cost, fill, and deployment time:

- Price Range: $26,400-$86,625
- Cubic Yards of Fill Required: 330-1,733
- Labor Hours: 55-83 hours
  - See Appendix A for a more detailed breakdown

These numbers vary according to the unit design chosen and the number of layers that are stacked (layers can be added to increase the height of a wall and improve the level of flood protection; however,
based on the configurations available, it is not possible to achieve exactly 4 feet of flood protection – for example, stacking two layers creates a 3’ 4” wall, while 3 layers generates a 5’ tall wall).

2.5 TFB 4: Rapid Deployment Flood Walls (RDFW) (GEOCELL SYSTEMS INC.)

RDFWs are comprised of a modular, collapsible plastic grid that is meant to replace traditional sandbag walls. The plastic grid is reusable, and has a life expectancy of 10 years (although it is unclear whether this number takes flood exposure into account). The main benefit of RDFWs is their durability and lightweight construction. Individual units are 8 ” high, 3.5’ wide, and 3.5’ long, and cost $27.93 per linear foot. To achieve greater flood protection the units may be stacked. After assembly and stacking the individual cells are filled with sand – they use half the amount of sand as traditional sandbags. Once the threat of flooding has receded the RDFW is lifted out of place, leaving behind a pile of sand. Unlike sandbags, which require disposal following use, leftover sand can be resold or repurposed, eliminating waste that would find its way into landfills otherwise. Geocell Systems claims that RDFWs are 100 times more labor efficient than using sandbags alone, and can withstand brutal flooding conditions. The US Army Corps of Engineers has evaluated RDFWs stability and protective capacity. Using a RFDW 50 feet long and 4 feet high, which was exposed to 40 hours of wave action (with wave heights ranging between 0.42 feet and 1.52 feet), the Army Corps of Engineers found the RDFW suffered only minimal, easily repairable damage, while only 8% of total sand was lost (Geocell Systems). An additional feature of
RDFWs is their nighttime illumination, which allows for installation during hours of darkness. Putting RDFWs into place requires at least one operator, two laborers, and a front-end loader. Each unit can be installed in approximately 10 minutes (this number applies whether dealing with a single unit or multiple stacked units). The figures below estimate the cost of installing a one-quarter-mile-long barrier that is 4 feet high, the number of labor hours involved, and the amount of fill material needed.

<table>
<thead>
<tr>
<th>RFDW Price</th>
<th>CY of Fill Required</th>
<th>Estimated Fill Cost</th>
<th>Deployment Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$221,206</td>
<td>679</td>
<td>$13,580</td>
<td>63 hours</td>
</tr>
</tbody>
</table>

CY = Cubic Yards

2.6 TFB 5: TrapBags (SENTINEL BARRIERS)

![Figure 2.5 TrapBags used in Fargo, ND During Spring 2011 Flooding](image)

Like many of the other TFBs discussed in this report, TrapBags have a cell-like structure that, once set up, are filled with earth, sand, aggregate, or other material to produce a sturdy wall. They consist of pentagon-shaped bags that are sloped on one side and connected to one another, creating an accordion-like appearance. TrapBags are made of high-density woven polyethylene, and come in a 100’ chain made up of 34 connecting bags. Each cell is self-contained, which means a failure in one bag will not result in total structural failure. Another notable feature of TrapBags is their resistance to damage by UV rays. While they have a life expectancy of 10 years, TrapBags cannot be reused because disassembly necessitates tearing the bags apart. However, this estimated life expectancy depends on the intensity of UV radiation – more intense radiation shortens the life of the bags. Thus, they offer a temporary, or semi-permanent solution. In addition to floods, TrapBags can also be used to mitigate the negative effects of earthquakes, hurricanes, landslides, rockslides, erosion, and other natural disasters.
TrapBags are suited for use in variable topographic settings, and are put into place using a Man Portable Deployment Unit (MPDU). This procedure involves unfolding segments of bags, placing them on the MPDU, and then filling each cell to a desired height. If circumstances warrant, emergency responders can also use a rapid deployment method, which entails hanging TrapBags along the guiderail of a mobile delivery device; a tractor then pulls this device while a hopper is filled using a front-end loader. With this method, a one-half mile of barrier can be installed in 4 hours with 4 people. The figures below estimate the cost of installing a one-quarter-mile long barrier that is 4 feet high, the number of labor hours involved, and the amount of fill material needed.

<table>
<thead>
<tr>
<th>TrapBags Price</th>
<th>CY of Fill Required</th>
<th>Estimated Fill Cost</th>
<th>Deployment Time (Rapid)</th>
<th>Deployment Time (Normal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50,160</td>
<td>594</td>
<td>$11,880</td>
<td>6 hours</td>
<td>12 hours</td>
</tr>
</tbody>
</table>

CY = Cubic Yards

2.7 TFB 6: MetalithH₂O (INFRASTRUCTURE DEFENSE TECHNOLOGIES)

MetalithH₂O barriers are made of prefabricated, corrugated aluminum panels that are linked together during assembly using stainless steel pins. Infrastructure Defense Technologies claims this system can be installed 2-3 times faster than other TFBs, and with 20 times the speed of laying sandbags. Installation requires a front-end loader, one operator, and at least two laborers. Individual units take approximately 20 minutes to install. One benefit of this system is that no special equipment is required for assembly; cells are pieced together and then filled with sand, earth, or other materials. Testing performed by the US Army Corps of Engineers has demonstrated the MetalithH₂O barriers are effective at preventing flooding, are durable, and, importantly, have low water seepage rates. Unlike other TFBs mentioned in this report, these barriers can be disassembled and stored (for decades) if they are needed again in the future. When exposed to the elements, temperature extremes, or sunlight, the product will not deteriorate; when “properly used,” the barriers have a product life of 40 years, far longer than any of
the other barriers. When the barriers reach the end of their life, the aluminum can be recycled, avoiding
the costly disposal that is associated with other technologies that use geotextiles or sandbag-like
technology. Based on the information that has been provided by the manufacturer, the figures below
estimate the price of a one-quarter-mile-long barrier (because of the production techniques, either a 3-
foot or 6-foot-high barrier is possible), the number of hours needed to install this, and the amount of fill
required:

<table>
<thead>
<tr>
<th>Barrier Price</th>
<th>CY of Fill required</th>
<th>Estimated Fill Cost</th>
<th>Deployment Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Foot Barrier</td>
<td>$42,240</td>
<td>578</td>
<td>$11,560</td>
</tr>
<tr>
<td>6-Foot Barrier</td>
<td>$84,480</td>
<td>1156</td>
<td>$23,120</td>
</tr>
</tbody>
</table>

CY = Cubic Yards

2.8 Summary and Recommendations

This portion of the report has reviewed different TFBs, noting their respective strengths and
weaknesses. The project study committee has specified that, for the purposes of this study, an optimal
barrier should be capable of a) offering protection against flood waters up to, but not exceeding, 4 feet
in height, and b) extend at least one-quarter of a mile in length. The recommendations that follow take
into account these criteria while giving consideration to expenses, labor, and the reusability of the
various TFBs.

Strictly adhering to the stated criteria immediately rules out three options – Defencell, MetalithH2O, and
TrapBags barriers. While each system has advantages, neither is configurable to achieve 4 feet of flood
protection. Another issue with Defencell units is the fact they are not reusable, which over the long-
term would add considerable replacement costs, despite the fact they are competitively priced
compared to the other options. For a similar reason, continuous sand-filled tubes are not a viable
option. There are several problems with this system, with the two most important being cost and their
potential to disrupt traffic flow along already-congested thoroughfares. While sand-filled tubes can be
put into place rapidly with a small work crew, the tubes are not reusable, which increases overall costs.
Similarly, a special machine (CAS Off-Road Environmental Track Machine) is required to get tubing into
place and fill it with sand. This vehicle has a high price tag – $428,000 for a new model. While some
municipalities may be able to afford this cost, to effectively mitigate flooding along longer stretches of
road will likely demand several machines working simultaneously. Another problematic aspect of this
system is transporting the machine to the site where it is needed, which could lead to delays and
exacerbate flooding damage. Further, the structural configuration of the sand tubes presents difficulties
for protecting roadways. Creating a barrier 4 feet high requires 10 tubes stacked in a pyramid shape.
Along narrow roadways this may constitute an obstruction and barrier to the smooth flow of traffic,
especially if the nature of the flooding calls for a barrier on either side of a road. This awkward shape
could mean the barrier may end up occupying a large amount of shoulder space, increasing the danger
to drivers, and the likelihood of vehicles coming into contact with the barriers, which heightens the
probability of rips or tears occurring in the tubing.

RDFW barriers offer a more practical option and meet the requirements of the study while having a long
(relatively) life expectancy – 10 years. The ease of replacing individual panels on RDFWs is a positive, as
is the nighttime illumination, which provides for rapid and safe deployment irrespective of the hour –
certainly, floods do not adhere to strict timelines. The major drawback of RDFWs is price, which is
$221,000 for a barrier that is a quarter mile. All of the other options discussed in this chapter have a
price point well below $100,000, and frequently have much longer product lives (e.g. MetalithH2O). Given the expenses involved, it would be difficult to justify purchasing RDFW barriers, as the potential return on investment is unpromising.

This leaves the Concertainer and Floodline Units as the most desirable and practical option for meeting the study criteria. They are durable, reusable, and relatively inexpensive. This is not to suggest they are the perfect option. April Walker, PE, and a Senior Engineer at the Storm Water Utility for Fargo, North Dakota, notes that Concertainer/Floodline units are best constructed atop hard surface; depending on the amount of water they are exposed to sliding can be a problem without additional bracing, and seepage can occur, sometimes at high rates. Removal and cleanup can also be a cumbersome process. Also, the amount of protection can vary; a barrier that is 4 feet high may only effectively establish 3 feet of flood protection. However, given the price and their reusability (up to 3 times) these units are likely the best option for meeting the strictly-defined study parameters.

That said, if the criteria were relaxed, arguably the MetalithH2O systems offer the most cost efficient and practical solution. Although these barriers are produced in 3’ and 6’ variations, their price is comparable to Concertainer/Floodline units, particularly given their much longer product life. Whereas Concertainer/Floodline units can be reused a maximum of 3 times, the MetalithH2O barriers have a product life of 20 years. For situations in which moderate flooding is expected, the 3’ barrier proves an ideal compromise – the amount of fill needed to establish these barriers is on par with the amount required for Concertainer/Floodline products. The only drawback is deployment time – there is a noticeable disparity, with MetalithH2O barriers (at the 3’ level) taking approximately 25 more hours to put in place. If waters rise slowly, and flooding is accurately forecast in advance the extra time would not pose considerable difficulties. Thus it is the recommendation of this report that:

- If rapid deployment is required, the Concertainer/Floodline TFBs are the most attractive option to mitigate flood damage to roadways.
- If there is more time available to install barriers, the MetalithH2O system has more appeal given the comparable pricing and much longer product life. Likewise, if flooding above the 4’ threshold is expected, MetalithH2O barriers offer a viable alternative to establish this protection.
- RDFWs do offer the benefit of being reusable (10 year life expectancy) and the nighttime illumination system, easing installation procedures during the overnight hours, and thus fit the criteria specified by the study committee. Despite these features a main stumbling block is the pricing ($221,000 for a quarter mile wall). So, while RDFWs would work, given their shorter product life and lengthy installation time, opting for them in lieu of MetalithH2O barriers would not be economically pragmatic.
- RDFWs should be considered that is not reusable.
- As noted in the introduction of this report the choice of barrier often hinges on context. Evaluation of different sites should be accomplished prior to the onset of flooding to determine the best context-sensitive solution.
The table below presents the estimated total costs for deploying each kind of flood barrier across a series of floods. While it does not take into account labor and equipment costs (which would add expense, particularly to the sandbag option), it gives readers a baseline comparison of the potential cost savings. We have excluded consideration of RDFWs here because they are not viewed as cost competitive.

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Flood 1</th>
<th>Flood 2</th>
<th>Flood 3</th>
<th>Flood 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandbags</td>
<td>26,330</td>
<td>52,660</td>
<td>78,990</td>
<td>105,320</td>
</tr>
<tr>
<td>Concertainer</td>
<td>48,038</td>
<td>59,778</td>
<td>71,518</td>
<td>83,258</td>
</tr>
<tr>
<td>Floodline</td>
<td>51,728</td>
<td>63,468</td>
<td>75,208</td>
<td>86,948</td>
</tr>
<tr>
<td>Metalith H₂O</td>
<td>53,800</td>
<td>65,360</td>
<td>76,920</td>
<td>88,480</td>
</tr>
</tbody>
</table>
Table 2.1 – Summary of TFB Features and Characteristics

<table>
<thead>
<tr>
<th>Variety of TFB</th>
<th>Model/Size</th>
<th>Unit Dimensions</th>
<th>Materials</th>
<th>Cost (/25 Mile)</th>
<th>Fill (/25 Mile)</th>
<th>Team</th>
<th>Deployment Time (Hours)</th>
<th>Reusable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Sand Filled Tubes</td>
<td>6 bags</td>
<td>H-3’ W-3’ L-1000’</td>
<td>Polypropylene tubes</td>
<td>$47,520</td>
<td>409.6</td>
<td>4-6 People</td>
<td>6.8</td>
<td>No</td>
</tr>
<tr>
<td>Concertainer</td>
<td>C-4315</td>
<td>H-4’ W-3’ L-15’</td>
<td></td>
<td>$36,298</td>
<td>587</td>
<td>3</td>
<td>30</td>
<td>Yes (3 times)</td>
</tr>
<tr>
<td>Floodline</td>
<td>F-4315</td>
<td>H-4’ W-3’ L-15’</td>
<td></td>
<td>$39,988</td>
<td>587</td>
<td>3</td>
<td>30</td>
<td>Yes (3 times)</td>
</tr>
<tr>
<td>Defencell</td>
<td>DT1: 2 Layers</td>
<td>H-3’-4” W-2’ L-16’</td>
<td>Polypropylene geotextile</td>
<td>$26,400</td>
<td>330</td>
<td>3</td>
<td>55</td>
<td>No (3 yr. life)</td>
</tr>
<tr>
<td></td>
<td>3 Layers</td>
<td>H-5’</td>
<td></td>
<td>$39,600</td>
<td>495</td>
<td>3</td>
<td>83</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>DC2: 2 Layers</td>
<td>H-3’-4” W-3’-7” L-16’</td>
<td></td>
<td>$34,650</td>
<td>495</td>
<td>3</td>
<td>55</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>3 Layers</td>
<td>H-5’</td>
<td></td>
<td>$51,975</td>
<td>743</td>
<td>3</td>
<td>83</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>DC3: 2 Layers</td>
<td>H-3’-4” W-5’-5” L-16’</td>
<td></td>
<td>$45,375</td>
<td>825</td>
<td>3</td>
<td>55</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>3 Layers</td>
<td>H-5’</td>
<td></td>
<td>$68,062</td>
<td>1238</td>
<td>3</td>
<td>83</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>DC4: 2 Layers</td>
<td>H-3’-4” W-7’-3” L-16’</td>
<td></td>
<td>$57,750</td>
<td>1155</td>
<td>3</td>
<td>55</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>3 Layers</td>
<td>H-5’</td>
<td></td>
<td>$86,625</td>
<td>1733</td>
<td>3</td>
<td>83</td>
<td>&quot;</td>
</tr>
<tr>
<td>RDFW</td>
<td>6 Layers</td>
<td>H-4’ W-3.5’ L-3.5’</td>
<td>Modular, collapsible Eastman plastic grid</td>
<td>$221,206</td>
<td>679</td>
<td>3</td>
<td>63</td>
<td>Yes (10 yr. life)</td>
</tr>
<tr>
<td>TrapBags</td>
<td>Medium</td>
<td>H-4’ W-3’ L-6’</td>
<td>High density polyethylene, high strength textile</td>
<td>$50,160</td>
<td>594</td>
<td>4</td>
<td>6</td>
<td>No (20 yr. life)</td>
</tr>
<tr>
<td>MetalithH2O</td>
<td>1 Layer</td>
<td>H-3’ W-4’ L-8’</td>
<td>Prefabricated corrugated aluminum panels</td>
<td>$42,240</td>
<td>578</td>
<td>3</td>
<td>55</td>
<td>Yes (20 yr. life)</td>
</tr>
<tr>
<td></td>
<td>2 Layers</td>
<td>H-6’ W-4’ L-8’</td>
<td></td>
<td>$84,480</td>
<td>1156</td>
<td>3</td>
<td>110</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Recommended TFBs shaded in light green. RDFW is a feasible option, but not the first choice because of cost, and is shaded in blue.
Chapter 3: Situational Analysis

3.1 Introduction

What follows are site descriptions of the roadways selected for investigation. The purpose of these situational analyses is to determine the appropriateness of using TFBs at each site during flooding events. Each description has a focus on the most relevant features of the road discussed as it pertains to TFB implementation (e.g. lane and shoulder width, any noticeable damage). A second concern addressed by each description is the road’s relationship with the surrounding landscape, in particular the latter’s topography and form. Emphasis is placed on aspects of the landscape that are liable to promote flooding during intense rainfall events. In some cases this threat is minimal. For each site recommended is a series of 2-4 photographs that have been chosen as representative of the road and landscape (these are labeled and located at the end of the chapter). Additionally, sites recommended for TFB implementation have additional photographs included from the Kentucky Roadway Photolog Viewer, which provides a motorists perspective of these stretches of road. All of these images aim to give the reader a sense of the overall landscape, and where applicable, zeros in on trouble spots that could be vulnerable during floods, or that could stymie traffic flow during evacuation situations. At the end of the Chapter there is a catalogue of images for those sites not recommended by this report for TFB usage. Table 3.1, located at the end of this chapter, summarizes the characteristics of each site. While it is not meant as a substitute for the more detailed descriptions below, it offers the reader a quick reference sheet by listing all features that are relevant to this analysis.

3.2 Site 1 – US 51 in Hickman County

This first portion of US 51 is a two-lane road that runs directly from south to north from MM 2.3 to MM 2.5 in a straight manner; the road lacks any curvature. Lanes are 12 feet wide. An open field sits on the western side of the road near the beginning of the site, while to the east wooded areas dominate. In the open field, during our field study, the bottommost 3 feet of a utility pole was waterlogged, indicating recent flooding or rainfall. At approximately the halfway point there is a bridge that spans a small stream that is 12-15 feet in width; the bridge is positioned 4-5 feet above the waterline. Water levels in the stream were less than one foot. In the run-up to the bridge, the shoulder measures 1.5 feet, widens to 3 feet on the bridge itself, and then, on the west side of the road, immediately after exiting the bridge, the shoulder extends to 8 feet on the west side. On the east side of the bridge, steeply-sloping banks inhibit the growth of riparian vegetation on either side of the channel. This portion of the stream may have undergone channelization for agricultural purposes given that there is pasturage on either side, which extends transversely away from the stream. A small levee is evident on the south side, which is likely a human artifact. To the west of the bridge riparian vegetation has densely colonized down to the bankline, reinforcing the banks’ stability. Because of the abundance of vegetation determining visually whether this portion of the channel has been modified is difficult, but certainly it has not been the target of intensive modification, like the eastern portion of the stream has been. Given the different channel morphologies on either side of the bridge, flooding risk may not be equal on the west and east side of the stream. The bridge reveals no obvious signs of structural deficiencies. A guardrail protects the bridge ends on the east and west side of it and continues for several feet past the north and south ends of the bridge. With the 4-5 feet of elevation above the water surface, the likelihood of the bridge suffering flooding is low except during exceptionally intense or long-lasting rainfall events. Past the bridge, the road is unencumbered by vegetation and passes through an open landscape with gently sloping swales present on the west side of the road. During the field visit there was evidence of flooding...
in this location. Near the end of this section the road dips slightly in elevation, which may increase its vulnerability to short-lived flooding.

**TFB Recommendation:** This site is not suitable for TFBs because the presence of a bridge indicates it is a headwater situation, which TFBs are not designed to withstand.

### 3.3 Site 2 – US 51 in Hickman County

This stretch of US 51 is located between MM 4.4 and 4.6. For its entire length the road is straight, with two 12-foot lanes and shoulders that are approximately 6 feet wide prior to the road crossing a small bridge. Beyond the bridge the shoulders narrow considerably to 1.5 feet. The roadway is fairly even with the landscape prior to the bridge crossing, however on the west side there is a swale 2-3 feet deep, while on the east side the topography is flat until approaching the creek. At this point, both sides of US 51 achieve a local elevation advantage over the surrounding landscape. The swale on the west side of the road contained standing water – during our field inspection, a utility pole located immediately south of the stream, and proximate to a swale, showed evidence of saturation that extended upwards of 8 feet, indicating the possible recent flooding. The bridge crosses a stream approximately 20-22 feet wide, with low water levels, on the order of 3-4 feet. Vegetation lines the stream on the north and south banks, however, most of the mature trees are located at least 8-10 feet from the bankline. Banks are steep and can only support grasses and weed cover in most areas. The steepness of the banks, along with evidence of undercutting along the south bank also suggest that flood activity and high water flows have taken place recently. However, the bridge itself is 10-12 feet above the water surface, indicating a total inundation of the bridge is unlikely except during the most severe flooding events.

**TFB Recommendation:** This site is not suitable for TFBs because the presence of a bridge indicates it is a headwater situation, which TFBs are not designed to withstand.

### 3.4 Site 3 – US 60 in Henderson County

This segment of US 60 is a straight roadway that moves over subtly rolling topography. Along the western portion of the road (MM 4), the landscape is elevated above the surface of the highway; here, lanes are 12 feet wide with shoulders that are 6 feet near MM 4.0, but they narrow down to 2-3 feet further east. Intervening between the road and adjoining land (which is partially wooded on the south side of the road), on both sides, are swales. Neither of the swales contained water during the field visit. Beside the swales the landscape is locally elevated – resulting in a berm-like feature. Moving eastward, the road widens due to the presence of a turn lane that sits in front of a school that is on the north side of the road. The landscape, aside from the school, consists mainly of farmland with scattered trees lining the road. Beginning at approximately MM 4.2, there is a series of three small lakes near the road that were flooded during the field visit. The water did not extend all the way to the road, but during significant rainfall events it is probable water inundates the road from these sources. At this juncture, the road is topographically even with the adjacent landscape, but further east there are more undulations, although there is not a significant difference in elevation between the road and the contiguous land. At MM 4.7, there is a dense strip of wooded area on the north side of US60. Towards MM 5 there are mildly depressed swales next to the roadway on the order of 1-2 feet.

**TFB Recommendation:** This site, located in District 2, is suitable for evaluating the efficacy of TFBs. Near the beginning of the route there is plenty of shoulder room, and while this narrows further on this should not present a problem for testing given that the site meets all of the other assessment criteria.
3.5 Site 4 – KY 502 in Hopkins County

Located between MM 4 and 5 along KY 502, the first half mile of the road is cradled by extensive wetlands. In this area the roadway provides an artificial levee of sorts as it divides the wetland in two, and has a 2-3 foot advantage in elevation over the wetlands. Lanes are 10 feet wide along this segment of the road with very minimal shoulder space. On both sides of the roadway the asphalt slopes towards the water and some grasses have encroached up onto the surface. In at least one spot evidence is present of asphalt failure, probably due to a combination of root burrowing and groundwater undermining the structural integrity of road. During prolonged rainfall events this area is surely vulnerable to flooding, however, with the narrowness of the lanes and lack of shoulders, installing any kind of TFB would prove challenging, and maintaining more than one lane of traffic is likely unfeasible. Through the wetlands, KY 502 remains straight, with only very minor curves. After moving past this area, the road becomes more curved and sinuous, with angles sharp enough to create two blind spots. This road segment is confined on both sides by extremely dense forest cover. On the east side of the roadway, the landscape is elevated above it; on the west side, the wooded spaces are situated below the road. The landscape’s downward-sloping gradient is oriented east to west. Abundant tree cover on the east side of the road will act as a protective barrier, helping to deter some erosion that might otherwise cause unconsolidated topsoil to spill onto the roadway. Moreover, along the most sinuous part of the road (as travelers approach MM 5) the shoulders widen on the west and east side to 2 and 3 feet, respectively, providing more of a buffer between the road and the landscape. Although, from the standpoint of offsetting the effects of flooding, the expanded shoulders offer little in the way of protection since the areas of the road most prone to inundation – in the wetlands – are well-exposed to water.

TFB Recommendation: This site is less suitable for TFBs because there are blind curves present along the route. These curves introduce a hazardous situation during the deployment of TFBs because they significantly reduce the amount of navigable roadways, which can pose dangers for motorists. Equally, workers installing TFBs could be at risk from drivers unaware of their presence on the road.

3.6 Site 5 – KY 919 in Ohio County

This segment of KY 919 is a narrow, two-lane road that initially runs east before sharply turning southward before abruptly turning northeastward. Individual lanes are 12 feet wide and lack shoulders. At MM 3.2 there is a wetland located north of the road; the road is elevated approximately 1-2 feet above the wetland atop what resembles a levee-like feature. At MM 3.4, where the road sharply curves there is another wetland feature positioned immediately adjacent to the road that has standing water next to the roadway. The lack of difference in elevation at this juncture suggests that it is prone to flooding, especially during locally intense rainfall events. At several points in the road the wetland is flush against the edge of the asphalt. Where the wetland comes to an end the road turns northeast and the landscape opens back up, revealing several homes, barns, and tree cover that is slightly less dense. Beyond this turn, as the road straightens out, there is an artificial lake located to the southeast of the road with a connecting swale. However, there is a steep lip encircling the depressed lake, and it appears any risk of flooding originating from this feature would be minimal. Moving towards MM 4, the road remains straight and relatively even with the adjacent landscape. On the southeast side of the road is open farmland with a very minor ditch situated between the road and a line of electrical poles. There is a similar ditch-like channel on the north side of the road, and the land cover consists mostly of various grasses and weeds; the road is at a slight elevation.
**TFB Recommendation**: This site is less suitable for TFBs because there are blind curves present along the route. These curves introduce a hazardous situation during the deployment of TFBs because they significantly reduce the amount of navigable roadways, which can pose dangers for motorists. Equally, workers installing TFBs could be at risk from drivers unaware of their presence on the road.

### 3.7 Site 6 – US 60 in Daviess County

This extended stretch of US 60 runs from MM 2.6 to MM 5.7. For the first mile US 60 parallels a railroad track, after which it briefly curves away from it towards the north, parabolically sweeps back eastward, and then assumes a southeasterly orientation as it cuts across the railroad, at which point it remains straight for the rest of the study area. The initial section of road (near MM 2.6) is lined by a number of houses on the north side, but a mildly depressed swale is sandwiched in between US 60 and the railroad track – this depression is on the order of 2-3 feet in most locations, and varies little spatially. Shoulders are narrow throughout this section – measuring 1.5-2 feet. Along this portion of the road the topography is relatively flat, however, there may be a slight elevation advantage on the south side, which beyond the rail tracks consists principally of agricultural land. These minor differences in elevation are unlikely significant. As the road turns to the north, briefly, a swale develops on the left-hand side of the road, however, this disappears as the road turns back toward the east. Around this curve the road is even with the surrounding landscape and there is no evidence of any slope advantages. Crossing the railroad tracks, US 60 enters an area populated by a number of homes, businesses, and other buildings. Just before MM 5.7 there is a bridge that crosses a small creek. Agricultural fields flank the eastern part of the creek, while on the southern side of the bridge there is dense, possibly overgrown riparian vegetation. Guardrails line the bridge, however, like the areas of US 60 further to the west, shoulder room is nominal.

**TFB Recommendation**: Because this is an extended stretch of road (approximately 3 miles), some areas are more suitable than others for TRB use. Near MM 5.7, where there is a bridge, TFBs would not be recommended because it suggests there is a headwater situation. However, towards the beginning of the route (MM 2-4), there are no impediments to using TFBs in cases where flooding in the adjacent swales threatens to spill onto the roadway. The shoulders are somewhat narrow, but the road appears wide enough to support TFBs if the need form them arises.

### 3.8 Site 7 – US 60 in Crittenden County

This stretch of US 60, moving from west to east, initially passes through a landscape dominated by homes and farmland. At approximately MM 22.5 a small culvert runs underneath the road and drains into a small lake. The topography undulates noticeably along this portion of US 60. Beginning at MM 22 the landscape is higher than the road (which at this point contains shoulders 1.5 feet wide). Progressing eastward, adjoining lands are lower than the road, which is particularly evident on the southern side of the road, where there is that small lake. There is little in the way of dense riparian vegetation near the lake or the culvert that empties into the lake. Vegetation consists of mostly grasses – no shrubs, trees, or other woody plants have been recruited to this side. As US 60 progresses towards the lake it deviates from its straight path, arching slightly to the north. Here, the shoulders widen out to 6 feet in width. After this slight curve the roadway straightens out and crosses the Tradewater River via a bridge that is located 40-45 feet above the water surface. Banks are steeply sloped and lack any vegetation in the first 6-8 feet above the bankline. The bridge footings show evidence of recent erosion, as do the exposed tree roots. Some trees upstream of the bridge appear to have been recently uprooted, or are tipping towards the water, suggesting the possibility of uprooting in the near future. This evidence indicates
recent flooding has significantly altered channel geometry and morphology, although given the considerable elevation difference between the bridge and water surface the probability of the bridge incurring significant damage due to flooding is very small.

**TFB Recommendation:** Based on the assessment criteria, this site represents a good point at which to evaluate TFBs in District 1. Although shoulder space is limited along some portions of the route, this should not be considered a barrier to conducting a test of the TFBs.

### 3.9 Site 8 – KY 94 in Fulton County

This portion of KY 94 is a two-lane highway located between mile markers (MM) 9.4 and 9.6. With the exception of a slight dip towards the south at MM 9.5, the road’s geometry is relatively straight. Lanes are 12 feet wide and shoulder room is minimal to non-existent. The adjacent landscape is lower than the road on both sides throughout the entire section of road. Running along the northern portion of the road is a stream that is intersected by a driveway, under which a culvert allows for throughflow; moving away from this small channel is open field. On the southern edge of the road is a series of swales that are relatively minor, and are located approximately 1-2 feet below the road’s surface. Moving eastward along KY 94, the roadway passes over a culvert that connects a small swale on the south side of the road, characterized by short grasses and flowers; some negligible channelization has occurred, but only very slight. On the northern fringe of the road, the culvert opens into an area of extensive riparian vegetation, consisting of tall grasses and abundant woody shrubs and trees. This location is a candidate for flooding during substantial rainfall events. In this same location, the landscape to the south and north is lower than the roadway, although not enough to protect it from inundation entirely.

**TFB Recommendation:** One of the problems with this site is the lack of an extensive shoulder, the other features of the site make it a viable one for TFB evaluation. Since one goal of this project is to evaluate TFBs at one site in each district, this is the only site in District 1 that would qualify based on the assessment criteria, and should therefore be considered as the most viable candidate site in District 1.

### 3.10 Summary of Findings

**Overall Recommendation:** To attain an evaluation in District 1 and District 2, this report suggests that Site 8, KY 94 in Fulton County, and Site 3, US 60 in Henderson County would be amenable for TFB testing. A secondary choice is Site 7, US 60 in Crittenden County (located in District 2). The lack of shoulder room at Site 7 makes it less ideal than other locations, but it would still be able to accommodate a TFB, although it would likely only be able to maintain one lane of traffic flow once TFBs are deployed. Site 6, US 60 in Daviess County, is potentially suitable, however, TFBs would not be an appropriate option in the area near the bridge. If flooding is problematic in locations away from the bridge, TFBs would be a feasible option.

### 3.11 TFB Recommendation for Each Site

As outlined in Chapter 2, the most viable TFBs from a cost perspective are the Concertainer and Floodline units. MetalithH2O systems are an option as well, however, achieving 4 feet of protection with them is approximately double the cost of the Concertainer/Floodline units. Based on this, the Concertainer/Floodline products are the more attractive choice from a cost standpoint. But they also offer an additional benefit: their compactness. MetalithH2O systems are 4 feet in width, whereas Concertainer/Floodline units are 3 feet in width. This savings of one foot may sound trivial, however, if
barriers are deployed on both sides of a road, going with the Concertainer/Floodline units saves 2 feet, which could be crucial for ensuring that traffic operations remain flowing smoothly. The question then becomes which is preferable – Concertainer or Floodline units. Each protects against floods, and the Concertainer units are approximately $3,500 cheaper per quarter mile compared to the Floodline units. As noted in Chapter 2, however, the Floodline units have added engineering features that make them particularly well suited to serve as a flood barrier. Specifically, the Floodline units are built to reduce their permeability, which adds in an additional safeguard against rising waters. Consequently, this report recommends that either the Concertainer or Floodline units would be good first choices at any of the test sites, however, for an added measure of security and protection it is probably worth the marginal additional expense to opt for the Floodline units.
3.11 Images From Site Analysis

The following pictures were taken at Site 8 (KY 94 in Fulton County), Site 3 (US 60 in Henderson County) and Site 7 (US 60 in Crittenden County). The first two sites represent preferred choices on which to test, and potentially utilize, TFBs.

3.11.1 KY 94 – Fulton County

Figure 3.1 KY 94 Fulton County (Kentucky Roadway Photolog Viewer)

Figure 3.2 Fulton County

Figure 3.3 Fulton County
3.11.2 US 60 – Henderson County
3.11.3 US 60 – Crittenden County

Figure 3.7 US 60 Henderson County (Kentucky Roadway Photolog Viewer)

Figure 3.8 US 60 Henderson County (Kentucky Roadway Photolog Viewer)

Figure 3.9 US 60 Crittenden County (Kentucky Roadway Photolog Viewer)

Figure 3.10 US 60 Crittenden County (Kentucky Roadway Photolog Viewer)
Figure 3.11 US 60 Crittenden County (Kentucky Roadway Photolog Viewer)

Figure 3.12 Crittenden County

Figure 3.13 Crittenden County
3.11.4 US 60 – Daviess County

Figure 3.17 Crittenden County

Figure 3.18 – Daviess County

Figure 3.19 – Daviess County
Figure 3.20 – Daviess County

Figure 3.21 – Daviess County
<table>
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<th>Hickman 1</th>
<th>Hickman 2</th>
<th>Henderson</th>
<th>Hopkins</th>
<th>Ohio</th>
<th>Daviess</th>
<th>Crittenden</th>
<th>Fulton</th>
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<tr>
<td></td>
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Recommended sites are shaded in light green. Sites 6 and 7 are alternate sites, and therefore shaded in light blue. Site 6, as noted in the report, requires further evaluation to determine potential sources of flooding and their proximity to the creek and bridge.
Chapter 4: Legal Issues Associated with TFBs

4.1 Liability and the Use of TFBs

This chapter briefly explores some of the legal issues that could potentially arise due to the installation of temporary flood barriers (TFBs). This discussion is based on analysis conducted by Kenneth Agent (2010; personal communication). The interpretations presented here are broad, and would demand refinement prior to the State, counties, or cities choosing TFBs. There are several possible liabilities that could emerge from the use of TFBs – first, motorists driving along narrowed roads (resulting from the deployment of TFBs) could suffer accidents at a higher rate than under normal conditions; second, because TFBs divert water away from highways, adjacent properties may be affected, potentially causing damage that would not have occurred had there been no barriers in place. But it is also worth noting, based on the experience of other states, that damage to property, or individuals suffering personal injury due to accidents, are likely to be rare occurrences. This fact is especially salient if the state, local government, and contractors responsible for designing and deploying the barriers follow careful planning procedures.

Other states that deploy TFBs carry liability insurance to hedge against negative impacts resulting from their use. Because KYTC does not commonly employ TFBs to mitigate the effects of flooding, it does not hold insurance coverage. Should the state decide to pursue the use of TFBs on a widespread basis, it is recommended that a cost-benefit analysis be undertaken to explore whether purchasing insurance would be a necessary investment. Another fact to bear in mind is that tort litigation is constitutionally limited at the state level in Kentucky (see below). Iowa, which made extensive use of TFBs when 2011’s catastrophic flooding devastated large portions of the state, did not have any liability claims filed against it pertaining to the use of TFBs. There are physiographic contingencies that partially explain why TFBs did not damage adjacent property. In Iowa, roadways are typically situated at elevations slightly higher than the surrounding property landscape. Given this elevation difference, TFBs posed little credible threat to land owners because the State of Iowa owns the road shoulder, and in some cases right-of-way parcels located next to the shoulder, before private land holdings begin. Consequently, when waters reach the road along most highways, the abutting private lands will already have been inundated with water. Advancing a claim that TFBs catalyzed inundation under these circumstances would be highly implausible. Because of the particularities of Iowa, its case is not generalizable to Kentucky (although in some areas it may be).

A complicated picture emerges with respect to the potential liability issues surrounding the use of TFBs. One concern raised has been whether individual state employees could be sued if TFBs fail, or if they cause damage because of their presence. Agent (2010: 18) argues that certain interpretations of Kentucky tort law, as it currently stands, may make state employees especially vulnerable to lawsuits. Agent has further noted that lawsuits have been leveled against state employees with increasing frequency of late (personal communication). In particular, three aspects of the state constitution converge to potentially saddle state employees with liability. First, the constitution and subsequent legislation grant state agencies immunity from, or limited liability to, lawsuits. Second, the Kentucky Supreme Court has interpreted this immunity as not existing to individual state employees. Taken together, these two aspects could make an employee a more attractive target for legal action than the agency employing them. Lastly, there are provisions in the constitution preventing the state from paying damages on behalf of an employee.
Section 231 of the Kentucky constitution states: “The General Assembly may, by law, direct in what manner and in what courts suits may be brought against the commonwealth” (State of Kentucky 1891: 146). The Kentucky Supreme Court has interpreted this as an assertion of sovereign immunity, a legal doctrine that prevents a government from being sued without its consent. This interpretation makes any agency controlled and funded by the central state government immune from lawsuit unless the General Assembly specifically passes a law waiving this right. The General Assembly has passed laws waiving this immunity, but only under specific circumstances and for limited claims. Specifically, the state can be sued for torts related to ministerial action but not for discretionary action (a distinction explained below), and for amounts only up to $200,000 for a single claim. It cannot be sued for damages related to pain and suffering or to mental distress. All claims must go through a specific agency, the Board of Claims (Agent 2010: 10–13).

The difference between ministerial and discretionary action is that between carrying out a routine task with little scope for individual decision (“ministerial”) and carrying out a directive under conditions where there are a choice of options and judgment (“discretion”) must be exercised. Put another way, a failure of ministerial action would be negligence of duty, while a failure of discretionary action would involve misjudgments of planning and design (Agent: 18–19). There is a substantial gray area between the two concepts, leaving much room for interpretation in specific cases, particularly in the case of TFBs. The design and implementation of TFBs may involve a series of engineering judgments that are left up to the discretion of those working on the scene, or emergency planners working in advance to determine the best way to deploy TFBs should the need arise. Thus it is possible to foresee situations arise which produce lawsuits under the reasoning that contractors and state employees applied inappropriate reasoning, which in turn led to decisions that directly led to either property damage or traffic accidents. Because it is impossible to predict when these situations might occur, the best protection the state can afford itself is properly documenting everything that goes into the decision-making process (see below).

Given the ambiguous legal relationship between individual state employees and sovereign immunity in the Kentucky context, and the potential for disproportionate liability falling on the employee, it makes sense to limit the latter’s exposure where possible. This can be partly achieved through the use of private contractors for on-site work with TFBs, although here the state remains liable for inspection/approval – to ensure the contract has been executed in accordance with the mandates stipulated by the state – and maintenance. The likelihood of a successful lawsuit against a state employee may be further limited through careful wording of contract documents, with regard to standard of care and the scope for ministerial versus discretionary decision-making. Further, careful documentation of the guidelines under which the TFB was installed and maintained is imperative because these establish the standard of care against which the performance of the TFB is judged. Violating that standard of care, or failing to update it when conditions warrant a change to the original plans, could place the state and its employees in a vulnerable legal position (Agent, personal communication).

There is no evidence to indicate that legal actions have been brought due to environmental harm, or traffic accidents, caused by the use of TFBs. This is not to argue lawsuits will not occur, but to suggest they are unlikely. TFBs divert water and sediment onto nearby properties, which can generate damage. At the sites evaluated for this report, the length of roadway potentially protected by TFBs is small – less than one mile. Of course, if KYTC recommends the widespread adoption of the barriers, longer stretches of road may be protected. Although we are unaware of any studies explicitly investigating the relationship between length of road protected and the likelihood of property damage/vehicle accidents, it is not unreasonable to conclude the risk of injury goes up, but not to unacceptably high levels.
4.2 Recommendations and Conclusions

While it would be the responsibility of the contractor to properly install TFBs, ultimately it would be the state’s duty to ensure they are properly implemented and maintained. Because of this, it is very unlikely the state could be shielded from liability due to TFBs that either malfunction, or result in an injury that would not have occurred in their absence. Officials at the state, county, and city level must be deliberate and careful in the execution of TFB installation. During the design phase when officials decide how TFBs should be installed (e.g. alignment, position on the roadway, and extent), there must be a proper standard of care articulated that provides instructions for the installation and maintenance of the TFBs. Although in emergency situations there may not be surplus time, officials should maintain extensive documentation justifying their decisions, and if the standard of care is altered at any time, those changes should be duly noted. This will not necessarily shield the state, contractors, counties, and cities from lawsuits, however there is a clear standard of care documented, and this has been executed with precision, it may dampen the possibility of a lawsuit. Despite these precautions it is still possible for individuals to bring lawsuits against a variety of parties involved with the implementation of TFBs. Going forward, KYTC needs to clarify at what jurisdictional level (e.g. state, county, city) the decision to use TFBs will be made at, and what entities will be responsible for design and maintenance. The doctrine of sovereign immunity applies to the State of Kentucky and individual counties. However, individual counties lack a Board of Claims. Without this body, individual employees have been subject to lawsuits with increasing frequency. If the implementation of TFBs is in fact delegated to the county level, there is the possibility that county employees could face lawsuits if TFBs fail. But state employees have also been subject to lawsuits as well. The main takeaway is that preventing all possible lawsuits is unlikely irrespective who is responsible for installing and then making sure the TFBs function properly. Past experience indicates both contractors and the state will be party to lawsuits. While it is the recommendation of the report to delegate the installation of TFBs to private contractors, this will not relieve the state of liability if TFBs lead to accidents or property damage. The most efficient method of potentially avoiding a lawsuit is to meticulously document all of the decision-making processes that go into the installation and care of TFBs. From an operational perspective, this means state, county and city officials should have in place plans for TFB implementation well before floodwaters begin to rise. The experience of other states indicates the probability of property owners suing over damages inflicted by TFBs is remote. However, that possibility always exists and it is exceedingly unlikely that the state could avoid litigation entirely given the unpredictability with which lawsuits arise. Nonetheless, the benefits of using TFBs to protect infrastructure and keep traffic flowing outweigh the potential costs (in the form of lawsuits), which may never materialize.

Conclusions:

- In using TFBs a proper standard of care must be articulated and documented (relating to installation and maintenance). Any changes to these standards should also be commensurately documented, with justifications provided for why a change was necessary. 
- Past cases demonstrate claimants will likely pursue litigation against the state and its contractors, and in some instances individual employees. 
- There should be a clear plan established regarding which authorities bear the responsibility for overseeing installation and maintenance. If KYTC delegates this duty to local officials, the likelihood of legal action being brought against individual employees (e.g. at the county level) will increase given counties enjoy sovereign immunity but lack a Board of Claims option which is available at the state level.
- If KYTC envisions using TFBs extensively, it should perform a cost-benefit analysis to determine whether the purchase of liability insurance – to cover damages inflicted by TFBs is justified.

References
Agent, Kenneth. 2010. Roadway Related Tort Liability and Risk Management. KTC-10-07/SPR 399-10-1F.

Agent, Kenneth. Personal Communication. 30 July 2012

Kentucky State Constitution, Section 231.
Chapter 5 – Conclusions and Final Recommendations

Based on the individual site analyses and the evaluation of different manufacturers’ TFBs, this report finds that TFBs are suitable for deployment, in Kentucky, to deal with flooding situations. The situational analyses indicate, however, that TFBs will not work under all circumstances. When roads are narrow, and where there are headwater situations present (i.e. a bridge nearby), TFBs are unlikely to be effective enough to either keep traffic flowing during evacuation procedures, or to thoroughly protect the structural integrity of roadways. Before using TFBs, emergency managers should conduct site analyses of areas potentially suited for their implementation. Doing so ensures that a) TFBs are an appropriate solution; and b) that the proper TFB has been selected based on a contextual analysis. The following recommendations reiterate the conclusions of the previous chapters, and provide a map the KYTC can follow as it decides the best pathway to comprehensively integrate TFBs into flood management.

Recommendation 1: TFBs are a viable solution for mitigating the effects of flooding on Kentucky roadways

Every year, Kentucky’s roadways are potentially threatened by flooding events. The severity of these can range from mild and innocuous, resulting in no damage to roads or adjacent property, to extremely intense episodes that threaten the structural integrity of highways and the communities which they link together. But establishing a response plan that emergency responders adhere to once floodwaters begin to rise can mitigate the worst effects of high water and flooding. Temporary flood barriers (TFBs) are a viable, economic, portable, and most importantly, time-saving tool that ameliorates the impact of floodwaters. Numerous case studies illustrate the effectiveness of TFBs. They have been used with great success throughout the United States, and in several instances, within Kentucky. In addition to protecting vulnerable infrastructure, TFBs also play an important role in keeping vital roadways open, safe, and functional during flooding events, which is especially crucial when evacuations are called.

Recommendation 2: The most economically viable, and effective, TFBs that could be used in Kentucky are the Concertainer/Floodline Units and the MetalithH₂O systems

Chapter 2 reviewed the relative strengths and weaknesses of various TFB systems. Specifically, this report has followed the criteria articulated by the study committee, which held that barriers should be able to: a) protect against flood water up to, but not exceeding, 4 feet; and b) extend at least one-quarter mile in length. This report suggests that Defencell, TrapBags, and continuous sand-filled tubes are not viable options because they do not offer the requisite protection. Sand-filled tubes, because of the costs incurred in purchasing necessary machinery to lay them down, are cost prohibitive. The most cost effective TFBs are the Concertainer and Floodline units. In addition to being economical, they are reusable up to 3 times as well. A second option is the MetalithH₂O system. This system is unable to achieve exactly 4 feet of protection because of its configuration – 3’ and 6’ options are available, however. Despite not meeting the exact criteria outlined by the study committee, MetalithH₂O systems are cost competitive with Concertainer and Floodline units and should be considered a viable option, particularly as they are reusable for a period up to 20 years. A final TFB discussed – Rapid Defense Flood Walls (RDFWs) – meet the study’s criteria, and have a 10 year life expectancy. The major drawback of RDFWs is their cost, which far exceeds that of the other two recommended options. As the labor hours required to construct RDFWs is greater than the Concertainer and Floodline units, and the MetalithH₂O system, justifying the additional expense of their purchase would be difficult. And there is no evidence that suggests RDFWs perform better than the other two systems.
Recommendation 3: The optimal sites for evaluating, and implementing, TFBs, based on site analyses are Site 3 (US 60 in Henderson County) and Site 8 (KY 94 in Fulton County). Alternate sites include Site 6 (US 60 in Daviess County) and Site 7 (US 60 in Crittenden County).

One aim of this research was to identify at least two sites, one in District 1 and one in District 2, on which to evaluate TFBs. This report suggests that Site 3, US 60 in Henderson County, and Site 8, KY 94 in Fulton County are best suited for this as they meet all the necessary criteria. Should the need arise, there are alternative options. US 60 in Daviess County is one possibility (Site 6). There is a bridge along this stretch of road. Assessing TFBs near bridges is not recommended because it is considered a headwater situation. But as this particular stretch of road is comparatively long in relation to the other sites evaluated, there are other spots potentially favorable for a test. Near the beginning of the route there are no impediments that would inhibit TFB installation; while there are narrow shoulders present, it is possible to construct TFBs, although it may entail sacrificing some of the usable roadway. Another potential is Site 7, US 60 in Crittenden County. The minimal shoulder room here makes it less ideal than other locations, but it would likely be able to accommodate a TFB, and keep at least one lane of traffic flowing.

Recommendation 4: To reduce liability risk to individual state employees, use private contractors and carefully worded contracts. These contracts should articulate, precisely, the standard of care that is used to govern the installation and maintenance of TFBs. While these steps will not mitigate lawsuits entirely, they can reduce the probability that they will arise.

Current legal interpretations of the doctrine of sovereign immunity, as it applies to Kentucky, create the potential for disproportionate liability to fall upon individual employees (rather than the state or the state agency) in the event of property damage or injury associated with the TFBs occurs. Previous cases show the likelihood of legal action is small, and no lawsuits have been filed against states that have adopted TFBs. But the risk of TFBs failing, causing traffic accidents, or damaging property cannot be eliminated totally, but it may be reduced through the use of private contractors (although it is up to the state to ensure all contracts related to TFB installation are executed to conform with the mandates the state has laid out). When contracts are drawn up, or when plans are designed to maintain the function of TFBs, there should be extensive documentation that elaborates, in detail, the standard of care. Should changes to these standards be modified, the appropriate individuals should justify and document why those changes were made. None of these precautions eliminate the possibility of lawsuits, but they may potentially diminish their likelihood. Further, it provides the state with ample documentation to justify the design and maintenance operations.

Summary Recommendation: Develop and implement a plan for the use of TFBs within Kentucky

Based on the findings of this report, the Kentucky Transportation Cabinet should move forward with the development and implementation of a plan for strategically using TFBs when flooding arises. This includes holding a product demonstration of those TFBs recommended in this report (Concertainer and Floodline Units, MetalithH2O, and if desired RDFWs) by the vendors to determine what style of TFB is best suited for flood control operations. Concurrent with this stage, a plan for the deployment of TFBs in emergency flooding situations should be developed in consultation with emergency managers and other appropriate personnel.
Appendix A: Images of Sites not Selected for TFBs

A.1 – Site 1 US 51 in Hickman County

Figure A.1.1 Hickman County (MM 2.3-2.5)

Figure A.1.2 Hickman County (MM 2.3-2.5)
A.2 – Site 2 US 51 in Hickman County

Figure A.1.3 Hickman County (MM 2.3-2.5)

Figure A.2.1 Hickman County (MM 4.4-4.6)

Figure A.2.2 Hickman County (MM 4.4-4.6)
Figure A.2.3 Hickman County (MM 4.4-4.6)

A.3 – Site 4 KY 502 in Hopkins County

Figure A.3.1 – Hopkins County

Figure A.3.2 Hopkins County
Figure A.3.3 Hopkins County

Figure A.3.4 Hopkins County

A.4 – Site 5 KY 519 in Ohio County

Figure A.4.1 Ohio County