WHY SHOULD I EVACUATE WHEN THE LEVEE ISN'T PREDICTED TO OVERTOP

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INTRODUCTION

A levee is a structure, usually an earthen embankment, designed with the principal aim of reducing or preventing the inundation of land from floodwater. Levees are designed to offer property protection against floods up to the magnitude of the levee design flood. Unless the levee design flood is the Probable Maximum Flood (PMF), which is usually not justifiable and generally not physically possible, there will come a time when a flood is predicted to exceed the design flood and therefore result in “failure” of the levee. In such a situation evacuation of the protected area is required to prevent potential injury and loss of life.

To avoid major difficulties during the evacuation process and to minimize the risk to evacuees and the emergency personnel executing the evacuation process, it is imperative that evacuation takes place before physical failure of the levee occurs and while evacuees can be evacuated using their own transport (i.e. before evacuation routes are cut by floodwater). It is also preferable that evacuation does not take place under adverse conditions, such as at night. In all situations the decision to evacuate is heavily reliant on confidence in the forecast of the timing and height of the flood.

Unfortunately flood height prediction is not an exact science and not all floods behave predictably as:

- catchment conditions, both across the catchment within a storm and from storm to storm, can vary significantly which affects the rainfall-runoff relationship;
- heights cannot be reliably estimated early in an event, particularly before all rain has fallen and predictions may only be for the flood category (minor, moderate or major);
- storms move through the catchments whereas modelling generally assumes static storms;
- patterns of rainfall (temporal and spatial) affect flood shape and therefore flood levels even where the overall volume of runoff is the same.

In view of the potential risk of injury and loss of life, the responsible emergency management authorities have to adopt a risk management approach when making decisions about the evacuation of a levee protected area. This approach sometimes results in the authorities being subject to criticism by communities, which, armed with the benefit of 20-20 hindsight, have made the observation, that after evacuation had been ordered, the levee did not actually fail and all the fuss and disruption appears to have been for nothing.

It is hoped that this paper will provide some insight into the limitations associated with:

- levee design and the various mechanisms that can lead to their “failure”;
- flood warning and flood height predictions; and
- evacuation issues.

LEVEE DESIGN FLOODS

As mentioned, a levee is a structure, usually an earthen embankment, designed with the principal aim of reducing or preventing the inundation of land from floodwaters. It needs to be recognised
that levees are designed to offer property protection up to a flood of a specific magnitude or frequency (the design flood) and no larger. In NSW and probably within Australia, very few urban levees have been constructed with design floods larger than the 1% Annual Exceedance Probability (AEP) or 1 in 100 years Average Recurrence Interval (ARI) event. A number of levees have been constructed with design floods significantly lower than the 1% AEP event, down as low as the 10% AEP (1 in 10 years ARI) for urban areas and much lower again in some coastal rural areas, such as the Lower Macleay River.

In NSW, levees for relatively small design floods (<1% AEP) tend to occur in coastal towns and cities where the variation of flood heights with changing AEP is relatively large. Under such circumstances providing protection up to the 1% AEP level may be difficult to justify economically and may have major practical difficulties due to the width of the levee footprint where the space available for levee construction is limited. In these situations it may still be cost effective to provide protection against relatively small, but frequent, flood events to restrict property damage and community disruption.

People on the other hand deserve a much higher level of protection, higher even than protection against the 1% AEP flood, and hence must be prepared to evacuate to safe high ground when there is a risk of “failure” of the levee. It needs to be recognised that the function of a levee is to protect property, not people. The justification for constructing a levee is always undertaken on the basis of the direct flood damage to property and infrastructure that can be avoided, restricting the indirect damages to the local and wider communities (clean up costs, loss of production/revenue, reduced wages and non provision of public services) and limiting the intangible damages that occur as a result of flooding (increased levels of insecurity, depression, marital stress, health issues, inability of a town to operate during a flood event including providing services to surrounding areas, and general post flood inconvenience). The justification for the construction of a levee is never based on an attempt to estimate the number of lives that might be saved or the injuries that may be avoided. Such an assessment is not feasible using any current methodology.

The heights of floods of various magnitudes or frequencies are usually measured at a particular point relevant to the levee in question, usually at a site where river heights have been measured for many years such as a stream gauging station. The corresponding design flood levels are usually based on an analysis of historical data and/or hydrologic and hydraulic modelling (with associated calibration and verification) to estimate flood levels along the length of river adjacent to the levee (the design flood profile).

To better appreciate the functioning of levees it is necessary to have a basic understanding of how the levee design flood profiles are estimated so that they can be put into perspective. The first thing to recognise is that levee design flood profiles are estimates of how a typical future flood of a chosen magnitude may behave, not the profile of an actual future flood. Design flood profiles can be estimated from historical flood behaviour or preferably from computer modelling.

Where the levee design flood profile is based on observed historical flood levels, these levels will not reflect any changes in the catchment that may have occurred since the historical event which may have occurred 30 to 50 years ago (clearing of vegetation, agricultural development, the impact of man made infrastructure – roads, levees, urban development etc). Furthermore it is necessary to make use of whatever observed flood level information is available. This information may be scarce, unevenly distributed around the levee, may be based upon observations that may not have occurred at the peak of the flood, may correspond to a flood that occurred prior to the construction of a levee and hence not reflect the impact of the levee on flood levels, may be of unknown accuracy and may reflect localised effects on flood levels (such as wave action that cannot be modelled).

More recently, design flood profiles have been based on computer modelling of the overall catchment and the floodplain in the vicinity of the levee. While this approach is able to broadly reflect the major features of the catchment and floodplain, it is unable to reflect any future changes
unless the modelling is regularly updated. Consideration of the development potential of the
catchment may enable some of these changes to be considered in smaller catchments but would
be impractical on many larger catchments. Furthermore, by necessity, the modelling has to make
assumptions about such things as the future spatial and temporal rainfall distributions that cause
floods, the state of vegetation at the time of future floods and how wet the catchment is
immediately prior to the future flood producing rain.

Today, in 2010, we do not know with any confidence where the rain will fall, the variations in rainfall
intensity across the catchment, the duration of the rainfall event(s) that produce the flood, whether
the catchment will be wet or dry, whether the flood will be short and sharp (small volume) or long
and flat (large volume) and whether the vegetation on the floodplain will be lush or sparse at the
time of the February 2023 flood. It is also uncertain what impact climate change will have on flood
behaviour as general indications are that flood producing rainfall events will become more severe,
however, reliable information on the scale of impacts requires significantly additional research.

All these factors impact on flood behaviour and flood levels. Therefore the derivation of design
floods from modelling is obliged to use what might be called “typical”, “average” or “likely” values
for the various factors and variables, based on the science currently available and knowledge of
the catchment derived from model calibration and verification from historic events. Irrespective of
the methodology used to estimate the design flood profile (historical flood or modelling) it is unlikely
that a future flood will perfectly match the design flood profile. If a levee is to be constructed there
must be some basis for the design flood profile and crest level. Guessing the design flood profile is
not an option. Testing for sensitivity to selected modelling parameters can determine how critical a
particular parameter is to the derivation of a design flood.

To ensure that the desired level of protection is achieved the levee is provided with freeboard i.e
the crest of the levee is at a level somewhat higher than the levee design flood. The freeboard
allows for a variety of factors including wind/wave action, local anomalies in the estimated flood
profile, variations in flood behaviour due different hydrologic, floodplain and catchment conditions
(no two floods behave identically), erosion and settlement of the levee, possible defects in the
levee such as cracks in the crest and the like. Freeboard can also allow for some limited variation
in rainfall patterns and other impacts due to climate change. It must be emphasised that freeboard
should not be relied upon to allow for the impacts of climate change in the long term.

LEVEE FAILURE MECHANISMS
The community perception is almost certainly that any levee is designed to keep out floodwater up
to the level of its crest. Notwithstanding the provision of freeboard, it is possible for a levee
(especially a poorly maintained levee) to fail at flood levels less than the design flood level. Some
of these situations are included in the levee failure mechanisms discussed below.

Before discussing specific failure mechanisms, it needs to be recognised that once actual flood
levels exceed the design flood level for the levee it has technically “failed” even though no
floodwater may have entered the protected area through overtopping of the crest or structural
failure of the embankment due to the provision of freeboard. In practice a levee may provide
protection against floodwaters that exceed the design flood levels however this should never be
relied on. The crest of a levee, particularly those levees in the inland where the climate is
dominated by hot, dry conditions can develop transverse surface cracks which can penetrate the
embankment to significant depth. Cracking is exacerbated where highly plastic soils are used to
construct embankments. Flood water entering such cracks can form flow paths which can enlarge
rapidly particularly if the embankment material is dispersive (dispersive soils tend to “loose structure” when wet and can be easily eroded).

Furthermore, if flood levels exceed the design flood levels there may be insufficient freeboard
remaining to cope with the factors referred to above. Reliance on a levee providing protection in a
flood event that exceeds the design event could result in a decision to evacuate being delayed
which may result in it being forced to be undertaken in adverse and perhaps rapidly deteriorating
conditions such as when evacuation routes are threatened. There is a serious potential for loss of life under such conditions.

In addition to the “technical” failure discussed above levees can fail structurally in a number of ways including:

- Overtopping of the levee crest
- Failure of levee foundations
- Surface erosion
- Internal erosion
- Slumping of the levee embankment or foundation material.

**Overtopping of the Levee Crest.** Levees are often designed with a relatively steep batter (or slope) on the inside (the dry or protected) face to reduce costs and the levee footprint. Floodwater overtopping a levee and flowing down the steep inside batter can reach velocities high enough to rapidly erode and damage the levee embankment. The extent of the damage depends on the depth and duration of overtopping, the slope of the levee batter, the resistance to erosion offered by any surface protection on the levee (grass cover etc), the nature of the embankment material and the regime of maintenance applied to protect the levee. In severe cases total structural failure of a section of the embankment can occur resulting in inundation of the protected area.

Concrete retaining walls are sometimes used as levees, often in combination with earthen levees, where the space required for the levee footprint is limited. The levee cross section may be purely a concrete wall tying into earthen levees or existing surface areas or may be a combination of concrete wall built upon an earthen levee.

Concrete retaining walls used as levees are not necessarily immune to damage in the event of either exposure to flooding or overtopping. While a concrete levee itself and its crest may be highly resistant to scouring, the turbulence at the base of the concrete wall due to both flow against the wall and during the process of flow overtopping the wall can result in the undermining of the wall’s foundations leading its catastrophic failure with the potential for a particularly dangerous situation in the vicinity of the breach.

The extent of inundation of the protected area depends on the size of the breach(s), the volume of the flood passing through the breach(s) in relation to the volume of the protected area and of course the peak height of the flood. Under some circumstances the size of the breach can develop rapidly which can lead to structural damage to property adjacent to the breach and rapid filling of the protected area.

The location of levee overtopping and the associated consequences can be managed if levees are constructed with properly designed and located spillways that allow controlled overtopping and flooding of the protected area in events that exceed the design flood(1).

**Failure of Levee Foundations.** In some situations, protecting important existing urban development requires levees being constructed in areas where there is some potential for a threat to the security of the levee to develop over time. Particularly vulnerable locations may include the outside of river banks where the river changes course sharply and where previous riverbank erosion is evident. Where a riverbank forms the foundations of a levee, failure of the riverbank could result in the catastrophic failure of the levee. Under some circumstances the process of undercutting a riverbank during a flood can progress quite rapidly. If the riverbank itself is covered by flood water the threat to the levee may be difficult to observe until failure is imminent leaving limited time to effect evacuation.

Levees foundations generally consist of natural materials which are unlikely to be uniform in nature or quality. Levees are usually very long structures, in some cases over 10km, and design investigations cannot economically examine every part of the foundations. It is not uncommon for discontinuous defects in the foundations (eg sand lenses within clay soils, decayed tree roots etc)
to remain undetected in testing. In some situations it may be necessary to construct a levee on foundation material that is permeable. If appropriate measures have not been taken during the design and construction phases to prevent or manage seepage under the levee uncontrolled seepage may result in seepage velocities high enough to remove material from the foundations, thus reducing the length of seepage path and accelerating erosion. Poor foundations, even when localised, can lead to the levee slumping or “piping occurring through the levee or its foundations. Undetected defects in the foundations of levees can therefore result in catastrophic failure of the levee and emphasising the need for continuous monitoring during flood events and careful inspection after floodwaters recede.

**Surface Erosion.** Generally speaking, the bigger the flood, the higher the velocity of the floodwater. Local anomalies in the pattern of flooding including those due to local obstructions can result in velocities that are sufficiently high to erode the levee embankment if it is not adequately protected by vegetation or revetment works. This situation can be exacerbated by heavy local rain falling on the levee itself resulting in erosion of the crest and batters.

Surface erosion can also be initiated by traffic, human and/or animal, over or along the levee (stock movement, bike riding etc). Such traffic commonly follows a defined and regular route which can produce a worn path over the levee. A “low point” in the crest can result together with a loss of protective vegetation. The “low point” provides an opportunity for concentrated overtopping which, together with the loss of vegetation, increases the vulnerability of the levee to structural failure once overtopping is initiated. Fencing to exclude traffic or appropriate design to incorporate defined crossing points which consider the potential traffic loadings and provide associated protection may reduce the damage potential.

However, the development and severity of this sort of erosion can be difficult to predict, reinforcing the need for a regular inspection and maintenance program between flood events and constant monitoring during flood events.

**Internal Erosion.** Because of the costs involved in importing material, earthen levees are usually constructed from local available soils. Some local soils can be dispersive, that is, the soil breaks down into smaller particles in the presence of water making it much more vulnerable to erosion. Erosion of dispersive soils used to construct embankments often results in the development of “pipes” through the embankment. Floodwater entering a “pipe”, even a small one, can form a flow path through the embankment which can enlarge very rapidly resulting in catastrophic failure of the embankment and rapid flooding of the protected area.

“Pipes” can develop along the outside of barrels of stormwater culverts and other service conduits that have been placed through levees unless special measures are undertaken to prevent this from happening. Levee failure can be particularly rapid in such cases due to the relatively high hydraulic heads involved.

While dispersive soils can be treated to reduce dispersive characteristics, good quality control is required to ensure that there are no isolated pockets of untreated material. Like a chain, a levee is only as good as its weakest link and failure at one isolated location can lead to the flooding of the whole protected area. Once a piping failure has been initiated it can be very difficult to stop, particularly under adverse weather conditions.

All the problems referred to above are exacerbated as the depth of floodwater against the levee increases. The potential for structural levee failure increases further once floodwaters exceed the levee design flood level.

**Slumping of the Levee Embankment or Foundation Material.** Soils loose their strength when wet. They also become heavier due to the additional weight of the absorbed water. Flooding results in the inundation of river banks and, if the flood is high enough, can result in floodwater being in contact with levees. Both the river banks and levees will absorb water as a result of being
in contact with floodwater. The degree of saturation will depend on the depth and duration of inundation and the nature of the materials involved. Slumping of a riverbank or levee embankment will occur if the weight of material being supported exceeds the strength of the supporting material.

This problem is exacerbated where we have a levee bank in close proximity to a steep riverbank. The additional weight of the levee increases the likelihood of a riverbank slumping. If the riverbank is supporting the levee, slumping of the riverbank can result in a collapse of the levee as the levee’s foundations are removed.

The problem is further compounded if the riverbank is also supporting the weight of large trees. While the root system of the tree may offer some resistance to slumping this may be overridden by the weight of the tree and movement of the tree if there is any wind.

It also needs to be recognised that a large tree on a river bank or in very close proximity to a levee can cause significant damage should it fall. Not only will the root ball remove a large amount of bank material, but the remaining bank material will be exposed to the relatively high local velocities as flood water swirls around the end of the tree.

The slumping of a levee embankment and/or the riverbank that is supporting it is more likely to occur on the falling limb of the flood (after the flood peak) particularly if the height of the floodwater is falling at a faster rate than the water can drain from the saturated soil/embankment material (rapid drawdown).

FLOOD WARNING AND FLOOD PREDICTIONS
Accurately predicting the stage height and flood peaks, both in terms of level and the timing, is a very difficult task due to a number of factors:

- Catchment conditions, both across the catchment within a particular flood producing storm and from storm to storm, can vary significantly which affects the rainfall-runoff relationship. Immediately prior to the onset of a storm event it is not known whether the catchment is uniformly “wet”. The amount of rainfall that runs off from “wet” areas of the catchment will be different to that of drier areas making it difficult to predict overall catchment behaviour. The state of the vegetation within the catchment, particularly those areas being used for agriculture, is highly variable and also affects flood behaviour.

- Storms move through the catchments whereas modelling generally assumes static storms. The movement of real storms across the catchment impacts on which parts respond first and affects the timing of the flows from the various tributaries and hence the overall behaviour of the flood.

- Patterns of rainfall (temporal and spatial) affect flood shape and therefore flood levels even where the overall volume of runoff is the same. It is not possible to predict with confidence the temporal and spatial pattern of rainfall for a storm in advance.

- Heights cannot be reliably estimated early in an event, particularly before all rain has fallen and predictions may only be for the flood category (minor, moderate or major).

- The behaviour of man made structures on the floodplain can impact on flood behaviour. The accumulation of flood debris can locally elevate flood levels and result in a redistribution of flood flows. Elevated embankments can overtop and scour, altering the pattern of flooding.

In order to make predictions of flood heights and their timing it is necessary to make assumptions about catchment conditions, the behaviour of man made structures on the floodplain, the movement of the storm across the catchment, the spatial and temporal distribution of rain including the rain that falls after the time the prediction is made. In making such assumptions we are effectively trying to predict the future. As all punters know, this is never easy.

Predictions, particularly early in the flood event are often for the timing of floods to reach or exceed particular levels rather than for a peak to be reached. Reliable predictions of the peak are not practically possible until a significant proportion of the rainfall has fallen and an understanding of
how this is translating to flows and flood levels in the river system for the particular flood event becomes clearer.

EVACUATION ISSUES

There is a logical and widely unrecognised outcome from the above discussion. This is simply that the default response position for the State Emergency Service (SES) in terms of a levee protected community has to be to assume evacuation will be required from the moment a flood forecast is received. Only when the Bureau can say with almost 100% confidence that a flood will not reach or exceed the levee design height (or imminent failure height of a suspect levee), is it possible to consider not evacuating.

Despite the best efforts of those responsible for preparing flood predictions and flood warnings there will always be some uncertainty involved. Those that have to interpret flood predictions and initiate appropriate timely responses to the threat, recognise these uncertainties and must adopt a risk management approach in their decision making. These decisions have to be made in real time and have to consider the time required to implement a response in relation to the amount of time available. A further issue to consider in the decision making process is whether evacuation corridors are cut by flood waters before the levee design flood height (or imminent failure height) is reached. If evacuations are required, they need to be initiated in sufficient time to permit orderly evacuation using the evacuees own transport before the corridors are cut if the difficulties, dangers and demands on limited resources required for assisted evacuation or rescue are to be avoided.

Given the uncertainties in flood prediction, the risk management approach effectively requires the question to be asked “What are the consequences if the forecast flood height is exceeded”. The answer to this question is of vital importance when the predicted flood level is close to the design flood level or imminent failure height. If a decision is made to evacuate and the levee does not fail, the evacuated community will have suffered significant inconvenience and disruption. However, on the other hand, if the decision is made to not evacuate and the levee subsequently overtops or otherwise fails, there could be catastrophic flooding and evacuation will be exceedingly difficult or impossible. In the case of levee failure the disruption to the community will be massive and there will be a very real likelihood that lives could be lost. Mass rescue is logistically unrealistic and in many cases it may not be possible to save all lives at risk.

In addition to predicted flood behaviour in relation to the levee design height, the emergency management authorities also have to take into account the likely maintenance regime that the levee may have been subject to since construction was completed. Inadequate maintenance increases the vulnerability of the levee to structural failure, even in floods that may be less severe than the levee design event.

Unless the levee owner keeps meticulous records regarding the condition of the levee and the maintenance it has received over the years there may be some doubt in the minds of the emergency management authorities as to whether the levee is still able to provide protection in floods up to the levee design flood. Such concerns will be heightened where the levee owner suffers from frequent turnover in critical staff resulting in the loss of corporate knowledge. Experience has shown that in some cases new staff responsible for the levee are not aware that a Levee, Operation and Maintenance Manual exists for their levee or that they may be unable to find it.

A further consideration is the timing of evacuation. If evacuation has not been completed prior to flood water entering the protected area the evacuation process will almost certainly encounter major difficulties. These difficulties, and the threat to the lives of the remaining evacuees and the emergency services personnel involved, will be exacerbated if the evacuation has to be completed under adverse weather conditions and/or at night. One of the critical difficulties is estimating the time available to complete the evacuation before the previously protected area is inundated to dangerous depths. The time available cannot be known with any confidence because it will depend on a number of factors including:
1. The total length of the breach(s),
2. The rate and extent (depth) of the development of the breach(s),
3. The volume of the floodwaters flowing through the breach(s) in relation to the volume of the area within the levee,
4. Whether evacuees can self evacuate to high ground and,
5. Whether evacuees have to evacuate locally or must travel further afield. In the case of a ring levee, the existence of any high, or at least relatively high, ground that may be suitable as an evacuation staging area may be some distance away.
6. The vulnerability of evacuation routes to flooding,

Many of the factors listed above depend, at least in part, on the likely behaviour of the flood itself including the rate of rise after overtopping, the peak flood level, the critical flood profile along the levee and the volume of the flood above the level of the breach(s). As previously discussed, flood behaviour is very difficult to predict. While acknowledging the many unknowns in estimating with confidence the time available to effect an evacuation in most cases information relating to the time required to inundate the protected area under standardised conditions is not available to the emergency management authorities to give them a “ball park” idea of the time that may be required\(^3\).

It should also be mentioned that actual or possible “failure” of a levee are not the only flood related scenarios that may require evacuation. While levees may protect development from riverine flooding they also prevent runoff from a local storm over the protected area from escaping to the river. Where required, levees are usually provided with gated culverts or stormwater pumps to allow the local stormwater to pass through or over the levee. Like the levee itself the culverts and/or pumps are designed to handle flows from storms up to a given magnitude. Larger events will result in some flooding within the leveed area, as occurred at Bourke in February 2009, which may require evacuation. Where internal stormwater is handled by gated culverts the problem is not confined to events larger than the system design storm. These culverts are closed during floods in the river system and if a local storm coincides with a river flood internal stormwater flooding can occur as a result of relatively minor storm events. The stormwater system within leveed areas needs to be given careful attention at levee design stage to ensure that the consequences of internal flooding, including evacuation if necessary, can be managed\(^4\).

CONCLUSION

The discussion above indicates that levees can fail through a variety of different mechanisms. Depending on the mechanism involved, levee “failure” may, but not necessarily, involve structural damage to the levee and flooding of the protected area. Predicting flood behaviour (flood height, timing etc), the likelihood, or otherwise, of the failure of a levee and the likely mechanism involved are very difficult tasks in view of the large number of unknowns involved.

Never-the-less the authorities involved in emergency management have a responsibility to consider the information available and make timely decisions for the well being of communities. Such decisions are usually made under very trying circumstances made more difficult by gaps in the information available on how the levee in question may respond in a failure scenario. While the authorities are mindful of the inconvenience and disruption that some of the decisions may have on the community, such as decisions to evacuate a community protected by a levee, their prime consideration is the personal safety of the individuals that make up the community, including all the emergency management crews involved. The significant responsibilities, potentially catastrophic consequences and the large number of unknowns involved indicate that a conservative risk management approach is the most appropriate one.

It is also apparent that there is a need for more information on consequences of overtopping floods for emergency response planning. As indicated earlier, the time available to effect the evacuation is an important factor and this is dependent on, amongst other things, the magnitude of the flood. A number of overtopping floods including the PMF should be investigated.
Levees are designed to provide the community with a known and specified level of protection for community property. It is not reasonable to expect or demand that a levee provides, with confidence, a level of protection above that it is designed to provide. The provision of freeboard caters for some of the unknowns and helps ensure that the designed level of protection is achieved. It is the responsibility of the levee owners to ensure that details of their levee(s), including an Operation and Maintenance Manual, are readily available and accessible to appropriate staff, appropriate staff are aware that the information is available and that the levee(s) is/are maintained so that it continues to be capable of providing the expected level of protection and that the community understands what this level of protection is.

Communities need to be more understanding when faced with an evacuation order and in the aftermath if the emergency management authority’s fears were ultimately not realised.

“TAKE HOME MESSAGES”
- Levees are designed to protect property and infrastructure and reduce the associated impacts of floods up to the magnitude of the design flood on communities. They are not designed to remove all danger to people. The levee crest is usually at a level somewhat higher than the design flood level due to the provision of freeboard to help ensure that the design level of protection is realised. The freeboard must not be relied on to provide protection against floods higher than the design flood.
- Levees can fail in a number of ways. A levee is considered to have “failed” if the flood level exceeds the level of the design flood – even if floodwater does not enter the protected area.
- Predicting flood heights and timing with confidence is a very difficult task and is generally not possible early in the flood event, even though this is when key emergency response decisions may need to be made. The many uncertainties involved and the potentially serious consequences of failing to initiate a timely evacuation effectively require a conservative risk management approach when emergency management authorities are considering the need for evacuation.

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REFERENCES