Time Savers for Levee Emergency Action Plans

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INTRODUCTION

This article describes two sources of approximated leveed area maps from readily available federal sources. The relative accuracy of these maps is examined for two levees by comparison to 2-dimensional flow model results. The levee failure flood wave arrives quickly and limits both the emergency response and any necessary evacuations. Flood waves resulting from levee failure that do not return to the source river are considered. While the author always recommends detailed analyses for delineation of levee failure inundation areas, limits on time or resources may limit a levee operator to utilizing off-the-shelf leveed area maps.

TWO FEDERAL SOURCES FOR LEVEED AREA MAPS

The Levee Safety Engineer's performance was almost as dismal as that of the levee being managed during a recent flood event. True, the levee held, and no one had to be evacuated. But what about next time? And what about next month's drill, called by management to learn how to do a better job during such flooding and to practice each component of the emergency response, including discussing an evacuation? How could this engineer develop an inundation area limits map without creating and debugging a model that breaks or overtops the levee? There isn't much time before the drill, and another flood could come in the meantime.

While this exact scenario may not play out in every community, every levee operator (or engineer, as applicable) needs an inundation area map when faced with practicing or enacting an emergency response. The simplest leveed area determination is typically a projection of the levee crest elevation to intercept the adjacent ground. The term 'leveed area' is typically utilized by the U.S. Army Corps of Engineers (USACE), while the Federal Emergency Management Agency (FEMA) typically uses 'protected area' or 'levee protected area.' For simplification, this article will use the term 'leveed area.'

Where could the Levee Safety Engineer, or any entity having a role in emergency preparedness for levee failures, obtain such a map, and quickly?

There are up to two federal sources for off-the-shelf levee inundation mapping: FEMA and the USACE. FEMA displays their approximation of the leveed area on Flood Insurance Rate Map (FIRM) Panels, which are easily accessed and readily available for both accredited levees. There are multiple avenues of access to the FIRM Panel for the community of interest:

- The most common access is via the internet, at the www.fema.gov website. Users will need to search for the applicable FIRM Panel for their community or levee of choice to obtain an image of the FIRM Panel.
- To obtain the native-format (i.e. shapefiles or similar) version of the FIRM Panel line work, visit the National Flood Hazard Layer at the Mapping Service Center website, https://msc.fema.gov/portal/advanceSearch#, and search for the specific community for the levee(s) of interest. This search is easily accomplished with the drop-down menus.
- If internet access is not available (as may be the case during a flood event), the local floodplain administrator at the city or county level (or the local Flood Control District) typically keeps a printed copy.
- A local engineering firm may have a copy of the FIRM Panel, or an excerpt in a report.

It is best to download or obtain the mapped leveed area well in advance of any flood threat or drill, particularly if a Levee Emergency Action Plan specific to the levee in question is not yet developed.

While FEMA generates floodplains for flood events with a 1% chance of occurring in any given year (commonly called the 100-year flood), the leveed areas shown on Flood Insurance Rate Maps are generally not specific to an actual flood event. Typically for the FIRM Panel leveed area, the levee crest is projected across to the landward side to intersect the ground. Since levees are required by FEMA to have freeboard, it naturally follows that a flood larger than the 1% flood is necessary to reach the levee crest.

Exceptions to leveed area mapping by projecting the levee crest elevation do exist. The leveed area water surface elevation could be a projection, not of the crest, but of the 1% water surface with the levee in place. For two levees on the Salt River in the Phoenix metropolitan area, the Flood Control District of Maricopa County (FCDMC) projected the 1% flood level into the leveed area. This is because a projection from the crest elevation would have resulted in an unreasonably large leveed area. In general, if the flood emergency response team needs to know whether the crest or the 1% flood level was projected into the leveed area, it is easy enough to check as time allows. The FIRM Panels clearly report the 1% water surface elevations, labeled as Base Flood Elevations (BFE's). With a topographic contour map, one could begin checking ground elevations at the leveed area edges to compare to the BFE.

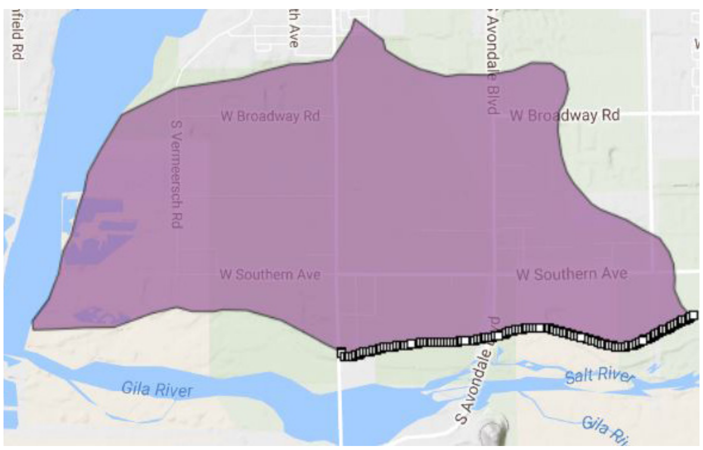

Figure 1 – A typical National Levee Database (NLD) leveed area, the Tres Rios North Levee on the Gila River.

The leveed area is also developed by the USACE for levees in its Rehabilitation (or Rehabilitation and Inspection) Program, a result of Public Law 84-99. (See www.usace.army.mil/Missions/CivilWorks/LeveeSafetyProgram/LeveeInspections.)

The USACE reports its leveed areas on the National Levee Database (NLD), at http://nld.usace.army.mil. Currently not shown on the NLD, however, are levees that are accredited, or provisionally accredited, by FEMA but are not in the USACE's Rehabilitation Program. Conversely, FEMA depicts the leveed area regardless of Rehabilitation Program participation.

As with FEMA's maps, there may be non-internet based sources for the NLD leveed area maps, such as the local sponsor's printed and electronic (disk) copies of the last Periodic Inspection Report. Likewise, the USACE usually shares copies of presentation slides from USACE risk assessment/levee screenings with local sponsors.

Although the NLD leveed area is typically for a Standard Project Flood (SPF), which is larger and less frequent than FEMA's 100-year return interval flood, it provides an indication of the land area that could be flooded in the event of levee failure via breach or overtopping (Figure 1). The emergency response could be about the same regardless of whether the levee threat is due to either a 1% flood or an SPF event.

The leveed area map typically becomes the starting point for any evacuation area map required by the emergency response team.

The leveed area shapefiles for both the FIRM Panels and the National Levee Database are made available to the local sponsor. It is highly recommended to obtain this line work in the desired format well in advance of the community's next flood event or drill.

COMPARISON AND VALIDATION OF READILY AVAILABLE INUNDATION AREA MAPS

Could the Levee Safety Engineer rely upon such a leveed area map, especially when it may be the basis for an evacuation of people, pets and livestock?

The author asserts that leveed area maps can significantly facilitate the risk management response when limited resources do not allow for more detailed studies. To investigate this premise, the FCDMC developed 2-dimensional levee breach flow models for two of its levees and then compared the results.

The FCDMC operates 21 levees within Maricopa County, Arizona. Maricopa County is an arid region and its rivers and washes generally flow for short time periods. Some of the levees are on major rivers, some are on smaller tributaries and each of them provides a level of risk mitigation for the adjacent property and the citizens that work and live there. Three of the FCDMC's levees have Emergency Action Plans. The Camelback Ranch Levee South (CBRLS), situated on the Agua Fria River, is about 1.6 km long, has a tributary area of more than 5,700 km^2, and is regulated with upstream dams. It is constructed of soil cement (aka Cement Stabilized Alluvium or CSA) with landside earth fill supporting the hardened riverside levee. Almost all of the 1.37 km^2 leveed area is developed with single-family residential housing in a suburban setting.

The Pass Mountain Diversion Channel (PMDC) Levee crosses multiple small washes, which together comprise a tributary area of about 1.8 km^2. The PMDC levee is about 2.1 km long and perpendicular to the flow direction from the contributing watersheds. This levee is constructed of compacted earth fill with no riprap for riverside erosion protection since the flow velocities are low. The 1% flood freeboard amount is at the FEMA-required minimum. Large lot residential development makes up 97% of the 7.77 km^2 leveed area. About 40% of the leveed area remains to be developed.

The Tres Rios North Levee (TRNL) is located on the largest river that traverses the Phoenix metropolitan area. This 3.2-kilometer-long levee is located on the Gila River, which drains over 111,000 km^2 at the levee and is regulated by numerous upstream dams. Recently constructed with compacted earth fill, riprap on the riverside protects

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this levee. Designed for a storm with a return interval of 100 years, the freeboard on this levee is set at the FEMA-required level. The 14.10 km² leveed area (per the NLD) shown in Figure 1 has mixed land uses, with subdivisions, agriculture, industrial, and other uses. Only 54% of the leveed area is currently developed.

The impact of subdivision perimeter walls should be considered when developing the inundation area. The walls could fail or could remain standing, depending upon the depth of water against the wall and the quality of wall construction. Indeed, identifying the critical walls is an important aspect of inundation modeling for emergency response. As an example, consider the CBRLS where the FCDMC wanted to know the effect of immediate wall failure at the subdivision perimeter wall and did not model any possible wall non-failure or partial failure scenarios. This is the same assumption apparently made by FEMA when it projected the levee crest into the landward side, without evaluating any flow hindrances. The remaining flow impediments were the houses themselves and the terrain, which were input into the 2-Dimensional flow (2D) model. For the CBRLS, the results of the model using the FEMA inundated areas with immediate wall failure compare favorably, as seen in Figure 2.

The 2D inundation area does not reach into the northeast corner as FEMA's line work does. The area at the southeast corner also varies slightly, with the 2D model showing a larger inundation area than FEMA's. However, both maps are quite similar overall; therefore, regardless of which map an emergency manager is using, the emergency response should be approximately equal since it is both easier and more effective to evacuate by block rather than by house. Accordingly, it would be prudent for the irregularly shaped inundation limits to be expanded outward by the emergency management team to definable streets.

For the Camelback Ranch Levee South, the FIRM Panel leveed area assumes the failure waters are able to flow back into the Agua Fria River at Indian School Road to the south, but this assumption does not take into account some of the realities of the local terrain and the magnitude of the levee failure water flows. In particular, Indian School Road would likely be overtopped, with floodwaters continuing to the south. For the local community's levees, considering return flow conditions adds to the community's flood preparedness.

For the Pass Mountain Diversion Channel Levee (Figure 3), the comparison between the FEMA inundation area and the modeled inundation area is useful. The modeled breach is at one assumed location; for other locations, a rough prediction of inundation extents is made by copying and moving the breach east or west along the levee length and by assuming the same inundation shape since the topography is approximately equal. Sequentially plotting the inundation areas from these three breaks occurring across the levee length yields the three inundation areas of Figure 4. The outside boundary, then, begins to resemble the FEMA-derived inundation area shown in red. Hence, given flooding from possible multiple breach locations, an appropriate emergency response may be to evacuate the entire leveed area landside of the levee.

Figure 2 – Comparison of FEMA's Leveed Area with 2D Inundation Area for the Camelback Ranch Levee South (CBRLS).

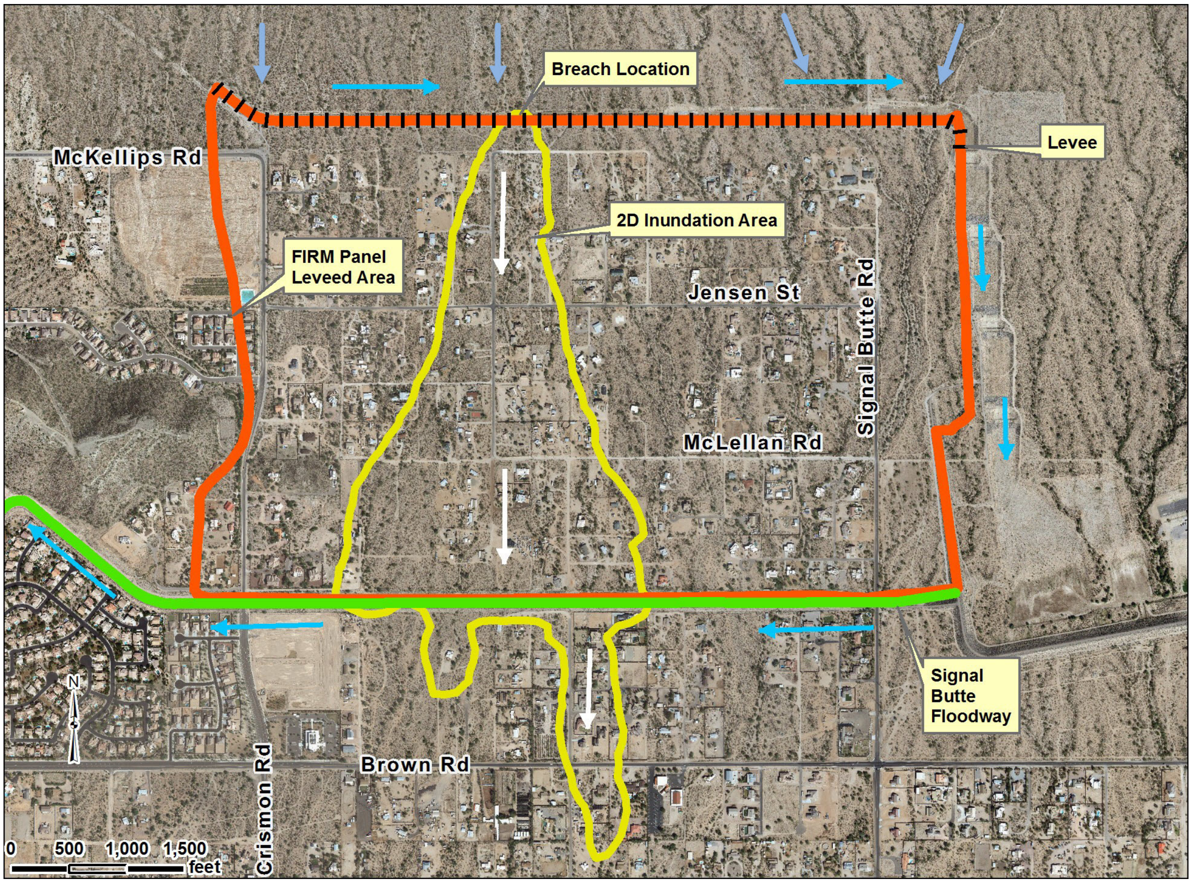

Figure 3 – Comparison of FEMA's Leveed Area with 2D Inundation Area for the Pass Mountain Diversion Channel Levee.

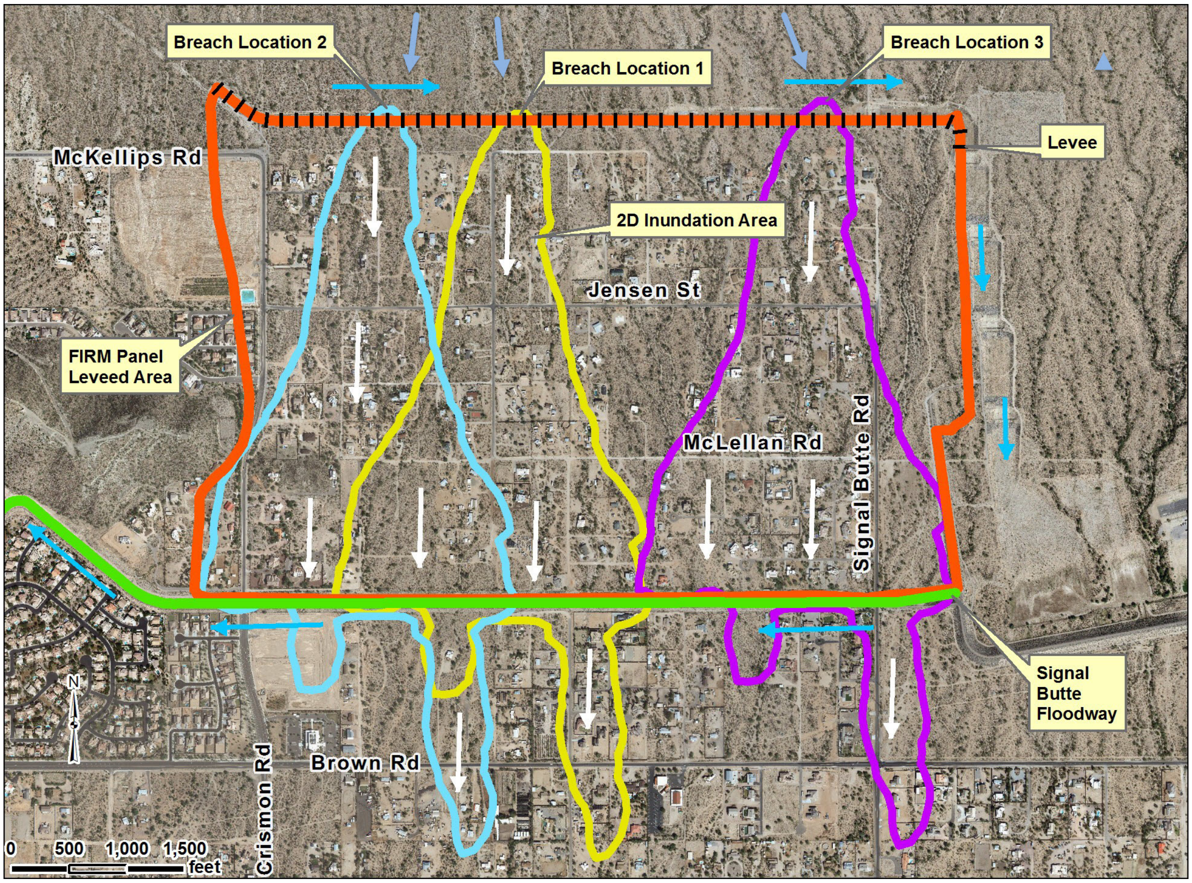

Figure 4 – Comparison of FEMA's Leveed Area to 3 adjacent 2D Inundation Areas for the Pass Mountain Diversion Channel Levee.

POSSIBLE NON-RETURN FLOWS AFTER LEVEE FAILURE

A local levee sponsor should evaluate if overtopping or breaching floodwater could return to the flooding source relatively quickly. There may be instances where the terrain or any downstream levees or structures could preclude the re-entrance of floodwaters, allowing the flooding to continue for a substantial downstream distance. All three of the levees described are subject to this condition.

When inundation from levee overtopping or breaching extends beyond the leveed area a reasonable stopping point should be identified. The PMDC levee is one example of an application of this procedure. As previously stated, this levee is sited transverse, or perpendicular, to the incoming flows. Floodwaters leaving the levee system never return to the levee's main channel. The logical stopping point is a downstream channel that is parallel to the levee, the Signal Butte Floodway (Figure 4). This open channel has the capacity to carry away most of the levee failure floodwaters. The land to the south receives the remainder, which becomes shallow and dissipates into the urban storm drainage system. Thus, this open channel effectively becomes the southern boundary for the leveed area. Persons utilizing off-the-shelf inundation mapping (FIRM or NLD sources) should investigate, on a "sunny-day" (without the stress of an exercise or flood event), the non-return of escaping floodwaters. Flood emergency responders must be aware of and consider such possibilities. This awareness could take the form of locating ground observers or aerial drones at the appropriate and safe locations.

THE QUICKNESS OF FLOOD WAVE ARRIVAL TIMES FOR LEVEE FAILURE

With one problem solved for quickly obtaining the flood inundation map, the Levee Safety Engineer turns his attention to the emergency response and wonders how much time there might be to evacuate.

Not depicted on a FIRM Panel is a sense of how quickly, or even from which direction, the floodwaters resulting from breach or overtopping travel through the inundation area. To address this concern, the FCDMC investigated the flood wave arrival times via 2-dimensional flow modeling for two of its levees.

The CBRLS 2-dimensional flow model assumes a breach location near the upstream levee end (Figures 2 and 5). Since the levee was not designed to be overtopped safely, it then must be assumed to breach. For this soil cement levee, breaching under overtopping conditions could occur as overtopping flows carry away the landside soils supporting the soil cement. After enough of the landside earthen embankment erodes, the unreinforced soil cement could crack and suffer a breach.

For the CBRLS, almost 50% of the inundation area is predicted to reach maximum depth in just 39 minutes per Figure 5. The sand and gravel mines are assumed to be full, by either local rainfall or the significant volume flowing into the breach. Within 82 minutes of a breach the levee failure analysis flows have covered almost the entire inundation area. Shown in Figure 5 as potential overflow, the levee

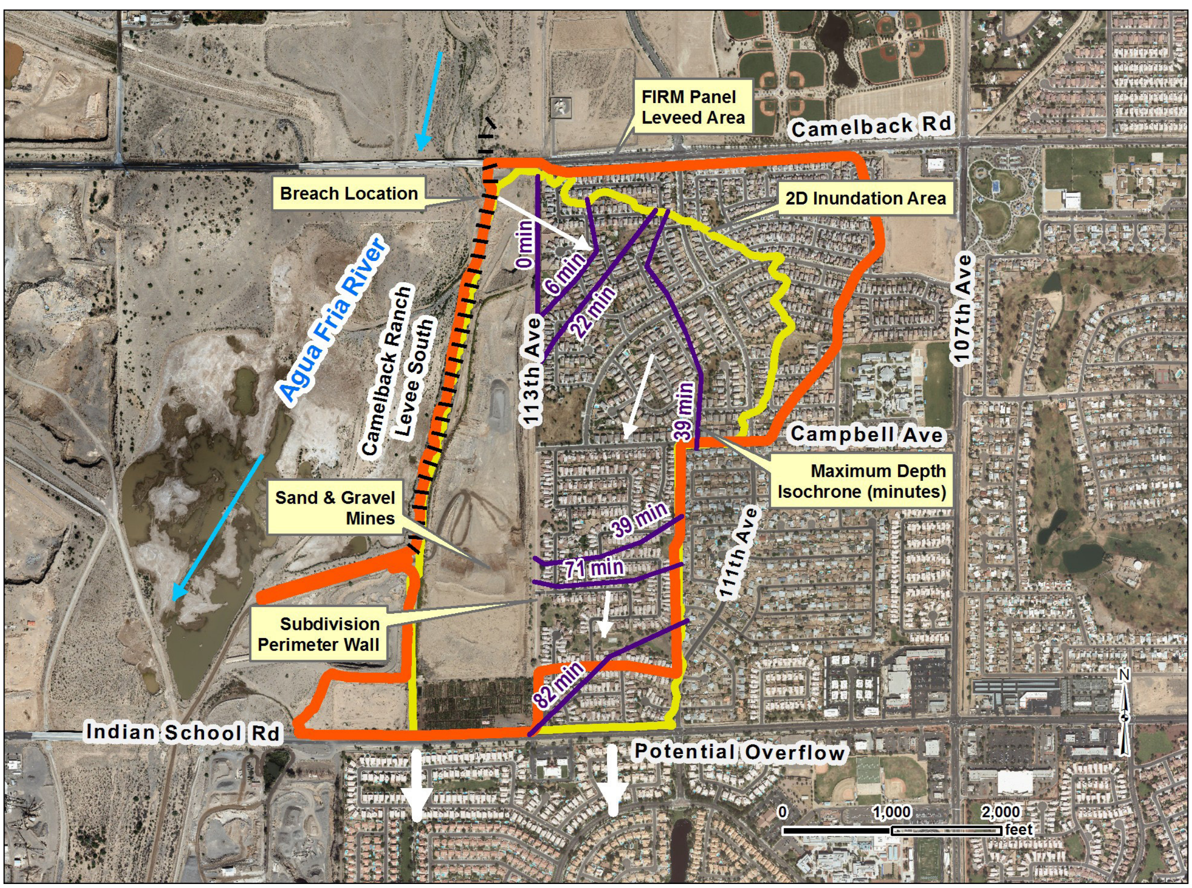

Figure 5 – Flood wave arrival times at maximum depth, Camelback Ranch Levee South.

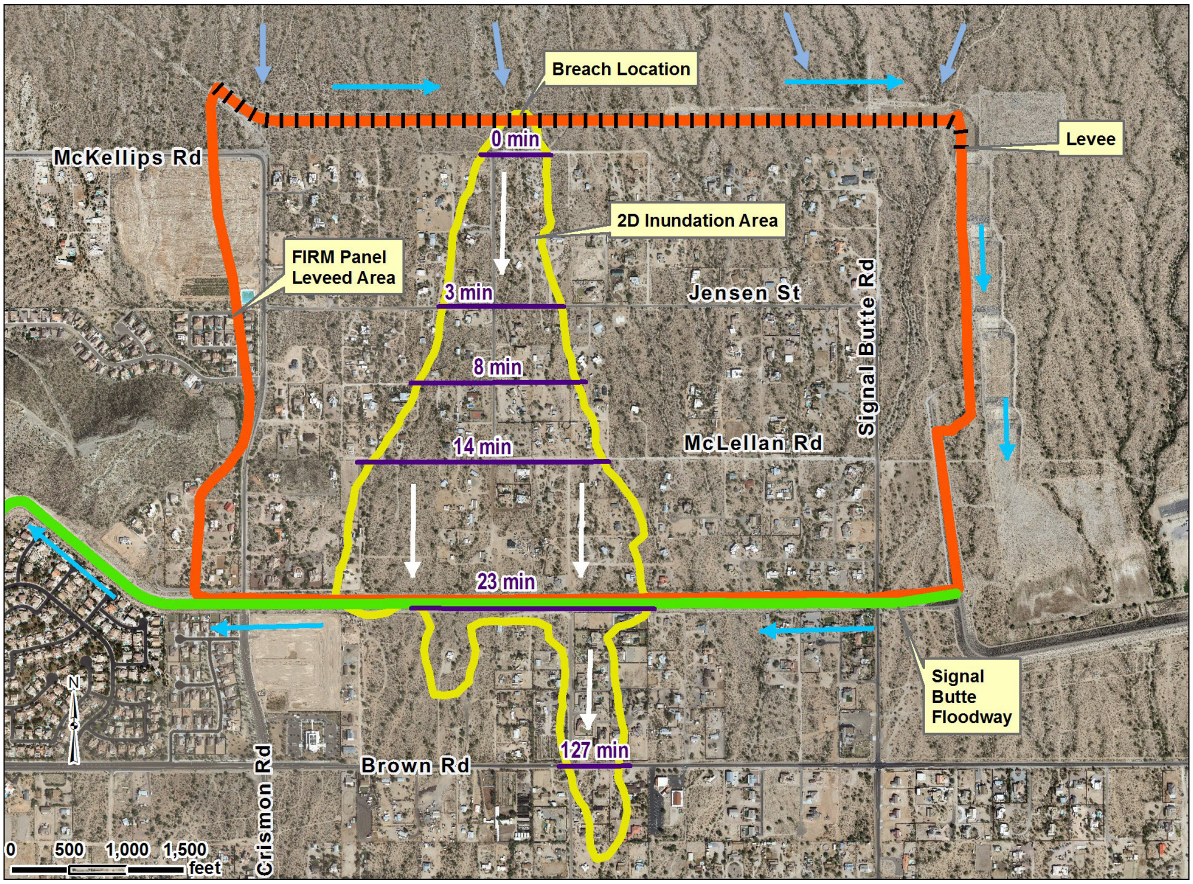

Figure 6 – Isochrones for a breach at the Pass Mountain Diversion Channel Levee.

Figure 7. Goodyear, AZ on August 30, 1951. Average flood depth of 0.3 m hinders travel and limits emergency response efforts.

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failure waters could overtop an arterial street (Indian School Road) and proceed further south. Hence, the emergency response team should monitor the potential for overtopping at appropriate points and post a ground observer (and/or a drone) in a safe location.

At the PMDC levee, the maximum depth at the south end of FEMA's leveed area is obtained in 23 minutes after overtopping followed by a breach, as shown in Figure 6. This southern limit is the Signal Butte Floodway, where the flood wave waters are stored temporarily as the floodway carries its capacity downstream (to the west). After almost 2 hours, the flood wave exceeds the limited capacity of the floodway, the floodway is overtopped, and the flood wave continues downstream. As a result, the 2D model shows an inundation area further south than FEMA's leveed area. If only using FEMA's leveed area map but noting the potential for non-returning flows, the emergency response team should place an observer at a safe location along the Signal Butte Floodway to monitor such overtopping. Thus, in this case, the team's emergency actions should not have been much different, whether acting solely upon FEMA's leveed area, or upon the 2D modeled inundation area.

Emergency responders have found that a 0.3 m water depth hampers evacuation and related emergency response efforts. Consider either Figure 5 or Figure 6 and imagine a time when there is about 0.3 m water depth within the inundation area map, now turned into an evacuation area map. Both travel time and travel hazards increase, since the road surface is not visible and could contain deep holes and other hazards. Figure 7 depicts such a point in time for a flooding event in Maricopa County (albeit not resulting from any levee failure).

The quickness of flood wave arrival times for levee failure astounds the levee safety engineer and gives pause to the local emergency manager. A levee operator facing a potential levee failure, without 2-dimensional modeling, may need to quickly determine the emergency response. A time saver for an operator needing a quick isochrones estimate is to ignore how a breach may develop, assume a travel velocity, and measure some distances to compute possible emergency response times. The isochrones figures presented herein may assist in this effort but are not a substitute for site-specific evaluation. The first to evacuate should be those immediately adjacent to the levee, keeping in mind the ideal situation is to evacuate all of the inundation area as soon as a credible levee threat is realized and acted upon by the proper authorities.

SUMMARY AND CONCLUSIONS

One advantage of utilizing FIRM panels for levee failure inundation area mapping is that they may yield reasonably accurate results with minimal effort expended by an agency or levee operator, as depicted in two test cases. In the author's opinion, the Inundation Area Maps from FIRM Panels or the NLD database can be utilized in the overall risk management of levees when limited resources do not allow for detailed Levee Emergency Action Plan inundation studies (aka Levee Failure Analysis, LFA) by the agency or entity responsible for the safe and proper operation of a levee. The federally published maps may be sufficient for flood fighting and/or emergency response, at least when no other similar or more accurate maps exist.

There are additional purposes for using a "canned" inundation area, namely there is insufficient time to create a map relying upon 2D dimensional flow model(s). Additional suitable situations occur during the development of a basic site-specific flood emergency response plan without hydraulic modeling, or when there is a need to approximate a geographic area to better determine the costs associated with a fully detailed response plan.

The Levee Safety Engineer now knows that he will be successful in next month's drill, and even better prepared than the rest of the emergency response team might guess.

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