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Flooding in Texas: Preparation and Response

TEXAS WATER CONSERVATION ASSOCIATION
FLOOD RESPONSE COMMITTEE

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Executive Summary

One year ago, Hurricane Harvey devastated the middle and upper coasts of Texas, causing unprecedented flooding and property loss. And though many are still rebuilding their lives and homes, the storm has forced policy makers and flood planners to examine the state's flood preparedness and look for viable steps that can be taken to limit damage from future flood events.

This document aims to summarize and analyze flood-related concepts and proposed solutions that have emerged in reaction to Hurricane Harvey. It begins with an overview of the different types of reservoirs in Texas, moves into a discussion of various flood mitigation strategies that have been proposed for implementation since the storm, and outlines notice procedures during flood events. It concludes with a summary of ways river authorities and reservoir owners/operators can assist in regional flood planning and response efforts.

At the outset, most planners acknowledge that it is impossible to fully plan or prepare for an event as unprecedented as Hurricane Harvey. However, the storm highlighted a need to leverage flood control projects for maximum regional benefit and increase coordination among planners. This document seeks to identify ways in which these goals can be accomplished by summarizing the potential benefits of both proven and unproven flood mitigation strategies, including prerelease, on-channel and off-channel reservoirs, aquifer storage and recovery, and dredging.

The scope of this document is limited to the actions of reservoir owners and operators (including cities), river authorities, and regional or local water districts. We do not explore land-use planning decisions, though city and county floodplain ordinances are arguably the most effective and cost-efficient way to minimize flood impacts, and we encourage a continued discussion on the important role of such strategies in reducing flood risk.

The Texas Water Conservation Association (TWCA) is a 501(c)(6) association of water professionals and organizations in the state of Texas. TWCA members represent river authorities, municipalities, navigation and flood control districts, drainage and irrigation districts, utility districts, groundwater conservation districts, municipalities, all kinds of water users, and general/environmental water interests. The membership includes engineers, hydrogeologists, attorneys, government administrators, and numerous other individuals committed to Texas water resource management. TWCA's Flood Response Committee, chaired by Dr. Bob Brandes, developed this document to further the discussion on flood mitigation and planning efforts happening across the state.

On behalf of TWCA, we hope the information contained in this collection of documents is helpful. We look forward to continuing this discussion in the future.

Water Supply and Flood Control Reservoirs in Texas

The purpose of this chapter is to briefly discuss the roles, value and limitations of the different kinds of large reservoirs in Texas. There are three primary reservoir types: 1) water supply; 2) flood control; and, 3) dual-purpose. With the exception of a dual-purpose reservoir, each has a specific role or roles, which at any point in time are mutually exclusive: reservoir storage can either be full, storing water for use, or it can be empty, ready to catch storm flows and mitigate downstream flooding. Once storage is full, it can no longer capture flood flows, and once it is empty, it can no longer be used for water supply. This distinction is vital to understanding why a given amount of reservoir capacity cannot simultaneously provide both water supply and flood control benefits.

Water Supply Reservoirs

The vibrant and burgeoning Texas of today exists because of the water supply reservoirs built by past leaders of the state. While considered visionary today, they were built after the painful lessons of drought; first in the early 1900s, followed by the 1930s and then in the 1950s. The dams they built throughout that time and in following years to secure the state's water supply have a simple purpose: capture water when it is available and store it for use during long, hot summers and all-too-frequent droughts. There are 150 dedicated, water supply reservoirs in Texas.[1]

Most existing water supply reservoirs are intended to be maintained as full as possible, a necessity that is fundamental to water planning in Texas. To use dedicated water supply storage for flood control usually requires abandoning – even if temporarily – some portion of a water rights holder's water supply. If that supply is temporarily abandoned and drought develops, parties dependent upon stored water may not have enough to meet demand.

However, water supply reservoirs operated according to their design do not cause flooding. The same volume of water that was behind a water-supply dam before a flood began will be there when the flooding is over, as stored water is not released during storm events.[2] Only additional water that would have flowed down river had the dam never been built is allowed to pass. This is called run-of-the-river operations, and is not intended to provide flood control benefits. Because those reservoirs release no more floodwater than would have flowed down river in their absence, their operations do not result in the inundation of additional downstream private property.

However, even though it is not the intent of their design, in most rainfall events, water supply reservoirs operating on a run-of-the-river basis provide some flood mitigation benefit by reducing the peak flow passing through the reservoir. Most water supply reservoirs have additional capacity above their normal pool elevation that is designated for temporary storage during a storm event. This temporary storage allows the reservoir to store some stormwater, which means that the peak

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[1] Includes both public and private reservoirs that provide over 5,000 acre-feet of storage capacity (or 1.6 billion gallons of water). Water supply includes any use of water recognized by the TCEQ under a water rights permit including municipal (drinking water), industrial (e.g. power generation, mining, manufacturing), agricultural, and recreation.

[2] A rare exception to this may occur if the structural integrity of the dam is in jeopardy. Under such a scenario, it may be necessary to release stored water to save the dam. However, this is done only under emergency conditions and to prevent catastrophic flooding and loss of life.

flow rate being discharged from the reservoir will be lower than the peak flow rate entering the reservoir. When this happens, water supply reservoirs can reduce the peak flow rate during storm events, providing unintended flood mitigation benefits.

Flood Control Reservoirs

There are eight major, dedicated flood control reservoirs in Texas. In exact contrast to water supply reservoirs, flood storage must be maintained as close to empty as possible to provide storage for capturing water during large storms to reduce the amount of flow in the river downstream of the reservoir. Captured flows are then released slowly over time, once the peak of the storm has passed, in order to free-up storage necessary to mitigate flooding from the next big storm. Releases are measured to minimize downstream flooding while protecting the reservoir's integrity.

Dual-Purpose Reservoirs

Thirty-five reservoirs in Texas have storage allocated to both water supply and flood control. However, the storage associated with each is clearly defined and is dedicated for that purpose. The storage dedicated to water supply is maintained as close to full as possible, and the storage dedicated to flood control is maintained as close to empty as possible.

Reservoir Design

The structural integrity of a dam is threatened if more water is captured than the reservoir (including the dam) was designed to hold. For this reason, some reservoirs are designed with emergency overflows to safely allow excess flows to pass over the dam. Other reservoirs use control gates or valves to pass stormwater, which allow for controlled releases.

In water supply reservoirs, there is often very little storage available between maximum design impoundment and the top of the gates. This distance is sometimes referred to as freeboard and should not be considered extra storage, as it is unsafe to operate in that manner. A reservoir that attempts to indefinitely impound stormwater without an emergency spillway will eventually overtop at the lowest elevation across the dam, usually the top of the control gates. This kind of operation is dangerous as it jeopardizes the integrity of the dam, potentially resulting in a dam failure. For this reason, reservoir operators follow specific flood operation protocols to ensure that the dam is not breached.

Conclusion

Texas reservoirs serve a variety of purposes, including water supply and flood storage. Though some reservoirs are solely intended to provide flood storage and others provide both flood storage and water supply storage, most Texas reservoirs serve exclusively in a water supply capacity. Water supply reservoirs operated according to their design do not cause flooding, as stored water is not released during storm events.

Flood Mitigation Strategies

This chapter addresses many of the flood mitigation strategies that have come to the forefront of the discussion since Hurricane Harvey. The overall purpose of this chapter is to provide information on these strategies in order to allow for informed policy decision making. Some of these methods, such as on-channel reservoirs, have proven to be effective in limiting flood impacts in certain instances. Others, such as prerelease, are unlikely to be effective flood control tools, and can actually exacerbate flooding in some cases. Before implementing any flood mitigation strategy, floodplain managers, river authorities, and reservoir owners/operators should work together to ensure that a proposed strategy will have the intended result.

Prerelease from Water Supply Reservoirs

"Texas is a land of perennial drought, broken by the occasional devastating flood."[3] For over a hundred years,[4] the foregoing pattern has proven more than an expression, but instead a fact of life in Texas. Texans have responded by constructing 150 single-purpose water supply reservoirs, designed and constructed exclusively for conservation storage, *i.e.*, without dedicated flood mitigation capacity. That storage enables the state to survive droughts without harm to human health and safety or catastrophic economic disruption from lack of water supply.

This subchapter briefly addresses the role, value, and limitations of prereleases from water supply reservoirs to mitigate downstream flooding. Many factors influence whether prerelease is a safe strategy, and those factors are basin and storm-specific. While prerelease may seem like a viable strategy when looking at historic storm events, the lack of certainty in weather predictions means its use could aggravate downstream flooding and place lives and property at risk that otherwise would not be. Accordingly, any legislative mandate to undertake prereleases would be, at best, hazardous and unwise.

What is prerelease in the context of a water supply reservoir? It is the discharge of stored water in anticipation of either predicted rainfall or the anticipated arrival of flood flows from upstream. Prerelease is not the same as the permanent or temporary conversion of conservation storage to flood storage. Conservation storage can be permanently converted to flood storage by constant maintenance of a lower pool elevation. Storage can also be temporarily converted to flood storage by maintaining a lower conservation pool during certain times of year (*e.g.*, hurricane season).

Prerelease is a reactive strategy, undertaken when either rain upstream has produced flood flows, or predicted rain over and around the reservoir could do so.

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[3] State Meteorologist, National Weather Service, 1927.

[4] A Study of Droughts in Texas, Bulletin 5914, Texas Board of Water Engineers (1959), available at: http://www.twdb.texas.gov/publications/reports/bulletins/doc/Bull.htm/B5914.asp (detailing eleven major droughts in Texas from 1891 to 1956).

Factors to Consider

The factors that influence whether prerelease may be of benefit (or detriment) include:

1. Predicted location and amount of rainfall in relation to a reservoir;
2. River-basin size and lag time;
3. Existing downstream flow; and,
4. Predicted weather conditions below a reservoir.

When rainfall occurs well upstream of a reservoir, some of the foregoing factors are more clearly established. However, when rainfall originates downstream of a reservoir and moves inland, as is the case in tropical storms and hurricanes, the impact of prerelease is much more difficult to measure. In those situations, prerelease must be approached with extreme caution to avoid exacerbating downstream flooding.

Each heavy rainfall situation is unique, and predictions of actual effects are inexact. Upstream and downstream weather forecast predictions are inherently uncertain, thus, deciding when and how much to prerelease is a game of chance with substantial risk. A well-intentioned and objectively reasonable decision to prerelease can, because of the imprecision of the predictions on which it is based, ultimately make downstream flooding worse rather than better. The primary concern must always be to avoid aggravating downstream flooding, because doing so places lives and property at risk.

Upstream Rainfall/Flooding

One potential application of prerelease exists in large basins, with precipitation occurring well upstream of a reservoir. In that situation, there is significant lag time between the flood-causing rainfall and its arrival in the downstream reservoir. This lag time enables an operator to more accurately determine the effect of upstream rainfall on reservoir levels, as flows on their way to the reservoir will likely be gaged at several intermediate locations.

Even in this case, prerelease can only be undertaken at a rate that the downstream waterway can accommodate within its banks, *i.e.*, without causing flooding by virtue of the prerelease itself. This limitation hinders a reservoir operator's ability to prerelease a sufficient volume of stored water to have a meaningful effect on downstream flooding.

The closer to a downstream reservoir heavy rainfall occurs, the less time a reservoir operator has to prerelease. This can occur in large basins with rainfall immediately upstream of a reservoir. It can also take place in small basins, with very little drainage area upstream of a reservoir. In smaller basins, which have smaller downstream waterways, the total impact of an upstream precipitation event will be realized more quickly than in a large basin with a precipitation event far upstream, leaving less time to prerelease without causing flooding.

Downstream Rainfall/Flooding

The value of prerelease is more limited, and its use far more hazardous, in the case of storms that move inland and discharge significant rainfall before reaching upstream reservoirs. The factors to consider, and the predictions they depend upon, are much less certain in these cases. Because the forecasted precipitation event originates downstream, the effect of precipitation on the reservoir cannot be gauged before its arrival as in the case of an upstream event. The effect on the reservoir can only be estimated based on forecasted precipitation. Lag time is effectively non-existent, and downstream waterways may already be full or nearly full from downstream precipitation that has already occurred before it reaches the reservoir. If a prerelease commences, and the downstream area is or has been hit with significant precipitation, water may overflow streams and riverbanks when it otherwise would not have. In short, in these events, the risk that prerelease could aggravate downstream flooding is high.

Hurricanes and tropical storms usually develop in the Gulf of Mexico and move inland. These storms are thus accompanied by significant downstream precipitation events before reaching inland reservoirs. While tempting from a purely visual or political perspective, the use of prerelease in these types of events is significantly more likely to place additional lives and property at risk. This is a case where the cost of making a mistake is far greater than that of inaction, because an affirmative decision that results in increased flooding is practically indefensible.

Weather Predictions

Common to both the upstream and downstream events described is the criticality of weather predictions in the prerelease analysis. In both events, weather predictions for the area downstream of a prereleasing reservoir must be given the highest priority in decision making. The banks of waterways below a prereleasing reservoir can only convey a certain amount of water before being overtopped. Any downstream rainfall once a prerelease has commenced can cause overbank flooding. The only data available at the time of the prerelease would be forecasted downstream rainfall and volume. If actual rainfall is more than forecasted, waterways already filled with prerelease flows could overtop banks. In that case, a prerelease would exacerbate flooding.

Hurricane Harvey

Many estimates exist of Hurricane Harvey's hydrologic impact. One such estimate indicates that Harvey dumped approximately 24.5 trillion gallons of water in Texas and southeast Louisiana,[5] the equivalent of roughly 75 million acre feet of water. Texas' statewide water conservation storage is approximately 31.5 million acre feet.[6] Hurricane Harvey could have filled all water supply reservoirs in Texas more than twice. These statistics illustrate that no amount of prerelease, and no amount of temporary or permanent conversion of water supply storage, would have appreciably reduced the magnitude of flooding caused by Hurricane Harvey.

[5] Fritz, Angela and Samenow, Jason. "Harvey unloaded 33 trillion gallons of water in US." Washington Post. September 2, 2017.

[6] Texas Water Development Board. Water data for Texas.

Liability

While public safety is of the utmost importance during a major flood event like Hurricane Harvey, the use of prerelease calls into question potential legal issues that should not be ignored. A reservoir operator that aggravates downstream flooding by an objectively reasonable prerelease would nonetheless be exposed to takings liability in that case. Liability for the taking of private property by government action is a function of the guarantees of the United States and Texas Constitutions. The Legislature cannot limit that liability by statute, and thus cannot confer protection upon reservoir operators, even if the decision to prerelease is objectively reasonable.

Conclusion

Prerelease is a strategy with inherent risk, because the decision making regarding its use is based on imperfect predictions. Every flood-producing storm and every basin is different. A legislative mandate to prerelease, in the absence of both sufficient study and situation-specific flexibility, carries the likelihood of exacerbating flood conditions and placing both lives and property at risk.

On-Channel Reservoirs

As described in the first chapter, on-channel reservoirs have been used extensively as flood control measures. Local and regional stormwater detention ponds are often designed for the temporary storage of flood flows, employed as a means to reduce the effects of increased runoff generated by the impervious cover that typically accompanies urban development. And, of course, storage of floodwater inflows is a fundamental purpose for large dual-purpose flood control reservoirs, such as Lake Travis on the Colorado River above Austin and Lake Whitney on the Brazos River above Waco. These reservoirs have hundreds of thousands of acre-feet of storage capacity dedicated to impounding floodwaters and reducing downstream flood flows. These flood control structures have demonstrated their significant benefits in terms of reduced downstream flooding and flood damage.

The obvious advantage of on-channel reservoirs compared to off-channel reservoirs is that on-channel reservoirs, being located directly on the channel of a river or stream, automatically capture flood flows as these flows enter or flow into the impoundment, whereas storing floodwater from a river or stream in an off-channel reservoir requires pumping and lifting the floodwater into the impoundment. Thus, a costly pump station and conveyance facilities are not needed for capturing and storing floodwater in an on-channel reservoir.

A major consideration when locating and permitting on-channel reservoirs is the increasing importance of environmental factors because of the potential impacts of new reservoirs on wetlands and bottomland hardwood forest habitat, along with aquatic health. Taking into account these factors and compensating for these impacts can be very costly and time consuming. What might be thought to be a relatively straightforward permitting process can turn into many years of studies, analyses, mitigation, and negotiations with regard to environmental concerns, particularly at the federal level.

Also, it is important to understand that the use of an on-channel reservoir for flood control and for reducing downstream flood impacts must be well planned and thoroughly investigated. Technical analyses must consider the size of the upstream watershed, the magnitude and duration of rainfall and flood events, the required storage capacity for effectively reducing flood flows versus available flood storage capacity, the downstream flood benefits in terms of lowered flood levels and reduced impacts, the environmental consequences and permitting requirements, and the cost of the flood control facility versus the value of the reduced flood damages. Implementation of a successful flood control project involving an on-channel reservoir can be a technically complex undertaking and can include a variety of challenging siting, construction, environmental, and economic issues.

Conclusion

Challenges aside, on-channel reservoirs are an important component of the flood mitigation discussion, and have demonstrated effectiveness in multiple areas of the state. As an added benefit, on-channel reservoirs also provide an opportunity to double as a major water supply source, as many of the state's dual-purpose reservoirs have done for decades. The lessons learned from Hurricane Harvey may present policy makers with an opportunity to explore the development of additional on-channel reservoirs and look for ways to remove some of the barriers that currently exist to their implementation.

Off-Channel Reservoirs

Off-channel reservoirs received attention as a water supply strategy in the 2017 Water Plan. The 2017 regional water planning groups recommended 26 new reservoirs (with more than 5,000 acre-feet of storage), including 12 off-channel reservoirs. Off-channel reservoirs are essentially pools that are constructed away from the channel of a river or stream, but generally close enough to be filled by pumping water from that same river or stream. Off-channel reservoirs are typically constructed with earthen dikes that enclose an area of natural ground, within which water can be stored for various uses, most commonly for water supply purposes. Depending on the amount and purpose for pumping water from a river or stream into an off-channel reservoir, a water right may be required from the Texas Commission on Environmental Quality.

Use in Flood Mitigation

Off-channel reservoirs for flood control have very limited effectiveness due to the significant size of the pumping, conveyance, and storage facilities that are necessary to be effective in capturing meaningful volumes of floodwater to achieve downstream flood reduction benefits. In addition, the hydraulics of diverting flood flows from a river or stream into an off-channel reservoir present a unique challenge: to be effective, diversions must be strategically phased during the rise and fall of the flood over the course of a flood event. As such, pumping flood water from a river or stream is generally not a feasible means of reducing downstream flood levels because the water cannot be moved fast enough.

As an example, a very large pump station for diverting flood flows could have a pumping capacity of 500,000 to 1,000,000 gallons per minute, which is equivalent to a flow rate of about 1,100 to 2,200 cubic feet per second. Peak flood flows in even small rivers and streams for moderate flood events can exceed these pumping rates more than ten times. Thus, even a massive pump station would not be capable of significantly lowering the river's or stream's flow rate to levels that might produce meaningful flood reduction benefits.

As with on-channel reservoirs, environmental considerations are important with regard to locating and constructing off-channel reservoirs, and these reservoirs are subject to the same environmental regulations as on-channel reservoirs. One advantage, however, is that the footprint of an off-channel reservoir can be tailored somewhat to avoid particularly significant and sensitive environmental sites and resources. The configuration of an off-channel reservoir does not have to conform to any prescribed shape as long as the confining levee or dike encompasses the desired volume of storage capacity.

Allens Creek – Hurricane Harvey Example

- Allens Creek Reservoir's drainage area is about 50 square miles; for comparison, the drainage area of the lower Brazos River basin from College Station to the Gulf is over 6,500 square miles.
- The maximum permitted pumping rate to divert water from the Brazos River into Allens Creek Reservoir is 2,200 cubic feet per second (cfs); for comparison, peak flow rates in the lower Brazos River resulting from Hurricane Harvey were in excess of 120,000 cfs.
- Reducing the flow in the Brazos by 2,200 cfs would have only lowered the water surface elevation of the Brazos River at the USGS gage at Richmond by approximately 2-3 inches at its peak flow rate during Hurricane Harvey. An increase in pumping rate to 5,000 cfs would reduce the water surface approximately 6 inches at an estimated additional pumping cost of approximately $40 million dependent on design elements of the facility.

As with many strategies, a major aspect of using off-channel reservoirs to lower flood flows in an adjacent river or stream is the cost of the required facilities versus the predicted flood reduction benefits. Based upon multiple studies in Texas, the cost of large pump stations, depending on supporting facilities, is estimated to range between approximately $15,000 and $20,000 per cubic foot per second of water being pumped. So, for a pump station capable of diverting 5,000 cubic feet per second of floodwater from a river into an off-channel reservoir, the cost of the pump station alone would be approximately $75 million. This estimate does not include any costs for the canal or pipeline to transfer the floodwater, nor any other costs associated with the diversion. The cost to benefit ratio of such projects can preclude their use as a flood mitigation strategy.

Conclusion

The use of off-channel reservoirs for flood control purposes has limited feasibility and effectiveness. In some situations, off-channel reservoirs can provide flood reduction benefits when other means cannot be implemented, but they are likely to be very limited due to the nature of their design and cost of implementation. Because they have little or no natural upstream drainage area, off-channel reservoirs have very little ability to capture significant volumes of natural runoff and instead rely on pumping from an adjacent or nearby water source. Furthermore, pumping capacity is small relative to flow rates and volumes that occur in a river system during floods. Pumping during floods may be further frustrated due to debris and heavy sediment loads carried by floodwaters and associated management issues regarding the diverted flood flow.

Aquifer Storage and Recovery

Aquifer Storage and Recovery (ASR) is a water supply strategy in which water from lakes, rivers, storage areas, treatment plants, or aquifers is delivered into underground aquifers where it is stored for future use, at which time it is pumped out of the aquifer, often from the same well that was used to put the water underground. Most often the aquifer is recharged using wells, but there are locations in which the water is put on the ground and allowed to infiltrate or into shallow storage chambers to recharge the aquifer. The purpose of this chapter is to highlight practical and beneficial ways in which this water supply strategy can be utilized in Texas.

There are more than 175 ASR systems installed around the country, and the number in Texas is increasing. San Antonio, Kerrville, and El Paso are currently utilizing ASR, and other water suppliers are actively studying its potential as a water supply strategy. Initial feasibility and pilot-testing studies are important, as ASR requires the right physical conditions (e.g. geology, ground slope, groundwater quality) to be feasible. It also must be economically competitive with other viable options.

This subchapter builds on the conclusion that ASR is an important water supply strategy and considers its use in two additional settings: stormwater capture and flood control.

Stormwater Capture

Stormwater typically refers to the water that runs off the ground during and after rainfall events and is captured by urban storm sewer systems or retention/detention basins (herein referred to as retention basins), or diverted directly into rivers and streams. In urbanized settings, these flows are controlled to avoid flooding structures when possible. Due to sizing and economic limitations, typical storm sewer systems are limited in capacity and generally cannot handle extreme rain events like a 100-year storm.

The most common stormwater control strategies include pipe systems to carry the water to rivers, buyout of structures in flood prone areas, protecting floodplains from development, retention basins to temporarily store stormwater until the peak of the storm has passed, and “low impact development” or “green infrastructure” strategies that replace concrete with areas that allow stormwater to percolate underground instead of running off the surface.

In some instances, stormwater that has been temporarily captured in reservoirs and retention basins can be recharged underground through wells that are drilled into local aquifers, thereby providing a water supply benefit in addition to a stormwater management benefit. Unlike ASR projects that are supplied from a reliable source of water, stormwater ASR often requires additional considerations, such as temporary storage due to the short-term duration and intermittent availability of stormwater, and water treatment, as state and federal laws include provisions to protect against the degradation of underground sources of drinking water. It also requires favorable aquifer conditions in the area of recharge.

Flood Control

The term “flood flows” typically refers to large flows in rivers, streams and lakes that overflow the banks. These flows come from rainfall runoff and include urban stormwater flows as described above. Every flood is different, depending on where the rain falls, how large an area the storm covers, the ground conditions prior to the storm, and the intensity and duration of the storm. “Control” of these large floods is typically accomplished through structural solutions like reservoirs and levees, and by protecting the floodplains from development. Recently, flood planners and water suppliers have been researching whether ASR can play a role in mitigating large-scale flooding situations.

For ASR to have any meaningful impact in an extreme flooding event, extensive off-channel storage would be required, because the rate at which water could be injected underground is so slow in comparison to the rate of flood flows. As such, the off-channel storage is actually the mechanism for mitigating the flood in this case, not the ASR system. Alternatively, ASR could also be used to draw down existing reservoirs to make room for flood flows, but it is improbable that enough water could be stored in the ASR system to create meaningful flood storage in the reservoir. In either case, treatment works would be required because water quality in large flood events is extremely degraded.

To make any appreciable dent in a large flood’s impact, an ASR system would have to be significantly oversized. Considering how infrequently the system would be used for flood control and the lack of a reliable water source to justify the expense from a water supply perspective, the ratio of cost versus use likely precludes ASR from being used for this purpose until it is economically competitive or other feasible options have been exhausted.

Conclusion

ASR has proven to be a practical and beneficial water supply strategy across the nation and in many parts of Texas. Water suppliers should continue to study its potential and build ASR systems where feasible and economically beneficial. ASR has also been deployed as either the primary component or as an element of stormwater capture strategies in some states, and tens of thousands of these wells exist. However, in Texas, the use of stormwater ASR wells is not widely utilized or well understood. As such, it is clear that additional study and pilot projects need to be conducted in Texas to better understand the benefits and costs of the use of stormwater ASR wells in areas prone to frequent stormwater events. As a flood control strategy, however, ASR cannot provide a first line of defense during an extreme storm event due to its need for extensive storage and treatment and its inability to compete economically with other solutions.

Dredging

This subchapter is focused on the general aspects of employing dredging as a means for mitigating flood impacts. Dredging relates to flood control because sediments carried by natural flows, particularly flood flows, are known to accumulate through deposition in portions of lakes and rivers. Sedimentation in flood control reservoirs, and even in water supply reservoirs, reduces storage capacity, which translates to less ability to store and detain floodwaters, with greater potential for downstream flooding. Sediment deposits in rivers and streams can alter channel flow patterns and impede flows, often causing water levels to rise with increased flooding of adjacent properties. Dredging of bottom sediments to remove them from lakes and rivers has been suggested as a means for potentially reducing flood levels and associated flooding during storm events.

Dredging is used for a variety of purposes. Maintenance dredging involves the removal of deposited sediments from the bottom of water bodies to improve and facilitate effectiveness and operations. Examples include the removal of sediment from a water supply reservoir to enhance its storage capacity, the removal of sediments from a particular area of a stream to improve its flow conveyance capacity, or the removal of sediments from a barge canal to facilitate navigation. Mining dredging most often pertains to the removal of sand and gravel from water bodies for commercial purposes, but the recovery of precious metals from water bodies can also involve dredging. Both maintenance dredging and mining dredging involve certain aspects that can be potentially beneficial with regard to reducing flooding impacts.

Dredging in Lakes and Reservoirs

Certainly, the dredging and removal of bottom sediments from a lake or reservoir, if in sufficient quantity and from the right places, can provide additional storage capacity for impounding flood flows that otherwise would pass downstream and possibly cause flooding, assuming the storage created by the dredging is not replaced with water.

The question of whether dredging of bottom sediments from an existing lake or reservoir should be undertaken to increase floodwater storage capacity in order to mitigate downstream flooding is one of feasibility and cost effectiveness. Extensive hydrologic analyses and flood routing studies are essential for assessing how much and where bottom materials would need to be dredged in order to effectively reduce downstream flooding. For significant floods such as the 50- or 100-year flood events on major rivers, the volume of storage capacity required to make a meaningful reduction in downstream flood levels can be substantial.

The San Jacinto River Authority recently undertook a study of Lake Conroe to investigate the potential downstream flood benefits along the West Fork of the San Jacinto River of operating the reservoir at different levels below its authorized conservation storage capacity in order to provide flood storage capacity. The study showed that starting the level of the reservoir two feet down at the outset of a 100-year flood event would result in lowering the flood level of the river by approximately three-quarters of a foot at a point about 15 miles downstream at IH-45. The storage volume equivalent of lowering the level of Lake Conroe two feet is about 37,400 acre-feet, which translates to a volume of approximately 60.3 million cubic yards if this same amount of flood storage capacity was to be created by dredging. This represents a lot of sediment to remove by dredging just to achieve a reduction in downstream flooding of 0.75 feet.

Furthermore, dredging costs can be prohibitive. Studies show that dredging to create storage capacity in an existing water supply lake or reservoir, at a minimum, would cost about twice as much as constructing a new lake or reservoir.[7]

Dredging in Rivers and Streams

The use of dredging to remove certain sediment and debris deposits from rivers and streams can have beneficial effects with regard to both upstream and downstream flood mitigation. Such deposits typically accrue along the inside bank of channel bends to form sand and gravel bars, but, depending on the historical evolution of a river or stream system and its man-made modifications, such deposits actually can occur anywhere throughout channel segments. Strategically removing these sand and gravel deposits and debris accumulations can increase the flow conveyance capacity of the stream channel, particularly under high flow conditions, and thereby reduce water levels in the stream and the potential for flooding of adjacent bank areas. It is important to recognize, however, that increasing the flow conveyance capacity of a river or stream segment by removing bottom sediments and debris allows floodwaters to move through the segment faster and potentially cause higher flood flows and higher flood levels downstream. Furthermore, removing sand and gravel deposits in some areas of a river or stream segment can adversely affect bank stability and potentially cause increased erosion of bank structure, so dredging to remove such sediments should be undertaken only with advanced planning and professional guidance.

In response to flood damages associated with Hurricane Harvey and other earlier storm events, the City of Houston and Harris County, working with the U. S. Army Corps of Engineers (USACE) Galveston District Office, are implementing an emergency project to dredge and remove sediment deposits and debris from a lower segment of the West Fork of the San Jacinto River for the specific purpose of improving flood flow conveyance and reducing flooding along the river. This project involves dredging and removing of approximately 1.8 million cubic yards of sediment and debris material from about 2.3 miles of the river channel immediately upstream of Lake Houston, and it includes disposal of the material in designated placement areas located along the river. The project is scheduled to begin in 2018.

Commercial dredging for sand and gravel along the San Jacinto River, as well as along the lower reaches of the Colorado and Brazos Rivers, is very active because of the high demand for these construction materials in the greater Houston area. This dredging occurs either within the channel of these rivers or in the overbank floodplain areas some distance away from the river channels. The preference of commercial operators, however, is to not dredge for sand and gravel within the river channels themselves, but rather to dredge in the adjacent overbank areas. This is because: 1)

[7] Alan Plummer Associates, Inc., “Dredging vs. New Reservoirs”, report to Texas Water Development Board, TWDB Contract #2004-483-534, December, 2005.

the in-channel removal of sand and gravel is subject to additional federal and state permitting requirements, including the federal Clean Water Act Section 404 permit and Section 401 state water quality certification and the Texas Parks and Wildlife Department sand and gravel permit; and, 2) for those channels considered to be legally navigable, the State of Texas claims ownership of the underlying minerals, thus subjecting the removal of these sand and gravel deposits to royalty payments to the State. Consequently, most of the sand and gravel mining has occurred outside of, but generally adjacent to, the river channels, using either draglines or dredges. It is significant to note that recently there have been discussions between the commercial sand and gravel mining operators along the San Jacinto River and certain interests in the region concerned with flood mitigation to explore common goals that possibly could be achieved by facilitating more in-channel dredging of certain strategically-located sand and gravel deposits. This effort is continuing and may result in proposed state legislation that could encourage and support such in-channel dredging activities, with appropriate checks and balances, but with limited permitting requirements.

Dredging Considerations

With regard to any dredging project, it is important to remember that the removal of sediment or debris from a water body is only the first part of the process. The dredged material, typically in the form of a slurry comprised substantially of water, then has to be disposed of, which can be a major and expensive undertaking. Dewatering of the slurry is essential in order to have a manageable quantity of relatively dry material that can be readily disposed of, generally by hauling off to a remote site for landfilling or for construction material. Often the slurry is discharged into leveed lagoons where the sediment particles settle over time, leaving a relatively clean liquid that can be returned back to the water body being dredged. Obviously, this requires significant land located in the immediate vicinity of the dredging operation. For its resaca restoration project, the Brownsville Public Utilities Board is dredging many miles of urban waterways where undeveloped land is not readily available for disposal of the dredged material, so a mechanical dewatering system comprised of material separators, screens, filters, and wash racks is being employed to dewater the dredged slurry, with the clean water discharged back into the resacas and the relatively dry material hauled to a land disposal site.

Dredging is an expensive undertaking. The total cost of a dredging project must be weighed against the benefits to be gained, in this case the flood mitigation benefits. The unit cost of dredging, i.e., dollars per cubic yard of sediment removed, can vary widely because of significantly different project conditions related to site location and access, water body type and configuration, man-made obstructions, total volume of material to be removed, sediment characteristics, and disposal options. Information based on several USACE dredging projects compiled by Alan Plummer Associates, Inc. (Plummer) in a 2005 study indicates that the unit cost for dredging can range from around one dollar up to more than ten dollars per cubic yard of material removed. To put these unit costs in perspective, dredging the top five feet of bottom material from a one-mile segment of stream channel 30 feet in width (29,300 cubic yards) could range in total cost from about $30,000 up to $300,000. Assuming $5 per cubic yard as an average unit cost based on the data compiled by Plummer, dredging the equivalent of the top two feet of storage capacity in Lake Conroe as described above to lower the 100-year flood level downstream on the West Fork of the San Jacinto River by approximately 0.75 feet would cost approximately $300 million, a substantial sum for the relatively small reduction in flood level realized. The contract awarded by the USACE Galveston District for the emergency dredging and debris removal project initiated by the City of Houston and Harris County for flood control purposes along the West Fork of the San Jacinto River near Lake Houston includes a cost of about $70 million. For the approximately 1.8 million cubic yards of material that are to be removed and disposed of, this translates to a unit cost of approximately $39 per cubic yard. While this unit cost certainly appears high compared to the typical range of dredging costs cited by Plummer, it likely reflects that the project is being undertaken on an emergency basis with a tight six-month time schedule and involves more than just routine dredging of bottom sediments, because of the extensive accumulations of debris that have to be removed using non-dredging methods.

Conclusion

It must be emphasized that dredging of sediment deposits, whether from lakes and reservoirs or from rivers and streams, for the purpose of reducing flood impacts must be well planned and thoroughly investigated to ensure positive results. What may seem like a straightforward flood mitigation solution by removing sediment could produce serious adverse effects that may do more harm than good and could be irreversible. The negative environmental impacts from dredging may make getting authorization to dredge areas or dispose of the dredged fill impossible in certain areas, as well. Adequate funding, not only for the dredging itself – which is expensive by its very nature, must be allocated to the initial planning, environmental, and technical analyses that are essential for a dredging project to successfully achieve its projected flood control benefits.

Reservoir Operators' Role in Providing Notice of Flood Events

Texas has more than 4,000 regulated reservoirs. Over 200 of these are considered major reservoirs, and are owned and operated by a myriad of federal, state, and local entities. The U.S. Army Corps of Engineers (USACE), river authorities, and regional water districts are the most common reservoir owners and operators in Texas. In some instances, reservoirs are owned by one entity and operated by another; usually a local sponsor in partnership with USACE. Nearly 90 percent of Texas reservoirs serve a water supply function, but some also include varying degrees of flood control as well. Very few major reservoirs, especially those operated by local entities, act solely in a flood control capacity. Barker and Addicks Reservoirs, owned and operated by USACE, are two examples of reservoirs designed exclusively for flood control.

During a major flood event, it is critical that those who may be affected receive timely and accurate information and a clear and consistent message of what to expect. It is also important that local emergency management officials stay informed so that they can make decisions within their jurisdiction such as the need for potential evacuations. Reservoir operators can and do play a major role in providing information related to flood releases and reservoir levels to both the public and local officials.

The purpose of this chapter is to focus on communication during a flood event, with particular attention to the ways in which reservoir operators notify local emergency management officials and the public of reservoir conditions and dam releases. Additionally, this chapter will discuss and provide specific recommendations for how these operations can be better communicated to the public during a flood event.

Sources of Flooding

Before discussing how reservoir operators handle water release and reservoir level notifications, it's important to identify the sources of flooding. Not all flood events involve or are contributed to by reservoirs.

Some floods occur due to heavy rainfall, runoff, and/or urban development downstream from the nearest reservoir and have no interaction with or contribution from reservoir operations. In these cases, reservoir operators typically do not provide notice because the flood event does not involve their operations. Some reservoir operators may still choose to post information regarding isolated local flooding on their websites or social media advising the public to be alert.

Additionally, there is a common misconception that the only water flowing in the river during a flood is water being released from an upstream dam. In fact, in many cases there is more water flowing in the river from rainfall and related runoff than is being released from a reservoir. It is important to remember that release information provided by reservoir operators during a flood event is just one piece of the flooding puzzle, which also includes rainfall, urban development, regular run-of-river conditions, soil moisture, and other variables.

For the purpose of this chapter, "release" means any water that passes through or around a dam in one of two ways, depending on the reservoir's design. One method is through a fixed spillway, which allows for water to "spill" over or adjacent to a dam once the reservoir reaches a certain level. Other reservoirs have dam gates which can be raised and lowered to let water through in varying quantities. In both cases, the reservoir operator is passing flood flows through or around the dam at roughly the same or a lower rate than the flows that are coming in. For reservoirs fitted with operable or moveable dam gates, release decisions are made in accordance with site-specific reservoir operating protocols or procedures that include:

1. Flood Operations Protocol/Procedures: the majority of discharges from a water supply reservoir do not constitute an emergency. These discharges are made pursuant to the reservoir's standard operating protocols or procedures, which are sometimes called a flood operations manual or water control manual.
2. Emergency Action Plan: Large or high-hazard dams in Texas are subject to the TCEQ Safety of Dams Program. Under this program, each regulated dam is required to have an approved Emergency Action Plan (EAP), which specifies actions to be taken and notifications to be made in the case of an emergency associated with the dam structure. This "emergency" may or may not be associated with a flood event.

As discussed in the first chapter of this document, when operating according to its design, water released from a water-supply reservoir during a storm event does not cause or exacerbate flooding beyond that which would have occurred in the absence of the reservoir's existence. The same volume of water that is behind a water-supply dam before a flood release begins will be there when the flooding is over; stored water is not released during storm events. The only water that passes is water that would have flowed down river had the dam never been built. This kind of operation is called run-of-the-river and is not intended to provide flood control benefits. However, without releases, floodwater would back up and flood communities upstream of the dam. More importantly, if releases are not made and water overtops the dam, its integrity could be compromised, acutely endangering life and property downstream.

The Role of Reservoir Operators

Each reservoir operator has a unique, site-specific process in place for making information available to the public regarding releases during flood events. In many cases, reservoir operators also have active websites and social media pages that are continually updated with release information. These sites are often manned and updated 24/7 during a flood event and include information such as streamflow, reservoir elevations, and rainfall data. Most operators also maintain contact with local media outlets in certain areas that may be affected in order to get information to a broader audience. Some reservoir operators use downstream call or notification lists. These systems allow those living around or downstream of a reservoir to sign up to receive a call, text, or email when flood releases of a certain volume are occurring. However, these systems are not foolproof and should never replace or supersede the formal emergency notification procedures of designated local partners, as discussed below.

An important responsibility of reservoir operators is to notify designated local partners of reservoir conditions, especially those with the authority to order evacuations or make widespread emergency management decisions. It is important to provide clear, consistent messages in an emergency, and the sources of public information should be limited for that purpose. It can be incredibly difficult and taxing to decipher multiple messages from different entities, especially in an emergency. Each community should have a designated entity for providing “Amber Alert” type notifications to the public related to weather conditions and flooding. When too many agencies work in silos and provide one-dimensional information to the public, it increases confusion and the burden on local entities, responders, and the public.

Designated Partners

Most local governments have an Emergency Operations Center (EOC) staffed by members of its various local agencies that is activated in response to an emergency. In addition, the National Weather Service (NWS) has historically been the entity charged with providing comprehensive weather and flood data, as it is in a position to process and combine all measurable data during a flood event. These organizations should serve in the leading role of providing clear messages to the public during flood events.

Emergency Operations Centers

In Texas, mayors and county judges have responsibility for emergency preparedness and response within their local jurisdictions. Generally, reservoir operators are members of the EOCs and work directly with the emergency management coordinator in each local jurisdiction. Reservoir operators provide the coordinator with release and flow information to aid the coordinator in the decision making process.

Emergency management coordinators at the local government level are responsible for emergency response, notifications, and evacuation orders when necessary, and pass those orders along to first responders. This model could benefit from some consistency and efforts to inform the public of its role, but in most jurisdictions the local emergency management office is an effective and powerful tool to combat conflicting and incomplete information from separate entities.

National Weather Service

There are three NWS river forecast centers that cover Texas (West Gulf River Forecast Center, Arkansas-Red Basin River Forecast Center, and Lower Mississippi River Forecast Center) and provide forecasts for river levels that are based on rainfall and river conditions, including information from reservoir operators that may be making flood releases. Importantly, these forecasts also include water that is already in the river or that may be flowing into the river from another area. As such, these forecasts are more accurate and reflect a better picture of flood potential in a given area.

While the river forecast centers run the models and provide the projections, the local NWS forecast offices implement weather watches, warnings, and emergency notifications. According to the NWS, it is the sole, official voice for issuing warnings during life-threatening weather situations in the United States. The NWS forecast offices coordinate this information directly with local emergency management officials.

Conclusion

During a flood event, it is important that evacuation orders and flood warnings come from a single, designated source to avoid confusion and ensure accurate information for the public. In Texas, the leading notification providers are local Emergency Operations Centers (EOCs) and the National Weather Service (NWS). Reservoir conditions are one piece of the flooding puzzle and operators must provide real-time information to EOCs and the NWS so those entities can weigh all contributing factors to provide the best possible flooding information to the public.

The Role of River Authorities in Flood Risk Reduction

The possible solutions to reducing flood risks are as diverse and complex as the state of Texas itself. Because the needs and challenges for each area of the state are unique, a one-size-fits-all solution will not work and can hamstring existing systems, many of which work very well. For example, different areas of the state have:

- Different existing local entities with varying flood management responsibilities and needs for partnerships, funding assistance, technology, etc.;
- Different local economic resources and challenges; and,
- Different geographies and types of flooding.

Overview of Current Roles and Potential Improvements

There are numerous federal, state, and local agencies that play a role in flood risk reduction; from long-range planning to emergency response during storm events. Each entity/agency that plays a role in flood risk reduction (e.g., Federal Emergency Management Agency, the United States Army Corps of Engineers, Texas Division of Emergency Management, Texas Water Development Board, river authorities, cities, counties, flood control districts, levee districts, etc.) has a distinct role to play and specific responsibilities. To effectively reduce the risk of flooding and improve public safety, there are four main goals that must be met:

1. Development standards must be updated and kept current based upon best-available data and ongoing studies;
2. Flood plain administration must be consistently and effectively implemented throughout the entire watershed;
3. Flood early warning and emergency response systems must be improved and enhanced; and,
4. New flood mitigation projects must be studied and developed.

Cities and counties are statutorily-authorized and are the appropriate entities to take the lead on items one and two listed above. River authorities can help to facilitate those discussions and coordinate those efforts, but the regulations and best management practices that affect land use and development must be adopted, implemented, and enforced at the local level. Goals one and two listed above will help to address local drainage issues and consequently have a positive impact to reduce regional flooding.

Regarding flood early warning and emergency response systems, river authorities can play a strong role in partnering with local offices of emergency management by providing more and better data during storm events. As described above, local offices of emergency management serve as the central, public-facing communication outlets during flood and other emergency events. They have the expertise and resources to perform this task (in coordination with other agencies such as the River Forecast Center of National Oceanic and Atmospheric Administration (NOAA)/National Weather Service), and it is critical that they continue to serve as the single, coordinating point of contact with the public during emergencies.

Regarding new flood mitigation projects, river authorities could partner with local entities to assist in securing funding and to deliver flood mitigation projects through the design and construction phase, and then transfer those assets to local entities upon completion. Alternatively, local entities could contract with river authorities to operate and maintain those assets.

It is important to note that every river authority is different. Some have territory that covers only a few counties while others cover over 50 counties and span from one side of the state to the other. Many river authorities have current obligations related to supplying water, developing new water resources to meet the needs of a growing population, and various other ongoing operations such as water and wastewater treatment and basin-wide environmental monitoring. Additionally, all river authorities have different funding mechanisms. Some possess taxing authority while others are entirely self-funded through the provision of water and other services. This means that each river authority's ability to participate with a local entity or entities on the types of projects described above will need to be considered on a case by case basis in light of a river authority's ongoing operations, funding, staffing levels, and other factors. Any statutory changes recommended to create these types of partnerships should contain permissive language stipulating that these are options for, and not mandates on, both local governments and river authorities.

Recommendations

1. River authorities have expertise in river and rainfall data gathering and make data (e.g., river gage, rain gage, and gate release data) available to federal, state, and local flood risk reduction entities and should continue to work with those entities to improve river data collection and dissemination infrastructure. These improvements could include additional integration with the Texas Water Development Board's new one-stop site for flood information (www.texasflood.org) or existing regional systems.
2. Areas of the state that lack sufficient local resources to effectively address flood management and planning could benefit from increased partnership and coordination with the river authority(ies) in their area. Depending on the local needs, river authorities could fill this role through interlocal agreements for specific services, coordination of regional studies, or the provision of direct staff services through full-time employees or consultants. These services could assist in various aspects of the three parts of a flood risk reduction system (planning, predicting, and responding), especially in providing expertise and assistance in obtaining state and federal funding, which should be provided through the Texas Water Development Board, Federal Emergency Management Agency, or the United States Army Corps of Engineers.
3. Most, but not all, river authorities and other Chapter 49 special districts have the legal authority to partner with local entities with flood control responsibilities (cities, counties, drainage districts, levee improvement districts, storm water control districts, soil and water conservation districts, certain water districts, etc.) to carry out flood management activities. The legislature should consider expanding or, where necessary, creating the legal mechanisms for river authorities and special districts to partner with local entities as needed in the various

roles of flood risk reduction within their basins. This would include the ability of river authorities to act as conduits to apply for and manage Texas Water Development Board funding not only for flood protection studies, but also for flood infrastructure funding and construction.

4. Local entities sometimes lack the expertise and financial means to design and construct large, regional flood mitigation projects that benefit numerous entities across a watershed. River authorities and other Chapter 49 districts with large regional jurisdictions typically have the experience and expertise to design and construct such projects, but they lack the power to collect a tax or a fee to do so. The legislature should consider clarifying the authority of river authorities and special districts to convey infrastructure that is constructed with third-party funds to local entities (i.e. municipalities, counties, etc.) at no additional cost to the local entities. While the responsibility for ongoing funding should be borne by the local entities who benefit from the project, the ongoing operation and maintenance responsibility could either be transferred to the local entity(ies) or remain with the river authority under an interlocal agreement. Some areas of the state already employ partnerships of this nature, and any legislation should recognize the diversity and complexity of these existing arrangements.

Funding

Funding for flood management efforts in Texas is currently complex and disjointed. Local entities with flood control responsibilities (cities, counties, drainage districts, levee improvement districts, stormwater control districts, soil and water conservation districts, certain water districts, etc.) generally focus their funding on strategies related to local drainage and development standards, but these efforts often miss important, regional strategies. Large-scale regional strategies, such as flood control reservoirs, do not have sufficient, dedicated funding sources and often benefit numerous local entities, which increases the complexity of funding and implementing the strategy.

Current state financial assistance *grant* programs are not funded at levels sufficient to meet the needs of historic flood management efforts, much less the increased needs since Hurricane Harvey. Further, existing state financial assistance *loan* programs designed to fund structural and non-structural flood mitigation measures (such as restoration of levees, raising of bridges and roads, or removal of structures from the floodway) have not seen patronage due to lack of a subsidy for incentives or a revenue source to pledge for debt issuance. Most local entities await limited federal grant funding for such projects. An effective state financial assistance source for flood mitigation grants and loans is necessary to support local efforts to mitigate the losses from flood events.

Ultimately, funding for flood management efforts will have to be a combination of local, state, and federal dollars. Some efforts can and should be funded at the local level, but many flood projects are simply too large to be absorbed by local entities.

Recommendations

1. Provide more grant funding for planning and study needs, such as the development of floodplain maps, models, U.S. Geological Survey gages, etc.
2. Amend Texas Water Code Chapters 15 and 49 to expand the scope of existing Texas Water Development Board flood-related grant funding to include design and construction of flood mitigation infrastructure.
3. Provide state grant and highly-subsidized loan funding for the implementation of flood mitigation measures, including to meet local match requirements for federal dollars.
4. Set aside Rainy Day funds (as with SWIFT/SWIRFT) and create a new subchapter for grants and loans under Texas Water Code Chapter 15 and/or grants under Texas Water Code Chapter 16, Subchapter I, to be administered by the Texas Water Development Board.
5. Provide express legislative authorization for local taxing jurisdictions to contract with river authorities to construct and maintain regional flood mitigation projects and use local tax dollars to repay loans or other indebtedness incurred by a river authority. This will allow local taxing jurisdictions the ability to combine efforts and financial resources to take advantage of loan programs for large-scale projects.