Paraíba do Sul Flood Control Plan Review

Paraibuna-Paraitinga Reservoir on the Paraíba do Sul river

USACE Document 2.2

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1.0 EXECUTIVE SUMMARY

This document is a technical review of ANA Document 2.2 ("The Experience of ANA in Complementary Studies for Flood Control Plan in the Paraíba do Sul River Basin"). ANA Document 2.2 details two studies performed in the interest of flood risk management in the Paraíba do Sul basin: the SISPREC study to develop a flood-forecasting system, and the SIEMEC study to select structural measures for flood risk reduction. The two studies are reviewed on technical grounds from the USACE perspective, identifying best practices and technical recommendations for use in future similar studies. Furthermore, by assessing ANA Document 2.2 as a case study of Brazilian flood risk management practices in general, guidelines and recommendations are developed for future development of Brazilian regulatory policy regarding flood risk management.

The overall technical review of ANA Document 2.2 reveals two studies that are sophisticated in their methods and ingenious in their design and management. By strategically linking the two studies, much greater capability was achieved for the same cost as compared to managing two separate studies. The modeling tools are comparable to what is commonly used in USACE; in fact USACE modeling software was used with custom-made "wrapper" software to help link the models together. An "atlas of floods" approach was used to make model output easy to access quickly during an emergency, with reduced reliance on real-time modeling. And an explicit formulation in terms of residual risk helps ensure that the public remembers that flood risk can never be completely eliminated. Each of these is a best practice worth copying in future studies, including in USACE studies.

The methodology developed in these studies also provides a solid foundation for future studies to build upon. Specific suggestions for the future include detailed descriptions of the use of survey data, detailed representations of the uncertainty of data including confidence bands, development of flood stages based on impacts in addition to flooded area, and opportunities for increased model accuracy through more complex modeling techniques if site-specific characteristics are favorable. As a case study for Brazilian flood risk management practice, some guidelines for further policy development are also presented. These include assessment of structural measures in terms of costs and benefits, a suggested methodology for life-safety risk assessment, and defined levels of reliability. Some of these suggestions may be infeasible in Brazil due to legal, economic, or cultural realities that are different from the United States. Some may reflect an ideal rather than present USACE practice. Nevertheless, they are recommendations developed from the USACE perspective in consideration of ANA's competencies, presented in the hope that they will be useful to ANA and help reduce flood risk for the people of Brazil.

2.0 INTRODUCTION

The Agência Nacional de Águas (ANA) and the US Army Corps of Engineers (USACE) entered into an agreement on 5 November 2013 to exchange technical expertise through a series of technical documents, workshops, visits, and courses. The objective of this partnership is for ANA to perform the duties required by Law 9984 of 17 July, 2000 related to prevention of the impacts of critical hydrologic events. In particular, the USACE delegation agreed to provide training and products to ANA relating to flood control planning, reservoir operation and management, regulatory policy-making, and the planning and operation of hydrologic networks.

This USACE Document 2.2 represents Product 5, a part of Task 2, as detailed in the Scope of Work dated 16 Feb 2014. This document is a technical review of ANA Document 2.2, the Flood Control Plan for the Paraíba do Sul River, but also evaluates that document from the USACE perspective as a case study for Brazilian flood control practices broadly. There are significant differences between ANA and USACE, and between the United States and Brazil. USACE is a much larger agency, with 35,000 employees working around the world in local offices, whereas ANA has approximately 400 employees, all in Brasília. USACE also has responsibility for some mission areas that ANA does not, such as coastal storm damage reduction. Despite these differences, guidelines and recommendations presented in this document have been developed to help ANA personnel develop Brazilian flood risk management policies, based on contrasts drawn between flood risk management practices in the two countries.

Although the scope of work describes USACE Document 2.2 as a review of the Paraíba do Sul Flood Control Plan, ANA Document 2.2 (titled "The Experience of ANA in Complementary Studies for Flood Control Plan in the Paraíba do Sul River Basin") is not a flood control plan *per se*, since it does not provide instructions for managing a flood. Rather, it describes the two major studies performed in support of flood risk management[1] in the Paraíba do Sul basin, along with background information on the physical characteristics of the basin and the institutional management of its water resources. Together with the eight other documents to be produced within Task 2 (six by USACE, two by ANA), these documents will lead to a "roadmap" for Brazilian flood control planning, so that comprehensive flood control plans can be written for this and other river basins in Brazil.

[1] In accordance with ANA's areas of legal responsibility, discussion of floods in this document is limited to flash flooding, riverine flooding, and dam safety. Risk is understood to include both the probability and consequences of floods. Flood risk management is understood to include all activities related to identifying, assessing, reducing, sharing, and communicating the risks of flooding.

3.0 TECHNICAL REVIEW OF ANA DOCUMENT 2.2 WITH RECOMMENDATIONS FOR FUTURE STUDIES

3.1 Overview

The following sections will provide a technical review of ANA Document 2.2 from the USACE perspective, assessing the tools and techniques employed in evaluating and mitigating flood risk in the Paraíba do Sul River basin. To facilitate the use of this critique, it uses the same structure and section numbering as ANA Document 2.2. In each sub-section a brief summary is provided of the corresponding sub-section in ANA Document 2.2, followed by technical comments and recommendations for future studies of a similar nature.

3.2 Basin of Paraíba do Sul River

ANA Document 2.2 begins with a description of the physical environment in the Paraíba do Sul basin, highlighting geographical, climatological, hydrologic, demographic, and economic information to explain the causes of flood risk in this basin. This basin is located in the southeast part of the country, in the states of Rio de Janeiro, São Paulo, and Minas Gerais. The basin is one of the most developed in Brazil both in terms of population and economy, with over 5 million inhabitants. Furthermore, the 8.7 million residents of metropolitan Rio de Janeiro are also dependent on the waters of the Paraíba do Sul, through the interbasin transfer of water to the Guandu River via the Santa Cecilia pumping station. The basin is also a significant source of hydropower, providing approximately 1.7% of Brazil's total electrical power. The Paraíba do Sul River itself is 1,150 km long with a net elevation change of approximately 1,800 m. As a rough comparison, the Yellowstone River in the United States is 1,114 km long with a vertical drop of 2,207 m, though its average discharge is roughly one third of the Paraíba do Sul's.

As this section of the report is of a descriptive nature, there are no technical review comments to provide. The description is sufficient to provide an understanding of the physical environment and management challenges of the basin.

3.3 Water Resource Management in the Paraíba do Sul Basin

Section 3 describes the institutions charged with management of the water resources of the Paraíba do Sul basin, their statutory authorities, and their functional methods. The water management institutions of this basin are organized in accordance with SINGREH, the National System for Water Resource Management, which provides the framework for collaboration between federal-level and state-level actors. At the state level, the boards of water resources (CERH) for the three basin states of São Paulo, Minas Gerais, and Rio de Janeiro define water resource management policies and solve conflicts relating to tributary basins lying wholly within their particular state, while the state governments are responsible for implementing those policies and issuing permits. At the federal level, the national board of water resources (CNRH) and the secretariat of water resources and urban environment (SRHU, within the ministry of environment) define policies for the larger Paraíba do Sul basin, while ANA is responsible for implementing policies and issuing permits.

	Policy-making authority	Executive Authority
Federal Level	National board of water resources (CNRH) and SRHU	ANA
State Level	State boards of water resources (CERH)	Multiple state agencies
Watershed Level	River basin committee (CEIVAP)	River basin executive agency (AGEVAP)

Table 1. Governance structure for water resources management in the Paraíba do Sul Basin.

Recommendations

The mis-alignment of political and hydrographic boundaries is a universal challenge for water resources management. The Brazilian National Policy of Water Resources (Law 9,433 of 8 Jan 1997) addresses this issue by specifying the river basin as the territorial unit for implementation of both the National Policy of Water Resources and the National System for Water Resources Management (the SINGREH). From the USACE perspective, this is a very sensible strategy. In fact, USACE divisions and districts are also defined roughly along watershed boundaries in order to facilitate integrated management of water-related resources and risks. However, this strategy means that governance structures depend on watershed delineations, which can be subjective or unclear at times. Particularly in flat areas and along coasts, watershed boundaries may be difficult to define.

Management along watershed rather than state boundaries may complicate intra-state, inter-basin transfers, though in Brazil this issue may be addressed through the use of river basin committees with delegates to interconnected basins. Watershed-based management may also be tested in instances where the benefits of water resource development accrue to one state and the costs to another, as in the headwater basins of the Paraíba do Sul in Minas Gerais which contribute to flooding in the state of Rio de Janeiro. Although the Basin Committee and Agency should be able to address this type of situation in theory, in practice their capacities are limited by their funding, which comes from the water use charges approved by the Committee. In situations where the river basin committees do not satisfactorily resolve these issues, perhaps interstate water compacts could be explored as a complementary tool. A water compact is a legal contract or agreement between states, normally requiring the upriver state(s) to deliver water to the downstream state(s) within certain guidelines. Compacts are discussed in detail in USACE Document 4.1, "Aspects Governing Water Allocation in the United States" (USACE 2014). This may also be an area for future collaboration between ANA and USACE.

In the Paraíba do Sul basin, as in all of Brazil, water resource management is as decentralized and participatory as is practicable, with users and communities participating on basin committees alongside state and federal actors. In contrast to the United States, where Federal agencies may have dozens of local offices and hundreds of local projects across the country, Federal agencies in Brazil tend to serve a facilitative and coordinating role. Brazilian agencies typically provide resources and incentives to state and local actors to increase their capacity, rather than managing water resources directly through construction or operational activities, for example. This approach has the advantage of increasing stakeholder involvement, but at the disadvantage that the effectiveness of resource and risk management will vary with the capacity of the local actors. Federal actors may have the mandate but not the capacity or funding to make significant improvements in the effectiveness of under-resourced local areas. The "ProGestão" program provides a way to incentivize the states to take steps in improving their capacity while providing some funding to do so, and the state situation rooms are an example of the federal government directly increasing state capacity. Nevertheless, overcoming the large differences in state capacity remains an ongoing challenge. Furthermore, the fact that ANA's mission is limited to river flooding, to the exclusion of other types of natural disasters, makes it difficult for ANA alone to incentivize the states to manage overall disaster risk in a comprehensive way. If Brazil intends to develop a comprehensive goal for overall acceptable levels of flood risk, a correspondingly comprehensive system should be developed to make that a reality despite varying levels of resources, but without losing the excellent levels of local stakeholder involvement created by the river basin committee system. One potentially helpful tool could be a national, interagency task-force on flood risk management, similar to the Permanent Working Group for Hydraulic Operation (GTOAH), a regional team established in response to drought in the Paraíba do Sul basin in 2014. State-level multi-agency teams similar to the Silver Jackets could be another mechanism for cooperation (the Silver

Jackets program is discussed further in USACE Document 2.3). Such teams would involve all Federal agencies involved in flood-risk management, whether those floods are generated by coastal, riverine, rainfall, or man-made causes. With a comprehensive perspective on flooding issues, these task-forces could work to identify and recommend holistic projects with the potential to benefit the nation, rather than just one state or individual river basin. In this way, serious flooding issues could be addressed regardless of state capacity or type of flood.

3.4 Water Resource Plans

Section 4 describes the water resource plans that are presently in place in the Paraíba do Sul basin and the nearby connected basins. As mentioned in the previous section, CEIVAP is responsible for approving the water resource management plan for the basin. The water resource management plan is presently in the process of being updated, but as of the writing of this document the latest CEIVAP-approved plan dates from 2007. The plan contains within it an Investment Plan for the basin, based on a 14-year planning horizon (2007-2020). The SISPREC and SIEMEC studies, described later, were necessary parts of the investment strategy detailed in this plan.

Section 4 also describes the Contingency Plan for water supply to the Guandu, Guandu-Mirin, and Guarda basins and neighboring areas. This plan was developed as part of an initiative of the Water Resources Plan of the Guandu Basin, Subcomponent 2.2. This was included because the Guandu Basin is dependent on the Paraíba do Sul River for a large portion of its flow, via the Santa Cecilia pumping station.

It is not possible to provide comments on the water resource plans in the Paraíba do Sul basin without performing a detailed review of those plans, which would be beyond the scope of this effort. However, the brief description of these plans shown in ANA Document 2.2 indicates that they are organized in a similar manner to USACE Operations Plans (OPLANs) and Implementation Plans (IPLANs), with mission areas and subcomponents that point to cross-cutting themes. Strategic planning could be another potential area for future collaboration between ANA and USACE.

3.5 Vulnerability of the Paraíba do Sul Basin and Muriaé and Pomba Sub-Basins to Critical Events

Section 5 describes the particular risks facing the Paraíba do Sul basin and its tributary basins, the Muriaé and Pomba. Several recent floods are described, including their causes, impacts, and contributing factors. In general, flood frequency is highest in the tributary basins of the Muriaé and Pomba rivers, which have relatively little water resource infrastructure, while the main Paraíba do Sul river experiences reduced probability of flooding due to the large dams that have been constructed along its upper section. In all parts of the basin, however, flood risk has been increased through anthropogenic activities such as land cover change, river channel modification, and construction of local dams for storage of mine tailings. The mine tailing dams in particular are a source of significant risk of both flooding and water pollution, and this section describes several recent examples of disastrous failures of these tailing dams.

Recommendations

As this section both states explicitly and makes clear through the use of examples, human activity has greatly increased flood risk in this area. First, occupation of the floodplain has been poorly organized in many areas, resulting in settlements that abut the margins of the rivers and occupy areas that are naturally subject to frequent floods. In addition, these settlements tend to require construction of roads, buildings, and other obstructions that block or restrict small watercourses, reducing their capacity and resulting in more frequent, more damaging floods. Laws and regulations exist to discourage this type of development, but they may not be effectively enforced in practice. Enforcement depends on both local capacity and on the level of cooperation between the federal, state, and local governments (this issue is explored further in USACE Document 2.1, which presents a review of Brazilian legal and institutional frameworks for flood risk management). Finally, poor land-use practices have also increased the probability of flooding. Deforestation and increased impervious surface area have increased the rate of rainfall runoff, while increased erosion leading to siltation in the river and a corresponding reduction in channel capacity has raised the river stage for a given discharge. In addition to these effects on flood risk, such land-use practices have also deleteriously affected water quality in the basin.

These findings make clear that improved land-use practices may be able to recover some of the ecosystem services formerly provided by the watershed, reducing flood risk to something closer to its natural level. Reforestation and restoration of natural waterways could be effective, relatively low-cost alternatives to more intensive structural measures, and could be considered in future studies (though they become costly in urban areas where large populations must be resettled). For example, providing education to farmers about the importance of soil conservation, possibly through cooperation with agricultural extension services provided by the Ministry of Agriculture, could help improve agricultural productivity while reducing the sediment input to the river. Landowners might also be encouraged to sell or donate conservation easements[2] to the government or to environmental organizations, preserving their ownership of the land while restricting further development or even allowing some restoration of a more natural environment. This could allow preservation or restoration of ecosystem services such as erosion control, stormwater storage, floodwave attenuation, groundwater recharge, and improved water quality. While these non-structural measures are not without cost, they may be less expensive than large structural projects under certain conditions, and/or may have other ancillary benefits.

3.6 Organization of the SISPREC and SIEMEC Studies

Section 6 describes how the SISPREC and SIEMEC studies were organized and carried out, in terms of project design and management. The SISPREC study resulted in the development of a system for the simulation and prediction of flood events, for the purpose of flood forecasting, as well as simulations of dam breaches and propagation of pollutants. The SIEMEC study resulted in the selection of a portfolio of structural measures for the reduction of flood risk on the Paraíba do Sul system. Despite the different purposes of the two studies, there are overlaps in data and tools that allowed certain efficiencies to be captured, compared to executing the two studies independently. This is a very reasonable approach.

While there may be some drawbacks in some cases to using the same tools for both studies, specific suggestions will be made in the section detailing each study. Therefore, there are no comments to be made on the general work process for these two studies.

3.7 Field Surveys

Section 7 describes the topographic and bathymetric surveys, as well as the cartographic studies, that were performed to support the SISPREC and SIEMEC studies. In order to maximize the limited resources available for surveys, priority areas were identified for intensive surveying, while more approximate information was made to suffice for the remaining areas.

[2] A conservation easement is a voluntary legal agreement to forgo some rights to development of land, often in exchange for payment or tax incentives.

3.7.1 Topographic and bathymetric surveys

Topographic and bathymetric surveys were performed in support of both the SISPREC and the SIEMEC studies. These surveys established the three-dimensional physical surface necessary for modeling of flood characteristics and impacts. Cross-sectional surveys combining both river channel bathymetry and floodplain topography were performed at a maximum interval of 5km along the long profile of the river, extending up to 500m from the riverbank on either side. Where the river crossed an urbanized area or a location of significant hydraulic influence such as a channel expansion/contraction, structure, or waterfall, additional cross-sections were added if the 5km rule would have otherwise omitted them. This resulted in a total of 354 cross-sections surveyed in a river 1,150 km long with a vertical drop of 1,800 m.

3.7.2 Cartographic Surveys

In contrast to the topographic and bathymetric surveys, cartographic surveys were designed only to inform the SIEMEC study, in attempting to define the structural measures that would be constructed to reduce flood risk in the Paraíba do Sul basin. The SIEMEC study required this detailed information in order to define the designs of the dams and other proposed alternative measures. The cartographic surveys consisted of orthorectified aerial photography at 1:10,000 scale in 18 polygons totaling 207 km^2.

3.7.3 Geophysical surveys

Geophysical surveys were performed to support the SIEMEC study, in order to define the appropriate locations for proposed dams. These surveys consisted of field visits by a geologist and ten vertical electrical soundings at each of four field sites. While very preliminary in nature, these surveys found that all four selected field sites are likely suitable for dam construction.

Recommendations

From the USACE perspective, the ideal number of bathymetric surveys for designing and calibrating a flood forecasting model is probably higher than what was used in the SIEMEC study. Future studies could investigate improving model performance with additional bathymetric surveys, to improve calibration and reduce the likelihood of mis-applying results. Although there is no firm rule for spacing of cross-sections in a USACE hydraulic model, many projects will space sections 300 m or less apart, though many of these may be interpolated rather than measured depending on the funding available for field data collection. A USACE Flood Control course given to ANA suggested general guidelines of moderate spacing of 150 to 600 m between cross sections, with a maximum of 1600 m. Given limited resources, however, it is commendable that the surveys that were collected were performed in a strategic, prioritized way. In fact, addressing data collection in consideration of limited resources and the level of information required to address the question at hand is reminiscent of "SMART Planning[3]," an approach that is still new within the Corps of Engineers. However, to make data collection truly strategic, a required level of forecast accuracy could be defined, and a sensitivity analysis performed to determine how model accuracy varies as a function of data availability. For example, a study team might determine that a mean error of 0.5m between modeled and observed crest stage data is the limit of tolerable accuracy. Additional interpolated cross-sections could then be added to the model to assess whether this change has any impact on modeled results. If adding cross-sections changes model output then additional field surveys may be justified. Cross-sections would then be added, focusing new surveys on areas where the channel is changing rapidly, until mean error is reduced to 0.5m.

It is recommended that in future studies, a target level of river forecast accuracy be defined at the outset of the study, to focus data collection. This level may be defined in various ways depending on the needs of the local responders. For example, a metric such as root mean squared error could be used to assess the closeness of a forecasted stage to the actual stage, or mean error could be used to assess the overall bias of the forecast. Alternatively, the timing of a flood peak could be more important than its magnitude, in which case a metric such as time from peak would be used. Finally, if a given stage of interest were defined for each forecast point, such as a flood stage, bankfull stage, or bridge height, then metrics could include the percentage of the time this stage occurred without being forecasted and the percentage of the time it was forecasted but did not occur. Each of these metrics is used by various offices of the Corps of Engineers and its partner agency for river forecasting, the National Weather Service. The choice of which metric is best, and how much accuracy is required, is always location-and situation dependent.

If the metrics mentioned above show that the model is not sufficiently accurate, sensitivity analysis may be used to determine whether additional field data would help. For example, if low model accuracy (modeled versus observed) indicates more field data may be needed, interpolated cross-sections may be added first. If this significantly changes the results, then more surveys may be collected. But if adding interpolated sections makes no difference in model output, there is no need to collect more survey data in this area.

[3] SMART Planning is a new method of USACE project planning that seeks to focus resources where they will be used most efficiently. Issues that will affect the final decision are emphasized and allocated more resources, while less important ones are de-emphasized. Ultimately this should help complete a plan more quickly and cheaply than if all aspects of the plan were given equal importance.

Topographic data that are collected for a particular study or design may also be very useful to a different study later on. It is recommended that ANA establish a central database for storage of topographic data and GIS files as they are created, for later use.

3.8 The SISPREC Study

The SISPREC (Sistema de previsão de eventos críticos na bacia do river Paraíba do Sul) study created a flood-forecasting system for the Paraíba do Sul basin, to help provide early warning of impending floods and dam breaches, as well as severe water pollution events.

3.8.1 SISPREC Data Collection

Many types of data were collected from a variety of sources for the SISPREC study. Digital cartographic maps from the Geography and Statistics Institute (IBGE) and the Geographical Service (DSG) were analyzed to create digital spatial datasets of hydrology, contour lines, localities, work sites, and buildings. Altitude data were derived from data collected by NASA’s Shuttle Radar Topography Mission (SRTM). Spatial data were also collected on land cover type, transportation infrastructure, geology, soil type, climate, sources of water pollution, locations of municipal water intakes, and locations and characteristics of dams. Rainfall, river discharge, and water quality time-series data were collected for model calibration and verification, and the extents of flooding from a series of past floods were mapped to compare against the inundation maps generated by the modeling system.

Recommendations

The technical review of ANA Document 2.2 did not identify any information relating to the accuracy or uncertainty of data collected for the SISPREC or SIEMEC studies. When discussing data sources in future studies, the estimated magnitude of error should be given along with estimated values, so users know how confident they should be in a given value. Risks can be managed more effectively when end users know much confidence they should have in data sources. Furthermore, providing data with estimates of uncertainty indicates which data sources represent the greatest sources of error in the final product. This allows efforts to reduce model error to be focused where they will be most effective.

The study utilized elevation data derived from the NASA Shuttle Radar Topography Mission (SRTM), which were coded relative to the WGS84[4] ellipsoid, but did not specify how these data were transformed into elevations relative to a geodetic datum. Presumably, some sort of warping or shifting of the SRTM data was necessary to force it to fit the reference points surveyed for the topographic and bathymetric surveys, so the two elevation datasets could be presented in the same frame of reference. For this study, the data transformation was most probably performed correctly by the survey contractor. However, the shifting methodology is an important topic to be included in future studies, as it may be a source of significant model error. Mis-matched survey data have caused serious errors in the past for USACE projects, such as the Hurricane Protection System in New Orleans before Hurricane Katrina, which used various unrelated and un-maintained survey datums. This resulted in variable and even unknown levee heights in many places. From the USACE perspective this is a subject that warrants detailed description.

3.8.2 Data assessment and processing

For purposes of modeling, the Paraíba do Sul basin was divided into seven major watersheds, which were then further subdivided into smaller sub-basins following a strategic delineation based on factors such as population, history of flooding, river confluences, and large dams. River gages were chosen based on their relevance to these sub-basins, as well as on their length of record and data quality. Gages with data showing shifts in datum, large amounts of missing data, extreme outliers, or regime changes such as those resulting from dam construction were eliminated from the analysis. Precipitation stations were selected for inclusion in the study based on their length of record, data quality, and spatial distribution within the watershed. Based on analysis of extreme rainfall at these stations, seven past water years were chosen for modeling of peak flow for model calibration and validation, and rainfall isohyets were created for each year.

Recommendations

Discussions with ANA staff indicated that while radar-rainfall estimates are not often readily available for recent events, these data may be available for some historical storms when sufficient time has passed to allow post-processing. Radar-estimated rainfall totals may therefore be available for some of the past extreme rainfall events examined in this

[4] The World Geodetic System of 1984 (WGS84) is the most recent revision of the standard reference ellipsoid used for defining position in three dimensional space on Earth. The reference ellipsoid is a smooth surface centered on the Earth's center rather than a gravitational equipotential surface (a geoid), so it cannot be used directly for surveying because it does not reflect local variations in gravity. A "geoid model" is used to transform ellipsoid heights into survey elevations.

section, such as the storms of 1997, 2000, and 2008. If such historical storms are used in future studies, radar-rainfall data could be requested of the Center for Weather Forecasting and Climate Studies (CPTEC) for comparison against the isohyets generated from raingages. Particularly in extreme rainstorms, the spatial variability of rainfall may be very high, so any extra data may be helpful for improving simulations, which in turn may help improve the management of flood risks.

3.8.3 Modeling and prediction of floods

The basic modeling process used in the SISPREC study has two parts: generation of inundation scenarios in advance of an event, and matching forecasted flow to an inundation scenario during an event. The procedure for generation of scenarios is as follows:

- compute rainfall events of specified frequency based on the best-fitting probability density function for the rainfall data at each rain gage,
- generate runoff from these extreme rainfall events in HEC-HMS using the SCS curve number method,
- route those flows through the sub-basin in HMS to the boundary of the HEC-RAS hydraulic model,
- route flows in RAS using a steady-state hydrodynamic modeling (with unsteady modeling in certain stretches of the rivers near gage stations used for verification),
- simulate reservoir operations in HEC-ResSim based on input hydrographs from HMS and RAS,
- use steady-state RAS again to route the outflows of reservoirs, and finally
- generate inundation maps for each flow based on the stages computed in RAS.

During a real flood event, flood forecasting is performed with the following procedure:

- run HMS using the Soil Moisture Accounting method with past and forecasted rainfall data to generate flows in each sub-basin the basin,
- use the flows from HMS to simulate reservoir operations and generate outflows in ResSim,
- route these outflows in HMS without the use of hydrodynamic modeling in RAS, and
- at each forecast point choose the inundation map corresponding to the flow that best matches the modeled flow as the forecast of flood extent.

In this way an impact scenario can be chosen from the atlas of pre-run scenarios, allowing a fast forecast with minimal modeling during the event.

Much more detail on the modeling process is available in ANA Document 2.2, and will not be repeated here.

Recommendations

The general modeling approach is quite ingenious and resourceful given the limited data and resources available for this study. Nevertheless, there are some specific areas that may be improved in future studies. The method of pre-running scenarios to create an atlas of events is very smart, but the particular modeling methods chosen could be improved upon to further leverage the atlas approach. An “atlas of floods” strategy is frequently proposed when model run-times make them impractical for real-time use during an event. However, steady-state hydrodynamic models and bathtub-style inundation mapping do not normally take very long to run. As long as the scenarios are being generated in advance, more complex, time-consuming modeling techniques could be used to yield more accurate scenarios. Future studies could use unsteady hydrodynamic modeling in the river channels with two-dimensional models in the floodplains to create much more accurate inundation maps, with more cost and complexity invested in the study phase but no additional time or investment required during the event. It should be noted that such a modeling system would exceed the typical current USACE practice, which relies on models that are simple enough to run quickly during an event. However, in complex multidimensional situations such as hurricane storm surges or deltaic rivers, multidimensional unsteady models are becoming more common, with atlases used to make results available quickly. If ANA were to use such an approach in a future study, it would be more aligned with where USACE practice is moving than where it is now.

At several points in the design of the models, decisions were made in the interest of conservatism. Conservative assumptions are a sensible response to uncertainty, but they are more appropriate when actually running a model than when designing it. In fact, over-conservatism in model structure can require parameters to be correspondingly over-adjusted in calibration, leading to reduced accuracy overall. For example, the sea level chosen for the downstream boundary condition where the river meets the sea in the model corresponds to the highest observed level at that location from 2000 to 2003 (though this assumption will become less conservative over time due to sea-level rise). Similarly, the rain-reduction coefficient (used to correct for the fact that extreme rainfall of a given likelihood will not fall simultaneously over the entire basin) was based on the worst observed relationship between mean and instantaneous rainfall rate as a function of basin size. It is recommended that in future studies, best-guess (median) estimates for watershed conditions be used for initial model design and calibration. For example, a median sea level could be used as the downstream boundary during calibration, since this condition will more often match the observed calibration data. After model calibration is complete, conservative assumptions such as a high sea level can then be applied when assessing particular scenarios. This will help ensure that the model is as accurate as possible when it is used as a tool for managing risks and resources during a flood.

Accurate and updated inundation maps are critical to public communication of flood risk. There have been many instances in the United States where members of the public, lacking good information about their true risk of flooding, made preparation and evacuation decisions based on personal experience with previous floods. When this experience was not repeated in the next flood, tragic consequences resulted. The inundation maps generated by this study depict flood extent and depth, as well as maximum velocity, for the each modeled flood of a given return period. From these data, three life-safety categories were developed corresponding to increasingly dangerous combinations of depth and velocity. As a planning tool, such maps are useful indicators of dangerous areas, and represent an improvement over the sort of arbitrary buffer distance from the water's edge specified in the forestry code for permanent preservation areas. Still, they might not be as useful in a particular event as they appear. Since the hydraulic modeling was steady-state and one-dimensional, the depicted velocities correspond to the average velocity across the cross-section, not to the actual velocity at any given point on the map. To improve the accuracy of such maps in future studies, these velocities could be validated with observed velocity data, if available. This would help avoid false confidence, which could prevent people from evacuating, and avoid panicking them unnecessarily. Whether or not the maps are improved in future studies, care should be taken to communicate carefully what the map can and cannot show with confidence. In the past, USACE inundation maps that were intended for a specific purpose have been accidentally released to the public and interpreted in unintended ways, with negative impacts for emergency preparedness. It is recommended that instead of relying on these maps alone for life-safety decision-making, future studies use impact-referenced flood stages be determined for each forecast point based on interviews with local emergency managers, to allow forecasts to be made for the time when an emergency situation is predicted to occur. Examples of such flood stages are given in Figure 6.

The soil moisture accounting model of future short-term flows, to be used in forecasting during a real flood event, used a validation dataset to assess model performance that was distinct from the calibration dataset used to refine the model. In contrast, the models used to simulate extreme events and generate inundation maps were calibrated to represent with confidence only the reference scenarios shown in the maps, so they used these datasets for both calibration and validation. It is always preferable for models to use a separate dataset for validation from the one used for calibration, to avoid over fitted models that do not perform as well in real life as they appear based on calibration data. Of course, withholding calibration data to use for validation means less data is available for calibration, so this approach requires sufficient data to be available.

The short-term flow model assessed model performance by computing the Nash-Sutcliffe efficiency (NSE) and Root Mean Squared Error (RMSE) of the model output versus observed data. Instead of computing such metrics, the hydrological and hydraulic models used for simulating extreme events simply compared observed versus simulated discharge. Although the results were good, showing that the simulated flow varied in a range from 0.75 times to 1.2 times the observed flow, an accuracy metric such as NSE or RMSE would provide more information on model performance. It is recommended that future model studies give more detailed descriptions of model error with each predicted value, so decisions can be made at the appropriate level of confidence.

Despite their drawbacks, the use of pre-generated inundation maps has several advantages that should be highlighted. They are an excellent tool for general risk characterization, helping to inform emergency preparedness and response. They can also greatly assist with communication of risk to the public. Finally, they may help identify areas for further investigation of potential risk-reduction measures. ANA Document 2.2 makes an excellent point when it specifies that the precision of the inundation maps is limited by the use of ASTER images to create the underlying digital elevation model, and that the maps should be interpreted accordingly. This caveat should be emphasized whenever these maps are shared with partner agencies and the public.

3.8.4 Study of Dam Breaches

The dam breach portion of the study served to characterize the flooding that would be expected to result from a failure of any of the major dams in the Paraíba do Sul basin, in much the same way that the previous section investigated the flood impacts of extreme rainfall. Failures of individual dams due to overtopping or structural failure were simulated, as were cascade-effect breaches when the failure of an upstream dam would exceed the spillway capacity of a downstream dam, causing it to fail as well. In addition, failures of the tailings dams at the mines in the basin were simulated to predict their potential impacts on water quality. Tailings dam breaches were not assessed for their potential to cause cascade-effect breaches on downstream dams, due to their much smaller relative volumes compared to the downstream reservoirs.

Recommendations

Many of the same recommendations provided on the modeling process in general can also be applied to the modeling of dam breaches. One additional point concerns the assumptions made regarding the reaction of the regulators of downstream dams in a cascade breach scenario. The study assumed that the regulators would fully open all floodgates and other structures in the event of a dam failure upstream, doing all they could to save their dam. Although this is certainly what the regulators should do, it assumes they have immediate information about the failure upstream and are able to react quickly, which may not be the case in an emergency. A USACE study would probably make the more conservative assumption that there would be no change from normal operation. In this study, this assumption may not affect the findings significantly, since the only dam considered capable of causing a cascade breach was Paraibuna-Paraitinga, and its volume is so large that it overwhelms the volume of all downsteam dam breaches. For future studies, this assumption could be reinvestigated.

The assumption of the tailings functioning as a Newtonian fluid and the assumption that the dam breaches will progress linearly could also influence the results, though this is unknown. A sensitivity analysis could be performed in future studies to evaluate whether these assumptions should be investigated further.

The study itself also suggests increasing the density of topographic and survey data to facilitate multi-dimensional modeling, which is a strong recommendation.

3.8.5 Propagation of Pollutants

This section discusses the modeling of contaminant fate and transport, for pollutants such as untreated sewage that are discharged continuously into the waters of the basin, but also for heavy loads of pollutants that are discharged suddenly, as with a mine tailings dam failure or a traffic accident on one of the many roads that cross the region's rivers and reservoirs. This section also provides a wealth of useful information on the general state of water quality in the basin.

Recommendations

For purposes of model calibration, water quality parameters related to degradation of organic matter, such as biological oxygen demand and fecal coliforms, were chosen as the pollutants of interest. This was probably necessitated by the available water quality data at the streamgages within the watershed. In future studies, more accuracy could be gained by modeling a conservative pollutant such as a heavy metal first, before adding the additional complexity of a non-conservative pollutant that changes as it moves through the system. This would allow model development to progress in steps from a simpler situation to a more complex one, with errors addressed at each step before moving on.

Another topic to be considered and possibly modeled in future studies is sediment transport. If any of the important pollutants in the river system has a known tendency to sorb to sediment in the river, this could be an important process for transport of pollutants. Contaminated sediment is a major issue at several USACE project sites.

One best practice in this section that deserves emphasis is the use of nomograms (e.g. Figure 99 in ANA Document 2.2) for illustrating the effects of a chemical spill. These diagrams allow the pre-modeled scenarios of pollutant transport to be analyzed quickly and easily during a crisis, without requiring additional modeling.

3.8.6 Proposed hydrometeorological network for critical event monitoring

This section describes the network of streamgages, precipitation gages, and water quality gages that are proposed to support monitoring of critical events in the Paraíba do Sul basin. A total of 186 gages were identified; 122 combination stream and rain gage stations, along with eight rainfall-only gages and 56 water quality stations.

Recommendations

The proposed design of the network appears reasonable, with a gage density that is roughly comparable to a typical river basin in the United States. In fact, the amount of data that the plan proposes to collect and transmit telemetrically appears ambitious. For a co-located river, precipitation, and water quality gage, a total of nine parameters would be collected and transmitted. This could be more than the normal GOES[5] transmission window will allow, depending on how the data is coded for transmission. For example, one gage in the USACE New Orleans District sends 14 parameters in 6 seconds, within the standard ten-second window for GOES transmissions. However, this USACE gage transmits only the hourly data from the present and the previous hour, whereas ANA gages often transmit the previous three hours of 15-minute data. Sending this much data requires using pseudo-binary format, which makes monitoring and troubleshooting a little more troublesome than the more natural SHEFFIX[6] format. It is recommended that further investigations be made into the necessity of transmitting the previous three hours of 15-minute data each hour. It may also be more efficient to log some of these parameters for later collection rather than transmitting them telemetrically.

[5] Geostationary Operational Environmental Satellite, a satellite operated by NOAA and used by ANA for telemetric transmission of data from remote gages to a central database.
[6] SHEFFIX is a version of Standard Hydrometeorological Exchange Format (SHEF) data encoding where data are positioned into fixed spacing to improve display and readability.

3.8.7 SISPREC Computational Interface

This section describes the interface the operator uses when using the SISPREC system for flood forecasting, water quality simulation, or dam breach analysis. The interface is designed to be a simple and quick tool to allow the user to select the most appropriate pre-modeled scenario.

There are no technical review comments to provide on the computational interface, which appears to be well-designed and intuitive.

3.9 The SIEMEC Study

The SIEMEC (Sistema de Intervenções Estruturais para Mitigaçao dos Efeitos das Cheias) study assessed the various structural measures proposed for flood risk reduction in the Paraíba do Sul basin, resulting in a selected array of measures. Much of the data collection and modeling for this study overlapped with that performed for the SISPREC study. Typically, the tools and data required for analysis of structural measures and for flood forecasting would be different, since structural measures would be assessed across the entire range of flows, while a forecasting system would optimized for high flows only. In this case, however, the fact that these structural measures were specifically assessed for flood risk reduction only helped ensure the two would be reasonably similar. SIEMEC was divided into three smaller projects, assessing storage facilities, river channel modifications, and diversion facilities. The floods with return periods of 2, 10, 25, 50, and 100 years were chosen for analysis in this study.

3.9.1 SIEMEC Data Collection

In addition to the field surveys described in section 2.7, field studies were completed by civil defense teams within the municipal secretaries of the environment and sanitation to determine areas of flood risk, as well as sources of potential pollution. Digital photographs were taken and referenced to locations using GPS. Existing studies and local suggestions for flood risk reduction projects were also collected to help develop a preliminary array of alternative measures.

Recommendations

Knowing when the river will reach a stage with a known local impact makes a forecast much more valuable, compared to a forecast of flooded area alone. Future studies could direct the civil defense teams to collect information about impact-based flood stages while they are collecting data on areas of risk in each municipality. For example, teams could interview local officials on the impacts of various river stages, determining when critical infrastructure such as hospitals and shelters flood, as well as when roads accessing these facilities become impassable (see Figure 7 for an example). If time and funding allows, elevation data such as first-floor elevations for houses may be collected. Civil defense teams may also be able to collect basic data on the economic value of the areas they investigate, such as the average size of houses, number and type of vehicles, and type of economic activity in each area. These data would allow future studies to make estimates of the damages of floods, and therefore damages prevented by proposed measures.

3.9.2 Role of Tributaries in Flood Generation

This section provides a description of the sub-basins that contribute to flood flows in the Paraíba do Sul basin. It also provides some physiographical characteristics of each sub-basin, such as curve number, time of concentration, and form factor. Based on the extreme flows computed in the SISPREC study, the discharge and discharge per unit area for each sub-basin was computed. This allowed a qualitative ranking of each sub-basin in terms of its contribution to flow at each downstream point of interest for floods of each of the five return intervals of interest. Critical points for hydraulic modeling were also identified, including rapids, confluences, and bridges.

As this section is descriptive, there are no comments to provide. The computations of flow per unit area and the maps of relative contribution to flooding are interesting and could be discussed further in future study reports. Future studies could use the computations showing which sub-basins contribute the most to floods to indicate the most effective areas for structural intervention. These computations could also be useful in regionalization studies to relate these sub-basins to others where less data is available.

3.9.3 Characteristics of Floods and the Floodplain

This is another descriptive section, consisting of modeled flows and stages at points of interest in the basin. There are also vulnerability maps showing the extent of the three hazard categories determined in the SISPREC study and described in section 2.8.3. A comparison of flood stages for various return periods to critical stages such as the riverbank elevation or heights of bridges was also made.

There are no comments on this descriptive section. However, the information shown in Table 27 (elevations for roads and bridges along the river as compared to river stages) represents a simple sort of impact-referenced flood stage. This information could be used in future SISPREC-type studies to allow forecasting of specific flood impacts. Furthermore, if data such as the elevation of habitable floors inside of buildings is available, this may be added to tables such as Table 27 in future studies.

3.9.4 General Overview of SIEMEC

This section describes the steps that were undertaken during the SIEMEC study.

3.9.4.1 Potential Sites for Structures

Nine sites for potential dams were chosen for the initial array, of which three were new proposals commissioned for this study and six were pre-existing proposals from earlier studies. Floods with return periods of 25, 50, and 100 years were simulated at each dam using the procedure described in section 2.8.3. Peak inflows and outflows were compared, and four proposed dams were eliminated. Each of the rejected dams reduced the peak flow by less than 10% for the 100-year event, but the rejection was not based on a defined rule; it was a subjective decision based on the performance of these alternatives in consideration of the other available options. However, during the study, the state government of Minas Gerais began construction of one of the proposed dams, based on the recommendation of a previous study. Therefore, this dam was assumed complete and made part of the without-project condition, with one of the previously rejected dams added back to the list of alternatives under consideration. These remaining five dams were simulated in various combinations to determine their combined impact on a key urban area of interest in each sub-basin, resulting in a final group of four dam sites retained for further consideration.

Recommendations

A very large number of potential dam sites could theoretically be proposed for consideration, leading to an extremely large number of potential combinations, making it impossible to model all possible combinations. A strategic process was used to reduce these combinations to a more reasonable number. For future studies, the decision criterion used to eliminate the dams from the first array could be made clearer, for example by defining a required percentage reduction in peak flow or deciding that the best-performing four dams would be kept for further consideration. For example, USACE flood risk reduction studies select alternatives primarily on the basis of maximizing benefits and minimizing costs. If benefits do not exceed costs, there is no federal interest in the project. This selection criterion is certainly not perfect, but it is simple and relatively easy to communicate. It also allows a large number of initial ideas to be quickly reduced to a few finalists, because approximate, optimistic cost and benefit figures can be used to screen out any projects that clearly do not provide a positive return on investment. Although in this study the difference in performance between those that were rejected and those that were kept was fairly obvious, future studies could benefit from more detail on the decision criteria used. This could allow the process to be better understood so it can be replicated later.

3.9.4.2 Criteria for Evaluation of Alternatives

The SIEMEC study used a unique set of evaluation criteria for the various structural alternatives proposed for flood risk reduction. Eight alternative plans were evaluated, each consisting of a combination of dams, channel modifications, and diversion channels. The basic process began with consideration of the critical stage for each urban area, described in section 2.9.3. For the floods with return periods of 25, 50, and 100 years, structural measures (dams, channel modifications, and/or diversion channels) were designed to reduce peak flood stages at all downstream analysis points to these critical stages (i.e. to manage the flood of that return period). To estimate the cost of each alternative, two criteria were used: the monetary cost of design and construction, and the social and environmental impact, estimated through the proxies of flooded area (for dams and diversions) and relocated area (for channel modifications). Impact areas were computed as one minus the ratio of each alternative's affected area to the area of the most impactful alternative (in other words, the percentage reduction in impact area for each alternative as compared to the alternative with the most impact area). Flooded and relocated areas were combined using a weighted average, with relocation area given a weight of 90% and flooded area 10%. Finally, the alternative with the best combination of low impact and low cost was chosen as the best. After the best combination of measures was chosen, the individual features were sized to optimize cost versus impact.

Recommendations

The optimization procedure used in this study is very unusual from the USACE perspective, where evaluations are normally based on maximization of net benefits[7]. Instead, this study made a comparison of cost to impact area, which is a more subjective analysis as the two units are different. It is recommended that a cost-benefit analysis to USACE standards be used for future studies, alongside a life-safety risk analysis to ensure that such risk also tolerable. Cost-benefit analyses are not perfect, and particularly struggle in valuation of social and environmental impacts. However, a cost-benefit analysis would provide an arguably simpler comparison of alternatives as well as a clearer justification for the project, because the project that provides the greatest return on

[7] USACE flood risk reduction projects are typically assessed using a benefit-to-cost ratio. Benefits are the damages prevented by the project, as compared to the without-project condition. Statistical analyses and computer models are used to estimate how the project changes the frequency of flooding. This frequency change, combined with the economic value of the property in the protected area, defines the annual benefits. Costs include the monetary costs of property acquisition, construction, maintenance, and operations, though these costs are often shared with partners such as state governments. Other concerns such as life safety, environmental impacts, and regional economic development must also be considered. Much more information about flood risk reduction project planning is given in USACE Documents 2.3 and 2.5.

investment could be identified. There may also be some benefits provided by a project while it is still under construction, which could be important to understand and communicate to the public. Quantifying benefits for such an analysis would require economic data which is not presently available for the Paraíba do Sul basin. However, available resources such as satellite imagery, real estate web pages, and local interviews could allow some estimates to be collected at relatively low cost. Finally, it is worth recognizing that there are important cultural differences between the United States and Brazil, and it may be considered acceptable in Brazil for projects to be executed for social reasons even if the cost-benefit tradeoff is not ideal. If the optimization method used in this study is chosen again for future studies, the following suggestions may help improve the process for future studies.

The economic analysis considered the cost of design, permitting, and construction of each measure. When assessing costs, considering all life-cycle costs is a best practice, including the costs of operation and maintenance. In particular, the sedimentation mentioned in section 2.5 and demonstrated in Figure 1 (change in cross-section of the Paraibuna River) indicates that dredging may be required to maintain the conveyance of the proposed channel modifications and the storage of the reservoirs in the future. These costs should be considered when comparing alternatives in future studies, as they may determine which plan is most cost-effective over the life of the project.

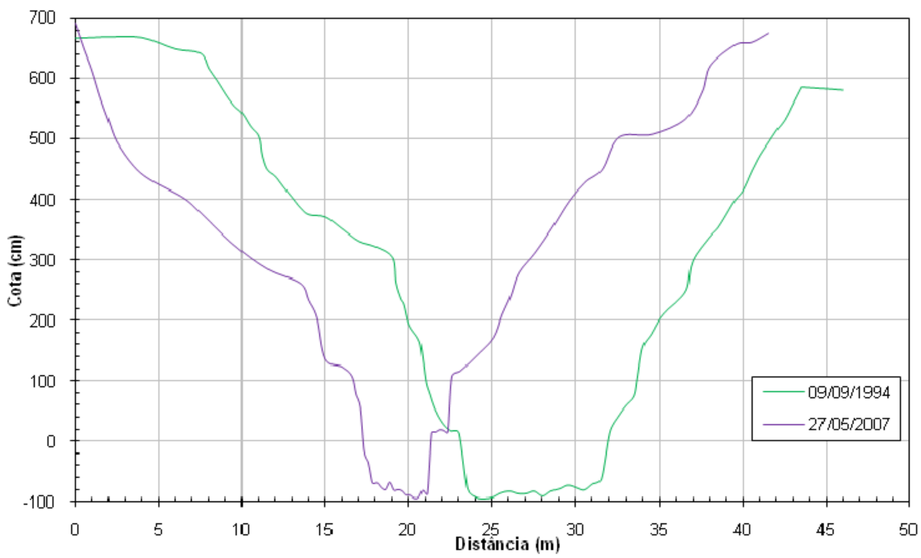

Figure 1 (Figure 45 in ANA Document 2.2), change in channel cross section over time at the Chapeau d'Uvas gage station. It is recommended that future studies include the cost of maintenance dredging when comparing the costs of proposed alternatives.

The conceptual designs of the proposed dams, used for cost estimation, utilized a spillway designed for the 1,000 year flood, with freeboard for the 10,000 year flood. Since these return periods are well beyond the period of record for the streamgage data that is normally available for a study, these flood magnitudes are extrapolations with significant uncertainty. Rather than computing these values using the best-guess (50% confidence) estimate, confidence bands as shown in Figure 2 may be computed for flow-frequency relationships in future studies, so decisions can be made at the appropriate level of confidence. For example, decisions involving life safety risks may be made at the 95% confidence level (the appropriate level of confidence will depend on the consequences of the decision and the risk tolerance of society). Since the SIEMEC study may be considered feasibility-level, such risk-based decision-making may be used when these dams are actually designed, as well as in future studies.

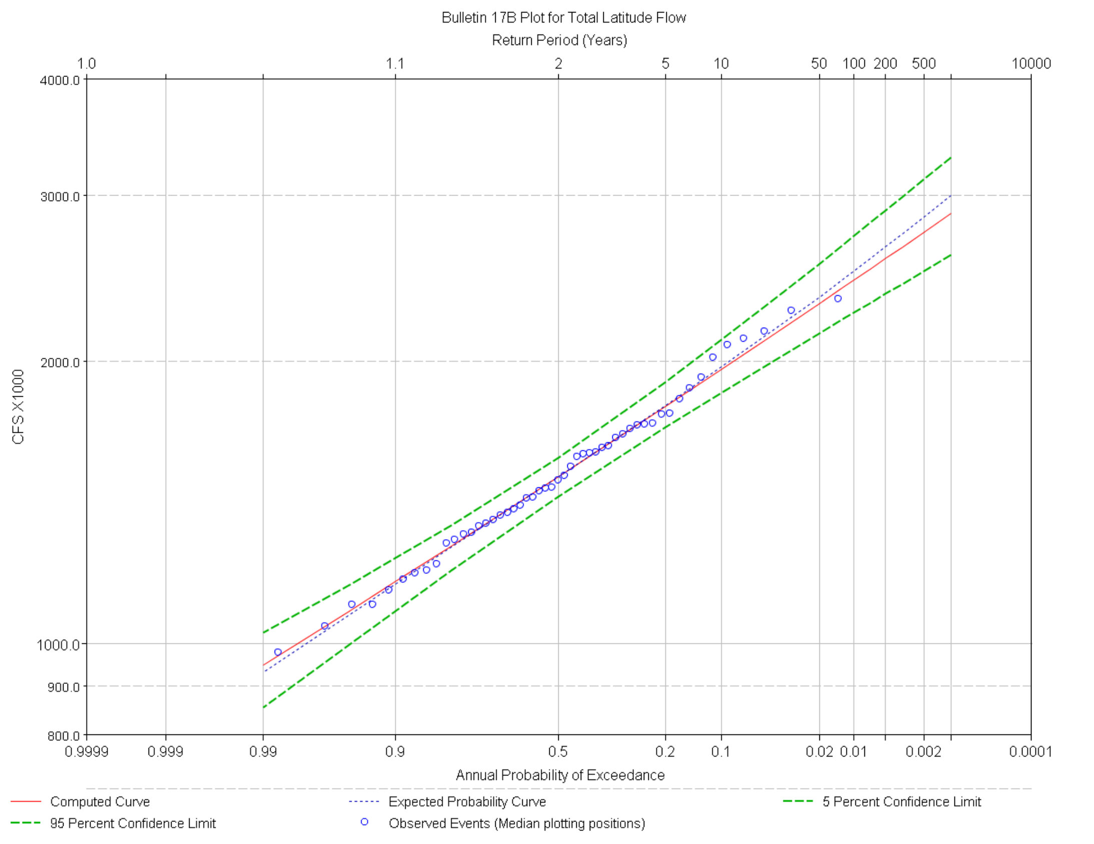

Figure 2, flow frequency curve for the Mississippi-Atchafalaya River system, showing confidence bands (green lines). There is a 90% chance that the true flow-frequency curve (red line) lies between these bands.

The design return periods of 25, 50, and 100 years were chosen based on a review of the relevant literature and the cumulative probability of system failure over the life of the project. The consideration of cumulative probability is wise, but it assumes that the marginal flood probability is unchanging throughout the project life. Given ANA's interest in climate change preparedness, it would be sensible for future studies to evaluate scenarios for climate-related changes in probability over the life of the project. Such scenarios could also illustrate the potential effects of uncertainty in the estimates of marginal flood probabilities. Future studies could project several potential future scenarios corresponding to different possible futures under climate change. USACE guidance for climate change adaptation to nonstationary riverine flood risk is currently being developed. While this guidance is under development, established guidance for sea level rise at coastal projects could serve as a model for how climate scenario analysis could be performed, though climate impacts on river flood frequency are more complex than a simple rise in sea level. Figure 3 demonstrates how USACE personnel would project future sea level scenarios for coastal projects; a similar projection could be used to show scenarios of river flood stages.

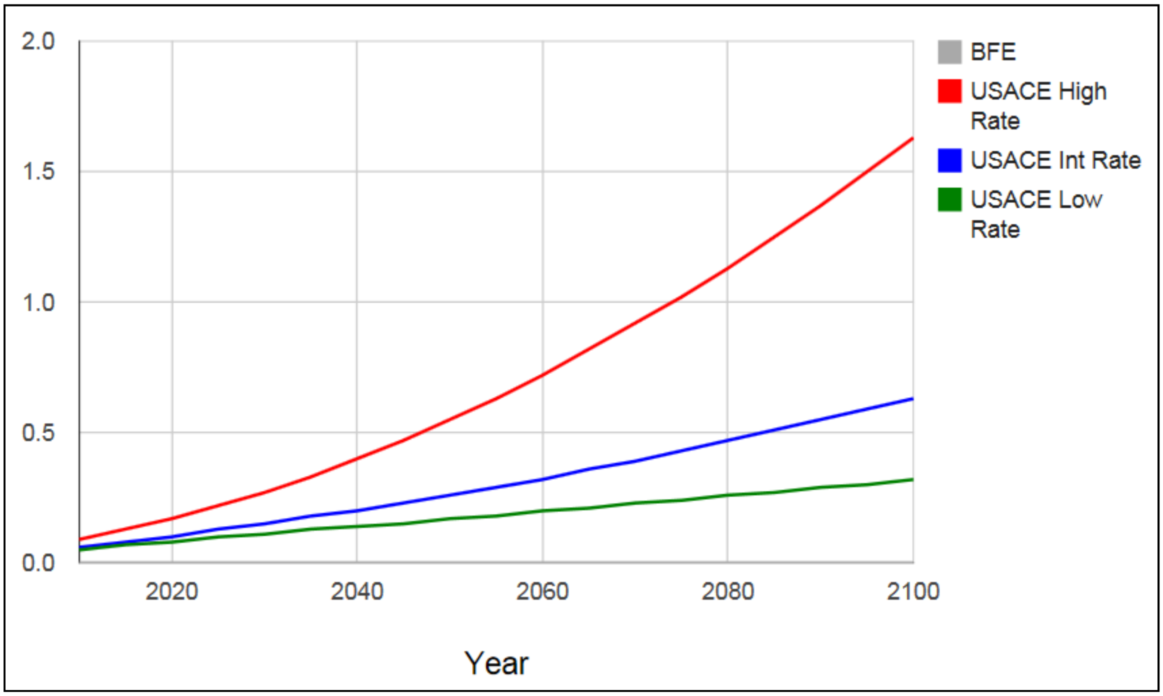

Figure 3 - Projected scenarios of future relative sea level rise at The Battery, NY, NY. Scenarios projected in accordance with USACE ETL 1100-2-1.

Clearly, a trend in sea level is a simpler situation than a changing flow frequency, since flow probabilities can change in multiple ways simultaneously, for example increasing the frequency of both floods and droughts. This makes adapting to such changes more complicated. Nevertheless, scenarios can be used to evaluate whether the selected design is robust to all reasonable futures, without adaptation. Future studies could use climate and flood scenarios in this way, based on available actionable science.

Cost and impact area were the metrics chosen for plan comparison. Future studies could use software such as HEC-FIA to assess the likely consequences of floods in terms of life safety, allowing this metric to be used as well for future plan selection. Alternatively, a simpler analysis could make use of the vulnerability maps that were already created in the SISPREC study, if the population density in each hazard zone could be determined. The study could then weight flooded area in terms of population at risk, helping optimize the design of each alternative. This would provide a bit more accuracy than assuming flooded area is a reasonable proxy for population at risk. Regardless of how the vulnerability of the population is estimated, all probable failure modes should be included when computing the probability of flooding for life safety purposes, rather than just the probability of overtopping. In other words, the probability of flooding is greater than the probability of the design event, because infrastructure can fail before the design event is reached. It is recommended that life safety studies recognize this so the true risk to the population is reflected in the results. For example, a geotechnical fragility curve describes the probability of a dam or levee failure as a function of the water level against it. Combining this curve with a flood-frequency analysis gives the probability of a dam or levee failure. These probabilities are a part of the overall flood risk, so they should be included in a life-safety analysis. Conversely, the failure of a dam or levee can actually reduce the flood risk in certain areas, so the overall risk of flooding in some areas may actually be less than what is computed assuming all infrastructure survives the flood. Consideration of this effect depends on the project purpose, since more accuracy in this case represents less conservatism.

Alternatives were formulated in terms of the residual risk of flooding (the return period of the flood that will overwhelm the system). This is a strong point of the study as it allows comprehensive flood risk planning in consideration of the effect of the structural measures (the remaining risk can be managed with insurance, evacuation plans, building codes, etc.). In contrast, some USACE projects are communicated in terms of risk reduced, a less easily understood measure. However, it is interesting that alternative groupings of measures were compared using a single return period, and then each measure was refined after its group was chosen for inclusion. Often, aggregation followed by disaggregation may lose information compared to assessing each possible size of each possible measure individually. The performance measures used for optimization (design return period, estimated implementation cost, and impacted areas) were already computed for the comparison of alternative groups, so in future studies it should be possible to compare all sizes of each alternative in a spreadsheet without aggregating first.

The study provided little explanation of the choice to weight area flooded by reservoirs at one-ninth the importance of area expropriated by channel modifications. Clearly, there is no perfect metric and some compromises and choices must be made when deciding how to compare plans. In future studies, more justification and explanation of this decision could be added to help stakeholders understand how their risks are being managed and compared, because the optimization formula chosen may have a large influence on the alternatives that are selected.

The criteria used for optimization of designs compared performance to the standard of the 1% annual chance exceedance event. Depending on the consequences of non-performance, there may be situations that call for different levels of performance. Future studies could investigate the consequences of flooding in order to optimize and justify the desired level of residual flood risk. For example, because USACE studies are based on the concept of maximizing the benefit/cost ratio, in this framework the return period of the design event results from the analysis and does not have to be determined in advance.

Future studies may benefit from consideration of a more extreme event, such as the 500-year event. Inclusion of an event larger than the design event can give insight into the consequences should be system be overwhelmed, which can be helpful for total risk assessment. It may also help differentiate between alternative plans that appear to perform similarly in a smaller flood. Of course the magnitude of such a large flood will be highly uncertain, and should be assessed in consideration of that uncertainty.

The structural alternatives considered included dams, channel modifications, and diversions, but storage areas were not identified as a possible solution. A storage area is an area that is authorized to flood before other areas, and is frequently managed during non-flood times as a park or an agricultural area. It may be imagined as an off-channel reservoir or as a diversion with a single entry and exit; by receiving water at the peak of a flood and releasing it slowly after the flood has passed, the additional storage lowers peak flood stages. Details about the four large storage areas (also known as backwater areas) that form a critical part of the Mississippi River and Tributaries Project can be found in Mississippi River Commission (2008). Authorized storage areas can be a useful tool for flood risk reduction for consideration in future studies.

Section 9.4 concludes with a very interesting and astute critique of levees (called "lateral dikes" in the report) as a structural alternative, stating that they induce flood risk by creating a sense of complacency in the population and then breaching quickly when overtopped, flooding areas too quickly to allow evacuation. On the basis of this critique, levees were eliminated from consideration as alternatives in this study. While the essence of the criticism is true, it is not reflective of how a levee system should function within a comprehensive risk-management system. Levees function well at stages below the design stage, but when a flood is forecasted that could overtop the levees, the population should be evacuated before the flood arrives. Furthermore, temporary measures such as sandbags can be used to fight floods if needed, and levees should be designed to be resilient to a certain amount of overtopping, so they do not fail catastrophically even when they cannot fully perform. Levees may also be combined with storage areas to ensure that loss of life and property damage is minimized in the event of overtopping or failure. Finally, the same criticisms about complacency and insufficient evacuation time could be made for dams, though all the proposed dams in this study were found to be justified. Levees are a useful tool in certain situations and could be considered in future studies. They serve in a similar way to channel modifications in that they do not affect flow rates, but simply prevent water from entering the populated area. Under appropriate conditions they can have lower life-cycle cost than channel modifications because they may not create as much of a need for maintenance dredging, though they do require frequent inspection, much like a dam. More information about levees and their use in flood risk management can be found in the International Levee Handbook (CIRIA 2013).

3.9.5 Directives for Implementation of Proposed Interventions

This section describes the process for implementing the structural measures that were selected in the previous section. As this section describes the process for contracting the construction of these measures, there are no technical comments to provide here. It may be worth emphasizing here that early coordination with stakeholders, such as environmental regulatory agencies, is always a best practice. In fact, this coordination should generally begin before the feasibility level analysis described in the previous section.

3.10 Monitoring Systems

Section 10 gives a brief description of the monitoring system in place in the Paraíba do Sul basin, in terms of hydrometeorological monitoring as well as reservoir status. This monitoring is distinct from the flood forecasting system developed in the SISPREC study. ANA provides both written bulletins and online information, and also supports the three basin states in improving their hydrometeorological networks and situation rooms.

Recommendations

During a critical event, ANA may have capacity, in the form of people or equipment, which might be deployed rapidly to the states where it is needed. Formalizing a system to get assistance to the states during or just before an event could improve flood risk management effectiveness at a lower overall cost than maintaining a large standing capacity in every state at all times. It is recommended that ANA investigate deploying its own personnel and/or incentivizing other states (where floods are not occurring) to send their experts to affected states to assist with flood management during or after a disaster, within its legal competencies. In addition to getting assistance where it is needed, such a system would serve as useful cross-training and could help strengthen working relationships between spheres of government.

4.0 CONCLUSIONS

The main elements of ANA Document 2.2 are summarized below.

Flood control plan. ANA Document 2.2 is not a flood control plan *per se*, because it does not specify the actions to take to manage floods. Nor is it a flood risk management plan, because it does not give a comprehensive plan for assessing, reducing, sharing and communicating flood risk. Instead, it gives background information on the flood risks facing the Paraíba do Sul basin and describes two studies on aspects of flood risk management in this basin. These studies describe systems for flood forecasting and proposed structural measures for risk reduction. Along with eight other documents to be produced as part of Task 2, these studies may be used to formulate a comprehensive flood risk management plan for the basin, which may in turn become part of a basin plan for integrated water resources management.

Flood risks and opportunities facing the Paraíba do Sul basin. The Paraíba do Sul basin faces serious flood risk management challenges, particularly on the tributary basins that presently have less water management infrastructure than the main river. The basin also has significant opportunities to improve risk management to support of development and environmental protection. The basin is home to a large population and a large economy, with robust activity in the industrial, agricultural, and mining sectors, as well as significant hydropower development. These activities are all significant users of water and can have serious environmental impacts. However, when managed well they can allow for strong and sustainable development. The combination of a large population and a relatively developed economy, in addition to the reliance of metropolitan Rio de Janeiro on the waters of the Paraíba, means that there is both interest and resources available for wise management of the basin's risks and resources.

Interagency water resource management across levels of government. Water resource management in the Paraíba do Sul basin, as in all of Brazil, is a shared endeavor requiring cooperation across all levels of government. The SINGREH system helps facilitate this cooperation, ensuring water is managed across state lines on a watershed basis. The CEIVAP river basin committee designs the management plan for the Paraíba do Sul basin in consultation with relevant stakeholders, while the states maintain committees for the tributary basins that lie entirely within their borders. The AGEVAP executive agency carries out the policies defined by CEIVAP, including plans for flood risk management.

Separate studies, with strategic overlaps. Flood risk management in the Paraíba do Sul basin has been advanced through two separate but related studies, the SISPREC and SIEMEC. These studies have different objectives (flood forecasting and flood risk reduction, respectively) but have significant overlaps in their tools and techniques.

Wisely, these commonalities were identified in advance of the project, so that resources could be used strategically to support both efforts.

The SISPREC study for forecasting floods. The SISPREC study resulted in a flood-forecasting system based on an atlas of pre-modeled extreme events, allowing the emergency manager to choose the most appropriate event from the atlas during a flood. This approach requires minimal actual modeling during a flood, minimizing the time, complexity, resources, and expertise needed during a crisis. It is an ingenious design given the governmental structure in place for water resource management in Brazil, in which the federal government uses its resources and expertise to facilitate the states in managing their own crises as much as possible. Because SISPREC used pre-run event scenarios, it also created inundation and hazard maps for these events. These maps are useful in an event but are also helpful for risk characterization and communication generally. Hazard maps were created for both river floods due to extreme rainfall and for dam-breach scenarios. This basin does not experience snowfall, and ANA's mission does not include coastal events or urban stormwater, so these are the only flood-generation mechanisms to study in this area. SISPREC also studied scenarios of water pollution resulting from tailings dam failures or traffic accidents along the roads crossing the region's rivers and reservoirs. These events were summarized in nomograms showing the pollutant concentration at selected downstream points after a given time interval, based on the initial mass of pollutant and the point of introduction. Finally, the SISPREC study resulted in a wealth of population, geographic, meteorological, hydrologic, economic, and water quality background information, which is summarized in ANA Document 2.2.

The SIEMEC study for structural flood risk reduction measures. The SIEMEC study resulted in the selection of a portfolio of structural measures for flood risk reduction in the Paraíba do Sul basin. In contrast to USACE policy of project planning on the basis of maximizing net economic benefits, the SIEMEC study selected projects based on optimizing cost versus impacted area, for a fixed level of performance. Using many of the same models as the SISPREC study, SIEMEC evaluated several conceptual designs for flood control dams, channel modifications, and diversion channels. It ultimately resulted in a determination that four dams and several channel modifications were justified, and then optimized the performance levels of those dams and modifications.

5.0 BEST PRACTICES IDENTIFIED

ANA Document 2.2 demonstrated several excellent flood risk management practices that deserve recognition. Other agencies, including USACE, may learn from these practices.

The watershed as an organizational unit. As a matter of policy, the designation of the watershed as the territorial unit for water resource management is very sensible, as it tends to facilitate integrated management of resources and risks. The system of river basin committees, with stakeholder participation and funding from water usage fees charged within the basin, ensures both involvement on the part of the basin residents and industries (because they have a forum to voice their demands) and accountability on the part of the water resource managers (because they depend on the stakeholders for their funding). Because the executive agency that is required to accomplish the committee's policies requires funding, this system also naturally self-regulates: large basins can have extensive policies and programs for improvement while smaller basins have more modest goals, or no committee at all if one is not needed.

Strategic project management business plan, leveraging overlaps between studies. The SISPREC and SIEMEC studies exhibited a highly strategic business plan, leveraging their commonalities to use many of the same models and tools in both studies. USACE personnel would be wise to coordinate across projects in this way when planning projects and studies. It is possible that compromising the design of each study to make it more compatible with the needs of the other could have had some influence on the accuracy of the results. Nevertheless, given the limited resources available for data collection and model development, it is likely that significantly more overall capability was achieved using this strategy, compared to designing and executing each project independently. Furthermore, data collection was carried out in a strategic, prioritized way, with an initial field campaign design narrowed down based on cost. This allowed limited resources to be used where they would do the most good.

Using an atlas of floods to reduce modeling during a crisis. The SISPREC flood forecasting system is based on an atlas of pre-simulated events, allowing forecasts to be produced during a crisis with minimal time, effort, computational resources, and expertise. USACE personnel have used a similar design for modeling of hurricane storm surges, which typically require significant high-performance computing power to simulate, but such practice is rare for forecasting of river floods. Particularly for complex, multidimensional situations such as dam breaks and contaminant fate and transport, this design should be considered more often. Furthermore, ANA Document 2.2 demonstrates deep understanding of the limitations of this approach, though these limitations must be carefully communicated to the end-users and the public.

Formulating in terms of residual risk. The SIEMEC study formulated alternatives in terms of design floods of given return periods. In other words, the selected structural alternatives serve to reduce residual flood risk at any given point to a known level. This is preferable to formulating based on risk reduced or on economic benefits alone (without computing residual risk) because it allows the measures to serve as part of a comprehensive flood risk management plan. When the amount of residual risk facing a community is known, further structural and nonstructural measures can be designed to manage this residual risk.

Awareness of the drawbacks with structural measures. The SIEMEC study also contains a very astute critique of levees, which may be applied to many kinds of structural measures. As the study points out, these measures tend to reduce the population's awareness of the risks they face, stimulate development, raise water levels, and fail catastrophically. As a result, they may actually increase overall risk if not managed and maintained properly. Many agencies would be wise to keep these caveats in mind when considering structural measures of all kinds.

6.0 RECOMMENDATIONS FOR FUTURE STUDIES SUPPORTING DEVELOPMENT OF FLOOD RISK MANAGEMENT PLANS

Examining ANA Document 2.2 as a case study for Brazilian flood risk management broadly, several areas for potential future improvement appear. These recommendations are not simply a proposal that ANA emulate USACE in every way. They are based in the USACE perspective on flood risk management, but in consideration of the unique realities facing ANA. Furthermore, they may not represent the state of USACE practice at this time. Rather, these are areas where ANA may focus its efforts in attempting to manage flood risk better. Some of these may be areas for improvement at all agencies.

Comprehensive risk management policy including acceptable levels of risk. The SISPREC and SIEMEC studies take steps to reduce flood risk in accordance with the planning performed by the river basin committee. It is important that a comprehensive plan for risk management also includes measures such as education, evacuation planning, insurance, etc., which work together to reduce flood risk to a specified, societally tolerable level. In order to construct a portfolio of measures to reduce flood risk in a given area, there must first be a clear understanding of what the target risk level is. “Beginning with the end in mind” allows a project to progress with clear goals and milestones, maximizing resources and effort on achieving the task at hand.

The optimization formula used to size the selected measures in the SIEMEC study rewards designs for reducing the probability of flooding toward 1% per year. Depending on the consequences of project non-performance, there may be situations that call for a different level of residual flood risk. Brazilian regulatory policy could define a framework for determining how a tolerable level of risk should be chosen for a particular area and why this level is justifiable. It is recommended that this policy consider both life safety and economic impact when defining acceptable risk levels. Levels of tolerable risk may vary depending on population density, type of economic activity, or other factors or they may be consistent across the nation, depending on the preferences of Brazilian society. While technical analysis can support policy development, ultimately the decision of how much risk is acceptable and how much is excessive should be developed with meaningful public engagement and participation. A policy that reflects the wishes of the people and was developed with their input will also be helpful when communicating residual risk to the public.

As an example of how such a policy could be formulated, the USACE dam safety program uses an f-N plot to delineate the boundary between acceptable versus unacceptable levels of risk. Engineering Regulation (ER) 1110-2-1156 (“Safety of Dams

– Policy and Procedures”) establishes the guidelines for acceptable levels of risk of life loss at new and existing USACE dams, illustrated in Figure 4.

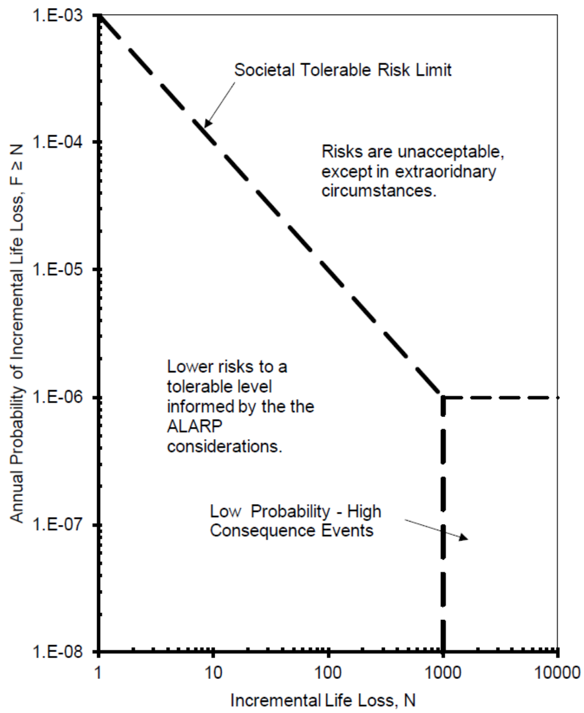

Figure 4 (Figure 5.3.b of ER 1110-2-1156) acceptable levels of risk of life loss at USACE dams.

The slope and intercept of the line shown in Figure 4 defines the boundary of acceptable risk, in this case the risk of life loss at USACE dams. With the number of lives lost on the x-axis and the corresponding probability of loss of life on the y-axis, the region above the dashed lines indicates a region of unacceptably high risk. Below the diagonal line, risk is acceptable but can be reduced further to the extent that is reasonably possible. The rectangular area in the lower-right of the figure corresponds to events with a low probability of occurrence (less than one event expected per million years) but high consequences (greater than one thousand lives lost). A detailed analysis of failure modes and consequences is required before a decision can be reached on acceptability in this region.

When an f-N curve is plotted for a flood risk management project, it takes a concave-down shape as shown in Figure 5. This figure contains f-N curves for 52 dike rings in the Netherlands, as well as the cumulative risk curve for all projects (the heavy red line). When plotted with the line in Figure 4, the f-N curve for a USACE dam must not cross into the unacceptable region. Although this framework is taken from USACE dam safety policy, it may serve as a model for defining acceptable flood risk levels in general. The USACE boundary has a 1-to-1 slope and intersects the single-fatality line at a probability of 0.001. However, the risk tolerance of Brazilian society may dictate that the boundary between acceptable and unacceptable risk in Brazil have a different slope and intercept than the line used for USACE dam safety. These specific parameters could be defined through public engagement and involvement. Another, similar curve could be used to define acceptable risk for non-life safety considerations, such as economic loss. While this report cannot specify what level of risk is appropriate for Brazil, it is recommended that ANA take steps to define these levels. This clarity will facilitate focused, comprehensive flood risk management using combinations of structural and non-structural approaches.

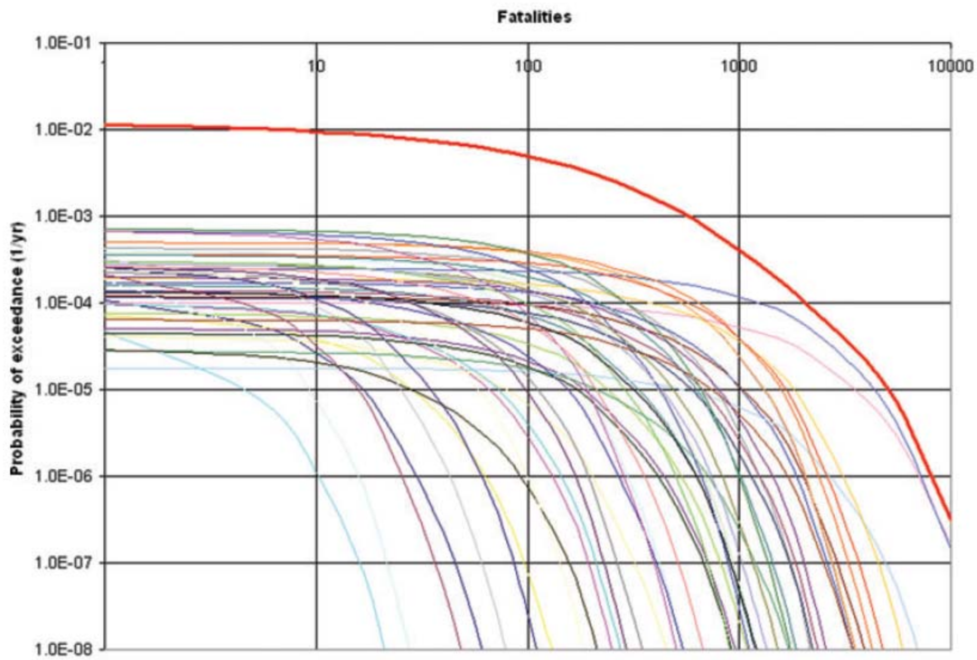

Figure 5 - f-N curves for 52 dike-ring systems in the Netherlands (Fig 6 from Jonkman et al 2011)

Statements of uncertainty. Ideally, every estimate should include both a most-likely value and a measure of uncertainty, but statements of the uncertainty of computed values used in the SISPREC and SIEMEC studies could not be found in ANA Document 2.2. Exceedance probabilities, flow forecasts, inundation maps, water quality indicators and other data are all presented as deterministic values in the SISPREC and SIMEC studies. By adding statements of uncertainty to these values in future studies, the true nature of these estimates can be understood and used at the level of precision that they merit. Confidence intervals are a useful tool for future studies to show the uncertainty around expected values, so these values can be used with confidence. USACE studies will typically use the 90% or 95% confidence intervals around a curve of expected values, though the 80% interval is sometimes used, depending on the application. This is preferable to using the expected value alone, because when no confidence interval is used, there is a one-in-two chance that the estimated value is too low (or too high).

Defined levels of reliability. Structural measures could have a required level of reliability defining the acceptable probability of failure. This helps to characterize the true flood risk to the project area. Monitoring this probability for compliance purposes will also define the most likely failure modes, helping focus maintenance funds and activities on the most critical areas. While this is not yet a common practice within USACE, our partners in the Netherlands use defined levels of reliability, availability and maintainability (RAM) to guide operations and maintenance at their storm surge barriers. For example, the Maeslant Barrier which protects Rotterdam from storm surge has a maximum allowable probability of failure of 1/100. With the target defined, operation and maintenance of this barrier can be focused on maintaining this level of reliability. Periodic inspections also update the probability of failure as conditions change and new information is found. Future studies in Brazil may similarly define the maximum allowable probability of failure for dams, diversions, and other structural measures. This will help focus maintenance actions and convey the true flood risk to the protected area.

Clear and consistent use of geodetic datums. The SISPREC and SIEMEC studies combined multiple sources of survey data when constructing their models and inundation maps, but ANA Document 2.2 did not discuss how these data were transformed into a consistent reference plane. USACE projects have experienced serious problems when survey data were not used appropriately, resulting in inaccurate or inconsistent project elevations. To avoid such problems, ANA could define a policy defining the datums that must be used in surveying for flood risk management projects. Independent of this policy development, however, future documents could make the use of survey datums in studies clearer.

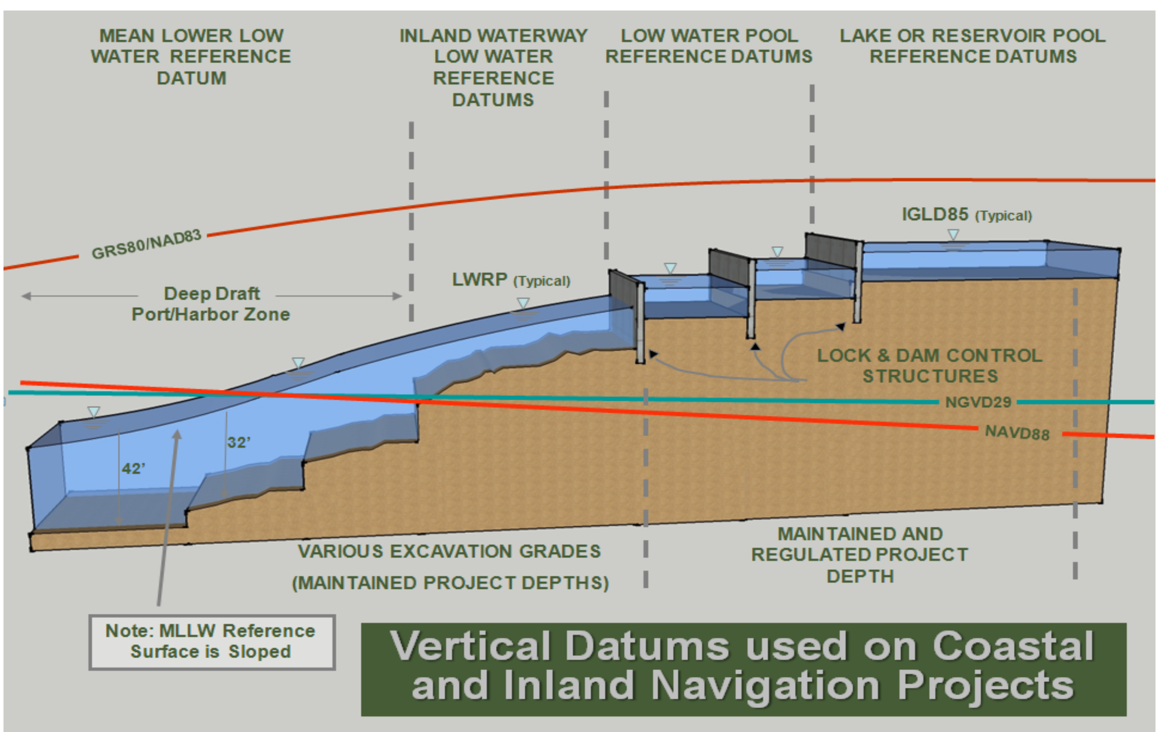

Figure 6 – Example of the numerous different datums used in USACE projects. Although this figure shows

datums for navigation projects, many of the same datums are used for flood risk reduction projects as well. Consistent use of datums is essential for survey data to be used accurately.

Cost-benefit analyses for project planning. The SIEMEC study compared structural alternatives on the basis of cost versus impacted area. Because cost and area use different units, it is difficult to determine which option or options best maximizes benefits versus cost. The study addressed this issue by using a Pareto optimization to determine the Pareto-efficient alternatives. While this analysis identifies those alternatives that lie along the Pareto frontier defining efficiency, it remains difficult to choose between several efficient alternatives. USACE studies use cost-benefit analyses in monetary terms, but other measures could be used instead, so long as the units being compared are the same. If a monetary cost-benefit analysis is to be performed in a future study, economic data will be required which are not presently available for the Paraíba do Sul basin. It may be possible to collect rough estimates for these data at relatively low cost. Satellite images, real estate companies (and their websites), census data, property tax/assessment data, expert opinion elicitation, and interviews (phone or in person) with local authorities could all be relatively inexpensive sources of economic data for computation of flood damages prevented.

Consideration of non-structural measures. The SIEMEC study considered dams, channel modifications, and diversion structures as alternatives for risk reduction (and diversion structures were only evaluated as a least-preferred option, being assumed to require such serious environmental impact as to necessarily provide less benefit per unit cost than the other two alternative types). Other structural measures such as authorized storage areas (see Mississippi River Commission 2008), levees (see CIRIA 2013), and floodwalls (see CIRIA 2013) could also be considered in future studies. More importantly, non-structural measures should be considered in future studies as part of a portfolio of measures for managing risk. These may include buy-outs or relocations of properties in vulnerable areas, elevation of buildings and other infrastructure, evacuation plans and routes, and insurance and related financial instruments. Measures to increase the resilience, or the ability of a community to recover from floods, may also be considered. In some cases, non-structural solutions may provide risk reduction for much less financial or environmental cost than structural solutions. However, because non-structural solutions reduce the impacts of floods without affecting their frequency, residents still have to endure the nuisance of floodwaters. As a result, these solutions tend to face more local opposition than structural solutions. To encourage their consideration in the face of this opposition and prevent them from being eliminated from consideration for political rather than technical reasons, it could be made a matter of policy that non-structural solutions must be considered in all flood risk management studies.

Development of impact-based flood stages. The SISPREC study allows inundation maps to be selected during a flood based on forecasted flows, but does not relate these flows or maps to local flood stages of interest. Future studies could determine the flood stages that will impact local areas, so the timing and duration of these impacts can be forecasted as well. In some cases these data may already exist: for example, Table 27 in ANA Document 2.2 contains some stage-impact data that were assembled in some areas for the SIEMEC study. In other cases, there may be opportunities to collect these data in conjunction with other activities, as when civil defense teams visited municipalities to determine their areas of vulnerability (section 9.1.1). Figure 6 gives an example of impact-based flood stages for the Red River at Alexandria, LA, developed by the National Weather Service. These show what the effects are for each listed river stage, making stage forecasts easier to understand and use.

45.23	The river is at its flood of record. Catastrophic flood damage will occur.
44	Approximate top of levees in Alexandria. Water reaches low point of steel on us 167 bridge. Widespread major river and backwater flooding occurs.
40	Extensive backwater flooding occurs near the confluence of the Cane River.
37.5	Water reaches top of the rails of the Texas and Pacific railroad bridge at Boyce. Considerable backwater flooding will occur.
35	Considerable overflow below Alexandria to the confluence with the Black River occurs. Backwater flooding begins along inflow bayous.
32	Flooding of lowland areas near the river occurs and recreational boating is affected.
28	Overflow occurs on floodway side of levee from gauge to Acme. Recreational boaters should use extreme caution due to high river flows.

Figure 7 - Example of impact-based flood stages developed by the US National Weather Service.

There are other ways to improve the study methodology for future use. The study used unsteady flow simulation to verify the roughness coefficient, but steady flow modeling was used to generate water surface profiles in the interest of conservatism. To improve the accuracy of the modeled scenarios, unsteady hydrodynamic models could be used in the river channels, and two-dimensional models used in the floodplains. These methods will require more modeling capability and longer model run-times to develop than the maps created in this case, but will be just as simple to reference in an event, thereby putting more capability into the hands of the emergency manager during a flood. Simple statistical models such as artificial neural networks or binary regression trees could also be used to provide more capability than an atlas, particularly when inundation is a function of more than one variable. These “meta models” are trained on the inputs and outputs of the hydrodynamic models and can often provide nearly comparable results in much less time than the full models.

Early engagement with stakeholders and partners. The process for design and construction of structural measures outlined in the studies includes coordination with environmental regulatory agencies after the measures have been planned. USACE project planners have found that engaging with these agencies, and all relevant stakeholders, as early as possible will minimize the potential for wasted time and effort.

Engaging early with stakeholders is particularly important for an agency like ANA, which operates in a facilitative manner rather than performing its own design and construction. States, which depend on the federal government for funding, and River Basin Committees, which receive relatively limited funding from usage fees, would also benefit from this increased efficiency. ANA could work to strengthen relationships within and across spheres of government by hosting trainings, meetings, and conferences, effecting knowledge transfer while also improving the personal and professional relationships that are critical when managing a crisis such as a flood. Strong partnership with the states as well as with other federal agencies such as CENAD, CEMADEN, CPRM, the military and the civil defense, among others, will be a key to managing flood risk for the people of Brazil in a cooperative and comprehensive way.

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