US Army Corps

of Engineers ®

Tulsa District

APPENDIX A: Engineering

Tulsa and West-Tulsa Levee Feasibility Study

August 2019

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1.1 General

The Tulsa and West-Tulsa (TWT) Levees System is located in northeast Oklahoma within the boundaries of Tulsa County. The TWT levees system extends from the City of Sand Springs downstream along the Arkansas River into the City of Tulsa. Levees A and B are on the left bank of the Arkansas River looking downstream and extend from river mile (RM) 531.1 to RM 524.1and Levee C spans from RM 526.7 to RM 521.3 on the right bank of the river.

The purpose of the study is to investigate the feasibility of improving the resiliency of the existing TWT levees system by reducing risk to life and damages to property within portions of Tulsa County and the City of Tulsa behind the levee system. Any catastrophic failure could pose significant public health and environmental concern. This failure mode is no “better or worse” than overtopping with breach in terms of possible life loss, property damage, and environmental consequences.

The following engineering designs were prepared to address issues with seepage and overtopping during flood events that load the levee system. Maintenance can easily be performed for each of the designs presented.

Figure A-1 below provides the reader the location of the existing structures located within the project area. The potential exist for each to be impacted with the proposed designs and will be discussed later in this appendix.

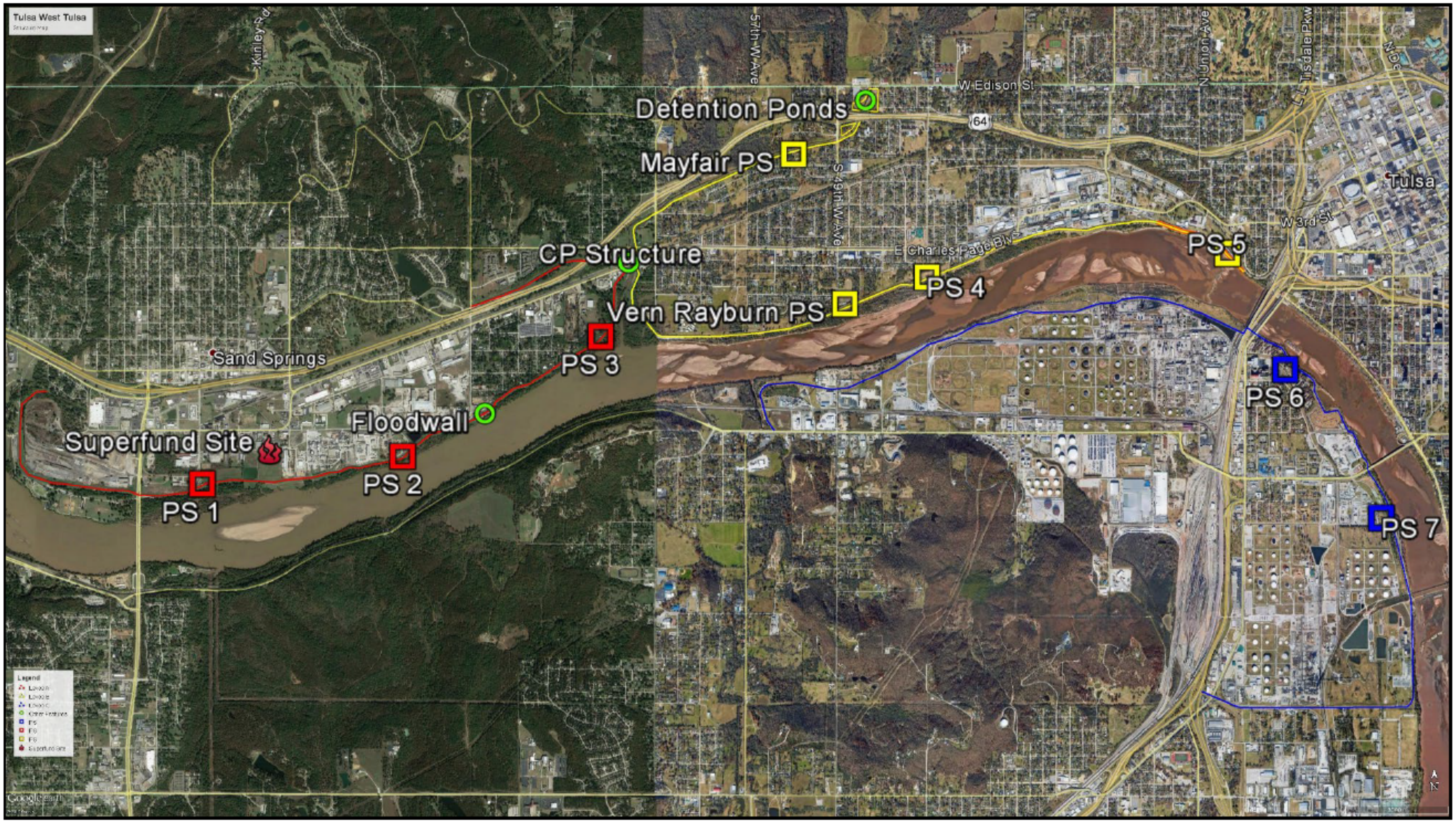

Figure A-1: Tulsa West Tulsa Structure Map

1.2 Hydrology and Hydraulics (H&H)

The complete H&H analysis is covered in Appendix B of this report and will provide a full explanation of the modeling that was performed. Change in climate is not expected to significantly alter the hydrologic analysis for the region and as a result was not specifically modeled for in the project. No climate change impacts have been included in the study.

1.3 Surveying, Mapping and Other Geospatial Data Requirements

Where available, Light Detection and Ranging method (LIDAR) data will be used in the preparation of the designs described in this section. LIDAR data is available for each levee segment. The existing LIDAR topographic data was collected in 2018 and used the horizontal datum of NAD83 and vertical datum of NAVD88. During the Preconstruction, Engineering and Design (PED) phase, this data will be utilized to develop the formal plans and specifications for construction.

The available LIDAR data will be used within the Bentley MicroStation INROADS software program to create 3D surface models of the proposed structures. The 3D surface and structure models will then be used to develop quantities used in the preparation of the cost estimates. These surfaces can create contour data as a byproduct of the computation process but contours are not needed to create quantities.

The estimated quantities were developed after reviewing the as-built drawings, other historical documents, and then using a typical cross section over a set length with no variation or change to that cross section. The data used provided a realistic basis for the quantities used in the cost estimates. Consideration was given in those areas where encroachments and other constraints were encountered.

1.4 Semi-Quantitative Risk Assessment (SQRA)

1.4.1 2016 SQRA

A Semi-Quantitative Risk Assessment (SQRA) was completed for the TWT levees in 2016. This higher-level risk assessment provided a thorough analysis of the levee system identifying potential failure modes and the resulting life loss and economic consequences. The results of the assessment assigned a risk category of Very High to Levees A and B and a risk category of High to Levee C.

This risk characterization is based on two factors, likelihood of levee failure and the associated life loss expected. The likelihood of levee failure from overtopping leading to breach as well as internal erosion leading to breach was determined to be Very High. The life loss estimates associated with a levee breach were also determined to be Very High.

The primary driver for the high likelihood of failure on the TWT system is found in the high annual chance of exceedance in any given year (ACE). The SQRA H&H analyses determined that the corresponding overtopping ACE along the Arkansas River is 1/230 for Levees A and B and 1/240 for Levee C. In terms of risk, these overtopping frequencies are in the Very High risk category.

The flow rates along the Arkansas River for these events are 334,000 cubic feet per second (cfs) for Levees A and B and 347,000 cfs for Levee C. This is a reduction in capacity from the original 1940s design, which determined the levees could pass 400,000 cfs with 1-foot of freeboard.

Other factors contributing to the high likelihood of levee failure include the potential for internal erosion. The earthen levees were constructed with the nearest materials available along the riverbank, which is primarily comprised of sandy silt. These materials are considered highly erodible. Approximately 340 conduit penetrations pass through the levee embankment throughout the levee system. It is likely that some are in poor condition due to age, thus increasing the risk of internal erosion of the levee embankment around/into the conduit.

The levees were found to have a history of poor performance. During the 1984 record rainfall event in Tulsa, Bigheart and Harlow Creeks overtopped the tieback levees causing extensive erosion damage and foundation failure of floodwalls at the Floodway Structure.

In 1986, the flood of record on the Arkansas River loaded levees to about 80 percent of their total height and a breach because of internal erosion. It took exhaustive and heroic flood fighting efforts to barely contain the flood waters. Significant repairs were made after both events but concerns remain with aging culverts, plugged toe drains and relief wells, and antiquated pumping stations.

The SQRA recommended a feasibility study on the TWT levees to address deficiencies and significant data gaps identified by the risk assessment. All potential failure modes (PFMs) are shown in Figure A-2 and Figure A-3.

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

PFM	Description
1	Overtopping of Mainstem Levee Embankment
11B	Floodway Headwall Foundation Failure
12B	CLE along wingwall/embankment contact
13B	Floodway Wing Wall Foundation Failure
15	Floodway Structure Flotation (Uplift)
27	Concentrated Leak Erosion Along a Conduit
28	Internal Erosion Into Conduit
34	BEP through Mainstem Levee Embankment
35	CLE along Sloped Construction Interface
36	Slope instability due to excessive uplift pressures
37	BEP thru Mainstem Levee Foundation

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

Figure A-2: Potential Failure Modes Levees A & B (Mainstem)

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

PFM	Description
1	Overtopping Breach of Levee Embankment
1T	Overtopping Breach of Levee Embankment (Tributary)
11	PSO Flood Wall Foundation Failure
24	Misoperation of Sandbag Closure at Southwest Blvd. (Tributary Loading)
27	Concentrated Leak Erosion Along a Conduit
28	Internal Erosion Into a Conduit
33S*	Concentrated Leak Erosion Along Stop Log Structure Contact
34	Backward Erosion Piping Through Levee Embankment
35	Concentrated Leak Erosion Along Sloped Construction Interface Through Levee Embankment
36	Slope Instability Due to Excessive Uplift Pressures at Landside Toe
37	Backward Erosion Piping Through Levee Foundation

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

* "S" stands for CLE along a stop log structure/embankment contact (CLE along other potential structure/embankment contacts was excluded)

Figure A-3: PFMs Levee C

1.4.2 2019 SQRA

The Southwestern Division (SWD) Cadre, the Risk Management Center (RMC), USACE Tulsa District (SWT), and local levee district representatives met in March 2019 to do this SQRA.

Multiple alternatives were presented during the SQRA for consideration. Each alternative is described in more detail in Part 2.3, however, a total of six alternatives with variations within each were developed. The alternatives were as follows:

- Alternative 1 – Berm with Filtered Exit (A, B, C, D)
- Alternative 2 – Cutoff Wall at Selected Locations (A, B, C, D)
- Alternative 3 – Cutoff Wall along Entire Levee System (A, B)
- Alternative 4 – Divert Water around TWT
- Alternative 5 – Nonstructural Buyout
- Alternative 6 – No Action

Alternatives 1A, 2A, and 3A were elicited for each levee. The B, C, and D alternatives were not elicited because they were similar to the A alternatives but had certain items left out. The team chose to do this based on the "A" option being the most comprehensive option for each alternative. The other options do not contain all of the corrective measures that the "A" option proposes, therefore will have either the same or higher probability of failure.

Consequences were updated (See Appendix C) based on the actions taken by the local sponsor, Tulsa County Emergency Management and other local agencies during a flood event. The warning times and evacuation procedures resulted in a 1.5 order of magnitude reduction in life loss. The following fN charts and tables (Figure A-4) depict the updated baseline for each levee based on revised consequences followed by summarized charts for each alternative (Figure A-5).

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

Figure A-4: 2019 SQRA Baseline fN Charts for Levee System

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

Figure A-5: 2019 SQRA fN Total Risk Charts for Levees A & B

Although PFMs for Levee B Tieback and Levee C did not plot on the fN chart for the baseline, the overall reduction to APF with each alternative was assessed. Levee B Tieback risk reduction See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074 [redacted]

1.5 Pump Stations

Seven pump stations (PS) are part of the TWT levees system. Each is identified in Figure A-1 above. PS1-3 are located within Levee A. PS4-5 are located within Levee B and PS6-7 are located within Levee C. There are an additional two pump stations operated by the City of Tulsa, Mayfair and Vern Rayburn, which were added after the original levee construction.

PS1 is located at levee station 85+18A on a 36-inch sanitary sewer and a 42-inch storm sewer serving the city of Sand Springs. The PS is also arranged to pump from a ponding area that collects overland drainage and the flow of a 96-inch storm sewer located at approximate levee station 101+75A, which is diverted to the ponding area during flood periods by means of an east-west lateral which is activated when the north-south, 96-inch line is over capacity. PS1 includes 4 pumps with a total capacity of 37,500 GPM and an option for a future pump to be added with a capacity of 30,000 GPM.

PS2 is located on a 36-inch combined storm and sanitary sewer near levee station 145+13A adjacent to the Sand Springs Wastewater Treatment Facility. PS2 includes three pumps with a total capacity of 4,100 GPM and an option for a future pump to be added with a capacity of 500 GPM.

PS3 is located near the mouth of the Lake Station Drainage Ditch at approximate levee station 213+77A. Storm runoff enters the PS by an open channel from the drainage ditch and adjacent ponding area. PS3 includes two pumps with a total capacity of 21,000 GPM and an option for a future pump to be added with a capacity of 20,000 GPM.

PS4 is located near 41st West Avenue, at approximate levee station 202+82B and adjacent to a 66-inch storm sewer. The storm flow from the protected area, including the flow of this sewer, is accumulated, during periods of high river stage, in an adjacent ponding area. PS4 includes two pumps with a total capacity of 28,000 GPM and an option for a future pump to be added with a capacity of 14,000 GPM.

PS5 is located near Newblock Park at the mouth of the Park View Drainage Ditch at levee station 295+81B. Storm runoff enters the PS from the Park View Drainage Ditch through a 96-inch RCP culvert under the Sand Springs Railway Company tracks. PS5 includes two pumps with a total capacity of 25,000 GPM and an option for a future pump to be added with a capacity of 22,000 GPM.

PS6 is located on a 60-inch storm sewer near the intersection of West 16th Place and South Nogales Street in West Tulsa, at approximate levee station 190+00C. PS6 includes five pumps with a total capacity of 40,000 GPM.

PS7 is located on a 96-inch storm sewer at approximate levee station 243+23C on the right bank of the Arkansas River, approximately ¼ mile south of the 21st Street Bridge. PS7 includes 4 pumps with a total capacity of 67,500 GPM and an option for a future pump to be added with a capacity of 20,000 GPM.

The pump stations are an integral part of the system as a whole. They are utilized to evacuate interior drainage from within the leveed areas either from the underground drainage systems or local runoff. The pumps allow for interior roads to be passible and free of water during flood events. They also prevent flooding to homes and other structures that are located in the lowest lying areas within the leveed area. Access routes out of the leveed area need to remain open in the event an emergency arises.

Seepage from sustained loading, as was observed during the May 2019 flood, also leads to additional interior flooding. The proposed measures to address internal erosion issues require all collected seepage to be removed from the system and pumped back into the river. In order for the system to operate as designed and intended, these low lying areas in the vicinity of the pump stations need to be free of water to effectively function. It is imperative the pump stations operate as designed during flood events, either from the Arkansas River or isolated tributary events similar to 1984.

1.6 Geotechnical

Limited geotechnical information is known about the areas where the proposed designs are to be located. Borings are available for the levee system with approximately 12-16 for each levee from original construction and six borings from 2017.

Prior to Preconstruction, Engineering and Design (PED) work, it is recommended that a thorough subsurface exploration be performed along Levee A & B. Laboratory testing on the soils should include at a minimum grain size distribution, Atterbergs and triaxial shear tests. This information will aid in the determination of filter material gradation requirements and stability analysis of the proposed designs.

Borings will also be required at the proposed detention pond locations. This material could potentially be utilized for construction of the other design features, specifically the filter berm.

A cutoff wall is proposed at the Superfund site along Levee A. The wall would be constructed upstream of the levee to avoid disturbing any contaminated soil that was not removed during the cleanup and remediation of the site.

Stone material for the project’s various construction activities is readily available from multiple quarries and can be delivered directly to the proposed staging areas.

1.7 Alternative 1 – Berm with Filtered Exit

Alternative 1 includes filtered berms with a toe drain, conduit replacement, full cutoff wall with impervious blanket, armoring of the landside slope at the selected overtopping location, anchoring and/or robust filter at Charles Page floodway structure, two stage filter along the tieback and construction of detention ponds. This alternative has five variations, titled A thru E respectively. This alternative is the Tentatively Selected Plan (TSP) and consist of the following elements.

> Alt 1A – This alternative will address all potential failure modes for the entire system primarily with filtered exits. Throughout the entire levee system (A, B and C), conduits deemed no longer necessary will be abandoned and those critical to the functionality of the system replaced. Each location will have a filtered exit constructed. At Levee A, the Charles Page culvert will be anchored and all joints sealed and a full cutoff wall to rock constructed at the Superfund site for approximately 15,000 feet. At Levee B, permanently raise the levee back to original design flow at Pump Station No. 5 for approximately 3,000 feet; construct a stability berm with a filtered exit and drainage at Pump Station No. 4; and a detention pond for 100-year storm along Levee B Tieback; and filter along the tieback. At Levee C, permanently raise the levee back to original

design flow at I-244 Corridor for approximately 1,000 feet; construct a landside berm with filtered exit and drainage for approximately 6,800 feet.

Alt 1B – Identical to Alternative 1A but without addressing Levee C.

Alt 1C – This alternative will address penetration failure modes (no overtopping failure modes) for the entire levee system (A, B and C) primarily with filtered exits. Throughout the entire levee system (A, B and C), conduits deemed no longer necessary will be abandoned and those critical to the functionality of the system replaced. Same as Alternative 1A but with no levee raise in Levee B or Levee C.

Alt 1D – Identical to Alternative 1C but without addressing Levee C.

Alt 1E – **This alternative is the TSP.** This alternative was surmised after the 2019 SQRA. It was suggested that each measure be optimized and combined into a single alternative without addressing Levee C. This alternative consist of constructing filtered berms with a toe drain along the entire length of Levee A & Levee B. Each conduit deemed no longer necessary will be abandoned and those critical to the functionality of the system replaced. A full cutoff wall to rock with an impervious blanket at the Superfund site at Levee A for approximately 2,000 feet. A robust filter will be constructed at the Charles Page floodway structure. The landside slope of Levee B at Pump Station No. 5 for approximately 3,000 feet, the selected overtopping location, will be armored. Detention ponds will be constructed upstream of Levee B Tieback. A two-stage filter will also be constructed along the entire length of Levee B Tieback. Reconstruction of pump stations 1-7 along the entire levee system. This includes replacing the entire pump station to include the building structure, trash racks, grating, discharge chamber embedded metals, fences, pumps, motors and all electrical components.

1.8 Alternative 2 – Cutoff Wall at Selected Locations

Alternative 2 includes full cutoff walls to rock in selected locations, conduit replacement and filtering, anchoring of the Charles Page floodway structure, armoring of the landside slope at the selected overtopping location and construction of detention ponds. This alternative has four variations, titled A thru D respectively.

Alt 2A – This alternative will address all potential failure modes for the entire system primarily with cutoff walls. Throughout the entire levee system (A, B and C), a cutoff wall will be constructed at each penetration for approximately 6,800 total feet and approximately 90 conduits replaced. Each location will have a filtered exit constructed. At Levee A, the Charles Page floodway structure will be anchored and all joints sealed and a full cutoff wall to rock constructed at the Superfund site for approximately 15,000 feet. At Levee B, a cutoff wall for approximately 3,000 feet at Pump Station No. 4, permanently raising the levee back to original design flow elevation at Pump Station No. 5 for approximately 3,000 feet and armoring the landside slope. A cutoff wall for approximately 9,000 feet along the tieback and a detention pond to store the 100 year storm will also be constructed. At Levee C, the landside slope at I-244 Corridor for approximately 1,000 feet will be armored. A cutoff wall for approximately 6,800 feet will also be constructed.

Alt 2B – Identical to Alternative 2A but without addressing Levee C. Throughout Levee A and B, a cutoff wall will be constructed at each penetration for approximately 3,600 total feet and replace approximately 65 conduits.

Alt 2C – This alternative is identical to Alternative 2A but does not address overtopping failure modes, thus no levee raise. Throughout the entire levee system (A, B and C), cutoff walls will be constructed at each penetration and the necessary conduits replaced.

Alt 2D – Identical to Alternative 2C but without addressing Levee C.

1.9 Alternative 3 – Cutoff Wall along Entire Levee System

Alt 3A - This alternative will address all potential failure modes for the entire system primarily with a permanent levee raise to 1/500 annual chance of exceedance (ACE) and permanent levee raise of 1/100 ACE for the tiebacks. Throughout the entire levee system (A, B and C), a cutoff wall will be constructed along the entire system (approximately 20 miles) and approximately 90 conduits replaced. Detention ponds will be constructed behind Levee A and Levee B Tiebacks.

Alt 3B – Identical to Alternative 3A except without raising the main-stem and/or tiebacks within the levee system and no issues addressed within Levee C. Reconstruction of pump stations 1-7 along the entire levee system. This includes replacing the entire pump station to include the building structure, trash racks, grating, discharge chamber embedded metals, fences, pumps, motors and all electrical components.

1.10 Alternative 4 – Divert Water around Tulsa/West Tulsa

Alternative 4 includes diverting the water released from Keystone around the TWT levees system.

1.11 Alternative 5 – Non-structural Buyout Alternative

Alternative 5 includes buyout of all residential structures within Levee A and B.

1.12 Alternative 6 – No Action

Other than normal Operation, Maintenance, Repair, Replacement and Rehabilitation requirements, the No Action Plan does not have planned major changes to existing structures.

1.13 Fragility Curves

The fragility curves utilized to aid in the development of the damage estimates were developed for the following flood events along the Arkansas River: 2-year, 5-year, 10-year, 20-year, 50-year, 100-year, 200-year and 500-year. Curves were also developed for Harlow Creek for the corresponding flood events: 2-year, 5-year, 10-year, 20-year, 50-year, 70-year, 85-year and 100-year.

1.14 May 2019 Flood Event

The May 2019 flood event loaded the levees significantly for the first time since 1986. This event provided actual evidence of potential issues and the locations where they first appear. The 2016 SQRA provided locations deemed most critical based on geologic logs, past events and engineering judgment. These areas did not correspond to the locations where issues arose during the 2019 flood exactly.

Two areas where seepage and internal erosion were most prevalent were See Table of [redacted] Another location was at the Charles Page floodway structure. Significant erosion issues were observed compared to potential uplift issues identified in the original SQRA. Erosion under and along the walls created significant voids (Figure A-7). Sandbag ring dikes were filled with sand, then overlain with gravel along the walls to prevent further erosion.

Figure A-6: Issues Noted See Table of Contents [redacted]

Figure A-7: Erosion at Charles Page Floodway Structure

1.15 Civil Design

Other than normal feature alignment details and site grading, limited civil design efforts are anticipated for the project.

1.16 Structural Requirements

The Charles Page Floodway Structure will be reanalyzed for potential uplift issues. The structural requirements will vary depending on the results of this analysis. Other structural requirements include those made to the pump stations which are necessary when updating each. These vary from no changes to the pump station structure to adding structural elements to aid in the testing of the pumps.

1.17 Electrical and Mechanical Requirements

Alternatives 1E and 3B have an above ground electrical power line. Power poles will need to be removed and replaced by the electric company. The impacted length of wiring serving the area is approximately 1,200 feet long. Design and construction of the electrical modifications would be performed by electric cooperative.

All electrical and mechanical components in the seven pump stations will be completely replaced as part of reconstruction. This includes but is not limited to electrical panels, wiring, pumps and motors.

1.18 Hazardous and Toxic Materials

There will be no hazardous or toxic materials utilized in this project; however, due to the historical use of hazardous/toxic materials around the levee system, the potential exist to encounter these types of materials during construction. A formal Hazardous, Toxic and Radioactive Waste (HTRW) survey may be deemed necessary for this project.

1.19 Construction Procedures and Water Control Plan

As the Arkansas River experiences flood events that potentially load the levee, all construction activities in the study area will be ceased. This is especially true for the excavation of the toe drain. Careful planning and monitoring of river and weather conditions will be required. Releases are regulated from Keystone Dam, so a minimum 24 hours of warning should be provided from USACE. Localized erosion control measures should be implemented for all construction activities.

The construction schedule for the project should take into account mobilization and demobilization of construction equipment and personnel during flood events.

1.20 Initial Reservoir Filling and Surveillance Plan

There are no reservoirs within the project area that would require a Reservoir Filling and Surveillance Plan.

1.21 Flood Emergency Plans

There are no dams within the project area that would require a Flood Emergency Plan.

1.22 Reservoir Cleaning

None required.

1.23 Operation and Maintenance

The project does not require physical operation of any of the features to be implemented. They are totally passive in nature and have no moving parts. The toe drain will require cleaning and video inspection every 5-7 years, or after flood events initiating flow, to monitor the condition of the system. The riprap protected landside slope along Levee B will require herbicide applications to prevent vegetative growth.

1.24 Access Roads

Access to the project areas will use the existing roads and structures serving the TWT Study area. The existing roads consist of primarily paved surfaces in the vicinity of the levees. The approach roads are aggregate stabilized surfaces capable of handling heavy equipment loads. However, the levee crest is not paved and consist of vegetative cover.

During the Preconstruction, Engineering and Design (PED) phase, the access roads should be re-evaluated to verify that no improvements are required since the preparation of this study. The Contractor will be required to maintain all new and existing access roads used during the projects construction.

1.25 Corrosion Mitigation

No metallic items are being considered in the project at this time. However, during the PED phase, if metallic items that are susceptible to corrosion are to be utilized, a system to prevent corrosion or other material options that are not susceptible to corrosion will be considered.

1.26 Project Security

No project security is required, since the location of the construction does not involve Government facilities that would require security to be present. During construction, the Contractor will be responsible for the protection of their equipment and personnel.

1.27 Cost Estimates

Cost estimates were prepared for the various alternatives and are included in Appendix G – “Cost Estimate”.

1.28 Schedule for Design and Construction

The schedule for the tentatively selected plan is located within Appendix G – “Cost Estimate”.

1.29 Special Studies

None required.

1.30 Plates, Figures and Drawings

Plates, Figures and Drawings have been included in Attachment A of the "Engineering Appendix". They include: plan views of the study area and typical cross sections of the proposed measures.

1.31 Data Management

During the feasibility study, electronic data was compiled and maintained on ProjectWise and in project folders for each discipline involved on the server. This data is backed up regularly by USACE's data manager (ACE-IT). The project's information will be available for the next phase of the project.

1.32 Use of Metric System Measurements

The Sponsor has not specifically requested that the project be designed in English units. However, the river mapping system and property surveys were all done originally in English units. Converting these survey drawings from English to Metric would have created additional work effort and potential translation errors, which could affect the design team's efforts, resulting in delays to the schedule and additional costs to prepare the study.