US Army Corps of Engineers ®

Tulsa District

APPENDIX D: SQRA Summaries

Tulsa and West-Tulsa Levee Feasibility Study

August 2019

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1 GENERAL

The TWT Levee System Integrated Feasibility Study utilized the previous risk assessments performed for the system in 2016 (Levee A&B) and 2017 (Levee C). These risk assessments provided the foundation for the study and also aided in the implementation of emergency actions and procedures by the levee district and local city authorities. These actions and procedures were considered for the 2019 update.

2 SEMI-QUANTITATIVE RISK ASSESSMENT (SQRA)

2.1 2016 SQRA

The Tulsa District and the New England Risk Cadre completed the semi-quantitative risk assessment (SQRA) for the Tulsa/West Tulsa Levee A&B System in general accordance with Best Practices (2015) and draft EC 1110-2-6072 (19 November 2014). Many of the principles intended for dams were considered as they should apply to levee systems and are explained as such in the text of the report. The SQRA consisted of a facilitated Potential Failure Mode Analysis (PFMA) and a semi-quantitative risk assessment of potential failure modes judged to be risk-drivers.

Incremental Risk

The incremental risks associated with a breach of the Tulsa/West Tulsa (TWT) Levee System (Levee A&B) are considered to be High. The TWT Levee A&B system consists of two levee segments (Levee A and Levee B). For this risk assessment, Levees A and B were broken into two regions; the Mainstem Levees and the Tieback Levees based on the anticipated hydrologic loading of each region. The Mainstem Levees are loaded by a flood event on the Arkansas River, while the Tieback Levees are loaded by the Harlow Creek and Bigheart Creek Tributary flood events. Flows from breach or overtopping of either Levee A or B can flow over the Charles Page Boulevard Floodway structure and inundate protected areas behind either levee.

Forty-five potential failure modes were identified by the SQRA team for consideration. Thirty-four were not developed in detail as they were not considered to be “risk-drivers” for the project or were deemed to be contributors to the “risk-drivers.” The list of risk driver potential failure modes are listed in Figure 2.1. In the description of the PFMs, if there is no letter after the PFM number, the PFM is associated with the Mainstem of Levee A or B only, and would be caused by Arkansas River loading. The letter “T” after the PFM number indicates that the PFM would be caused by Tributary loading and would be associated with the Tieback Levee segments or the Floodway Structure. The letter “B” indicates that the PFM is uniquely applicable to Levee B or the Floodway Structure. In some cases there is a corresponding PFM only applicable to Levee

A, but that PFM was excluded.

Since flows from a breach/failure of either Levee A or B can flow over the Charles Page Boulevard Floodway structure and inundate protected areas behind either levee, Levees A&B

were analyzed as one segment. Even though critical locations were examined and evaluated by the team along both Levees, based on anticipated loading and incremental consequences, Levee B was thought to pose the highest incremental risk to the Levee System. Therefore, all risk driving failure modes were evaluated along portions of Levee B, and the risk of Levee A was qualitatively assessed relative to the risk assessed for Levee B.

The incremental risks are primarily driven by the potential for breach due to overtopping along Levee B; internal erosion into deteriorated conduit penetrations; slope instability due to malfunctioning or destroyed relief well systems; concentrated leak erosion along conduit penetrations; and backward erosion piping through the embankment (tieback levees only). Both Mainstem Levees have a history of poor performance related to concentrated leak erosion into or along known and/or abandoned conduits; a partial breach occurred along Levee A and a near breach along Levee B during the 1986 flood event, at an approximate 1/200 Annual Chance Exceedance (ACE) Arkansas River flood event. Though many conduits have been replaced since the mid-1980s, many remain unaltered, and many others are suspected to be undocumented. Floatation of the Floodway Structure is thought to pose moderate risk to the Levee system. The 1984 Harlow and Bigheart Creek Tributary event caused significant performance issues for the Floodway structure related to headwall and wingwall foundation stability. Significant repairs were performed just prior to the 1986 Arkansas flood event. Performance issues of the Floodway Structure were again observed during the 1986 event in the form of artesian flow from the Floodway conduit joints flooding Charles Page Boulevard, as well as some separation and leakage through the riverside Floodway wingwalls.

[redacted] See Table of Contents Due to the number of potential failure modes which were evaluated for the Tulsa/West Tulsa Levees A&B, a separate risk matrix was created for the Mainstem and Tieback portion of the levees. Incremental life loss varies from Moderate to Very High depending on Levee Control “Breach” Location (LCL) along the Mainstem and Tieback Levees. A total of eight general breach locations were modeled for Levees A&B. The control locations chosen corresponded to historical breach and/or overtopping locations, large concentrations of infrastructure areas, large population concentration areas, higher levee locations, and/or incipient overtopping locations. Locations were chosen to be representative of various portions of the levee system so the results could be directly applied and/or interpolated to the desired location.

Failure likelihood along Levee B was assessed at the 1/230 ACE Arkansas River event, which corresponds to the incipient overtopping elevation at Pump Station 5. During a 1/260 ACE Arkansas River event, Levee B will be overtopped by two feet at the same location; consensus was that the Levee would not be able to withstand this level of overtopping and would breach. The remaining control locations along the Mainstem Levees and the Floodway structure do not get overtopped during the 1/260 ACE event. Failure along Levee A was assessed at the 1/260 ACE event, which would provide the maximum loading on Levee A prior to overtopping breach on Levee B initiating.

For the evaluation of all breach prior to overtopping failure modes along the Tieback Levee B, a breach was assumed to initiate at the highest Water Surface Elevation (WSEL) during the 1/85 ACE Tributary event. This corresponds to the incipient overtopping elevation along the tieback

(Sta. 13+00B). This allowed the team to assess the maximum incremental risks associated with a failure/breach at each control location.

The incremental risks along Levee A are assessed to be lower than those along Levee B. This is mostly due to incremental life loss, which is estimated to be an order of magnitude lower than that estimated for Levee B for both overtopping and prior to overtopping failures. Multiple warnings that would be issued prior to a breach occurring along Levee A contribute to the lower incremental life loss. Incipient overtopping of Levee A initiates at an approximate 1/375 ACE Arkansas River event, and Levee A is overtopped by 2 feet during an approximate 1/500 ACE Arkansas River event. Flood events of this magnitude would overtop Levee B by several feet at multiple locations, likely failing Levee B, and inundating areas behind Levee A prior to the initiation of overtopping along Levee A. Inundation within the Levee A interior from Levee B overtopping breach flows would commence at an approximate 1/260 ACE event, the same event which overtops Levee B by 2 feet. Therefore, all breach prior to overtopping failure modes along Levee A were assessed for the 1/260 ACE event to evaluate the maximum incremental risk of Levee A prior to overtopping breach on Levee B initiating.

Failure likelihood for all evaluated failure modes along Levee A is estimated to be the same or no more than ½ an order of magnitude lower than that assessed along Levee B, with the exception of internal erosion into conduits (PFM 28). Due to the highly industrialized area, combined with performance history and past observations along Levee A, the failure likelihood for this failure mode was assessed to be ½ order of magnitude higher than that assessed for Levee B.

The population at risk (PAR) for all Mainstem Levees and Floodway failure modes ranges between 2,613 and 5,724; for failure modes along the Tieback Levees, PAR varies between 1,043 and 3,541. The area protected by the system is comprised of a mixture of residential, commercial, and heavy industry structures which will be inundated by up to 15 feet of water due to a breach of the Mainstem Levees at a 1/230 ACE Arkansas River flood event. The maximum depth of inundation from a breach at the Tieback Levee B during a 1/85 ACE Tributary flood event is estimated to be just over 9 feet. Demographic and evacuation factors suggest that a very low mobilization rate (maximum of 73% after 8 hrs) could be expected in an emergency.

The incremental life loss for all Mainstem Levee failure modes was generally considered to be Moderate (1-10) to Very High (greater than 100). For all breach prior to overtopping failure modes, the incremental life loss estimates for the 1/230 ACE Arkansas event on Levee B range from 7 to 212 for warning issuance at breach initiation. The incremental life loss estimates for the 1/260 ACE Arkansas event (overtopping breach on Levee B), ranged from 57 to 64 for warning issuance 12 hours prior to Keystone Dam releases that could potentially overtop the TWT Levee system. The incremental life loss estimates for the 1/260 ACE Arkansas flood event along Levee A for all breach prior to overtopping failure modes are based on multiple warnings and range between 8 and 17. Incremental life loss for the 1/500 ACE Arkansas flood event that would overtop Levee A by 2 feet is estimated to be minimal, due to inundation of the leveed area by overtopping failures along Levee B prior to Levee A overtopping. Incremental life loss

for all breach prior to overtopping failure modes along Levee A was considered to be Moderate (1-10) to High (10-100).

Incremental life loss for the Tieback Levees was considered to be Moderate (1-10) to High (10-100). Incremental life loss estimates for the Tieback Levee for all prior to overtopping failure modes (1/85 tributary event) ranged from 2 to 12 for warning issuance at breach initiation and 25 to 31 from overtopping failure (1/1000 tributary event) of the Levee B Tieback. Due to significant industry behind the Levee System, especially Levee A, there could be environmental impacts and impacts on life safety due to the release of hazardous materials into the Arkansas River that have not been quantified in this risk assessment but are worth considering while evaluating overall risk.

Incremental direct economic consequences were considered to be significant damages to private and public property which would be incurred by a failure of the project. The damage categories included in the analysis of economic impacts are damages to structures and their contents, including residential, public and commercial structures. Incremental Direct Economic Consequences for all Mainstem failure modes were considered to be Moderate to Moderate-High ($27 to $95 million); for the Tieback Levees they were considered to be Low to Moderate ($4.6 to $22 million).

Environmental Impacts

There is significant industry behind the Levee System, especially Levee A, such as the Sand Springs Superfund (ARCO) Site and the Sheffield Steel Co. that house hazardous materials with some hazardous material releases historically reported. A breach or overtopping of the Levee A&B system could result in the release of hazardous materials from the Sand Springs Superfund site, or from one of the many industrial entities behind the levee system. Hazardous materials could enter the Arkansas River, a major waterway, and affect communities and habitats downstream. The impacts on life safety, as well as costs related to cleanup due to hazardous material releases during flooding have not been quantified for this assessment. However, they were qualitatively discussed by the SQRA team during the risk assessment process. The magnitude of these consequences is uncertain, but it is worth noting when considering overall risk.

Non-Breach Risk

The TWT Levee System overtops at events ranging from a 1/25 ACE Tributary event (Tieback Levee A) to greater than a 1/230 ACE Arkansas River event (Mainstem Levee B). The life loss caused by nonbreach flow from a 1/260 ACE Arkansas River event, resulting in 2 feet of overtopping of the Mainstem Levee B, is estimated to be Low-Moderate (around 1). The economic consequences resulting from nonbreach flow from a 1/260 ACE Arkansas River event overtopping Levee B are anticipated to be Moderate ($15 million). The 1/260 ACE Arkansas River event results in overtopping of the Mainstem Levee B for 12 hours to approximately 1 week. Overtopping along Levee A is estimated to initiate at an approximate1/375 ACE Arkansas

River event, at which time Levee B would have entirely overtopped and breached, inundating the Levee A protected area.

Life loss for a 1/1,000 ACE Tributary flood event, resulting in 2 feet of overtopping of the Tieback Levee B, is estimated to be 2 (Moderate). The economic consequences resulting from non-breach flow from a 1/1000 ACE Tributary event are also Moderate ($26.5 million). The non-breach life safety and economic risk matrices for this project are shown in Figure 2.3.

Confidence and Major Uncertainties

The SQRA team generally had low to moderate confidence in the incremental risks described above, such that additional data may change incremental risk. The key uncertainties are the location and condition of a significant number of conduits through the levee, as well as construction practices during remediation and abandonment efforts, condition and effectiveness of the relief well/toe drain system, frequency of loading from Tributary events due to lack of gages at the Tributary streams, material properties of foundation and embankment, and compaction records of the levee embankment. Additional information that would impact key factors could reduce uncertainty and have either positive or negative impacts to the incremental risk.

Levee Evaluation for NFIP

The TWT Levee A&B System was evaluated for breach and non-breach in order to evaluate an initial screening related to NFIP requirements. Based on the current evaluation, non-breach risk is driven by the Tieback Levees which overtop during 1/25 and 1/85 ACE Tributary events for Levee A and Levee B, respectively. Confidence in this estimate is Low to Moderate due to uncertainty in the frequency of loading. Additionally, the breach prior to overtopping evaluation indicates that the “breach prior to overtopping” failure mode PFM 34T was judged to have a Very High likelihood of failure (1/100 to 1/1,000), given a 1/85 ACE Tributary loading, with Moderate confidence; the failure likelihood of PFM 28 was considered to be High with Low confidence. Due to the risk associated with the Tieback Levee overtopping and breach prior to overtopping, as well as breach prior to overtopping of the Mainstem Levee, the TWT Levee System would not likely meet the NFIP levee system evaluation requirements.

The initial screening of the TWT Levee System indicates that additional studies and modifications to the levee system are likely needed to address breach prior to overtopping risk as well as overtopping which will occur at the Tieback Levees for the system to be considered potentially favorable for NFIP accreditation. The risk assessment did not directly address internal drainage related flooding that could also impact NFIP mapping.

Levee Safety Action Classification (LSAC) Evaluation

The Tulsa/West Tulsa (TWT) Levee A&B system is currently categorized as an overall LSAC 1, with an LSAC 2 for overtopping and an LSAC 1 for prior to overtopping based on the Levee Screening Tool (LST). The LSAC for the TWT Levee A&B system was evaluated as a unit

during the LST process. The primary reasons for the LSAC 1 rating was the potential for inundation due to breach prior to overtopping, due to anticipated poor performance, in combination with loss of life and economics that was assessed to result in Very High Risk. The breach risk was attributed to erosion around or into penetrations through the levee, failure of the relief well/toe drain system, and Floodwall instability. The LSAC 2 rating for overtopping was due to the relatively frequent likelihood of overtopping of the Tieback Levees. For this risk assessment, the Mainstem and Tieback segment of the levees were evaluated separately.

Hydrologic analyses conducted for this study indicate that the Mainstem Levee B will be overtopped by 2 feet at an approximate 1/260 ACE Arkansas River event. The incremental risks for overtopping failure were assessed to be High. Therefore, it is recommended that the LSAC for overtopping failure be remain LSAC 2 (High Risk). The Mainstem Levees have a history of poor performance related to internal erosion into or along known and/or abandoned conduits. Though many conduits have been replaced, many remain unaltered, and many others are suspected to be undocumented. Additionally, the relief well system along the landside toe of the levee has not been maintained, with some performance issues documented during the 1986 flood event. Based on this risk assessment, it is recommended that LSAC for failure prior to overtopping be reclassified to LSAC 2 (High Risk). An overall LSAC 2 (High Risk) for the Mainstem Levees is recommended since the likelihood of failure resulting in significant life threatening inundation is High.

Based on the recent H&H analyses, Tieback Levee B will experience incipient overtopping during a tributary event of 1/85 ACE and will overtop by 2 feet during a tributary event of 1/1000 ACE. Tieback Levee A will experience incipient overtopping at a 1/25 ACE tributary event. The Tieback Levees have a history of poor performance related to overtopping and embankment erosion that nearly breached Tieback Levee B during the 1984 tributary event (ACE ~ 1/500) that overtopped the levee by ~ 1.5 feet, The incremental risk for overtopping failure was assessed to be High mostly due to the frequency (1/85 ACE) of the incipient Tributary overtopping event, past performance, and the erodibility of the embankment soils. It is therefore recommended that the LSAC for overtopping failure be classified as LSAC 2 (High

Risk). Incremental risk for failure prior to overtopping was also assessed to be High due to backward erosion piping concerns through the embankment from a combination of excessive animal burrow activity and highly erodible embankment soils. It is recommended that the LSAC for failure prior to overtopping be classified LSAC 2 (High Risk). An overall LSAC 2 (High Risk) is recommended since the likelihood of inundation in combination with life loss is considered to be High.

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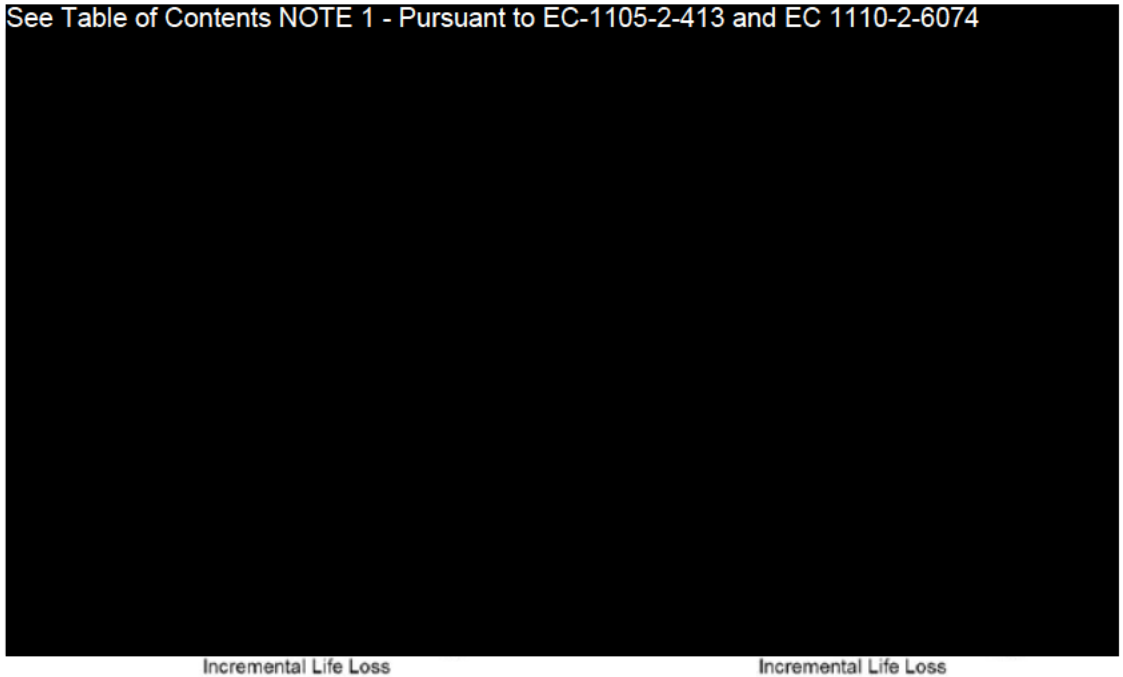
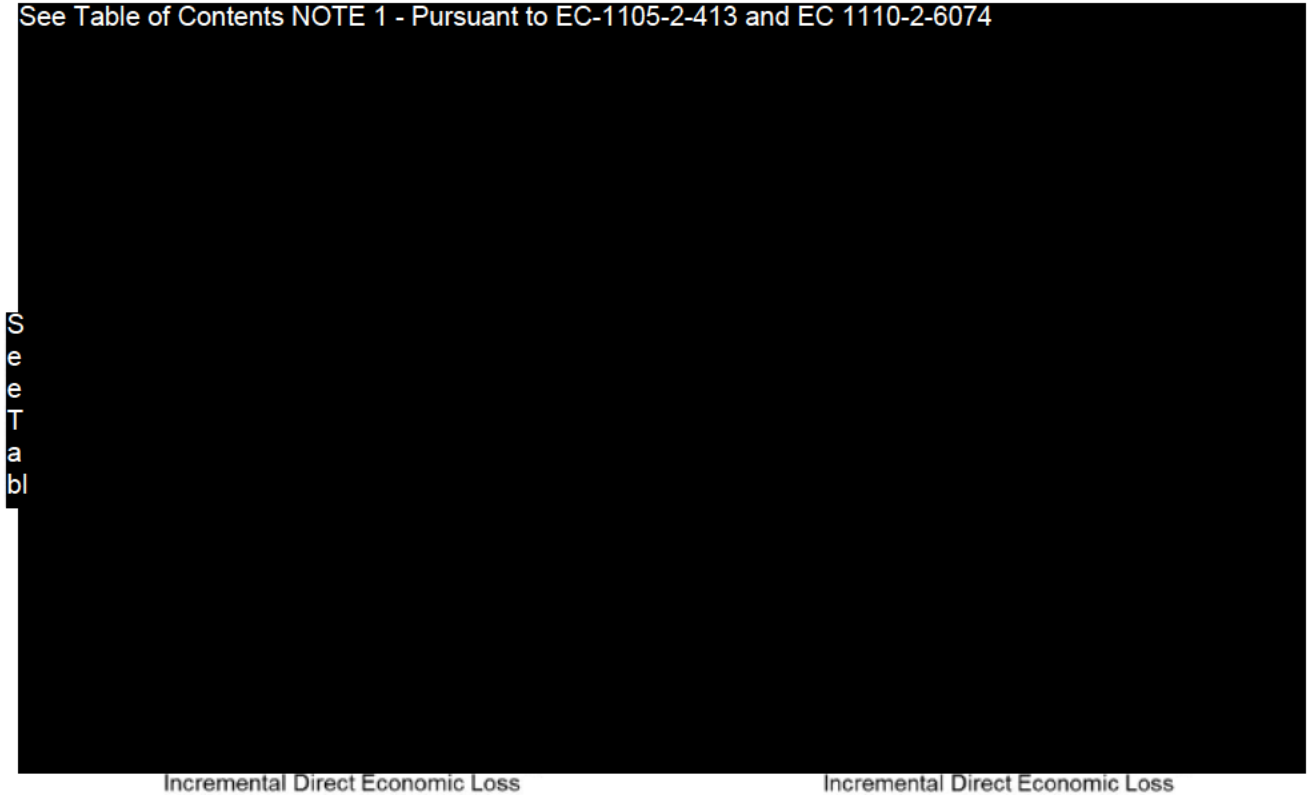


PFM	Description	See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074
1	Overtopping of Mainstem Levee Embankment	
11B	Floodway Headwall Foundation Failure	
12B	CLE along wingwall/embankment contact	
13B	Floodway Wing Wall Foundation Failure	
15	Floodway Structure Flotation (Uplift)	
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	

Figure 2.1: Incremental Life Safety Risk Matrix – Levees A & B (Mainstem & Tieback)

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



See Table

Incremental Direct Economic Loss Incremental Direct Economic Loss

PFM	Description
1T	Overtopping of Tieback Levee Embankment
11BT	Floodway Headwall Foundation Failure
12BT	CLE along wingwall/embankment contact
34T	BEP through Tieback Levee Embankment
37T	BEP thru Tieback Levee Foundation

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

Figure 2.2: Incremental Direct Economic Loss Matrix – Levees A & B (Mainstem & Tieback)

Figure 2.3: Non-Breach Incremental Life Safety & Direct Economic Loss Matrix – Levees A & B (Mainstem & Tieback)

2.2 2017 SQRA

The Tulsa District and the New England Risk Cadre completed the semi-quantitative risk assessment (SQRA) for the Tulsa/West Tulsa Levee C System in general accordance with Best Practices (2015) and draft EC 1110-2-6072 (19 November 2014). Many of the principles intended for dams were also considered as they should apply to levee systems and are explained as such in the text of the report. The SQRA consisted of a facilitated Potential Failure Mode Analysis (PFMA) and a semi-quantitative risk assessment of potential failure modes judged to be risk-drivers.

Incremental Risk

The incremental risks associated with a breach of the Tulsa/West Tulsa (TWT) Levee C are considered to be Moderate. Forty-two potential failure modes were identified by the SQRA team for consideration. Eleven of these were considered to be risk-driving potential failure modes, and are listed in Figure 2.4. Thirty-one potential failure modes were not considered to be “risk-drivers” for the project or were deemed to be contributors to the “risk-driver” potential failure modes and were therefore not developed in detail. In some cases there is a letter after the PFM number in the list of the risk driving failure modes in Figure 2.4 and excluded failure modes. The letter is intended to differentiate between potential failure modes that apply at different locations, structures or hydraulic loading conditions along Levee C.

The incremental risks for this right bank levee segment are primarily driven by the potential for breach due to overtopping; the misoperation of the sandbag closure where Southwest Blvd. crosses the tieback levee alignment; internal erosion into and/or along deteriorated conduit penetrations; and potential slope instability due to malfunctioning or destroyed toe drain and relief well systems. Misoperation of the sandbag closure at Southwest Blvd. during a Cherry Creek flood event is considered to pose one of the highest risks to Levee C. Without the sandbag closure in place, incipient overtopping of an approximately 130-foot wide and just over 2-feet deep low spot on Southwest Blvd. will commence at a 1/25 Annual Chance Exceedance (ACE) Cherry Creek flood event; the water surface profile will reach the levee crest at an approximate 1/50 ACE Cherry Creek flood event. Inundation behind the levee in this location was reported during the 1984 flood. However it is unknown whether the sandbag closure was in place during this event.

Levee C does not have any other reported history of poor performance during past flood events. It is unclear whether adverse conditions did materialize but were not reported, whether poor performance developed but was not observed due to access issues, or was observed but not reported. Similarly constructed left bank levee segments (Levee A&B) have experienced performance issues related to internal erosion into or along known and/or abandoned conduits. A partial breach occurred along Levee A and a near breach occurred along Levee B during the 1986 Arkansas River flood event (1/200 ACE event). Additionally, a shallow sloughing failure on the land side slope of Levee A was attributed to excessive seepage and uplift pressure during this event. Boils at the western end of Levee A shortly after construction were also attributed to inadequately spaced relief wells. Although many conduits have been replaced along Levee C

since the 1990s, several remain unaltered, others may be buried, and it is suspected that other penetrations and utility crossings are present and undocumented. The relief wells and portions of the collector system, intended to reduce potential excess hydrostatic pressures underneath the landside toe of the levee, are likely plugged, removed or destroyed by others and are no longer functioning as designed.

Incremental life loss varies from Low to Moderate-High depending on Levee Control (Breach) Location (LCL) along Levee C. A total of eight general breach locations were modeled for Levee C; three additional breach locations were evaluated, but not fully modeled. The control locations chosen corresponded to large concentrations of infrastructure areas, large population concentration areas, higher levee locations, and/or incipient overtopping locations. Locations were chosen to be representative of various portions of the levee system so the results could be directly applied and/or interpolated to the desired location. The incremental life safety risk matrix for this project is shown in Figure 2.4.

The population at risk (PAR) for all Arkansas River flood event failure modes range between 1 and approximately 4,500; PAR for failure modes resulting from a Cherry Creek flood event on the tieback levee is anticipated to be minimal due to the anticipated shallow inundation depths at the tieback location along Southwest Blvd. The leveed area behind Levee C is comprised predominantly of heavy industry and a densely-developed residential area in the northeastern corridor. The leveed area will be inundated by up to 13 feet of water, in very limited areas, due to a breach of the Levee C embankment during a 1/240 ACE Arkansas River flood event. Conversely, the maximum depth of inundation from a breach at the tieback levee during a 1/50 ACE Cherry Creek flood event is estimated to be approximately 2 feet. Demographic and evacuation factors suggest that a low to very low mobilization rate (maximum of 73% after 8 hours) could be expected in an emergency.

The incremental life loss for all failure modes was generally considered to be Low (0-1) to Moderate-High (2-21). The incremental life loss estimates for the 1/240 ACE Arkansas River flood event range from 0 to 21 for warning issuance at breach initiation for all breach prior to overtopping failure modes. The incremental life loss estimates for the 1/270 ACE Arkansas River flood event, overtopping with breach, was estimated to be Moderate (1-10) for warning issuance 12 hours prior to Keystone Dam releases that could potentially overtop the TWT Levee system. The incremental life loss resulting from the misoperation of the sandbag closure during a Cherry Creek flood event is anticipated to be Low-Moderate (around 1) due to population attempting to drive though floodwaters during a flashy Cherry Creek flood event.

Incremental direct economic consequences were considered to be significant damages to private and public property expected to be incurred by a failure of the project. The damage categories included in the analysis of economic impacts are damages to structures and their contents, including residential, public and commercial structures. Due to the industrial nature of the leveed area, economic consequences can also result from loss of production or release of hazardous materials. These consequences have not been included in the estimates provided by this risk assessment. Incremental Direct Economic Consequences for failure modes resulting

from an Arkansas River flood event were considered to be Low to High ($5.6 to $150 million). Incremental direct economic consequences were not calculated for a Cherry Creek flood event but were considered to be Low due to limited inundation depths.

Environmental Impacts

There is significant industry behind Levee System C, such as Westside Chemical Co., Ozark fluorine Specialties, Inc., Koch Industries, Holly Refineries, PSO, McMichael Concrete, etc., that house hazardous materials with some hazardous material releases historically reported. A breach or overtopping of the Levee C System could result in the release of hazardous materials from the Holly Refinery, or from one of the many industrial entities behind the levee system. Hazardous materials could enter the Arkansas River, a major waterway, and affect communities and habitats downstream. The impacts on life safety, as well as costs related to cleanup due to hazardous material releases during flooding have not been quantified for this assessment. However, they were qualitatively discussed by the SQRA team during the risk assessment process. The magnitude of these consequences is uncertain, but it is worth noting when considering overall risk.

Non-Breach Risk

The TWT Levee C System overtops at events ranging from a 1/50 ACE Cherry Creek flood event at Southwest Blvd., to greater than a 1/240 ACE Arkansas River flood event beneath the I-244 Bridge. The life loss caused by non-breach flow from a 1/270 ACE Arkansas River flood event, resulting in 2 feet of overtopping of the mainstem levee, is estimated to be Moderate (1 to10). Life loss for a Cherry Creek flood event that overtops the tieback levee at Southwest Blvd. is estimated to be Low (0 to 1). The Non-Breach economic consequences resulting from a 1/270 ACE Arkansas River event are anticipated to be Low ($0.6 million), and those resulting from non-breach flow from a Cherry Creek flood event, even though not specifically modeled, are also considered to be Low. The 1/270 ACE Arkansas River flood event results in overtopping of the mainstem of Levee C for 14 hours and is estimated to last for approximately one week. The non-breach life safety and economic risk matrices for this project are shown in Figure 2.5.

Confidence and Major Uncertainties

The SQRA team generally had Moderate confidence in the incremental risks described above, such that additional data may possibly change the assessed incremental risk. The key uncertainties are the location and condition of a significant number of conduits through the levee, as well as construction practices during their remediation and abandonment efforts; frequency of loading from tributary (Cherry Creek) flood events due to lack of stream gages along the tributary streams; uncertainty on whether the Southwest Blvd. closure section could be installed; material properties of the levee foundation and embankment; compaction records from the original levee embankment construction; and the present condition and effectiveness of the relief well/toe drain system. Loss of production, as well as health and environmental impacts from potential release of hazardous materials have not been quantified, likely underestimating the economic consequences portrayed in this risk estimate. Additional information that would

impact key factors could reduce uncertainty and have either positive or negative impacts to the incremental risk.

Levee Evaluation for NFIP

The TWT Levee C System was evaluated for breach and non-breach during the 1/100 ACE flood event in order to evaluate an initial screening related to NFIP requirements. Based on the current evaluation, non-breach risk is driven by overtopping of the tieback levee at the Southwest Blvd. crossing which overtops during a 1/50 ACE Cherry Creek flood event. Confidence in this estimate is Low to Moderate due to uncertainty in the frequency of loading. Additionally, the breach prior to overtopping evaluation indicates that PFM 24 was judged to have a Very High likelihood of failure (1/100 to 1/1,000), given a 1/25 ACE Tributary loading, with Low confidence. Due to the risk associated with the tieback levee overtopping and misoperation of the sandbag closure (PFM 24) prior to overtopping, it is unlikely that the TWT Levee System will meet the NFIP levee system evaluation requirements. This initial screening of the TWT Levee System also suggests that modifications to the levee system are needed to address breach prior to overtopping risk as well as the overtopping risk which will occur at the tieback levee for the system to be considered potentially favorable for NFIP accreditation. The risk assessment did not directly address internal drainage related flooding that could also impact NFIP mapping.

Levee Safety Action Classification (LSAC) Evaluation

The TWT Levee C is currently categorized as an overall LSAC 2, with an LSAC 3 for overtopping and an LSAC 2 for breach prior to overtopping based on the Levee Screening Tool. The primary reasons for this rating was the potential for inundation due to breach prior to overtopping, due to anticipated poor performance, in combination with loss of life and economics which was assessed to result in High Risk. The breach risk was attributed to closure issues as well as seepage and stability concerns.

Based on significant H&H efforts completed for this risk assessment, Levee C will experience incipient overtopping at a 1/240 ACE Arkansas River flood event and will overtop by 2 feet during a 1/270 ACE flood event. It is recommended that the LSAC for overtopping failure remain as LSAC 3 (Moderate risk) due to anticipated poor performance from overtopping flood events. The incremental risks for failure prior to overtopping were also assessed to be Moderate due to the potential misoperation of the sandbag closure at Southwest Blvd as well as anticipated poor performance due to the presence and unknown condition of penetrations through the levee, in combination with life loss and economic consequences. Therefore, it is recommended that the LSAC for failure prior to overtopping be reclassified LSAC 3. Due to the industrialized area behind Levee C, it is anticipated that additional economic losses due to loss of production, as well as environmental and health impacts related to the potential release of hazardous materials could occur. These costs have not been quantified in this risk assessment and are likely to increase the economic consequence estimates.

Based on this current risk assessment, it is recommended that the overall rating for Levee C be reclassified LSAC 3, since the likelihood of failure resulting in significant life threatening inundation economic and environmental consequences are estimated to be Moderate.

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

Incremental Life Loss

Incremental Direct Economic Loss

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

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

Figure 2.4: Incremental Life Safety & Direct Economic Loss Risk Matrix – Levees C

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

Figure 2.5: Non-Breach Incremental Life Safety & Direct Economic Loss Matrix – Levee C

2.3 2019 SQRA

The Southwestern Division Cadre (SWD), 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, E)

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

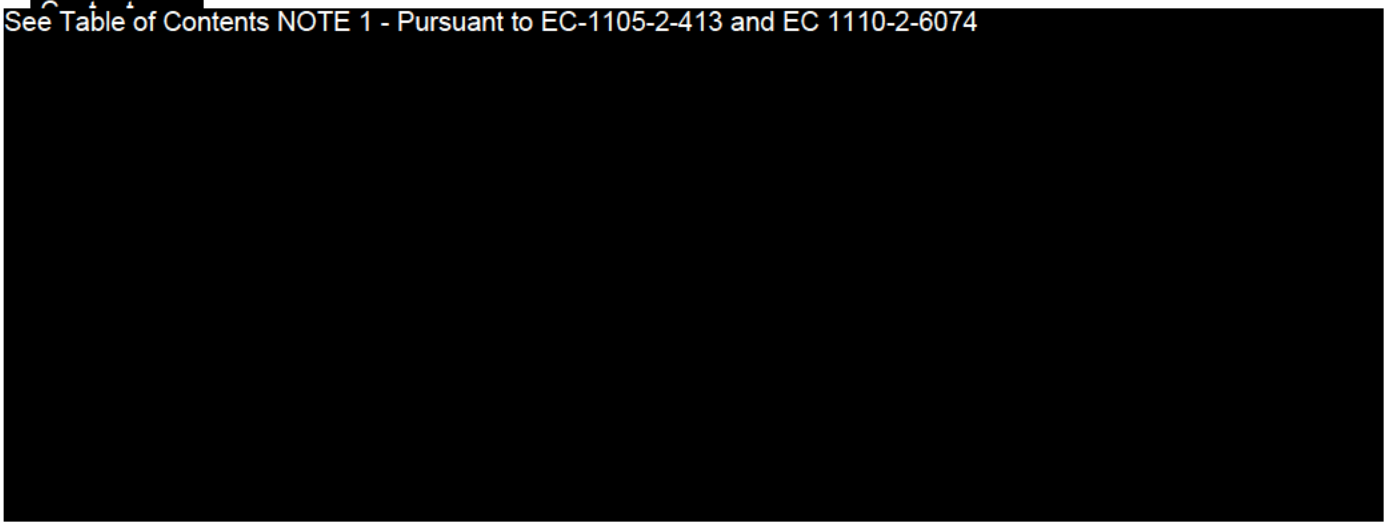
Alternative 5 – Nonstructural Buyout

Alternative 6 – No Action

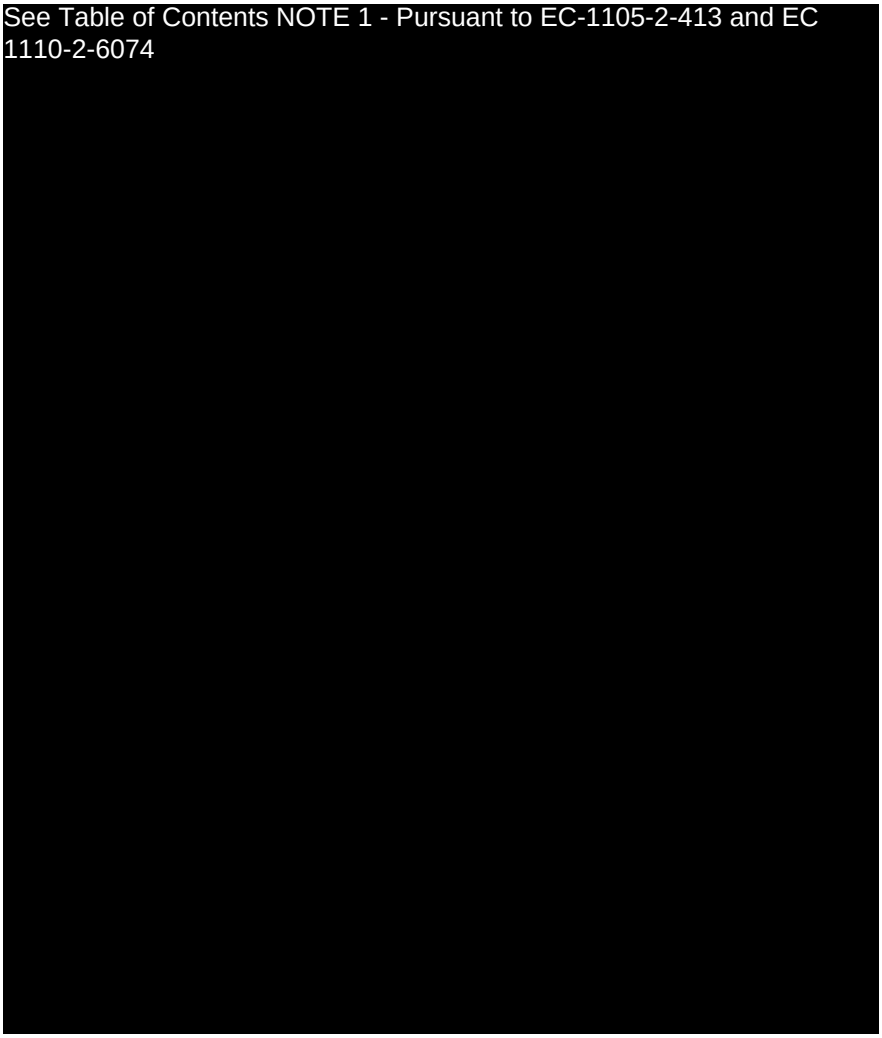
Alternatives 1A, 2A, and 3A were elicited for each levee. The B, C, and D alternatives were not elicited because they were similar to the A alternatives but had certain items left out. The team chose to do this based on the "A" option being the most comprehensive option for each alternative. The other 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 2.6) depict the updated baseline for each levee based on revised consequences followed by summarized charts for each alternative

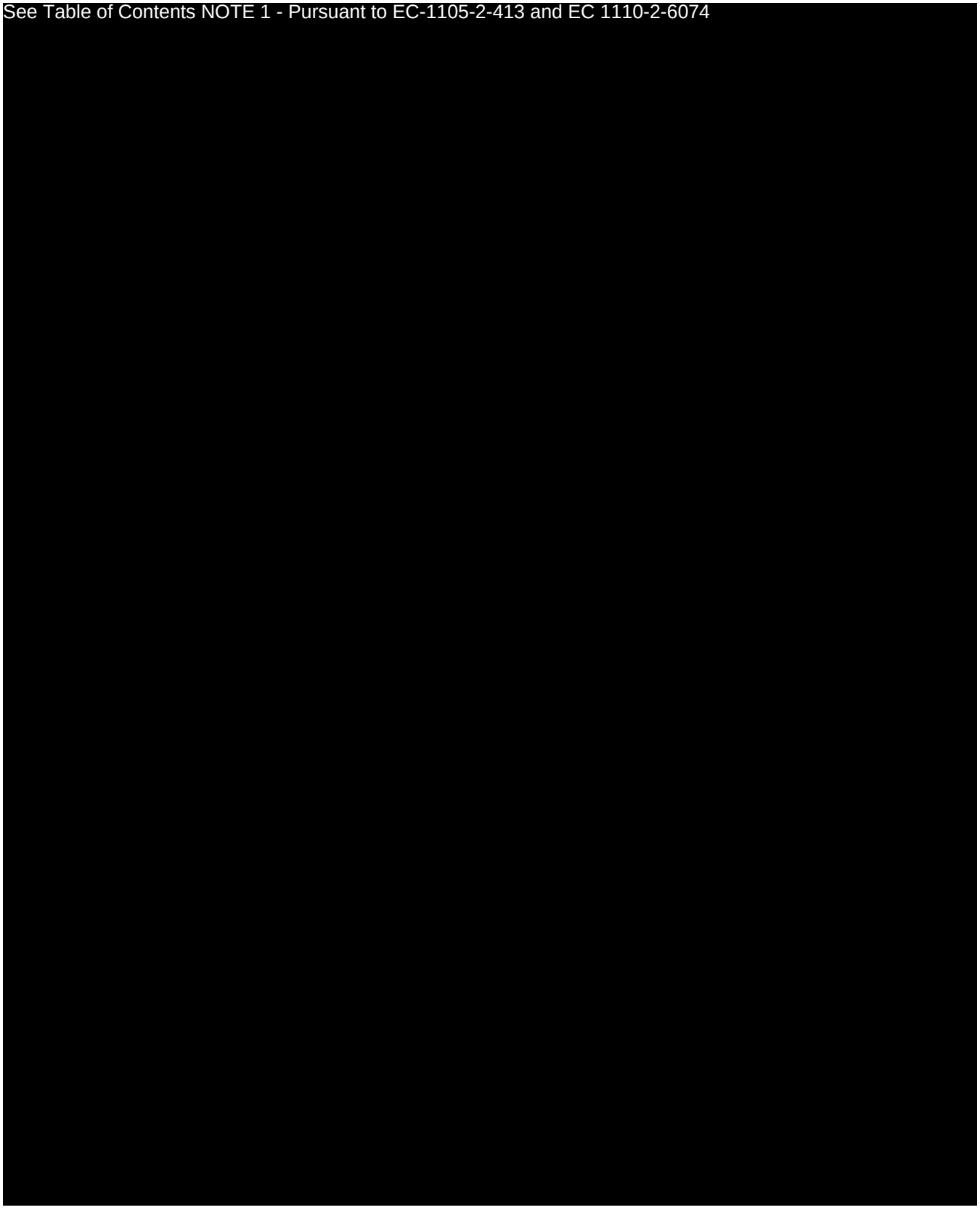
See Table of



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



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



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