5.0 DAM RISK INVENTORY

Since Storm 2006, the City of El Paso has performed a number of investigations and studies to address dam safety. These studies have included:

- Inspection of 22 dams to assess flood damage and current conditions (URS, December 2006);
- Hydrologic and hydraulic analyses of selected dams per Texas Commission on Environmental Quality (TCEQ) 2007 Guidelines (URS, February 2008);
- Concept designs and cost estimates for improvement of selected dams estimated to require upgrades per TCEQ Guidelines (URS, July 2008); and
- Preparation of an Emergency Action Plan (EAP) for 27 El Paso dams (URS, June 2008).

The above studies focused on current dam condition and hydraulic adequacy. The purpose of the dam risk assessment undertaken for the SMP was to address other modes of failure (e.g. piping failure) not considered previously, and to rank dam safety needs in terms of risk for prioritizing associated capital improvements.

5.1 Methodology

In 2004, the FEMA and American Society of State Dam Safety Officials (ASDSO), with the help of URS, developed a risk-based dam safety prioritization system for assessing an inventory of dams. The City of El Paso dams were evaluated using this system. This system is a simplified version of what is used by the United States Bureau of Reclamation (USBR). Risk, for the purposes of this section, is defined as the product of probability of failure and consequences of failure. The probability of failure for a given failure mode was estimated using the data available from previous studies (URS December 2006, February 2008, June 2008, and July 2008), information in the City of El Paso, and TCEQ files that were available at the time of the analysis.

The prioritization process:

- builds on the successful elements of various dam safety ranking systems currently in use;
- simplifies potential failure modes analysis and dam risk assessment processes;
- is based on accepted international standards; and
- is flexible and quantitative.

The process covers the most important failure modes for a wide variety of dam types and explicitly quantifies risks posed by different failure modes. This allows the likelihood of each failure mode and its consequences to be computed and graphed. The failure mode risk and overall dam risk quantified are compared against risk tolerability criteria.

Risk was only analyzed for failure modes where there was sufficient information to warrant an analysis. The failure modes evaluated for the El Paso Earthfill/Earth Rockfill Dams included:

- Threshold Failure Flood (failure due to flood overtopping);
- Piping Potential (failure due to internal erosion of the dam due to piping of fine material);
- Normal Stability (failure precipitated by a slope failure of the embankment);
- Emergency Spillway Erosion (failure due to headcutting erosion in the spillway during spillway flows that would affect the integrity of the dam);
- Principal Spillway/Outlet Conduit (failure of the dam due to a failing conduit system); and
- Piping along Conduit (failure of the dam due to piping of fines through the dam along the outside of a conduit).

Failure modes not analyzed:

- For Earthfill Dam: Earthquake (insufficient information on the seismic design criteria for the structures); and
- For Outlet Works: Tower Stability (failure mode is for earthquake loading and there was no information in the files on the design of the towers related to seismic criteria).

Most of the City of El Paso is in Seismic Zone 1, with some outlying areas in Zone 2. High Hazard Class dams in Zone 2 require special investigation (United States Department of Agriculture [USDA] Natural Resources Conservation Service [NRCS}, July 2005). A more current National Seismic Hazard Map released by the USGS in May 2008 shows the earthquake peak horizontal acceleration (PHA) that as a 10% chance of being exceeded in 50 years has a value between 4 and 5% g for El Paso (USGS, May 2008).

Some of the failure modes can only occur with a substantial sustained head of water impounded. A factor was applied to the probability of failure to account for the fact that the reservoirs are dry most of the year and only impound water for short periods after rain events.

The risk categorization of each dam was established by taking the calculated risk level and ranking its position consecutively relative to recognized risk criteria. Each dam was ranked by total risk and by individual failure mode risk. Risk categories parallel those used by the USBR and reflect different levels of risk used in this evaluation. The risk categories used for the El Paso dams are:

- Priority A - Annualized risk greater than 10^{-2} (1 in 100);
- Priority B - Annualized risk between 10^{-3} and 10^{-2}; and
- Priority C - Annualized risk less than 10^{-3} (or 1 in 1,000).

These risk values are not analogous to an annual probability, such as the 0.01 annual exceedance probability associated with a flood with a 100-year return period, for two basic reasons:

1) Risk is a multiple of an estimated probability of event (in this case dam failure) occurrence times a numerical value for potential consequences. The 100-year flood only reflects an estimated probability of event (in this case a flood of an estimated magnitude);

2) The 100-year flood is statistically derived from storm or flow data collected at local gauges, and as such, typical statistical parameters such as confidence limits can be used to define the accuracy of the return period estimate. For the dam risk analysis both the estimated probability of event (dam failure) and the estimated consequences are consensus-based values derived from nationwide dam engineering professionals; and their purpose is to provide a profession-wide basis for identification of structures that have issues to be considered for action. There is no statistical means to estimate confidence limits or other accuracy indicators on the values selected.

5.2 Dam Analysis Results

A complete presentation of risk assessment results is in Appendix D. The most useful means to review the assessment results is to focus on two aggregations of the failure modes: overtopping (i.e. risk due to hydraulic inadequacy) and piping/conduit, and to review those results separately.

Figure 5-1 shows the risk by piping and conduit failure modes and expresses the probability of failure of the 24 dams. According to Figure 5-1, analyzing only piping and conduit failure modes, 10 of the 24 El Paso dams receive Priority A classification. Of the remaining dams, 11 dams are Priority B, and 3 dams are below Priority C. An analysis of this risk demonstrates that the consequence of failure (e.g. lives at risk) rather than probability of failure drives the high risk ranking in almost all cases. In other words, the density of population downstream of the dam is so high that even a low risk of failure results in the failure mode receiving priority attention.

Figure 5-2 presents the results of the risk analysis for the overtopping flood failure mode. This analysis shows that when considering flood failure mode alone, only 5 of the 24 El Paso dams receive Priority A classification, 1 dam is Priority B, 2 dams are Priority C, and the remaining 12 dams are below Priority C. This clearly demonstrates that the risk of dam failure due to overtopping of the dam is not a major concern for the majority of the dams. The five Priority A dams for flood failure mode are Van Buren Dam, Dam 7, Dam 4, Dam 3, and Dam 2. The return period for the storms estimated to cause overtopping of these Priority A dams are each substantially less frequent than the 1,000-year flood; i.e. the risk of overtopping is substantially less than the risk of flooding associated with each project identified in Section 6.0. As with piping and conduit failure, a review of this analysis shows that the consequences rather than the probability of failure are the driving force behind the high-risk values. The elevated estimated risk of these dams is created by the large populations located immediately downstream. These dams are all in the Central Watershed.

5.3 Recommendations

The dam safety-related projects recommended for inclusion in the CIP derive from three sources: the risk analysis (discussed above), previous dam inspection, and previous study of hydraulic adequacy per TCEQ rules.

5.3.1 Recommended Projects per Dam Risk Analysis Study

It should be noted that the seismic-related failure modes were not analyzed due to lack of information in the files regarding seismic design basis of the embankments or the outlet works. Based on El Paso's seismic region, it is very likely that many dams could be classified as high risk (above Priority A line) due to seismically inadequate design based on current standards. Notwithstanding the seismic failure modes, the following recommendations are based on the above-described dam risk analyses, in order of priority in terms of dam safety risk.

Upgrade of Dam 9. The existing corrugated metal pipe (CMP) principal spillway would be replaced by a reinforced concrete pipe (RCP) principal spillway. An upgrade to modern construction with concrete cylinder pipe and filter protection to prevent piping along the conduit would lower the probability of failure and resulting total risk several orders of magnitude.

Upgrade of Van Buren Dam. The concept design for this project is provided in *Concept Designs And Cost Estimates For Improvement Of Selected Dams Estimated To Require Upgrades Per TCEQ Guidelines* (URS, July 2008), and consists of the following major components:

- Install roller compacted concrete (RCC) stepped spillway;
- Install parapet wall (maximum height approximately 5 feet) around the top of embankment;

- Plug one of the two 72-inch CMP outflow pipes;
- Excavate area in southwest corner of reservoir; and
- Install stilling basins and line outflow channel to protect against erosion and reduce velocities downstream.

Upgrade of Keystone Dam. Construct a toe drain system to mitigate seepage per previous URS Technical Memos (URS, February 2008). This project will lower the probability of failure due to seepage-induced piping in the embankment. Inspections by TCEQ (TCEQ, September 2006) and URS (URS, February 2008) each noted the presence of ongoing seepage through Keystone Dam.

Early Warning System Development. Ten additional dams have estimated risk above the Priority A line and no recommended capital improvements. In this circumstance (low, but apparent probability of failure coupled with high consequences of failure), the recommendation is for the installation of early warning systems/procedures to address the elevated risk. A project is recommended for the CIP to design and implement early warning procedures.

5.3.2 Recommended Project per Previous Dam Inspection

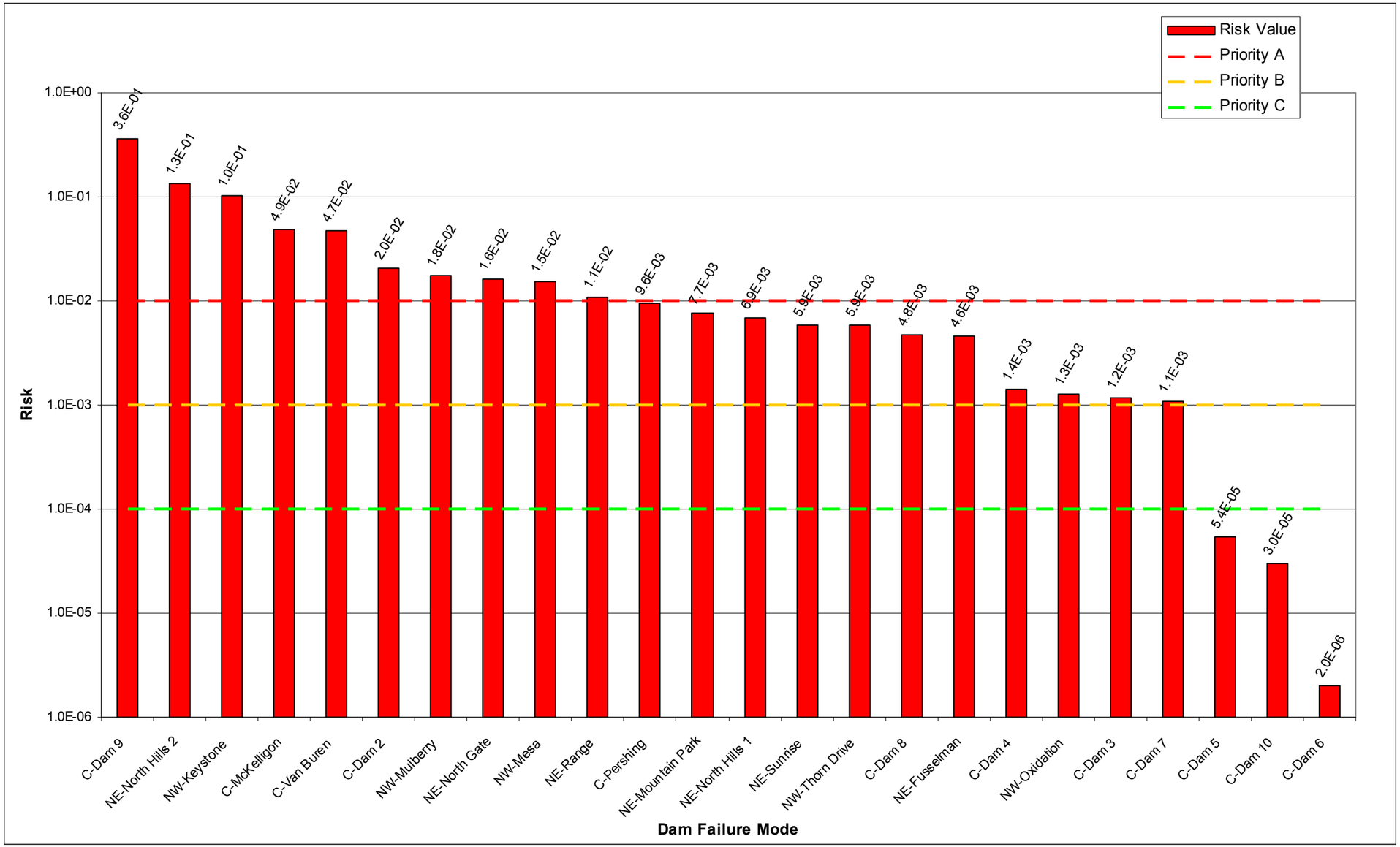
Upgrade of Pershing Dam. The Storm 2006, coupled with the 2008 URS inspection of Pershing Dam, helped to identify the lack of flood pool between the elevation of the principal spillway and auxiliary spillway. URS developed a concept design to address this issue (URS, July 2008). Since the lack of flood pool results in relatively high frequency flooding, this project should be allocated a relatively high priority within the CIP.

5.3.3 Recommended Projects per Previous Study of Hydraulic Adequacy per TCEQ Rules

A previous study (URS, February 2008) by URS of a selected series of El Paso dams identified Dam 4, Dam 5, Dam 10, Keltner Dam, and Van Buren Dam as not meeting TCEQ standards for hydraulic adequacy. Concept designs to meet TCEQ standards and to provide additional benefits (e.g. expand the flood pool) were developed as a follow-on (URS, July 2008) for these structures.

Since the development of these designs, TCEQ issued proposed revised dam safety rules (TCEQ, 2008) which revised the definition of a regulated dam. This new definition is expected to be adopted by TCEQ in 2009. In the previous definition, a dam was a structure over 6 feet in height (with no volume stored criterion); in the revised definition, dams of relatively tall height (up to 70 feet tall) but very small storage (15 acre-feet or less) are excluded from Texas Dam Safety Regulation. Based upon the new definition, Dam 4, Dam 5, Dam 10, and Keltner Dam are each excluded from Texas Dam Safety Regulation; only Van Buren Dam will be regulated by TCEQ.

All five of these improvements are recommended for inclusion in the CIP, but it is recommended that improvement of Van Buren Dam receive significantly higher priority than improvement of the other structures, which will no longer be considered regulated.



Risk Profile by Piping and Conduit Failure Modes

El Paso Stormwater Master Plan

Date: 03/05/2009 | Figure 5-1

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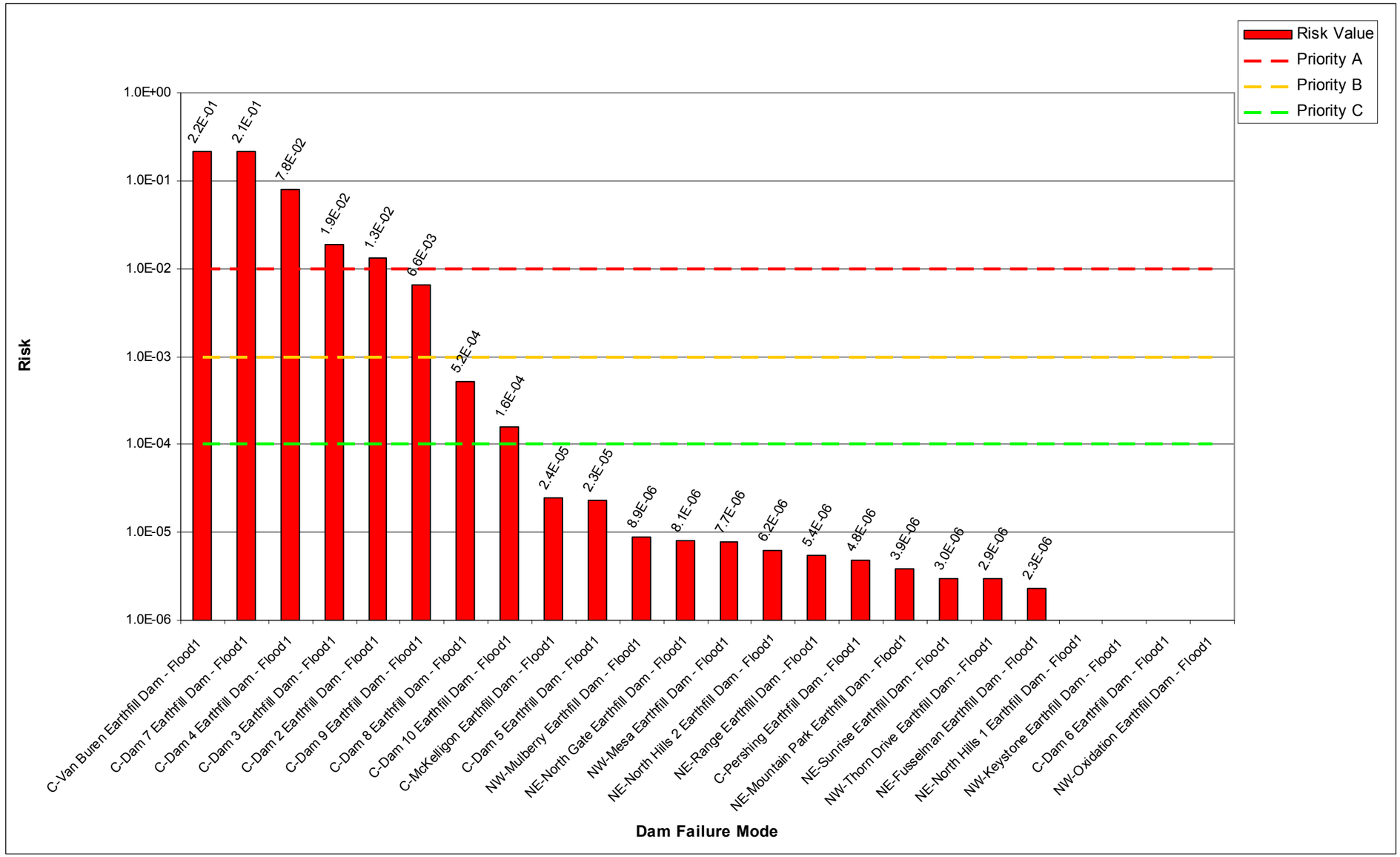

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Risk Profile by Flood Failure Mode

El Paso Stormwater Master Plan

Date: 03/05/2009 | Figure 5-2