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Risk Analysis Memorandum
McMicken Dam
Fissure Risk Zone Remediation Project
Contract FCD 2002C011, Work Assignment No. 1

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Submitted to:

Flood Control District of Maricopa County
Phoenix, Arizona

Registered Professional Engineer (Civil)
CERTIFICATE NO.
13872
LAWRENCE A.
HANSEN
Date Signed 9/17/03
ARIZONA, U.S.A.

Submitted by:

AMEC Earth & Environmental, Inc.
Phoenix, Arizona

17 September 2003

AMEC Job No. 2-117-001066

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Bobbie Ohler, P.E.
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009-6399

Dear Ms. Ohler:

Re: Risk Analysis Memorandum
McMicken Dam Fissure Risk Zone Remediation Project
Contract FCD 2002C011, Work Assignment No. 1

Transmitted herewith are eight copies of the Risk Analysis Memorandum for the McMicken Dam Earth Fissure Risk Zone Remediation Project. The memorandum details the procedures and results of the risk analysis workshop held on 4 and 5 February 2003. The memorandum also presents a summary of the important conclusions drawn from the results of the workshop.

Should you have any questions, please do not hesitate in contacting the undersigned.

Respectfully submitted,

AMEC Earth & Environmental, Inc.

Registered Professional Engineer (Civil)
CERTIFICATE NO. 13872
LAWRENCE A. HANSEN
9/17/03
Date Signed
ARIZONA, U.S.A.

Lawrence A. Hansen, Ph.D., P.E.
Senior Vice President

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c: Addressee (8)
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1.0 INTRODUCTION

This memorandum, which was prepared by AMEC Earth & Environmental, Inc. (AMEC), presents the results of a risk analysis of selected alternatives developed for the modification of McMicken Dam. The alternatives considered were selected on the basis of an initial screening and secondary screening process completed by AMEC in conjunction with Stantec Consulting, Inc. (Stantec) and the Flood Control District of Maricopa County (FCDMC, referred to herein as the District). The purpose of the structured risk assessment was to quantify the potential risk associated with each alternative considered. The design concepts were developed at a reconnaissance level of detail only to allow comparison of the alternatives. The initial list of alternatives and the alternatives analysis process are intended to satisfy the US Army Corps of Engineers (USACOE) 404b(1) process, including consideration of potential environmental and land use consequences.

This memorandum was prepared as part of the alternative analysis being completed for the District. The alternative analysis is being conducted for the District in accordance with the McMicken Dam Fissure Risk Zone Remediation (FRZR) Project, Work Assignment 1 of Contract FCD 2002C011 between AMEC and the District. The purpose of the McMicken Dam FRZR Project is to mitigate the risk associated with the earth fissures that have been identified near the south end of the dam, and which may intersect the dam and its foundation. The intent of the alternatives analysis process is to select a preferred alternative for mitigation of the fissure risk zone, thereby enhancing the safety of dam. The final report for the project will present a preliminary design (15 percent plans) for the preferred alternative.

2.0 RISK ANALYSIS PROCESS AND INPUT PARAMETERS

2.1 Background

The structured risk analysis workshop was completed on 4 and 5 February 2003. Larry Von Thun, P.E., a consultant retained by AMEC, was the facilitator for the analysis. He also is the principal reviewer of this draft report summarizing the findings of the risk analysis. The risk analysis workshop included the following participants:

- Lawrence A. Hansen, Ph.D., P.E., AMEC
- Ralph E. Weeks, P.G., AMEC
- Tom R. Renckly, P.E., FCDMC
- Larry K. Lambert, P.E., FCDMC
- Bobbie Ohler, P.E., FCDMC
- Michael D. Greenslade, P.E., FCDMC
- George H. Beckwith, P.E., FCDMC
- Bob Stevens, FCDMC

- Charles V. Gopperton, P.E., Stantec
- George V. Sabol, Ph.D., P.E., Stantec
- Jon Benoist, P.E., Arizona Department of Water Resources

All of the participants have had previous involvement with projects completed for McMicken Dam, either in an investigation capacity or in a review capacity, and have been involved with the on-going alternatives analysis.

Prior to the risk analysis workshop, AMEC provided Mr. Von Thun with several documents pertaining to McMicken Dam for his review prior to the meeting. These included:

- A presentation on the Fenne Knoll earth fissures located near the southern end of the dam,
- The draft initial screening report prepared by AMEC,
- The 1982 geotechnical investigation report prepared by Sergent, Hauskins & Beckwith,
- The 2002 geotechnical investigation report prepared by AMEC,
- The 2002 earth fissures investigation report prepared by AMEC,
- The subsidence data review prepared by the District, and
- The 2002 draft structure assessment report prepared by URS Corporation.

Mr. Von Thun considered various data and observations presented in these documents in establishing an agenda for the workshop and in establishing the conditions required for failure of the alternatives considered in the workshop.

2.2 Procedural Aspects

The risk analysis addressed only the issue of potential failure related to the existence of an earth fissure, since a separate failure modes and effects analysis addressing other potential failure modes had been completed for McMicken Dam by others. Further, the risk analysis was limited to alternatives for mitigation of the section of the dam located in the high hazard zone. In general, risk is defined as the risk of a particular adverse outcome given a particular loading condition:

$$\text{Risk} = P_L \times P_{F/L} \times \text{Adverse Consequence}$$

where:

P_L = load probability, and
$P_{F/L}$ = probability of failure given the load.

It is noted that an adverse consequence has a probability component (P_c) and a magnitude component.

In general, the risk is computed for various alternatives and compared to a base condition, in this case, that of not modifying the existing dam to provide protection against the presence of an earth fissure. However, determination of the consequences of failure, such as economic loss or the number of lives at risk, was not completed prior to the workshop, and the analysis was limited to the computation of the first two terms in the above equation. However, it was agreed by the workshop participants that breaching of the dam with a full impoundment level would have a high consequence (Consequence A) in terms of both economic loss and the likelihood that loss of life could occur. It was also agreed that breaching of the dam with only a low impoundment would have a lower consequence (Consequence B) with lower economic loss and much less likelihood that loss of life could occur. A third consequence (Consequence C) was defined as loss of the reservoir through seepage without a breach occurring and, thus, would have an even smaller economic loss than Consequence B and no loss of life. A fourth consequence (Consequence D) was associated with specifically defined events having less water available and, thus, would have a much lower economic loss than Consequence C.

The load probability (P_L) is the probability of a flood event occurring within a given range. The load probability is presented in Table 1 for a series of flood ranges encompassing the 25-year return event to the Probable Maximum Precipitation (PMP) event. In comparison, the stage behind McMicken Dam for events with various return frequencies is listed in Table 2. Comparing Tables 1 and 2, the crest of the emergency spillway (elevation 1354 feet) is approximately equal to the stage of the 100-year return event. Mr. Von Thun proposed and the workshop participants agreed that the lowest stage elevation of concern to the potential failure of the dam is about 1351 feet, which corresponds to about the stage of the 25-year return event. Thus, two flood load ranges were defined: the range represented by the 25-year to the 100-year events, which has a total probability of occurrence of 0.03 and results generally in Consequence B; and the range represented by the 100-year to PMP events, which has a total probability of 0.01 and results generally in Consequence A.

For each of the alternatives considered, the probability of failure given the load probability ($P_{F/L}$) was determined by establishing a series of conditions leading to a consequence, or an event tree, and then having the workshop participants individually estimate the probability of the initial condition occurring, and estimate the probability of a following condition occurring given that the preceding condition has occurred. Prior to assessing these estimates, factors related to the likelihood of the condition occurring were discussed and tabulated. Generally, the initial condition for failure was that an earth fissure was present beneath the existing dam, or would develop at the onset of flooding, beneath the alternative structure being considered that could pass water under the existing dam or the alternative structure. The annual probability of occurrence of a consequence was then determined as the product of the flood load range and the probabilities of the various conditions leading to failure or another consequence. Median, average, high and low estimates of the annual probability of occurrence were determined for each consequence.

The chance or likelihood (L) that an event will occur can be computed as:

$$L = 1 - (1-P)^n$$

where:

P = the annual probability of occurrence, and
n = the number of years being considered (100 for this study).

The likelihood of occurrence was computed for some of the computed probabilities and is discussed for comparative purposes in the analysis results for the alternatives presented in Section 3 of this report.

2.3 Alternatives Considered

The workshop participants initially addressed the existing section of McMicken Dam located in the high hazard zone, since the alternatives analysis focused on mitigation of only this zone. Alternatives representative of each of the three broad categories of mitigation were proposed for further analysis by Mr. Von Thun and agreed to by the workshop participants. These included rehabilitation of the existing structure by construction of a new embankment dam located immediately upstream of the existing structure (Alternative 3A), by construction of a new embankment dam or dam extension within the impoundment (Alternative 4A2), and by segmenting the existing dam by constructing a dam extension within the impoundment (Alternative 5C) and allowing a low volume of water to be impounded by the existing dam or contained within a basin. A fourth alternative, rehabilitation of the existing structure by construction of a roller compacted concrete (RCC) dam located immediately downstream of the existing dam (Alternative 3E), also was considered in the analysis.

Conceptual design details for each of the alternatives were presented to the workshop participants. Design sketches depicting these design details are not presented in this report, but are included in the secondary screening report. Key components of the mitigation alternatives that are pertinent to a risk analysis addressing the impact of potential earth fissures include the following:

- Alternatives 3A and 3E will be constructed in the high hazard zone. These alternatives include removal of the erosive Holocene soils and construction of two cutoffs extending 15 feet into the underlying Pleistocene soils. The barriers will be constructed of a flowable backfill and will have a geomembrane liner on their upstream face. The two barriers are intended to protect against erosion of earth fissures and to increase the flow path under the new structures, thus minimizing the exit gradient at the downstream toe of the structure. A geomembrane barrier at the foundation between the two cutoffs also is proposed for Alternative 3A to protect the embankment against erosion. Both alternatives include upstream geomembrane/geotexile barriers to flow through the new structures, which are connected to the cutoff located nearest to the upstream face of the embankment.

- Alternatives 4A2 and 5C include the same defensive procedures described for Alternative 3A, where the new dam or the dam extension is located within the moderate hazard zone. However, for Alternative 4A2 where the new dam or dam extension is located within the low hazard zone, the design includes removal of the Holocene soils, but does not include construction of cutoffs extending into the Pleistocene soils. Alternative 5C includes construction of a northern and a southern dam extension, with the northern dam extension segmenting the structure such that the section of the existing dam within the high hazard zone impounds flows from only the much smaller watershed located directly upstream of this section of the existing watershed. A diversion channel intended to divert flow from the much smaller watershed will be located between the new north and south structures and a small gated outlet will be constructed to pass collected flows.

As a final part of the workshop, the participants also discussed and tabulated the factors influencing other considerations related to the alternatives analysis. These considerations included locating the new dam or dam extension upstream (Alternative 5C) rather than constructing it adjacent to the existing McMicken Dam (Alternative 3A), and constructing a new RCC or soil cement structure (Alternative 3E or 3H) rather than an embankment structure. The tabular summaries of these discussions are presented in Section 3 of this report.

3.0 RISK ANALYSIS RESULTS

3.1 Overview

Details and results of the risk analysis are presented in the following appendices to this report:

- Appendix A --- Existing McMicken Dam located in the high hazard zone,
- Appendix B --- Alternative 4A2, upstream embankment, without dam extension,
- Appendix C --- Alternative 5C, dam extension that segments the existing dam,
- Appendix D --- Alternative 3A, adjacent upstream embankment, and
- Appendix E --- Alternative 3E, adjacent downstream RCC dam.

The format of the appendices, generally, is to present, in order, the conditions leading to an adverse response, the factors influencing the probability that the conditions will occur, and estimates of the probabilities of the conditions occurring. Typically, the analysis for the lower flood range (25-year to 100-year event frequency) is presented first, followed by the analysis for the higher flood range (100-year to PMP event frequency). The computed probabilities for the resulting consequences are then presented in a summary table.

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3.2 Existing McMicken Dam in High Hazard Zone

The team established three steps or conditions that would need to occur for a failure or adverse response at McMicken Dam (see page A-1). The initial condition (Condition 1) that would lead to a potential adverse response of the existing McMicken Dam in the high hazard zone is the potential presence/development of a fissure that will pass flow under the dam. Subsequently, the fissure could erode in a manner that produces potentially erosive flow at the foundation contact, or creates a cavity in the foundation that allows flow from the dam (Condition 2). The dam then either erodes, collapses and breaches leading to either Consequence A or Consequence B, depending on the flood level loading, or survives with a foundation tunnel developing and the dam being less affected leading to Consequence C for either flood level loading (Condition 3). The factors influencing the probability that these conditions will occur, as determined by the workshop participants, are listed on pages A-2 through A-3.

Estimates of the probability of each condition occurring are listed on page A-5 for the lower flood level loading and on page A-8 for the higher flood level loading. In general, the workshop participants estimated a higher probability of adverse consequence occurrence under a higher flood loading for each of the three conditions. For the initial condition, a median probability of 0.50 was estimated for the lower flood loading compared to a median probability of 0.60 for the higher flood loading. Similarly, the estimated median probabilities for the lower and higher flood loadings are 0.85 and 0.90, respectively, for the second condition and 0.50 and 0.75, respectively, for the third condition.

The workshop participants also considered a local storm event occurring only within the three small subbasins located upstream of the high hazard zone. It was assumed that the storm would need to be a 500-year return event, or larger, to initiate an adverse response (comparable to a general storm impacting the entire dam that ponds water to an elevation of about 1354 feet). It was judged that the consequence of such an event, designated Consequence D, would be much less adverse, given that much less water would be available. The median probability of the consequence occurring was determined to be 0.00043, as presented on page A-11, or an order of magnitude less than the median probabilities determined for Consequences A, B and C.

As determined by multiplying through the probabilities estimated for each branch of the event trees included in Appendix A and summing as appropriate to obtain the total for each consequence, the median total annual probabilities for Consequences A, B and C are 0.0041, 0.0064 and 0.0078, respectively, as presented on page A-12. The somewhat higher condition probabilities determined for the higher flood loading are offset by the lower probability of this flood loading occurring (0.01) as compared to the probability of the lower flood loading occurring (0.03). The range in probability of occurrence estimates is similar for each of the consequences, varying from a low of 1.0×10^{-4} or slightly less to 0.01 or slightly higher. The corresponding likelihood (median value) of Consequences A, B and C occurring are 34%, 47% and 54%, respectively.

As a point of reference/information only, the team considered a flood loading of the 10,000-year or greater return event only, as presented on page A-11. The contribution of this event to median probabilities of Consequences A and C was determined to be 0.41×10^{-4} and 0.14×10^{-4}, respectively.

3.3 Alternative 4A2 (New Dam)

Risk analysis of Alternative 4A2 initially was completed for the lower flood loading, considering separately the sections of new embankment located in the moderate and low hazard zones, and the differing defensive design features proposed for these zones. The adverse response is Consequence B, the same as that for the existing dam in the high hazard zone for the lower flood loading.

As with the existing dam, the initial condition leading to an adverse response scenario of the new embankment dam (see page B-1) is the presence of a fissure that will pass flow under the dam. Subsequently, for an adverse response to occur within the moderate hazard zone, the water must bypass the cutoffs provided and reaches the embankment toe with enough force to cause erosion (Condition 2), then a progressive breach occurs resulting in failure of the new dam (Condition 3). Finally, failure of the existing McMicken Dam occurs as a result of flow through an upstream fissure present beneath the dam (Condition 4). The factors influencing the probability that these conditions will occur, as determined by the workshop participants, are listed on pages B-2 through B-4.

Estimates of the probability of the conditions occurring are listed on page B-5. The median probability estimated for an earth fissure being present under the new dam, or developing during the flooding, that will pass flow was 0.20, which appropriately is less than the median probability of 0.50 estimated for the existing dam in the high hazard zone. The varying opinions of the workshop participants concerning the effectiveness of the cutoffs in impeding flow is indicated by the estimates of Condition 2 occurring varying from 0.001 to 0.85, with a median of 0.02. The high probability of 0.85 estimated by one participant is based on the consideration that there would be no impediment to flow. The opposing consideration is that the water could just as readily flow downward into the fissure. A similar broad range in estimated probabilities of Condition 3 occurring, 0.0001 to 0.05 with a median of 0.01, was recorded, with some consideration that sufficient water and time would not be available to cause a breach of the new structure. The median probability of failure of the existing dam in the high hazard zone was estimated to be 0.21, as indicated on page B-5. This probability was reduced to 0.10, considering that the new dam would have to fail first, and the resulting more controlled release (and less probable length of earth fissure) would lower the probability of failure of the old dam.

Event trees showing the probability of Consequence B occurring are presented on pages B-6 and B-7.

The initial condition leading to an adverse response is the same for the new dam in the low hazard zone (see page B-8), followed by the water causing erosion of the native soils along the foundation contact between the native soils and the embankment, resulting in failure of the new dam (Condition 2). The final event again is failure of the existing dam (Condition 3). The factors influencing the probability that the first two of these conditions will occur, as determined by the workshop participants, are listed on pages B-9 and B-10.

Estimates of the probability of the conditions occurring are listed on page B-11. The median probability estimated for an earth fissure being present under the new dam within the low hazard zone that will pass flow was 0.05, which appropriately is less than the median probability of 0.20 estimated for the new dam in the moderate hazard zone, and an order of magnitude less than the median probability of 0.50 estimated for the existing dam in the high hazard zone. The range of estimated probabilities for Condition 2 occurring is relatively narrow, 0.01 to 0.20 with a median of 0.10. The workshop participants agreed to a probability of failure of the old dam of 0.10, as discussed above for the new dam in the moderate hazard zone. Decision trees listing the probability of Consequence B occurring are presented on pages B-12 and B-13.

In considering the higher flood loading, Mr. Von Thun proposed and the workshop participants agreed, as a short cut to the risk analysis, to address the question "How much worse is the higher flood loading (1/100 yr – 1/PMP) than the lower flood loading (1/25 yr – 1/100 yr) ?" in assessing an adverse response of the new dam in each of the hazard zones. Estimates in response to this question in the form of factors of 1.0 or larger were tabulated separately for the new dam in the moderate and low hazard zones, as presented on page B-14. For the moderate hazard zone the factors ranged from 1.00 to 1.25 with a median of 1.10, indicating the participants were of the opinion that there is little difference in response to flood loading. For the low hazard zone, the factors ranged from 1.00 to 2.00 with a median of 1.20, indicating a slightly greater impact.

Considering the larger volume of water available and the longer duration of the event, it was agreed that Consequence A would result from a failure under the higher flood loading. The probability of occurrence of Consequence A was then computed by factoring the previous risk analysis results for the lower flood loading by the ratio of the probabilities of the flood loadings occurring (0.01/0.03) and the factors estimated. The analysis results are presented on pages B-15 and B-16.

The median total annual probability estimates of Consequences A and B occurring are presented in the summary table on page B-17. These were obtained by summing the contributions for the moderate and low hazard zones for each of the consequences. Leaving the existing McMicken Dam in place, rather than removing it to provide material for the new dam, provides an added degree of protection – i.e., reduces the failure of probability of either Consequence A or Consequence B occurring by a factor of 10. The total annual probabilities are listed separately for the existing dam left in place or removed. With the existing dam remaining, the median total estimated annual probability of Consequence A occurring is 0.60 x 10^{-5} with a range of 0.10 x 10^{-6} to 0.08 x 10^{-4}, and the median total annual probability of Consequence B occurring is 0.15 x 10^{-4} with a range of 0.30 x 10^{-6} to 0.16 x 10^{-3}. The corresponding likelihood (median value) of Consequences A and B occurring are 0.06% and 0.15%, respectively. Thus, the likelihood for significant adverse consequences (A or B) with Alternative 4A2 is approximately two orders of magnitude less than the value calculated for the existing McMicken Dam in the high hazard zone.

3.4 Alternative 5C (Dam Extensions Avoiding the High Hazard Zone)

As a result of the risk estimates for Alternative 4A2, the workshop participants noted that a greater portion of the risk came from the section of the new dam in the low hazard zone than from the section in the moderate hazard zone. This was due to the provision of cutoffs for the part of the dam in the moderate hazard zone. Thus, a revision to Alternative 5C was made during the workshop to include cutoffs in the section of the extension through the low hazard zone. This change in design is accounted for below.

Alternative 5C includes dam extensions at locations similar to the location of the new dam of Alternative 4A2, and a diversion structure connecting two dam extensions. For the risk analysis the northern dam extension located in the moderate hazard zone is the same as the section of the new dam of Alternative 4A2 located in the moderate hazard zone. Thus, the risk estimates are the same. However, for the risk analysis the southern dam extension located in the low hazard zone was assumed to have two cutoffs extending into the Pleistocene soils, the same as the northern dam extension located in the moderate hazard zone. As with the analysis for Alternative 4A2, the lower flood loading results in Consequence B and the higher flood loading results in Consequence A.

The computed probabilities for the northern dam extension (which are identical to Alternative 4A2) for the lower flood loading are listed on page C-2 and for the higher flood loading on page C-3. As for Alternative 4A2, the computed probabilities considering the existing McMicken Dam remains or is removed are both listed. For the southern dam extension (low hazard zone), the risk estimate was obtained from the previously computed probabilities for Alternative 4A2 by simply factoring the ratio of the probability that an earth fissure that will pass flow is present in the low hazard zone to the probability that an earth fissure that will pass flow is present in the moderate hazard zone. For example, the computed median probability, as indicated on pages C-2 and C-3, is reduced by a factor of 0.05/0.20, or 0.25. Thus, it can be seen that rather than the low hazard zone contributing a greater portion of the risk (as it did for Alternative 4A2), it now contributes only one-quarter of the risk associated with the moderate hazard zone.

A separate failure mode of the existing McMicken Dam left in place under this alternative and impounding a small amount of water was considered. This scenario assumed the dam extensions remain, but the diversion channel fails as a result of an earth fissure or because it is obstructed, and flow is impounded behind the existing McMicken Dam or in a constructed basin. The probability of this adverse consequence (Consequence D) was not re-computed, as indicated on page C-1, but was reasonably assumed to be the same as the probability of failure of the existing dam in the high hazard zone for the lower flood loading. The median probability is 0.0064 with a range of 1.0×10^{-4} to 0.025.

Discussion of this potential failure mode, and the flood loading from the much smaller watershed, indicated that a northern dam extension with a diversion channel, a diversion structure, a containment basin or none of these features would have essentially the same risk, and Consequence D would result. The probability of avulsion of an adjacent watershed located to the south into the watershed located directly upstream of the section of McMicken Dam outside of the influence of the dam extension also was discussed. It was agreed by the workshop participants that the probability of avulsion would be the same as the occurrence of the PMP event, or 0.0001 or less, and that Consequence D likely would result.

The median estimated total annual probabilities of Consequences A and B occurring for Alternative 5C are presented in the summary table on page C-4. The estimated total annual probabilities are listed separately for the existing dam left in place or removed. With the existing dam remaining, the median total annual probability of Consequence A occurring is 0.55×10^{-6} with a range of 0.10×10^{-10} to 0.45×10^{-4}, and the median total annual probability of Consequence B occurring is 0.15×10^{-6} with a range of 0.33×10^{-10} to 0.11×10^{-3}. The corresponding likelihood (median value) of Consequences A and B occurring are 0.01% and less than 0.01%, respectively. In comparison, the likelihood of Consequence D occurring is 47%.

3.5 Alternative 3A (New Embankment Dam Immediately Upstream of the Existing McMicken Dam)

The initial condition leading to an adverse response of a new dam located upstream of the existing McMicken Dam in the high hazard zone (see page D-1) is the presence of a fissure that will pass flow under the dam. Subsequently, the fissure could bypass the cutoffs of the new embankment and erode the Holocene soils present under the existing McMicken Dam (Condition 2). The existing dam then erodes, collapses and breaches (Condition 3). Finally, flow at the toe of the new dam results in erosion and failure of the new dam, leading to either Consequence A or Consequence B, depending on the flood loading (Condition 4). The factors influencing the probability that Conditions 2 and 3 will occur, as determined by the workshop participants, are listed on pages D-2 and D-3.

For the lower flood loading, which results in Consequence B, the probability that an earth fissure is present that will pass flow under the dam was assigned the same probability as that for the existing McMicken Dam in the high hazard zone, as indicated on page D-4. Estimates of the probability of Conditions 2 and 3 occurring for the lower flood loading also are listed on page D-4. A median probability of 0.01 with a range of 0.001 to 0.05 was estimated for Condition 2, and a median probability of 0.001 with a range of 0.0001 to 0.02 was estimated for Condition 3. These relatively large ranges in estimates reflect the varying assessments of the workshop participants of either of these conditions occurring.

For the lower flood loading, there was discussion of the nature and sequence of how the new dam would fail. In one case the controlling judgment was based on the likelihood of there being enough time and water after erosion of the existing dam to erode and fail the new dam. In the second case, the controlling judgment was the likelihood that something had already happened to the new dam in the process of failure of the existing McMicken Dam, resulting in the probability of the breach or collapse of the new dam being higher. Two of the participants were of the opinion that the latter was more likely and estimated a probability of 0.01 for this condition. The median probability estimated by the remaining participants was 0.001 with a range of 0.0001 to 0.005. These varying opinions were carried forward in the risk analysis as Options A and B, respectively, as indicated on page D-4, and on the event trees included on pages D-5 and D-6.

For the higher flood loading, the workshop participants agreed that the probability of failure was not significantly different from that for the lower flood loading. Thus, the probabilities of failure for the higher flood loading were determined by multiplying the probabilities of failure for the lower flood loading by the ratio of the probabilities of the two flood loadings, or 0.01/0.03, as indicated on page D-7. The result of the higher flood loading is Consequence A, although possibly enough water had been used in the process of failure, or it took long enough for failure to occur, that Consequence B results.

For the alternative of the existing McMicken Dam having been removed, the probability of failure of the new dam immediately upstream is the same as the probability of the failure of Alternative 4A2 in the moderate hazard zone with the existing dam removed, but adjusted for the new embankment dam being constructed in the high hazard zone. The adjustment is the ratio of the probability of an earth fissure being present in high hazard zone that can pass flow to that of an earth fissure being present in the moderate hazard zone that can pass flow. As indicated on page D-8, the ratios for the lower flood loading are 0.50/0.20 = 2.5 for the median value and in excess of 1.0 for the average value and upper bound, as would be expected. However, the lower bound estimates resulted in a ratio of 0.05/0.10 = 0.50, which would not be expected.

For the alternative of the existing McMicken Dam having been removed, for the higher flood loading, the probabilities determined by the lower flood loading were adjusted in the same manner as the probabilities for Alternative 4A2, as indicated on page D-9. The previously computed ratios (see page B-15) for higher flood loading to lower flood loading were applied, and the ratio of probability of higher flood loading to lower flood loading (0.01/0.03), were applied to probabilities determined for the lower flood loading.

The median estimated total annual probabilities of Consequences A and B occurring for Alternative 3A are presented in the summary table on page D-10. The total annual probabilities are listed separately for the existing dam left in place (for both Option A and Option B) or removed. With the existing dam remaining in place, the median total annual probabilities of Consequences A and B occurring (for Option A) are 0.50×10^{-10} and 0.15×10^{-9}, respectively. The corresponding likelihood (median value) of Consequences A and B occurring are less than 0.01%. However, with the existing dam removed, the computed total annual probabilities for Consequences A and B are 0.11×10^{-5} and 0.33×10^{-5}, respectively, which are significantly higher. The difference is much larger than the probability of failure of the existing McMicken Dam of 0.10 assumed for the analyses of Alternatives 4A2, 5C and 3E. However, the computed probabilities for Alternative 3A are not directly comparable to the computed probabilities for the other alternatives because of the differing assumptions related to the existing and new dams acting as one.

3.6 Alternative 3E (New Soil Cement Dam Immediately Downstream of the Existing McMicken Dam)

The initial condition leading to an adverse response of a new RCC dam located downstream of the existing McMicken Dam in the high hazed zone (see page E-1) is the presence of a fissure that will pass flow under the dam. Subsequently, flow through the fissure could erode a large hole in the Pleistocene soils, but progress no further (Condition 2), leading to Consequence C. Alternatively, the hole could expand and the RCC structure displace or crack and fail (Condition 3). The workshop participants agreed that is was equally likely that when the RCC dam fails the existing McMicken Dam has already failed or that it remains. The existing dam then erodes, collapses and breaches (Condition 4) leading to either Consequence A or Consequence B, depending on the flood loading. The factors influencing the probability that Condition 3 will occur, as determined by the workshop participants, are listed on page E-2.

For the lower flood loading, which results in Consequence B, the probability that an earth fissure is present that will pass flow under the dam was assigned the same probability as that for the existing McMicken Dam in the high hazard zone, as indicated on page E-3. Estimates of the probability of Conditions 2 and 3 occurring for the lower flood loading also are listed on page E-3. A median probability of 0.001 with a range of 0.0001 to 0.01 was estimated for Condition 2, and a median probability of 1.0×10^{-4} with a range of 1.0×10^{-6} to 1.0×10^{-3} was estimated for Condition 3. These relatively large ranges in estimates reflect the varying assessments of the workshop participants of either of these conditions occurring. The workshop participants assigned a probability of 0.10 (see page E-1) to the failure of the existing dam, considering that

the new dam would have to fail first. Event trees for the lower flood loading for Conditions 1 through 3 only are presented on pages E-4 and E-5.
For the higher flood loading, the workshop participants agreed that there is no significant difference in the probability of response as compared to the lower flood loading. Thus, the ratio of the probability of the higher flood loading to the lower flood loading (0.01/0.03) was applied to probabilities determined for the lower flood loading to determine the probability of failure for the higher flood loading, as indicated on page E-6. For the higher flood loading, failure results if Consequences A and C.

The median estimated total annual probabilities of Consequences A, B and C occurring are presented in the summary table on page E-7. The total annual probabilities are listed separately for the existing dam left in place. With the existing dam remaining in place, the median total annual probabilities of Consequences A and B occurring are 0.50×10^{-10} and 0.15×10^{-9}, respectively, the same as for Alternative 3A. The corresponding likelihood (median value) of Consequences A and B occurring are less than 0.01%. However, with the existing dam removed, the computed total annual probabilities for Consequences A and B are an order of magnitude less, or 0.50×10^{-9} and 0.15×10^{-8}, respectively. These are significantly lower than the probabilities of failure computed for Alternative 4A with the existing McMicken Dam removed. The median total annual probability of Consequence C occurring, whether the existing dam remains or is removed, is 0.20×10^{-4}, and the corresponding likelihood of the consequence occurring is 0.20%.

3.7 Factors Influencing Other Decisions

As the final part of the workshop, but not an integral part of the risk analysis, the participants addressed three issues that have importance to the alternatives analysis. First, factors influencing the decision to construct a dam extension (Alternative 5C or a revised and shortened Alternative 4A2) rather than a new embankment adjacent to the existing McMicken Dam (Alternative 3A) were discussed. The factors are listed in Table 3. Second, factors influencing the selection of a hard embankment (RCC or soil cement) rather than an earthen embankment were discussed. These factors are listed in Table 4. Finally, factors influencing the decision to construct a new structure adjacent to the existing McMicken Dam rather than upstream were discussed. This discussion is essentially a subset of the discussion to construct a new dam extension rather than a new embankment adjacent to the existing McMicken Dam. These factors are listed in Table 5.

4.0 SUMMARY AND CONCLUSIONS

The estimated, relative risks of adverse Consequences A and B occurring are presented in Tables 6 and 7, respectively, for the existing McMicken Dam in the high hazard zone and for all of the alternatives considered. Risk in the context of the analysis that was completed is the total annual probability of either Consequence A or Consequence B occurring, since further definition of the consequences (economic loss, loss of life or other parameters) was not completed. Comparing the median values for the alternatives in Tables 6 and 7, it is apparent that the risk of Consequence B occurring is slightly higher than the risk of Consequence A occurring for any of the alternatives. It is likely, however, that the annual probability of the economic loss (or another undefined parameter) is higher for Consequence A than for Consequence B, because Consequence A likely has a much larger impact than Consequence B.

In terms of risk reduction (comparing the median risk associated with any of the alternatives with that of the existing McMicken Dam), it is apparent that for either Consequence A or Consequence B, the risk is reduced by three or more orders of magnitude by any of the alternatives. It is further apparent that if the existing McMicken Dam is left in place, Alternatives 3A and 3E provide a significantly greater reduction in risk (about two orders of magnitude) than Alternative 5C, which in turn provides a significantly greater reduction in risk (again about two orders of magnitude) than Alternative 4A2. With the existing McMicken Dam removed, the reduction in risk is lowered by one order of magnitude for Alternatives 4A2, 5C and 3E, but by about four orders of magnitude for Alternative 3A. However, the actual values of the risk associated with the alternatives, except Alternative 4A2, perhaps, with a risk of about 0.60 x 10^{-4} for the old dam removed, are on the order of 1.0 x 10^{-6} for the old dam removed. Thus, leaving the existing McMicken Dam in place provides a greater risk reduction, but the incremental risk reduction may not be as significant as the risk reduction associated with any of Alternatives 5C, 3A and 3E.

The failure probability for Alternative 4A2 with the old dam left in place for either flood loading is primarily the failure probability of the section of the dam extension in the low hazard fissure zone. For example, for the lower flood loading leading to Consequence B, the median failure probability is 0.15 x 10^{-4} (see page B-12) for the section of the dam in the low hazard fissure zone compared to 0.12 x 10^{-6} (see page B-6) for the section of the dam in the moderate hazard fissure zone. This reflects the assumption that the dam was assumed to have cutoffs extending in to the Pleistocene soils in the moderate hazard fissure zone but not in the low hazard fissure zone. Since the total probability is the sum of these (see page B-17), the lower value essentially is ignored.

Because Alternative 3A also has cutoffs, a more direct comparison is that of Alternative 4A2 in the moderate hazard fissure zone with Alternative 3A. The median failure probability of Alternative 3A for the lower flood loading is 0.15 x 10^{-9} (see page D-5), which still is much less than the median failure probability for Alternative 4A2 in the moderate hazard zone. The difference is related to the assumption that the probability of failure of the old dam after the new dam has failed (Condition 4) for Alternative 4A2 is 0.10 (see page B-5). In comparison, the probability of failure of the old dam for Alternative 3A (Condition 3) was estimated to be 0.001. Also, the probability of failure of the new dam (Condition 3) was estimated to be 0.01 for Alternative 4A2 (see page D-4) compared to either 0.001 (Condition 4A) or 0.01 (Condition 4B) for Alternative 3A. The net effect is to further lower the failure probability for Alternative 3A compared to Alternative 4A2 by two or three orders of magnitude. It also appears to reflect that Alternative 3A results in two structures that are connected and act as a unit, rather than the two structures in Alternative 4A2 being separate and acting independently.

The result of these different assumptions and estimates is indicated in Table 7, which shows the median probability of failure for Alternative 4A2 for the lower flood loading leading to Consequence B to be 0.15×10^{-4}, compared to 0.15×10^{-9} (Option A) or 0.15×10^{-8} (Option B) for Alternative 3A. For the higher flood loading leading to Consequence A, the same general differences were estimated, since the analyses for both Alternative 4A2 (see pages B-14 and B-15) and Alternative 3A (see page D-7) built on the analyses for Consequence B.

The much lower failure probability of Alternative 3A without the old dam as compared to with the old dam is directly the result of the assumption that the failure probability of Alternative 3A without the old dam is the same as the probability of failure of Alternative 4A2 in the moderate hazard fissure zone with the old dam removed and adjusted for Alternative 3A being in the high hazard fissure zone (see page D-8). Thus, a separate, step-by-step (or condition-by-condition) analysis was not completed, and the differences in the analyses for Alternatives 4A2 and 3A noted in the second paragraph above have a large impact on the results. Because of the short cut employed in the analysis, direct comparison of the failure probabilities estimated for Alternative 3A without the old dam and Alternative 3A with the old dam may not be valid.

Considering the large reduction in risk afforded by Alternatives 5C, 3A and 3E, in particular, and to some degree by Alternative 4A2, all are technically viable and provide a positive approach to mitigating the earth fissure hazard present at McMicken Dam. Barring any other factors, such as are listed in Table 4, it appears that selection of the preferred alternative can be based on the comparative design and construction costs of the alternatives.

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TABLES

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TABLE 1
Flood Load Probability

Flood Range		Probability		Δ Probability	
1/25-yr	– 1/100-yr	0.04	– 0.01	0.03	Σ = 0.3*
1/100-yr	– 1/200-yr	0.01	– 0.005	0.005	
1/200-yr	– 1/500-yr	0.005	– 0.002	0.003	
1/500-yr	– 1/10,000-yr	0.02	– 0.0001	0.0019	
1/10,000-yr	– 1/PMP	0.0001	– ~0	0.0001	Σ = 0.01**

*The lower flood loading range is 1/25-yr – 1/100-yr with a cumulative annual probability of occurrence of 0.03.

**The higher flood loading range is 1/100-yr – 1/PMP with a cumulative annual probability of occurrence of 0.01.

TABLE 2

Stage-Frequency Data for McMicken Dam (based on 1929 NAVD datum)

Storm Event Return Frequency	Stage Elevation (feet)
10	1348.5
25	1351.2
50	1353.2
100	1354.3

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TABLE 3
Factors Influencing Decision to Construct a Dam Extension (Alternative 5C) Rather than Rehabilitation (Alternatives 3)

Positive

- The southern section of McMicken Dam is taken out of the watershed.
- There is a potential reduction in project cost since a shorter dam length would be required.
- The risk is reduced since the dam extension will not be in the high hazard zone.
- It may be possible to divert Waterfall Wash to behind the south end of McMicken Dam.
- There would be no dam within the high hazard zone.
- It would provide the opportunity to optimize the alignment.
- The length of the dam exposed to the earth fissure would be reduced.

Negative

- The upstream washes present an erosion hazard.
- The low flow channel could be cut off (a vegetation issue).
- The upstream washes are impacted (cutoff).
- The alignment could be in future high hazard zone.
- The alignment would be transverse to the fissure zone.
- A new outlet would be required.

TABLE 4
Factors Influencing the Selection of RCC/Soil Cement Structure Rather than an Earthen Embankment

Favoring RCC/SC Structure

- RCC/SC structure has less associated reduced risk than an embankment dam.
- RCC/SC design has less associated risk of regulatory questioning, but there is not much chance for regulatory questioning of the embankment dam alternative.
- RCC/SC structure would require significantly less maintenance.
- A regulatory waiver would be needed for the single line of defense included in the design of an embankment dam.
- Material for a SC structure appears to be available within the impoundment.
- The risk perception associated with an embankment dam is higher than for a RCC/SC structure.

Favoring Embankment Dam

- Cost for an embankment dam is significantly less.
- The risk associated with an earthen embankment is acceptable (Is it? What is acceptable?)
- An earthen embankment would be much easier to construct in a desert environment than a RCC/SC structure.
- There would be aesthetics and safety issues with a RCC/SC structure unless it is covered with an embankment.
- The breach of a RCC/SC structure would result in a larger peak outflow.
- Material acceptable for a RCC structure may not be available within the impoundment.

TABLE 5
Factors Influencing Construction Adjacent to the Existing McMicken Dam

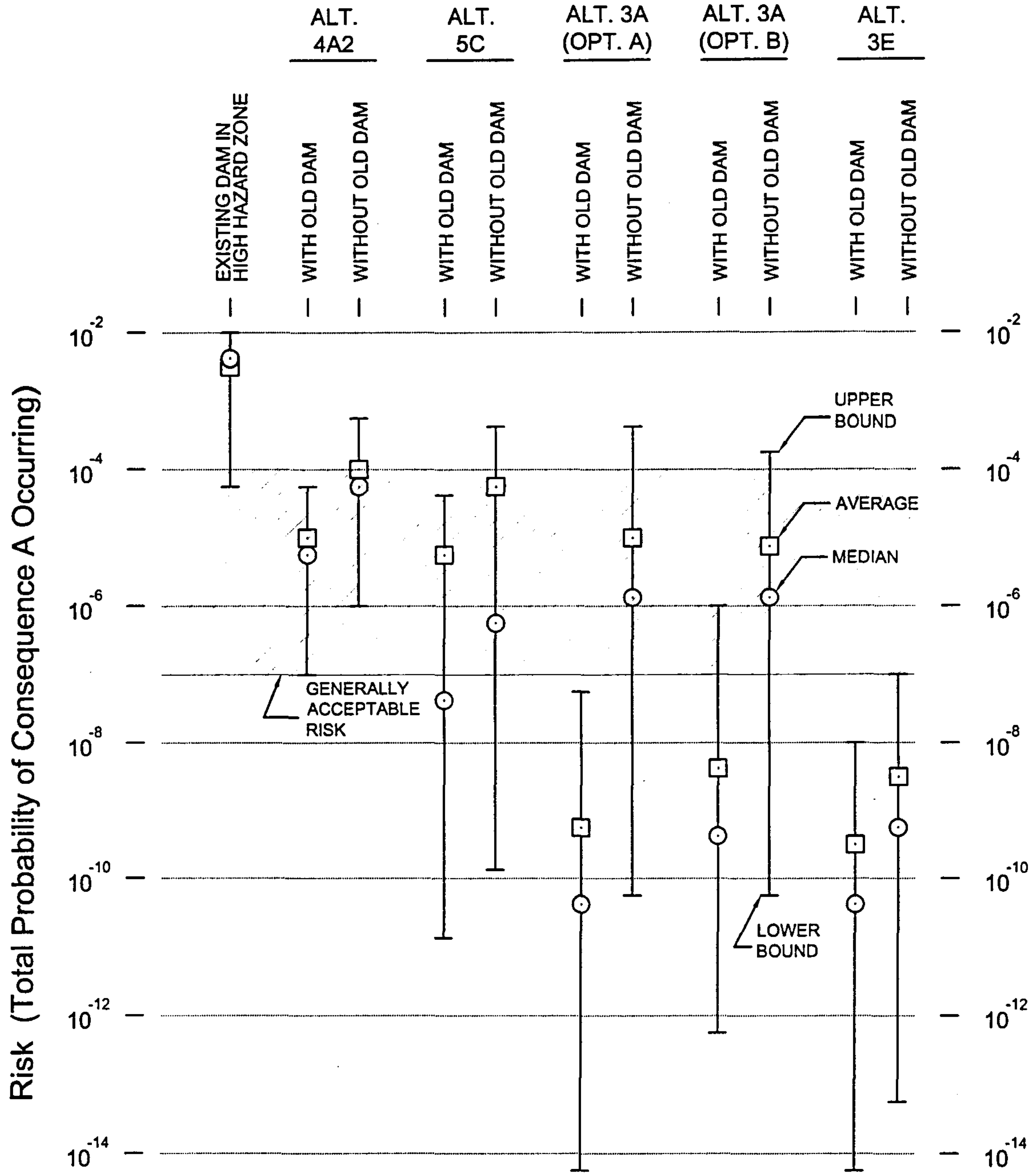
Positive

- The risk of failure is reduced if the new dam is built upstream of the existing dam and the existing dam is left in place.
- It would provide the opportunity to divert Waterfall Wash to behind McMicken Dam.
- A new outlet would not be required.
- It would have less of an impact on the environment.

Negative

- The cost potentially could be higher.
- The McMicken Dam reservoir extends to the southern end of the dam.

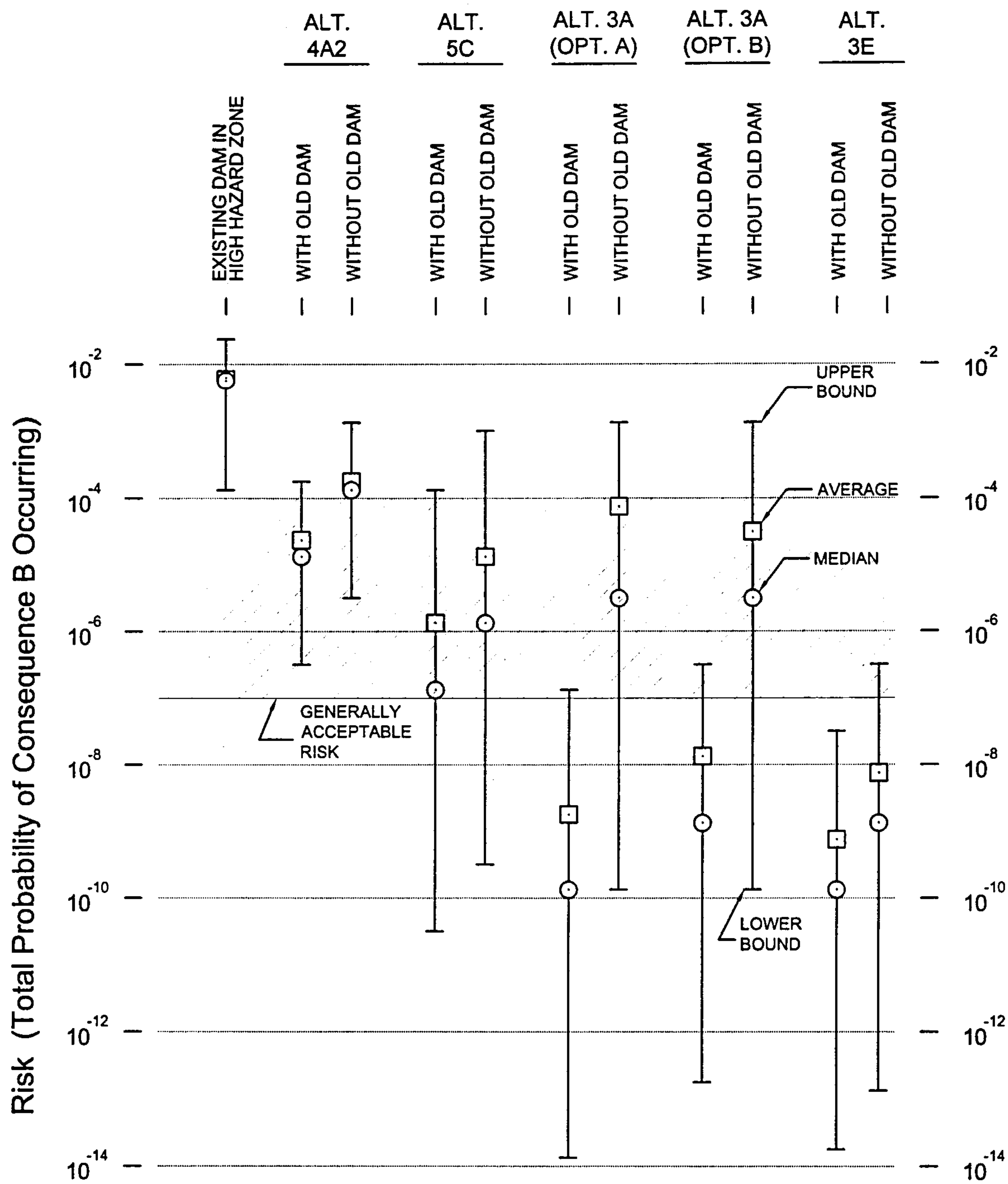
Table 6
Risk of Consequence A Occurring



JOB NO. 2-117-001066	Summary of Risk Analysis - Consequence A McMicken Dam FRZR Project		amec
DESIGN: LAH			
DRAWN: TJF	Flood Control Disrtict of Maricopa County FCD Contract 2002C011 - Work Assignment No. 1		
DATE: 9/2003			
SCALE: NTS			

Table 7

Risk of Consequence B Occurring



JOB NO. 2-117-001066	Summary of Risk Analysis - Consequence B McMicken Dam FRZR Project	amec
DESIGN: LAH		
DRAWN: TJF		
DATE: 9/2003	Flood Control District of Maricopa County FCD Contract 2002C011 - Work Assignment No. 1	
SCALE: NTS		

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A.
Existing McMicken Dam
in High Hazard Zone

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard Zone

Conditions leading to adverse response:

1. Fissure is present that will pass flow under the dam.

2. Fissure erodes in a manner that produces potentially erosive flow at the foundatioin contact or creates a cavity that allows flow from the dam.

3. Dam erodes, collapses and breaches leading to Consequence B (flood loading of {1/25 yr – 1/100 yr = 0.03) <u>or</u> Consequence A (flood loading of {1/100 yr – 1/PMF}=0.01) <u>or</u> a foundation tunnel develops and the dam is less affected leading to Consequence C (either flood loading).

Factors influencing the probability that Condition 1 will occur:

Likely

- Known earth fissures are located just upstream and downstream of the dam and historically the known earth fissures have moved closer to the dam with time.
- The probable location of the earth fissures is near the terminus of the dam.
- Subsidence, the causal mechanism for earth fissure formation, is ongoing and the process is dynamic.
- An earth fissure gully can develop with the onset of a storm because of the presence of the low flow channel, which is being further developed.
- An initiating earth fissure can develop over time.
- Holocene soils are present beneath the dam and Holocene soils are erosive.
- An embankment crack can transmit water to an earth fissure beneath the dam, which apparently occurred at Picacho Dam.

Not Likely

- The position of the earth fissures is unknown.
- The rate of subsidence is decreasing.
- The existing earth fissures may have released the subsidence-induced strain.
- On first time wetting of the earth fissure, the water may go down, not laterally.

Factors influencing the probability that Condition 2 will occur given that Condition 1 has occurred (including the case of little or no Holocene soils being present, but could have erosion of the embankment):

Likely

- The Holocene soil deposits are shallower at the southern end of the dam (1 to 9 feet).
- If Holocene soils are near surface then erosion and expansion of the earth fissure is more likely to occur (75% probability).
- Recent broken pipe event in Nevada is an example of what likely would occur. (Released 2.3 million gallons of water in 3 to 6 hours, and water flowed down into an existing fissure (3/8- to 5/8-inch wide) and formed a gully in Holocene soils.
- Water could move.
- Multiple storms could impound water for a longer period of time.
- There is a potential for the base of the dam to erode directly.
- Case histories of large-scale developments with less water supplied that captured flows.

Not Likely

- Flow could flow downward into the fissure, rather than laterally, and need plugging to occur to force lateral flow. (Hawk Rock test indicated water flowed down into the fissure, fissure then plugged and the water moved laterally, water again went down and the process repeated.)
- Could take more than one flooding event to result in rapid lateral flow.
- Multiple storm effect is not as pronounced an effect at the south end of the dam.
- If Pleistocene soils are near the surface then less likely to occur (25% probability).
- Impoundment was the source for the embankment soils, and 90% of these have low erosion potential based on results of laboratory testing, thus the base of the dam is not likely to erode.
- Downstream geotextile cutoff could help prevent erosion through Holocene soils.
- The erosion resistance of the inconsistent embankment soils is not a certainty.

Factors influencing the probability that condition 3 will occur given that Condition 2 has occurred:

Likely

- The dam is brittle and desiccation cracking could exacerbate the situation.
- The center drain/cutoff could drop, creating a void in the dam (drain effect).
- At Centennial Wash erosion leading to failure occurred in similar hard soils in 5 to 6 hours.
- The earth fissure could also be present in the dam or extend through the dam.
- Cracking of the dam may be present as a result of subsidence and horizontal strain.

Not Likely

- Embankment material at the south end of the dam is coarser and less erosive. (Friction angle of 32 degrees, cohesion 1 to 5 ksf, PI approximately 8 {range of 0 to 20})
- The center drain/cutoff could drop, plugging the eroded tunnel (drain effect).
- At Centennial Wash the main breach may have been in less cohesive soils. (Embankment material at McMicken Dam very cohesive and less erosive.
- Effect would be a change from pressurized to no pressurized flow.
- There are case histories where tunnels have form below dams.
- The center drain/cutoff is in place to guard against flows through cracks and/or fissures.

Probability of Adverse Response Given Existing McMicken Dam in High Hazard Zone and Given Flood Loading of (1/25 yr – 1/100 yr) = 0.04 - 0.01=0.03

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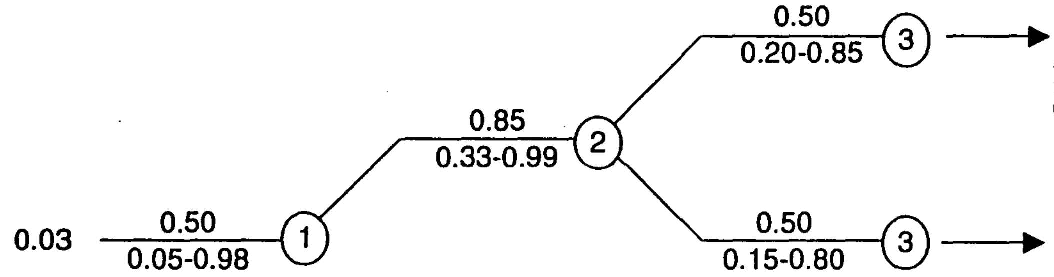
	Estimates of Condition Occurring Given The Previous Condition Has Occurred		
	1	2	3
Probability	0.05	0.33	0.20
	0.50	0.50	0.25
	0.50	0.75	0.40
	0.50	0.75	0.40
	0.50	0.80	0.50
	0.50	0.85	0.50
	0.50	0.85	0.50
	0.75	0.90	0.50
	0.75	0.90	0.70
	0.90	0.99	0.75
	0.98	0.99	0.85
Lower	0.05	0.33	0.20
Median	0.50	0.85	0.50
Average	0.58	0.78	0.50
Upper	0.98	0.99	0.85

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard Zone
And Given Flood Loading of (1/25 yr – 1/100 yr) = 0.04 – 0.01=0.03
(Median Values)

Loading → Response → Annual Probability of Consequences B and C



B

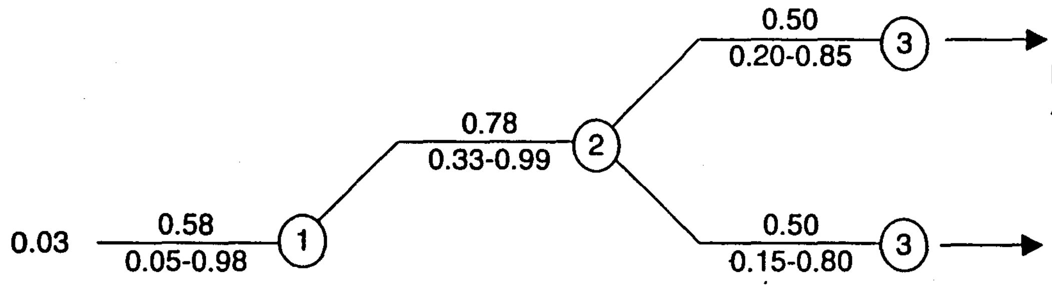
Lower	0.03(0.05)(0.33)(0.20) = 1.0×10^{-4}
Median	0.03(0.50)(0.85)(0.50) = 0.064
Upper	0.03(0.98)(0.99)(0.85) = 0.025

C

Lower	0.03(0.05)(0.33)(0.15) = 0.74×10^{-4}
Median	0.03(0.50)(0.85)(0.50) = 0.0064
Upper	0.03(0.98)(0.99)(0.80) = 0.023

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard Zone
And Given Flood Loading of (1/25 yr – 1/100 yr) = 0.04 - 0.01=0.03
(Average Values)

Loading → Response → Annual Probability of Consequences B and C



B

Lower	0.03(0.05)(0.33)(0.20) = 1.0×10^{-4}
Average	0.03(0.58)(0.78)(0.50) = 0.068
Upper	0.03(0.98)(0.99)(0.85) = 0.025

C

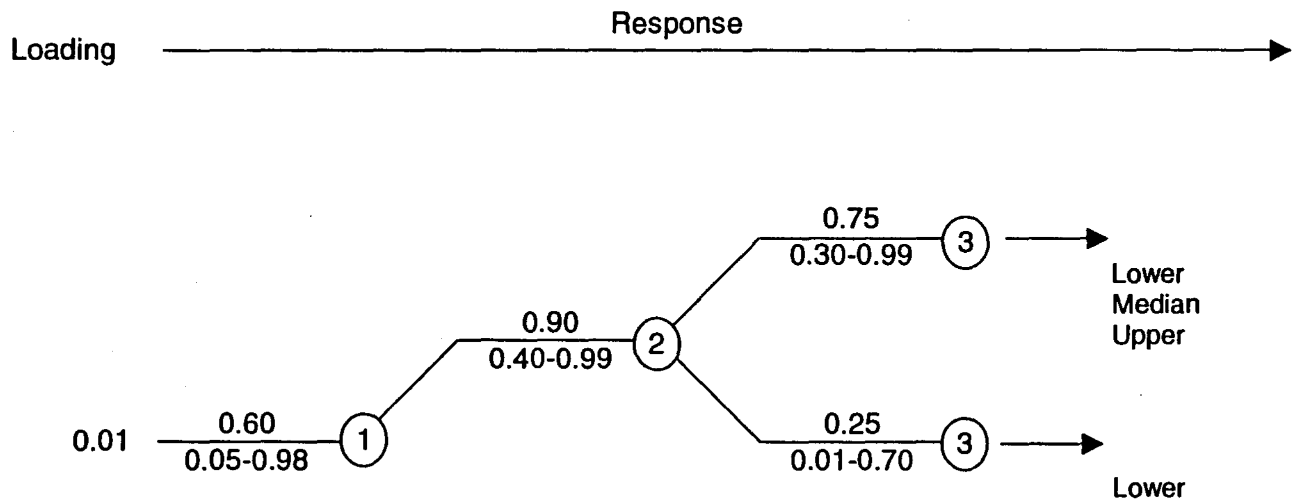
Lower	0.03(0.05)(0.33)(0.15) = 0.74×10^{-4}
Average	0.03(0.58)(0.78)(0.50) = 0.0068
Upper	0.03(0.98)(0.99)(0.85) = 0.023

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard
Zone Given Flood Loading of
(1/100 yr – 1/PMF) = 0.01-0.00 = 0.01

Estimates of Condition Occurring Given The Previous Condition Has Occurred

	1	2	3
Probability	0.05	0.40	0.30
	0.25	0.75	0.50
	0.50	0.80	0.60
	0.50	0.90	0.60
	0.50	0.90	0.70
	0.60	0.90	0.75
	0.75	0.90	0.80
	0.80	0.95	0.80
	0.90	0.95	0.80
	0.90	0.99	0.80
	0.98	0.99	0.99
Lower	0.05	0.40	0.30
Median	0.60	0.90	0.75
Average	0.61	0.86	0.69
Upper	0.98	0.99	0.99

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard
Zone and Given Flood Loading of
(1/100 yr – 1/PMF) = 0.01 – 0.00=0.01
(Median Values)



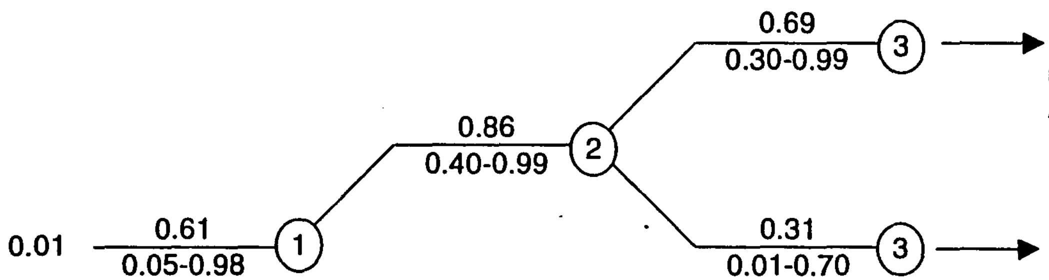
Annual Probability of Consequences A and C

	A
Lower	$0.01(0.05)(0.40)(0.30) = 0.60\times10^{-4}$
Median	$0.01(0.60)(0.90)(0.75) = 0.0041$
Upper	$0.01(0.98)(0.99)(0.99) = 0.0096$

	C
Lower	$0.01(0.05)(0.40)(0.01) = 0.20\times10^{-4}$
Median	$0.01(0.60)(0.90)(0.25) = 0.0014$
Upper	$0.01(0.98)(0.99)(0.70) = 0.0068$

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard
Zone and Given Flood Loading of
(1/100 yr – 1/PMF) = 0.01 – 0.00=0.01
(Average Values)

Loading —— Response ——→ Annual Probability of Consequences A and C



A

Lower	$0.01(0.05)(0.40)(0.30) = 0.60\times10^{-4}$
Average	$0.01(0.61)(0.86)(0.69) = 0.0036$
Upper	$0.01(0.98)(0.99)(0.99) = 0.0096$

C

Lower	$0.01(0.05)(0.40)(0.01) = 0.20\times10^{-4}$
Average	$0.01(0.61)(0.86)(0.31) = 0.0016$
Upper	$0.01(0.98)(0.99)(0.70) = 0.0068$

Probability of Adverse Response
Given Existing McMicken Dam in High Hazard Zone

Consider a localized storm occurs within the 3 subbasins upstream of the high hazard zone. Likely the storm would be a 500 year event or larger, comparable to a storm that has a stage of 1354 feet. Then the probability analysis is similar to that for Consequence B except the flood loading is (1/500 yr – 1/PMF) = (0.002 – 0.000) = 0.002 rather and (1/25 yr – 1/100 yr) = 0.04 – 0.01=0.03. The probabilities, then, are:

(0.002/0.03)(0.0068) = 0.00045 Average
(0.002/0.03)(0.0064) = 0.00043 Median

Much less of an adverse response will result (Consequence D) because of the much lower amount of water available.

Considering a flood loading of 1/10,000 yr only, then the annual probability is 0.0001, and the contribution to Consequence A is:

(0.0001/0.01)(0.0041) = $0.41\text{x}10^{-4}$ Median
(0.0001/0.01)(0.0036) = $0.36\text{x}10^{-4}$ Average

And contribution to Consequence C is:

(0.0001/0.01)(0.0014) – $0.14\text{x}10^{-4}$ Median
(0.0001/0.01)(0.0016) = $0.16\text{x}10^{-4}$ Average

Probability of Adverse Response Given Existing McMicken Dam in High Hazard Zone And Given Flood Loading of (1/25 yr – 1/PMF yr) = 0.04-0.00 = 0.04

Summary of Computed Probabilities of Consequences A, B, C and D Occurring

	Total Annual Probability		
Consequence	Median	Average	Range
A	0.0041	0.0036	0.60×10^{-4} – 0.0096
B	0.0064	0.0068	1.0×10^{-4} – 0.025
C	0.0078	0.0084	0.76×10^{-4} – 0.030
D	0.00043	0.00045	0.67×10^{-4} – 0.0017

B.
New Upstream Embankment
Alternative 4A2

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Conditions leading to adverse response:

1. Fissure is present that will pass flow under the dam.
2. Water bypasses the cutoffs extending into the Pleistocene and reaches the embankment toe with enough force to cause erosion.
3. Progressive breach and failure of the new embankment dam occurs.
4. Failure of old dam occurs as a result of the collapse of upstream fissure extending through or beneath the structure.

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Factors influencing the probability that Condition 1 will occur:

Likely

- The dam is on the projection of earth fissures present in the high hazard zone.
- Interferometry data indicate that differential subsidence is occurring within the zone.

Not Likely

- There are no fissures in the zone presently, which reduces the probability.
- A reduction in horizontal strain is expected in the future, also reducing the probability.
- Depth to bedrock is increasing, indicating the potential for more subsidence and strain.
- The settlement profile through the zone is relatively flat.

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

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Factors influencing the probability that Condition 2 will occur given that Condition 1 has occurred:

Likely

- The fissure is wide enough to flow water.
- The Pleistocene soils are widely variable and 10 percent may be erosive.
- There may or may not be head loss through the earth fissure extending below the cutoffs.

Not Likely

- Water flow in the fissure may be downward rather than lateral.
- Though variable, 90 percent of the Pleistocene soils are like calcrete and are not erosive.
- The cutoffs are designed to force the water lower into less erosive soils.
- Flow would have to erode upward through the Holocene soils.
- There will limited head available to cause erosion.

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Factors influencing the probability that Condition 3 will occur given that Condition 2 has occurred:

Likely

- Pool will develop downstream and flow may drain down the fissure causing erosion.

Not Likely

- Intervention by the District is likely if a pool develops downstream.
- Leaving old dam in place adds warning time.
- The new dam will be well compacted, minimizing erosion or slope failure potential.
- The retention system is redundant and well designed.
- The cutoff on the upstream face of the new dam prevents development of head.
- It is unlikely that a large enough flow of water will develop.

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Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03

Estimates of Condition Occurring Given The Previous Condition Has Occurred

	1	2	3	4*
Probability	0.10	0.001	0.0001	
	0.10	0.01	0.001	
	0.10	0.01	0.01	
	0.10	0.01	0.01	
	0.20	0.02	0.01	
	0.20	0.02	0.01	0.10
	0.25	0.02	0.01	
	0.40	0.05	0.01	
	0.60	0.05	0.01	
	0.70	0.10	0.02	
	0.75	0.85**	0.05	
Lower	0.10	0.001	0.0001	0.10
Median	0.20	0.02	0.01	0.10
Average	0.32	0.10	0.013	0.10
Upper	0.75	0.85	0.05	0.10

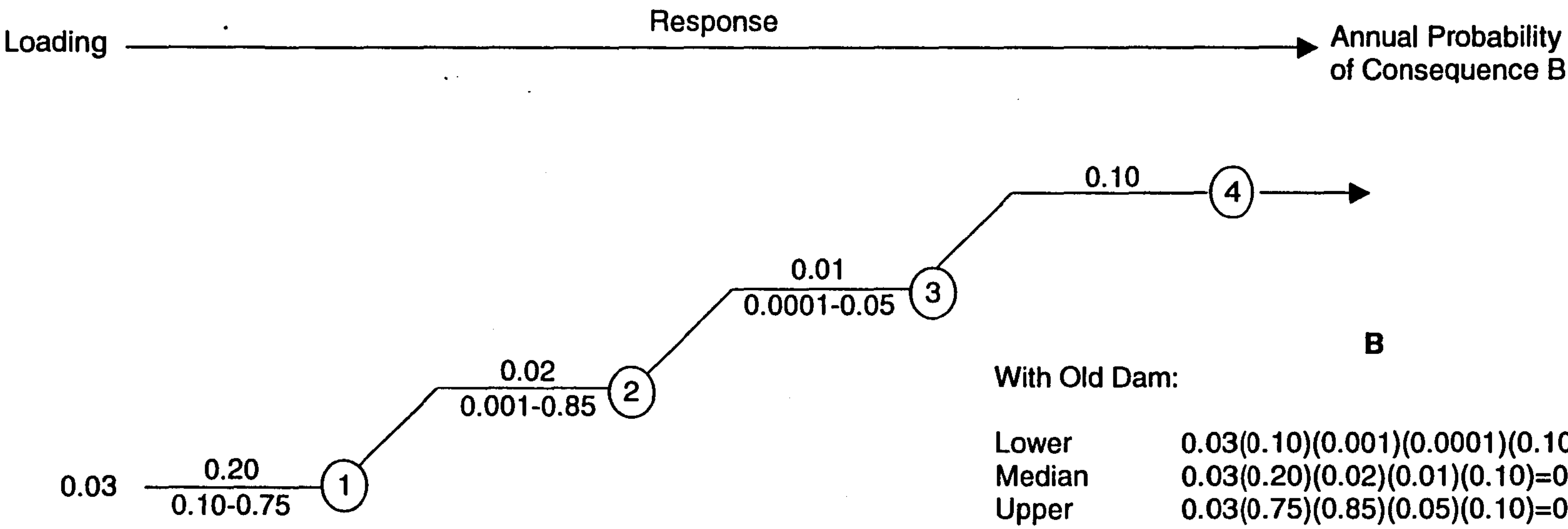
* Condition 4 is the failure of the old dam given a flood occurring and failure of the new dam also occurring. The probability of the failure of the old dam was previously estimated as (see Page A-5):

0.58(0.78)(0.50) = 0.26 Average
0.50(0.85)(0.50) = 0.21 Median

The group reduced this probability to 0.10, considering that the new dam would have to fail first and the resulting more controlled release (and less probable length of earth fissure) would lower the probability of failure of the old dam.

** The high probability of 0.85 estimated by one group member is based on the consideration that there would be no impediment to flow: Water would readily flow through the earth fissure to the ground surface resulting in erosion. The opposing consideration is that the water could just as readily flow downward into the fissure.

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 (Median Values)



B

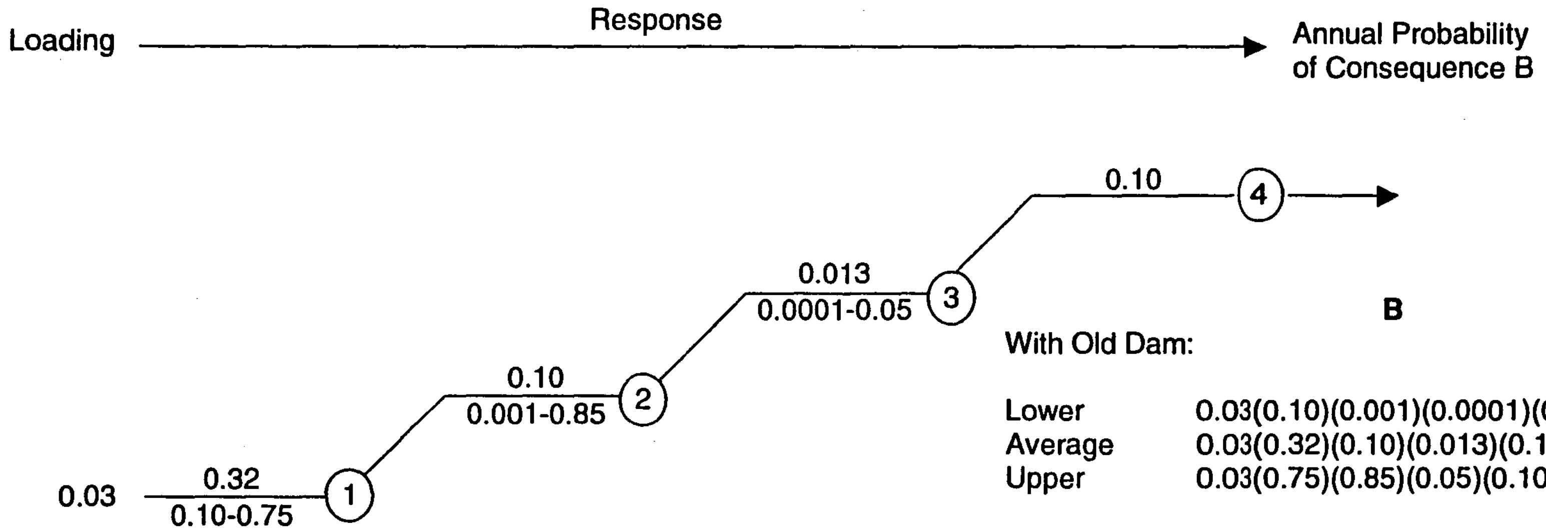
With Old Dam:

Lower	0.03(0.10)(0.001)(0.0001)(0.10)=0.30×10^{-10}
Median	0.03(0.20)(0.02)(0.01)(0.10)=0.12×10^{-6}
Upper	0.03(0.75)(0.85)(0.05)(0.10)=0.96×10^{-4}

Without Old Dam:

Lower	0.30×10^{-9}
Median	0.12×10^{-5}
Upper	0.96×10^{-3}

**Probability of Adverse Response
Given New Upstream Embankment in
Moderate Hazard Zone (Holocene Soils
Removed and Cutoffs Provided into
Pleistocene Soils) and Given Flood Loading as
(1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03
(Average Values)**



With Old Dam:

Lower	$0.03(0.10)(0.001)(0.0001)(0.10)=0.30\times10^{-10}$
Average	$0.03(0.32)(0.10)(0.013)(0.10)=0.12\times10^{-5}$
Upper	$0.03(0.75)(0.85)(0.05)(0.10)=0.96\times10^{-4}$

Without Old Dam:

Lower	0.30×10^{-9}
Average	0.12×10^{-4}
Upper	0.96×10^{-3}

Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Conditions leading to adverse response:

1. Fissure is present that will pass flow under the dam.
2. Water causes erosion along the contact between the new dam and the native foundation soils and results in the failure of the new dam.
3. Old dam fails.

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Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Factors influencing the probability that Condition 1 will occur:

Not Likely

- Fissure development is parallel to the zone, trending away, which reduces the probability.
- The zone is not in the principal zone of strain.
- There are no fissures in the zone presently, which reduces the probability.
- There were no seismic anomalies identified in the zone.
- Interferometry data indicate that differential subsidence is not occurring within the zone.
- The condition of ancient features is indicative of stability.

Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided into Pleistocene Soils) – Alternative 4A2

Factors influencing probability that Condition 2 will occur given that Condition 1 has occurred:

Likely

- An earth fissure may result in a crack developing through the dam.
- Dam materials are somewhat erosive and erosion of the dam could occur.
- The Pleistocene soils supporting the new dam may be erosive.

Not Likely

- The Holocene soils will have been removed.
- A cutoff (HDPE) is present on the upstream face of the dam to provide protection.
- The new dam will be well constructed.
- Any future fissure likely would be oriented oblique to the new dam.
- There is a limited supply of water available.

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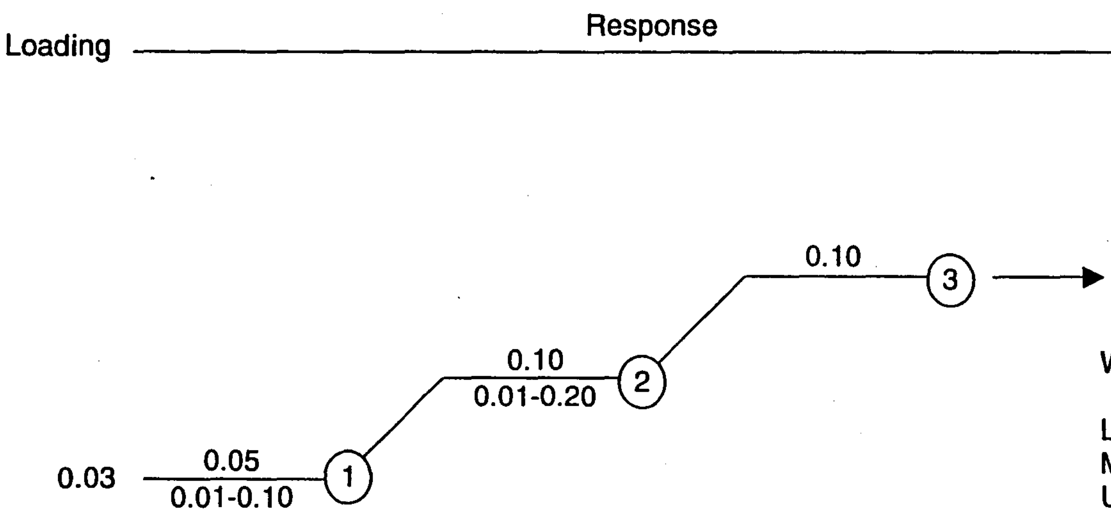
Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided into Pleistocene Soils) and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03

	Estimates of Condition Occurring Given the Previous Condition Has Occurred		
	1	2	3*
Probability	0.01	0.01	
	0.01	0.04	
	0.02	0.05	
	0.05	0.05	
	0.05	0.10	
	0.05	0.10	0.10
	0.05	0.10	
	0.05	0.20	
	0.10	0.20	
	0.10	0.20	
	0.10	0.20	
Lower	0.01	0.01	0.10
Median	0.05	0.10	0.10
Average	0.054	0.11	0.10
Upper	0.10	0.20	0.10

* The group agreed to a probability of 0.10; see discussion for moderate hazard zone on Page B-5.

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone (Holocene Soils Removed and Cutoffs Provided into Pleistocene Soils) and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 (Median Values)



B

With Old Dam:

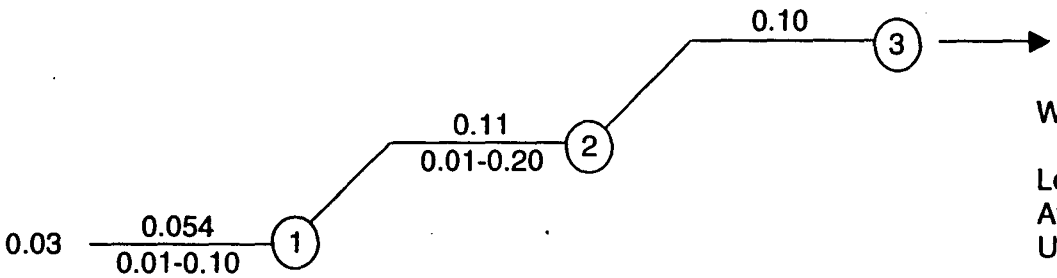
Lower	0.03(0.01)(0.01)(0.10) = 0.30×10^{-6}
Median	0.03(0.05)(0.10)(0.10) = 0.15×10^{-4}
Upper	0.03(0.10)(0.20)(0.10) = 0.6×10^{-4}

Without Old Dam:

Lower	0.30×10^{-5}
Median	0.15×10^{-3}
Upper	0.60×10^{-3}

Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided in Pleistocene Soils) And Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 (Average Values)

Loading —— Response ——► Annual Probability of Consequence B



B

With Old Dam:

Lower	0.03(0.01)(0.01)(0.10) = 0.30×10^{-6}
Average	0.03(0.054(0.11(0.10) = 0.18×10^{-4}
Upper	0.03(0.10)(0.20)(0.10) = 0.6×10^{-4}

Without Old Dam:

Lower	0.30×10^{-5}
Average	0.18×10^{-3}
Upper	0.60×10^{-3}

Probability of Adverse Response Given New Upstream Embankment in Moderate Hazard Zone and in Low Hazard Zone And Flood Loading of (1/100 yr – 1/PMF) = (0.01-0.00) = 0.01 Alternative 4A2

As a short cut, the group agreed to address the question "How much worse is the higher water condition(flood loading of {1/100 yr – 1/PMF}) than the lower water condition (flood loading of {1/25 yr – 1/100 yr})?" Also, failure results in Consequence A because of the larger volume of water available and the longer duration of the event.

Estimates of How Much Worse the Higher Water Condition is than the Lower Water Condition

	Moderate Hazard Zone	Low Hazard Zone
	1.00	1.00
	1.01	1.01
	1.02	1.02
	1.05	1.10
	1.10	1.20
	1.10	1.20
	1.20	1.20
	1.20	1.25
	1.20	1.50
	1.25	2.00
	1.25	2.00
Lower	1.00	1.00
Median	1.10	1.20
Average	1.13	1.32
Upper	1.25	2.00

Probability of Adverse Response
Given New Upstream Embankment in
Moderate Hazard Zone (Holocene Soils
Removed and Cutoffs Provided into
Pleistocene Soils) and Given Flood Loading of
(1/100 yr – 1/PMF) = (0.01-0.00) = 0.01

Response is Consequence A.

With Old Dam:

Lower	$(0.01/0.03)(0.30 \times 10^{-10})(1.00) = 0.10 \times 10^{-10}$
Median	$(0.01/0.03)(0.12 \times 10^{-6})(1.10) = 0.44 \times 10^{-7}$
Average	$(0.01/0.03)(0.12 \times 10^{-5})(1.13) = 0.47 \times 10^{-6}$
Upper	$(0.01/0.03)(0.96 \times 10^{-4})(1.25) = 0.40 \times 10^{-4}$

Without Old Dam:

Lower	0.10×10^{-9}
Median	0.44×10^{-6}
Average	0.47×10^{-5}
Upper	0.40×10^{-3}

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Probability of Adverse Response Given New Upstream Embankment in Low Hazard Zone (Holocene Soils Removed but No Cutoffs Provided into Pleistocene Soils) and Given Flood Loading of (1/100 yr – 1/PMF) = (0.01-0.00) = 0.01

Response is Consequence A.

With Old Dam:

Lower	$(0.01/0.03)(0.30\text{x}10^{-6})(1.00) = 0.10\text{x}10^{-6}$
Median	$(0.01/0.03)(0.15\text{x}10^{-4})(1.20) = 0.60\text{x}10^{-5}$
Average	$(0.01/0.03)(0.18\text{x}10^{-4})(1.32) = 0.78\text{x}10^{-5}$
Upper	$(0.01/0.03)(0.60\text{x}10^{-4})(2.00) = 0.40\text{x}10^{-4}$

Without Old Dam:

Lower	$0.10\text{x}10^{-5}$
Median	$0.60\text{x}10^{-4}$
Average	$0.78\text{x}10^{-4}$
Upper	$0.40\text{x}10^{-3}$

Probability of Adverse Response Given New Upstream Embankment (Alternative 4A2) and Given Flood Loading of (1/25 yr – 1/PMF) = 0.04 – 0.00 = 0.04

Summary of Computed Probabilities of Consequences A and B Occurring

Consequence	Total Annual Probability: Median	Average	Range
With Old Dam			
A	$0.60x10^{-5}$	$0.83x10^{-5}$	$0.10x10^{-6}$ – $0.08x10^{-4}$
B	$0.15x10^{-4}$	$0.19x10^{-4}$	$0.30x10^{-6}$ – $0.16x10^{-3}$
Without Old Dam			
A	$0.60x10^{-4}$	$0.83x10^{-4}$	$0.10x10^{-5}$ – $0.80x10^{-3}$
B	$0.15x10^{-3}$	$0.19x10^{-3}$	$0.30x10^{-5}$ – 0.0016

C.
Dam Extension
Alternative 5C

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Probability of Adverse Response Given Dam Extension (Removal of Holocene Soils and Cutoffs Provided in Both Low and Moderate Hazard Zones)

Failure probability is the same as the failure probability computed for Alternative 4A2 with the dam extension in the moderate hazard zone the same as before, but with the dam extension in the low hazard zone having cutoffs extending into the Pleistocene soils (in essence, the low hazard zone is treated the same as the moderate hazard zone).

Failure of the old dam only was assigned Consequence D. Probability was not computed, but was assumed equal to the failure of the existing dam for flood load of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03. The computed probabilities (see Pages A-6 and A-7) are:

Lower	1.0×10^{-4}
Median	0.0064
Average	0.0068
Upper	0.025

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Probability of Adverse Response Given Dam Extension (Removal of Holocene Soils and Cutoffs Provided in Both Low and Moderate Hazard Zones) and Given Flood Loading of (1/25 yr – 1/100 yr) = 0.04 – 0.01 = 0.03

Response is Consequence B.

No difference in failure probabilities computed for Alternative 4A2 for the moderate hazard zone:

	With Old Dam	Without Old Dam
Lower	$0.30x10^{-10}$	$0.30x10^{-9}$
Median	$0.12x10^{-6}$	$0.12x10^{-5}$
Average	$0.13x10^{-5}$	$0.13x10^{-4}$
Upper	$0.96x10^{-4}$	$0.96x10^{-3}$

With the treatment of the low hazard zone as a moderate hazard zone, the previously computed failure probabilities for Alternative 4A2 need to be factored by the ratio of the probability of a fissure being present that will pass flow under the dam for the two zones. Failure probabilities are:

	With Old Dam	Without Old Dam
Lower	$0.30x10^{-10}(0.01/0.10) = 0.30x10^{-11}$	$0.30x10^{-12}$
Median	$0.12x10^{-6}(0.05/0.20) = 0.30x10^{-7}$	$0.30x10^{-6}$
Average	$0.13x10^{-5}(0.054/0.32) = 0.22x10^{-6}$	$0.22x10^{-5}$
Upper	$0.96x10^{-4}(0.10/0.75) = 0.13x10^{-4}$	$0.13x10^{-3}$

Probability of Adverse Response
Given Dam Extension (Removal of Holocene Soils
and Cutoffs Provided in Both Low
and Moderate Hazard Zones) and Given
Flood Loading of (1/100 yr – 1/PMF) = (0.01-0.00) = 0.01

Response is Consequence A.

No difference in failure probabilities computed for Alternative 4A2 for the moderate hazard zone:

	With Old Dam	Without Old Dam
Lower	$0.10x10^{-10}$	$0.10x10^{-9}$
Median	$0.44x10^{-7}$	$0.44x10^{-6}$
Average	$0.49x10^{-5}$	$0.49x10^{-4}$
Upper	$0.40x10^{-4}$	$0.40x10^{-3}$

With the treatment of the low hazard zone as a moderate hazard zone, the previously computed failure probabilities for Alternative 4A2 need to be factored by the ratio of the probability of a fissure being present that will pass flow under the dam for the two zones. Failure probabilities are:

	With Old Dam	Without Old Dam
Lower	$0.10x10^{-10}(0.01/0.10) = 0.10x10^{-11}$	$0.10x10^{-10}$
Median	$0.44x10^{-7}(0.05/0.20) = 0.11x10^{-7}$	$0.11x10^{-6}$
Average	$0.49x10^{-5}(0.054/0.32) = 0.83x10^{-6}$	$0.83x10^{-5}$
Upper	$0.40x10^{-4}(0.10/0.75) = 0.53x10^{-5}$	$0.53x10^{-4}$

Probability of Adverse Response
Given Dam Extension – Alternative 5C
And Given Flood Loading of
(1/25 yr – 1/PMF) = 0.04 – 0.00 = 0.04

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Summary of Computed Probabilities
of Consequences A, B and C Occurring

	Total Annual Probability		
Consequence	Median	Average	Range
With Old Dam:			
A	$0.55x10^{-6}$	$0.57x10^{-5}$	$0.11x10^{-10} – 0.45x10^{-4}$
B	$0.15x10^{-6}$	$0.15x10^{-5}$	$0.33x10^{-10} – 0.11x10^{-3}$
D	0.0064	0.0068	$1.0x10^{-4} – 0.025$
Without Old Dam:			
A	$0.55x10^{-6}$	$0.57x10^{-4}$	$0.11x10^{-9} – 0.45x10^{-3}$
B	$0.15x10^{-5}$	$0.15x10^{-4}$	$0.33x10^{-9} – 0.11x10^{-2}$

D.
Dam Rehabilitation
New Upstream Embankment
Alternative 3A

Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment and Old Dam Left in Place – Alternative 3A

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Conditions leading to adverse response:

1. Fissure is present that will pass flow under the dam.

2. Water bypasses the cutoffs of the new embankment and erodes the Holocene soils present under the old dam.

3. Old dam erodes or collapses into the hole that forms and fails.

*4. New dam erodes from flow causing erosion at its toe and breaches.

* The issue is if there is enough water available and enough time to have the breach occur – the options are that there is not enough of either (Option A) or something must have happened to the new dam in the process of failure of the old dam and the probability of the breach or collapse of the new dam is higher (Option B).

Factors influencing probability that Condition 2 will occur given that Condition 1 has occurred:

Likely

- Erosive Holocene soils are present under the dam.
- Any cracks present will expand when flooding occurs.
- May have continuity of earth fissures.
- There will be some water available to potentially cause erosion.

Not Likely

- There is a limited supply of water, likely not enough to cause erosion.
- There is a longer flow path, with exit gradient significantly less (about ½).
- Flow will not be long enough to form tunnel and cause erosion.
- Earth fissure may terminate and/or reoccur elsewhere.
- New upstream dam eliminates the available volume of water.
- Water may flow downward rather than laterally in the earth fissure.

Factors influencing the probability that Condition 3 will occur given that Condition 2 has occurred:

Likely

- A crack could form in the dam.

Not Likely

- There is less water available, and not a sufficient amount to cause failure.
- The duration of the flooding is insufficient to result in failure.
- There is less likelihood of plugging that would allow flow at the surface.
- The presence of the center drain/cutoff and the downstream geotextile will tend to mitigate the flow.

Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment and Old Dam Left in Place and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03

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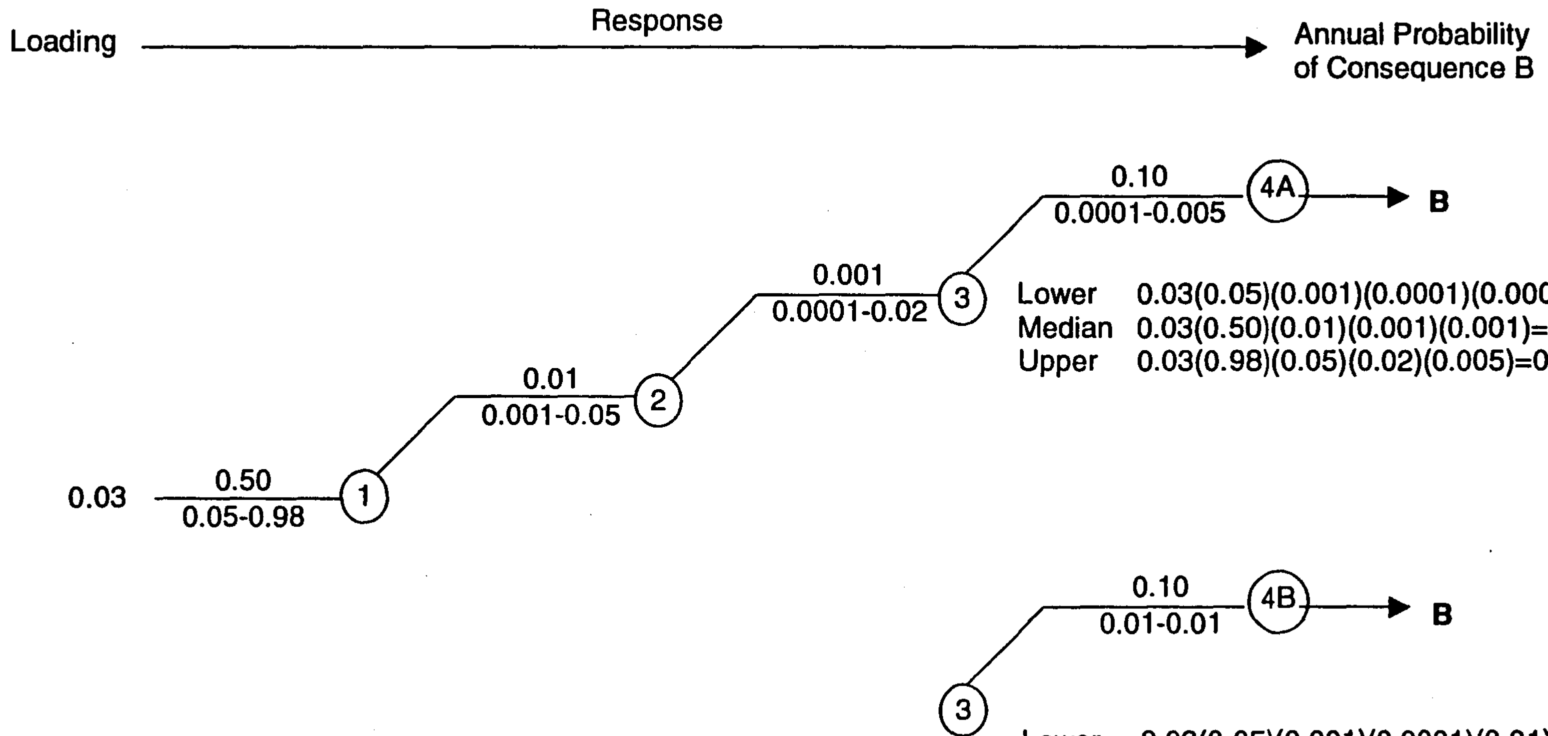
	Estimates of Condition Occurring Given the Previous Condition Has Occurred				
	1*	2	3	4A	4B
Probability	0.05	0.001	0.0001	0.0001	0.01
	0.50	0.001	0.001	0.0001	0.01
	0.50	0.01	0.001	0.0001	
	0.50	0.01	0.001	0.001	
	0.50	0.01	0.001	0.001	
	0.50	0.01	0.001	0.001	
	0.50	0.01	0.001	0.001	
	0.75	0.02	0.01	0.001	
	0.75	0.02	0.01	0.005	
	0.90	0.05	0.01		
	0.98	0.05	0.02		
Lower	0.05	0.001	0.0001	0.0001	0.01
Median	0.50	0.01	0.001	0.001	0.01
Average	0.58	0.017	0.0051	0.0011	0.01
Upper	0.98	0.05	0.02	0.005	0.01

* Same as probability for existing McMicken Dam in the high hazard zone.

Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment and Old Dam Left in Place and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 (Median Values)



Lower 0.03(0.05)(0.001)(0.0001)(0.0001)=0.15x10^{-13}
Median 0.03(0.50)(0.01)(0.001)(0.001)=0.15x10^{-9}
Upper 0.03(0.98)(0.05)(0.02)(0.005)=0.15x10^{-6}

Lower 0.03(0.05)(0.001)(0.0001)(0.01)=0.15x10^{-11}
Median 0.03(0.50)(0.01)(0.001)(0.01)=0.15x10^{-8}
Upper 0.03(0.98)(0.05)(0.02)(0.01)=0.29x10^{-6}

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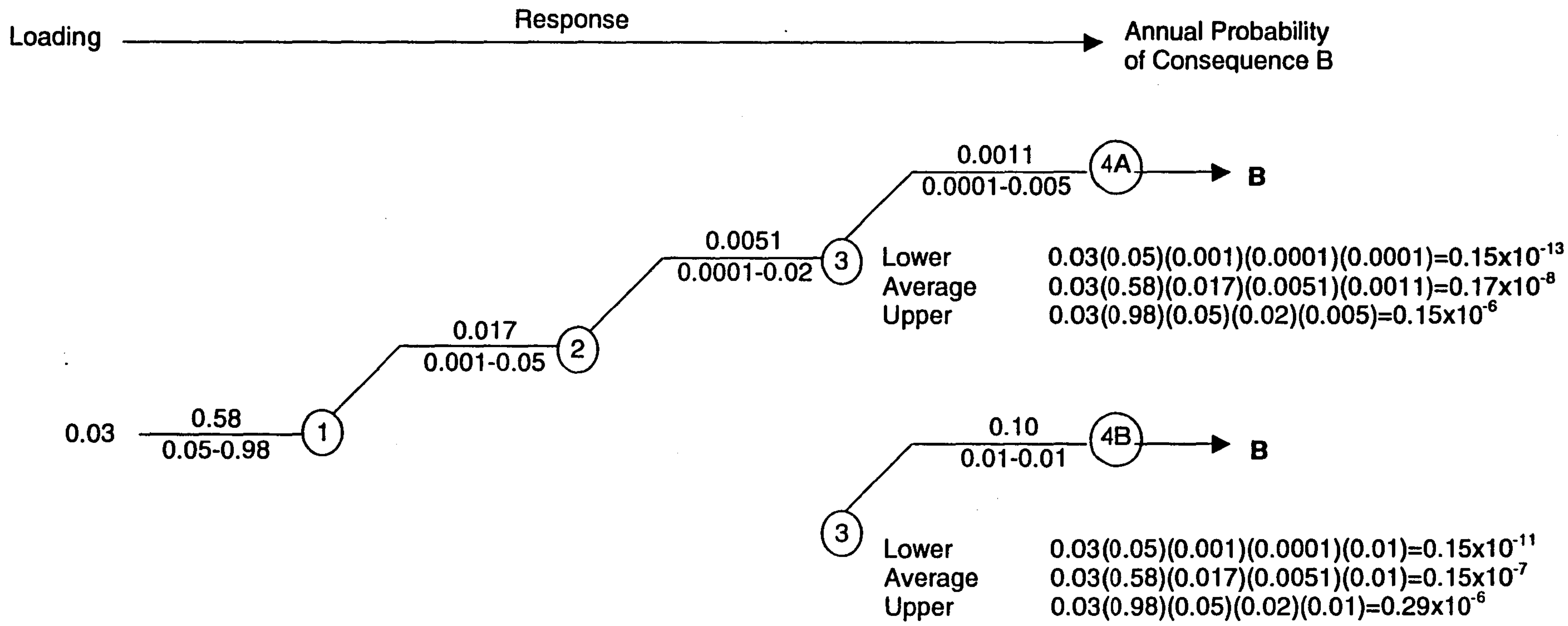
Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment and Old Dam Left in Place and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 (Average Values)



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Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment and Old Dam Left in Place and Given Flood Loading of (1/100 yr – 1/PMF) = (0.01-0.00) = 0.01

The group agreed that the probability of failure is not significantly different from that for the flood loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03. Thus, factor the (1/25 yr – 1/100 yr) flood loading probabilities by 0.01/0.03 = 0.333. The result is Consequence A, although possibly used enough water (or it took long enough for failure to occur) that Consequence B results.

Probabilities for Consequence A:

Option A:

Lower	$(0.01/0.03)(0.15\times10^{-13}) = 0.50\times10^{-14}$
Median	$(0.01/0.03)(0.15\times10^{-9}) = 0.50\times10^{-10}$
Average	$(0.01/0.03)(0.17\times10^{-8}) = 0.57\times10^{-9}$
Upper	$(0.01/0.03)(0.15\times10^{-6}) = 0.50\times10^{-7}$

Option B:

Lower	$(0.01/0.03)(0.15\times10^{-11}) = 0.50\times10^{-12}$
Median	$(0.01/0.03)(0.15\times10^{-8}) = 0.50\times10^{-9}$
Average	$(0.01/0.03)(0.15\times10^{-7}) = 0.50\times10^{-8}$
Upper	$(0.01/0.03)(0.29\times10^{-6}) = 0.97\times10^{-7}$

Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment but Old Dam Removed and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03

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If the old dam is not in place, the probability of failure is the same as the probability of failure of Alternative 4A2 in the moderate hazard zone with the old dam removed, but adjusted for the rehabilitation (new embankment dam) occurring in the high hazard zone.

Adjust by ratio of probabilities for Condition 1 occurring:

Lower	$(0.05/0.10)(0.30\text{x}10^{-9}) = 0.15\text{x}10^{-9}$
Mean	$(0.50/0.20)(0.12\text{x}10^{-5}) = 0.30\text{x}10^{-5}$
Average	$(0.58/0.32)(0.13\text{x}10^{-4}) = 0.24\text{x}10^{-4}$
Upper	$(0.98/0.75)(0.96\text{x}10^{-3}) = 0.0013$

And the result is Consequence B.

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Probability of Adverse Response Given Rehabilitation of Old Dam with New Upstream Embankment but Old Dam Removed and Given Flood Loading of (1/100 yr – 1/PMF) = (0.01-0.00) = 0.01

Adjust probabilities for flood load of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03 by previously determined ratios of higher water condition to lower water conditions determined for Alternative 4A2:

Lower	$(0.01/0.03)(1.00)(0.15\times10^{-9}) = 0.50\times10^{-10}$
Mean	$(0.01/0.03)(1.10)(0.30\times10^{-5}) = 0.11\times10^{-5}$
Average	$(0.01/0.03)(1.13)(0.24\times10^{-4}) = 0.90\times10^{-5}$
Upper	$(0.01/0.03)(1.25)(0.0013) = 0.54\times10^{-3}$

And the result is Consequence A.

Probability of Adverse Response Given Rehabilitation of Old Dam With New Upstream Embankment (Alternative 3A) and Given Flood Loading of (1/25 – 1/PMF) = 0.04 – 0.00 = 0.04

Summary of Probabilities of Consequences A and B Occurring

	Total Annual Probability		
Consequence	Median	Average	Range
With Old Dam (Option A)			
A	0.50×10^{-10}	0.57×10^{-9}	$0.50 \times 10^{-14} - 0.50 \times 10^{-7}$
B	0.15×10^{-9}	0.17×10^{-8}	$0.15 \times 10^{-13} - 0.15 \times 10^{-6}$
With Old Dam (Option B)			
A	0.50×10^{-9}	0.50×10^{-8}	$0.50 \times 10^{-12} - 0.97 \times 10^{-7}$
B	0.15×10^{-8}	0.15×10^{-7}	$0.15 \times 10^{-11} - 0.29 \times 10^{-6}$
Without Old Dam			
A	0.11×10^{-5}	0.90×10^{-5}	$0.50 \times 10^{-10} - 0.54 \times 10^{-3}$
B	0.30×10^{-5}	0.24×10^{-4}	$0.15 \times 10^{-9} - 0.0013$

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E.
Dam Rehabilitation
New Downstream RCC Structure
Alternative 3E

Probability of Adverse Response Given Rehabilitation of Old Dam with New Downstream RCC Structure and Old Dam Left in Place – Alternative 3E

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Conditions leading to adverse response:

1. Fissure is present that will pass flow under the dam.

2. Large hole erodes in the Pleistocene soils, but progresses no further, leading to Consequence C.

3. Hole expands, the RCC dam displaces or cracks and fails and the existing dam has already failed <u>or</u> the RCC dam fails and the existing dam remains.*

4. The old dam fails.**

* The group decided either was likely to happen, or probability is 0.50 that old dam remains.

** The group assigned a probability of 0.10 to Condition 4 occurring, considering the new dam would have to fail first. See discussion for Alternative 4A2 on Page B-5.

Factors influencing the probability that Condition 3 occurs given that Condition 2 has occurred:

Likely

- An eroded hole in the Pleistocene soils can expand.

Not Likely

- The flow volume and power decrease and are not sufficient to expand an eroded hole.
- The eroded hole may be finite in size because its growth will be limited by the presence of non-erosive materials.
- Limited source of water and insufficient time to expand an eroded hole.
- The cutoffs included in the design form a side boundary to the expansion of an eroded hole.
- There is inadequate head available.
- There is a high percentage of non-erosive material (90 percent) in the Pleistocene soils.

Probability of Adverse Response Given Rehabilitation of Old Dam with New Downstream RCC Structure and Old Dam Left in Place and Given Flood Loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03

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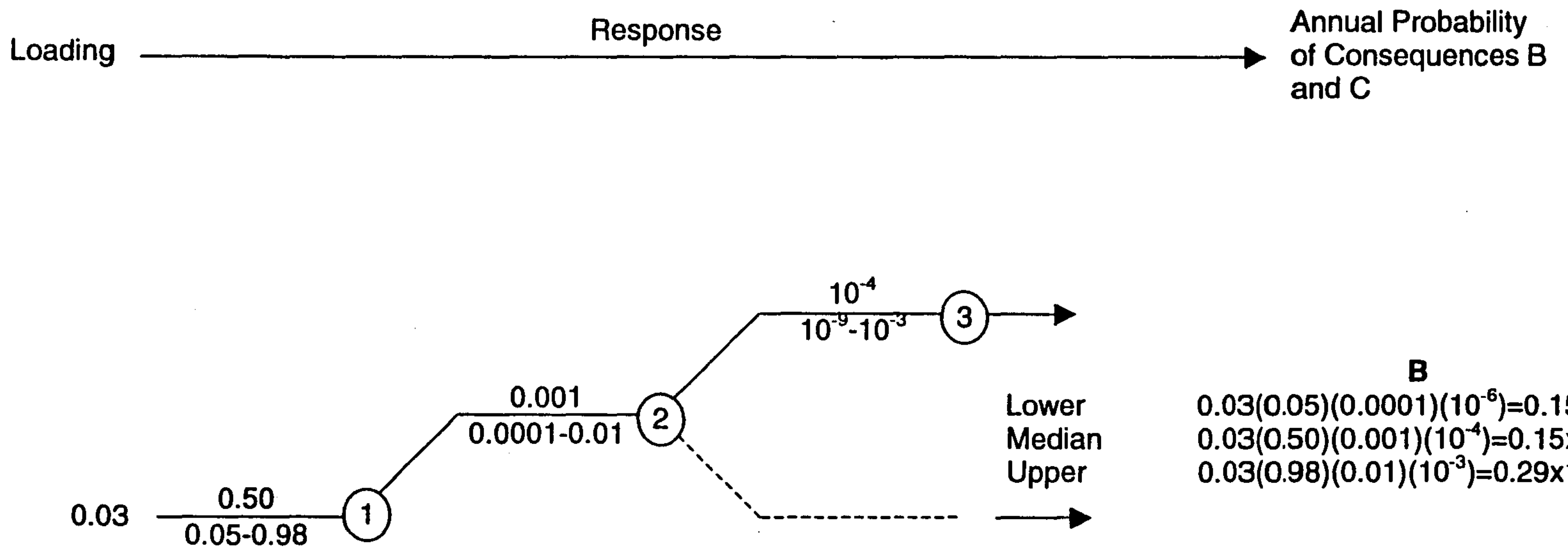
Estimates of Condition Occurring Given the Previous Condition Has Occurred

	1*	2	3	4
Probability	0.05	0.0001	10^{-6}	
	0.50	0.001	10^{-6}	
	0.50	0.001	10^{-6}	
	0.50	0.001	10^{-5}	
	0.50	0.001	10^{-5}	
	0.50	0.001	10^{-4}	0.10
	0.50	0.001	10^{-4}	
	0.75	0.005	10^{-4}	
	0.75	0.01	10^{-4}	
	0.90	0.01	10^{-4}	
	0.98	0.01	10^{-3}	
Lower	0.05	0.0001	10^{-6}	0.10
Median	0.50	0.001	10^{-4}	0.10
Average	0.58	0.0037	0.14×10^{-3}	0.10
Upper	0.98	0.01	10^{-3}	0.10

*Same as probability for existing McMicken Dam in the high hazard zone.

Probability of Adverse Response
Given Rehabilitation of Old Dam
With New Downstream RCC Structure
And Old Dam Not Left in Place and
Given Flood Loading of
(1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03
(Median Values)



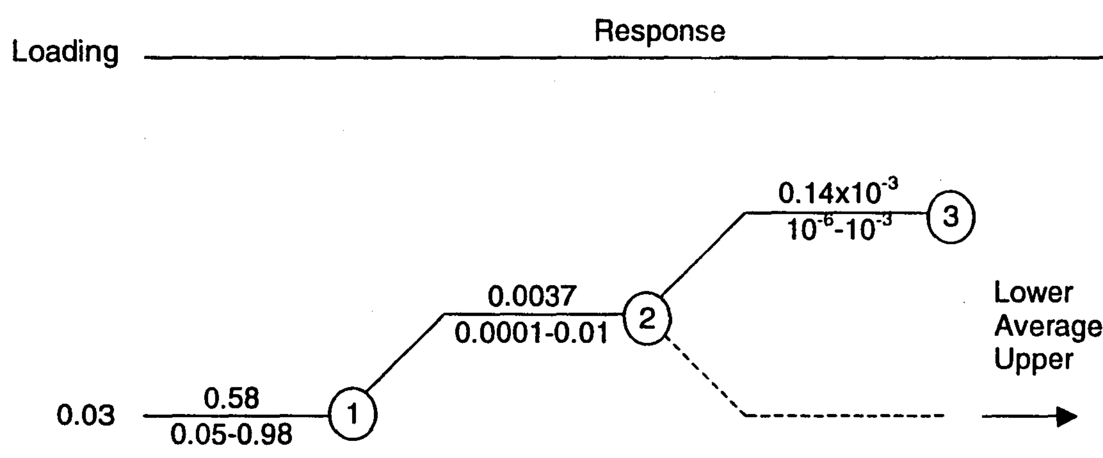
B

Lower	$0.03(0.05)(0.0001)(10^{-6})=0.15\times10^{-12}$
Median	$0.03(0.50)(0.001)(10^{-4})=0.15\times10^{-8}$
Upper	$0.03(0.98)(0.01)(10^{-3})=0.29\times10^{-6}$

C

Lower	$0.03(0.05)(0.0001)=0.15\times10^{-6}$
Median	$0.03(0.50)(0.001)=0.15\times10^{-4}$
Upper	$0.03(0.98)(0.01)=0.29\times10^{-3}$

Probability of Adverse Response
Given Rehabilitation of Old Dam
With New Downstream RCC Structure
And Old Dam Not Left in Place
And Given Flood Loading of
(1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03
(Average Values)



Annual Probability of Consequences B and C

B

Lower $0.03(0.05)(0.0001)(10^{-6})=0.15\times10^{-12}$

Average $0.03(0.58)(0.0037)(0.14\times10^{-3})=0.90\times10^{-8}$

Upper $0.03(0.98)(0.01)(10^{-3})=0.29\times10^{-6}$

C

Lower $0.03(0.05)(0.0001)=0.15\times10^{-6}$

Average $0.03(0.58)(0.001)=0.64\times10^{-4}$

Upper $0.03(0.98)(0.01)=0.29\times10^{-3}$

Probability of Adverse Response Given Rehabilitation of Old Dam with New Downstream RCC Structure and Given Flood Loading of (1/100 yr – 1/PMF) = 0.01-0.00 = 0.01

Group determined there is no significant difference in failure probabilities as compared to flood loading of (1/25 yr – 1/100 yr) = (0.04-0.01) = 0.03, thus the probabilities are the same as computed for that flood loading but need to be factored by 0.01/0.03 = 0.333. Failure results in Consequences A and C.

Consequence A:

Lower	$(0.01/0.03)(0.15\times10^{-12}) = 0.50\times10^{-13}$
Median	$(0.01/0.03)(0.15\times10^{-8}) = 0.50\times10^{-9}$
Average	$(0.01/0.03)(0.90\times10^{-8}) = 0.30\times10^{-8}$
Upper	$(0.01/0.03)(0.29\times10^{-6}) = 0.10\times10^{-6}$

Consequence C:

Lower	$(0.01/0.03)(0.15\times10^{-6}) = 0.50\times10^{-7}$
Median	$(0.01/0.03)(0.64\times10^{-4}) = 0.50\times10^{-5}$
Average	$(0.01/0.03)(0.64\times10^{-4}) = 0.21\times10^{-4}$
Upper	$(0.01/0.03)(0.29\times10^{-3}) = 0.10\times10^{-3}$

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**Probability of Adverse Response
Given Rehabilitation of Old Dam
With New Downstream RCC Structure
(Alternative 3E) and Given Flood Loading of
(1/25 yr – 1/PMF) = 0.04 – 0.00 = 0.04**

**Summary of Probabilities of
Consequences A, B and C Occurring**

	Total Annual Probability		
Consequence	Median	Average	Range
With Old Dam			
A	$0.50x0^{-10}$	$0.30x10^{-9}$	$0.50x10^{-14} - 0.10x10^{-7}$
B	$0.15x0^{-9}$	$0.90x10^{-9}$	$0.15x10^{-13} - 0.29x10^{-7}$
C	$0.20x10^{-4}$	$0.85x10^{-4}$	$0.20x10^{-6} - 0.39x10^{-3}$
Without Old Dam			
A	$0.50x10^{-9}$	$0.30x10^{-8}$	$0.50x10^{-13} - 0.10x10^{-6}$
B	$0.15x10^{-8}$	$0.90x10^{-8}$	$0.15x10^{-12} - 0.29x10^{-6}$
C	$0.20x10^{-4}$	$0.85x10^{-4}$	$0.20x10^{-6} - 0.39x10^{-3}$