Zoar Levee and Diversion Dam
Final Draft Report

Dam Safety Action Classification I Projects: Engineering Risk and Reliability Analysis-Independent External Peer Review

Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Prepared for
Engineering Risk and Reliability
Directory of Expertise
U.S. Army Corps of Engineers
Pittsburgh District

Contract No. W911NF-07-D-0001
Task Control Number: 09128
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December 7, 2009

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Battelle
The Business *of* Innovation

(This will be signed at the completion of the Final Report)

The Independent External Peer Review (IEPR) Panel has completed its review of Zoar Levee and Diversion Dam, Engineering Risk and Reliability Analysis for the Independent External Peer Review - Dam Safety Action Classification Group I contained within this Final Report dated TBD. All comments, responses, issues and concerns resulting from this IEPR have been fully addressed.

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Jeff Bradley, P.E., D.WRE, Ph.D.

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Keith Ferguson, P.E.

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Steve Poulos, P.E., Ph.D.

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EXECUTIVE SUMMARY

DSAC Classification of Zoar Levee and Diversion Dam

The U.S. Army Corps of Engineers (USACE) recently re-classified the Zoar Levee (Levee) and Diversion Dam in Ohio from Dam Safety Action Classification (DSAC) II to DSAC I (Urgent and Compelling) in accordance with EC 1110-2-6064, *Interim Risk Reduction Measures for Dam Safety*. The purpose of the current report is to summarize an Independent External Peer Review (IEPR) Panel's (hereafter referred to as the Panel) evaluation of the dam, submit the Panel's opinion of the DSAC classification, and present the Panel's recommendations for action by the Huntington District of the USACE (hereafter referred to as the District). This IEPR report is based on observations made by the Panel during the June 24 – 26, 2009, site visit data collected in summer 2009, and project related reports provided to the Panel by the USACE (Appendix B). The Panel completed the Draft Report in November 2009; their opinions reflect the information available during the stated timeframe.

Based on the criteria and information provided and reviewed, the Panel concurs that the classification of the Levee and Diversion Dam system should be DSAC I. This opinion is based on the following:

a) Compelling evidence that a seepage failure mode has initiated at a number of locations along the landside toe and in the rock knoll in the right abutment of the Levee, and at in the right abutment of the Diversion Dam. Erosion and piping of foundation materials occurs during each period of loading at each structure.

b) Seepage distress indicators are changing as a result of each cycle of flood loading. The seepage quantities are increasing, and new seepage and piping locations are developing.

c) The risk rating of two highlighted potential foundation seepage and piping failure modes, as well as the potential consequences of failure of either the Levee or the Diversion Dam, require that expedited action be taken to reduce the risk of failure. The risk rating is based on only two of a wide range of potential failure modes, and does not provide an indication of the total risk rating of the project, which would be even more critical. The risk ratings are consistent with the observed seepage distress indicators at the site and a DSAC I classification.

Modes of Failure

Following review of the information that was provided, it is the opinion of the Panel that all of the potential failure modes (PFMs) listed below should be considered as part of detailed risk evaluation and during the development of permanent remediation alternatives:

<u>Zoar Levee</u>

1. Abutment seepage and piping failure at the rock knoll in the right abutment.

2. Foundation seepage and piping of the sections of the Levee sited on alluvial foundation materials
3. Stability failure of the landside slope of the Levee leading to overtopping failure
4. Seepage and piping failure along the outlet works conduit
5. Overtopping

Diversion Dam

6. Clogging of the outlet works and spillway with woody debris, leading to overtopping failure
7. Overtopping failure due to the effects of backwater from Dover Reservoir
8. Abutment and foundation seepage leading to seepage and piping failure
9. Seepage and piping failure along the outlet works conduit.

With regard to PFMs 1 and 2 above, failure may occur through the alluvial foundation beginning in the ballpark area, and extending to the area around the pump station, or through the rock knoll in the right abutment south of the pump station. The Panel believes that these are two distinct failure modes with different conditions and failure mode development processes. Each should be analyzed separately to judge the overall risk of failure of the Levee.

Interim Risk Reduction Measures (IRRM)

The District has developed an Interim Risk Reduction Measure Plan (IRRMP) in accordance with the guidance outlined in EC 1110-2-6064. The Panel reviewed this plan and recommends that the District implement the following additional IRRMs:

- Improve monitoring of groundwater pressures, seepage flow quantities, and piping at various locations along the ballpark and rock knoll sections of the Levee. The existing system of instruments and monitoring frequency should be evaluated in light of what has been learned from the observed seepage and from the failure modes and risk analyses completed to date. This is particularly important relative to the potential for clogging and pressure buildup beneath the recently placed seepage berms. Weirs with troughs should be installed at selected locations to route seepage so that flow quantities can be measured and sediment can be collected. Frequent analyses of monitoring data should be completed and reports prepared that show the instrumentation data and their evaluations. Provide any needed recommendations with each report.
- Improve the ability to monitor flows and potential water storage behind the Diversion Dam.
- Repair rodent holes and damage from rodent activities on both the upstream and downstream slopes of the Diversion Dam.

There is relatively high potential for clogging and subsequent failure of seepage berms constructed as IRRMs at seepage discharge locations at both the Levee and Diversion Dam.

Clogging could result in two outcomes during future flooding events: 1) seepage will emerge from an unfiltered location; or 2) the berm will heave and rupture. In either case, the continuation or progression of the failure mode is expected to occur, possibly at a rapid rate. It will be critical to monitor the performance of the berms during any future flooding event. Permanent mitigation of the seepage defects should be completed as soon as possible.

Consequences of Failure

Under current conditions, the potential for dam failure is increasing with each flooding event. The consequences of failure of the Zoar Levee or Diversion Dam will be constrained to the village of Zoar and the roads into and out of the village, including State Route 212. Because of the limited extent of the area of potential consequences, the implementation of emergency action procedures, including warning and evacuation of residents and the implementation of road blocks may significantly lower the potential for loss of life on an interim basis.

The potential to mitigate consequences through an emergency action plan (EAP) as a long-term (permanent) solution should be evaluated and considered in risk analyses and corrective action studies under the "as-low-as-reasonably-practicable"(ALARP) provisions of the Tolerable Risk Guidelines of USACE.

The Panel notes that emergency preparations and actions may not fully mitigate the potential for loss of life, and, hence, may not significantly reduce the estimated risk rating.

Other Findings and Recommendations

Stage vs. Frequency Evaluations

The Panel recommends that the USACE update the Stage vs. Frequency relationship for the Dover Reservoir and include reservoir routing effects in the evaluation of the pool level at the Levee. A Stage vs. Frequency relationship for the Diversion Dam should also be updated with consideration of the potential for clogging of both the low-level outlet works intake and the Diversion Channel (spillway) with woody debris. The backwater effects from Dover Reservoir should be included in the analysis.

Three-Dimensional Geologic Model of the Project Area

The Panel recommends that a three-dimensional geologic model of the project area be developed to characterize the bedrock surface, hydrogeology, and geomorphology of the Tuscarawas River alluvial channel to evaluate the presence or absence of highly permeable zones and to confirm all potential seepage pathways and hazards.

The continuity of the possible confining clay layer that covers the Levee site and the characteristics of the pervious outwash materials below it should be determined. In situ tests should be performed during drilling to verify the in situ horizontal permeability of the sands and gravels and the Lugeon values for the bedrock in the rock knoll area of the Levee and in the abutments of the Diversion Dam. The drilling program should include borings between the site

of the Levee and the Tuscarawas River to determine whether alluvial sands and gravels beneath the Levee are hydraulically continuous to the river and the reservoir.

Three-Dimensional Groundwater Model

Development of a three-dimensional groundwater model using the three-dimensional geologic model should be considered. Such a model may be useful for design and for understanding the regional southerly flow of groundwater under Zoar Village toward the Levee and potential influence on the groundwater regime on water pressures that develop under and along the landside toe of the Levee during flood events. In addition, the model will be useful in the future to help understand any changes of groundwater flow patterns and their effects after any remediation has been completed.

Levee Investigations

Borings should be drilled through the Levee at selected locations to confirm the internal zoning, to obtain samples for laboratory testing, and to measure penetration resistance and in situ horizontal permeability of each zone of the dam. Laboratory tests should be performed on samples of materials from each zone to measure their gradation, plasticity, and shear strength, as needed.

Alternatives for Permanent (Long-term) Modifications

The USACE is currently evaluating Dover Dam, Zoar Levee and Diversion Dam, Bolivar Dam, and other upstream dams located in the local portion of the Muskingum Flood Protection System on an individual basis. The decisions related to IRRMs and permanent modifications within this portion of the Muskingum Flood Protection System are interrelated. The Panel, therefore, recommends that all of the structures be studied as a group so that IRRMs and the design of permanent repairs are coordinated to avoid problems that could arise if the structures are not considered together as a system.

The following is a summary of the Panel's recommendation related to potential permanent modification alternatives:

General

- A PFMA (Potential Failure Modes Assessment) and subsequent risk assessment should be completed for all of the highlighted failure modes outlined above and in Section 9.1, as well as any other credible failure modes identified during the PFMA.
- Concepts for reducing risk should be developed for each of the failure modes having a significantly high contribution to the total risk rating and contributing to a DSAC I or DSAC II action classification.
- Alternatives should be developed that provide appropriate total risk reduction by combining remediation concepts from the individual failure modes.

Zoar Levee

- The Panel believes that a risk assessment of the potential foundation failure modes along the portions of the Levee situated on alluvial foundation materials will show the need for corrective action. This is in addition to the corrective action for the rock knoll failure modes that have been previously evaluated. Consequently, a cutoff wall along the entire length of the Levee may be appropriate.
- Other potential failure modes associated with stability of the Levee slopes and seepage along the outlet conduit will likely require corrective actions that should be incorporated into the alternatives evaluation.
- Raising the Levee to provide additional risk reduction for overtopping failure modes should be included in the alternatives evaluation.
- The feasibility of installing a clay seepage blanket on the river side of the Levee should be evaluated and considered, as appropriate, in the alternatives evaluation. However, it should not be placed unless the groundwater model indicates that such a blanket will significantly decrease the flow through the pervious foundation materials.

Diversion Dam

- Consider raising the crest elevation of the existing Diversion Dam to provide additional risk reduction for overtopping failure modes.
- Remove and replace the existing Dover Dam and outlet works and replace using appropriate foundation treatment, to mitigate potential foundation failure modes. Removal and replacement of the existing dam should eliminate any seepage-induced damage that may have previously occurred in the embankment or in foundation soils immediately below the embankment.
- Widening and deepening of the Diversion Channel should be evaluated. Deepening of the Diversion Channel could eliminate the need for the existing outlet works. Elimination of the outlet works, and removal and replacement of the existing Diversion Dam should be considered if deepening of the Diversion Channel is feasible; this would essentially create a ring levee around the village of Zoar.
- The stability of the intake tower should be evaluated. The elevation of the tower and operating system should be raised so that the gates can be operated during high pool elevations.
- The power supply to the outlet tower should be modified by raising it above the maximum pool elevation.
- Options to prevent clogging of the outlet works intake and Diversion Channel should be included in the design concepts.

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1 INTRODUCTION

1.1 Background of Program

The Dam Safety Action Classification (DSAC) program was created by the U.S. Army Corps of Engineers (USACE) to validate the high risk status of Flood Risk Management dams through an independent assessment of the project. In particular, this Independent External Peer Review (IEPR) addresses the analyses related to the DSAC I recommendation, focusing on the technical soundness of the Screening Portfolio Risk Analysis (SPRA) report's assumptions, methods, and calculations.

Battelle Memorial Institute (Battelle), as a nonprofit science and technology organization with experience in establishing and administering peer review panels, was engaged to coordinate the IEPRs of several dam safety projects for USACE. The IEPRs are conducted and managed using contract support from an outside eligible 501(c)(3) organization to ensure independent objectivity, along with a high degree of flexibility and responsiveness, which is essential for USACE to meet deadlines, and complement the Agency technical review. The IEPRs follow the procedures and guidance described in the U.S. Department of the Army's CECW-CP Memorandum and *Guidance for Peer Review Decision Documents* (EC 1105-2-410) dated August 22, 2008 , as well as guidance in the *Engineering and Design, Quality Management* (ER 1110-1-12), dated July 21, 2006.

1.2 USACE Dam Safety Action Classification Groups

The objective of the Dam Safety Program is to ensure that USACE structures do not present an unacceptable risk to public safety, property, and welfare. Over the past several years, USACE has developed and implemented risk-based screening tools for the purpose of identifying high-risk dams and prioritizing investments. National teams composed of multi-disciplinary engineers (structural, geotechnical, and hydraulic), economists, and geologists have been deployed across the nation to analyze a portion of the USACE's portfolio of dams.

Over 600 flood-damage reduction, low-head navigation, or high-head navigation dams have been scheduled for initial screening using the SPRA tool; this assessment is slated to be completed by the end of 2009. The results of the screening will be compared to a Baseline Dam (a new dam with similar features) and rated as Adequate, Probably Adequate, Probably Inadequate, or Inadequate (see below for ratings and definitions). As part of the screening analysis, engineering ratings were assigned to over thirty different project features using existing studies, performance data, criteria, project characteristics, and engineering judgment. The following is a brief description of the ratings assigned to each dam feature by USACE:

- Adequate (A): Judged to perform well under specified loading conditions with a high level of confidence backed up by data, studies, or obvious project characteristics and judged to meet current engineering standards and criteria.
- Probably Adequate (PA): Judged to perform well under specified loading with a low level of confidence and may not specifically meet criteria. Requires additional investigation or studies to confirm adequacy.

- Probably Inadequate (PI): Judged to not perform well under specified loading with a low level of confidence and requires additional studies and investigations to confirm. Judged to not meet current criteria.
- Inadequate (I): Judged to not perform well under specified loading with a high level of confidence. Physical signs of distress are present. Analysis indicates factor of safety near stated limit.

The results of USACE's screening effort were also used to categorize projects into Action Classification groups based on the likelihood of unsatisfactory performance and/or consequences of failure. Dams found to be on a continuum leading to failure (often one or more PI or I ratings) were categorized within Dam Safety Action Classification Group I (DSAC I). Projects classified as DSAC I are targeted for immediate risk reduction measures and expedited remediation.

The USACE is working towards a risk-informed management strategy for Dam Safety. The first step in this process was the development of the SPRA process. In January of 2005, the Zoar Levee experienced a record pool condition which resulted in significant foundation seepage problems. The resulting 2006 SPRA report was entitled *Documentation for Screening for Zoar Levee and Diversion Dam (Dover Dam Project)*, (USACE, 18 April 2006, NIDID: OH00003-06); this initial report classified the dam as a DSAC II. However, due to a second record flood event in 2008, the Zoar Levee and Diversion Dam facility was reclassified as a DSAC I (Urgent and Compelling), in accordance with the ETL 1110-2-6064, *Interim Risk Reduction Measures for Dam Safety*. The 2006 SPRA report was used to shape the improvements and future investigations.

During the IEPR, panel members evaluated the 2006 SPRA report recommendations, first independently and then again in a collaborative group format. Panel members participated in a site visit to the project Levee and Diversion Dam from June 24-26, 2009. Additionally, the panel members reviewed and analyzed data associated with the project provided by the District during the summer 2009 through the September 16, 2009, the submission of the Preliminary Draft Report to the District Office. The panel provided their recommendations based on the site visit and the data received during this timeframe. A project timeline is shown in Table 2.1

2 INDEPENDENT EXTERNAL PEER REVIEW PROCESS

This section describes the methods involved in selecting the IEPR panel members and in planning and conducting the IEPR. The IEPR followed the process described in the Draft Work Plan, which was developed specifically for this project, and was conducted following procedures described in USACE's guidance cited in Section 1.2 and in accordance with the Office of Management and Budget's *Final Information Quality Bulletin for Peer Review*, released December 16, 2004. In addition, supplemental guidance was also followed on conflicts of interest (COIs) evaluation using the National Academies' *Policy on Committee Composition and Balance and Conflicts of Interest for Committees Used in the Development of Reports*, dated May 12, 2003.

2.1 Planning and Schedule

Table 2.1 defines the schedule followed in execution of the IEPR.

Table 2-1 DSAC I Projects: Engineering Risk and Reliability Analysis IEPR Milestones and Deliverables Schedule by Task (deliverables are indicated by an asterisk*).

Task	Action	Due Date
	Notice to Proceed	April 30, 2009
	Review Documents available	June 8, 2009
Task 1	Battelle submits draft Work Plan/directive to USACE*	May 15, 2009
Task 2	Select no more than 4 panel members Complete subcontracts for panel members	March 27, 2009
Task 3	Battelle submits draft Critical Items List (CIL) to panel Battelle submits directive to panel members Panel submits Preliminary CIL to Battelle	May 13, 2009 May 22, 2009 Not available
Task 4	USACE /Panel/Battelle Kick-Off Teleconference	June 15, 2009
Task 5	Site Investigation: Huntington District and panel Panel submits Site Investigation Report Battelle submits IAR Reports (3) to USACE*	June 24-26, 2009 July 7, 2009 July 20, 2009
Task 6	Collaborative Teleconference	July 31, 2009
Task 7	Preliminary Draft Report* Draft Report* Final Draft Report*	September 16, 2009 November 2, 2009 December 7, 2009
Task 8	Internal Communications Plan* Media Round Table Discussion*	January 2010 January 2010
Task 9	USACE Senior Briefing PowerPoint Presentation*	February 2010

2.2 Identification and Selection of IEPR Panel members

Battelle identified six panel candidates who had the requisite areas of expertise for the DSAC projects. The candidates were identified using referrals, Internet searches, and personal contacts. All six candidates were contacted and screened for their technical expertise, potential Conflict of Interest (COI), previous performance on similar reviews, and availability to meet the schedule mandated by the client. Of the six that were identified, three candidates were selected to review the DSAC project based on their qualifications, lack of COI, interest, and availability. See Section 3.0 for additional details on the recruitment process and selection/exclusion criteria. Battelle established subcontracts with the panel members who indicated their willingness to participate and confirmed the absence of COIs (through a signed COI form).

The panel members were screened for the following *potential* exclusion criteria or COIs:

- Involvement in any part of the Documentation for Screening for Howard Hanson Dam, 5 May 2007, NIDID: WA00298
- Involvement in any part of the development of Documentation for Screening for Zoar Levee and Diversion Dam (Dover Dam Project), 18 April 2006
- Current employment by the USACE
- Current or previous employee or affiliation with other project sponsors
- Current personal or firm involvement with other USACE projects, notably if those projects/contracts are with the Huntington or Seattle District
- Previous employment by the USACE as a direct employee or contractor (either as an individual or through your firm) within the last 10 years
- A significant portion (i.e., greater than 50%) of personal or firm revenues within the last 3 years came from USACE contracts
- Any publicly documented statement made advocating for or against the subject project
- Any other perceived COI not listed, such as: repeatedly served as a USACE technical reviewer; paid or unpaid participation in litigation related to the work of the USACE; or any other perceived COI not listed.

In selecting final panel members from the list of candidates, an effort was made to select those who best fit the criteria and factors described above. The selection of the final three panel members was based on these considerations.

2.3 Preparation of the Directive

The directive for peer review is based on technical direction received from USACE and guidance provided in Department of the Army, U.S. Army Corps of Engineers EC 1105-2-410, *Review of Decision Documents*, and the Office of Management and Budget's *Final Information Quality Bulletin for Peer Review*, released December 16, 2004. Technical input was also gathered from telephone conferences with the panel members and the Huntington District.

The directive for peer review is divided into the following tasks:

- Conduct kick-off teleconferences with USACE , Huntington District Office, panel members, and Battelle
- Prepare a draft Critical Items List (CIL)
- Conduct a site investigation, including a review of relevant project documents (construction drawings, records, design documents, periodic inspection reports, emergency action plans, and special reports for each project) and completion of site investigation checklist/recording photographs
- Prepare an Independent Assessment Report (competed by each panel member)
- Provide a collective Panel assessment of the dam facility, culminating in an IEPR Report.

Battelle provided the panel members with electronic copies of the directive and the review documents received. The USACE provided these documents to Battelle via an FTP site for distribution to the panel members. Battelle provided this information to the panel members on CD ROMs and via Battelle's FTP site.

2.4 Preparation of Critical Items List

The Critical Items List (CIL) and detailed instructions on completion of this list were supplied to each panel member by Battelle after the project kick-off teleconference and prior to the site inspection. The panel members were directed to complete an initial independent assessment of project components, discussing the criticality of each item including:

- Potential failure scenarios
- Potential failure mode
- Potential cause of failure
- How the potential failure may be detected
- Consequence(s) of potential failure
- Severity of potential failure (Mild, Moderate, Severe)
- Potential risk-reduction measures.

A CIL was prepared by each panel member during his independent assessment and was used in the preparation of this Independent Assessment Report (see deliverable dates listed in Table 2-1).

2.5 Conduct of the Peer Review

In order for the panel members to be able to review and synthesize as much project data as possible prior to the site inspection, a teleconference was conducted with the Huntington District, Battelle, and the panel members. Prior to this meeting, panel members had reviewed the 2006 SPRA report for the Zoar Levee and Diversion Dam and materials provided by USACE. During this teleconference, additional site information was requested by the panel members, and particular Huntington District personnel were asked to attend the site inspection.

The site investigation meeting for Zoar Levee and Diversion Dam occurred over a 3-day period, June 24th through June 26th, 2009. Day One included a project briefing by the Huntington District at the Muskingum Office, followed by a detailed site inspection of the Zoar Levee system and Diversion Dam. On Day Two and Day Three, the panel members and Battelle met with USACE personnel at the District Headquarters in Huntington, West Virginia, to discuss the site inspection findings and obtain more detailed information on specific site features.

As part of the site investigation, the following tasks were completed by the panel members:

- Panel members reviewed the list of project materials provided by Battelle and the Huntington District, and prepared the preliminary CIL.
- Prior to conducting the actual site inspection, USACE held a project briefing at the Muskingum Office. Mr. Charles Barry, P.E., Chief of the District Dam Safety Section presented an update of the safety program; Mr. Adam Kays gave a presentation on the geotechnical information related to historic and current seepage at the ballpark section of the Levee. The IRRM was also briefly reviewed.
- Panel members conducted a review of relevant project documents provided by the USACE Huntington District, as described in Section 2.3, including construction drawings, records, design documents, periodic inspection reports, emergency action plans, and special reports for each project.
- Panel members documented the site investigation using the Site Checklist, photographs, and notes.

Approximately 8 working days after the site inspection was completed, the panel members collectively assembled a Site Inspection Report for Zoar Levee and Diversion Dam. This report ensured that each member of the panel had received identical information for the project, assuring that the Individual Assessment Reports would be developed using the same baseline data. The Site Inspection Report summarized the panel members' preliminary findings and recommendations based on the initial briefing and site visit. The following information was included in the Site Inspection Report:

- Preliminary findings and recommendations based on DSAC I rating
- Design approach
- Potential modes of failure and consequences
- Interim Risk Reduction

- Seismic hazards
- Probable Maximum Flood
- Completed Site Inspection Checklist, including photographs
- Documentation of the Huntington District site meeting
- List of relevant project documents reviewed to date
- Outline of request for additional information.

Of particular interest was the outline of additional information requested by the panel members. In order to expedite the information transfer, Battelle staff and panel members worked closely with the Huntington District Office. Information was discussed and posted on the USACE FTP site for quick access by the Panel.

2.6 Individual Assessment Reports

Within 15 business days of the completion of the site visit, panel members prepared individual Independent Assessment Reports (IARs). As shown below, the IAR reports contained an overview of the project by each Panel member at the half-way point of the Panel's detailed review. The table of contents for the IAR was prepared by Battelle and approved by USACE. The IAR included a review of relevant project documents received to date and a technical evaluation of likely failure modes and deficiencies. Each IAR contained the following information:

- Introduction
- Summary of Panel member qualifications
- Site visit and briefings
- Preliminary findings and recommendations
- DSAC rating and other potential deficiencies
- Modes of failure
- Consequences
- Interim Risk Reduction Measures (IRRM)
- Probable Maximum Flood (PMF)
- Seismic hazards
- Supplemental exploration and additional data requirements
- Pertinent site inspection photographs
- Reference materials utilized

Upon submission of the IARs by the panel members, Battelle conducted an editorial review of each report. Teleconferences were conducted with panel members to ensure technical format was consistent. The three IARs were submitted as a single report to USACE.

Upon approval by USACE IEPR Project Manager, copies of the IARs were distributed to the Huntington District Office. All requests for additional project information were forwarded to the USACE Project Manager and the Huntington District Office.

After the IARs were delivered to the USACE, Battelle developed a working outline of the Preliminary Draft Report, combining the independent comments from the Panel members. The collaborative meeting was held via teleconference on July 31, 2009, to provide a forum for the panel members to evaluate the consistency of opinions and to resolve, or to agree not to resolve, any contradictory comments.

The goal of this teleconference was to produce overall themes/issues identified in the individual site visit and IARs to be included in the Preliminary Draft Report. As appropriate, Battelle consolidated the comments to eliminate redundant or overlapping comments and to identify dissenting or diverging comments.

2.7 Preparation of Final Report

The Final Report has been developed through a three-step draft process (Preliminary Draft, Draft, and Final Draft), requiring review by USACE Division and Huntington District staff. The Preliminary Draft and Draft Report review process was used to seek accuracy of facts and statements, with a focus on instrumentation readings, documented performance and behavior, construction and design information, and historic documentation from the Huntington District. The panel members considered this additional information and the Final Draft report was revised accordingly.

To accommodate the intensive fact-checking process, 2 weeks were allowed for USACE review of the Preliminary Draft Report. For the Draft Report review process, 1 week was allowed for the Huntington District to confirm that edits identified in the Preliminary Draft Report were addressed.

The Final Report will be almost identical to the Final Draft Report with the exception of the submittal date and minor revisions. The Final Report will be used for the media round table discussion. The Final Report will be provided in electronic pdf format and one hard-bound copy.

Note that this Final Draft report is based on observations made by the Panel during a site visit in June 2009, data received from the District as a result of the project initiation, site visit, as well as data requested by the Panel during preparation of the Site Investigation Report and Independent Assessment Reports. Additionally, the panel members received comments and additional information from the District Office based on the District's review of the Preliminary Draft and Draft Report. The Panel's recommendations contained in this report are based on this data.

2.8 Dissenting Views

The panel members have been provided a framework to express a dissenting view or views in the form of a non-concurrence report. This report represents the consensus of the entire Panel. No member of the Panel has provided a dissenting opinion. Each panel member has reviewed this report in its present form.

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3 PANEL DESCRIPTION

Potential IEPR panel member candidates were identified through recommendations from USACE and Battelle's IEPR expert database, trade organizations, engineering societies, targeted internet searches using key words (e.g., terms focusing on technical area and geographic region), searches of websites of universities or other compiled expert sites, and through referrals.

3.1 Required IEPR Panel Expertise

All IEPR panel members met at least two of the three following minimum requirements:

- Nationally recognized technical experts with specific recent and relevant geotechnical experience, including experience with seismic hazards, seepage, and piping deficiencies, all relating to dams and levee structures.
- Current and appropriate professional licensing.
- One subject matter expert served as the lead for the Panel.

Panel members in each discipline also were required to have specific technical experience in the areas summarized below.

(1) Geotechnical Engineering Panel Members. Two geotechnical engineering panel members will be provided. Each should be a registered professional engineer from academia, a public agency whose primary mission is flood damage prevention, or an architect-engineer or consulting firm with a minimum 10 years demonstrated experience in geotechnical studies and design of flood control works such as dams, levees, floodwalls and closure structures with a minimum M.S. degree or higher in geotechnical engineering.

The geotechnical engineering panel members' experience should be particularly strong in site investigation planning and implementation, including subsoil investigation, in situ soil testing, and state-of-the-art static and dynamic laboratory testing on disturbed and undisturbed soil samples. The geotechnical engineering panel members should have an extensive experience in geotechnical evaluation of flood-control structures, such as static and dynamic slope stability evaluation, evaluation of the seepage and piping deficiencies through earthen embankments and under-seepage through the foundation of the flood control structures, including dam and levee embankments, floodwalls, closure structures and other pertinent features, and in settlement evaluation of the flood control structures. Experience should also include design and remediation of flood control structures and foundations, including foundation soil improvement, such as cutoff walls and grouting practice. All panel members should be familiar with geotechnical practices used in the subject project areas, and active participation in related professional societies is encouraged.

(2) Hydraulic Engineering Panel Member. This panel member should be a registered professional engineer with a minimum of 10 years experience in hydraulic engineering. The hydraulic engineer's background should have an emphasis on large public works projects, or this panel member should be a professor from academia with extensive background in hydraulic theory and practice, with a minimum M.S. degree or higher in engineering. Active participation

in related professional societies is encouraged. The panel member should be familiar with USACE application of risk and uncertainty analyses in flood damage reduction studies. The panel member should also be familiar with standard USACE hydrologic and hydraulic computer models, drawdown studies, hydraulic modeling for flood insurance studies, dam break inundation studies, hydrologic modeling and analysis for dam safety investigations, analysis of dam failure and debris flow.

(3) Academic Community Panel Member. One academic community panel member will be provided. The academic panel member should be an active faculty member of a university or college in a geotechnical or hydraulic engineering department. The panel member must have experience conducting research and have significant publications in the subject areas of foundation and earth dam engineering, and geotechnical engineering design and construction. Additional expertise is desired related to the design of dams, levees, dikes, and slurry walls, including seepage analysis, stability analysis, seismic analysis, and deformation analysis. The academic panel member should also have construction expertise including selection of materials, construction techniques and equipment, compaction requirements, and treatment of site water runoff. Note, if the Academic Community panel member also has the qualifications detailed in the geotechnical or hydraulic engineering above, the total number of peer review panelists can be reduced to three (3).

3.2 Selection of IEPR Panel Members

In selecting the final panel members from the list of candidates, an effort was made to select experts who best fit the criteria and factors described above. The selection of the final three panel members was made with concurrence from the USACE and based on consideration of both expertise and confirmed absence of COI.

Once selected, Battelle prepared scopes of work for each of the selected panel members describing the project expectations. A request for quotation, including the scope of work and a conflict of interest inquiry form, was prepared and sent to each potential panel member. Upon receipt of the panel members' written quotations indicating willingness to participate and the signed COI form confirming the absence of COI, Battelle established contracts with the panel members at agreed upon rates and hours to ensure/secure participation. A nondisclosure agreement was also required for the panel members.

A summary of the credentials and IEPR-related qualifications of the three panel members is presented in Table 3.1. A resume including more detailed biographical information for each panel member and his technical areas of expertise is presented in Appendix D.

Table 3-1. IEPR Panel Members.

Discipline/Name	Affiliation	Location	Education	P.E.	Years of Experience
Hydrologic and Hydraulic Engineer					
Jeffrey B. Bradley	WEST Consultants	Salem, Oregon	Ph.D., Hydraulics	Yes	32
Geotechnical Engineer					
Keith A. Ferguson	Kleinfelder West, Inc.	Golden, CO	MS, Civil Engineering	Yes	32
Geotechnical Engineer/Academic Community					
Steve J. Poulos	Poulos Consulting	Winchester, MA	Ph.D., Engineering	Yes	54

Jeffrey B. Bradley, Ph.D., P.E., D.WRE

Dr. Bradley is a registered professional engineer in seven states. He is a certified Diplomat and past-president of the American Society of Civil Engineers (ASCE), American Academy of Water Resources Engineers. Dr. Bradley is past president of the ASCE Environmental and Water Resources Institute. He is a nationally recognized expert with 32 years experience in hydraulics, hydrology and sediment transport. He has worked in the private sector as president of WEST Consultants, Inc., for 21 years, with the U.S. Army Corps of Engineers, and on the research faculty at Colorado State University. Dr. Bradley has unique knowledge and work experience on mud and debris flows and their effects on alluvial fan flooding.

He has worked on a diverse range and large number of water resource investigations. In recognition of his expertise and many years of project experience, Dr. Bradley has served on a number of expert review panels regarding dam safety and levee certification. This experience includes:

- External Peer Review Panel for Screening Levee Risk Assessment, Corps of Engineers, Office of the Chief of Engineers, 2007–2009
- Independent Technical Review, Hydrology and Hydraulics, Natomas Levees, Sacramento Huntington District, U.S. Army Corps of Engineers
- External Peer Review Panel for DSAC Class I Dams, U.S. Army Corps of Engineers, Office of the Chief of Engineers, Martis Creek Dam, Isabella Dam, Wolf Creek Dam, Center Hill Dam, Clearwater Dam, Herbert Hoover Dike, 2006–2008
- Board of Expert Consultants, Creekside Dam, Canyonville, OR
- Board of Expert Consultants, Scoggins Creek Dam, OR.

Dr. Bradley has also coordinated and lectured in a number of short courses, including Dam Removal, Bridge Scour, HEC-RAS, and Streambank Stabilization for the ASCE; HEC-6, Sedimentation in Rivers and Reservoirs, and Streambank Stabilization for the International

Erosion Control Association; and courses in Sedimentation in Forested Watersheds, and Mudflows and Alluvial Fan Flooding.

Dr. Bradley has edited three books and written over 75 professional papers and reports in the fields of hydraulics, hydrology, and sedimentation engineering.

Keith A. Ferguson

Mr. Ferguson is a registered professional engineer in 18 states and has over 32 years of experience in the field of dam safety engineering, remediation of existing dams, design of new dams, and construction of dam and dam safety projects across the U.S. and abroad. He is a recognized expert in seepage and stability analysis of embankment dams, roller compacted concrete (RCC) for dams and hydraulic structures, risk assessment and analysis for dam safety decision making, and the formulation and evaluation of alternatives under NEPA and Section 404(b)(1) of the Clean Water Act. Mr. Ferguson has lead the inspection, investigation, evaluation and/or design of over 150 existing or new embankment, concrete gravity (conventional and RCC), concrete faced rock fill, composite earthfill/rockfill dams, spillways, outlet works, diversion dams, canals, levees. As a recognized expert, Mr. Ferguson has served on a number of senior review panels or performed Independent Technical Reviews including the following dam projects:

- Fern Ridge Dam, OR — USACE
- San Vicente Dam, CA — SDCWA
- Proctor Dam, TX — USACE
- Wolfcreek Dam, KY — USACE
- Center Hill Dam, TN — USACE
- Clearwater Dam, MO — USACE
- Isabella Dam, CA — USACE
- Martis Creek Dam, CA — USACE
- Herbert Hoover Dikes, FL — USACE
- Mosul Dam, Iraq — USACE
- Lewisville Dam, TX — USACE
- Keystone Dam, OK — USACE
- Canton Dam, OK — USACE
- Bear Creek River Dam, AL — TVA
- Blue Ridge Dam, GA — TVA
- Scoggins Dam, OR — Clean Water Services/USBR

Dr. Steve J. Poulos

Dr. Poulos is a founding principal of Poulos Consulting and GEI Consultants, Inc. He is a registered professional civil engineer specializing in soil and rock mechanics, earth dam engineering, foundation engineering, and groundwater hydraulics. Dr. Poulos has managed over 900 projects, covering all aspects of geotechnical engineering design and construction, as well as expert testimony for litigation purposes.

Dr. Poulos has carried out analyses related to the design of the geotechnical aspects of many dams, including seepage analysis, stability analysis, testing of the engineering properties of soils, filter design, groundwater studies, selection of materials, selection of construction techniques and equipment, selection of compaction requirements, design of slurry trench walls, erosion control of surfaces, cracking analysis, seismic analysis, and deformation analysis. He has inspected and conducted Phase I geotechnical evaluations of approximately 40 dams in connection with the National Dam Inspection Program. In addition, he has designed dikes for several large sedimentation basins required to treat construction site water and runoff.

Dr. Poulos introduced the principle of steady-state of deformation and has been instrumental in applying it to practice, particularly for analysis of liquefaction potential of loose sands and soft clays due to seismic triggering. For this purpose, he developed field procedures for undisturbed sampling of sands, which previously had not been considered feasible Dr. Gonzalo Castro and Dr. Poulos developed laboratory test procedures to measure steady-state undrained shear strength, and procedures for analyzing stability based on initial and post-earthquake conditions. He has analyzed more than 30 cases using these procedures for dams from 20 to 400 feet high.

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4 PROJECT DESCRIPTION

4.1 Overview of the Zoar Levee and Diversion Dam System

Portions of the following information were taken from briefing materials presented to the Panel during a site visit on June 24, 2009, from the report *Documentation for Screening for Zoar Levee and Diversion Dam (Dover Dam Project)* (USACE, 2006), and from other information provided for review. In the report sections that follow, figures are labeled by section number (i.e. all figures in this section begin with the number 4). Photos are referenced in sequential order and are provided in Appendix A.

The project consists of two primary components protecting the village of Zoar, Ohio; Zoar Levee and the Diversion Dam. The project is part of the Muskingum Flood Protection System, illustrated on Figure 4.1. Key information on Dover Dam and the components of the project are summarized in Table 4.1, based on information provided to the Panel during the site visit.

Figure 4.1- Project Location/Muskingum Flood Protection System

Table 4-1. Information for Zoar Levee, Diversion Dam, and Dover Dam

		NGVD 1926 (ft)	NAVD[1] 1988(ft)
Zoar Levee:	Old dam crest (1937)	919.0	918.3
	Raised dam crest (1951)	928.6	927.9
	By-pass conduit inlet	883.3	882.6
	By-pass conduit outlet	880.1	879.4
	Water level when pump station is activated	886.0	885.3

Pump Station: A third pump and piping are being installed and the existing generator is being replaced with new power unit capable of operating all three pumps with a total capacity of 50,000 cfs.

Diversion Dam:			
	Spillway crest	916.0	915.3
	Dam crest	932.7	932.0
	Outlet works intake invert	898.0	897.3
	Outlet works downstream invert	892.0	891.3
Dover Dam:			
	Spillway crest	916.0	915.3
	Dam crest (current – being raised)	930.0	929.3
	Currently DSAC II with pool restriction	909.0	908.3
	Estimated PMF	937.4	936.7
	Top of new dam parapet wall	940.7	940.0

The freeboard for the redesigned Dover Dam is 3.31 feet

[1] Note that the NGVD 1929 datum is 0.673 feet higher than the NAVD88 datum being used for the Dover Dam modification designs. Numbers in the table above have been rounded to the nearest 0.1 foot.

The general layout of the Zoar Levee and Diversion Dam components is shown on Figure 4.2.

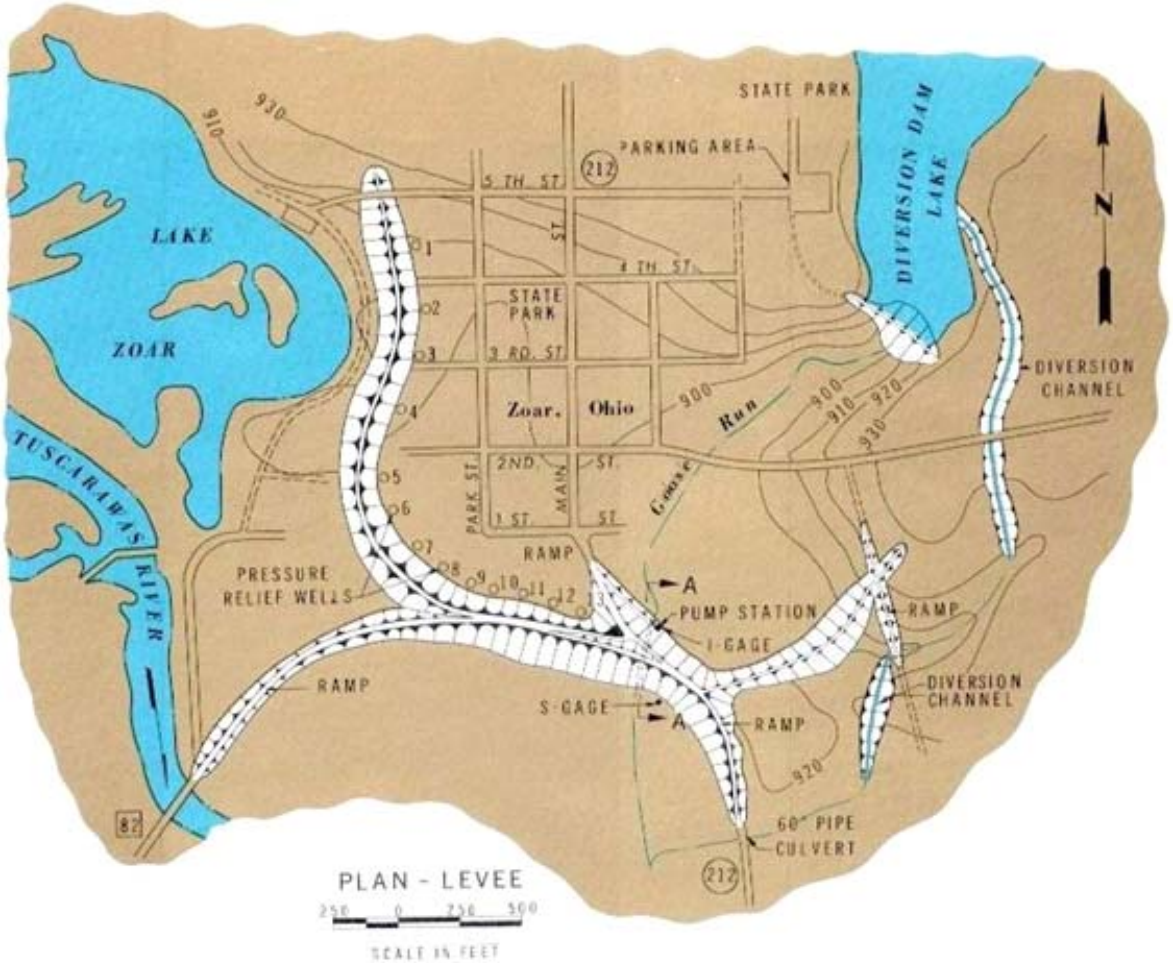


Figure 4.2. Layout of Project Components

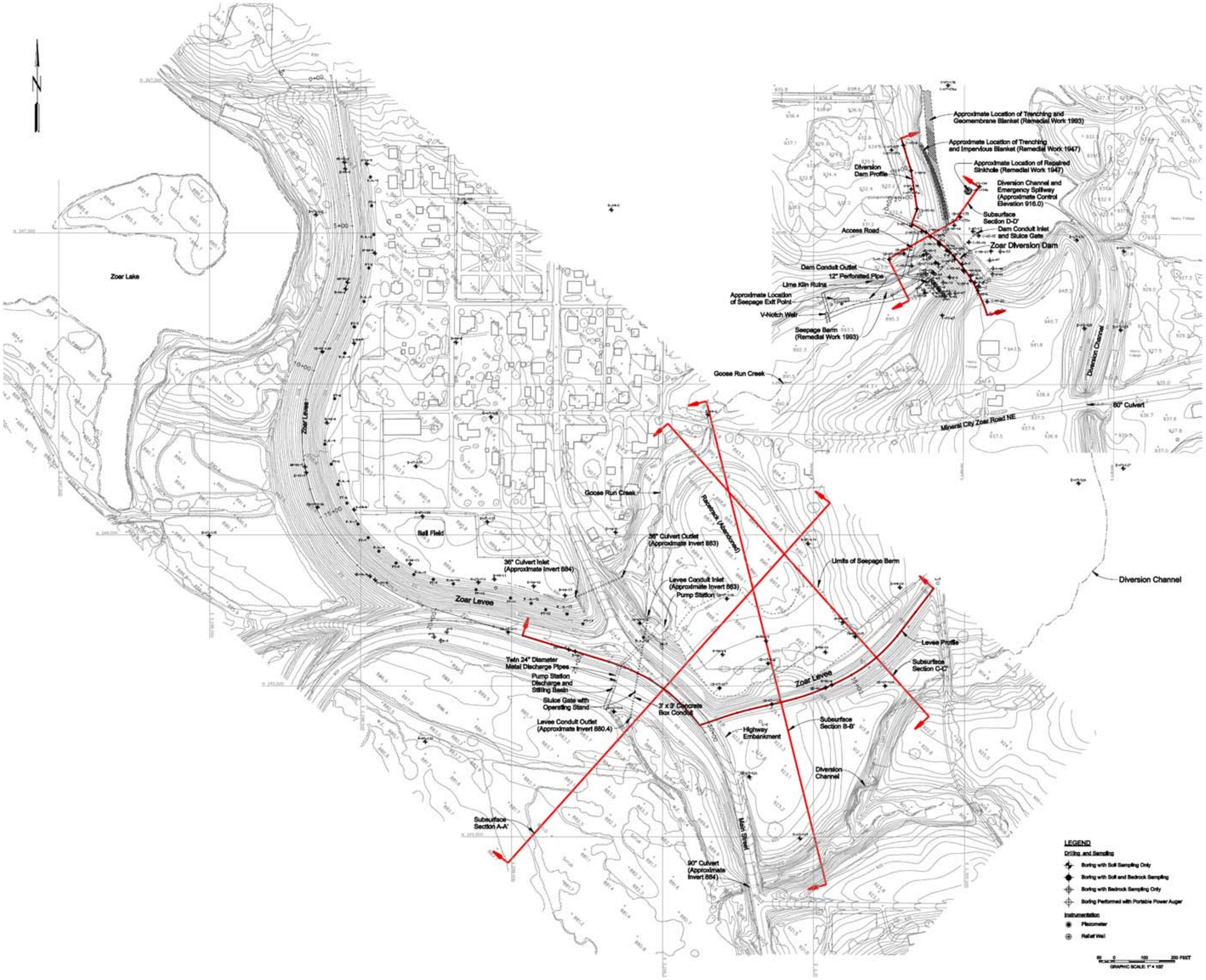
The Levee protects the village of Zoar, which lies within the Dover Reservoir flood inundation pool. The project is located about 4.7 miles north (upstream) of Dover Dam. The village of Zoar is located in northern Tuscarawas County, Ohio. The USACE selected the option of protecting the town as opposed to relocating it because of its historical significance (USACE, 1949, *Design Memorandum for Pump Station Capacity*).

Because of the safety concerns that have arisen at the site, a significant amount of site exploration, instrumentation, and instrumentation monitoring has been completed at both the Zoar Levee and the Diversion Dam sites. A detailed map of the project area showing topography, locations of borings and instrumentation, and locations of several cross sections developed for evaluation of the Zoar Levee and Diversion Dam are shown on Figure 4.3.

4.2 Zoar Levee

The present-day Levee structure has a crest length of 3,893 feet with a maximum height of about 45 feet, measured from the riverside toe to the Levee crest. The crest elevation varies

Figure 4.3. Detailed Project Layout



along the length of the Levee from a low point of 928.6 near Station 14+50 to a high point of 932.3 at Station 26+50. The riverside slope is 3(H): 1(V) (Horizontal to Vertical), and the landward slope is 2.5(H): 1(V). The crest width of the Levee varies from a minimum of 8 feet to as much as 60 feet at locations where roadways meet the crest. Appurtenant structures include the pump station, the Diversion Dam, and the Diversion Channel. Dover Road and State Route 212 traverse portions of the Levee crest.

When originally built in 1937, the Levee actually consisted of two sections separated by a high ridge east of the present pump station. The original crest was at elevation 919.0 - only 3 feet above the Dover Dam spillway crest (El. 916 NGVD). This inadequacy was recognized after a 1947 flood event, and the Levee was raised 9.5 feet, effectively joining the two levee sections into one embankment with a new crest elevation of 928.5.

As shown in Figure 4.4, the original Levee embankment consisted of a central clay core surrounded by silty sand outer shells. The Levee was raised using available clay materials from a nearby borrow area. The clay was placed over blanket drains that connected the old shells (both upstream and downstream) to the exterior of the Levee. This detail allows water to saturate the riverward side shell of the old levee section when the Dover Reservoir pool rises, and water to drain from the shell when the pool recedes. The drainage blanket under the landside toe allows drainage of the landside shell of the Levee. As part of this modification, a pump station, 14 perforated bituminous-coated corrugated metal pipe (CMP) relief wells with a depth of about 30 feet, and 15 piezometers were installed. During the embankment modification, the original relief wells were modified by adding horizontal extensions. In 1992, above-ground access housings and discharge pipes were added to 10 of the wells. The other four have been grouted and replaced by three new wells.

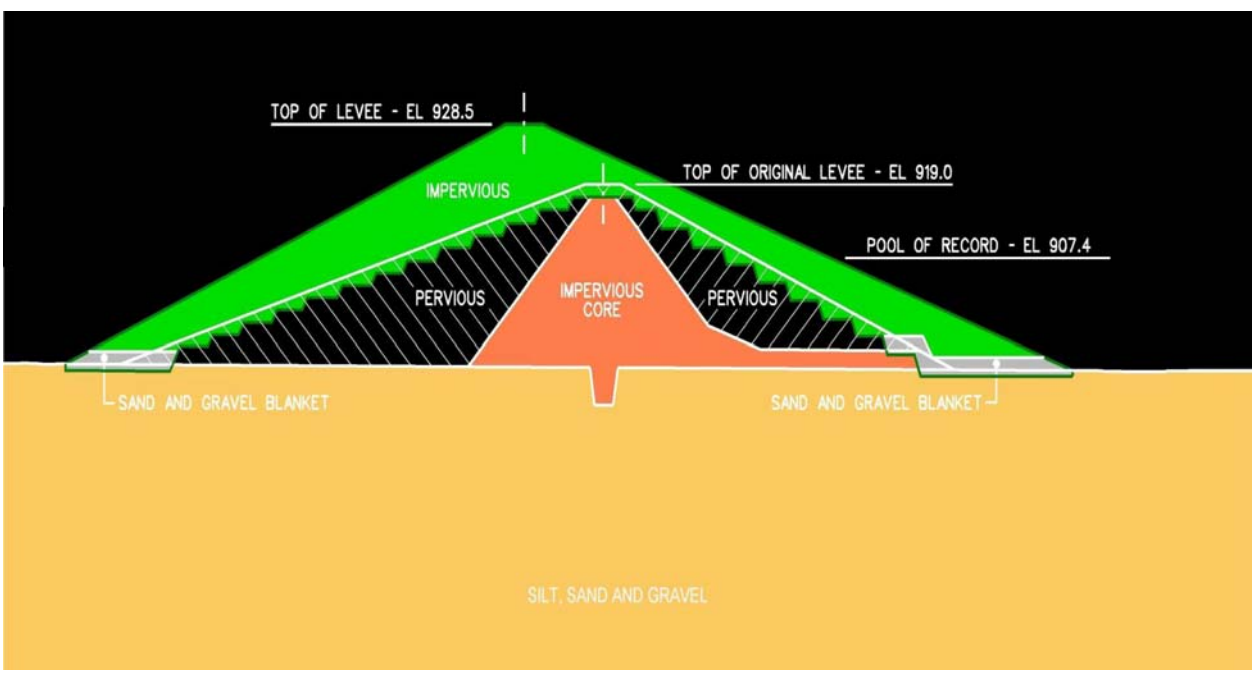


Figure 4.4. Schematic Cross-Section of Zoar Levee

There are two penetrations through the Levee: 1) a box culvert for routing normal flows from Goose Run Creek (discharging from the Diversion Dam outlet works) through the Levee; and 2) pipes from the pump station, which carry pumped water from the landside toe area to the Dover Reservoir pool.

The box culvert is a 3-foot-square, 330-foot-long concrete box culvert that extends through the base of the Levee embankment. The culvert has an inlet elevation of 883.3 and an outlet elevation of 880.1, creating an overall slope of about 0.1 percent (1 foot vertical in 100 feet horizontal)(FMSM, 1997). The datum for these elevations is NGVD29. Flow through the conduit is controlled by an operating stand and sluice gate located on the riverward side of the Levee. The operating stand has a top elevation of 910.0.

Current operating procedures require Zoar Levee and Diversion Dam sluice gates to be closed when the Dover Reservoir stage exceeds elevation 883.0. At this time, surface water runoff from the Diversion Dam and area between the Dam and the Levee collects in a small ponding area just upstream of the pump station. (The pump station and ponding area can be seen in Photo 5, Appendix A.) When the water surface elevation in the ponding area reaches elevation 886.0, the pumps activate and remove water from the ponding area and send the collected water through pipes to the Dover Reservoir side of the Levee using the twin 125-horsepower pumps. The pumps have a total capacity of 30,000 gallons per minute (gpm).

The USACE completed a flood frequency analysis of the Dover Dam reservoir pool based on level pool routing methods. Results of this analysis are summarized on Figure 4.5, and indicate the estimated recurrence intervals associated with different reservoir pool elevations (based on NGVD 1929). Information on this figure suggests that the low point of the Levee at elevation 928.6 will overtop for flood events with estimated recurrence intervals of greater than 1,500 years. More recently, the USACE has been updating the original routing analysis and these results suggest routing effects on the upstream side of Dover Reservoir. The Panel's recommendations related to updating the stage vs. frequency relationship for Dover Reservoir are discussed in a later section of this report.

4.3 Diversion Dam

The Diversion Dam is a high-hazard structure constructed in 1935 as an appurtenant structure to Levee. It is located east of the village of Zoar, as shown on Figures 4.2 and 4.3. It was designed to intercept and store storm water runoff from Goose Run Creek. When the reservoir pool level behind the Diversion Dam exceeds the spillway crest elevation at 916.0 (NGVD 1929), flows empty into the Diversion Channel and are routed around the village. When river stages permit, water stored in the Diversion Dam reservoir can be released through a 3-foot-square concrete-box culvert.

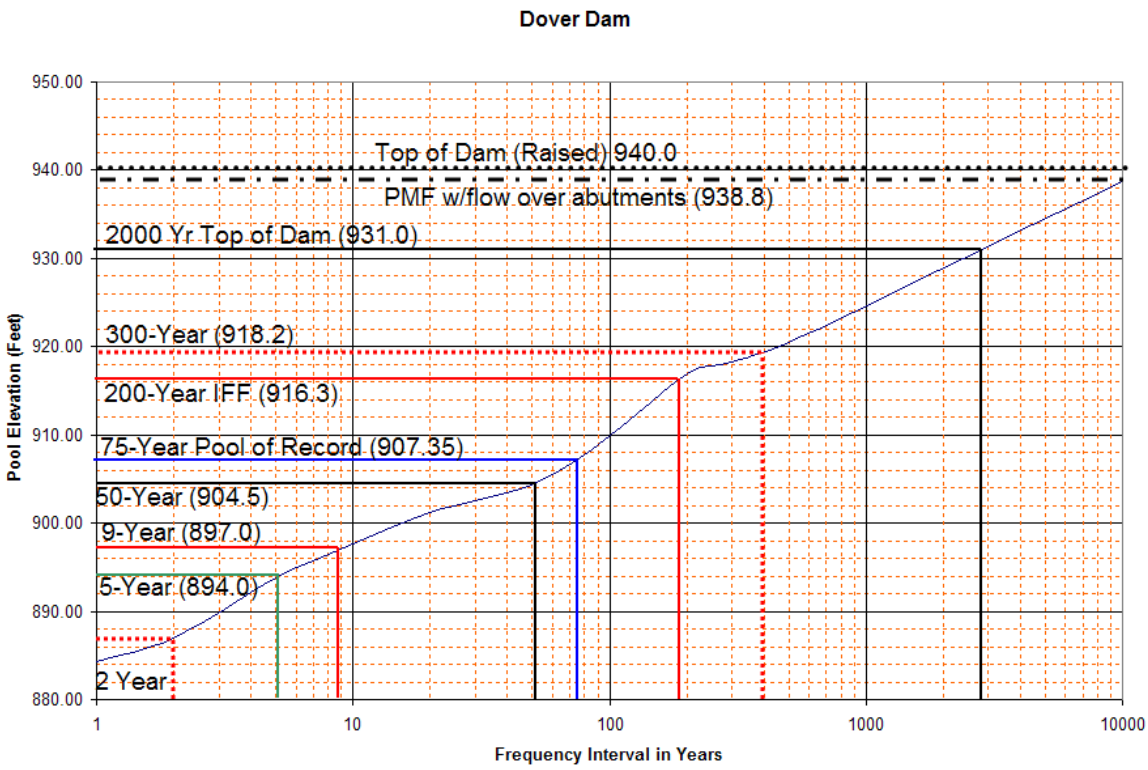


Figure 4.5. Dover Dam Reservoir Stage vs. Frequency Relationship

The Diversion Dam is a zoned earth embankment with a central clay core and silty sand outer shells as shown on Figure 4.6. The dam has a crest length of about 440 feet and a maximum height of 42 feet, measured from the downstream toe to the top of the crest. The crest elevation varies along the length of the dam from a low point of 932.4 near Station 0+25 to a high point of 933.8 at Station 2+50. The upstream and downstream slopes of the dam are approximately 3(H):1(V), and the crest width is 16 feet.

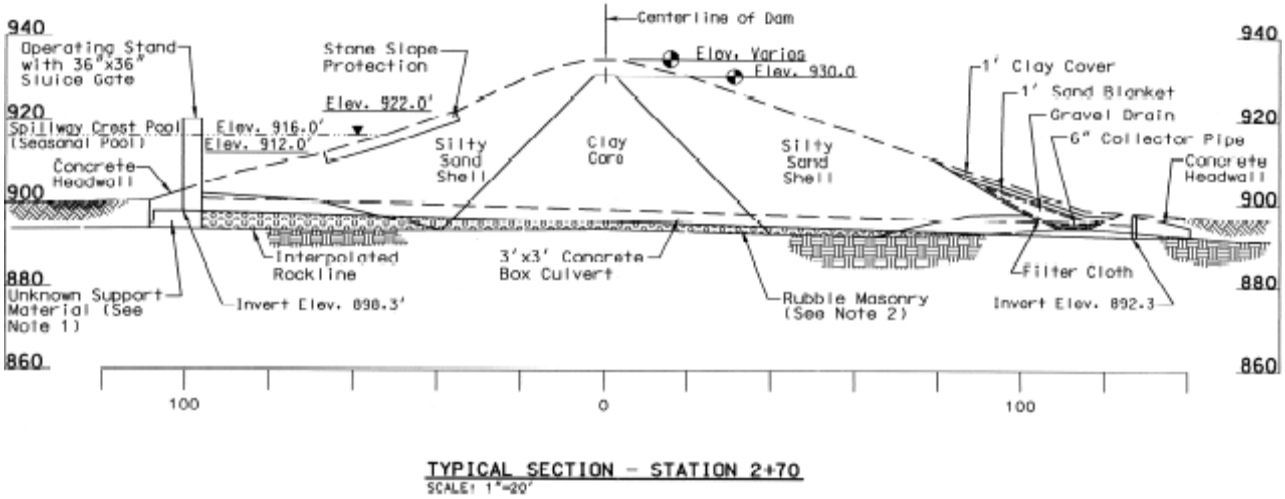


Figure 4.6. Cross-section of the Diversion Dam

The outlet works has a length of 220 feet and extends through the base of the embankment. The conduit was founded on a rubble masonry leveling base throughout most of its 220-foot length. Anti-seep collars were provided along the length of the conduit, and they theoretically increase the seepage path by about 28 percent. Such seepage collars have been shown in past cases to be ineffective. If the rubble is pervious, seepage could pass along the base of the conduit, especially if the rubble on the bottom extends below the bottom of the collars. A proper filter around the downstream end of the conduit would be preferred. Releases are controlled from a concrete gate stand and the sluice gate on the upstream end of the conduit as shown on Figure 4.7.

Figure 4.7. Diversion Dam Outlet Works Intake Structure and Sluice Gate

The Spillway/Diversion Channel inlet is located in the upstream, left abutment area. The control section of the spillway and downstream Diversion Channel has a bottom width of approximately 20 feet, and 2H:1V grassy side slopes. The eastward extension of Second Street crosses the Diversion Channel approximately 600 feet south of the Diversion Dam (see Figure 4.2). At this crossing, flow within the channel is directed into a 60-inch-diameter pipe culvert.
The normal flow of Goose Run Creek passes through the Diversion Dam, down the creek channel, to the pump station area, and then through the Levee via a 3-foot-square, reinforced-concrete conduit. Additional upstream control of Goose Run was to be provided by the Diversion Dam. As originally designed, once Goose Run Lake (i.e., the Diversion Dam Reservoir) reached elevation 916.0 (the Dover Dam spillway level), it was to be diverted to the riverward side of the Levee via a Diversion Channel.

A reservoir stage vs. frequency evaluation for the Diversion Dam has been completed, and the results are summarized on Figure 4.8. This curve was developed assuming that the outlet works gate structure closes halfway once the ponding-area water levels reach elevation 890, and is fully closed once the ponding-area water levels reach elevation 892. After the outlet gates close, all water is routed through the reservoir and out the spillway/Diversion Channel on the left abutment of Diversion Dam.

The stage vs. frequency curve for the Diversion Dam only considers local storm events and does not include consideration of backwater effects from Dover Reservoir. The results indicate that a local storm flood event with an estimated recurrence interval of once every 7,000 years would overtop the Diversion Dam. The Panel notes that the stage vs. frequency curve for Dover Reservoir, shown on Figure 4.5, indicates that backwater from the Dover Reservoir would flow up the Diversion Channel, fill the Diversion Dam reservoir, and overtop the Dam during a flood

with an estimated recurrence interval of 1 in 3,000 years, an event significantly more frequent than that shown on Figure 4.8, which does not account for backwater flow. The Panel recommends that the stage vs. frequency curve for the Diversion Dam be updated to include backwater effects from Dover Reservoir.

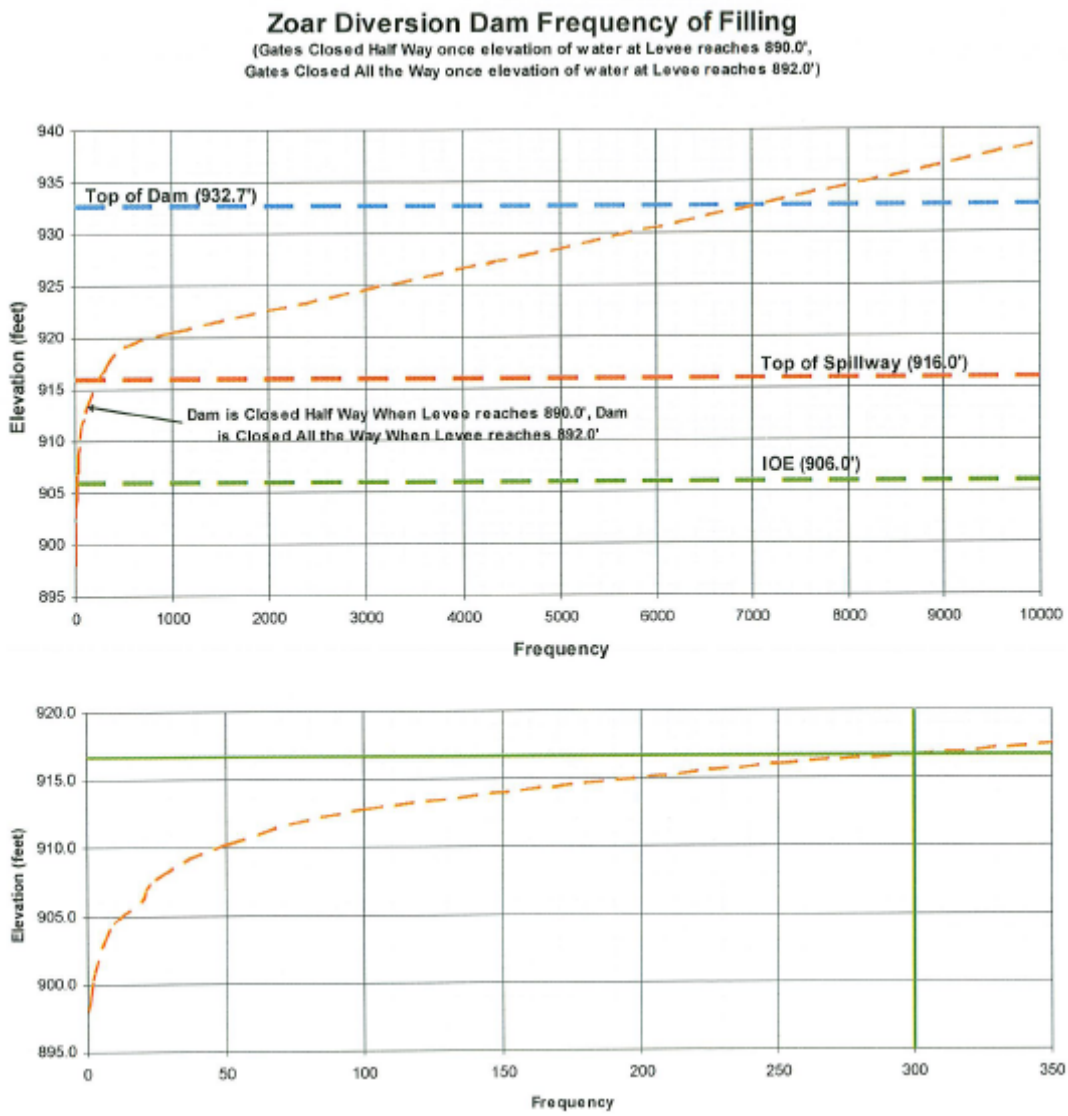


Figure 4.8. Stage vs. Frequency Curve for Diversion Dam.

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5 HISTORY OF PROBLEMS AND OBSERVATIONS

5.1 Zoar Levee

Seepage and safety-related issues and concerns were first recorded at the Levee during a June 1947 flood event, when the Dover Dam Reservoir pool reached an elevation of 902.7. This corresponds to a 33-year recurrence interval event, using the Dover Reservoir stage vs. frequency information shown on Figure 4.5. A chronology of the significant milestones and notable events is summarized below:

- 1936-37: Zoar Levee Sections 1 and 2 were constructed to elevation 919, along with the Diversion Dam, and Diversion Channel
- 1947: The Dover Dam Reservoir pool reaches elevation 902.7. (Note the maximum water depth in the reservoir acting on the Levee was about 20 feet, and occurred adjacent to the pump station (which was not yet built). The net total head between the maximum reservoir level and the ground surface along the landside toe of the Levee at the pump station location was slightly less than 20 feet (see Figure 4.3). Zoar Village was damaged by seepage through the foundation of the Levee.
- 1948: 14 relief wells (40 feet deep on 125-foot spacing) were installed along the landward toe of the Levee in response to seepage observations during the June 1947 flood event; 13 piezometers were installed at locations between the wells.
- 1950-51: The Levee embankments were raised and joined with a crest elevation of 928.5. The pump station was constructed.
- 1975-Present: Shallow slope failures (landslides) occur in the Levee embankment.
- 1992: New manhole extensions and outlet pipes are installed on existing Levee relief wells.
- 1994-95: Three replacement relief wells (RW-11, 12, and 13) are installed. Five piezometers are added for monitoring water pressures in the Levee foundation.
- 1997: The Levee Embankment Re-analysis Report and the Diversion Dam Adequacy Analysis Report are completed.

5.1.1 Pool of Record, January 2005

During this event, the Tuscarawas River reached an elevation of 907.4 adjacent to the Levee. This flood event and the reservoir pool elevation correspond to a recurrence interval of about 75 years. Pervasive seepage was observed along the length of the Levee. This included pin boils in two large areas within the western reach of the Levee and sand boils producing 30 to 40 gpm in the area adjacent to the rock knoll south and east of the pump station. The entire Levee was closely monitored throughout this flood event. Attempts were made to place granular material on the boils near the rock knoll, but equipment could not be maneuvered over the saturated ground around the boils until the pool receded. A general overview of the seepage areas is shown on Figure 5.1.

Figure 5.1. General Overview of Levee-Related Seepage Areas during the January 2005 Flood Event

5.1.2 High Water Event, March 2008

During the March 2008 high-water event, flooding raised the Tuscarawas River to an elevation of 904.6 adjacent to the Levee. Adverse seepage conditions again developed. However, during this event, the seepage distress showed a pronounced increase at a water elevation 2.8 feet lower than the elevation reached during the pool of record in January 2005. For example, seepage south and east of the pump station was estimated to be approximately 5,000 gpm, and numerous boils produced up to 300 gpm. Seepage conditions were deteriorating at a rapid rate, prompting the USACE to undertake emergency risk-reduction measures in the form of construction of a large seepage berm, as described below. Figure 5.2 shows a general overview of the seepage areas during this event. Photographs 1 and 2 in Appendix A illustrate some of the types of seepage distress indicators present during the high-water period.

Conditions at the Levee were monitored on a continual basis by the District's geotechnical personnel during the flood. As seepage conditions worsened, continuous 24-hour surveillance was employed. As during the 2005 event, a line of seepage could be seen emerging near the base of the rock knoll. Sand bag rings were constructed around the most significant boils. These rings were enlarged as seepage and sediment from the boils increased. Several of the sand-bagged boils enlarged to diameters greater than 1 foot by the time the pool elevation reached 904

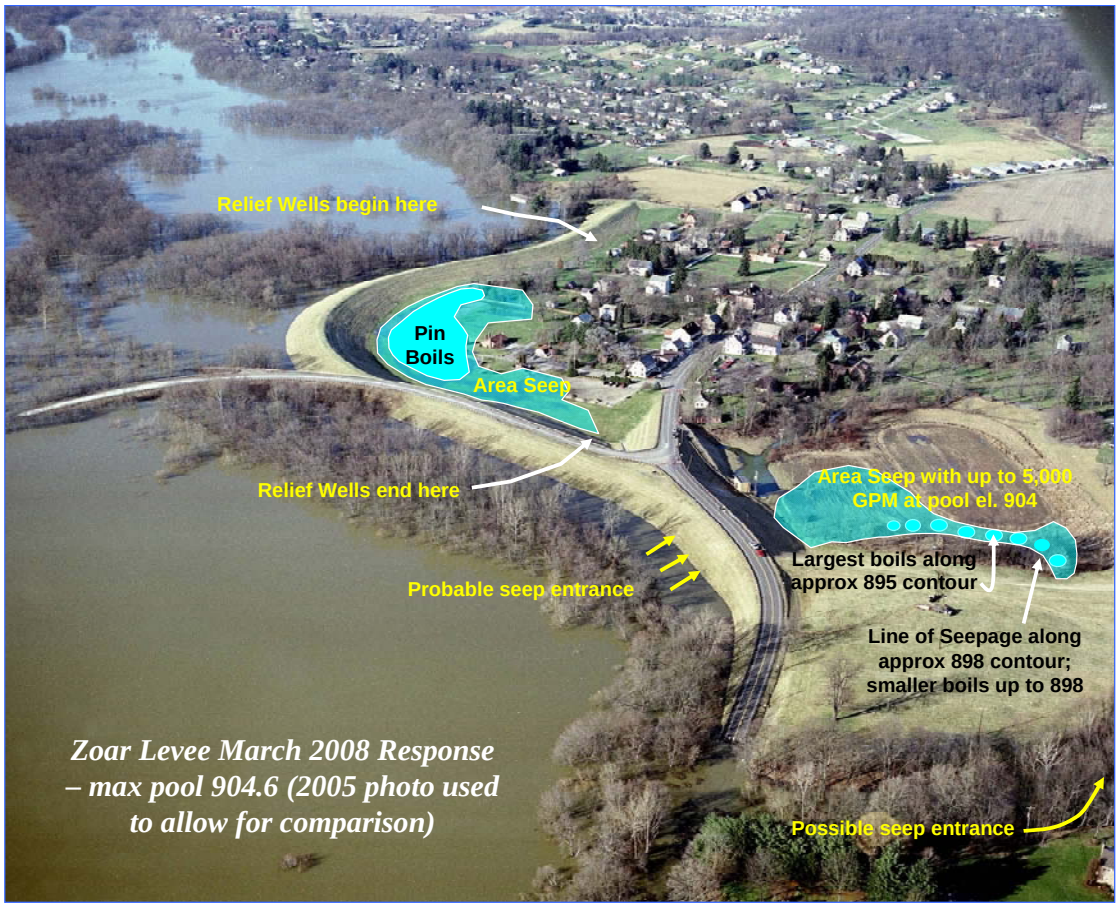

Figure 5.2. General Overview of Levee-Related Seepage Areas during the March 2008 Flood Event

and substantial amounts of sediment were being deposited around the boil openings. In some areas, smaller boils began to coalesce to create larger boils, and large unstable regions were developing. Sand bag rings began to fail due to piping of material from beneath them. The exit elevation of the seepage was generally rising, and new boils were developing rapidly. These observations were consistent with rising piezometric head readings from nearby instruments (Figure 5.3).

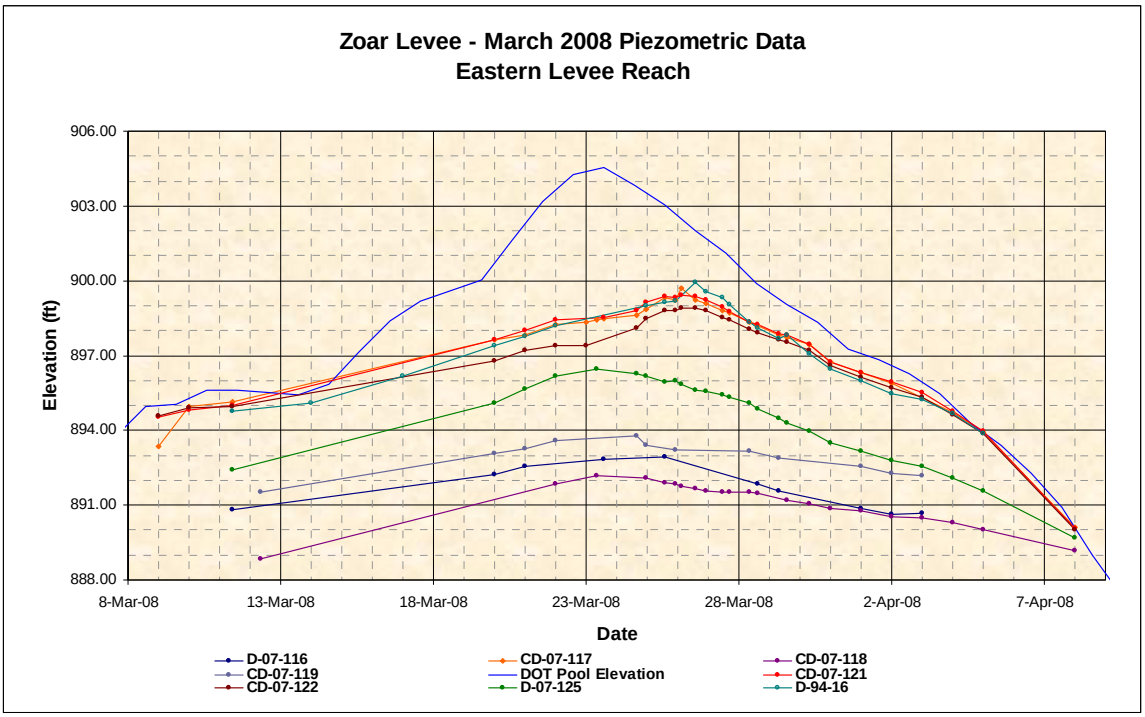

Figure 5.3. Increasing Elevation of Piezometer Readings during the March 2008 Flood Event

On March 23, 2008, 2 weeks into the flood, USACE personnel decided that a granular blanket was needed to control the severe seepage and piping near the rock knoll area of the Levee. Construction of the granular blanket began the following day. Over the next 150 hours, the conditions were continuously monitored, and 37,000 tons of granular blanket materials were placed. By the time the blanket was completed, the Dover Dam pool began to recede. The monitoring and berm-construction activities had succeeded in preventing a Levee breach. Photographs 3 and 4 illustrate the construction of the seepage berm.

5.2 Diversion Dam

The Diversion Dam was originally designed as a detention facility with no permanent pool. Significant seepage through the right abutment of the Diversion Dam was first noted during a flood that created a high pool event in June 1947 (10 years after Dam construction). The first notable incident was formation of a sinkhole on the reservoir bottom, about 150 feet upstream of the Dam, which was observed when the pool was drained following the 1947 high pool event. The sinkhole was backfilled with concrete to the top of rock surface and then with compacted clay to the ground surface. Due to concerns about seepage entering the right abutment rock, an impermeable “clay blanket” was also constructed in the upstream right abutment area. This blanket consisted of a 300-foot-long, 8-foot wide, 8-foot deep trench that was backfilled with compacted clay. The location of the sinkhole and this first abutment treatment are indicated on Figure 4.3.

Following completion of this work, the outlet works gate was closed, and a permanent pool was established in the Diversion Dam reservoir. Seepage apparently continued through the right abutment of the dam after the permanent pool was established, but no significant problems were noted until the time of the first official dam inspection in 1971. At that time, seepage was observed saturating the downstream toe area of the embankment, and a location downstream of the right abutment.

Continued observations of seepage prompted the installation of 11 piezometers in 1976, and then the construction of an embankment toe drain in 1978. During an inspection in 1990, a piping cavity measuring about 8 inches across and 4 feet deep was noted downstream of the right abutment (Photo 4). In 1991, the estimated seepage flows from this feature were as high as 500 gpm. A plot of the lake level from January through December 1991 is shown on Figure 5.4. This plot indicates other notable effects of the seepage. First, the lake level dropped 10 feet from the middle of April to the middle of August as a result of seepage through this feature. Further, seepage volume actually increased five-fold between mid-April and early June as the pool was dropping. This suggests that a continuous seepage pathway had developed between the point of discharge and the reservoir, and that the failure mode may have entered a progression stage (EC1110-2-6064, Appendix C). Once the pool reached an elevation of about 905, the seepage decreased to 10 gpm. This suggests that the source of the water exiting the seepage feature may be at or near elevation 905.

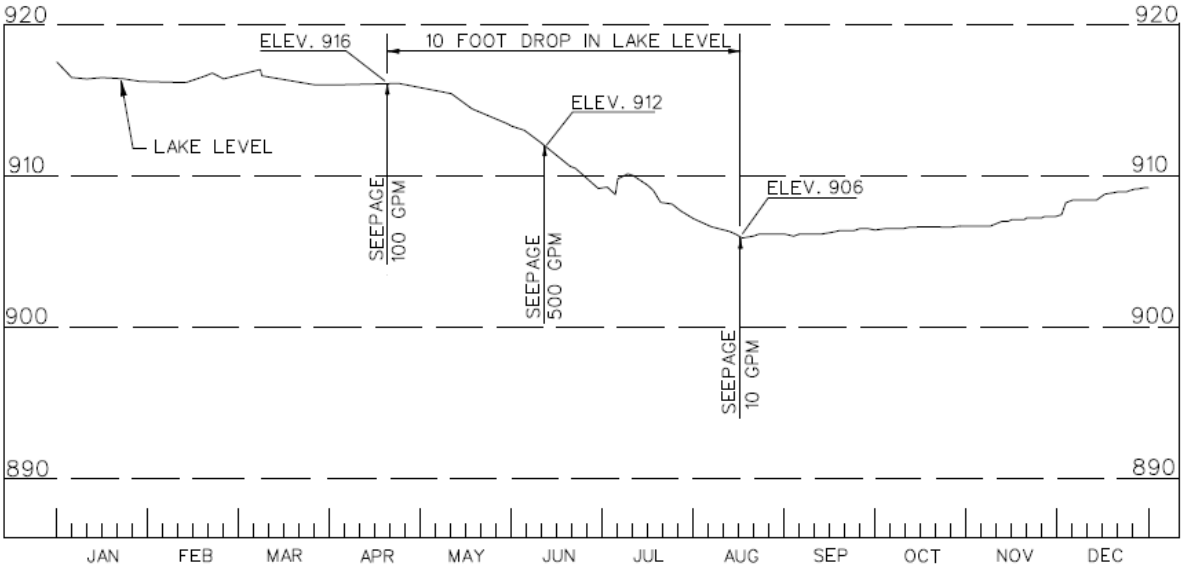

Figure 5.4. Plot of Diversion Dam Reservoir Level Drop Following Development of a Large, Downstream Right Abutment Seepage Feature

As a result of this seepage incident, the pool behind the dam was drained in 1992, and additional repairs were completed in 1993. The outlet works sluice gate has remained fully opened since that time. The repairs included installation of a geomembrane along the upstream right abutment and a gravel berm/drainage blanket along the downstream right abutment at the locations indicated on Figure 4.3. It is not known whether this membrane actually covers the point of entry of seepage into the abutment, as discussed above. Photo 8 shows the downstream blanket

as observed during the Panel site visit in June 2009. The pool behind the Diversion Dam has been drained since 1992, and there has been no significant storage in its reservoir since that time. No further seepage-related incidents have been reported at the Diversion Dam.

6 PREVIOUSLY ASSESSED POTENTIAL FAILURE MODES

6.1 SPRA Failure Modes - General

SPRA (Screening Portfolio Risk Assessment) is an internal tool developed by USACE to carry out initial risk characterizations of the USACE dam inventory, and to identify the highest risk projects for risk management decision making. The Zoar Levee and Diversion Dam were originally screened on April 18, 2006 (USACE, 2006), and were rated as a DSAC II. In 2008, the rating was changed to DSAC I due to seepage conditions in the Levee's left abutment foundation. These seepage conditions developed during March 2008, when the adjacent Dover Reservoir pool reached elevation 904.6, and led to the construction of an emergency seepage berm over the zone where sand boils occurred.

Figure 6.1 shows the rating of each failure mode considered by the USACE in April, 2006. Following the March 2008 flood, the rating of the foundation seepage and piping failure mode for the Levee was reclassified from probably inadequate (PI) to inadequate (I). In addition to the failure modes rating, consequences were estimated for Levee or Diversion Dam failures under various loading conditions ranging from extreme (PMF) to normal, and sunny day. The resulting consequence estimates, as presented in the SPRA documentation, are provided in Table 6.1.

Table 6-1. Summary of Consequences Presented in SPRA Documentation

Loading Condition	Damage	Population at Risk	Loss of Life
PMF-with failure	$38,800	193	8
PMF-no failure	$16,000	193	8
Unusual-with failure	$32,700	120	2
Unusual-no failure	0	0	0
Normal-with failure	$24,400	30	0
Normal-no failure	0	0	0
Sunny day-with Failure	$10,000	0	0

The following sections present a brief summary of the dam failure modes that were rated as inadequate by the USACE under the conditions listed.

Engineering Rating Summary					
Feature Flood Control Dam	Normal Water Level	50% Exceedence Duration Normal Water Level with OBE	50% Exceedence Duration Normal Water Level with MDE	Unusual (300yr)	Extreme - (PMF)
Concrete Gravity Section					
External Stability	NA	NA	NA	NA	NA
Internal Stability	NA	NA	NA	NA	NA
Foundation Stability	NA	NA	NA	NA	NA
Foundation - Seepage & Piping	NA	NA	NA	NA	NA
……..Void ……	NA	NA	NA	NA	NA
Abutment Foundation Stability (Dam Structure)	NA	NA	NA	NA	NA
Spillway and/or Stilling Basin System					
Structural Stability	NA	NA	NA	NA	NA
Structural Capacity	NA	NA	NA	NA	NA
Walls - Overtopping	NA	NA	NA	NA	NA
Gates - Structural, Electrical and Mechanical	NA	NA	NA	NA	NA
Gate Piers - Structural Capacity	NA	NA	NA	NA	NA
Erodibility	NA	NA	NA	NA	NA
……..Void ……	NA	NA	NA	NA	NA
Sill	NA	NA	NA	NA	NA
Outlet Works and Conduits					
Embankment Piping at Conduit	A	A	A	PI	PI
Gates - Structural, Electrical and Mechanical	A	PA	PA	PA	PI
Intake Tower Stability	NA	NA	NA	NA	NA
Intake/Tunnel/Conduit Structural Failure	A	PA	PA	PA	PI
Tunnel/Conduit Joint Failure	A	PA	PA	PA	PI
Embankment					
Embankment Seepage & Piping	A	A	A	PI	PI
Erosion: Toe, Surface & Crest	A	A	A	A	I
Abutments Seepage & Piping	PA	A	A	PA	PI
Abutments Stability and/or Liquefaction	A	A	PA	PA	PI
Foundation Seepage & Piping	PI	A	A	I	I
Embankment Stability and/or Liquefaction	A	A	NA	PA	I
Foundation Stability and/or Liquefaction	A	A	PA	PA	PI
Reservoir Rim					
Stability - Landslide	A	A	A	A	A
Loss of Storage Capacity - Silt	A	A	A	A	A
Erosion	NA	NA	NA	NA	NA
Mines	NA	NA	NA	NA	NA
Other Features					
Pump Station	A	PA	PA	PI	I
Diversion Dam	PI	A	PA	I	I
Feature 3	NA	NA	NA	NA	NA
Feature 4	NA	NA	NA	NA	NA

Figure 6.1. Engineering Rating Summary (April 2006)

6.2 Failure Modes under Normal Loading Conditions

Normal operations are described in EC 1110-2-6064 as follows:

> "Loading on the dam resulting from day-to-day pool operations to achieve authorized purposes. (For the purposes of a screening analysis for dry dams, or where pool elevations fluctuate widely and no historical normal pool elevation had been established, the normal loading is usually correlated to a 1 to 10 year return period.)"

Stage vs. frequency analyses of the Dover Reservoir flood pool (see Figure 4.5) indicates that an elevation just over 897 at Dover Dam has a recurrence interval of about 10 years. Dover Reservoir is a long and highly vegetated basin, and it is likely that some backwater effects occur

during floods. Thus, a pool elevation of 897 at the dam would result in a higher pool elevation adjacent to the Levee. If routing effects have not been considered in the development of the reservoir stage vs. frequency curve shown on Figure 4.5, or if elevations have not been appropriately adjusted to reflect reservoir conditions adjacent to the Levee, all estimated loading frequencies presented for the Levee are higher than indicated. In other words, a pool elevation of 907.35 at the Levee would not have an estimated recurrence interval of 1 in 75 years; the recurrence would be more frequent.

A stage vs. frequency analysis of the reservoir pool behind the Diversion Dam has been completed and is shown on Figure 4.8. The drainage basin above the Diversion Dam is highly vegetated, and the low-level outlet is only a 3-foot by 3-foot opening. Similarly, the entrance to the Diversion Channel is relatively small. The outlet works and spillway of the Diversion Dam may be prone to clogging by woody debris during significant local flood events. In Section 11.3 of this report, the Panel recommends performing a stage vs. frequency analysis for the Diversion Dam pool under various assumed percentages of plugging.

The following paragraphs present a summary of the potential failure modes presented by the SPRA team (USACE, April 2006). Some additional discussion, description, or clarifications have been added to the failure mode descriptions prepared by the SPRA, as deemed appropriate by the Panel.

6.2.1 Embankment (Levee) Foundation Seepage and Piping

This potential failure mode was originally deemed as Probably Inadequate (PI) based on observed behavior of the foundation of the Levee during the January 2005 record pool event, when extensive seepage and small boils occurred along the landside toe of the Levee. The pool of record has an estimated recurrence interval of about once every 75 years. This potential failure mode rating was changed to Inadequate (I) following the flood of March 2008, when the adjacent Dover Reservoir pool reached an elevation of 904.5 (estimated recurrence interval of once every 50 years). Significant seepage distress, including development of large sand boils (Photo 6) and significant seepage flows began when the pool reached an elevation of 894. The amount of seepage and sand boils that were observed in 2008 was significantly greater than that observed in 2005, suggesting that a seepage failure mode had initiated and was likely in the early stages of "progression" (Appendix C, EC 1110-2-6064, or Appendix N of pending new regulation ER 1110-2-1156).

6.2.2 Diversion Dam Abutment and Foundation, Seepage and Piping

This potential failure mode was rated as Probably Inadequate (PI) based on conditions observed when the Diversion Dam pool was drained in 1991 after sinkholes appeared in the lake. The pool was partially drained through the sinkhole. Remediation efforts to rehabilitate the foundation of the reservoir were unsuccessful. The District decided to permanently drain the reservoir at that time by fully opening the low-level outlet works.

Additionally, groundwater levels in instruments installed at the top of rock indicated a relatively high pore pressure that had changed over time, which indicates a deteriorating foundation under all pool conditions in a thin layer of karst limestone in the lower right abutment of the dam. This limestone layer, and the sedimentary layers immediately above and below the limestone, could

also contain open joints that contact the base of the dam. There is no information available on any efforts that may have been used to effectively treat these seepage hazards during construction.

6.3 Failure Modes under Unusual Loading Conditions

Unusual loading conditions are those defined as occurring during a flood event with an estimated recurrence interval of once every 300 years or less frequently. For the Levee, this would correspond to a Dover Reservoir pool elevation of about 918 adjacent to the Levee, and perhaps several feet higher due to the routing effects described in Section 4.2. The spillway outlet of the Diversion Dam is at elevation 916; hence a 300-year pool in Dover Reservoir will back water through the Diversion Channel and into the Diversion Dam reservoir pool to an elevation of at least 918. Local flooding and routing effects could raise the pool behind the Diversion Dam substantially higher.

6.3.1 Embankment (Levee) Foundation Seepage and Piping

See discussion in Section 6.2. This potential failure mode was rated as Inadequate (I).

6.3.2 Diversion Dam Abutment and Foundation Seepage and Piping

See discussion in Section 6.2. This potential failure mode was rated as Inadequate (I).

6.3.3 Embankment (Levee) Seepage and Piping along Outlet Works Conduit

This potential failure mode was rated as Probably Inadequate (PI). Existing seepage collars alone are not considered adequate to control 45 feet of hydraulic head on the outlet Levee section. (Note: It is not explicitly clear if this rating is for the drainage conduit through the Levee or for the outlet works conduit through the Diversion Dam)

6.3.4 Zoar Levee Seepage and Piping

This potential failure mode was rated as Probably Inadequate (PI). The Levee embankment, which was raised in 1951 from elevation 919 to elevation 928.5, was founded on pervious sand and gravel fill beneath the clay shells. This feature allows the reservoir pool to be connected to the pervious reservoir-side shell of the original Levee. This will allow a significant portion of the reservoir head to act on the original impervious core at an elevation of 917 within the embankment near the landward-side slope. As a result, the seepage path through the embankment is shorter, and high exit gradients and seepage breakout on the landward side Levee slope can occur.

6.3.5 Pump Station

This potential failure mode was rated as Probably Inadequate (PI). A1991 study of various pumping and diversion alternatives indicates that it is possible that the pump station electrical equipment would be flooded during a standard project flood (SPF). The unusual loading condition is likely close to a SPF, and could result in water levels several feet higher than the elevation 894 pump station floor and could cause a failure of the pump motors.

6.4 Failure Modes under Extreme Loading Conditions

6.4.1 Levee Seepage and Piping

This potential failure mode was rated as Probably Inadequate (PI). See discussion in Section 6.3.

6.4.2 Levee Foundation Seepage and Piping

This potential failure mode was rated as Inadequate (I). See discussion in Section 6.2.

6.4.3 Diversion Dam Abutment and Foundation Seepage and Piping

This potential failure mode was rated as Inadequate (I). See discussion in Section 6.2.

6.4.4 Outlet Conduits (all features)

These potential failure modes were rated as Probably Inadequate (PI). The levee is overtopped by 10 feet from the PMF. The Diversion Dam would be overtopped by 6.4 feet. If the overtopping failure occurs first at the location of the outlet works for the levee, it is likely the embankment and all the outlet works would be washed out. If the failure mode development were to occur in another location (e.g. Sta 14+50, the lowest point along the levee where overtopping would first occur as described in Section 4.2), it is likely the failure mode would not expand to the location of the outlet works, and the outlet works would remain intact. Overtopping of the Diversion Dam would likely lead to complete embankment failure as well as loss of the outlet works.

6.4.5 Embankment Overtopping Erosion

This potential failure mode was rated as Inadequate (I) for both the Levee and Diversion Dam. During extreme events, the Levee and Diversion Dam would overtop by as much as 10 feet and 6.4 feet, respectively. The embankments, excluding any clay core materials, are constructed of highly erodible materials.

6.4.6 Zoar Levee Stability

This potential failure mode was rated as Inadequate (I). The 1997 embankment re-analysis report (FMSM, 1997) states that the factor of safety for downstream (landward side) slope stability failure is at the threshold limit of 1.0 for a pool elevation of 928 (top of Levee). The SPRA documentation is silent on the stability rating of the Diversion Dam.

6.4.7 Levee Foundation and Abutment Stability

This potential failure mode was rated as Probably Inadequate (PI). The 1997 embankment re-analysis report states that the factor of safety for a foundation stability failure is as low as 1.3 for a pool elevation of 928 feet (top of Levee). The analysis did not consider the potential for high uplift pressures in the foundation under the embankment due to the surface confining layer and pervious nature of the alluvial foundation materials. The SPRA team considered that the actual factor of safety for failure surfaces through the foundation would likely be lower than 1.3.

6.4.8 Pump Station

This potential failure mode was rated as Inadequate (I). The pump station and all its electrical components would be completely under water during an extreme (PMF) loading condition.

6.4.9 Levee Seepage and Piping along Outlet Works Conduit

This potential failure mode was rated as Probably Inadequate (PI) in the Engineering Rating Summary table ((Figure 6.1), but is not described in the SPRA documentation. As noted in Section 6.3, existing seepage collars alone are not considered adequate to control 45 feet of head on the Levee outlet section. The head on the outlet conduit would be higher than 45 feet for the extreme loading condition. (The report is not explicitly clear if this rating is for the drainage conduit through the Levee or for the outlet works conduit through the Diversion Dam).

6.5 Bedrock Failure Modes Expert Elicitation Workshop and Evaluation Results

As part of ongoing studies and design effort by the Huntington District for a Major Rehabilitation Report, a risk assessment was recently completed by using an Expert Elicitation approach to evaluate foundation seepage and piping failure modes in the bedrock under the Diversion Dam and its abutments, and through the rock knoll under the eastern end of the Levee. As part of this work, system response probabilities were developed for reservoir loadings up to the crest elevation of each structure. For pool levels above the crest of the embankments, failure was assumed to result directly from overtopping. In addition to evaluating existing conditions of both structures, three rehabilitation options were considered for seven pool levels adjacent to the Levee and for six pool levels for the Diversion Dam. A summary of the estimated annual failure probabilities of failure for the Levee and Diversion Dam are provided in Tables 6.2 and 6.3, respectively (Stantec, 2009).

Table 6-2. Summary of Estimated Annual Performance Level Probabilities for All Pool Levels up to the Levee Crest, El. 928.5, for the Zoar Levee

Condition	Performance Level 1 No Impacts[1]	Performance Level 2 Impacts without Failure[2]	Performance Level 3 Catastrophic Failure[3]	Performance Level 4 Catastrophic Failure[4]
Existing Condition	9.88×10^{-1}	5.53×10^{-3}	5.82×10^{-3}	6.61×10^{-3}
Option 1: Cutoff Wall	9.99×10^{-1}	7.47×10^{-5}	9.31×10^{-5}	8.92×10^{-4}
Option 2: Grouting with Interior Drainage Berm	9.99×10^{-1}	2.36×10^{-4}	1.07×10^{-4}	9.06×10^{-4}
Option 3: Move Levee Off Knoll	9.99×10^{-1}	9.99×10^{-7}	1.00×10^{-7}	8.00×10^{-4}

[1,2,3,4] Conditional Performance Levels are defined as follows:

1 The embankment performs satisfactorily. Additional efforts or expenditures, increased surveillance, and changes in operations are not required.

2 The embankment does not fail, but significant cost impacts are expected. For a given pool elevation, several potential impacts were considered in estimating the costs associated with this performance level (see Stantec, 2009).

3 For pool levels ranging up to the Levee and Diversion Dam crest elevations, the embankment fails and is breached, with rapid, uncontrolled release of the pool. Economic, environmental, and (perhaps) loss of life impacts occur downstream of the Diversion Dam or on the protected side of the Levee. Until such a breach is repaired, additional adverse impacts would result from the loss of flood protection.

4 This level includes overtopping failure mode for Dover Reservoir elevations between 928.50 and 941.00. The Diversion Dam or Levee embankment fails and is breached, with rapid, uncontrolled release of the pool that causes economic, environmental, and (perhaps) loss of life impacts downstream of the dam or on the protected side of the Levee. Until such a breach is repaired, additional adverse impacts would results from the loss of flood protection.

Table 6-3. Summary of Estimated Annual Performance Level Probabilities for All Pool Levels up to the Dam Crest, El. 932.0, for Diversion Dam

Condition	Performance Level 1 No Impacts[1]	Performance Level 2 Impacts without Failure[2]	Performance Level 3 Catastrophic Failure[3]	Performance Level 4 Catastrophic Failure [4]
Existing Condition	7.87×10^{-1}	1.85×10^{-1}	**2.78×10^{-2}**	**2.80×10^{-2}**
Option 1: Cutoff Wall	9.99×10^{-1}	9.11×10^{-4}	**1.52×10^{-4}**	**3.62×10^{-4}**
Option 2: Grouting with Downstream Drainage Berm	9.99×10^{-1}	1.06×10^{-3}	**1.30×10^{-4}**	**3.41×10^{-4}**
Option 3: Rebuild Dam	1.00×10^{-0}	1.00×10^{-6}	**1.00×10^{-7}**	**2.11×10^{-4}**

[1,2,3,4] Performance levels are as defined for Table 6.2.

The estimated probabilities shown in the last column of Tables 6.2 and 6.3, and the range of estimated consequences presented in Table 6.1, have been approximately plotted on an f-N diagram (Figure 6.2) showing the USACE proposed new risk tolerance guidelines. (For additional details on the risk tolerance guidelines, see Figure 5.6 in the new USACE regulation 1110-2-1156, [USACE, 2008]). Based on the most recent risk rating and consequence information available, there is justification to take expedited action to reduce risk at both the Levee and Division Dam. Further, the proposed corrective actions evaluated as part of the Expert Elicitation Workshop, when plotted on Figure 6.2, suggest that additional corrective action will be required to reach an acceptable risk rating for the project.

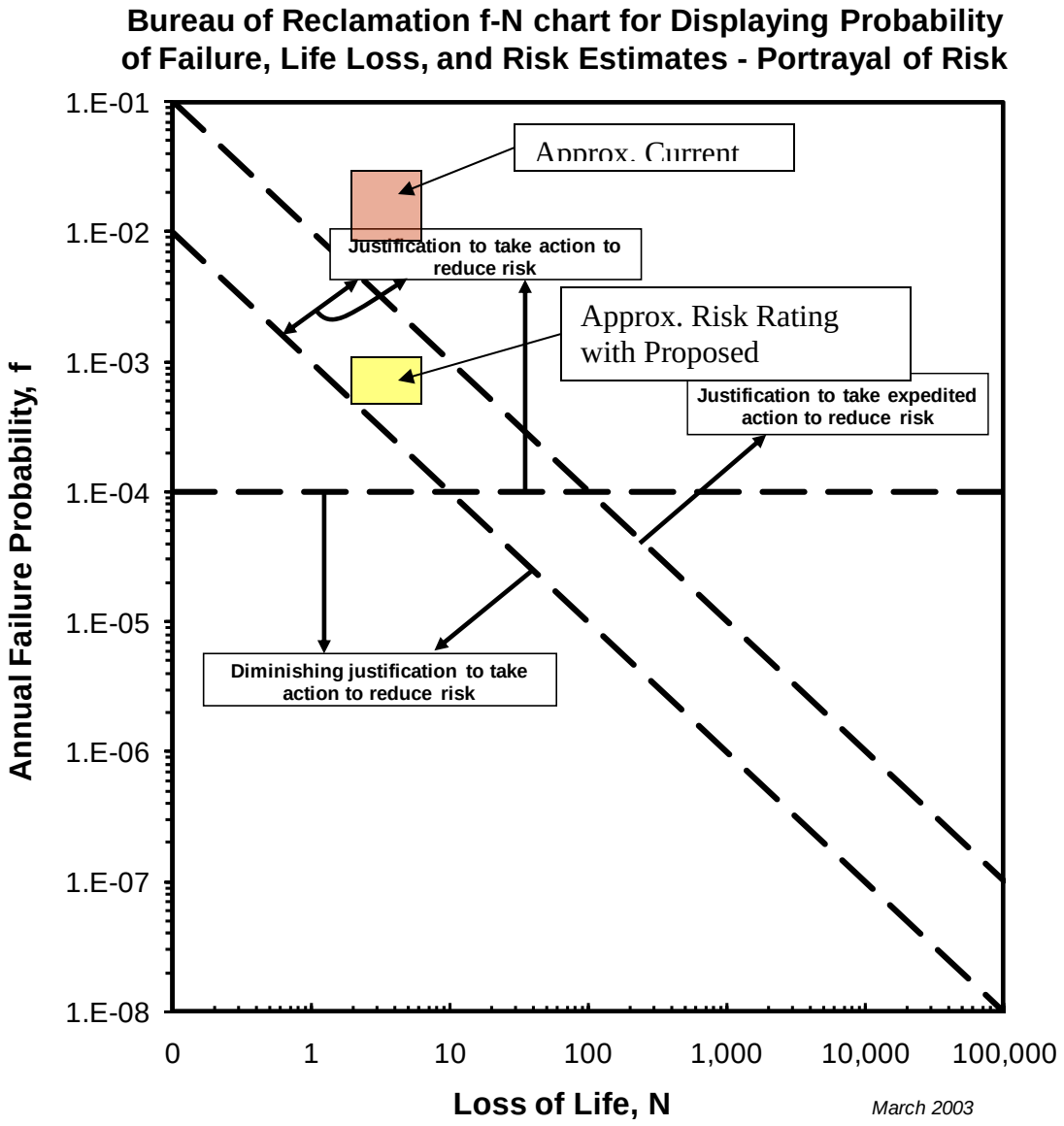

Figure 6.2. f-N Chart Showing Risk Rating for Foundation Bedrock Failure Modes Relative to New USACE Risk Tolerance Guidelines*

It should be noted that the risk rating information shown on Figure 6.2 represents a single foundation-related seepage and piping failure mode at both the Levee and at the Diversion Dam. The total risk rating, which considers all credible and highlighted potential failure modes as presented in Section 5 of this report and as further discussed in Section 9, has not been estimated for the project.

6.6 Panel Opinion on DSAC I Rating

Based on the information received and reviewed by the IEPR Panel, it is the Panel's opinion that the DSAC I designation for both the Levee and Diversion Dam is appropriate. This opinion is based on the following:

a) Compelling evidence indicates that a foundation seepage failure mode has initiated at a number of locations along the landside toe of the Levee and the right abutment of the Diversion Dam. Erosion and that piping of foundation materials are actively occurring during each period of loading at each structure.

b) Seepage distress indicators are changing as a result of each cycle of flood loading. The changing distress indicators include increasing seepage quantities, new seepage locations where episodic sediment-laden seepage is occurring, and enlargement of openings where concentrated seepage is discharging. For example, the Levee was tested in 2005 and 2008 by two floods. In 2005, the pool level rose to elevation 907.4 NGVD and in 2008, it rose to elevation 904.6 NGVD. The estimated seepage flow volume observed at the landside toe of the Levee was estimated to be roughly 10 times greater during the 2008 flood event than in the 2005 event, even though the earlier flood pool was about 3 feet higher than the 2008 flood pool. Piping of soils was observed. The large increase of the estimated seepage rates over a few years and the observed piping indicate that the dam and/or its foundation soils are deteriorating significantly during each flood event.

c) The risk rating of two highlighted potential foundation seepage and piping failure modes, and the potential consequences of failure of either the Levee or Diversion Dam, suggest there is justification to take additional expedited action to reduce project risk. The risk rating is based on only two of a wide range of potential failure modes, and does not provide an indication of the total risk rating of the project, which would be even more critical. The risk ratings are consistent with the observed seepage distress indicators at the site and with a DSAC I classification.

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7 SITE VISIT OBSERVATIONS

The Panel completed a site visit and held several discussions with USACE personnel from June 24 to June 26, 2009. The following is a summary of the site visit activities. Photos taken during the site visit are included in Appendix A.

7.1 DAY 1

The Panel members and Battelle personnel arrived at the site at 12:30 p.m. Mr. Charles Barry, P.E., Chief of the Huntington District Dam Safety Section, gave the initial general overview briefing on the Levee. A summary of key elevation and operation information was provided to the Panel during the briefing discussions for Dover Dam and the Zoar system structures, as described and summarized in Table 4.1.

Mr. Adam Kays (Hungtinton District Geotechnical Engineer) then presented geotechnical information on the historic seepage associated with the ballpark Levee section, the seepage issues that developed adjacent to the rock knob south and east of the pump station in March 2008, the design and construction of the seepage berm constructed during the March 2008 flooding, and the ongoing rehabilitation studies, including recent seepage- and risk-related analyses and evaluations. Copies of the briefing materials were provided to the Panel for additional evaluation.

The overall Interim Risk Reduction Measures (IRRM) for the Dover and Zoar projects were also briefly reviewed. The presentation included information on the rehabilitation of the relief wells, the installation of the new toe drain along the landside toe of the ballpark portion of the Levee, and the efforts to rehabilitate a number of old relief wells that were buried beneath the landside toe of the raised Levee section.

The Panel, Battelle personnel, and seven USACE personnel then went to the site and inspected the Zoar Levee and Diversion Dam system, including the pump station, the ongoing efforts to rehabilitate relief wells and install a toe drain system along the landside toe of the Levee, the seepage berm constructed in 2008 in the seepage area adjacent to the rock knob section, the Diversion Dam, and the exposed rock outcrops adjacent to the Diversion Dam drainage channel where it discharges to the Tuscarawas River. The USACE personnel described the site thoroughly and answered many questions during the visit to improve the Panel's understanding of the structures.

7.2 DAY 2

The Panel and Battelle personnel drove to the District Headquarters in Huntington, WV and arrived at about 1 p.m. The Panel and Battelle personnel first met privately to study and discuss the information and documents that had been provided by the District. During this time, the Panel discussed specific issues with a number of District personnel.

7.3 DAY 3

The Panel and Battelle personnel met to develop a list of additional information required and a preliminary findings and recommendations. At approximately 10:30 a.m. ET, the Panel and Battelle personnel met with approximately 10 District personnel to provide and discuss the Panel's preliminary findings. In this part of the meeting, questions were raised and discussions followed, making it very useful for the Panel. The Panel left the Huntington District office at noon.

8 CONTINUUM OF FAILURE TIMELINE

8.1 Graphic Depiction of Continuum of Failure Timeline

The panel members were part of the team of experts that provided IEPR of the first six USACE DSAC I dams. As part of the work of that team, a graphical depiction of a seepage failure mode continuum was developed and was presented to the USACE in a memorandum dated December 14, 2006. The failure continuum was subsequently included in Appendix C of EC 1110-2-6064 (USACE, 2007) and is proposed for inclusion in Appendix N of the new regulation, 1110-2-1156. The failure continuum, shown on Figure 8.1, summarizes four stages of failure development and three corresponding intervention strategy categories as seepage characteristics progress along the continuum.

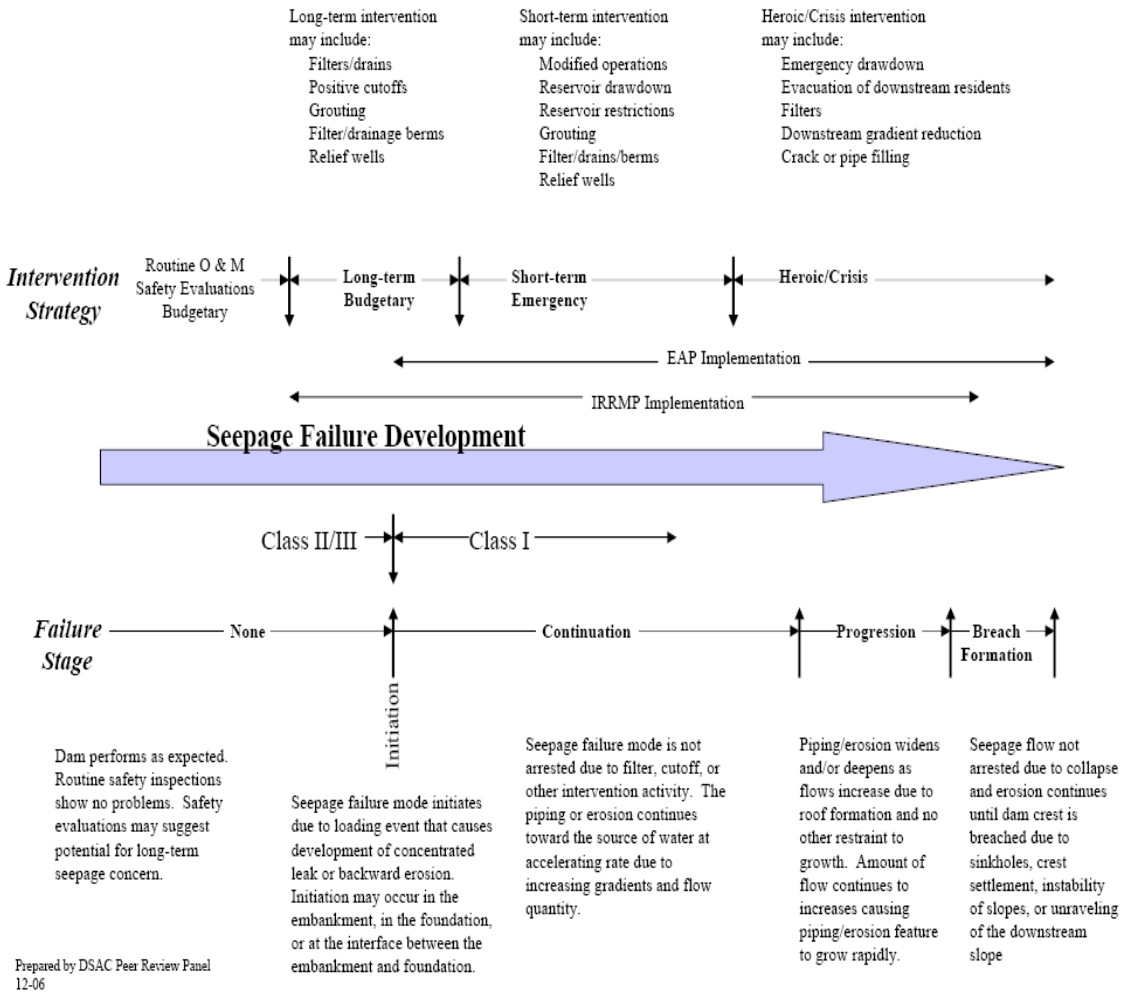

Figure 8.1. Continuum of Failure Timeline, Potential Seepage Failure Modes

The location of the vertical arrows on the Seepage Failure Stage line, shown on Figure 8.1, gives an indication of the DSAC classification relative to the initiation of a seepage failure mode. The DSAC classification, as indicated on this chart, is a function of the initiation or resumption of particle movement relative to normal operations of the reservoir, (up to a 10-year recurrence-interval event), as defined in Section 6.2 (If initiation or movement of particles occurs during normal operations, the structure would, in the Panel's opinion, classify as a DSAC I. If initiation or movement of particles occurs during flood pool stages above the normal operation level, the dam may be classified as a DSAC II or DSAC III.

8.2 Status of Zoar Levee and Diversion Dam in Context of the Failure Continuum

The Panel's assessment of the safety of the Zoar Levee and Diversion Dam is shown along the Failure Continuum on Figures 8.2 and 8.3, respectively. Two assessments for each structure are provided: 1) prior to construction of seepage berms; and 2) following construction of the seepage berms. Photographs of the seepage berms as they existed at the time of the Panel's site visit are shown in Appendix A.

The Panel's assessments shown on Figures 8.2 and 8.3 indicate that seepage-related failure modes have previously initiated at both structures. The appearance of the concentrated seepage points, and the changes in the quantities of seepage over time and during subsequent flood loading conditions, indicate that a seepage failure mode development has not only initiated, but has significantly advanced along the continuum, and has the potential to progress at relatively rapid rate at each structure during future flooding events. The colored arrows on the figures illustrate the Panel's opinion that the Levee and the Diversion Dam are both susceptible to seepage failure unless permanent remedial measures are taken.

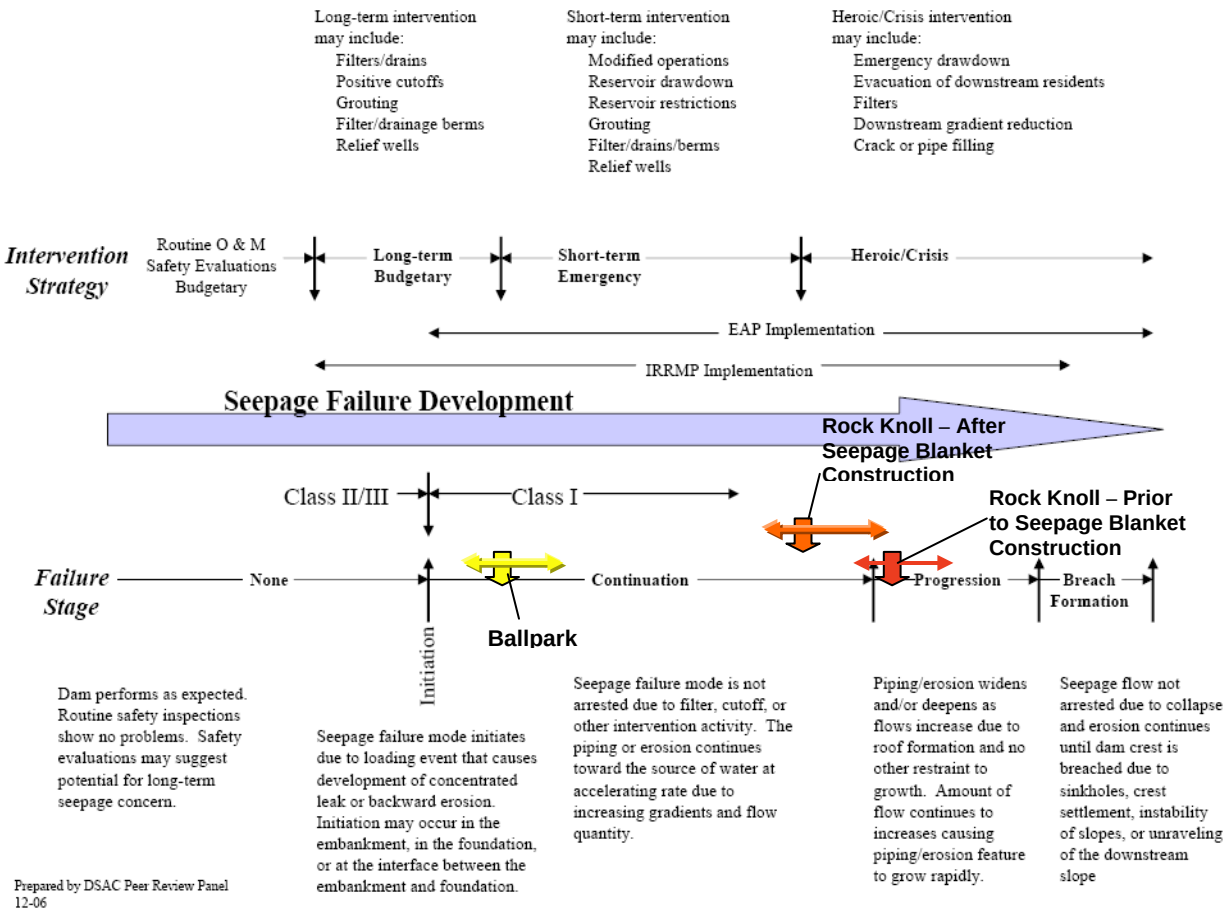

Figure 8.2. Estimated Seepage Failure Mode Status, Zoar Levee

The construction of the seepage berms at the landside toe of the Levee near the rock knoll and along the downstream right abutment of the Diversion Dam provides some risk reduction benefit. The amount of benefit and the length of time such benefit will continue are uncertain.

It is important to note that filter berms at seepage discharge locations are prone to clogging, particularly if the active erosion face or area is in the developing-failure mode, and if the sources of seepage flows are not mitigated to prevent further particle movement. Without eliminating the potential for future soil movement through a developing seepage defect, particles will be eroded, transported to, and then trapped at the filter face of the berm during future flood events. As finer particles accumulate, the filter face will begin to impede seepage flow, and water pressures will begin to build beneath the base of the berm.

Two significant outcomes then become possible and even likely: 1) seepage will emerge from an unfiltered location; or 2) the berm will heave and rupture. In either case, the failure mode continuation or progression will then begin anew, sometimes at a very rapid rate. The active erosion locations and source of seepage water have not been mitigated in the rock knoll area. Similarly, is uncertain whether the water source at the Diversion Dam has been cut off. Hence,

the potential for clogging and subsequent failure of these berms is relatively high. It will be critical to monitor the performance of the berms during any future flooding event. Permanent mitigation of the seepage defects should be completed as soon as possible.

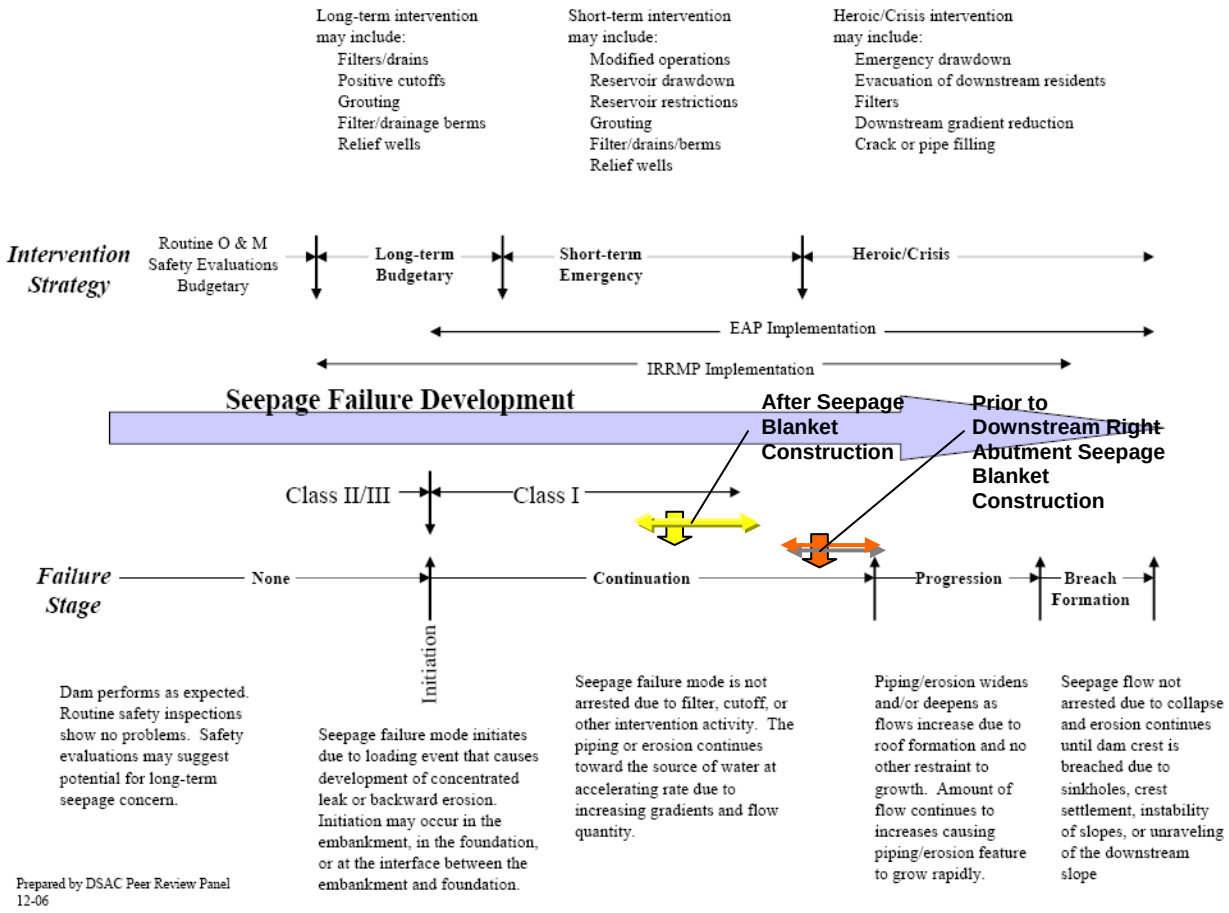

Figure 8.3. Estimated Seepage Failure Mode Status,– Diversion Dam

9 FAILURE MODES AND PROPOSED RISK-REDUCTION MEASURES HIGHLIGHTED BY THE PANEL

9.1 Failure Modes of Primary Concern

General categories of potential failure modes developed by the USACE during the SPRA, along with brief descriptions of those failure modes, are presented in Section 6 of this report. The Panel has reviewed these potential failure modes and generally agrees with the ratings that were assigned at that time.

Following review of the information that has been provided to the Panel, it is the Panel's opinion that all of the potential failure modes (PFMs) listed below should be considered as part of detailed risk evaluation, and during the development of permanent remediation alternatives:

Zoar Levee

1. Abutment seepage and piping failure near the rock knoll in the right abutment.
2. Foundation seepage and piping of the sections of the Levee on alluvial foundation materials
3. Stability failure of the landside Levee slope leading to overtopping failure
4. Seepage and piping failure along the outlet works conduit
5. Overtopping

Diversion Dam

6. Outlet works and spillway clogging by woody debris leading to overtopping failure
7. Overtopping failure due to backwater from Dover Reservoir
8. Abutment and foundation seepage leading to seepage and piping failure
9. Seepage and piping failure along the outlet works conduit

Note that the list above includes two foundation failure modes for Levee (PFMs 1 and 2). Failure may occur through the rock knoll in the right abutment, south of the Pump Station or it may occur through the alluvial foundation beginning in the ballpark area and extend to the area around the pump station. The Panel believes that these are two distinct failure mode domains where conditions and failure mode development processes are different. While they are both foundation failure modes, they should be analyzed separately to judge the overall risk of failure of the Levee.

9.2 USACE Proposed Risk Reduction Measures

An Interim Risk Reduction Measure Plan (IRRMP) was prepared for the Zoar Levee and Diversion Dam system in 2008 (USACE, 2008). Eighteen separate Interim Risk Reduction Measures (IRRMs) were identified and described in the plan. A list of the IRRMs is provided in Table 9.1.

Table 9-1. Listing of Interim Risk Reduction Measures from May 2008 IRRMP

Zoar Levee:

1. **Establish Evaluation and Surveillance Pools**
2. **Installation of Alarm System/Evacuation**
3. **Install Granular Seepage Blanket/Patches**
4. **Stockpile/access Granular Materials**
5. **Store Sandbags on Site**
6. **Flood Fighting Assistance Equipment**
7. **Emergency Exercise**
8. **Communications Plan**
9. **Assessment and Rehabilitation of Existing Relief Wells**
10. **Perform Crest Profile of Levee**
11. **Install Drainage Collection System for Relief Wells**
12. **Interim Surveillance Plan**
13. **Upgrade Pump Station with 3rd Pump**
14. **Upgrade Pump Station with New Generator**
15. **Utilize Mobile Generator (LRH or Contractor)**
16. **Automate the Pump Station**
17. **Emergency Resource Plan**
18. **Infrared Camera Technology**

Diversion Dam:

1. **Interim Surveillance Plan for ZDD**
2. **Dredge the Diversion Channel**

9.3 Recommended Additional IRRMs

The Panel has reviewed the IRRM Plan described in the preceding section and recommends that the District implement the following additional IRRMs:

- Improve monitoring of groundwater pressures, seepage flow quantities, and piping at various locations along the ball park and rock knoll sections of the Levee. The existing system of instruments and monitoring frequency should be evaluated and improved so that the possible development of seepage or stability failures can be continuously monitored. Instruments should be added to monitor the potential for clogging and pressure buildup beneath the seepage berms. Seepage weirs with troughs should be installed in locations where flow quantities can be measured and sediment can be collected. Frequent analyses of monitoring data should be completed and reports prepared that show the instrumentation data and their evaluations. Provide any needed recommendations with each report.
- Improve the ability to monitor flows and potential water storage behind the Diversion Dam.
- Repair rodent holes and damage from rodent activities on both the upstream and downstream slopes of the Diversion Dam.

10 PROPOSED PERMANENT CORRECTIVE ACTIONS

10.1 Design Approach

During discussions between the Panel and USACE personnel familiar with these dams, the Panel was told that Bolivar Dam, located 6.2 miles upstream from Levee, and possibly the Magnolia Levee, also located upstream from the Levee, are Class II dams that probably will need modifications. Modifications of Dover Dam are also being planned.

The USACE is now considering each of these structures (Dover Dam, Zoar Levee and Diversion Dam, Bolivar Dam, and other upstream dams) on an individual basis. The decisions related to IRRMs and permanent modifications within this portion of the Muskingum flood control system are interrelated. The Panel, therefore, recommends that all structures with identified deficiencies or concerns be studied as one project so that IRRMs and designs of permanent repairs are coordinated to avoid problems that could arise if the structures are not considered together as a system.

10.2 Permanent Modifications under Consideration

The most comprehensive information provided to the Panel with regard to potential permanent modifications to both the Levee and Diversion Dam is the recently completed Expert Elicitation for Bedrock Seepage Report (Stantec, 2009). A range of possible alternatives was elicited and documented in notes from a workshop. From the brainstorming session, three overall rehabilitation options for each structure were developed and considered in the risk ratings developed for the abutment bedrock potential failure modes, as discussed in Section 6.5 of this report. These three options for each structure are provided below.

10.2.1 Zoar Levee

Option 1. Install Cutoff Wall into Bedrock

For this option, a 3-foot-thick concrete cutoff wall would be installed along the Levee centerline for a length of about 700 feet from Sta. 29+20 to Sta. 36+20. This corresponds to the rock knoll area. The remainder of the Levee is untreated. Concerns related to hydraulic gradients at the ends of the cutoff wall and the untreated portions of the Levee were identified but not addressed.

Option 2. Grouting with Interior Drainage Berm

This option involves a combination of grouting, interior drainage, and a toe berm. An upstream grout curtain would be used to reduce seepage through fissures in the rock knoll. Because it may not be possible to permanently seal the rock, a berm of drainage material would be placed on the land-side of the Levee. The grout curtain would follow the river-side toe of the Levee in the area of the rock knoll. It would extend down to an elevation of 830 feet (about 98.5 feet deep) between Sta 27+50 and 38+00. The existing seepage blanket would be removed (and materials reused) and a larger drainage berm would be constructed of 3 feet of sand overlain by 7 feet of stone aggregate.

Option 3. Move Levee Away from the Rock Knoll

This option involves construction of a new levee immediately north of the existing Levee, over the rock knoll. The new embankment would be built to the same crest elevations, cross the area of the abandoned racetrack north of the rock knoll, tie into the natural topography just north of the current Levee abutment, and tie into the existing Levee near the current location of the pump station. Steel sheet piling would be driven to rock along the centerline of the new embankment to control under-seepage through soil. Modification of roadways, the pump station, and the existing outlet conduit would be required.

10.2.2 Diversion Dam

Option 1. Install Cutoff Wall into Bedrock

A 3-foot-thick concrete cutoff wall would be constructed the length of the Diversion Dam. The bottom of the wall would penetrate into a shale formation that underlies limestone and sandstone beneath the Diversion Dam. The estimated bottom of the wall would be at elevation 860 (depth of 72 feet), between Sta 0+50 and 4+50.

Option 2. Grouting with Downstream Drainage Berm

This option involves a combination of grouting, interior drainage, and a toe berm. The grout curtain would be installed along the dam centerline, with the bottom at elevation 830 (depth 102 feet) over a length of 400 feet between Sta 0+50 and 4+50. A drainage berm would be constructed downstream of the Diversion Dam to the same elevation as the existing berm along the downstream right abutment. A new toe drain would be installed at the downstream toe of the dam. The outlet conduit would be extended, and the toe drain/berm system would be designed to provide an appropriate filter diaphragm around the downstream portions of the conduit.

Option 3. Renovate Embankment Dam

This option involves removing and rebuilding the existing embankment at the same location and to the same crest elevation. It would incorporate an appropriate foundation, designed to current design standards and practice, and would include excavation of a 15-foot-deep cutoff trench and treatment of the bedrock. Details of the foundation design were not developed as part of this study, but are deferred to the design stage of the project.

10.3 Comments on Proposed Permanent Modifications

The Panel recognizes the limited scope of the alternatives developed during the Expert Elicitation Study. The Panel further recognizes that the District is currently developing an expanded set of alternatives as part of a Major Rehabilitation Study effort. The following presents a summary of the Panel's recommendations related to potential permanent modification alternatives.

10.3.1 General

- A PFMA (Potential Failure Modes Assessment) and subsequent risk assessment should be completed for all of the highlighted failure modes outlined in Section 9.1, as well as for any other credible failure modes identified during the PFMA.
- Concepts should be developed for reducing the risk associated with each of the failure modes that make a significant contribution to the total risk rating.
- Alternatives should be developed that provide appropriate total risk reduction by combining remediation concepts from the individual failure modes.

10.3.2 Zoar Levee

- The Panel believes that a risk assessment of the potential foundation failure modes along the portions of the Levee sited on alluvial foundation materials will show the need for corrective action. These are in addition to the rock knoll failure modes that have been previously evaluated. Consequently, a cutoff wall along the entire length of the Levee may be appropriate.
- Other potential failure modes associated with stability of the Levee slopes and seepage along the outlet conduit will likely require corrective actions that should be incorporated into the alternatives evaluation, as appropriate. Some corrective actions could impact multiple failure modes. For example, a cutoff wall along the entire length of the Levee may eliminate or mitigate a potential stability failure mode, as well as potential foundation, abutment, and embankment seepage failure modes.
- The alternatives evaluation should include raising the Levee to provide additional risk reduction for overtopping failure modes in. The effects of modifications to Dover Dam should be included in the evaluation of Levee-raising concepts.
- The addition of an impermeable blanket on the river- side of the Levee should be evaluated with the aid of the proposed groundwater model.

10.3.3 Diversion Dam

- Raising the elevation of the existing Diversion Dam crest should be considered as a means to provide additional risk reduction for overtopping failure modes.
- Remove and replace the existing Diversion Dam and outlet works. Include appropriate foundation treatment to mitigate potential foundation failure modes. Removal and replacement of the existing dam would eliminate any seepage-induced damage that may have occurred previously.
- Widening and deepening of the Diversion Channel should be evaluated**.** Deepening of the Diversion Channel could eliminate the need for the existing outlet works. Elimination of the outlet works, and removal and replacement of the existing Diversion Dam should be considered if deepening of the Diversion Channel is feasible; this would essentially create a ring levee around the village of Zoar.

- The stability of the intake tower should be evaluated. The elevation of the tower and operating system should be raised so that the gate can be operated during higher pool elevations.
- The power supply to the outlet tower should be modified to raise it above the reservoir pool area.
- Options to prevent clogging of the outlet works intake and Diversion Channel should be included in the design concepts.

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 DSAC Classification

Based on the criteria and information provided and reviewed, the Panel concurs that the classification of the Zoar Levee and Diversion Dam system is DSAC I. This opinion is based on the compelling evidence (see Section 6.6) that a foundation seepage failure mode has initiated at a number of locations along the landside toe of the Levee and in the right abutment of the Diversion Dam. Erosion and piping of foundation materials are actively occurring during each period of loading at each structure.

11.2 Consequences

The consequences of failure of the Zoar Levee and the Diversion Dam will be constrained to the village of Zoar and to the roads into and out of the town, including State Route 212. Because of the limited extent of the area of potential consequences, implementation of emergency action procedures, including warning and evacuation of residents and implementation of road blocks may significantly lower the potential for loss of life on an interim basis.

The potential to mitigate consequences through an emergency action plan (EAP) as a long-term solution should be carefully evaluated and considered in risk analyses and in corrective action studies under the "as-low-as-reasonably-practicable" (ALARP) provisions of the Tolerable Risk Guidelines of the USACE.

The Panel notes that emergency preparations and actions may not fully mitigate the potential for loss of life during each potential flood and, hence, may not significantly reduce the estimated risk rating. Under current conditions, the potential for dam failure is increasing with each flooding event. Permanent corrective actions should be completed as soon as possible. As noted in Section 10.1, permanent modifications within this portion of the Muskingum River Flood Control system are interrelated; all structures with identified deficiencies or concerns should be first studied as one project so that IRRMs and designs of permanent repairs are coordinated.

11.3 Interim Risk Reduction Measures (IRRM)

The District has developed an Interim Risk Reduction Measure Plan in accordance with the guidance outlined in EC 1110-2-6064. The Panel has reviewed this plan and recommends that the District implement the following additional IRRMs:

- Improve the monitoring of water pressures, seepage flow quantities, and erosion at various locations along the ballpark and rock knoll sections of the Levee. This will require an evaluation of the existing system of instruments and monitoring frequency in light of what has been learned from the failure modes and risk analysis completed to date. This is particularly important relative to the potential for clogging and pressure buildup beneath the seepage berms. Opportunities to pass seepage through weirs where flow quantities and sediment can be collected and evaluated should be identified and implemented.

- Improve the ability to monitor flows and particle movement at existing seepage exits on the downstream side of the Diversion Dam. Such measurements will enable evaluation of whether the seepage is increasing with each flood event and whether piping is occurring at the Diversion Dam.
- Repair rodent holes and damage from rodent activities on the upstream and downstream slopes of the Diversion Dam.

The construction of the seepage berms at the landside toe of the Levee near the rock knoll and along the downstream right abutment of the Diversion Dam have been implemented as IRRMs. These berms provide some risk-reduction benefit. However, the amount of benefit and the permanence of such benefit are uncertain.

Filter berms at seepage discharge locations are prone to clogging, particularly if active erosion is developing, and if the sources of seepage flows are not mitigated to prevent further particle movement. Thus, during future flood events, particles will be eroded, transported to, and then trapped at the filter face of the berm. As finer particles accumulate, the filter face will begin to impede seepage flow, and water pressure will begin to build beneath the base of the berm.

Two significant outcomes then become possible and even likely: 1) seepage will emerge from an unfiltered location; or 2) the berm will heave and rupture. In either case, the failure mode continues or progresses, sometimes at a very rapid rate. The active erosion locations and source of seepage water have not been mitigated in the rock knoll area. Similarly, it is not certain that the water source at the Diversion Dam has been cut off. Hence, the potential for clogging and subsequent failure of these berms is relatively high. It will be critical to monitor the performance of the berms during any future flooding event. Permanent mitigation of the seepage defects should be completed as soon as possible.

11.4 Stage vs. Frequency Evaluations

The Panel recommends that the USACE update the stage vs. frequency relationship for the Dover Reservoir and include reservoir routing effects in the evaluation. In addition, a stage vs. frequency relationship for the Diversion Dam should be developed that considers the potential for clogging of both the low-level outlet works intake and the Diversion Channel (spillway) with woody debris. The backwater effects from the Dover Reservoir should be included in the analysis.

11.5 Supplemental Exploration and Additional Data Requirements

11.5.1 Three-Dimensional Geologic Model of the Project Area

The Panel recommends that publically available geological information on the region related to groundwater wells and groundwater resources be compiled. In addition, geophysical explorations and a number of additional borings should be performed to characterize the bedrock surface beneath the site, the hydrogeology of the site, the geomorphology of the Tuscarawas River alluvial channel in order to determine the presence or absence of highly permeable zones, to identify potential seepage pathways and hazards, and to take samples for gradation testing. All

of the above explorations should be done within the reservoir area of the Levee and within the village of Zoar.

The continuity of the possible confining clay layer that covers the site to an unknown extent should be determined. In situ tests should be carried out during drilling to verify the in situ horizontal permeability of the sands and gravels and the Lugeon values for the bedrock in the rock knoll area of the Levee and in the abutments of the Diversion Dam. The drilling program should include borings in the area between the site of the Levee and the Tuscarawas River to determine whether sand and gravel beds at the site are continuous to the river.

11.5.2 Three-Dimensional Groundwater Model

Using the three-dimensional geologic model described above, development of a corresponding three-dimensional groundwater model should be considered. Such a model may be useful for understanding how groundwater flowing under the Levee during floods interacts with the normal regional southerly groundwater flow under the village of Zoar. The model also will be useful for design and for understanding the potential influence on the groundwater regime on water pressures that develop under and along the landside toe of the Levee during flood events. The model will be useful in understanding any future changes of the groundwater flow patterns after remediation is completed.

11.5.3 Levee Investigations

Borings should be drilled through the Levee at selected locations to confirm the internal zoning, to obtain samples for laboratory testing, to measure the penetration resistance and in situ horizontal permeability of each zone of the Levee, and to obtain samples for laboratory tests on samples of each zone to measure their gradation, plasticity, and shear strength, as needed.

11.6 Options for Permanent Modifications

The District is currently evaluating a number of potential alternatives to reduce the risk of failure of both the Levee and Diversion Dam. Based on our understanding of potential failure modes, the following presents a summary of Panel recommendations related to potential permanent modification alternatives:

11.6.1 General

- A PFMA (Potential Failure Modes Assessment) and subsequent risk assessment should be completed for all highlighted failure modes outlined in Section 9.1, as well as for any other credible failure modes identified during the PFMA.
- Concepts should be developed for reducing the risk associated with each of the failure modes that make a significant contribution to the total risk rating.
- Alternatives should be developed by combining remediation concepts from the individual failure modes that provide appropriate total risk reduction.

11.6.2 Zoar Levee

- The Panel believes that a risk assessment of the potential foundation failure modes along the portions of the Levee sited on alluvial foundation materials will show the need for

corrective action. These are in addition to the rock knoll failure modes that have been previously evaluated. Consequently, a cutoff wall along the entire length of the Levee may be appropriate.

- Other potential failure modes associated with stability of the Levee slopes and seepage along the outlet conduit will likely require corrective actions that should be incorporated into the alternatives evaluation, as appropriate. Some corrective actions could impact multiple failure modes. For example a cutoff wall along the entire length of the Levee may eliminate or mitigate a potential stability failure mode as well as potential foundation, abutment, and embankment seepage failure modes.
- The alternatives evaluation should include raising the Levee to provide additional risk reduction for overtopping failure modes. The effects of modifications to Dover Dam should be included in the evaluation of Levee-raising concepts.
- The addition of an impermeable blanket on the river side of the Levee should be evaluated.

11.6.3 Diversion Dam

- Raising the elevation of the existing Diversion Dam crest should be considered as a means to provide additional risk reduction for overtopping failure modes.
- Remove and replace the existing Diversion Dam and outlet works. Include appropriate foundation treatment to mitigate potential foundation failure modes. Removal and replacement of the existing dam would eliminate any seepage-induced damage that may have occurred previously.
- Widening and deepening of the Diversion Channel should be evaluated**.** Deepening of the Diversion Channel could eliminate the need for the existing outlet works. Elimination of the outlet works, and removal and replacement of the existing Diversion Dam should be considered if deepening of the Diversion Channel is feasible; this would essentially create a ring levee around the village of Zoar.
- The stability of the intake tower should be evaluated. The elevation of the tower and operating system should be raised so that the gate can be operated during higher pool elevations.
- Power supply to the outlet tower should be modified to raise it above the reservoir pool area.
- Options to prevent clogging of the outlet works intake and Diversion Channel should be included in the design concepts.

Appendix A

Photos

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Photo 1 - Typical sand boil near Levee rock knoll during March 2008 flood

Photo 2 - Seepage at base of rock knoll on March 23, 2008. Total estimated flow was approximately 5,000 gallons per minute

Photo 3 - Emergency seepage berm construction in the Levee rock knoll area 24 hours after contractor mobilization, March 2008

Photo 4 – Emergency berm construction on March 24, 2008 showing challenges with soft ground conditions

Photo 5 – Completed rock knoll seepage blanket as seen during Panel site visit, June 2008

Photo 6 – Close-up view of completed seepage blanket at Levee toe

Photo 7 - Concentrated seepage from the downstream right abutment of Zoar Diversion Dam in 1991

Photo 8 – seepage berm installed along downstream right abutment of Diversion Dam (Photo taken in June 2006)

Appendix B

References and Sources of Factual Data

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REFERENCES AND SOURCES OF FACTUAL INFORMATION

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10. USACE, Zoar Levee & Zoar Diversion Dam Interim Risk Reduction Measures Plan, May 2008
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12. USACE, Soils IEPR Presentation, June 23, 2009.
13. USACE, Zoar Levee – General Background for IEPR Presentation, June 23, 2009.

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Appendix C

Final Peer Review Conflict of Interest Inquiry Form

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Dear (Peer Reviewer -- insert name):

You have been requested by the U.S. Army Corps of Engineers (USACE) to serve as an external peer reviewer for the Dam Safety Action Classification 1 (DSAC-1) Projects Engineering Risk and Reliability Analysis IEPR. Your participation in this review will be greatly appreciated. However, it is possible that your personal affiliations and involvement in particular activities could pose a conflict of interest or create the appearance that you lack impartiality in your involvement for this peer review. Although your involvement in these activities is not necessarily grounds for exclusion from the peer review, you should consult the contact named below or other appropriate official to discuss these matters. Affiliations or activities that could potentially lead to conflicts of interest might include:

a) current work or arrangements concerning future work in support of industries or other parties that could potentially be affected by developments or other actions based on material presented in the document (or review materials) that you have been asked to review;
b) your personal benefit (or benefit of your employer, spouse or dependent child) from the developments or other actions based on the document (or review materials) you have been asked to review;
c) any previous involvement you have had with the development of the document (or review materials) you have been asked to review;
d) any financial interest held by you (or your employer, spouse or dependent child) that could be affected by your participation in this matter; and
e) any financial relationship you have or have had with USACE such as employment, research grants, or cooperative agreements;
f) a significant portion of your personal or firm's revenues within the last 3 years came from USACE contracts;
g) you or your firm made a publicly documented statement advocating for or against the subject project.

If you have any concerns over a potential conflict of interest, please contact Mr. Michael Genovese, Battelle, at GenoveseM@battelle.org, (614) 424-4007, to discuss any potential conflict of interest issues at your earliest convenience, but no later than two (2) days after receiving this request.

If you agree to be on this peer review panel, please check one of the following boxes, sign this form, and fax to Ms. Karen Tracy, Battelle, at (614) 458-4028 no later than two (2) days after receiving this request. She may be reached with questions at (614) 424-4028 or TracyK@battelle.org.

This form does not constitute an authorization to participate in this review; authorization for performance will come from Battelle's Government Subcontracts office.

[ ] I have no known existing or potential conflicts of interest associated with this task.

[ ] I have identified and disclosed in writing all known existing or potential conflicts of interest associated with this task.

_____ _____

Signature *Date* *Printed Name*

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Appendix D

Panel Member Resumes

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Experience
____ years

Expertise

Education
Ph.D., Engineering, Harvard University, 1964
M.S., Civil Engineering, Massachusetts Institute of Technology, 1955
B.S., Civil Engineering, Massachusetts Institute of Technology, 1954

Registration
Professional Civil Engineer:
Massachusettes, #_____
Vermont, #_____

Professional Affiliations

Specialized Training

Summary of Experience

Dr. Poulos is a founding principal of GEI. He is a registered professional civil engineer specializing in soil and rock mechanics, earth dam engineering, foundation engineering, and groundwater hydraulics. At GEI, Dr. Poulos has managed over 900 projects, covering all aspects of geotechnical engineering design and construction, as well as expert testimony for litigation purposes.

Dr. Poulos has carried out analyses related to the design of the geotechnical aspects of many dams, including seepage analysis, stability analysis, testing of the engineering properties of soils, filter design, groundwater studies, selection of materials, selection of construction techniques and equipment, selection of compaction requirements, design of slurry trench walls, erosion control of surfaces, cracking analysis, seismic analysis, and deformation analysis. He has inspected and made Phase I geotechnical evaluations of approximately 40 dams in connection with the National Dam Inspection Program. In addition, he has designed dikes for several large sedimentation basins required to treat construction site water and runoff.

Dr. Poulos introduced the principle of steady-state of deformation and has been instrumental in applying it to practice, particularly for analysis of liquefaction potential of loose sands and soft clays due to seismic triggering. For this purpose, he developed field procedures for undisturbed sampling of sands, which previously had not been considered feasible. He and Dr. Gonzalo Castro developed laboratory test procedures to measure steady-state undrained shear strength, and procedures for analyzing stability based on initial and post-earthquake conditions. He has analyzed more than 30 cases using these procedures for dams from 20 to 400 feet high.

Dr. Poulos has managed design and construction observation for many projects involving cooling water and effluent pipelines, water supply lines and sewage lines. He has directed a number of projects related to the design, installation, performance evaluation, and repair of buried fiberglass pipes. He has been involved with the design and construction of six underwater pipelines, including twin 9-foot-diameter cooling water lines for a nuclear power plant in Maine. He has directed investigations into the failure of several fiberglass pipes and developed recommendations for repair procedures. He has evaluated fiberglass pipe designs for more than 20 projects for two manufacturers to identify potential liability exposures.

Dr. Poulos has directed geohydrologic studies related to closure, expansion, and contamination investigations for several landfills and has performed technical studies to demonstrate the suitability of clays, silts, glacial tills, soil-bentonite mixtures, and synthetic fabrics for use as impervious caps and liners for landfills and lagoons. He is a recognized expert in groundwater flow analysis and has provided consultation and expert testimony in support of litigation for industry, insurance companies, utilities, and government agencies. Prior to founding GEI, Dr. Poulos taught mathematical aspects of groundwater flow at Harvard University.

Experience

Dams

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Harriman Dam, Vermont. Principal-in-charge of field explorations, instrumentation installation, laboratory testing, and seismic stability analysis of existing 220-foot-high semi-hydraulic fill dam. Evaluations of potential for earthquake-induced liquefaction of the dam and of expected earthquake-induced deformations were included.

Sherman Dam, Monroe Bridge, Massachusetts. Principal-in-charge of field explorations, instrumentation installation, laboratory testing, and static and seismic stability analyses of existing 110-foot-high semi-hydraulic fill dam. Evaluated potential for earthquake-induced liquefaction of the dam and estimated earthquake-induced deformation of the dam. Used a computer-assisted, two-dimensional finite element analysis to estimate earthquake shear stresses for use in the analysis.

San Justo Dam, California. Member of Board of Review for design of proposed United States Bureau of Reclamation (USBR) earth dam in California, which is located between the Calaveras and San Andreas faults.

Phase I Dam Inspection, New England. Conducted Phase I inspections for almost 45 earth and concrete dams in New England as part of the United States Army Corps of Engineers (USACE) National Program of Dam Inspection.

Five Dams in Vermont, Rhode Island, and Connecticut. Principal-in-charge for design of remedial measures for dam safety deficiencies.

Bass Lake and Trout Lake Dams, North Carolina. Principal-in-charge of development of conceptual designs for USBR to remedy dam safety deficiencies for 40-foot-high Bass Lake Dam and 25-foot-high Trout Lake

Dam, both of which are embankment dams. For both dams, the safety deficiencies consisted of the dams' inability to pass the inflow design floods.

Anderson Ranch Dam, Indiana. Principal-in-charge for USBR of safety evaluation of an existing 350-foot-high earth dam. Planned and supervised field explorations, laboratory testing, and analyses.

Casitas Dam, California. Principal-in-charge of laboratory and field investigation for liquefaction evaluation of Casitas Dam, which is owned by the USBR.

Lucky Peak Dam, Indiana. Principal-in-charge of evaluation of liquefaction potential for this USACE dam.

Mine Tailings Dam, Alberta, Canada. Principal-in-charge for study of potential for liquefaction of the 160-foot-high mine tailings dam. Provided recommendations for compaction, carried out detailed undisturbed sampling of tailings, evaluated their liquefaction potential, and developed a correlation between liquefaction potential and penetration resistance for use in other zones of the dam.

Hinckley Dam, New York. Principal-in-charge of liquefaction evaluation and conceptual and final designs of Federal Energy Regulatory Commission (FERC) mandated safety modifications for loose foundations soils. The dams are owned by the New York Power Company.

Earth Dams. Principal-in-charge of evaluating liquefaction potential and deformations at about 20 dams for the Federal Government, New England Power, New York Power, and other owners.

National Panel. Served as chair of an external panel of 6 consultants to review the degree of safety of 6 dams that are considered by the USACE as being most in need of remediation, based on a review of their inventory of about 600 dams. The review was completed between October 2006 and June 2008.

Amistad Dam. Member of a panel of consultants for this 16-kilometer-long dam on the Rio Grande River near Del Rio, Texas. It is owned half by Mexico and half by the United States. It is being reviewed to determine whether remediation may be needed.

Clearwater Dam. Consultant to the Little Rock District of the USACE from 2003 to 2005, and member of a 3-person consulting panel from 2005 to present. The dam is located in Piedmont, Missouri and is being remediated to increase its degree of safety.

Canton and Keystone Dams. Member of a 3-person consulting panel to review the degree of safety of these dams operated by the USACE's Tulsa District Office.

Geohydrology

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managed over 900 projects, covering all aspects of geotechnical engineering design and construction, as well as expert testimony for litigation purposes.

Dr. Poulos has directed geohydrologic studies related to closure, expansion, and contamination investigations for several landfills and has performed technical studies to demonstrate the suitability of clays, silts, glacial tills, soil-bentonite mixtures, and synthetic fabrics for use as impervious caps and liners for landfills and lagoons. He is a recognized expert in groundwater flow analysis and has provided consultation and expert testimony in support of litigation for industry, insurance companies, utilities, and government agencies. Prior to founding GEI, Dr. Poulos taught mathematical aspects of groundwater flow at Harvard University.

The Gillette Company, South Boston, Massachusetts. Principal-in-charge of development of a complete three-dimensional model for groundwater flow at the site using Modflow software. The work included the effects of 10 dewatering wells used for construction of the access road across to the Ted Williams Tunnel, which crosses Gillette property. Sixteen recharge wells were installed and modeled to determine the effect of dewatering on the groundwater levels so that any potential settlement of the buildings could be avoided. Both the dewatering wells and recharge wells are 200 to 300 feet deep. Natural and altered conditions were both modeled and the model was used to help select the locations at which to install the recharge wells and to understand the changed directions of groundwater flows.

Zone II Delineation Study for Municipal Well, Duxbury, Massachusetts. Served as In-House Consultant for hydrogeologic investigation and modeling to define the Zone II Wellhead Protection Area for an existing 400-gallon-per-minute municipal well. Provided guidance for evaluation of pump and rebound test to determine aquifer characteristics. Developed preliminary evaluation of potential for salt water intrusion.

Groundwater Model for Proposed New England Power Nuclear Station Site, Charlestown, Rhode Island. Model was done to estimate salt water intrusion, determine the relation between groundwater on barrier reef and groundwater onshore, recharge areas for site groundwater, determine the effect of dewatering on site on nearby potable water wells, determine the effect of runoff during construction on turbidity, and design calculations for the sedimentation pool to collect and clarify runoff.

Meta Systems Inc. Evaluated the technical basis for the patented "zero gradient" system for controlling movement of pollutants through groundwater. Developed the technical justification for the patent application.

Construction Drawdown Effects on Well, Pilgrim Station Unit 2. Predicted drawdown, evaluated potential effect of 4-year-long construction dewatering on adjacent cranberry bogs and water supply well, prepared graphic displays, and presented testimony for various court and regulatory hearings. Drilled borings, developed groundwater model, and performed analyses. Appeared as witness before official hearing of the Department of Environmental Quality Engineering (DEQE).

Environmental Engineering

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Charles George Landfill Site, Tyngsboro, Massachusetts. Consultation to the Potentially Responsible Parties Generator's Committee. Reviewed design of cap being proposed for use at the 67-acre site to determine cost-effectiveness and reliability. Review entailed investigation of degree of reported groundwater contaminations evaluation of numerous alternative cap designs, potential borrow sources for impervious soils, construction techniques and cost estimates, and evaluation of potential long-term settlement of landfill. Also prepared report comparing use of synthetic and impervious-soil liners for the site.

Hingham Shopping Center, Hingham, Massachusetts. Principal-in-charge of mounding study for a leaching field that will accept 54,000 gallons per day. Determined the height of mounding with a three-dimensional model used in the Modflow software.

Contaminated Groundwater Removal and Treatment System. Reviewed previous studies and remedial action design at a 37-acre site for chlorinated volatile organic contamination in overburden and bedrock aquifer at a large manufacturing facility in Massachusetts. Studied the subsurface information and designed and implemented an innovative, inexpensive, but effective groundwater removal and treatment system. Observed construction of the system, which was approved by Massachusetts Department of Environmental Protection (DEP) and has been operating since 1985.

Groundwater Contamination Study. Directed the geohydrologic investigation and remedial action design for a leaking underground tank farm for a confidential client.

Hobbs Brook Reservoir Sodium Chloride Contamination Study, Massachusetts. Evaluated a Massachusetts Department of Public Works (DPW) salt storage facility to determine its contribution of sodium to Hobbs Brook drinking water reservoir. All sources were evaluated and a mass balance developed to assess relative contributions. Conducted an 18-month study, including a 12-month data collection effort, to support a sodium transport model. Proposed remedial measures to substantially reduce the sodium flow into the reservoir from several sources. This study set the standards for future drainage and salt studies.

Norridgewock Landfill, Maine. Directed the design of a monitoring system for a double-lined secure landfill for consolidated wastes.

Gas Plant Remedial Investigation, Spencer, Massachusetts. Directed the evaluation of in-ground contamination at a site due to an old coal gasification plant. Evaluated methods of containing and/or removing the organic contaminants and prepared a study of the relative costs.

Contamination Investigation and Remediation. Directed the measurement of volatile organics in the vadose zone and in the groundwater of a site for a confidential client. Designed a removal system and a cap.

Petroleum Contamination Investigation. Directed the recommendations made for cleanup of a diesel fuel spill at a site for a confidential client. Tested underground tanks to determine where the leaks had come from and recommended options for their replacement and for protection of a nearby stream from this fuel spill.

Preparation of a Spill Prevention Control and Countermeasure (SPCC) Plan, Tewksbury, Massachusetts. Principal-in-charge for the preparation of a SPCC plan and design of containment structures for a major electrical substation. The spill control was to prevent potential contaminants from transformer oil from entering waterways in the event of an on-site accident.

Massachusetts Contingency Plan (MCP) Investigation and Remedial Design. Project Manager for MCP Response Actions at dense nonaqueous phase liquid (DNAPL) site situated within 1/2 mile of a Secondary Water Supply Reservoir First Site Waivered by DEP in 1988.

Gas Plant Remedial Investigation Spencer, Massachusetts. Directed the evaluation of in-ground contamination at a site due to an old coal gasification plant. Evaluated methods of containing and/or removing the organic and inorganic contaminants, and prepared a study of the relative costs.

Water Supply Well. Directed the evaluation of potential effects on water quantity and quality of rock blasting near a private water supply well.

MCP Phase II Comprehensive Site Assessment, Bostik, Inc., Middleton, Massachusetts. In-house Consultant for Phase II investigations at a 60-acre adhesives manufacturing facility. A Priority (Tier IA) Site, the Bostik facility abuts the Ipswich River, a secondary water supply for downstream communities. Volatile organic compound (VOC) contamination from a tank farm on site was detected in 1987. GEI implemented a Short Term Measure using 27 extraction wells and a PACT biological treatment system to create a hydrologic barrier to capture and treat contaminated groundwater. Additional investigations detected Polychlorinated Biphenyls (PCBs) in surface water sediments on-site and in the Ipswich River. A 2- to 3-acre waste disposal area on site is currently under investigation as are other areas where historic use of VOCs, PCBs, and Acid Base Neutrals (ABNs) has been documented.

Landfill Expansion and Closure, Concord, Massachusetts. Principal-in-charge for geohydrologic study to determine areal extent and level of

contamination from existing landfill. Estimated potential effects of leachate on nearby town well and historic Walden Pond. Provided geotechnical testing and design recommendations for use of glacial till as impervious cap for existing landfill closure and as liner for landfill expansion. Directed construction phase field and laboratory testing to document suitability of cap and liner.

New England Power, Salem Station, Salem, Massachusetts. Evaluated in detail flow of contaminants from coal pile into groundwater and offshore into mussels. Made field study of leachate characteristics and contamination of soil and groundwater to judge effect of leachates from 4-acre coal pile. Tested for contaminants in mussels in the ocean nearby. Evaluated outflow from treatment basins into groundwater for comparison with background water quality.

Mill Brook Interceptor, Lexington, Massachusetts. Exploration and geotechnical design for a 30- to 36-inch-diameter interceptor sewer with two tunnels, three pipe jacking sections, and special dewatering (wellpoints or deep wells) required for about 16,000 linear feet of the line.

Petroleum Contamination Investigation. Directed the recommendations made for cleanup of a diesel fuel spill at a site for a confidential client. Tested underground tanks to determine sources of leaks and recommended options for their replacement and for protection of a nearby stream from the fuel spill.

Brayton Point Oil Ash Basins, Somerset, Massachusetts. Measured groundwater quality before and after construction of sludge basin and monitored groundwater quality during use for submission to DEP. Directed the stability evaluation to design a sludge basin at Brayton Point, Massachusetts.

Spill Prevention Control and Countermeasure (SPCC) Plan, Tewksbury, Massachusetts. Principal-in-charge for the preparation of an SPCC plan and design of containment structures for a major electrical substation. The spill control was to prevent potential contaminants from transformer oil entering waterways in the event of an on-site accident.

Lead Remediation Oversight, Egleston Square Neighborhood Association, Roxbury, Massachusetts. Consultant for the former Massachusetts Bay Transportation Authority (MBTA) Station Site in Egleston Square, which was targeted for development by the City of Boston as an economic enhancement to the community. However, significant lead contamination at the Site needed to be remediated prior to development. The local citizen action group, ESNA, was in favor of the development project, but concerned that the remediation be performed to minimize both current and future health risks associated with inhalation and/or ingestion of lead-contaminated soils. Under a public involvement grant provided to ESNA by the MBTA, GEI reviewed each step of the investigation, remediation, and development of the Site and provided the community with technical comments and educational information on the MCP process, public health issues related to lead in the environment, and soil remediation technologies.

Foundation Engineering

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Seabrook Nuclear Station, Seabrook, New Hampshire. Principal-in-charge for the geotechnical engineering aspects of the Seabrook Nuclear Station as consultant to United Engineers for Yankee Atomic. Designed and supervised site investigations, testing, foundation engineering, specification writing, and construction control for the structures and intake and discharge structures, and writing of the relevant Preliminary Safety Analysis Report (PSAR) and Final Safety Analysis Report (FSAR) sections. Developed detailed compaction control procedures to ensure that the specified degree of compaction would be achieved in the field. All procedures were observed and verified in situ.

Midland Nuclear Plant, Michigan. Consulted to the U.S. Nuclear Regulatory Commission (NRC) on underpinning the Midland Nuclear Plant. Analyzed the permissible settlements for a very heavy, existing, and critical structure that settled, and reviewed in detail the geotechnical aspects of the design of underpinning and monitoring system. He also prepared portions of the Supplementary Safety Analysis Report and presented testimony on behalf of the NRC at Atomic Safety and Licensing Board (ASLB) hearings.

The Gillette Company, South Boston, Massachusetts. Foundation evaluation and design of many buildings for the Gillette Company (1972 to present). Experienced with measuring building settlements, evaluating effects of subways on foundation design, developing foundation designs for vibrating machines, and evaluating building vibrations. Also developed foundation underpinning schemes for buildings with deteriorated wood piles.

Seabrook, New Hampshire. Directed an investigation of the usefulness of tunnel boring machine spoil as structural backfill. The spoil was widely graded, gravelly, silty sand. The studies resulted in development of guidelines for use of the spoil as compacted backfill.

Safety Analysis of Wharf, Boston, Massachusetts. Performed an analysis of stability of an existing 1,100-foot-long wharf structure owned by the Massachusetts Port Authority.

University of New Hampshire. Foundation design for science and engineering center.

Beth Israel Hospital, Boston, Massachusetts. Foundation design recommendations for Feldberg Building, entrance building, and 6-story parking garage.

Mary Hitchcock Hospital, Hanover, New Hampshire. Foundation design.

AMCA Headquarters, New Hampshire. Foundation design.

Harvard Herbarium Extension. Foundation design recommendations for extension adjacent to existing building.

Subway Kiosk, Prudential Station, Boston, Massachusetts. Foundation design recommendations for subway kiosk at Prudential Station.

New England Journal of Medicine Building. Foundation design.

Public Library, Andover, Massachusetts. Foundation design for addition to public library.

Potential Nuclear Plant Sites, Vermont. Preliminary foundation analysis and comparison of three potential nuclear plant sites, including preliminary design of 120-foot-high earth dam.

Air Traffic Control Center, Nashua, New Hampshire. Foundation design recommendations for Air Traffic Control Center.

Skating Rink, Fitchburg, Massachusetts. Foundation design.

Nahant Substation, Massachusetts. Foundation design.

Boston Edison, Boston, Massachusetts. Foundation design for Kingston Street Substation.

Housing for the Elderly, Melrose, Massachusetts. Foundation design recommendations.

Groton Substation, Massachusetts. Foundation design recommendations.

Everett-Wellington Electric Duct System. Foundation design recommendations for Everett-Wellington electric duct system (river crossing).

Bretton-Woods Housing Project. Foundation design recommendations.

Abu Dhabi Hospital. Foundation design recommendations for hospital in Abu Dhabi.

Housing for the Elderly, Whitman, Massachusetts. Foundation design recommendations.

Regency II Apartments, Medford, Massachusetts. Foundation design recommendations.

Public Safety Facility, Medford, Massachusetts. Foundation recommendations.

New England Nuclear Power Station, Charlestown, Rhode Island. Geotechnical services, including foundation design, geohydrology, and erosion control.

Medford Swimming Pool, Massachusetts. Foundation design.

Pilgrim Station. Foundation design for administration, shop, indoctrination, and support facilities.

Wedgewood House Condominiums, Winchester, Massachusetts. Foundation design.

Pumping Station, South Windsor, Connecticut. Foundation design.

Lynn Industrial Park, Massachusetts. Foundation feasibility study.

Sewer Line Cost Overruns. Evaluated cost overruns and prepared technical evaluation for a lawsuit concerning a 2,000-foot-long sewer line.

Cofferdam Modifications, Fort Point Channel, South Boston, Massachusetts. Principal-in-charge of thermal studies of Fort Point Channel performed over a 4-month period to evaluate the cost effectiveness of obtaining cooler channel water for industrial use. Provided recommendations for shallow dredging of part of the channel, in front of the cofferdam, and relocation of the existing take points; enabling the present cooling water system to obtain the cooler water near the bottom of the channel. Obtained the required federal, state, and local permits for licensing the existing cofferdam and for dredging small quantities of silt.

Timber-Pile Supported Wharf, East Boston, Massachusetts. Evaluation of existing timber-pile-supported wharf. Borings, field inspection and evaluation of feasibility of dredging adjacent to existing wharf structures.

Granite Retaining Wall, South Postal Annex, Boston, Massachusetts. Evaluation of damaged wood-pile-supported granite block seawall. Performed field and laboratory investigations and provided recommendations for the design and construction of the repairs for the wall.

Seawall, South Boston, Massachusetts. The stability of a wood-pile-supported granite wall against earth pressure, seismic loads, and surcharge loads was studied to determine its stability and to make repair recommendations.

Cofferdam Scheme around Charles River Dam, Boston, Massachusetts. Evaluation of a new cofferdam scheme around Charles River Dam. Design of a realignment of a cofferdam scheme as part of a value-engineering proposal to the United States Army Corps of Engineers (USACE). The design included establishing new limits for dredging, stability analysis of the cofferdam scheme and adjacent slopes, and recommendation for field observations and instrumentation to monitor drawdown within the cells and within the excavation during dewatering of the cofferdam.

Litigation Support

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Massachusetts Turnpike Authority. Provided expert testimony regarding contamination of soils and groundwater to establish effective means for proper removal of the contamination in accordance with the Massachusetts Contingency Plan.

Massachusetts Turnpike Authority. Provided expert hydrogeologic services and testimony through MTA's legal counsel, Widett, Slater & Goldman, P.C. Dr. Poulos addressed water quality issues and the potential pathways, concentrations, and rate of salt transport from the Turnpike roadways.

Expert Witness Testimony, Massachusetts Department of Environmental Protection (DEP) Hearing, Pilgrim Nuclear Station Site. Gave testimony to indicate the general nature of groundwater conditions and the specific effects of site work on groundwater levels and drawdown of local water supply wells and cranberry bogs due to 4 years of pumping at approximately 4,000 gallons per minute. Conducted a complete analysis of groundwater at the site for the purpose of assessing environmental impact of the past and proposed construction. Drilled borings, developed groundwater model, and performed analyses. Evaluated potential for salt contamination of nearby potable water wells and provided design recommendations to avoid the predicted affects. Prepared graphic displays and presented testimony for various court and regulatory hearings, including the Department of Environmental Quality Engineering (DEQE).

Clair Buick. Reviewed design documents and provided expert opinion on whether the geotechnical design for a structure which experienced substantial post-construction settlement conformed to generally accepted standards of practice. Building was founded on a preloaded peat deposit that had not been preloaded sufficiently.

Construction Drawdown Effects on Well, Pilgrim Station Unit 2. Predicted drawdown, evaluated potential effect of 4-year-long construction dewatering on adjacent cranberry bogs and water supply well, prepared graphic displays, and presented testimony for various court and regulatory hearings. Drilled borings, developed groundwater model, and performed analyses. Appeared as witness before official hearing of the DEQE.

Dewatering Evaluation. Provided technical evaluation and expert opinion on the effect of a dewatering system failure during building demolition on the cost of demolition. Evaluated viability of claims for the costs of consequential damages.

Federal Distilleries Building. Provided technical evaluation and expert opinion on whether damages to a structure were caused by excavation and dewatering for construction of an adjacent pumping station/treatment facility and associated sewers. Reviewed and evaluated depositions, reports, and construction documents in detail.

Expert Witness Testimony, Central Vermont Hospital. Provided expert testimony before Zoning Board and Conservation Commission relative to the effects of drawdown in a well on the 23 nearby wells in the same bedrock aquifer. Performed a 21-day pumping test to evaluate long-term capacity of the well to produce water at a higher volume for this hospital, projecting 20 years into the future. Analyzed the gradual buildup of salt in these wells

over a 12-year period before and after construction of an interstate highway exit nearby.

Failure of Spaulding Pond Dam, Norwich, Connecticut. Performed detailed analyses, prepared graphic displays, and provided expert testimony to a jury concerning the cause of failure of a 20-foot-high earth dam, which resulted in loss of several lives in 1963. Analysis included effects of water level, embankment design, frost effects, embankment construction, and maintenance.

Hartwell Road Well Field, Bedford, Massachusetts. Directed a detailed evaluation of sources of organic contaminants and high iron levels in three public water supply wells that pump approximately 500 gallons per minute. Carried out a 45-day pumping test to determine potential sources, analyzed the contamination at each source through an extensive field program, and analyzed the effect of each source and each contaminant on the well. Presented testimony at arbitration.

Joe Pool Dam. Evaluated causes of overruns during construction of Joe Pool Dam, prepared exhibits, and gave two days of testimony in the Federal Court of Claims in connection with major lawsuit by contractor who built this $25,000,000 earth fill dam for the Corps of Engineers.

Dedham-Westwood Wellfield, Dedham, Massachusetts. Provided technical assistance to the Massachusetts Water Resources Authority (MWRA) in connection with the geohydrologic aspects of litigation over the contamination of water supply wells in Dedham, Massachusetts. Work included evaluation of the methodology and results of previous field investigation and analysis of contamination of the wells, recommendation of additional field studies, computer modeling of the potential for future contamination, and technical review of litigation briefs.

Midland Nuclear Station. Analyzed causes and effects of settlements of compacted fill on major, very rigid structures by studying the methods of compaction in detail. Prepared and presented testimony before Atomic Safety Licensing Board (ASLB) and other hearings.

Northside Generating Station, Jacksonville, Florida. Reviewed and certified manufacturer's design calculations for a 196-inch-diameter buried fiberglass line.

Sewer Line Cost Overruns. Evaluated cost overruns and prepared technical evaluation for a lawsuit concerning a 2,000-foot-long sewer line.

Town of Hudson, New Hampshire. Provided analysis of cause of settlements resulting from town-wide sewer construction (22 miles). Predicted future settlements and damage to house connections due to improper compaction. Made detailed measurements of percent compaction achieved.

Trinity Church, Boston, Massachusetts. Analysis of the cause, magnitude, and rate of movement of the church over its entire history (since 1867), including evaluation of design and construction sequence of retaining wall

for the adjacent new (1967) John Hancock building. Provided expert testimony to jury with graphs and displays.

Underwater Pipe Failure, Mobile, Alabama. Investigated cause of liquefaction failure of buried underwater fiberglass pipe and provided recommendations and construction observation for repair procedures.

Gas Explosion, Reading, Massachusetts. Analysis of effect of construction of a sewer below an under 8-inch cast-iron gas main on possible settlement and break of gas main one year later. Included effects of traffic, overburden, frost action, and corrosion (graphitization) on the likelihood of break of pipe which led to explosion and loss of life.

Salt in Groundwater. Analysis of the cause of high salt concentration in wells used for a town water supply. Evaluated various sources, paths, and rates of salt movement from salt storage area, highway, and town roads.

Bradlee's Warehouse. Analyzed whether frost action or other factors could be the cause of failure of a steel structure that had been partially constructed.

Four Seasons Hotel, Boston, Massachusetts. Complete analysis and report on cause of movement of a 30-foot-high sheet-pile wall, including effects on utilities (gas, main, sewer, and water) in adjacent road.

Beacon Hill, Boston, Massachusetts. Complete evaluation of causes of groundwater lowering at two locations as expert in geohydrology for the MWRA. Information used in connection with litigation.

Nuclear

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Midland Nuclear Plant, Michigan. Consultant to the U.S. Nuclear Regulatory Commission (NRC) on underpinning for the Midland Nuclear Plant in Michigan. Reviewed the geotechnical aspects of and recommended changes, as needed, to the design of the underpinning construction procedures and monitoring system. Wrote portions of the Supplementary Safety Analysis Report and presented testimony on behalf of NRC at ASBL hearings.

Pilgrim 2 Nuclear Power Plant, Plymouth, Massachusetts. Principal-in-charge of foundation design recommendations including allowable bearing pressures and evaluation of liquefaction potential. The scope of work included laboratory cyclic load testing of undisturbed and laboratory-compacted specimens, detailed evaluation of subsoils in 6-foot-diameter by 50-foot-deep test pit, detailed evaluation of groundwater conditions, the potential effects of construction pumping on wetlands and a nearby shallow well, and salt water intrusion from the shore. Provided testimony at NRC hearings on the plant, particularly related to liquefaction potential. The work included a review of all geotechnical data related to seismic response for the site, including data generated during design of Pilgrim 1. Provided

testimony at Department of Environmental Protection (DEP) hearing regarding effects of construction dewatering.

New England Power Nuclear Station Site, Charlestown, Rhode Island. Principal-in-charge of complete foundation investigation and design recommendations. The work included an extensive subsurface investigation program at the site and in the surrounding area, including offshore. Instrumentation was installed and foundation design recommendations were being developed at the time the plan was canceled by New England Power.

Maine Nuclear Plant, Cooling Water Pipelines, Wiscassett, Maine. Geotechnical analysis for design of 9-foot-diameter fiberglass intake and discharge lines for nuclear plant, including 3,900-foot offshore section in open ocean water up to 45 feet deep. Study covered trenching, installation, bedding and backfill of pipe, and hold down system for diffuser. Observation of installation and monitoring of instrumentation to demonstrate adequate performance of the pipe. Evaluated potential for liquefaction of the pipelines and the stability and design of the dam that was constructed to form the forebay. Reviewed design by carrying out stability analyses and foundation exploration, provided design recommendations, and inspected construction for 25-foot-high earth dike to contain cooling water built by Maine Yankee. Dam was founded on 0 to 60 feet of soft clay and, hence, had high cracking potential.

Potential Nuclear Plant Sites, Vermont. Preliminary foundation analysis and detailed comparison of three potential nuclear plant sites, including preliminary design of 120-foot-high earth dam.

Pipeline Design and Construction

Dr. Poulos is a founding principal of GEI. He is a registered professional civil engineer specializing in soil and rock mechanics, earth dam engineering, foundation engineering, and groundwater hydraulics. At GEI, Dr. Poulos has managed over 900 projects, covering all aspects of geotechnical engineering design and construction, as well as expert testimony for litigation purposes.

Dr. Poulos has managed design and construction observation for many projects involving cooling water and effluent pipelines, water supply lines and sewage lines. He has directed a number of projects related to the design, installation, performance evaluation, and repair of buried fiberglass pipes. He has been involved with the design and construction of six underwater pipelines, including twin 9-foot-diameter cooling water lines for a nuclear power plant in Maine. He has directed investigations into the failure of several fiberglass pipes and developed recommendations for repair procedures. He has evaluated fiberglass pipe designs for more than 20 projects for two manufacturers to identify potential liability exposures.

Underwater Pipe Failure, Mobile, Alabama. Investigated cause of liquefaction failure of buried underwater fiberglass pipe and provided recommendations and construction observation for repair procedures.

Fiberglass Pipe Designs, Various Locations. Reviewed manufacturer's designs for about 15 fiberglass pipe projects to identify areas of potential liability exposure. Study included evaluation of bid documents for each project to determine whether design loads, performance criteria, and

installation conditions and procedures were adequately specified and incorporated into the design.

American Crystal Sugar, Minnesota. Investigated cause of leakage from 30- and 36-inch-diameter fiberglass pipes buried up to 12 feet deep for a sugar beet refinery. Recommended reinstallation procedures to minimize cost and prevent delays in refinery operations. Provided field guidance to contractor during reinstallation.

Fiberglass Pipe Testing. Directed laboratory test program to determine tensile and flexural properties of spiral-wound wall sections of reinforced fiberglass pipe. Evaluated strength and stress-strain properties of the material.

Cooling Water Pipelines, Wiscassett, Maine. Geotechnical analysis for design of 9-foot-diameter fiberglass intake and discharge lines for nuclear plant, including 3,900-foot offshore section in open ocean water up to 45 feet deep. Study covered trenching, installation, bedding and backfill of pipe and hold down system for diffuser. Observation of installation and monitoring of instrumentation to demonstrate adequate performance of the pipe.

Al Jobail, Saudi Arabia. Reviewed design loading conditions and project specifications for pipe backfill. Provided manufacturer with recommendations for pipe loading conditions and backfill properties to be used in design of 60-inch-diameter buried fiberglass pipe.

Northside Generating Station, Jacksonville, Florida. Reviewed and certified manufacturer's design calculations for a 196-inch-diameter buried fiberglass line.

St. Lucie II Nuclear Generating Station. Consulted on design of 16-foot-diameter offshore fiberglass pipe, including recommendations for properties of underwater backfill and loads due to waves.

Sewer Outfall Pipeline, Portland, Maine. Reviewed pipe design and construction data and evaluated causes of damage to 54-inch-diameter offshore buried fiberglass pipe during installation.

Fort Point Channel Cooling Water Intake, Boston, Massachusetts. Technical evaluation of proposed 3,800-foot-long, 84-inch-diameter extension of cooling water intake pipe beneath Fort Point Channel. Study included pipe foundation requirements, protection from storm and ship damage, and feasibility of inspection and maintenance.

Fort Square Pump Station and Interceptor Sewer, Quincy, Massachusetts. Performed explorations and analyses and provided recommendations for construction of an 8- by 10-foot box culvert and an interceptor sewer below a bridge abutment, and for design and construction of a pump station.

Lowell Interceptor Sewer, Lowell, Massachusetts. Exploration, geotechnical design, and construction observation for an interceptor sewer up to 96 inches in diameter, much of which was located adjacent to a river and required significant dewatering.

Mill Brook Interceptor, Lexington, Massachusetts. Exploration and geotechnical design for a 30- to 36-inch-diameter interceptor sewer with two tunnels, three pipe jacking sections, and special dewatering (wellpoints or deep wells) required for about 16,000 linear feet of the line.

Transportation

Dr. Poulos is a founding principal of GEI. He is a registered professional civil engineer specializing in soil and rock mechanics, earth dam engineering, foundation engineering, and groundwater hydraulics. At GEI, Dr. Poulos has managed over 900 projects, covering all aspects of geotechnical engineering design and construction, as well as expert testimony for litigation purposes.

Boston Marine Industrial Park Tunnel, California/THT Design Section D004A, Boston, Massachusetts. Principal-in-charge for the geotechnical engineering aspects of the final design. Managed the preparation of designs for dewatering systems, earth support systems, and slurry walls, including slurry walls integrated with the ventilation building, tie-downs for slab uplift resistance, and groundwater equalization systems. He also managed seismic design analyses for slurry wall and tunnel and boat sections, and provided input to other design team's members for use of slurry walls in lieu of underpinning adjacent structures.

Publications

Poulos, S.J. (1988). "Strength for Static and Dynamic Stability Analysis." *ASCE Conference on Hydraulic Fill Structures '88*, Principal Speaker, Session 3, Fort Collins, Colorado, August.

Poulos, Steve J. (1988). "Liquefaction and Related Phenomena." *Chapter 9 of Advanced Dam Engineering for Design, Construction, and Rehabilitation*, Robert Jensen Ed., Van Nostrand Reinhold, New York, New York, pp. 292-320.

Poulos, Steve J. (1988). "Compaction Control and the Index Unit Weight." *Geotechnical Testing Journal, ASTM,* pp. 100-108, June.

Poulos, Steve J., Castro, Gonzalo, and Davis, Alton, P. (1988). "Strengths Backfigured from Liquefaction Case Histories." *Proceedings, Second International Conference on Case Histories in Geotechnical Engineering*, Vol. 3, June 1-5.

Poulos, Steve J., Robinski, E., and Keller, T.O. (1985). "Liquefaction Resistance of Thickened Tailings." *Journal of the Geotechnical Engineering Division, ASCE,* Vol. 111, December.

Castro, G., Poulos, S.J., and Leathers, F.D. (1985). "A Re-examination of the Slide of the Lower San Fernando Dam." *Journal of Geotechnical Engineering Division, ASCE,* Vol. 111, No. 9, pp. 1093-1107, September.

Poulos, S.J., Castro, G., and France, J.W. (1985). "Liquefaction Evaluation Procedure." *Journal of the Geotechnical Engineering Division, ASCE,* Vol. 111, GT6, June.

Poulos, Steve J. and Laws, A. Charles (1985). "Gradient Control for Containment of Pollutants." *5th National Symposium and Exposition on*

Aquifer Restoration and Ground Water Monitoring, Columbus, Ohio, May.

Poulos, Steve J. (1982). Closure discussion for "The Steady State of Deformation." *Journal of the Geotechnical Engineering Division, ASCE,* Vol. 108, GT8, pp. 1087-1091, August.

Poulos, S.J. (1981). "Discussion of Soil Testing Practices." *Laboratory Shear Strength of Soil, ASTM STP 740*, R.N. Yong and F.C. Townsend, Eds. ASTM, pp. 659-666.

Poulos, Steve J. (1981) "The Steady State of Deformation." *Journal of the Geotechnical Engineering Division, ASCE,* Vol. 107, GT5, pp. 553-562, May.

Castro, G. and Poulos, S.J. (1980). Closure Discussion for paper entitled "Factors Affecting Liquefaction and Cyclic Mobility." *Journal Geotechnical Division, ASCE,* pp. 211-214, February.

Poulos, S.J. (1979). "Effects of Large Strains on Shear Strength Selection for Stability Analysis." *BSCES Geotechnical Lecture Series on Embankment Dams Design and Construction,* Boston, December.

Sangrey, D.A., Castro, G., Poulos, S.J., and France, J.W. (1978). "Cyclic Loading of Sands, Silts, and Clays." *Proceedings on Specialty Conference Earthquake Engineering and Soil Dynamics,* Pasadena, California, pp. 836-851, June.

Pollard W.S., Sangrey, D.A., and Poulos, S.J. (1977). "Air Diffusion Through Membranes During Triaxial Tests." *Technical Note in Journal Geotechnical Division, ASCE,* Vol. 103, GT10, pp. 1169-1173, October.

Castro, G. and Poulos, S.J. (1977). "Factors Affecting Liquefaction and Cyclic Mobility." *Journal Geotechnical Division, ASCE,* Vol. 103, GT6, pp. 501-516, June.

Hirschfeld, R.C. and Poulos, S.J. (1973). Editors, Contributions to Embankment Dam Engineering-The Casagrande Volume, Wiley, New York, March. (Reprinted 1987 by Krieger V Publishing)

Poulos, S.J. and Hed, A. (1972). "Density Measurements in a Hydraulic Fill." *Submitted to Symposium on Relative Density, ASTM 75th Annual Meeting,* Los Angeles, June 25-30.

Poulos, S.J. (1971). "The Stress-Strain Curves of Soils." *Geotechnical Engineers Inc.,* January.

Casagrande, L. and Poulos, S.J. (1969). "On the Effectiveness of Sand Drains." *Canadian Geotechnical Journal,* Vol. VI, No. 3, pp. 287-326, August.

Poulos, S.J. (1968). "Report on Session III, Densification after Placement (Drains)." *ASCE Conference on Placement and Improvement of Soil to Support Structures,* Cambridge, Massachusetts, pp. 43-52.

Poulos, S.J. (1964). Discussion of an Article entitled "Importance of Free Ends in Triaxial Testing," by Peter W. Rowe and Liang Barden. *Journal Soil*

Mechanics Division, ASCE, Vol. 90, SM6, pp. 177-179, November.

Casagrande, A. and Poulos, S.J. (1964). "Fourth Report on Investigation of Stress-Deformation Characteristics of Compacted Clays." *Harvard Soil Mechanics Series,* No. 74, October.

Poulos, S.J. (1964). "Control of Leakage in the Triaxial Test." *Harvard Soil Mechanics Series,* No. 71, March.

Casagrande, A., Hirschfeld, R.C., and Poulos, S.J. (1963). "Third Progress Report on Investigation of Stress Deformation and Strength Characteristics of Compacted Clays." *Harvard Soil Mechanics Series,* No. 70, Harvard University (32 pages, 15 tables, and 99 figures).

Hirschfeld, R.C. and Poulos, S.J. (1963). "High Pressure Triaxial Tests on a Compacted Sand and an Undisturbed Silt." *Symposium on Laboratory Shear Testing of Soils,* Ottawa, September.

Keith A. Ferguson, P.E.
Senior Water Resources Engineer

Experience
__ years

Education
BS, Civil Engineering, University of Colorado at Boulder, Boulder, CO, 1976
MS, Civil Engineering, University of Colorado at Boulder, Boulder, CO, 1977

Registrations
Professional (P.E.) - Civil: Colorado (19046), North Dakota (3205), Wyoming (5544), Utah (0851909110), Montana (10579PE), Idaho (6834), Virginia (0402025960), Nebraska (E-7682), Texas (70650), South Dakota (5327), Illinois (062-047395), California (C050851), North Carolina (19498), Oregon (16917PE), Washington (232-010030946), Missouri (E-026816)

Professional Affiliations
American Society of Civil Engineers (ASCE)
United States Society on Dams (USSD)
Association of State Dam Safety Officials/Chair, Editorial Committee (ASDSO)
American Society for Testing and Materials (ASTM)
National Public Projects Coalition (NPPC)

Summary of Experience

Mr. Ferguson specializes in water resources planning, permitting, soil and rock mechanics, dam and levee safety, dam engineering, and foundation engineering. Since 1978, he has participated in over 180 projects involving embankment, concrete-faced rockfill, concrete-gravity, roller-compacted concrete, and multiple-arch concrete and tailings dams and appurtenant structures (spillways, outlet works, diversion dams etc.); new and existing levee safety evaluations and designs; pipeline and tunnel designs; water resources evaluations; and drainage and flood control projects in 18 states, Mexico, Puerto Rico, Iceland, and Bolivia. Mr. Ferguson is a recognized expert in dam and levee safety, seepage and stability analysis of levees and dams, and with Roller Compact Concrete (RCC). He has supervised multi-disciplined projects, many of which have involved large-scale field exploration programs, site surveys, geotechnical and engineering geology analyses, risk analysis, hydrologic/hydraulic analyses, hydrogeologic analyses, structural analyses, preparation of conceptual designs, final designs and preparation of construction documents, construction observation and supervision, and construction management. He has also been responsible for preparation of Environmental Assessments (EA) and Environmental Impact Statement (EIS) reports. He has successfully developed decision support systems for formulation and evaluation of alternatives for water supply projects, with estimated total costs in excess of up to $12 billion. These decision support systems have been lauded by such regulatory agencies as the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency (EPA).

Representative Dam Safety Expert Experience

U.S. Army Corps of Engineers Office of the Chief, Various Locations, US: Mr. Ferguson was chosen to be on a national panel of experts composed of multi-disciplinary engineers (geotechnical, geological, and hydraulic engineers) to evaluate a portion of the United States Army Corps of Engineer's portfolio of dams. The projects being evaluated by the Panel include Wolf Creek Dam, KY; Center Hill Dam, TN; Herbert Hoover Dike and flood control system (Lake Okeechobee), FL; Clearwater Dam, MO; and Isabella and Martis Creek Dams, CA.

US. Army Corps of Engineers, Lake Isabella Dam, Central California: Mr. Ferguson is serving as principal technical consultant and project manager assisting the Sacramento District with a comprehensive evaluation of Lake Isabella Dam on the Kern River above Bakersfield.

U.S. Army Corps of Engineers, Keystone and Canton Dams, Oklahoma: Mr. Ferguson is serving as a member of a senior review panel for the Tulsa District assisting with investigations and evaluation of these two major water storage and flood detention dams to address potential seepage related deficiencies.

U.S. Army Corps of Engineers, Lewisville Dam, Texas: Mr. Ferguson is serving as a member of a senior review panel for the Fort Worth District assisting with investigations, evaluation, preparation of a MRR, and preparation of final designs addressing identified seepage deficiencies.

U.S. Army Corps of Engineers, Fern Ridge Dam, Oregon: Mr. Ferguson was retained a subject matter expert to serve on a senior review board. Based on the review, the Board determined that the dam was in an active state of failure and that immediate corrective actions were required. With assistance from the Board, the Corps completed the review, designs, and construction of over $17M in repairs to the dam in less than 1 year.

U.S. Army Corps of Engineers, Clearwater Lake Dam, Missouri: Mr. Ferguson was one of several experts reviewing the formation of a large sinkhole on the upstream face of this dam and the corrective actions being proposed by the USACE. The dam is founded on Karst Dolomite bedrock.

Tenessee Valley Authority, Bear Creek River Dam, Alabama. Mr. Ferguson is serving as a senior consultant and member of a two-member expert panel to the Tennessee Valley Authority (TVA) for the final design of an 80-foot-high replacement dam to the existing embankment dam founded on a Karstic limestone with significant seepage problems.

Bureau of Reclamation, Deerfield Dam, Comprehensive Facility Review, South Dakota: Mr. Ferguson served as the Senior Engineer for the Bureau of Reclamation team reviewing safety of these facilities.

Bureau of Reclamation Salton Sea Restoration, Riverside and Imperial Counties, California: Planning level designs including extensive engineering evaluations and cost estimates were recently completed for the U.S. Bureau of Reclamation for the restoration of the Salton Sea in southern California. Mr. Ferguson was the project manager in the evaluation of alternative construction material sources for various embankment alternatives, seepage and stability analysis, deformation analyses, risk analysis, optimization of dam and levee embankment cross-section designs, and construction cost estimates for the embankment portions of the alternatives being evaluated that ranged from $1.3 to over $12 billion dollars.

Representative Levee Experience

Summary of Levee Evaluation and Design Experience; Mr. Ferguson has been involved with the evaluation and design of new, or rehabilitation of existing levee projects since 1988. A summary of this experience is as follows:

Fountain Creek Flood Improvements, Pueblo Colorado: Project Geotechnical Engineer responsible for all geotechnical aspects of the final design of $7 million in flood improvements. This project included over 15,000 cubic yards of soil-cement levees and riprap erosion protection.

Mississippi River Levee Restoration Projects: Following the devastating flooding of the Mississippi River in the 1990's, Mr. Ferguson assisted the US Fish and Wildlife service with the investigations and rehabilitation design of three separate levees along the Mississippi and Illinois Rivers vital to the operation of three national wildlife refuges.

Yuba River Supplemental Flood Control Project, California*:* Mr. Ferguson was the Project Manager and Project Engineer for a feasibility

study of flood control elements to resolve long-standing flood control issues on the Yuba and Feather Rivers in northern California. Mr. Ferguson also worked on establishing program objectives to provide up to 500-yr flood protection, evaluation of alternatives, screening methodology, and costs associated with new levees on the Feather and Bear Rivers; flood control dams; detention dams, multi-purpose dams, flood bypasses, reservoir re-operation, and other elements.

Natomas and West Sacramento Levee Rehabilitation Project, California: Mr. Ferguson is currently involved in ongoing investigations and design of levee improvements being completed by the Sacramento Area Flood Control Agency (SAFCA) for the rehabilitation of over 20 miles of levee that are protecting the Natomas and West Sacramento areas.

Herbert Hoover Dike, Florida: Mr. Ferguson has recently served as a member of a national panel of experts to review the safety and design of rehabilitation measures for the 140 miles of dikes (levees) surrounding Lake Okeechobee in central Florida.

Publications and Papers

Co-author with Dr. Donald Bruce, *Embankment Dams on Karstic Limestone, Solubleand Erodible Foundations: Challenges and Solutions, Proceedings of the 2008 National Dam Safety Conference, Association of State Dam Safety Officials, Palm Springs, CA, September 2008.*

Invited speaker and Co-author with R. Costa, *2007 SAME National Levee Conference, Seepage and Piping in California Levees, Sacramento, CA, July 26, 2007*.

Co-author with J. W. France, *Selection of Spillway Design Floods Based on an Incremental Damage Assessment*, Proceedings of ICOLD Conference, San Francisco, California, 1988.

Co-author with Y .K. Choi and D. D. Boyer, *Dam Safety Evaluation and Seepage Problems for a Concrete-Face Rockfill Dam*, Proceedings of the Association of State Dam Safety Officials, 1991 Annual Conference, San Diego, California, September 1991.

Co-author with D .D. Boyer and Y. K. Choi, *Three-Dimensional Foundation Stability Analysis of New Elmer Thomas Dam*, Proceedings of the Association of State Dam Safety Officials, 1994 Annual Conference, Boston, Massachusetts, September 1994.

Co-author with D. D. Boyer, *Foundation Seepage and Stability Evaluations for an Embankment Dam Founded on Glacial Materials*, Proceedings of the Association of State Dam Safety Officials, 1994 Western Regional Conference, Salt Lake City, Utah, May 1994.

Co-author with Y. K. Choi, *Stability of Lake Ilo Dam and Spillway*, Proceedings of the Association of State Dam Safety Officials, 1994 Western Regional Conference, Salt Lake City, Utah, May 1994.

Author, *Rehabilitation of the Lake Darling Dam Outlet Works, North Dakota*, Proceedings of the Fourteenth Annual USCOLD Lecture Series, Phoenix, Arizona, June 1994.

Author, *RCC Materials Engineering*, Proceedings of the 1995 RCC Dams Short Course, Sponsored by GEI Consultants, Inc., CH2M Hill, USBR, and Portland Cement Association, Monterey, California, December 1, 1995.

Author, *Evaluating Seismic Risks to Dams in the Western United States*, Presentation to the Western Regional Special Technical Conference, Association of State Dam Safety Officials, Kemmerer, Wyoming, May 4, 1995.

Author, *Foundation Modifications for Service and Emergency Spillway, Lake Ilo Dam, North Dakota*, Proceedings of the Association of State Dam Safety Officials Western Regional Conference and Technical Seminar, Red Lodge, Montana, May 22-25, 1995.

Author, Planning & Permitting Water Projects, The Military Engineer, January-February 2003, Volume 95, Number 621, p33-38.

Author, Advance Seepage Short Courses *prepared for ASDSO/FEMA and conducted at MIT, University of Colorado - Boulder, Georgia Tech, University of California at Davis, and in Tampa, Florida between 2003 and 2005*

Co-author with R. Hannen, J. Talbot, and F. Walberg, ,Assessment and Repair of Active Foundation Piping and Erosion at Fern Ridge Dam, Oregon, *Proceedings of the United States Society on Dams Conference and Technical Seminar,San Antonio, TX, May 1-5, 2006*

Co-author with G. L. Cowen and F.Y. Abdo, New RCC Dam Replaces 70-year Old Concrete Dam, *Portland Cement Association, E-briefing, August 25, 2006*

Co-author with G. L. Cowen and J. P. Ballegeer, Design and Construction of New Big Cherry Dam, Virginia, *Proceedings of the Association of State Dam Safety Officials Annual Conference and Technical Seminar, Boston, Massachusetts, September 10-14, 2006*

Bradley Jeffrey, Ph.D., P.E.
WR Engineer

Experience
32 years

Education
Ph.D. (C.E. - Hydraulics) Colorado State University, Fort Collins

M.S. (C.E. – Water Resources, Geotechnical) Oregon State University, Corvallis

B.S. (Civil Engineering) Oregon State University, Corvallis

Registrations
Professional Civil Engineer California C030245 6 other states

Diplomate, American Academy of Water Resources Engineers

Professional Affiliations
American Geophysical Union

American Public Works Association

American Society of Civil Engineers

American Society of Engineers for Social Responsibility

American Water Resources Association

Association of State Floodplain Managers

International Association for Hydraulic Research

International Erosion Control Association

Summary of Experience

Dr. Bradley is President of WEST Consultants, Inc. He is a Registered Professional Engineer in California, Arizona, Colorado, Idaho, Hawaii, Oregon and Washington. He is a certified Diplomate and past-President of the American Society of Civil Engineers (ASCE), American Academy of Water Resources Engineers. Dr. Bradley is past President of the ASCE Environmental and Water Resources Institute. He is a nationally recognized expert with thirty-two years experience in hydraulics, hydrology and sediment transport in the private sector, while with the Corps of Engineers, and at Colorado State University. Dr. Bradley is also nationally and internationally recognized for his work on mud and debris flows and their effects on alluvial fan flooding. He has worked on many investigations including External Peer Review Panels for the Corps of Engineers Chief of Engineers Office on Class 1 Dam Safety and Screening Levee Risk Assessment, an Independent Technical Review for levee certification of the Natomas Levees for the Sacramento District of the Corps, for FEMA flood insurance studies throughout Regions IX and X, the John Day Dam drawdown studies, the Upper Mississippi cumulative effects study, hydraulic modeling for flood insurance studies, bridge scour assessments throughout the US, dambreak inundation studies, hydrologic modeling and analysis for dam safety investigations, development of a geomorphic stream classification scheme for the state of Washington, development of a stream classification expert system for the sediment transport model, BRISTARS, Mount St. Helens sedimentation studies, the analysis of the Lawn Lake Dam failure and debris flow, the Lake Estes sedimentation study, the development of sedimentation study methodologies for the U. S. Fish and Wildlife Service, sedimentation impact studies on fisheries throughout the Northwest, extensive investigation of high sediment concentration flow phenomena, and the Kern and Peace River ordinary high water litigations. Dr. Bradley has also coordinated and lectured in a number of short courses, including Dam Removal, Bridge Scour, HEC-RAS, and Streambank Stabilization for the American Society of Civil Engineers, HEC-6, Sedimentation in Rivers and Reservoirs, Streambank Stabilization for the International Erosion Control Association, Sedimentation in Forested Watersheds, Mudflows and Alluvial Fan Flooding, and HEC-RAS River Analysis System for the National Highway Institute.

Dr. Bradley has written over seventy-five professional papers and reports in the fields of hydraulics, hydrology, and sedimentation engineering. Dr. Bradley is editor of the books: *The Physics of Sediment Transport by Wind and Water: A Collection of Hallmark Papers by R.A. Bagnold* and *"Gravel Bed Rivers and the Environment".* He has written a sedimentation manual for the U.S. Fish and Wildlife Service. He wrote an appendix for the new ASCE Sedimentation Manual, No. 110. He is past Chair of the Executive Committee for the ASCE Water Resources Engineering Division. He has served as a member of ASCE task committees on the Effects of High Concentrations on Flow and Sediment Transport, Sedimentation and Stream Habitat Evaluation, and Bridge Scour. He has been a control member of the ASCE Task Committee to revise Manual 54 - *Sedimentation Manual* and is a past chair of the ASCE Sedimentation Committee. Dr. Bradley is a Fellow of ASCE, and has served on national ASCE Engineering Management Division committees, ASCE Presidential Committees, and has held several committee chairs in Colorado and Oregon, as well as having been Director and Treasurer of the Oregon Section.

PROFESSIONAL REGISTRATION

- Diplomate, American Academy of Water Resources Engineers, No. 000001
- Professional Engineer, California No. C030245
- Professional Engineer, Arizona No. 21974
- Professional Engineer, Colorado No. 19737
- Professional Engineer, Oregon No. 10646
- Professional Engineer, Washington No. 0000928
- Professional Engineer, Idaho No. 7794
- Professional Engineer, Hawaii No.11557

NATIONAL PANELS AND BOARDS ON LEVEES AND DAMS

- External Peer Review Panel for DSAC Class 1 Dams,-Corps of Engineers, Office of the Chief of Engineers, Martis Creek Dam, Isabella Dam, Wolf Creek Dam, Center Hill Dam, Clearwater Dam, Herbert Hoover Dike, 2006-2008
- External Peer Review Panel for Screening Levee Risk Assessment, Corps of Engineers, Office of the Chief of Engineers, 2007-present
- Independent Technical Review, Hydrology and Hydraulics, Natomas Levees, Sacramento District Corps of Engineers
- Board of Expert Consultants, Creekside Dam, Canyonville, Oregon

NATIONAL, COMMITTEE AND CONFERENCE ASSIGNMENTS

- President, ASCE's, American Academy of Water Resources Engineers, 2004-2007
- Chair and Member, Federal Interagency Sub-Committee on Sedimentation, 2005-Present
- Conference Chair-IAHR 2009 Convention, Vancouver, BC, 2005-Present
- Chair, ASCE National Water Policy Committee, 2002 – 2006
- Member, ASCE President's Task Committee on Institute Operations, 2001 – 2004
- Member, ASCE President's Task Committee on Governance, 2001 – 2004
- President, Governing Board Member, Environmental and Water Resources Institute, ASCE 1999 – 2002
- Chair, EWRI Awards and Nominations Committees, 2000 - 2002
- Chair, ASCE Executive Committee, Water Resources Engineering Division, 1994 -1998
- Control Member, ASCE Task Committee to Revise Manual 54, The Sedimentation Manual, 1991-Present
- Chairman & Member, ASCE Sedimentation Committee, 1987 – 1991
- Member, ASCE Organizing Committee, National Conference on Hydraulic Engineering, San Diego 1990
- Corresponding Member, ASCE Task Committee on the Analysis of Laboratory and Field Sediment Data Accuracy and Availability, 1987 - 1990
- Conference Coordinator, Colorado Water Engineering and Management Conference, Ft. Collins, Colorado, February 1987
- Corresponding Member, ASCE Sedimentation Committee, 1986 - 1987
- Corresponding Member, ASCE Task Committee Sedimentation and

Stream Habitat Evaluation, 1986 -1989
- Working Member, AWRA Groundwater Group, 1986 - 1987
- Control Member, ASCE National Task Committee on Effects of High Concentrations on Flow and Sediment Transport, 1983 - 1986
- Zone III Member, ASCE Committee on Engineering Management at the Individual Level (EMIL), 1985 - 1989
- Corresponding Member, ASCE Committee on Engineering Management at the Individual Level (EMIL), 1983 - 1985

STATE COMMITTEES
- Chairman, ASCE Seattle Section, Engineering Management Committee, 1993 - 1996
- Chairman, ASCE Colorado Section Program Committee, 1986 - 1987
- Chairman, ASCE Colorado Section Awards Committee, 1985 - 1986
- Chairman, ASCE Colorado Section Continuing Education Committee, 1984 - 1985
- Treasurer, ASCE Oregon Section, 1981-1982
- Delegate, Engineers Coordinating Council of Oregon, Council Reports to Governor on Engineering Appointments in State, 1981 - 1982
- Director, ASCE Oregon Section Board of Directors, 1980
- Chairman, ASCE Oregon Section Membership and Memoirs Committee, 1978 - 1979

INSTRUCTIONAL EXPERIENCE
- Dam Removal for ASCE, multiple locations
- Streambank Stabilization for ASCE, multiple locations
- Bridge Scour for ASCE, multiple locations
- HEC-RAS for ASCE and the National Highway Institute, multiple locations
- Advanced HEC-2 for King County, Seattle, Washington
- Two-Dimensional Modeling Class, ASCE Water Resources Planning & Management Conference, Seattle, Washington
- HEC-2 Short Course by WEST Consultants, San Diego, California
- Sedimentation in Forested Watersheds, U.S. Forest Service, Alaska and Montana
- Short Course on Bank and Channel Protection in Rivers, International Erosion Control Association, Vancouver, British Columbia, Canada

- Open Channel Hydraulics, graduate level course at San Diego State University, CA
- HEC-6 Short Course, Hydrologic Engineering Center, Davis, California
- Mudflows and Alluvial Fan Flooding Short Course, WEST Consultants, San Diego, California
- Suspended Sediment and the Riverine Environment, Oregon State University
- Flood Plain Management, short course by FEMA and CSU, Colorado Springs, Colorado
- Professional Engineer Review Course, Portland State University, Portland, Oregon
- Fluid Mechanics, Hydraulics, Portland State University, Portland, Oregon
- Short Course on Sediment Problems in Rivers, Oregon State

University, Corvallis, Oregon

PARTIAL PROJECT EXPERIENCE

Water Quality and Groundwater

- Development of Watershed Analysis Methodology, Cumulative Effects, Washington
- Tibbetts Creek, Washington EIS
- Tolt River, Washington, Gravel Quality Study
- Cedar River, Washington, Study of Incipient Motion of Spanning Gravel
- East Fork Lewis River, Washington, Gravel Mining EIS
- Keene Ranch, California, Groundwater Modeling Study
- Willamette River Greenway Study
- Young's Bay Environmental and Sedimentation Assessment
- Strube Dam Temperature Study, WRE Temperature Model
- Elk Creek and Lost Creek Dams Turbidity Studies

Sedimentation and Erosion

- Upper Mississippi River Cumulative Effects Study, Rock Island District Corps of Engineers
- Bridge Scour, Hydraulics and Erosion, Washington Department of Transportation
- Bridge Scour, Hydraulics and Erosion, Oregon Department of Transportation
- Snoqualmie Ridge, Washington, Sedimentation Study
- Tongass National Forest, Alaska, Sedimentation and Fisheries Evaluation
- Development of Geomorphic-based Stream Classification for the State of Washington
- Gila and Salt Rivers, Arizona, Pipeline Erosion Studies
- Grande Ronde River Sedimentation Study

- Mount St. Helens, Washington, Sedimentation Studies, HEC-6, and Other Analyses
- Lake Estes, Colorado, Sedimentation Study Following the Lawn Lake Dam Failure
- Movable Bed Sediment and Water Routing Models, U.S. Fish & Wildlife Service
- Sediment Transport Methodologies for Field Applications, National Park Service
- Zink Dam, Oklahoma, Sedimentation Study (HEC-6, FESWMS-2DH)
- Okanogan River, Washington, Sediment Litigation
- Nooksack River, Washington, Gravel Removal Study, Project Delineation
- Erosion Assessment of San Juan Mainline Gas Pipeline Expansion, New Mexico and Arizona
- Erosion Assessment of Baja Pipeline, Arizona
- Pipeline Scour Assessments during January 1993 Arizona Floods

Hydraulics & Stable Channel Analysis

- FEMA Flood Insurance Studies throughout Regions IX and X, Hydraulics and Hydrology

- John Day Drawdown Studies, Portland District Corps of Engineers
- Stehekin River, Washington, Streambank Stabilization
- South Snoqualmie River and Tolt River Flood Mitigation Study, Washington
- Gee Creek Flood Insurance Study, Vancouver, Washington
- Cowlitz River Flood Insurance Study, Washington
- Grants Pass Flood Insurance Study, Oregon
- Dambreak Inundation Studies, NWS DAMBRK Model, Applegate Dam, Lookout Point Dam, Dorena Dam, Cottage Grove Dam, Dexter Dam, Oregon
- Development of a River Classification for Use in an Expert System, BRISTARS Computer Model, Channel Widening Simulation Model, FHA
- Buena Vista Creek, California, Channel Design
- Kern River, California, Litigation

Hydrology

- Non Federal Dam Safety Investigations: Goodrich Dam, Mercer Dam, Wallowa Dam, and Winchester Dam, Oregon
- Pearson Airpark and Steigerwald Lake Interior Drainage Studies, Washington
- Portland Urban Study, Penn State Urban Runoff Model
- Washougal, Rogue, and Applegate Rivers Discharge Frequency Studies, Oregon
- Nestor Creek Hydrologic Study, California
- Lane County Flood Insurance Study, Oregon
- Elk Creek Incremental Flood Damage Analysis, HEC-1, Oregon

Other

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- Tolt River Stream Migration Litigation, Washington
- Stillaquamish River Flood Litigation, Washington
- Columbia River Irrigation Depletion Study
- Numerous Instream Flow Determinations
- Peace River, Florida, Litigation on Ordinary High Water
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