The National Dam Safety Program

Research Needs Workshop: Outlet Works

FEMA

Preface

One of the activities authorized by the Dam Safety and Security Act of 2002 is research to enhance the Nation's ability to assure that adequate dam safety programs and practices are in place throughout the United States. The Act of 2002 states that the Director of the Federal Emergency Management Agency (FEMA), in cooperation with the National Dam Safety Review Board (Review Board), shall carry out a program of technical and archival research to develop and support:

- improved techniques, historical experience, and equipment for rapid and effective dam construction, rehabilitation, and inspection;
- devices for continued monitoring of the safety of dams;
- development and maintenance of information resources systems needed to support managing the safety of dams; and
- initiatives to guide the formulation of effective policy and advance improvements in dam safety engineering, security, and management.

With the funding authorized by the Congress, the goal of the Review Board and the Dam Safety Research Work Group (Work Group) is to encourage research in those areas expected to make significant contributions to improving the safety and security of dams throughout the United States. The Work Group (formerly the Research Subcommittee of the Interagency Committee on Dam Safety) met initially in February 1998. To identify and prioritize research needs, the Subcommittee sponsored a workshop on Research Needs in Dam Safety in Washington D.C. in April 1999. Representatives of state and federal agencies, academia, and private industry attended the workshop. Seventeen broad area topics related to the research needs of the dam safety community were identified.

To more fully develop the research needs identified, the Research Subcommittee subsequently sponsored a series of nine workshops. Each workshop addressed a broad research topic (listed below) identified in the initial workshop. Experts attending the workshops included international representatives as well as representatives of state, federal, and private organizations within the United States.

- Impacts of Plants and Animals on Earthen Dams
- Risk Assessment for Dams
- Spillway Gates
- Seepage through Embankment Dams
- Embankment Dam Failure Analysis
- Hydrologic Issues for Dams
- Dam Spillways
- Seismic Issues for Dams
- Dam Outlet Works

In April 2003, the Work Group developed a 5-year Strategic Plan that prioritizes research needs based on the results of the research workshops. The 5-year Strategic Plan ensures that priority will be given to those projects that demonstrate a high degree of collaboration and expertise, and the likelihood of producing products that will contribute to the safety of dams in the United States. As part of the Strategic Plan, the Work Group developed criteria for evaluating the research needs identified in the research workshops. Scoring criteria was broken down into three broad evaluation areas: value, technical scope, and product. The framework adopted by the Work Group involved the use of a "decision quadrant" to enable the National Dam Safety Program to move research along to produce easily developed, timely, and useful products in the near-term and to develop more difficult, but useful, research over a 5-year timeframe. The decision quadrant format also makes it possible to revisit research each year and to revise research priorities based on current needs and knowledge gained from ongoing research and other developments.

Based on the research workshops, research topics have been proposed and pursued. Several topics have progressed to products of use to the dam safety community, such as technical manuals and guidelines. For future research, it is the goal of the Work Group to expand dam safety research to other institutions and professionals performing research in this field.

The proceedings from the research workshops present a comprehensive and detailed discussion and analysis of the research topics addressed by the experts participating in the workshops. The participants at all of the research workshops are to be commended for their diligent and highly professional efforts on behalf of the National Dam Safety Program.

Acknowledgments

The National Dam Safety Program research needs workshop on Outlet Works was held on May 25-27, 2004, in Denver, Colorado.

The Department of Homeland Security, Federal Emergency Management Agency, would like to acknowledge the contributions of the U.S. Army Corps of Engineers, Hydrologic Engineering Center, which was responsible for the development of the technical program, coordination of the workshop, and development of these workshop proceedings. A complete list of workshop facilitators, presenters, and participants is included in the proceedings.

TABLE OF CONTENTS

TABLE OF CONTENTS

EXHIBITS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

ATTACHMENTS

LIST OF ABBREVIATIONS

Abbreviation	Definition
ASCE	American Society of Civil Engineers
ASDSO	Association of State Dam safety Officials
AWWA	American Water Works Association
CMP	Corrugated metal pipe
EPRI	Electric Power Research Institute
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FRS	Flood Retarding Structure
HDPE	High-density Polyethylene
ICOLD	International Committee on Large Dams
NEHRP	National Earthquake Hazard Reduction Program
NRCS	National Resources Conservation Service
NSRB	National Dam Safety Review Board
REMR	Repair, Evaluation, Maintenance, and Rehabilitation
RFP	Request for proposal
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geologic Survey
USSD	United States Society on Dams
WRRI	Water Resources Research Institute

1.1 INTRODUCTION AND SCOPE OF REPORT

This workshop was sponsored by FEMA and was organized and facilitated by URS Corporation. The product of the workshop is this written report, produced by URS, documenting the results of the workshop. The report will be included in FEMA's National Dam Safety Program Act Report Series and will be posted on FEMA's website, http://www.fema.gov/fima/damsafe.

The workshop consisted of convening and facilitating a group of experts in the field of dam outlet works design and maintenance. The objectives of the workshop and the resulting written report were to document:

1. A state-of-practice concerning the cost effective techniques for maintenance and replacement of dam outlet works;
2. The short-term (immediate) and long-term research and development needs of the Federal and non-Federal dam safety communities with respect to dam outlet works; and
3. A recommended course of action for the Federal and non-Federal dam safety communities to address these needs based on priorities relating to potential benefit and cost/ease of implementation.

The workshop was held in Denver, Colorado, on May 25, 26, and 27, 2004. The workshop was a successful undertaking that produced open communication among a wide range of experts in the field and identified research and development opportunities that could significantly improve the state-of-the-practice in the field.

A group of 22 individuals was assembled for a three-day workshop on Issues, Remedies, and Research Needs Related to Dam Outlet Works. Workshop participants were selected to provide a broad representation of individuals involved in the topic and included the authors of the six white papers presented. Participants included 7 representatives of five different U.S. federal agencies, 2 representatives from two different state dam safety and environmental agencies, 7 representatives of six different consulting companies, 4 independent consultants, one university professor, and one representative of a hydropower organization. The group included individuals from 10 different U.S. states, the District of Columbia, and Canada.

During the three days, the workshop participants addressed the following six topics:

1. Outlet Works Failure Modes including consideration of failure by seepage and piping along the outlet works conduit.
2. Conduit Materials, Selection Criteria, and Construction Methods including pipe material types and their advantages, disadvantages, and appropriate applications; hard foundations; soft foundations; pressure conduits (high pressure and low pressure); and non-pressure conduits.
3. Gates, Valves, and Controls, including types of gates and valves and their applications; gate and valve locations; gate, valve, and control configurations; rehabilitation, and maintenance.
4. Energy Dissipators including stilling basins and energy dissipating valves.
5. Rehabilitation of Conduits including in-place rehabilitation and replacement; capacity – reservoir evacuation criteria; and economic considerations.
6. Outlet Works Inspection including discussions about determination of appropriate frequency; systems, methods, and techniques; and consideration of design criteria to accommodate inspection.

These specific topics were selected to coincide with the six topics for which white papers were prepared and distributed to participants in advance of the workshop.

Each topic was treated in the following manner:

- A "strawman" state-of-the-practice white paper was prepared and presented by one of the invited experts; a written copy of the white paper was distributed to the participants in advance of the workshop.
- The entire group was then led in a facilitated discussion of refinements, modifications, and clarifications to the state-of-the-practice.
- The group developed a list of possible research and development ideas for the topic being considered.
- The possible research and development ideas were prioritized by the group considering potential benefit, probability of success, and cost/ease of implementation.

The top four or five research and development ideas for the topic were assigned to small work groups for development of preliminary implementation plans.

- The small work groups reported back to the entire group on their preliminary implementation plans for each of the selected research and development ideas.

- Each participant then ranked the identified research and development ideas according to considerations of potential benefit and cost/ease of implementation.

The “strawmen” state-of-the-practice white papers are presented in Attachments 4 through 9 of this report, and brief summaries of these papers are presented in Section 4. The discussions of the states-of-the-practice for the six topics are also summarized in Section 4 of this report, and some of the more significant points from those discussions are presented later in this Executive Summary. The research and development ideas generated by the group for all six workshop topics, and the preliminary implementation plans developed for the 20 leading ideas generated for these topics are also presented in Section 4.

In the closing session on the last day of the workshop the participants provided input for an overall ranking of the leading research and development ideas for all six topics. The overall rankings were also based on consideration of potential benefit, and cost/ease of implementation. The overall rankings of the leading research and development ideas are discussed in detail in Section 5 and are summarized later in this Executive Summary.

2.1 STATE-OF-THE-PRACTICE

During the state-of-the-practice white paper presentations and the ensuing discussions, it became apparent that there are several challenges to defining a single state-of-the-practice for any of the topics being considered. Much of this may be attributed to the absence of any single, consistent set of standards and guidelines covering the various topics discussed that could be used across various regions and organizations. The presented white papers provided a basis for further discussions of the state-of-the-practice for the various topics discussed. Consequently, much of the discussion centered on trying to develop consensus among the group of invited experts on what the state-of-the-practice should be for various aspects of outlet works design, maintenance, inspection and rehabilitation. All of the discussions on state-of-the-practice are documented in Section 4, but some of the more significant insights gleaned from the white papers and the ensuing discussions are presented below and are grouped according to the six topics addressed in the workshop.

2.1.1 Outlet Works Failure Modes

1. The primary causes of outlet works failures are: foundation related failures, structural deterioration, the absence of timely rehabilitation and repair, structural failures, mechanical failures, failures related to hydraulics, failures related to ice and sediment loadings, and operator error. There is also an unwillingness of those involved to acknowledge the viability of different failure modes and to devise creative solutions for these problems. It has also been observed that many owners/operators will allow a known problem to persist without repair for long periods of time.
2. Methods that can be used to minimize the occurrence of failure of outlet works include: having an experienced mechanical engineer design components of the outlet works; using reliable standard designs that have been developed and tested over time; locating structures on a rock foundation to reduce settlement effects; and addressing air demand requirements, seismic loading (particularly of intake towers), ice loading, and vibration effects in the design.

3. The three primary ways of minimizing the failure potential of outlet conduits are: 1) Filtering the dam embankment in the vicinity of the outlet conduit to prevent internal erosion of the embankment along or near the conduit; 2) Constructing outlet conduits on rock foundations when possible; and 3) Designing conduits with redundant features to prevent water seepage from the conduit into the embankment resulting in the piping of embankment materials.
4. To minimize the occurrence of control structure failure the following steps are recommended: 1) An engineer experienced in the design of gates, valves and mechanical systems for dam outlet works should involved with both new design and rehabilitation activities; 2) Routinely test, operate and maintain components of control structures; and 3) replace antiquated and unreliable components of control structures with newer, more reliable equipment.
5. To prevent the uncontrolled erosion of the downstream channel in cases of direct discharge, care should be taken in the design and maintenance of discharge mechanisms including the use of energy dissipation structures.

2.1.2 Conduit Materials, Selection Criteria, and Construction Methods

1. Due to the absence of any single recognized standard for designing dam outlet works there is currently great inconsistency in design rationale and review processes for this design aspect of small and medium sized embankment dam facilities. The need for a single design standard is further underscored by the fact that outlet works have been identified as a significant contributor to the occurrence of embankment dam failures.
2. A single, nationally recognized standard would lead to greater consistency between similar project designs, facilitate more effective and consistent review of proposed designs, and result in increased potential for safer more reliable facilities. The National Dam Safety Review Board (NSRB) is in the process of preparing a manual to be used for designing and maintaining outlet works for significant high-hazard dams. The manual covers topics for the design, construction, maintenance, and repair of conduits for embankment dams. It is recommended that in the interim the guidelines presented in this manual be used to form a design basis for smaller facilities.
3. The use of standards not intended for use in designing pressurized outlet systems for embankment dams is the most common practice that introduces additional risk to outlet works for smaller embankment dams.
4. Recommended approaches to the design of outlet conduits on soft foundations include: 1) Placement of freestanding pressurized outlet pipe inside of a cast-in-place reinforced concrete conduit; 2) Use of a non-pressurized outlet works system; 3) Use of welded steel outlet pipe encased in reinforced concrete; 4) Use of articulated joints for the outlet conduit; and 5) Protecting the foundation's integrity during construction.

2.1.3 Gates, Valves and Controls

1. The types of gates commonly used at newer dam sites are: Slide gates, Knife gates, Jet-flow gates, Clamshell gates, Radial gates, and Hinged Crest gates. Slide gates, also known as Sluice gates, are the most common type of gate used for dam outlet works.

However, it should be noted that there have been frequent problems with leakage of slide gates mounted in the unseating direction relative to the head (i.e. the slide gates are placed downstream of the headwall).

2. For applications where the head does not exceed 100 feet, the two types of slide gates commonly used are the Cast Iron Slide gate and the Fabricated Slide gate. For applications where the head exceeds 100 feet, Bonneted Slide gates and Wheel gates are commonly used. Jet-flow gates are commonly used as freely discharging devices. The Clamshell gate which is specially designed by the USBR works well in submerged installations.

3. Due to susceptibility to corrosion and the build up of deposits that increase friction and affect the operation of its roller train, the use of Roller gates is increasingly avoided even though this was a type of slide gate that was also used for high head applications.

4. Valve types commonly used are: Butterfly valves, Gate valves, Fixed-Cone valves, and Sleeve valves. Butterfly valves are commonly used at power plants and water facilities. However, problems with the corrosion of the busing or stems of butterfly valves have been reported resulting in valves that did not fail in the intended position. A Gate valve is a variation of a slide gate, with a circular body and disk. They are often used for guard gates upstream of regulating valves, or used for throttling flow in low-head applications. A Fixed-Cone valve is commonly used for regulating the flow of water from a dam outlet works. Sleeve valves are used as energy dissipaters, both in-line and at the end of a conduit and are usually operated to provide precise flow control.

5. Due to high costs and problems with corrosion, seat erosion, cavitation damage, or general maintenance difficulties there has been a decreased use of Needle valves and Hollow-Jet valves.

6. The four basic types of gate operation systems are: manual operators, electric motor-operators, hydraulic operators, and pneumatic operators. Improved hydraulic fluids suitable for outdoor use, the ability to have submerged hydraulic operation, use of better seals, and automated operation features has inspired increased use of hydraulic components in the design of gates and valves. Hydraulic operation is most often used on large gates and valves operating at high head, but is becoming more common for small equipment at low heads for particular installations.

7. The knowledge and experience base in the design and fabrication of gates and valves in the United States is continually being eroded with decreased funding for research and development in control mechanisms and the increased occurrence of offshore fabrication and the disappearance of longstanding US-based designers and manufacturing firms.

2.1.4 Energy Dissipators

1. Energy dissipators that have been successfully used at outlet works include: stilling basins, baffled apron drops, stepped spillways, impact basins, stilling wells, various types of valves, sudden enlargements, in-line orifices, flip buckets, and plunge pools. Most outlet works incorporate a combination of different types of energy dissipators. The types of energy dissipators used depend on the design reservoir head, discharge requirements, and cost constraints of a particular design. However it should be noted that

problems with backflows in USBR-type stilling basins have been reported. Backflows have drawn rock and soil materials into the basins, sometimes leading to ball-milling and related damage. Public safety is also a concern for these structures due to the high incidence of people using these structures for recreation activities like swimming even though egress from basins can be difficult.

2. USBR Engineering Monograph 25 provides a thorough discussion of the design elements for stilling basins, impact basins, flip buckets, and baffled aprons. General guidelines for designing outlet works are provided in both USACE Engineering Manual EM 1110-2-1602 and in *Design of Small Dams* published by the USBR.
3. The combination of chute blocks, which create shear zones, and baffle blocks, which create additional turbulence, allows the length of stilling basins to be reduced. The use of baffle blocks also allows air content of discharge water to be regulated, and by releasing or entraining air in the water flowing through the baffles, water quality of the discharge flow is improved.
4. Although the USBR limits the dimensions and discharges of impact basins to relatively low energy levels, the basins have been used successfully at much higher energy levels by scaling the recommended dimensions to the larger sizes.
5. There is lack of widespread, definitive knowledge on reliable repair techniques for energy dissipators and lack of specific guidelines on the extent and size of riprap required downstream of energy dissipators.

2.1.5 Rehabilitation of Conduits

1. Corrugated metal pipe (CMP) commonly serves as the conduit found in small earthen embankment dams ranging in height from 10 to 50 feet constructed between 30 and 50 years ago in the southeastern United States. Compared to conduit materials used in newer dams, CMP is highly susceptible to deterioration and becomes a problem when a spillway conduit has reached or exceeded its design service life, generally considered to be 25 to 30 years. Deterioration of these conduits generally consists of leaking joints, corrosion, and holes in the pipe.
2. The main risk associated with the deterioration of these conduits is piping of the surrounding embankment soils into the conduit, which can lead to the eventual failure of the earthen embankment.
3. The four primary remediation options most applicable to earthen embankment dams less than 50 feet in height are: 1) Replacement of the existing pipe conduit using cut and cover methods; 2) Sliplining the existing conduit; 3) Grouting along the exterior of the existing conduit; and 4) constructing either a siphon spillway or "short" riser and new outlet conduit after the existing conduit has been abandoned. Cured-in-place (CIP) linings like Insituform™ have also been used for outlet conduit rehabilitation.
4. Option 1 typically offers the most thorough rehabilitation for impaired conduits through dams, but can be cost-prohibitive. Option 2 offers the possibility of increasing the hydraulic capacity of the outlet pipe and increases the service life to the existing conduit spillway. Option 3 is classified as a temporary repair solution and does not extend the

design life of the existing conduit material. The depth of the conduit below the embankment surface also limits this method. Option 4 is generally limited to small drainage basins with relatively small peak inflows. The installation of the new siphon requires excavation of the embankment below normal pool. Siphon spillways do not typically exceed 12-inches in diameter and may be constructed of flexible conduit materials like PVC, HDPE, or ductile iron. Epoxy paints have become the preferred standard for paint used to coat outlet works conduits.

2.1.6 Outlet Works Inspection

1. Inspection of cut-and–cover outlet works typically includes review of features including: the entrance channel; intake structure; conduit(s); terminal structures; and the downstream channel. The advantages and disadvantages of each method should be assessed with due consideration given to the ease and efficiency with which inspection objectives can be met; compliance with health and safety guidelines, and cost.
2. The purpose of an outlet works inspection program is to ensure that conduits through dams are safely and efficiently operated and maintained. While inspection designations may differ among the various state and federal agencies/organizations, the types of inspections primarily vary according to frequency and scope.
3. Initial or formal inspections include in depth review of all pertinent data available for the outlet works to be inspected. Design and construction data are evaluated relative to current state-of-the-art guidelines to identify potential dam safety problems or areas requiring particular attention. Detailed crack survey mapping should be used on a repeated basis to monitor structural deterioration.
4. Scheduling periodic outlet works inspections may be influenced by the following factors: provision of sufficient notice to dam owners and operators allowing necessary arrangements and pre-inspection activities to be completed and needed clearances to be obtained; the ability to access most or all of the major components of the outlet works; and the opportunity to observe features operating under a wide range of conditions.
5. Inspections of features like intake structures and upstream conduits that are usually submerged require special coordination with the dam owners since the timing of such inspections has to be carefully planned.
6. Good preparation and planning is key to the success of an inspection. Factors to be considered include: selection of the inspection team; review of the existing project data for the dam to be inspected; and the preparation of a detailed inspection plan. Factors to be considered in planning conduit inspections should include: conduit diameter, the presence and angle of bends in the conduit, the inclination of the invert slope, and the distance between access entry locations.
7. Specialized inspections of inundated or hard to access features often utilize a combination of divers, remotely operated vehicles (ROVs), and closed circuit television (CCTV). Considerations that must be accounted for if divers are to be expected to conduct inspections include depth, altitude, access, leakage, currents, visibility, size of opening, and length of conduit requiring inspection. ROVs are good alternatives to dive inspections when conditions like depth, diameter, or length become prohibitive. CCTV

can be used to inspect submerged portions of intake structures, conduits, and terminal structures.

8. Permanent markers and thorough documentation should be used to facilitate easy location of intake structures that are usually submerged. GPS could also be used to aid location of inundated structures but a repeatable methodology incorporating reliable equipment needs to be developed.

2.2 RESEARCH AND DEVELOPMENT IDEAS

Before the research and development ideas were ranked, some 48 separate research and development (R&D) ideas were generated for the six different topics addressed in the workshop. During this phase, Topic 3 on Gates and Valves and Topic 4 on Energy Dissipators were combined and R&D ideas generated for the combined topic. In order to reduce the number of R&D ideas to 20, only four ideas from each topic receiving the highest number of votes from workshop participants was advanced to the preliminary planning phase.

Based on all of the input from participants and the combined ranking of R&D ideas assessing potential benefit and cost/ease of implementation, the five leading research and development ideas (including a two-way tie for 4th position) identified in the workshop are as follows:

1. Develop a best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments. (R&D Topic 1B)
2. Develop a best-practices guide for selection of gates and valves for outlet works structures. (R&D Topic 3A)
3. Develop guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works. (R&D Topic 3B)
4. Develop a best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, and configuration. (R&D Topic 4A)
5. Design guidance and guide specifications for sliplining outlet conduits. (R&D Topic 5A)

These five R&D topics were ranked in the top 10 in both of the overall ranking methods used to prioritize the research and development ideas assessing potential benefit and overall cost/ease of implementation. These R&D ideas were also ranked 1 though 4 when the ranking from both ranking methods were averaged as will be discussed in Section 5. Consequently, it is the authors' opinion that these R&D topics are the highest priorities for implementation. The R&D topic designations given in parentheses after the research and development ideas are the designations assigned during the workshop and used in Sections 4 and 5 of this report. The preliminary implementation plans for the R&D topics are presented in Section 4 using those designations.

After the five R&D topics listed above, the remaining five ideas in the top 10, based on the average of the rankings from two ranking considerations were:

1. Develop a best-practices guide for mechanical and electrical design and for automated control for outlet works. (R&D Topic 1C)
2. Compile case studies on outlet works rehabilitation including lesson learned, performance and comparative costs. (R&D Topic 5B)

3. Develop a best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components. (R&D Topic 6B)
4. Develop a list of failure modes for outlet works. (R&D Topic 1D)
5. Develop a best-practices guide for inspection frequency and method for typically accessible outlet works conduits. (R&D Topic 6C)

R&D topics 1C, 6B and 1D were ranked in the top 10 in both benefit and cost/ease of implementation rankings while R&D topic 5B was among the top 10 in the ranking of potential benefit, while R&D topic 6C was the second most favorable R&D idea from a cost/ease of implementation perspective. Consequently, it is the authors' opinion that these five R&D topics should be considered high priority, but not as high as the top five ideas previously indicated.

Other R&D topics that received a top 10 ranking in at least one of the two overall ranking methods used to prioritize ideas were:

1. Develop a best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, and the practice of selective withdrawals. (R&D Topic 2A)
2. Develop a short course with the possibility of a companion video/DVD format on design, operation, and maintenance of outlet works conduits. (R&D Topic 3C)
3. Develop a best-practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement. (R&D Topic 5D)

These R&D topics deserve some consideration for implementation, but at a lower priority than the 10 ideas previously indicated.

The remaining seven R&D topics received marginally less support in the overall rankings of the ideas with none of them ranked in the top 10 of either of the two assessment gauges used.

While a numerical ranking and average were calculated for the purposes of being able to rank all of the R&D ideas considered, the graph shown in Exhibit 5-4 indicates clustering of ranking data. According to this analysis tool, fifteen R&D ideas could be classified as high benefit with low cost/easy to implement, or as providing a high benefit with corresponding high cost/easy to implement.

In reviewing the leading R&D topics, it is interesting to note that none of them involve basic laboratory testing. Rather most of the R&D topics involve collecting or compiling available information and developing guidelines for dissemination to practitioners and to enable consistency in design, maintenance, and inspection activities throughout the field of practice. This suggests that the overall challenges associated with various aspects of outlet works design, maintenance and inspection result from the absence of documented information, inconsistencies among available information, misuse or misapplication of the available information by some practitioners, or lack of knowledge of available information by some practitioners. It also seem to reflect a feeling that the information on the overall topic is too dispersed for the profession to make the best use of lessons-learned from past performance, and that compilation of information into more readily available sources would be beneficial.

2.3 CLOSURE

A review of the leading R&D topics indicates that none of them involve basic laboratory testing. Most of the R&D topics involve collecting or compiling available information and developing guidelines for dissemination to practitioners to enable consistency in design, maintenance, and inspection activities throughout the field of practice. This suggests that the overall challenges associated with various aspects of outlet works design, maintenance and inspection result from the absence of documented information, inconsistencies among available information, misuse or misapplication of the available information by some practitioners, or lack of knowledge of available information by some practitioners. It also seems to reflect a feeling that the information on the overall topic is too dispersed for the profession to make the best use of lessons-learned from past performance, and that compilation of information into more readily available sources would be beneficial.

This discussion of the workshop process is divided into the following three topics:

- Selection of Workshop Participants
- Selection of Workshop Topics
- Workshop Mechanics

3.1 SELECTION OF WORKSHOP PARTICIPANTS

Workshop participants were selected to address the interest and knowledge base of Federal and Non-Federal dam owners, engineering practitioners, and academicians. Facilitators (white paper authors) were then selected from the participants based upon their recognized knowledge and expertise in the identified subject matter.

The workshop participants were a diverse group, including:

- 7 representatives of five different U.S. federal agencies;
- 1 representative from a state dam safety agency;
- 1 representative from a state environmental agency;
- 7 representatives of six different consulting companies;
- 4 independent consultants;
- 1 university professor;
- 1 representative of a hydropower organization; and
- Individuals from 10 different U.S. states, the District of Columbia, and Canada.

3.2 SELECTION OF WORKSHOP TOPICS

To accomplish as much as possible within the relatively short duration of the workshop, it was judged necessary to pre-select specific topics to be addressed. In pre-selecting the topics, the following three goals were established. Those goals were:

- To document the state-of-the-practice concerning cost-effective techniques for maintenance and replacement of components associated in dam outlet works.
- To outline a scope for both the short-term (immediate) and long-term research and development needs with respect to dam outlet works. Research and development were broadly defined to include "technology transfer."
- To recommend a course of action to address the needs identified based on priorities factoring in potential benefit and cost/ease of implementation considerations.

Considering the three-day duration of the workshop, it was judged that six topics, each being addressed for about one-half day, was the maximum number of topics that could be addressed in any reasonable depth.

The six selected topics are presented in Exhibit 3-2. Furthermore, in order to focus discussion of the selected topics, white papers were prepared by invited experts and distributed to participants in advance of the workshop for review. A summary of the white paper topics and their authors is presented in Exhibit 3-3.

3.3 WORKSHOP MECHANICS

The workshop was conducted over three full days divided into six half-day periods. By grouping the presentation and discussion of Gates, Valves, and Controls (Topic 3), and Energy Dissipators (Topic 4) into one half-day period on the second day, the six selected topics were covered in five half-day periods, allowing the last half-day period to be allocated to reviewing, discussing, and prioritizing the leading research and development needs. The generic agenda for each of the five half-day periods during which the selected topics were discussed was as follows:

- One-half hour – Presentation of a "State-of-the-Practice" white paper, prepared in advance by one or two (in the case of one paper) of the workshop participants.
- One-half hour – Facilitated discussion of the white paper by all workshop participants to identify revision, modifications, and refinements to the "State-of-the-Practice" presented by the white paper author(s).
- One-half hour – Facilitated brainstorming of possible research and development ideas that could advance the state-of-the practice.
- One-quarter hour – Prioritization of possible research and development ideas that could advance the state-of-the-practice.
- One hour – Small work groups established to develop preliminary implementation plans for the highest priority research and development ideas. (Typically 4 to 5 participants.)
- One-half hour – Oral reports from the Implementation Work Groups were given to participants on preliminary implementation plans developed.

Upon conclusion of the fifth half-day session on the third day, approximately 1 hour was devoted to reviewing, and discussing all of the leading research and development ideas for which preliminary implementations plans had been developed. Approximately 45 minutes were then allocated for each of the workshop participants to individually rank each of the research and development ideas according to both potential benefit and cost/ease of implementation.

The discussions, research and development ideas, and preliminary research and development plans were captured on flipcharts and comment forms used during the workshop, for compilation and inclusion in this report.

Some of the specific aspects of the workshop mechanics are discussed further below.

3.4 WHITE PAPERS

After the six topics were selected and prior to the workshop, some of the workshop participants were invited to prepare "white papers" to provide documents that would be "strawmen" for definitions of state-of-the-practice relative to the six topics. The white paper authors were also invited to put forward suggestions for research and development ideas related to their topics, if they so desired, but their primary responsibility was to develop "strawmen" to facilitate discussion of the state-of-the-practice.

The authors all prepared their white papers for distribution to the participants in advance of the workshop. They are owed a debt of gratitude for their contribution to the success of the workshop. The white paper authors are all listed in Exhibit 3-3, and the individual white papers are presented in Section 4 of this report.

3.4.1 Discussion of White Papers

The revisions, modifications, and refinements to the white papers provided by the participants were captured on flipcharts during the workshop and are reported in Section 4 of this report. The state-of-the-practice discussions for each of the six selected topics identified key areas of deficiency in both design and practice that need to be addressed either through the development of uniform standards for the various components of dam outlet works across the country or through further research and development initiatives. The discussions also indicated a widespread failure to routinely test components of dam outlet works to ensure their proper future functioning during the occurrence of an emergency condition. The adverse affects of human interference, tampering with operating equipment, and continued facility operations with known problems were also identified as pervasive and widespread problems that continued to be in need of redress.

3.5 IDENTIFICATION AND PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS

For each topic, the potential research and development ideas were compiled from a brainstorming process with the entire group. The ideas were listed on flipcharts visible to all participants. The research and development ideas for each topic were then prioritized in a simple voting process, in which each participant was given a fixed number of "stick-on-dots" that they could place next to the individual ideas. The number of dots (votes) given to each participant was typically about N/3, where N is the total number of research and development ideas being considered. The participants were allowed to cast their votes however they saw fit; there were no limits on the number of votes that a participant could cast for a particular idea. A participant could cast all of his votes for one research and development idea, if he thought it was a high enough priority. Before they cast their votes, the participants were instructed to balance the following three criteria in prioritizing the research and development ideas: 1) potential benefit, 2) probability of success, and 3) cost/ease of implementation.

All of the research and development ideas generated in the workshop as well as the results of the prioritizations for all six topics are presented in Section 4 of this report.

3.6 PRELIMINARY IMPLEMENTATION PLANS

After the prioritization was completed, the top four or five ideas for each topic were selected for development of preliminary implementation plans. The workshop participants were divided into small work groups (about 4 or 5 people per group), and each work group was assigned the responsibility to develop a preliminary implementation plan for one research and development idea. The small groups work independently for a period of time, and then all of the workshop participants reconvened to hear and discuss reports from all of the small work groups. The composition of the small work groups was shuffled for each topic, so that the same people were not working together all of the time. Work group leadership was rotated among workshop attendees with responsibility rotated among most of the participants over the course of the three days.

The implementation plans developed by the work groups are presented in Section 4 of this report.

3.7 OVERALL PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS

The overall prioritization of the 20 leading research and development ideas resulting from consideration of the six different topics was completed at the workshop using the same voting technique used for prioritizations of preliminary ideas considered for each of the six different topics. Participants were then asked to make an assessment of each R&D idea's potential benefit and associated implementation cost/ease of implementation by assigning a value between zero and ten as follows: high potential benefit would be indicated by assigning a value closer to 10, while an idea with low potential benefit would be indicated by assigning a value closer to 0; favorable low cost or ease of implementation would be indicated by assigning a value closer to 10, while unfavorable high cost or difficulty to implement the R&D idea would be indicated by assigning a value closer to 0. The values for each of the research and development ideas assigned by each of the 16 participants were then averaged in order to determine overall rankings for each of the research and development ideas according to potential benefit, cost/ease of implementation, and on the combination of both factors.

The prioritization of the 20 leading research and development ideas is discussed in detail in Section 5 of this report.

EXHIBIT 3-1

WORKSHOP PARTICIPANTS

ORGANIZATION	NAME	ADDRESS	PHONE/FAX	EMAIL
BC Hydro	Charles Holder	6911 Southpoint Drive Burnaby, BC V3N 4X8	P: 604-528-2418 F: 604-528-8133	charles.holder@bchydro.com
Consultant	Jack Cassidy	2884 Saklan Indian Drive Walnut Creek, CA 94595	P: 925-933-5994 F: 925-287-0802	jcassidys@aol.com
Consultant	Hank Falvey	P.O. Box 4 Conifer, CO 80433	P: 303-838-4920 F: 303-825-4920	h.falvey@worldnet.att.net
Consultant, URS	Lee Gerbig	8181 East Tufts Avenue Denver, CO 80237	P: 303-740-3906 F: 303-694-3946	lee_gerbig@urscorp.com
Consultant	Ed Rossilon	6505 West 31st Avenue Denver, CO 80214	P: 303-233-2480	rosie6617@juno.com
Department of Homeland Security, EPR/FEMA	Gene Zeizel	500 C Street, S.W., Room 416 Washington, D.C. 20472	P: 202-646-2802 F: 202-646-3990	gene.zeizel@dhs.gov
Federal Energy Regulatory Commission	Dave Ricketts	San Francisco Regional Office 901 Market Street, Suite 350 San Francisco, CA 94103-1778	P: 415-369-3396 F: 415-369-3322	dave.ricketts@ferc.gov
Freese and Nicholls	Ron Waters	4055 International Plaza, Suite 200 Fort Worth, TX	P: 817-735-7333 F: 817-735-7490	rhw@freese.com
Gannett Fleming	Robert Kline, Jr.	PO Box 67100 Harrisburg, PA 17106	P: 717-763-7211 x. 2657 F: 717-763-1140	rkline@gfnet.com
MWH Americas, Inc.	Mark Hammer	2353 130th Avenue NE, Suite 200 Bellevue, WA 98005	P: 425-896-6961	mark.a.hammer@mwhglobal.com
NRCS-NDCSMC	Wade Anderson	501 W. Felix, Bldg. 23 Fort Worth, TX 76115	P: 817-509-3764 F: 817-509-3753	wade.anderson@ftw.nrcs.usda.gov

EXHIBIT 3-1
WORKSHOP PARTICIPANTS
-CONTINUED-

ORGANIZATION	NAME	ADDRESS	PHONE/FAX	EMAIL
Schnabel Engineering Company	Jimmy Crowder	5975 Shiloh Road, Suite 114 Alphraretta, GA 30005	P: 770-781-8008 F: 770-781-8003	jcrowder@schnabel-eng.com
State of Colorado	Mark Haynes	Dam Safety Branch Colorado Division of Water Resources 1313 Sherman Street, Room 818 Denver, CO 80203	P: 303-866-3585 x. 8276 F: 303-866-3589	mark.haynes@state.co.us
State of New Hampshire	Jim Gallagher	Department of Environmental Serv. P.O. Box 95, 6 Hazen Drive Concord, NH 03302-0095	P: 603-271-1961 F: 603-271-2982	jgallagher@des.state.nh.us
URS Corporation	Sal Todaro	8181 East Tufts Avenue Denver, CO 80237	P: 303-740-2685 F: 303-694-3946	salvatore_todaro@urscorp.com
URS Corporation	John France	8181 East Tufts Avenue Denver, CO 80237	P: 303-740-3812 F: 303-694-3946	john_france@urscorp.com
URS Corporation	Richard Millet	8181 East Tufts Avenue Denver, CO 80237	P: 303-740-3812 F: 303-694-3946	richard_millet@urscorp.com
U.S. Army Corps of Engineers	Ken Halstead	P.O. Box 1159 Cincinnati, OH 45201-1159		kenh@lrh.usace.army.mil
U.S. Army Corps of Engineers	Eric Holand	P.O. Box 1159 Cincinnati, OH 45201-1159		eric.p.holand@saj02.usace.army.mil
U.S. Army Corps of Engineers	Robert Taylor	P.O. Box 1159 Cincinnati, OH 45201-1159	P: 513-684-3804 F: 513-684-6361	robert.e.taylor@lrdor.usace.army.mil
U.S. Bureau of Reclamation	Chuck Cooper	P.O. Box 25007, Mail Code D8130 Building 67, Denver Federal Center Denver, CO 80225-0007	P: 303-445-3262 F: 303-445-6490	ccooper@do.usbr.gov
Utah Water Research Laboratory	Michael Johnson	USU Research Foundation	P: 435-797-3176 F: 435-797-0296	mikejnsn@cc.usu.edu

EXHIBIT 3-2

WORKSHOP TOPICS

1. Outlet works failure modes including consideration of failure by seepage and piping mechanisms along outlet works conduits.
2. Review of selection criteria, construction methods and the various conduit materials utilized in dam outlet works. Discussions included pipe material types and their advantages, disadvantages, and appropriate applications; hard foundations, soft foundations, and the operation of conduits under various pressure conditions.
3. Discussion about the role and types of gates, valves, and controls used in the design of dam outlet works. Gate, valve, and control configurations, rehabilitation, and maintenance considerations were topics that were also discussed.
4. Discussion about the role and various types of energy dissipators used in dam outlet works including stilling basins and energy dissipating valves.
5. Rehabilitation of pipe conduit spillways through dams including in-place rehabilitation, replacement, reservoir evacuation criteria, and economic consideration.
6. Review of the current state-of-the-practice regarding the frequency and scope of outlet works inspection. Systems, methods, techniques, and design criteria to accommodate inspection were also included in the discussion.

EXHIBIT 3-3

WHITE PAPER AUTHORS AND TITLES

Author(s)	White Paper Title/Focus
Sal Todaro	Outlet Works Failure Modes
Sal Todaro	Design and Construction of Outlet Works Conduits for Embankment Dams
Lee Gerbig	Gates and Valves
Henry Falvey	Energy Dissipators
James Crowder	Rehabilitation of Pipe Conduit Spillways Through Dams
Chuck Cooper	Outlet Works Inspection

In this section of the report, the results of the workshop are presented and discussed separately for each of the six topics listed in Exhibit 3-2. For each topic, the following items are discussed:

1. The state-of-the-practice white paper.
2. Refinements to the state-of-the-practice white paper.
3. Identification and prioritization of research and development ideas.
4. Preliminary research and development implementation plans.

Consideration of each topic resulted in the selection of four or five research and development ideas for which preliminary implementation plans were developed. Preliminary implementation plans were developed for four research and development for the combined topic of gates valves, controls and energy dissipators. Section 5 of the report discusses overall prioritization of the 20 potential research and development plans that were developed separately for the six topics considered.

4.1 TOPIC 1 – OUTLET WORKS FAILURE MODES

4.1.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by Rich Millet and Sal Todaro, and is presented in full in Attachment 4 of this report. A brief summary of the highlights of the paper is presented here.

The primary causes of outlet works failures are: foundation related failures, structural deterioration, structural failures, mechanical failures, failures related to hydraulics, failures related to ice and sediment loadings, and operator error. In addition to being one of the leading causes of embankment dam failures, outlet works failures can also result in less catastrophic consequences like: the inability to make required reservoir releases; structural or mechanical conditions requiring emergency draining of the reservoir; or the uncontrolled release of water from the reservoir. The components of outlet works systems generally include intake structures, conduits or tunnels, control structures and energy dissipation structures when they are incorporated into the overall system design. Therefore failure in one or more parts of these system could lead at best to failure of the outlet works, and at worst, result in catastrophic failure of the embankment dam.

Intake structures are those where water enters the outlet works and can be submerged structures, tower structures with multiple level inlet ports, or inclined structures located on a dam abutment with a single bottom inlet or with multiple level inlet ports. Intake gates, valves, and trash racks are the principle mechanical features on intake structures. These features are usually operated by mechanical control systems that include manual, motor driven, and hydraulic systems. The primary causes of gate and valve malfunction and failure include: the collection of debris, cavitation, ice, operator error, malfunctioning of gate operating mechanisms, lack of exercise, and deterioration from corrosion. Trash rack failure and malfunction usually result from plugging due to sediment, debris, or from plugging with frazil ice.

The most common failure modes for intake structures are as follows:

- Poor foundation condition resulting in differential settlement between the intake structure and the outlet conduit. Care should be taken to locate intake structures on firm bedrock whenever possible;
- Premature deterioration of intake structures usually resulting from accelerated aging due to adverse environmental conditions including: damage from freeze-thaw processes; the use of poor concrete materials like alkaline aggregates; and exposure to water with either excessively high or low pH values which can accelerate the corrosion of reinforcement and cause concrete to deteriorate;
- Loading from expanding reservoir ice usually resulting in damage to trash racks, gate stems, intake towers and piers for intake tower access;
- Seismic loading from an earthquake resulting in the inoperability of components of the intake structures;
- Accumulation of sediments in intake structures resulting from improper reservoir operation, upstream construction, and other land clearing activities like forest fires;
- Hydraulic failures including cavitation of intake gates or areas at the intake structure or in the conduit downstream of the intake gate;
- Air/Water related failures including the inadequate supply of air to control gates causing cavitation and vibration of the intake towers. Air blowback also creates operational problems and is caused when air and water are blown violently back into the intake structure in the reverse direction through the conduit; and
- The occurrence of structural fatigue caused by vibration or collapse that results from the progressive plugging of the intake structure.

Methods that can be used to prevent the failure of intake structures include:

- Locating the intake structure on a rock foundation in order to reduce the magnitude of settlement effects;
- Designing these structures to ensure that air demand requirements to prevent blowback, pipe collapse, and cavitation of control gates are satisfied;
- Designing these structures to account for ice loading. Using bubbler systems to prevent ice formation is recommended;
- Using an experienced mechanical engineer to design the mechanical components of outlet works systems;
- Using reliable standard designs that have been developed and tested over time;
- Locating the inlets of the intake structure to minimize sediment collection; and
- Including consideration of vibration affects on trash racks.

Conduit outlets are usually constructed through dams and can increase the risk of failure of embankment dams because of the potential for embankment piping near the conduit. Outlet conduits are usually made of cast-in-place concrete or constructed from manufactured pipe while pre-cast concrete, plastic, steel and ductile iron are materials commonly used in pipe fabrication. The four most common failure modes of outlet conduit through embankment dams are:

1. Internal erosion of embankment into the conduit;
2. Pressurized defects in the conduit casing resulting in embankment piping;
3. Piping of the embankment along the outlet conduit; and
4. Seepage through a fracture in the embankment near to the conduit.

The three primary ways of minimizing the failure potential of outlet conduits are: 1) Filtering the dam embankment in the vicinity of the outlet conduit to prevent internal erosion of the embankment along or near the conduit; 2) Constructing outlet conduits on rock foundations when possible; and 3) Designing conduits with redundant features to prevent water seepage from the conduit into the embankment resulting in the piping of embankment materials into the conduit. By contrast, tunnel outlet works are separated from the dam embankment and are generally considered to be a safer than conduits. These tunnels are usually lined with cast in place concrete or welded steel. However, even if cost considerations allow a tunnel outlet works system to be considered a viable design alternative, construction of the tunnel too close to the dam can result in internal erosion of a dam's embankment, even though the occurrence is rare.

As the name implies, a control structure is one in which flow through the outlet works is controlled. Control structure location directly impacts the type of control devices used. Typically control valves may be located at intake structures, gate chambers or in a valve house at the downstream toe of the dam. The most common failure modes of these structures are associated with the failure or malfunction of gates, valves, or control systems used to operate these devices. To minimize the occurrence of failure therefore, it is recommended that the following be done: retain a mechanical engineer experienced in the design of gates, valves and mechanical systems for dam outlet works for both new design and rehabilitation activities; routinely test, operate and maintain components of control structures; and replace antiquated and unreliable gates, valves, and operators with newer, more reliable equipment.

Finally, in order to prevent the uncontrolled erosion of the downstream channel in cases of direct discharge, care should also be taken in the design and maintenance of discharge mechanisms and in the use of energy dissipation structures.

4.1.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- Unwillingness of those involved to acknowledge viability of failure modes and resistance to thinking outside of the box.
- Misoperation or lack of operation of outworks components because of the failure of automatic control systems stemming from conflicting program instructions, and the expiration of these programs.
- Structural deterioration because of water chemistry and reaction with air and the deterioration of concrete because of the presence of hydrogen sulfide (H_2S) in the water which can be evident in the presence of cavitation.

- Cavitation because of inadequate air vents.
- Seismic loading on intake towers.
- Cracked concrete encasement resulting from earthquake loading and a discussion of allowable pressure on metal pipe, and the presence and role of buckled pipe in failure mechanisms.
- Lateral or longitudinal joint offsets also know as embankment spreading due to earthquake loading.
- Rupture of pressurized prestressed concrete cylinder pipe.
- Plugging of air vents by those annoyed with the sound (e.g. campers).
- The fact that entities will sometimes operate for a long time with a known problem.
- Vandalism of operating equipment.

4.1.3 Prioritization of Research and Development Ideas

The group brainstorming process resulted in the generation of 11 potential research and development ideas, which were then prioritized by the group. The 11 ideas and the results of the prioritization are presented in Exhibit 4-1.

4.1.4 Preliminary Research and Development Plans

The top five ideas listed in Exhibit 4-1 were selected for development of preliminary implementation plans, and those plans are presented in Exhibits 4-2 through 4-5. Note that in some cases, the individual work groups reworded the research and development idea, so the ideas listed in Exhibit 4-1 may not exactly match the ideas listed in Exhibits 4-2 through 4-5.

4.2 TOPIC 2 – CONDUIT MATERIALS, SELECTION CRITERIA, AND CONSTRUCTION METHODS

4.2.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by Sal Todaro, and is presented in full in Attachment 5 of this report. A brief summary of the highlights of the paper is presented here.

Due to the absence of any single recognized standard for designing dam outlet works there is currently great inconsistency in design rationale and review processes for this design aspect of small and medium sized embankment dam facilities. The need for a single design standard is further underscored by the fact that outlet works have been identified as a significant contributor to the occurrence of embankment dam failures. While the similar design of outlet works at all small and medium sized embankment dams is not proposed, consistency should exist in the guidelines and criteria used to prepare designs for these structures. Design guidelines could include recommendations for pipe encasement, the need for redundancy, seepage control, methods for addressing compressible foundations, pipe selection, joint details, and criteria for reinforced concrete conduit design.

A single, nationally recognized standard would lead to greater consistency between similar project designs, facilitate more effective and consistent review of proposed designs, and result in increased potential for safer more reliable facilities. The National Dam Safety Review Board (NSRB) is in the process of preparing a manual to be used for designing and maintaining outlet works for significant high-hazard dams. The manual covers topics for the design, construction, maintenance, and repair of conduits for embankment dams. It is recommended that in the interim the guidelines presented in this manual be used to form a design basis for smaller facilities.

By determining best practices for designing and constructing outlet works, and by preparing nationally accepted standards to be used for engineering review, important improvements in outlet works design methods and construction procedures can be achieved. Furthermore, dam safety officials could then require and enforce minimum standards for all new non-federal designs, simplifying the task of design engineers by providing a consistent standard for design they know will be accepted by review agencies.

Presently, the use of standards not intended for use in designing pressurized outlet systems for embankment dams is the most common practice that introduces additional risk to outlet works for smaller embankment dams. Examples of the misapplication of design standards to design outlet works include the following:

- Use of State Highway Department standard plans for culverts and culvert structures even though culvert designs for highways were not intended for use in dams.
- Use of Natural Resources Conservation Service (NRCS) standards for the structural design of flood control outlets to design high-hazard pressurized outlet facilities even though these standards were not intended for such application, and
- Use of the precast concrete outlet pipe detail with partial encasement shown in the USBR's *Design of Small Dams* for pressurized outlet works for high-hazard dams. This detail allows embankments to be placed directly against the pipe surface which is an area where leakage from the pipe joint has direct access to the embankment.

The creation of an approved standard would therefore reduce the use of inappropriate design standards. The USBR and U.S. Army Corps of Engineers (USACE) design standards for outlet works combined with the forthcoming NSRB manual could form a basis for preparing a single design and construction standard for smaller dam outlet facilities.

Appropriate modifications that may be required due to variability in foundation conditions should also be included in the proposed design manual. Where possible, outlet works structures should be founded on firm non-erodable foundations. However, variable foundation conditions may result in the founding of outlet works structures upon compressible foundations that are subject to differential foundation settlement and movement. Soft foundation conditions incur greater risk of embankment piping and structural distress of the conduit. Foundation movements are especially dangerous for rigid outlet pipes with open gasketed joints. Therefore outlet conduit should be located on uniform foundations whenever possible to prevent abrupt changes in conduit settlement.

Recommended approaches to the design of outlet conduits on soft foundations include: 1) Placement of freestanding pressurized outlet pipe inside of a cast-in-place reinforced concrete conduit; 2) Use of a non-pressurized outlet works system; 3) Use of welded steel outlet pipe encased in reinforced concrete; 4) Use of articulated joints for the outlet conduit; and 5) Protecting the foundation's integrity during construction.

While various pipe materials have particular advantages and disadvantages, the ones most commonly used for outlet works conduits are: cast-in-place reinforced concrete; welded steel pipe encased in reinforced concrete, high density polyethylene (HDPE) pipe, ductile iron pipe, and reinforced concrete pressure (RCP) pipe.

While not usually considered as a design alternative where soft ground conditions are encountered, tunnel outlet works present several distinct technical advantages when compared to cut-and-cover outlet conduit designs, especially for pressurized outlets. These advantages include:

- Elimination of embankment failure modes associated with conduit outlet works.
- Stream diversion capabilities around the dam site during construction.
- Construction of tunnel outlet works independent of embankment construction.
- Embankment placement unobstructed by the outlet conduit
- Elimination of special compaction requirements, and the need for special filter placement required for conduit systems.

However, tunnel outlet works systems are often more expensive than conduit systems and typically involve more cost risk for overruns. Thus, development of cost curves for tunnel outlets based on outlet diameter would be helpful allowing engineers to compare cost/ease of implementations for preliminary evaluations of tunnel and conduit outlets. The design standard would therefore provide a consistent design approach, and allow various design alternatives to be evaluated and considered in a systematic and rational manner.

4.2.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- Conduits need to be large enough for inspection and repair.
- Bends in conduit alignments can eliminate repair/rehabilitation options (e.g. slip-lining).
- Concrete-encased, welded steel pipe conduits need to be designed for full reservoir pressure on the outside of the pipe. Leaks in the encasement and associated buckling failures have been caused by pressure between the steel pipe and the encasement.
- Conduit sizing criteria (e.g. for evacuation) vary among different jurisdictions, and sizing criteria do not exist for some jurisdictions.
- There are a number of negative factors for conduit configurations through embankments in addition to those sited in the white paper:

- Lack of sufficiently detailed geotechnical information along the alignment to calculate settlements (total and differential).
- Differential settlement at material contacts (embankment zones and different foundation materials) is expected.
- Many opportunities exist for improper construction to lead to problems.

- Diving technologies are available for maintaining, rehabilitating, and replacing deep, underwater, upstream gates; however, these technologies are very expensive.
- Outlet tower/intake configurations vary widely. Examples include freestanding, upstream towers; inclined, on-slope, upstream intakes structures; towers within the embankment between the upstream toe and the crest, with an upstream, underwater inlet.
- There has been an increasing desire from some owners and some material manufacturers to use plastic pipes (e.g. HDPE), but accepted standards for use of this type of pipe in dams do not exist. FEMA is sponsoring a Best-Practices Guide for use of plastic pipe in embankment dams, which should address this issue.
- Some engineers and owners still propose use of corrugated metal pipe (CMP) conduits in embankments, but it is unusual. Most regulators will not accept it for high and significant hazard dams.
- Analysis methodologies have improved dramatically: 3-D analysis now available instead of 1-D; and soil structure interaction included in many programs like FLAC, and Plaxis.
- For design loads, we are still typically using old guidance (e.g. Marston equations), even with a sense that these loads are conservative (i.e. too high).
- AWWA guidelines and ASCE penstock guidelines are available for steel pipe design. ASCE guidelines are more appropriate for high pressure and transient flow.
- Pressurized downstream control conduits exist in some older facilities and in some retrofits for inoperative upstream gates. Proposals for new installations with downstream control are typically concrete-encased steel, but there are exceptions.

4.2.3 Prioritization of Research and Development Ideas

The group brainstorming process resulted in the generation of 7 potential research and development ideas, which were then prioritized by the group. The 7 ideas and the results of the prioritization are presented in Exhibit 4-6.

4.2.4 Preliminary Research and Development Plans

The top four ideas listed in Exhibit 4-6 were selected for development of preliminary implementation plans, and those plans are presented in Exhibits 4-7 through 4-10. In some cases, the individual work groups reworded the research and development idea, so the ideas listed in Exhibit 4-6 may not exactly match the ideas listed in Exhibits 4-7 through 4-10.

4.3 TOPIC 3 - GATES, VALVES, AND CONTROLS

4.3.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by Lee Gerbig, and is presented in full in Attachment 6 of this report. A brief summary of the highlights of the paper is presented here.

Releases from outlet works are often controlled to maintain river flows, provide water for irrigation, to a water treatment facility, or to an industrial user, and to lower reservoir levels in the event of an emergency. Gates and valves are the two general names for the types of equipment used to control the release of water in outlet works systems. A gate is a mechanical device with a sliding flat member within a square or rectangular framework or structure that controls the flow of water. A valve is usually a circular structure with a sliding member, flat or circular, that controls the flow of water.

The types of gates commonly used at newer dam sites are: Slide gates, Knife gates, Jet-flow gates, Clamshell gates, Radial gates, and Hinged Crest gates. Slide gates, also known as Sluice gates, are the most common type of gate used for dam outlet works. These devices have a movable leaf or disk which slides against bearing surfaces in the frame. The frame is attached to a conduit or wall, which provides support against the water load of the gate. The gate leaf is moved by a gate stem, which is operated by a manual hand wheel or crank, electric motor-operator, or hydraulic cylinder.

For applications where the head does not exceed 100 feet, the two types of slide gates commonly used are the Cast Iron Slide gate and the Fabricated Slide gate. As the name implies, both the rectangular gate leaf and frame of a Cast Iron Slide gate is fabricated from cast iron. Gate leakage from this type of slide gate is usually very low, seldom exceeding 0.1 gal/minute/foot of the perimeter of the leaf gate. Fabricated Slide gates are made from a variety of materials including steel, stainless steel, and aluminum. The gate leaf uses the metal plate as a sliding surface against low friction material attached to the frame. Typical leakage from this type of slide gate is 0.05 gal/minute/foot of the perimeter of the leaf gate.

For applications where the head exceeds 100 feet, Bonneted Slide gates and Wheel gates are commonly used. Bonneted slide gates are similar in design to Fabricated Slide gates, except that the body is fabricated to completely enclose the gate leaf. This type of slide gate is usually embedded in reinforced concrete to provide additional structural reinforcement for the pressurized gate body. In Wheel gates, the gate leaf is fitted with multiple wheels that ride on rails attached to the face of the structure. It should also be noted that Wheel gates could be designed to close by gravity in the event of an emergency. However, one of the main drawbacks with Wheel gates is difficult installation due to the critical alignment that is required to achieve smooth operation and effective sealing. Due to susceptibility to corrosion and the build up of deposits that increase friction and affect the operation of its roller train, the use of Roller gates is increasingly avoided even though this was a type of slide gate that was also used for high head applications.

Knife gates and Jet-flow gates are two other variations of the slide gate. While Knife gates are not commonly used in the hydropower or dam industry, Jet-flow gates are commonly used as freely discharging devices. The gate has a circular opening with a sliding disk that moves over a floating, sloping orifice shaped opening. The sloping orifice concentrates the flow to help introduce air to prevent cavitation. The Clamshell gate is a special design used by the U.S. Bureau of Reclamation consisting of two leafs operating in an arc over the end of a conduit, and machined to match the arc of the gate leafs. The gate leafs move in a symmetrical manner to provide uniform flow between the two leafs and allow this device to work very well in submerged installations. Radial gates have been used for many installations at spillways, canal check structures, and canal turnouts. Hinged Crest gates are used at the crest of a spillway, to allow flow overtopping the gate to regulate the reservoir or pool elevation. The gate consists of a flat or slightly curved plate structure, with a hinge system at the bottom to allow the gate to rotate from near vertical to horizontal.

Valve types commonly used are: Butterfly valves, Gate valves, Fixed-Cone valves, and Sleeve valves. Butterfly valves are commonly used at power plants and water facilities and have a circular body with a circular disk in the fluid way that rotates around a shaft in the centerline of the valve, perpendicular to the flow. The flow velocities through butterfly valves are usually limited to 25 to 30 feet per second, although high-performance butterfly valves can operate up top 50 feet per second. Butterfly valve operating forces are very low, with very little friction and hydraulic effects. They may be operated manually, by electric motor-operators, or by hydraulic operation. A Gate valve is a variation of a slide gate, with a circular body and disk. They are often used for guard gates upstream of regulating valves, or used for throttling flow in low-head applications. A Fixed-Cone valve is commonly used for regulating the flow of water from a dam outlet works. This cylindrical valve has a sliding sleeve that covers the opening at the downstream end of the valve. Sleeve valves are used as energy dissipaters, both in-line and at the end of a conduit and are usually operated to provide precise flow control. Due to high costs and problems with corrosion, seat erosion, cavitation damage, or general maintenance difficulties there has been a decreased incidence of Needle valves and Hollow-Jet valves.

The four basic types of gate operation systems are: manual operators, electric motor-operators, hydraulic operators, and pneumatic operators. Manual operation usually involves use of a crank or handwheel connected to the gate or valve operating mechanism with threaded stems or a gearbox arrangement. Electric motor-operators also provide either linear motion with threaded stems or rotary motion converted to linear motion. Electric motor-operators are usually designed for outdoor applications, with weatherproof enclosures. In the event of an interruption in power, hand wheels are usually provided on these units for back up manual operation. Hydraulic operation is most often used on large gates and valves operating at high head, but is becoming more common for small equipment at low heads for particular installations. Pneumatic operators are rarely used for operating gates and valves. The problem with pneumatic operation in typical gates and valves is that, with the air, being compressible, it is difficult to maintain a set position. Portable drills, portable hydraulic operators, and chain saw operators are the most common portable operators that are available to work in conjunction with manual operators.

With increased equipment reliability and performance, remote and hydraulic operation of gates and valves occurs more frequently. Remote sensing may be achieved using electric motor operators, hydraulic cylinders, and inclinometers. Improved hydraulic fluids suitable for outdoor use, submerged hydraulic operation, use of better seals, and automated operation features has inspired increased use of hydraulic components in the design of gates and valves.

However, the design and fabrication of gates and vales has increasingly shifted overseas with major US manufacturers in the process emerging from bankruptcy proceedings. However the ultimate effect of offshore fabrication and the disappearance of longstanding US-based gate and valve manufactures is the significant decrease in the number of gate designers in the United States. Moreover, with government agencies like USBR, USACE, and TVA scaling back dam design and construction phases of work, there has also been a corresponding decrease in the amount of available research on new equipment and operation.

4.3.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- There are two versions of hoods on fixed-cone valves: in one configuration the hood is connected to the body of the valve and moves with the valve, while in the other the hood is separate from the body of the valve and stays in a fixed position.
- A hood on the fixed cone valve limits the applicable head to about 175 feet.
- A bullnose bottom should be used if a slide gate will be used for regulating the flow. This works well up to heads of at least 75 feet, and possibly as much as 100 feet.
- Although it is desirable to design outlet works with non-pressure conduits, it can be difficult to design upstream control for outlet works systems for high heads. There is a lack of confidence in the available gates and valves for these high head, flow control applications.
- Gates intended to close against head may not be as reliable as we would like.
- AWWA standards for design of stems and operators may not be adequate for dam outlet works. The stems can be too easily overloaded and buckle.
- There have been frequent problems with leakage of slide gates mounted in the unseating direction (relative to the head).
- There is a lack of industry-wide knowledge of the potential for catapulting of gates because of insufficient airflow.
- Butterfly valves and operators can be designed to fail in the open or closed position. Design needs to consider which is preferred for that particular installation. If the valve fails in the closed position, dampers may be needed to slow the rate of closing to prevent surge damage.
- There have been problems with the corrosion of butterfly valve bushings or stems, resulting in valves that did not close, as intended.

4.3.3 Prioritization of Research and Development Ideas

Since this topic had been combined with the topic on energy dissipators, the group brainstorming process resulted in the generation of 10 potential research and development ideas for the combined topics. The group then prioritized these topics and an overall ranking of research and development ideas for the combined topics was generated. The 10 ideas and the results of the prioritization are presented in Exhibit 4-11.

4.3.4 Preliminary Research and Development Plans

The top four ideas listed in Exhibit 4-11 were selected for development of preliminary implementation plans. The ideas directly related to the topics of gates, valves, and controls are presented in Exhibit 4-12, Exhibit 4-14, and Exhibit 4-15. In some cases, the individual work groups reworded the research and development idea, so the ideas listed in Exhibit 4-11 may not exactly match the ideas listed in Exhibit 4-12 and Exhibits 4-14 and 4-15.

4.4 TOPIC 4 – ENERGY DISSIPATORS

4.4.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by Henry Falvey, and is presented in full in Attachment 7 of this report. A brief summary of the highlights of the paper is presented here.

Almost every outlet works requires an energy dissipator so that the high-energy flow from the reservoir does not damage the downstream channel or structures. While the laws of conservation of energy technically prohibit energy from being "dissipated," energy dissipators enable energy conversion for high energy water flows by: creating fine grain turbulence; and creating a loss through a change in the flow's momentum. Wide varieties of structures are available to designers to dissipate high head-high energy flows from outlet works. Many designs have been developed for site-specific installations that have not appeared in the literature and it should be also noted that some of these designs have also not been verified by either modeling or prototype tests.

However, energy dissipators that have been successfully used at outlet works include: stilling basins, impact basins, stilling wells, various types of valves, sudden enlargements, in-line orifices, flip buckets, and plunge pools. Outlets works can incorporate a combination of different types of energy dissipators. The types of energy dissipators used depend on the design reservoir head, discharge requirements, and cost constraints of a particular design.

USBR Engineering Monograph 25 provides a thorough discussion of the design elements for stilling basins, impact basins, flip buckets, and baffled aprons. General guidelines for designing outlet works are provided in both USACE Engineering Manual EM 1110-2-1602 and in *Design of Small Dams* published by the USBR.

The USBR defines three types of hydraulic jump stilling basins. The Type I Basin is simply the combination of a hydraulic jump with a horizontal apron with energy dissipation accomplished by turbulence created within the jump. Type II Basins contain chute blocks located at the end of the basin and a dentated end sill. The chute blocks create shear zones that generate fine grain turbulence while the end sill prevents downstream erosion and does not contribute significantly to energy dissipation. The Type III Basin contains an additional set of baffle blocks within the horizontal apron to create additional turbulence. The combination of chute blocks and baffle blocks allows the length of the stilling basin to be reduced.

Reclamation classifies impact basins as Type VI Basins. In these structures energy is dissipated by turbulence that is generated when a jet of water makes impact with a vertical wall. Although Reclamation limits the dimensions and discharges of impact basins to relatively low energy levels, the basins have been used successfully at much higher energy levels by scaling the recommended dimensions to the larger sizes.

Stilling wells are frequently used for low discharge flows into canals. Energy dissipation is achieved by the change in momentum between the water entering the well through the pipe and the flow up the square well. Flow is controlled by changing the size of the opening using a sleeve valve on the bottom of the down comer pipe.

For applications with high head or high flow requirements, fixed-cone valves are normally used to dissipate energy. These valves can use the principle of impinging jets and baffles downstream of the valve to provide energy dissipation. It should be noted however, that the distance between the end of the fixed cone valve and the hood is critical as severe blowback has been experienced in prototype installations where this distance was off by only an inch or two.

Sudden enlargements occurring within or at the end of a pipeline can be very effective energy dissipators. Precautions must be taken during the design of these features to ensure that the formation of cavitation within the structure is minimized even though some ranges of operating conditions will still generate cavitation. Incorporation of a series of in-line orifices into a pipeline also utilizes the energy dissipation function of sudden enlargements.

Flip buckets are often used at the end of an outlet chute to throw discharge flow away from the toe of the dam. Flip buckets are actually not energy dissipation devices although they are designated as such in the USBR Engineering Monograph No. 25. Dentates are frequently used to spread the compact jet and increase the area over which the jet enters the plunge pool thereby decreasing the energy per unit area of the inflow jet.

Plunge pools are commonly used in combination with flip buckets and are designed to minimize the erosion of the downstream channel that a plunging jet of water can cause. Care must be taken in the design of these structures since material excavated by a plunging jet of water can raise the tailwater in the pool such that it sufficiently drowns out the effects of the flip bucket.

4.4.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- There have been problems with backflows in USBR-type stilling basins. The backflows have drawn rock and soil materials into the basins, sometimes leading to ball-milling and related damage.
- There is a lack of available information on ultimate development of plunge pool basins in rock including ultimate size and depth. A Swiss engineer is doing some work in this area, as is George Annandale, with work to be published soon.

- There have been cases where energy dissipation characteristics have been affected by valve changes. Examples offered at the workshop include changing geometry/dimensions for fixed-cone valve installations and replacement of needle valves with fixed-cone valves.
- There is a lack of widespread, definitive knowledge about reliable repair techniques for energy dissipators – one available source is the USACE REMR documents.
- There is a lack of specific guidelines on the extent and size of riprap required downstream of energy dissipators. This can contribute to a ball-milling problem, if the riprap is small enough to be drawn into the stilling basin. Grouted riprap has sometimes been used to address this concern.
- The sleeve valve concept has been modified in some applications to consist of a fixed section of pipe with holes and an upstream control valve. This concept has been used for intermittent flows with a limited range of discharge.
- No guidelines are available on the appropriate frequency of inspection of stilling basins.
- With increased use of failure modes analysis, downstream erosion and undercutting of stilling basins or concrete dams is becoming an increasingly frequent concern. Methods for reliably evaluating this issue are not readily available.
- Vandalism leading to ball-milling is a problem which often results from people throwing rocks into stilling basins. This has lead to measures to make it more difficult to throw rocks into the structures.
- Public safety can be an issue for stilling basins. People will swim in the basins, and sloping downstream ends of the basins can make it difficult for people to get out of them. Steps in place of the sloped surface have been used to address this safety concern.

4.4.3 Prioritization of Research and Development Ideas

Since this topic had been combined with the topic on gates, valves and controls, the group brainstorming process resulted in the generation of 10 potential research and development ideas for the combined topics. The group then prioritized these topics and an overall ranking of research and development ideas for the combined topics was generated. The 10 ideas and the results of the prioritization are presented in Exhibit 4-11.

4.4.4 Preliminary Research and Development Plans

The top four ideas listed in Exhibit 4-11 were selected for development of preliminary implementation plans. The idea directly related to the topic of energy dissipators is presented in Exhibit 4-13.

4.5 TOPIC 5 – REHABILITATION OF CONDUITS

4.5.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by James Crowder, and is presented in full in Attachment 8 of this report. A brief summary of the highlights of the paper is presented here.

Corrugated metal pipe (CMP) commonly serves as the conduit found in small earthen embankment dams ranging in height from 10 to 50 feet constructed between 30 and 50 years ago in the southeastern United States. Compared to conduit materials used in newer dams, CMP is highly susceptible to deterioration and becomes a problem when a spillway conduit has reached or exceeded its design service life, generally considered to be 25 to 30 years. Earthfill embankments of this vintage were often constructed with CMP spillway conduits passing through the base/foundation of the embankment. The deterioration of these conduits generally consists of leaking joints, corrosion, and holes in the pipe.

The main risk associated with the deterioration of these conduits is piping of the surrounding embankment soils into the conduit, which can lead to the eventual failure of the earthen embankment. Owners of most old embankment dams exhibiting problems with CMP conduits usually have a number of concerns or issues that will usually involve several remediation or repair options. The four primary options discussed, including the advantages and disadvantages of each method, are based upon the experiences of the author in the Southeast United States and are mainly limited to CMPs in earthen dams having a maximum height of 50 feet. These options include:

- Replacement of the existing pipe conduit using cut and cover methods;
- Sliplining the existing conduit;
- Grouting along the exterior of the existing conduit; and
- Constructing either a siphon spillway or "short" riser and new outlet conduit after the existing conduit has been abandoned.

In order to replace the existing conduit, excavation of the earthen embankment, removal of the deteriorated conduit, installation or construction of a new conduit, and backfill of the excavation is required. The side slopes of the excavation through embankment dams are typically limited to 2H: 1V or flatter, in order to facilitate compaction of the replacement backfill against the existing embankment. On relatively high embankments in narrow valleys, the excavation required to remove the existing low-level conduit may necessitate the removal of nearly the entire dam. The replacement option typically offers the greatest operational flexibility among the spillway rehabilitation options. This option typically offers the most thorough rehabilitation option for impaired conduits through dams, although this option can be cost-prohibitive.

Sliplining an existing pipe consists of placing a new pipe with a smaller diameter inside the existing deteriorated conduit and grouting the annular space between the two pipes. Depending on the pipe used, sliplining may increase the hydraulic capacity of the outlet pipe, even when reducing the inside diameter of the original pipe by reducing the roughness of the pipe. When designed and installed properly, the slipline technique will also add additional years to the service life to the existing conduit spillway. A sand diaphragm drain is typically installed around the downstream portion of the existing conduit to limit the potential for soil piping as the CMP eventually corrodes and deteriorates.

Grouting along the exterior of an existing conduit is often used to rehabilitate conduits that exhibit seepage through joints or deteriorated portions of the existing pipe wall. Grouting fills voids that may have been created, and to plug openings in the pipe walls or joints. Cementitious or chemical grouts are typically utilized for the purpose. Injection of the materials can be performed either from the surface of the embankment or from the interior of the conduit. This approach requires the availability of working room for grouting equipment and personnel. Use of this method, however, is limited by the depth of the conduit below the embankment surface, and whether the remediation is performed with the lake full. Injection of the grout from the interior of the pipe typically offers a better opportunity to deliver the grout to specified areas. Drilling through the embankment to grout along the conduit is usually performed for small diameter conduits or when the pipe is very shallow within the embankment. The greater the depth of fill over the conduit, the less certainty the grouting procedures are impacting the targeted areas. Drilling through the embankment is not practical for situations in which the lake cannot be drained and portions of the conduit within the upstream slope of the dam are to be grouted. Moreover, this type of repair is generally classified as "temporary" and does not extend the design life of the existing conduit material. Grouting of the exterior of a conduit pipe also retains the stage/discharge relationship of the existing spillway.

Abandonment consists of completely grouting the interior of the existing CMP with either a sand/cement grout or a gravel/sand/cement grout. In either scenario, an expansive chemical admixture is typically included in the grout mix to control or reduce shrinkage during curing of the grout. Siphons have been used successfully in the southeast but are generally limited to small drainage basins with relatively small peak inflows. Siphons can be constructed of flexible conduit such as PVC, HDPE, or Ductile Iron. Siphon spillways do not typically exceed 12-inches in diameter. Abandonment of an existing conduit and construction of a short riser and pipe spillway may be considered to be a modified version of the traditional pipe-and-riser spillway system or an economical hood inlet spillway system. Usually, the riser invert is set a vertical distance below normal pool equal to $^{1}/_{5}$ to ¼ of maximum water depth at the upstream toe of the dam. The conduit invert should be a minimum depth of 1.5 diameters below the pool elevation to avoid the capture of air due to surface water drawdown, and the associated "slugging" under full flow conditions. Installation of the siphon also requires excavation of the embankment below normal pool.

4.5.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- There is limited guidance available on siphon outlet design. EPRI published a document a number of years ago.

- Lack of guidelines for design of sliplining rehabilitation, including issues such as design criteria, grout characteristics (shrinkage), construction issues, etc.
- Feasibility of sliplining can be limited by configuration of conduit and associated gates and valves – e.g. difficulty often exists in sealing the lining located next to the gate or valve.
- BC Hydro has done some replacement of underwater, upstream structures, including control/guard gates.
- Cured-in-place (CIP) linings (e.g. Insituform) have been used for outlet conduit rehabilitation.
- NRCS has done one installation in Texas replacing a conduit by augering through an embankment dam. NRCS is considering use of microtunneling for other projects.
- Tunneling and microtunneling through a rock (sometimes soft rock) abutment with a lake tap with a full reservoir has been used and example of which was at Standley Lake located in Westminster, Colorado.
- A case was cited where an outlet works in a concrete dam in Texas was rehabilitated to replace the upstream gates and line the conduits. The upstream square-to-round transition was found to be badly deteriorated and was reformed using Belzona polymer.
- Epoxy paints have become the preferred standard for paint coatings of outlet works conduits.
- Repainting of conduits can be very difficult – hard to get moisture and temperature in a suitable range for application of a durable coating application; also access is difficult, and in some cases impractical, for small diameter conduits.
- Lead paint on existing structures can cause problems in repainting of conduits and other outlet components. There are a few products available that can be used to render the lead paint debris non-hazardous.
- Asbestos in some operating equipment can cause some environmental problems with rehabilitation.

4.5.3 Prioritization of Research and Development Ideas

The group brainstorming process resulted in the generation of 13 potential research and development ideas, which were then prioritized by the group. The 13 ideas and the results of the prioritization are presented in Exhibit 4-16.

4.5.4 Preliminary Research and Development Plans

The top four ideas listed in Exhibit 4-16 were selected for development of preliminary implementation plans, and those plans are presented in Exhibits 4-17 through 4-20. In some cases, the individual work groups reworded the research and development idea, so the ideas listed in Exhibit 4-16 may not exactly match the ideas listed in Exhibits 4-17 through 4-20.

4.6 TOPIC 6 – OUTLET WORKS INSPECTION

4.6.1 State-of-the-Practice White Paper

The strawman state-of-the-practice white paper for this topic was prepared by Chuck Cooper, and is presented in full in Attachment 9 of this report. A brief summary of the highlights of the paper is presented here.

Inspection of cut-and–cover outlet works typically includes review of features including: the entrance channel; intake structure; conduit(s); terminal structures; and the downstream channel. While there are several methodologies that may be employed in inspections, the advantages and disadvantages of each method should be assessed with due consideration given to the ease and efficiency with which inspection objectives can be met; compliance with health and safety guidelines, and cost.

The purpose of an outlet works inspection program is to ensure that conduits through dams are safely and efficiently operated and maintained. Factors to be considered in specifying inspection programs include inspection frequency; consideration of the systems, methods, and techniques used for inspection; and compliance with design criteria. Inspection intervals may vary depending on the overall conditions determined from previous inspections and the existence of any dam safety concerns. Inspections primarily vary according to scope, and frequency. The five types of inspections generally conducted are: initial or formal; periodic or intermediate; routine; special; and emergency.

Initial or formal inspections include in depth review of all pertinent data available for the outlet works to be inspected. Design and construction data are evaluated relative to current state-of-the-art guidelines to identify potential dam safety problems or areas requiring particular attention. During these inspections, an attempt is made to operate all mechanical equipment through their full operating range, if possible. Periodic or intermediate inspections are conducted between formal inspections and all mechanical equipment may not be tested during a particular inspection. Field or operating personnel typically conduct routine inspections. The primary focus in these inspections is the current condition of the outlet works. These inspections may be scheduled on a regular basis or performed in conjunction with other routine tasks. Special inspections are conducted when a unique opportunity, like low water conditions, exist. Emergency inspections are performed when an immediate dam safety concern is present or in the event of an unusual or potentially adverse condition like those resulting from the occurrence of an earthquake.

Scheduling periodic outlet works inspections may be influenced by the following factors: provision of sufficient notice to dam owners and operators allowing necessary arrangements and pre-inspection activities to be completed and needed clearances to be obtained; the ability to access most or all of the major components of the outlet works; and the opportunity to observe features operating under a wide range of conditions. Inspections of features like intake structures and upstream conduits that are usually submerged require special coordination with the dam owners since the timing of such inspections has to be carefully orchestrated and planned for.

Factors that should be considered when determining the frequency of inspection for features that are usually inundated include:

- The critical function of the feature to overall dam operations;
- Operational history and performance record of the feature since its last inspection;
- Condition of the concrete;
- Age of the feature;
- Condition of the embankment and foundation and the presence of faults in the foundation;
- Observed seepage;
- Changes in the discharge capacity of the outlet works;
- Observed damage or deterioration to visible features in the vicinity of the submerged feature;
- Water quality detrimental to concrete;
- Consideration of the secondary inspection costs including costs associated with lost water and power revenues, to provide inspection access to a feature;
- Design and construction considerations;
- Changes in relevant standards or guidelines;
- Presence of unfavorable stresses conducive to arching;
- Lack of filters and drainage material around the conduit downstream from the impervious zone of the embankment to convey seepage safely; and the
- Presence of any site conditions that may compromise the safety of the feature, and ultimately the safety of the dam.

The USBR has designated three inspection frequencies at which high hazard dams are inspected in order to detect potential dam safety deficiencies at a site. They are: annual, periodic, and comprehensive. Generalist engineers familiar with the dam and its operations, who can readily distinguish changes from year to year at the site, conduct annual inspections. Periodic inspections, also known as Periodic Facility Reviews (PFR) occur on a 6-year cycle and are conducted by a team from a regional office of the USBR that includes the regional examination specialist. Comprehensive inspections, also known as Comprehensive Facility Reviews (CFR) alternate on six-year cycles with the PFR and include examination and evaluation of the dam facility by a team of specialists from USBR's Technical Service Center.

The NRCS requires the sponsor/owner of a dam to be responsible for making inspections after the sponsor/owner assumes responsibility for a dam. Special, annual, and formal (once every 5 years) inspections are performed by personnel trained in conducting the inspections.

The U.S. Army Corps of Engineers (USACE) performs periodic, intermediate, and informal inspections on the basis of project size, importance, or potential hazard as follows:

- Initial periodic inspection – includes inspection and evaluation of a new earth or rockfill dam and is carried out immediately after topping out of the embankment prior to impoundment of the pool.
- Second periodic inspection – performed no later than one year after impoundment is initiated.
- Subsequent periodic inspections – performed at one-year intervals for the next two years of dam life. The next two inspections are performed at two-year intervals and then extended to a maximum interval of five years.
- Intermediate inspections – are performed for all or some of the features of dams on a five-year inspection cycle, if warranted. Selection is based on consequences of failure, age, degree of routine observation, a natural event (e.g. earthquake), performance record and history of remedial measures.
- Informal inspections – are performed by appropriate employees at the project at frequent time intervals to identify and report abnormal conditions and evidence of distress.

Good preparation and planning is key to the success of an inspection. Factors to be considered include: selection of the inspection team; review of the existing project data for the dam to be inspected; and the preparation of a detailed inspection plan.

The inspection of outlet works conduits is directly affected by the size of conduit to be inspected. A minimum diameter of 36 inches is required if the feature is to be inspected using man entry, or a minimum diameter of 48 inches if it is to be inspected by a diver. Specialized inspections of inundated or hard to access features often utilize a combination of divers, remotely operated vehicles (ROVs), and closed circuit television (CCTV).

Considerations that must be accounted for if divers are to be expected to conduct inspections include depth, altitude, access, leakage, currents, visibility, size of opening, and length of conduit requiring inspection. ROVs are good alternatives to dive inspections when conditions like depth, diameter, or length become prohibitive. CCTV can be used to inspect submerged portions of intake structures, conduits, and terminal structures. They can also be used to inspect structures or conduits where confined space entry issues arise. CCTV inspection equipment consists of a video camera attached to a self-propelled transport vehicle known as a crawler. An operator remotely controls both the transport vehicle and camera and video images are recorded and stored for future evaluation and documentation. Modifications to the crawler and to the camera size enable CCTV technologies to be applied to a wide range of conduit sizes.

It is further recommended that permanent markers and thorough documentation be used to facilitate easy location of intake structures that are usually submerged. Therefore, factors to be considered in planning conduit inspections should include: conduit diameter, the presence and angle of bends in the conduit, the inclination of the invert slope, and the distance between access entry locations.

4.6.2 State-of-the-Practice Refinement

The discussion of the white paper resulted in the identification of the following items to further refine the understanding of the state-of-the-practice:

- Inspection terminology, evident in the use of a term like periodic, differs among different agencies and organizations like the USACE, USBR, and FERC. Information in white paper on USACE methods, frequency, etc. is not what USACE is currently doing.
- Inspection activities should include required inspections of gates, valves, and operators. Input is needed from mechanical and electrical engineers concerning various elements that should be included in required inspections.
- Required/recommended frequencies of inspections vary among different organizations.
- GPS could be used to locate underwater structures, so they can be found more easily for future inspection. Could be done for new structures or when the structures are actually located underwater for existing structures.
- There is no clear consensus on need for periodic inspection of difficult/inaccessible features.
- Need to open valves that haven't been operated for a long time, especially for low flow (small) valves. Owners are reluctant because they are afraid the valve will not close or they are afraid of sediment flushing downstream which could result in an environmental problem.
- Emergency gates are often (sometimes) not exercised and may not work when needed.
- Full emergency gate exercise under load is rare – USACE has an operating requirement to do this test if the gate was designed to operate under load.
- Hydro-acoustic surveys of stilling basins have been done successfully by the USACE.
- Dewatering/unwatering of outlet works for gate and conduit inspections can be difficult, because of leaky gates or bulkheads.
- Requirements differ between permit-required and non-permit-required confined spaces.
- Use of air monitoring devices is recommended for outlet works inspections.
- There has been some movement toward replacing bulkheads with upstream guard gates as has been done by Denver Water.
- Conduits are not typically surveyed on a periodic basis for elevation and alignment – this is typically done only if a problem is identified.
- Ultrasonic tests can be used to test for material deterioration, however, there can be problems distinguishing between good steel and bad steel (it may all look like thickness).

- Detailed crack survey mapping (on a repeated basis) has been used to monitor structural deterioration.

4.6.2 Prioritization of Research and Development Ideas

The group brainstorming process resulted in the generation of 7 potential research and development ideas, which were then prioritized by the group. The 7 ideas and the results of the prioritization are presented in Exhibit 4-21.

4.6.3 Preliminary Research and Development Plans

The top four ideas listed in Exhibit 4-21 were selected for development of preliminary implementation plans, and those plans are presented in Exhibits 4-22 through 4-25. In some cases, the individual work groups reworded the research and development idea, so the ideas listed in Exhibit 4-21 may not exactly match the ideas listed in Exhibits 4-22 through 4-25.

EXHIBIT 4-1
PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS
WORKSHOP TOPIC 1
OUTLET WORKS FAILURE MODES

Number of Votes	Rank	Research and Development Idea
13*	1	Guidance on air inlets and blow-back.
11*	2 (Tie)	Best practices guide for conduits through <u>small</u> embankment dams.
11*	2 (Tie)	Best practices for mechanical and electrical equipment.
9*	4	Best practices for automated control of gates and valves.
8*	5	Developing lists of failure modes for various components of outlet works – baseline, not “cookbook.”
6	6	Solutions to H_2S issues for structure deterioration.
3	7 (tie)	Develop recommended exercise schedule for outlet works equipment.
3	7 (tie)	Development of requirements for dam and outlet works designers.
3	7(tie)	Application of risk and reliability to assessment of failure modes.
1	10	Development of guidance for operator training requirements.
0	11	Development of a “no-fault” reporting system of incidents not leading to failure.

* - Idea selected for development.

Note: Best practices for mechanical and electrical equipment was combined with best practices for automated control gates and valves for preliminary plan development.

EXHIBIT 4-2

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 1A
GUIDELINES FOR VENTING CONDUITS**

1. Description

A. Why is this a priority research/development item?

Poor venting can cause operational problems that lead to catastrophic failure.

B. What is the expected outcome?

Better guidelines for design, remediation and operation.

2. Project Tasks and Needs

A. What tasks are to be done?

A literature search to produce a bibliography of existing information.

B. How is the problem to be solved?

Additional physical model studies at large and small embankment dams, additional analytical work, and additional prototype testing should be conducted.

3. Project Lead and Contact

A. Who is working in this area?

Possibly European specialist in this area.

B. Who might be able to lead the project?

Some universities and private laboratories located in the United States.

C. Who are good candidates to complete the work?

1. The University of Utah and Colorado State University. Both universities have large discharge and head capacities that are capable of physically modeling the airflow.
2. A private independent consultant or a university professor might be a good source for the literature review.

EXHIBIT 4-3

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 1B
BEST PRACTICES GUIDE FOR CONDUITS
THROUGH EMBANKMENT DAMS**

1. Description

A. Why is this a priority research/development item?

No established guidelines exist, especially for consultant use. Furthermore, established standards that can be enforced by dam safety officials currently do not exist.

B. What is the expected outcome?

Guidelines for use of design engineers, inspectors, and dam safety officials.

2. Project Tasks and Needs

A. What tasks are to be done?

Use the “Conduits through Embankment Dams” document and expand for use with smaller dams.

B. How is the problem to be solved?

1. Use the existing FEMA team and expand team with additional state members and consultants.
2. Conduct research into long term performance into conduit materials.
3. Conduct research into failure of preferred outlet conduit designs.
4. Compile and evaluate different outlet conduit design standards.
5. Clearing house for updating design references to be used in the guidelines. ASDSO would be an agency to consider.
6. Develop a brochure for the new document for distribution to the engineering community that can also be posted on the FEMA website. Data from the guidelines summarized in the brochure could be used to update documents published by organizations like the AWWA. The guidelines should be used during the design of conduits for embankment dams.

3. Project Lead and Contact

A. Who is working in this area?

It is currently not known if anyone is working in this area.

B. Who might be able to lead the project?

Chuck Cooper currently of the U.S. Bureau of Reclamation.

C. Who are good candidates to complete the work?

Mr. Sal Todaro, currently of URS Corporation and independent consultant Ed Rossilson.

EXHIBIT 4-4

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 1C
BEST PRACTICES FOR MECHANICAL AND
ELECTRICAL DESIGN AND AUTOMATED CONTROL**

1. Description

A. Why is this a priority research/development item?

Lack of knowledge leads to failure modes, agencies and consultants could benefit, and mechanical/electrical design is often secondary to civil design.

B. What is the expected outcome?

Transfer of knowledge and technology.

2. Project Tasks and Needs

A. What tasks are to be done?

Find knowledgeable people and define a process to gather data and information which should be processed into a usable form.

B. How is the problem to be solved?

No answer provided.

3. Project Lead and Contact

A. Who is working in this area?

To the best knowledge of workshop team members no one is currently working in this area.

B. Who might be able to lead the project?

The USBR, USACE, and the USSD.

C. Who are good candidates to complete the work?

Retirees and experienced designers, operations and maintenance personnel, field technicians, gate designers, and manufactures of related components.

EXHIBIT 4-5

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 1D
DEVELOP A LIST OF FAILURE MODES FOR OUTLET WORKS

1. Description

A. Why is this a priority research/development item?

Reduce future outlet works failures by making dam designers and owners aware of potential failure modes of outlet works components.

B. What is the expected outcome?

A compendium of potential failure modes for use in design, inspection, and operation of outlet works to ultimately reduce outlet works failures.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Identify forms of failure.
2. Basic research and literature review of outlet failure modes.
3. Solicit input from various federal dams, state, dam safety organizations in order to develop a list of failure modes
4. Convene workshop to refine list
5. Incorporate comments from federal and state agencies
6. Publish final list.

B. How is the problem to be solved?

No answer provided.

3. Project Lead and Contact

A. Who is working in this area?

FERC, the USACE, BC Hydro, USBR, ICOLD and Swede Power.

B. Who might be able to lead the project?

Dr. David Bowles (Utah State University), Marty McCann of the NPDP, Dr. Des Hartford, and Larry Von Thun, consultant.

C. Who are good candidates to complete the work?

No answer provided.

EXHIBIT 4-6

PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS
WORKSHOP TOPIC 2
CONDUIT MATERIALS, SELECTION CRITERIA,
AND CONSTRUCTION METHODS

Number of Votes	Rank	Research and Development Idea
15*	1	Best practices guidelines for intake towers – configuration, access, debris/trash control, seismic performance, selective withdrawal.
13*	2	Guidance on application of tunnels to outlet works – including consideration of microtunneling and of soft ground and hard ground tunneling alternatives.
12*	3	Compile data on performance of conduits through embankments for cases where the conduits have experienced significant settlement (such as some of those shown in the white paper presentation).
6*	4	Guidance on seismic effects on conduits and how conduits should be analyzed/designed for these effects – embankment spreading, fault offset, propagation of earthquake waves.
5	5	Measurement of loads on conduits for comparison to predicted loads,
1	6 (tie)	Revision to the ASCE penstock guidelines.
1	6 (tie)	Guidance on use and applicability of siphon outlet works – update earlier EPRI document.

* - Idea selected for development.

EXHIBIT 4-7

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 2A
BEST PRACTICES FOR INTAKE TOWERS INCLUDING LOCATION, CONFIGURATION, ACCESS, DEBRIS/TRASH CONTROL, SEISMIC PERFORMANCE, AND SELECTIVE WITHDRAWALS**

1. Description

A. Why is this a priority research/development item?

1. Changes in the state-of-the-practice in the application of seismic loads.
2. Changes in water quality requirements.
3. Past experience with poorly designed and positioned intake towers.

B. What is the expected outcome?

Development of a best practices guide.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Identify features of intake towers that merit study.
2. Survey existing owners and operators of intake towers via the ASDSO.
3. Gather available literature.
4. Compile information gathered into a summary document with recommendations.

B. How is the problem to be solved?

Development of a best practices guide.

3. Project Lead and Contact

A. Who is working in this area?

The USACE, independent consulting engineers, and the USSD.

B. Who might be able to lead the project?

FEMA.

C. Who are good candidates to complete the work?

The USBR and the USACE.

EXHIBIT 4-8

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 2B
GUIDANCE ON APPLICATION OF TUNNELS FOR OUTLET WORKS
INCLUDING MICROTUNNELLING IN SOFT AND HARD GROUND

1. Description

A. Why is this a priority research/development item?

1. The high rate of failures due to piping accounting for approximately one quarter (25%) of embankment dam failures.
2. Penetration through dams needs to be eliminated.

B. What is the expected outcome?

1. A document or manual to provided guidance to help decide whether to use a tunnel or not, and to provide design guidance and costs.
2. Define appropriate geotechnical conditions for tunnel construction.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Literature search on the use of tunnels and on the rationale for the use of tunnels in dams. Case studies where tunnels were used or selected for design should be researched and compiled.
2. Develop pros and cons of the use of tunnels versus conduits in dam outlet works.
3. Develop selection criteria including relative cost.
4. Cost benefit analyses of the inclusion of tunnels should be performed.

B. How is the problem to be solved?

No answer provided.

3. Project Lead and Contact

A. Who is working in this area?

To the best knowledge of workgroup team members, no one is currently working in this area.

B. Who might be able to lead the project?

FEMA, ASDSO, USBR, and experienced designers.

C. Who are good candidates to complete the work?

Former USBR tunnel designers, non-government tunnel designers, experienced tunnel expert, and geotechnical designers with tunneling experience. The USACE also has experience with microtunneling under levees.

EXHIBIT 4-9

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 2C
COMPILE DATA ON PERFORMANCE OF CONDUITS
WITH SIGNIFICANT SETTLEMENT AND LATERAL MOVEMENT**

1. Description

A. Why is this a priority research/development item?

There are procedures to estimate settlement and lateral movement that have not been validated.

B. What is the expected outcome?

Verification of the existing procedures used to estimate settlement and lateral movement.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Gather existing data on USBR and USACE conduits along with site specific conditions.
2. Collect conduit data and site specific conditions on NRCS dams.
3. Compare actual settlements and lateral movements with estimates using current design procedures.
4. Look for site specific conditions or construction procedures that may lead to satisfactory performance.
5. If current analysis procedures prove incorrect, conduct a computer analysis to fit the data and develop new design guidance.

B. How is the problem to be solved?

No answer provided.

3. Project Lead and Contact

A. Who is working in this area?

The USACE and the USBR may be collecting some data.

B. Who might be able to lead the project?

FEMA could assist with the acquisition of data.

C. Who are good candidates to complete the work?

1. A representative from USBR, USACE, and NRCS is recommended.
2. State and city agencies that may have some data
3. Several consultants involved in design, inspection, and analysis of conduits.

EXHIBIT 4-10

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 2D
GUIDANCE ON SEISMIC EFFECTS ON CONDUITS AND HOW
TO ANALYZE AND DESIGN FOR THEM INCLUDING EMBANKMENT SPREADING,
FAULT OFFSET, AND THE PROPAGATION OF EARTHQUAKE WAVES**

1. Description

A. Why is this a priority research/development item?

A priority because it is a dam safety concern with limited documented available for analysis and design.

B. What is the expected outcome?

A document or chapter or section in a larger document of reference material and design guidance.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Literature research of currently available documentation and design guidance.
2. Address various types of material i.e. soil, rock, etc., that will be encountered.
3. Establish a multi-disciplined team/committee to formulate the framework/outline of the document and to identify available information and areas of need or where gaps in information exist.
4. Distinguish the difference between analysis of existing conduits and the design and construction of new conduits.

B. How is the problem to be solved?

Solicit information from state and federal agencies by surveys/questionnaires dealing with earthquakes where their structures are located.

3. Project Lead and Contact

A. Who is working in this area?

The USGS, NEHRP, and the University of California at Berkeley.

B. Who might be able to lead the project?

EPRI, the ASDSO, and the dam safety groups of western states.

C. Who are good candidates to complete the work?

1. Blast research groups like those at the USACE, and the University of Florida.
2. The USBR and the USACE, particularly units located in the western states.

3. Furthermore, since this is a multidiscipline issue, we propose that a professional society like ASCE produce a design manual, or solicit papers for a conference and publish the proceedings.

EXHIBIT 4-11

**PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS
WORKSHOP TOPIC 3 AND TOPIC 4
GATES, VALVES, CONTROLS AND ENERGY DISSIPATORS**

Number of Votes	Rank	Research and Development Idea
11*	1	Best practices for selection of gates, valves, and controls – considering heads, velocities, configurations, etc.
10*	2	Best practices for energy dissipators – considering heads, velocities, configurations, etc.
9*	3	Guidelines for maintenance and exercise of gates and valves and for cavitation repair.
7*	4	Develop and present a short course on gates and valves for dams – design, operation, and maintenance – (consider videotaping the course?)
4	5	Develop expert videos (DVDs) as has been done for other dam safety topics (e.g. Peck, Idriss) for gates and valves and energy dissipators.
1	6 (tie)	Research to develop guidance for variation of air demand for fixed-cone valves
1	6 (tie)	Compile understanding of international efforts in gates and valves and energy dissipators.
1	6 (tie)	Develop guidance for incorporation of seismic requirements into design of gates, valves, and operating systems.
0	9 (tie)	Guidance document for environmentally-acceptable fluids for hydraulic controls.
0	9 (tie)	Develop an information document on current gate and valve manufacturers – domestic and international.

* - Idea selected for development.

EXHIBIT 4-12

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 3A
BEST PRACTICES FOR SELECTION OF GATES AND VALVES

1. Description

A. Why is this a priority research/development item?

- It would aid in transferring information.
- To aid in preventing errors in selection, operation, and placement of gates and valves.

B. What is the expected outcome?

An up-to-date manual on selection, operation, and system layout.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Identify a sponsor like ASME or EPRI.
2. Identify a team.

B. How is the problem to be solved?

Team effort with perseverance.

3. Project Lead and Contact

A. Who is working in this area?

- Consulting firms.
- Chinese water resources.

B. Who might be able to lead the project?

An active consultant.

C. Who are good candidates to complete the work?

- Consultants.
- Technical personnel from manufacturers in both the United States and Europe.
- Western European engineers.

EXHIBIT 4-13

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 4A
BEST PRACTICES FOR ENERGY DISSIPATORS –
CONSIDERING HEADS, VELOCITIES, CONFIGURATIONS, ETC.

1. **Description**

   A. Why is this a priority research/development item?

   Experienced engineers are rapidly becoming fewer and their knowledge and experience needs to be captured.

   B. What is the expected outcome?

   1. Individual publications on each energy dissipator (E.D.).
   2. Report with overview of all energy dissipators with advantages, disadvantages, and applications based on variety of parameters, e.g. head (H) versus flow (Q).

2. **Project Tasks and Needs**

   A. What tasks are to be done?

   1. Develop theoretical model for each E.D.
   2. Gather empirical data for each E.D.
   3. Calibrate theoretical to empirical.
   4. Characterize range of satisfactory behavior.
   5. Identify gaps in range of application.
   6. Identify environmental effects.
   7. Summarize findings in overview report.

   B. How is the problem to be solved?

   - Criteria need to be examined and updated.
   - Lessons learned and experience needs to be captured.
   - Theories were developed years ago and applications need to be assessed.

3. **Project Lead and Contact**

   A. Who is working in this area?

   Many people might be working on individual aspects, but it all needs to be brought together.

   B. Who might be able to lead the project?

   The laboratories of the USACE (ERDC).

C. Who are good candidates to complete the work?

Individuals like Jim Gordon, Will Hager, State and Federal Agencies, or Chinese researchers/specialists in this area.

EXHIBIT 4-14

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 3B
GUIDELINES FOR MAINTENANCE AND EXERCISE OF
GATES AND VALVES AND CAVITATION REPAIRS**

1. Description

A. Why is this a priority research/development item?

1. It is well documented that poor maintenance of outlet works is a problem and represents a dam safety concern.
2. Currently in cases of emergency, gates and valves are assumed to be operational without the exercise of these components on a routine basis.

B. What is the expected outcome?

1. Guideline documents for maintenance and exercise of gates and valves.
2. Training device for dam owners to show the importance of maintaining the facility in an operable condition.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Research on known cases of failure of outlet works gates and valves.
2. Research on corrosion effects of water chemistry on operation and/or maintenance.
3. Survey federal, state, and large private dam owners, consultants in the field, and dam regulators about maintenance concerns, programs, and past experiences.
4. Impress upon members of academia the importance of maintenance consideration along with the design of outlet gates and valves.
5. Standardize inspection protocol by preparing a review checklist.

B. How is the problem to be solved?

ASDSO needs to be the vehicle to develop a document for the procedures and means of maintenance and exercise of gates and valves.

3. Project Lead and Contact

A. Who is working in this area?

Currently no one is working in this area to the knowledge of the workgroup team.

B. Who might be able to lead the project?

FEMA and ASDSO with contributions from USACE, FERC, and the USBR.

C. Who are good candidates to complete the work?

FEMA and ASDSO.

EXHIBIT 4-15

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 3C
DEVELOP SHORT COURSES WITH VIDEO/DVD OPTIONS ON
DESIGN, OPERATION, AND MAINTENANCE OF GATES AND VALVES**

1. Description

A. Why is this a priority research/development item?

We are losing knowledge of senior experts and technology in the United States is declining due to not building new dams while at the same time we have an aging infrastructure of existing dams that will need rehabilitation.

B. What is the expected outcome?

A transfer of knowledge and technology to current and future practitioners.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Develop scope of short course (including such topics as history, state of the practice discussions, world practices, lessons learned, and best practices).
2. Identify target audiences that would include civil engineers, mechanical engineers, electrical engineers, and other individuals to be identified whose professional practice would be benefited by such a knowledge transfer.

B. How is the problem to be solved?

1. Through a contract RFP. The selected contractor needs to bring recognized experts as instructors. A major factor in selection will be the knowledge and experience breadth of experts brought to the courses.
2. Evaluation of the video/DVD needs to be an option of the RFP and needs to be considered within the structure of the short course.

3. Project Lead and Contact

A. Who is working in this area?

No single entity is working in this area and as such a composite team would be required.

B. Who might be able to lead the project?

This project could be sponsored by FEMA, ASDSO, USSD, and EPRI.

C. Who are good candidates to complete the work?

The composite team of members from the sponsoring agencies could be lead by an expert or practicing consulting firm.

EXHIBIT 4-16

PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS
WORKSHOP TOPIC 5
REHABILITATION OF CONDUITS

Number of Votes	Rank	Research and Development Idea
14*	1 (tie)	Design guidance and guide specifications for sliplining of outlet conduits.
14*	1 (tie)	Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs.
8*	3 (tie)	Assessment of microtunneling and boring technologies for application to outlet conduit rehabilitation.
8*	3 (tie)	Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement.
7	5	Design guidance and guide specifications for cured-in-place lining of outlet conduits – considering high velocity flows, end constraints, etc..
6	6 (tie)	Research/guidance on methods for rehabilitation of conduit deterioration from chemical attack (e.g. H_2S).
6	6 (tie)	Best practices guide for abandonment of outlet conduits in-place.
2	8 (tie)	Grout materials research on grout properties for sliplining applications.
2	8 (tie)	Assessment and development of paint technologies for application in damp, cool, confined spaces and for operation in high velocity environments.
1	10 (tie)	Research on aging and thermal properties of HDPE pipe materials and installations.
1	10 (tie)	Applicability and appropriateness of using downstream controls to replace difficult-access upstream gates and valves – special requirements for converting non-pressure pipe to pressure pipe.
1	10 (tie)	Best practices guide for design, construction, and operation of siphon outlet works/spillways.
1	10 (tie)	Consideration of effects on seepage pattern in embankments after relining a leaky conduit.

* - Idea selected for development.

EXHIBIT 4-17

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 5A
DESIGN GUIDANCE AND GUIDE SPECIFICATIONS FOR SLIPLINING**

1. Description

A. Why is this a priority research/development item?

1. Potential big market given the large number of projects in need, particularly those that have either reached or are fast approaching the end of their service life.
2. Need cost effective solutions given owner's ability to pay i.e. cost sensitivity is critical.
3. Limited information is available, especially for material selection, and primarily from pipe suppliers.

B. What is the expected outcome?

1. Material selection (paint, pipe, grouts) guide specifications for grouting procedures.
2. Standard design details, especially for special arrangements.
3. Distinguish between pressure versus non-pressure conditions.
4. A list of design considerations including corrosion, erosion, head, flow and hydraulic capacity.
5. A logic tree to aid in the evaluations of response modes including abandonment, sliplining, or other options like excavation and replacement.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Data search
2. Develop case studies through discussions with designers, owners and contractors. Find out what experience exists.
3. Offer a symposium or conference potentially sponsored by the USSD, at which white papers are presented.
4. Form a committee to develop guidelines and provide examples.
5. Work with ASCE, FEMA, and USSD to publish results of all R&D activities previously indicated.

3. Project Lead and Contact

A. Who is working in this area?

USBR, NRCS, and consultants.

B. Who might be able to lead the project?

NRCS.

C. Who are good candidates to complete the work?

USBR, NRCS, pipe suppliers, grout manufacturers, contractors, and designers.

EXHIBIT 4-18

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 5B
COMPILATION OF CASE STUDIES ON OUTLET WORKS
REHABILITATION – LESSONS LEARNED, PERFORMANCE,
AND COMPARATIVE COSTS**

1. Description

A. Why is this a priority research/development item?

1. It provides a forum for lessons learned to be discussed.
2. Allows for the transfer of experiences among practitioners.

B. What is the expected outcome?

1. A decision tool for selecting rehabilitation alternatives for a specific application.
2. Transfer experiences.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Distinguish between low versus high need application
2. Distinguish access versus pipe size methods.
3. Survey agencies, private industry, and consultants.
4. Have a conference or forum from which the proceedings can be published.
5. Summarize trends similar to USSD and ICOLD publications in a document that should be updated on a periodic basis.
6. An audit group or committee should be assembled to balance bias with information that is too generalized.
7. Review case studies to ensure that sensitive specifics about actual projects are removed to eliminate concerns about liability or disclosure of failures.

3. Project Lead and Contact

A. Who is working in this area?

ASCE has previously published lessons learned.

B. Who might be able to lead the project?

A group committee comprised of engineers with a range of experience in both small and large dams should be comprised of members from professional organizations.

C. Who are good candidates to complete the work?

Water Resources Research Institute (WRRI) for land-grant colleges, university professors (although a drawback is that this individual may have limited hands-on experience), Earl Eiker of USSD's Hydraulics Committee, and ASCE's Hydraulics Structures Committee. The knowledge and experience of FEMA's incident response group should be tapped for larger-scale problems. The Department of Homeland Security may also fund incident investigations.

EXHIBIT 4-19

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 5C
ASSESSMENT OF MICROTUNNELLING AND BORING TECHNOLOGIES FOR APPLICATION TO OUTLET CONDUIT REHABILITATION

1. Description

A. Why is this a priority research/development item?

Because these techniques are being applied to low head dams in limited applications and there are no guidelines.

B. What is the expected outcome?

Guidelines for appropriate or inappropriate use of these techniques.

2. Project Tasks and Needs

A. What tasks are to be done?

A literature search fro application of micro-tunneling in embankment and foundation material including upstream seepage cutoffs backing filter systems and stilling systems for steep pipe applications.

B. How is the problem to be solved?

Explore contracts and manufacturer's associations for funding this research and application. Back up by advisory board of dam consultants.

3. Project Lead and Contact

A. Who is working in this area?

NRCS applications in upgrade of existing FRS facilities about normal water pool as seen at Standley Dam's outlet works in Westminster, Colorado where the abutment was rehabilitated.

B. Who might be able to lead the project?

The dam groups of the NRCS, Fish and Wildlife, and the Bureau of Indian Affairs, and dam consultants.

C. Who are good candidates to complete the work?

NRCS' national engineering group with the assistance of consulting engineers.

EXHIBIT 4-20

RESEARCH AND DEVELOPMENT IMPLEMENTATION PLAN, R&D TOPIC 5D BEST PRACTICES GUIDE FOR DESIGN AND CONSTRUCTION METHODS TO REBUILD EMBANKMENT SECTIONS FOR CONDUIT REMOVAL AND REPLACEMENT

1. Description

A. Why is this a priority research/development item?

1. There are currently no design or construction guidelines for reconstruction of breaches through embankment dams for outlet works replacement.
2. No preferred method of replacement or rehabilitation of outlet works structures has been identified.
3. There is more of a need to replace outlet works than currently practiced.
4. If the maximum section of a dam is not constructed properly, failure could result.
5. There are currently unaddressed concerns with the treatment of soft foundations.
6. New embankments need to be tied into zoning of the existing embankment with draining systems an area of particular concern.

B. What is the expected outcome?

Guidelines to address the issues of the reconstruction of partial removal of dam embankments to be used by consultants and dam regulators.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Conduct literature research of existing guidelines like the Levee Design Manual developed by the USACE, and case histories. Information gathered from a compilation of case studies should be used to develop a set of guidelines for this R&D topic.
2. Survey designers, contractors and designers to develop documentation of experience resources.
3. Develop guidance documents to be peer reviewed.
4. Produce the final product in the form of a published set of embankment rebuilding and conduit removal and replacement guidelines.

3. Project Lead and Contact

A. Who is working in this area?

Currently no one is working in this area to the knowledge of the workgroup team. Most practitioners have their own independent in-house practices that they follow.

B. Who might be able to lead the project?

NRCS, ASDSO, and consultants.

C. Who are good candidates to complete the work?

Mr. David Hammer, formerly of the USACE who has experience with the construction of embankments around existing outlets, and who has also authored several papers. Mr. Art Walhs with Garnett-Flemming, and Mr. Clark Stanage, formerly of the USACE would also be good candidates to conduct this work.

EXHIBIT 4-21

PRIORITIZATION OF RESEARCH AND DEVELOPMENT IDEAS
WORKSHOP TOPIC 6
OUTLET WORKS INSPECTION

Number of Votes	Rank	Research and Development Idea
13*	1	Applications of nondestructive testing to inspection of outlet works.
11*	2 (tie)	Best practices for inspection of gates, valves, and operators (mechanical and electrical components).
11*	2 (tie)	Best practices guide for inspection frequency and methods for more-typically accessible outlet works features.
9*	4	Develop consensus recommendations for inspection of normally inundated structures and very-difficult-to-inspect structures.
2	5	Use of digital imaging or other technologies to improve the efficiency of crack mapping or defect mapping.
1	6 (tie)	Updating the TADS modules to reflect newer methods, technologies, and standards.
1	6 (tie)	Establish practical and environmentally acceptable methods and materials to seal leaking gates and bulkheads to allow inspection of outlet works.

* - Idea selected for development.

EXHIBIT 4-22

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 6A
APPLICATIONS OF NON-DESTRUCTIVE TESTING (NDT)
FOR INSPECTION OF OUTLET WORKS**

1. Description

A. Why is this a priority research/development item?

1. Non Destructive Testing provides a unique and consistent technique enabling the inspection of outlet works.
2. There is currently no clear description of the capabilities of NDT for application to outlet works inspections.
3. Consistent guidelines of how to interpret the results of non-destructive tests need to be developed.

B. What is the expected outcome?

Non-destruction tests being used to confirm the structural integrity of outlet works structures.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Conduct a survey of suppliers or manufacturers of what equipment is available on the market.
2. An inventory of what is needed that is currently unavailable needs to be made.
3. The state of the practice today needs to be documented.
4. A best practices guide on the use of equipment including costs, capabilities, and applications needs to be developed to increase the understanding of non-expert practitioners.
5. Develop tests to confirm theoretical projections of performance with actual conditions.

3. Project Lead and Contact

A. Who is working in this area?

Mr. Chuck Copper of the USBR, the Vicksburg, MS or Champagne, IL divisions of the USACE, and Hydro Quebec.

B. Who might be able to lead the project?

USBR.

C. Who are good candidates to complete the work?

USBR.

EXHIBIT 4-23

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 6B
BEST PRACTICES FOR INSPECTION OF GATES, VALVES,
AND OPERATORS, INCLUDING MECHANICAL
AND ELECTRICAL COMPONENTS**

1. Description

A. Why is this a priority research/development item?

1. To avoid the failure of these features.
2. These features are exposed elements and more sensitive than other components of the dam and need to be more closely monitored.

B. What is the expected outcome?

1. Guidelines for the inspection of mechanical and electrical equipment.
2. Increased confidence in the reliability of operation of the equipment.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Research existing practices of federal and non-federal dam owner organizations, including international experience e.g. ICOLD.
2. Consult with equipment manufacturers about recommended practices.
3. Investigate alternative testing procedures.

B. How is the problem to be solved?

1. Developing guidelines.
2. Consideration of additional state regulations.

3. Project Lead and Contact

A. Who is working in this area?

No one to the knowledge of the workgroup team.

B. Who might be able to lead the project?

Dam Safety organizations like ASDSO, and USSD.

C. Who are good candidates to complete the work?

An interdisciplinary team consisting of regulators, dam owners, equipment manufacturers, and mechanical and electrical designers is believed best suited for this work.

EXHIBIT 4-24

**RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 6C
BEST PRACTICES GUIDE FOR INSPECTION FREQUENCY AND
METHODS OF INSPECTION FOR TYPICALLY ACCESSIBLE CONDUITS**

1. Description

A. Why is this a priority research/development item?

1. No consistency on frequency and methods of inspection.
2. Problems may be uncovered that may not otherwise be noted where no inspections are done.
3. May provide guidelines that state or federal agencies may use to require dam owners to follow.

B. What is the expected outcome?

1. Inspection guidelines including frequency of inspection tied to hazard potential conduit materials and the age of the outlet.
2. May influence state or federal policy on outlet inspections.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Literature search on current practices. Develop table of practices and provide a list of references.
2. List and discuss various remote monitoring techniques and advantages and disadvantages.

B. How is the problem to be solved?

1. Solicit input from various dam safety agencies at both the state and federal level, private consultants for inspections versus the type of outlet.
2. Prepare a question and answer sheet to be answered by private consultants from both state and federal agencies.
3. Workshop to provide best recommendations.

3. Project Lead and Contact

A. Who is working in this area?

1. ASDSO, ASCE, USSD, USBR, and Mr. Larry Von Thun. This work might also include revisiting the inspection portion of the Model Dam Safety Law.

B. Who might be able to lead the project?

FEMA through its internal R&D mechanisms.

C. Who are good candidates to complete the work?

The same team leading this project is a good candidate to complete work tasks.

EXHIBIT 4-25

RESEARCH AND DEVELOPMENT
IMPLEMENTATION PLAN, R&D TOPIC 6D
INSPECTION OF NORMALLY INUNDATED STRUCTURES
AND DIFFICULT TO ACCESS AREAS

1. Description

A. Why is this a priority research/development item?

1. This subject is of high priority because this work is often deferred and does not get done.
2. No guidelines currently exist to determine the importance or necessity.

B. What is the expected outcome?

1. Develop guidelines for go/no-go procedures that might include consideration of outcomes, water quality, design margins, and operation history.
2. Develop guidelines for inspection frequency.
3. Develop methods and/or technologies for actually performing inspections.
4. Possible recommendations or design considerations to facilitate future inspections.

2. Project Tasks and Needs

A. What tasks are to be done?

1. Identify type of structure first.
2. Data search and case studies to get a feel for the risks that are involved.
3. Probability and risk assessment of structure to rank priorities.

3. Project Lead and Contact

A. Who is working in this area?

No one is currently working in this area to the knowledge of the respondent.

B. Who might be able to lead the project?

The USBR.

C. Who are good candidates to complete the work?

Dam owners and diving and inspection agencies.

As discussed in Section 4, the prioritization of the research and development ideas for each of the six topics (with Topic 3 and Topic 4 combined) considered in the workshop resulted in the identification of 20 leading ideas (4 ideas for each topic), for which preliminary implementation plans were developed.

The potential benefit and associated implementation cost of each of the 20 R&D topics were assigned a score between zero and ten by sixteen workshop participants as will be discussed below. The scores, which were based on consideration of the balance of benefit to practice and cost/ease of implementation, were then averaged in order to determine overall rankings for each of the research and development ideas.

Potential Benefit

In order to provide an assessment of potential benefit, workshop participants were asked to use the form shown in Attachment 3 to assign a score from 0 to 10 with 0 being least beneficial and 10 most beneficial. to each of the 20 R&D ideas selected to develop preliminary plans. As may be seen on Exhibit 5-1, the top 11 R&D ideas (including a tie for the 10th position) generated by assessing this factor provided by 16 participating workshop respondents were as follows:

1. Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments. (R& D Topic 1B)

2. Best-practices guide for selection of gates and valves for outlet works structures. (R&D Topic 3A)

3. Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs. (R&D Topic 5B)

4. Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc. (R&D Topic 4A)

4. Design guidance and guide specifications for sliplining of outlet conduits. (R&D Topic 5A)

6. Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works. (R&D Topic 3B)

7. Best-practices guide for mechanical and electrical design and for automated control for outlet works. (R&D Topic 1C)

8. Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components. (R&D Topic 6B)

9. Best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, selective withdrawals, etc. (R&D Topic 2A)

10. Develop a list of failure modes for outlet works. (R&D Topic 1D)

10. Develop short course (with video/DVD option) on design, operation, and maintenance of outlet works gates and valves. (R&D Topic 3C)

Please note that this list includes ideas tied at ranks of 4 and 10.

Cost/ Ease of Implementation

To provide an assessment of cost or perceived difficulty/ease of implementation associated with the same 20 R&D ideas selected for preliminary development, workshop participants were asked to assign a score for this factor from 0 to 10 with 0 indicating unfavorable high cost/difficulty of implementation and 10 indicating favorable low cost or perceived easy implementation. As may be seen on Exhibit 5-2, the top 10 R&D ideas as ranked by the same 16 participating workshop respondents were as follows:

1. Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works. (R&D Topic 3B)

2. Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits. (R&D Topic 6C)

3. Best-practices guide for selection of gates and valves for outlet works structures. (R&D Topic 3A)

3. Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments. (R&D Topic 1B)

5. Develop a list of failure modes for outlet works. (R&D Topic 1D)

5. Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement. (R&D Topic 5D)

5. Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components. (R&D Topic 6B)

8. Best-practices guide for mechanical and electrical design and for automated control for outlet works. (R&D Topic 1C)

8. Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc. (R&D Topic 4A)

8. Design guidance and guide specifications for sliplining of outlet conduits. (R&D Topic 5A)

As seen above, ranking according to this measure resulted in ties at ranks 3, 5, and 8.

Overall Prioritization of Research and Development Ideas

In reviewing the results of the overall ranking according to potential benefit (Exhibit 5-1) and favorable cost/ease of implementation (Exhibit 5-2), it is seen that the priority order of R&D ideas varied somewhat between the two factors assessed. However, by averaging the scores from both assessments an overall average score and ranking of the 20 R&D ideas for which preliminary plans were developed could be obtained as seen in Exhibit 5-3. The resulting top 10 ideas are:

1. Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments. (R&D Topic 1B)

2. Best-practices guide for selection of gates and valves for outlet works structures. (R&D Topic 3A)

3. Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works. (R&D Topic 3B)

4. Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc. (R&D Topic 4A)

4. Design guidance and guide specifications for sliplining of outlet conduits. (R&D Topic 5A)

6. Best-practices guide for mechanical and electrical design and for automated control for outlet works. (R&D Topic 1C)

7. Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs. (R&D Topic 5B)

7. Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components. (R&D Topic 6B)

9. Develop a list of failure modes for outlet works. (R&D Topic 1D)

9. Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits. (R&D Topic 6C)

This combined ranking generated ties at rank 4, 7, and 9 and is believed to indicate some degree of prioritization among R&D ideas. The cost-benefit comparison chart shown in Exhibit 5-4 further indicates that the top 10 R&D ideas from the overall rankings would all generate high benefit and had a comparatively low associated implementation cost.

Based on the combination of the rankings, the following five topics should be considered highest priority for research and development:

- Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments. (R&D Topic 1B)
- Best-practices guide for selection of gates and valves for outlet works structures. (R&D Topic 3A)
- Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works. (R&D Topic 3B)
- Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc. (R&D Topic 4A)
- Design guidance and guide specifications for sliplining of outlet conduits. (R&D Topic 5A)

All five of these ideas ranked in the top 10 in both assessments of potential benefit and cost/ease of implementation, and were ranked 1 through 4 (with a tie for 4th) in the average ranking.

The next five research and development ideas listed in Exhibit 5-3 should also be considered high priority R&D ideas, but not as high as the first four topics indicated above. These five topics are:

- Best-practices guide for mechanical and electrical design and for automated control for outlet works. (R&D Topic 1C)
- Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs. (R&D Topic 5B)
- Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components. (R&D Topic 6B)
- Develop a list of failure modes for outlet works. (R&D Topic 1D)

- Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits. (R&D Topic 6C)

R&D topics 1C, 6B and 1D were ranked in the top 10 in both benefit and cost/ease of implementation rankings while R&D topic 5B was among the top 10 in the ranking of potential benefit, while R&D topic 6C was the second most favorable R&D idea from a cost/ease of implementation perspective. Consequently, it is the authors' opinion that these five R&D topics should be considered high priority, but not as high as the top five ideas previously indicated.

Other R&D topics that received a top 10 ranking in at least one of the two overall ranking methods used to prioritize ideas were:

- Develop a best-practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement. (R&D Topic 5D)
- Develop a best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, and the practice of selective withdrawals. (R&D Topic 2A)
- Develop a short course with the possibility of a companion video/DVD format on design, operation, and maintenance of outlet works conduits. (R&D Topic 3C)

These R&D topics deserve some consideration for implementation, but at a lower priority than the 10 ideas previously indicated.

The remaining seven R&D topics did not receive top 10 ratings in either of the two assessment gauges used, and therefore should be considered much lower on the priority scale for implementation.

Observations Concerning Research and Development Ideas

As discussed in Section 2, a review of the leading R&D topics indicates that none of them involve basic laboratory testing. Rather most of the R&D topics involve collecting or compiling available information and developing guidelines for dissemination to practitioners to enable consistency in design, maintenance, and inspection activities throughout the field of practice. This suggests that the overall challenges associated with various aspects of outlet works design, maintenance and inspection result from the absence of documented information, inconsistencies among available information, misuse or misapplication of the available information by some practitioners, or lack of knowledge of available information by some practitioners. It also seems to reflect a feeling that the information on the overall topic is too dispersed for the profession to make the best use of lessons-learned from past performance, and that compilation of information into more readily available sources would be beneficial.

EXHIBIT 5-1

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON INDIVIDUAL SCORES FOR POTENTIAL BENEFIT

TOPIC NUMBER	RESEARCH/DEVELOPMENT TOPIC(S)	SCORE 0 to 10[1]	RANK
1B	Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments.	8.1	1
3A	Best-practices guide for selection of gates and valves for outlet works structures.	7.6	2
5B	Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs.	7.5	3
4A	Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc.	7.4	4
5A	Design guidance and guide specifications for sliplining of outlet conduits.	7.4	4
3B	Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works.	7.1	6
1C	Best-practices guide for mechanical and electrical design and for automated control for outlet works.	7.0	7
6B	Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components.	6.8	8
2A	Best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, selective withdrawals, etc.	6.7	9
1D	Develop a list of failure modes for outlet works.	6.4	10
3C	Develop short course (with video/DVD option) on design, operation, and maintenance of outlet works gates and valves.	6.4	10

Note: (1) 0 is lowest benefit and 10 is highest benefit.

EXHIBIT 5-1

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON INDIVIDUAL SCORES FOR POTENTIAL BENEFIT

-CONTINUED-

TOPIC NUMBER	RESEARCH/DEVELOPMENT TOPIC(S)	SCORE 0 to 10(1)	RANK
6C	Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits.	6.2	12
1A	Guidelines for venting outlet works.	6.1	13
2C	Compile data on performance of conduits with significant settlement and lateral movement.	6.1	13
2D	Guidance on seismic effects on conduits and methods for analysis and design to address those effects (e.g. embankment spreading, fault offset, propagation of earthquake waves).	6.1	13
5D	Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement.	5.9	16
6D	Guidelines for inspection of normally inundated structures and other difficult-to-access features.	5.4	17
2B	Guidance on application of tunnels for outlet works – including consideration of microtunneling and of both soft-ground and hard-ground tunneling.	5.3	18
5C	Assessment of microtunneling and boring technologies for application to outlet conduit rehabilitation.	5.3	18
6A	Applications of non-destructive testing (NDT) for inspection of outlet works.	5.3	18

Notes: (1) 0 is lowest benefit and 10 is highest benefit.

EXHIBIT 5-2

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON INDIVIDUAL SCORES FOR COST/EASE OF IMPLEMENTATION

TOPIC NUMBER	RESEARCH/DEVELOPMENT TOPIC(S)	SCORE 0 to 10(1)	RANK
3B	Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works.	6.5	1
6C	Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits.	6.4	2
3A	Best-practices guide for selection of gates and valves for outlet works structures.	6.3	3
1B	Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments.	6.3	3
1D	Develop a list of failure modes for outlet works.	6.2	5
5D	Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement.	6.2	5
6B	Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components.	6.2	5
1C	Best-practices guide for mechanical and electrical design and for automated control for outlet works.	6.1	8
4A	Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc.	6.1	8
5A	Design guidance and guide specifications for sliplining of outlet conduits.	6.1	8

Note: (1) 0 is unfavorable high cost/difficulty of implementation and 10 is favorable low cost/ease of implementation.

EXHIBIT 5-2

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON INDIVIDUAL SCORES FOR COST/EASE OF IMPLEMENTATION

-CONTINUED-

TOPIC NUMBER	RESEARCH/DEVELOPMENT TOPIC(S)	SCORE 0 to 10[1]	RANK
6D	Guidelines for inspection of normally inundated structures and other difficult-to-access features.	5.8	11
5B	Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs.	5.5	12
1A	Guidelines for venting outlet works.	5.4	13
6A	Applications of non-destructive testing (NDT) for inspection of outlet works.	5.4	13
5C	Assessment of microtunneling and boring technologies for application to outlet conduit rehabilitation.	5.2	15
2A	Best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, selective withdrawals, etc.	4.9	16
2C	Compile data on performance of conduits with significant settlement and lateral movement.	4.7	17
2D	Guidance on seismic effects on conduits and methods for analysis and design to address those effects (e.g. embankment spreading, fault offset, propagation of earthquake waves).	4.6	18
2B	Guidance on application of tunnels for outlet works – including consideration of microtunneling and of both soft-ground and hard-ground tunneling.	4.4	19
3C	Develop short course (with video/DVD option) on design, operation, and maintenance of outlet works gates and valves.	3.6	20

Note: (1) 0 is unfavorable high cost/difficulty of implementation and 10 is favorable low cost/ease of implementation.

EXHIBIT 5-3

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON THE COMBINATION OF INDIVIDUAL SCORES FOR POTENTIAL BENEFIT AND COST/EASE OF IMPLEMENTATION

		INDIVIDUAL SCORES (1)			
TOPIC NUMBER	**RESEARCH/DEVELOPMENT TOPIC(S)**	**POTENTIAL BENEFIT**	**COST**	**SCORE 0 to 10(2)**	**RANK**
1B	Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments.	8.1	6.3	7.2	1
3A	Best-practices guide for selection of gates and valves for outlet works structures.	7.6	6.3	7.0	2
3B	Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works.	7.1	6.5	6.8	3
4A	Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc.	7.4	6.1	6.8	4
5A	Design guidance and guide specifications for sliplining of outlet conduits.	7.4	6.1	6.8	4
1C	Best-practices guide for mechanical and electrical design and for automated control for outlet works.	7.0	6.1	6.6	6
5B	Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs.	7.5	5.5	6.5	7
6B	Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components.	6.8	6.2	6.5	7

Note: (1) From Exhibits 5-1, and 5-2.

(2) Arithmetic average of the two individual scores.

EXHIBIT 5-3

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON THE COMBINATION OF INDIVIDUAL SCORES FOR POTENTIAL BENEFIT AND COST/EASE OF IMPLEMENTATION

-CONTINUED-

TOPIC NUMBER	RESEARCH/DEVELOPMENT TOPIC(S)	INDIVIDUAL SCORES (1) POTENTIAL BENEFIT	COST	SCORE 0 to 10(2)	RANK
1D	Develop a list of failure modes for outlet works.	6.4	6.2	6.3	9
6C	Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits.	6.2	6.4	6.3	9
5D	Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement.	5.9	6.2	6.1	11
2A	Best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, selective withdrawals, etc.	6.7	4.9	5.8	12
1A	Guidelines for venting outlet works.	6.1	5.4	5.8	13
6D	Guidelines for inspection of normally inundated structures and other difficult-to-access features.	5.4	5.8	5.6	14
2C	Compile data on performance of conduits with significant settlement and lateral movement.	6.1	4.7	5.4	15

Note: (1) From Exhibits 5-1, and 5-2.

(2) Arithmetic average of the two individual scores.

EXHIBIT 5-3

RANKING OF RESEARCH/DEVELOPMENT IDEAS BASED ON THE COMBINATION OF INDIVIDUAL SCORES FOR POTENTIAL BENEFIT AND COST/EASE OF IMPLEMENTATION

-CONTINUED-

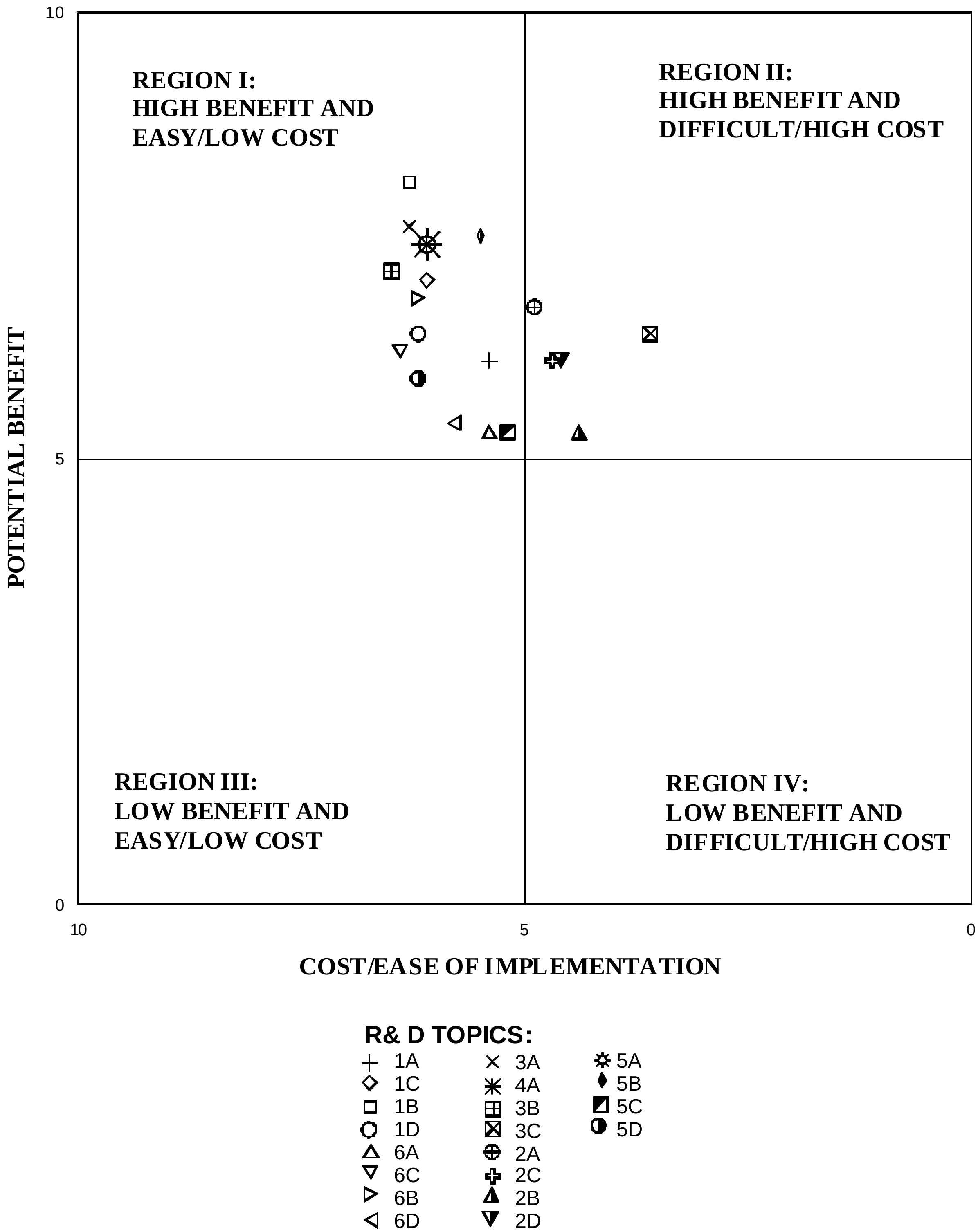
		INDIVIDUAL SCORES (1)			
TOPIC NUMBER	**RESEARCH/DEVELOPMENT TOPIC(S)**	**POTENTIAL BENEFIT**	**COST**	**SCORE 0 to 10(2)**	**RANK**
2D	Guidance on seismic effects on conduits and methods for analysis and design to address those effects (e.g. embankment spreading, fault offset, propagation of earthquake waves).	6.1	4.6	5.4	16
6A	Applications of non-destructive testing (NDT) for inspection of outlet works.	5.3	5.4	5.4	16
5C	Assessment of microtunneling and boring technologies for application to outlet conduit rehabilitation.	5.3	5.2	5.3	18
3C	Develop short course (with video/DVD option) on design, operation, and maintenance of outlet works gates and valves.	6.4	3.6	5.0	19
2B	Guidance on application of tunnels for outlet works – including consideration of microtunneling and of both soft-ground and hard-ground tunneling.	5.3	4.4	4.9	20

Note: (1) From Exhibits 5-1, and 5-2.

(2) Arithmetic average of the two individual scores.

EXHIBIT 5-4

COST-BENEFIT COMPARISON OF RANKED R&D TOPICS



All of the white papers authors provided reference lists in cases where references were cited, which can be found in the footnotes or bibliographies provided at the back of the white papers presented in Attachments 4 through 9.

In addition, due to recommendations of several authors that standardized guidelines to be used in outlet works design and consistent guidelines for the various topics included in this workshop be developed, the following internet addresses may prove useful in locating the most recent outlet works publications.

www.usace.army.mil/publications/

www.usbr.gov/pmts/hydraulics_lab/

www.ferc.gov/industries/hydropower/safety.asp

www.info.usda.gov/CED/

Attachment 1

AGENDA

FEMA WORKSHOP
ISSUES, REMEDIES, AND RESEARCH NEEDS RELATED TO DAM OUTLET WORKS

May 25, 26, and 27, 2004

Denver, Colorado

Day 1 - Tuesday, May 25, 2004			
8:00	to	8:15	Self- Introductions
8:15	to	8:30	Workshop Introduction
8:30	to	9:00	White Paper Presentation – Failure Modes
9:00	to	9:30	Discussion of State-of-Practice – Failure Modes
9:30	to	10:00	Brainstorming of R & D Needs – Failure Modes
10:00	to	10:15	Morning Break
10:15	to	10:30	Prioritization of R&D Needs – Failure Modes
10:30	to	11:30	R & D Implementation Work Groups – Failure Modes
11:30	to	12:00	Implementation Work Group Reports – Failure Modes
12:00	to	1:00	Lunch
1:00	to	1:30	White Paper Presentation – Inspection
1:30	to	2:00	Discussion of State-of-Practice – Inspection
2:00	to	2:30	Brainstorming of R & D Needs – Inspection
2:30	to	2:45	Prioritization of R&D Needs – Inspection
2:45	to	3:00	Afternoon Break
3:00	to	4:00	R & D Implementation Work Groups – Inspection
4:00	to	4:30	Implementation Work Group Reports – Inspection
4:30	to	5:00	Day 1 Closure

AGENDA

FEMA WORKSHOP
ISSUES, REMEDIES, AND RESEARCH NEEDS
RELATED TO DAM OUTLET WORKS

May 25, 26, and 27, 2004

Denver, Colorado

Day 2 - Wednesday, May 26, 2004			
8:00	to	8:30	White Paper Presentation – Energy Dissipators
8:30	to	9:00	White Paper Presentation – Gates and Valves
9:00	to	9:30	Discussion of State-of-Practice – Energy Dissipators and Gates and Valves
9:30	to	10:00	Brainstorming of R & D Needs – Energy Dissipators and Gates and Valves
10:00	to	10:15	Morning Break
10:15	to	10:30	Prioritization of R&D Needs – Energy Dissipators and Gates and Valves
10:30	to	11:30	R & D Implementation Work Groups – Energy Dissipators and Gates and Valves
11:30	to	12:00	Implementation Work Group Reports – Energy Dissipators and Gates and Valves
12:00	to	1:00	Lunch
1:00	to	1:30	White Paper Presentation – Conduits
1:30	to	2:00	Discussion of State-of-Practice – Conduits
2:00	to	2:30	Brainstorming of R & D Needs – Conduits
2:30	to	2:45	Prioritization of R&D Needs – Conduits
2:45	to	3:00	Afternoon Break
3:00	to	4:00	R & D Implementation Work Groups – Conduits
4:00	to	4:30	Implementation Work Group Reports – Conduits
4:30	to	5:00	Day 2 Closure

AGENDA

FEMA WORKSHOP
ISSUES, REMEDIES, AND RESEARCH NEEDS
RELATED TO DAM OUTLET WORKS

May 25, 26, and 27, 2004

Denver, Colorado

Day 3 - Thursday, May 27, 2004			
8:00	to	8:30	White Paper Presentation – Rehabilitation
8:30	to	9:00	Discussion of State-of-Practice – Rehabilitation
9:00	to	9:30	Brainstorming of R & D Needs – Rehabilitation
9:30	to	9:45	Prioritization of R&D Needs – Rehabilitation
10:00	to	10:15	Morning Break
10:15	to	11:15	R & D Implementation Work Groups – Rehabilitation
11:15	to	11:45	Implementation Work Group Reports – Rehabilitation
11:45	to	12:45	Lunch
12:45	to	1:45	Recap and Discussion of R&D Needs
1:45	to	2:30	Prioritization of Leading R&D Needs
2:30	to	3:00	Day 3 - Closure

Attachment 2

FEMA WORKSHOP ON ISSUES, SOLUTIONS AND RESEARCH NEEDS RELATED TO DAM OUTLET WORKS

MAY 25, 26, AND 27, 2004
DENVER, COLORADO

1. Title/Description of Research/Development Item

2. Description

    A. Why is this a priority research/development item?
    B. What is the expected outcome?

3. Project Tasks and Needs

    A. What tasks are to be done?
    B. How is the problem to be solved?

3. Project Tasks and Needs - continued

4. Project Lead and Contact

   A. Who is working in this area?
   B. Who might be able to lead the project?
   C. Who are good candidates to complete the work?

Attachment 3

RANKING OF RESEARCH AND DEVELOPMENT IDEAS

No.	Research and Development Idea	Benefit Ranking, 0 to 10 (1)	Difficulty/ Cost Ranking, 0 to 10 (2)
1	Guidelines for venting outlet works.		
2	Best-practices guide for mechanical and electrical design and for automated control for outlet works.		
3	Best-practices guide for outlet works conduits through embankment dams, emphasizing small embankments.		
4	Develop a list of failure modes for outlet works.		
5	Applications of non-destructive testing (NDT) for inspection of outlet works.		
6	Best-practices guide for inspection frequency and methods of inspection for typically accessible outlet works conduits.		
7	Best-practices guide for inspection of outlet works gates, valves, and operators, including mechanical and electrical components.		
8	Guidelines for inspection of normally inundated structures and other difficult-to-access features.		
9	Best-practices guide for selection of gates and valves for outlet works structures.		
10	Best-practices guide for energy dissipators for outlet works structures, considering heads, velocities, configuration, etc.		
11	Guidelines for maintenance and exercise of gates and valves and for cavitation repairs for outlet works.		
12	Develop short course (with video/DVD option) on design, operation, and maintenance of outlet works gates and valves.		
13	Best-practices guide for outlet works intake towers, considering such factors as location, configuration, access, debris/trash control, seismic performance, selective withdrawals, etc.		

Notes: (1) 0 is lowest benefit and 10 is highest benefit.
(2) 0 is unfavorable high cost/difficulty in implementation and 10 is favorable low cost/easy implementation.

RANKING OF RESEARCH AND DEVELOPMENT IDEAS

No.	Research and Development Idea	Benefit Ranking, 0 to 10[1]	Difficulty/ Cost Ranking, 0 to 10[2]
14	Compile data on performance of conduits with significant settlement and lateral movement.		
15	Guidance on application of tunnels for outlet works – including consideration of microtunneling and of both soft-ground and hard-ground tunneling.		
16	Guidance on seismic effects on conduits and methods for analysis and design to address those effects (e.g. embankment spreading, fault offset, propagation of earthquake waves).		
17	Design guidance and guide specifications for sliplining of outlet conduits.		
18	Compilation of case studies on outlet works rehabilitation – lessons learned, performance, comparative costs.		
19	Assessment of microtunneling and boring technologies for application to outlet conduit rehabilitation.		
20	Best practices guide for design and construction methods to rebuild embankment sections removed for outlet conduit removal/replacement.		

Notes: (1) 0 is lowest benefit and 10 is highest benefit.
(2) 0 is unfavorable high cost/difficulty in implementation and 10 is favorable low cost/easy implementation.

Attachment 4

OUTLET WORKS FAILURE MODES

FEMA Outlet Works Workshop
May 25- 27, 2004 Denver, Colorado

By Sal Todaro

1.0 INTRODUCTION

This paper overviews the ways in which outlet works can fail and methods that can be used to prevent failures. Outlet works features are grouped into four basic structures (1) Intake Structures, (2) Conduits and Tunnels (3) Control Structures and (4) Energy Dissipators. Gates, valves and other mechanical features are discussed with the structures where they are located. Causes of outlet works failures include: foundation related failures, structural deterioration, structural failures, mechanical failures, failures related to hydraulics, failures related to ice and sediment loadings, and operator error. Methods are recommended to prevent failures in new design, by retrofitting existing facilities, and by facility operation.

The outlet works is an important cause of dam failures, since approximately 25 percent of embankment dam failures are associated with the outlet works.[1] Outlet works failures can also result in less catastrophic consequences than dam failure such as: the inability to make required reservoir releases, structural or mechanical conditions requiring emergency draining of the reservoir, or the uncontrolled release of the reservoir.

2.0 INTAKE STRUCTURES

2.1 Intake Structures

The intake structure is where water enters the outlet works. Intake structures can be either gated or ungated.

2.2 Types of intake structures and their application

Intake structures can be submerged structures, tower structures with multiple level inlet ports, inclined structures located on an abutment of the dam with a single bottom inlet or with multiple level inlet ports.

2.3 Mechanical Features of Intake Structures

The principal mechanical features of intake structures are the intake gates and the trash racks. Ungated inlets are often fitted for the installation of a removable bulkhead gate that could be installed using divers.

[1] Foster, M., R. Fell, and M. Spannagle. 2000. *The statistics of embankment dam failures and accidents.* Canadian Geotechnical Journal. Volume 37, Number 5, pp. 1000-1024. October.

- Intake Gates and Valves- Causes of gate and valve malfunction and failure include: debris, cavitation, ice, operator error, and malfunction of gate operating mechanisms, lack of exercise, deterioration and corrosion. Use of obsolete equipment is common because it is often difficult and costly to replace this equipment. Agencies that would not consider driving a Model T car commonly use similar vintage equipment to release water from major dams.

- Control Systems to open and Close Gates and Valves-Mechanical control systems can include motor driven, hydraulic, and hand operators. Hydraulic control systems include hydraulic power units and hydraulic cylinders to open and close gates and valves.

- Trash racks- Failure and malfunction of trash racks can result from: plugging due to sediment or debris or collapse of trash racks resulting for plugging from frazil ice.

2.4 Failure Modes of Intake Structures

- Foundation Related Failures of Intake Structures - It is important for the designer to locate the intake structure on firm bedrock whenever possible. A firm foundation for the intake structure is important to reduce differential settlement between the intake structure and the outlet conduit. A rock foundation will not only reduce settlements but also provide rock mass for anchoring the structure to the rock foundation. Small or undetectable settlements at low or submerged inlet structures can be magnified several times at high intake towers. No engineer wants to be responsible for the design an intake tower that looks like the Leaning Tower of Pisa. Rock foundations can also be used for anchoring high intake towers to resist seismic loadings

- Structural Deterioration - Intake structures can prematurely deteriorate over time because of the following: aging; freeze thaw damage which open intake towers can be especially susceptible to; poor concrete materials such as alkali aggregates; or poor water quality (excessively low or high pH can accelerate corrosion of reinforcement and cause deterioration of concrete).

- Ice loading – Loading from expanding reservoir ice have caused damage to trash racks, gates stems, intake towers and piers for intake tower access.

- Seismic Failure- It is important that intake structures are operable after earthquakes so that the outlet works can be used for emergency reservoir evacuation or to provide water to surrounding communities following a disaster.

- Sedimentation of Intake Structures- Sedimentation of intake structures has caused serious operational problems at many dams. Sedimentation of intakes can be caused by: improper reservoir operation, upstream development, forest fires or design deficiencies.

- Hydraulic Related Failures- Hydraulic related failures at intake structures could include cavitation of intake gates or at areas of the intake structure or in the conduit downstream of the intake gate.

- Air/Water Related Failures - Inadequate air supply to control gates can cause cavitation and vibration at intake towers. Another air /water related operational problem is air blowback caused by air coming out solution in the conduit violently blowing air and water into intake structure. This type of air blowback resulted in serious damage at the Bureau of Reclamation's Navajo Dam. Air blowback also caused the loss of the trash racks at Denver Water's Dillon Dam by ejecting them into the reservoir.

- Structural fatigue caused by vibration, or collapse as a result plugging such as at Yard's Creek Dam as seen in Photo 1.

Photo 1 – Collapse of Trash Rack at Yard's Creek Dam.

2.5 Methods to Prevent Failure of Intake Structures

Methods that can be used to prevent failures of intake structures include the following actions:

- Locate the intake structure on a **rock foundation** whenever possible to reduce settlement and to provide cohesion and rock mass for anchorage to the foundation rock to increased seismic stability

- Design for **air demand** requirements to prevent blowback, pipe collapse, and cavitation of control gates.

- Design for **ice loading** and consider the use of bubbler systems to prevent ice formation. Gate stems which will pass through a reservoir ice cover should either have a bubbler system to prevent ice formation or the gate stem should be located in an oil filled pipe. This is a standard detail that can be supplied by the gate manufacturers.

- Use a **mechanical engineer** experienced in design of systems for dams to design the mechanical features of the outlet works. This engineer should be responsible for selection of intake gates, operators, and operating systems. This engineer should conducting inspections of the installation and testing of gates and other critical operating systems.

- Use reliable **standard designs** that have been developed and tested over time. Standardized reliable designs can be used to design most intake structures. Use of standardized designs will reduce design time and also help provide the owner with a tested design.

- Use **standardized design criteria**, for loading condition and allowable stress.

- **Locate the intake structure to reduce sediment** and debris accumulation. The design may require invert of the intake structure to be located at a higher elevation to reduce sediment accumulation.

- **Operate the reservoir to reduce movement of reservoir sediment** to the intake structure**.** At Twitchell and Strontia Dams, reservoir fluctuation is minimized since draw down lowering of the reservoir can transport sediment to the lower depths of the reservoir.

- Consider the **vibration** in design of trash racks.

3.0 CONDUITS AND TUNNELS

3.1 Conduits and Tunnels for Dams

Conduits and tunnels are used to convey outlet works discharges from the reservoir through the dam. Conduits can be constructed of cast in place or manufactured pipe. Conduit outlets are usually constructed through dams and can increase the risk of failure of embankment dams because of the potential for embankment piping near the conduit. Tunnel outlet works are separated from the dam embankment and are generally considered to be a safer than conduits.[2]

3.2 Types of Conduits

The two general types of outlet conduits through dams are cast in place concrete conduits and conduits constructed using manufactured pipe. Pipe materials used to construct outlet conduits include of pre-cast concrete, plastic, steel and ductile iron.

3.3 Tunnels

Tunnels for dams are usually constructed in hard rock conditions however soft ground tunnels have also been used for dam outlet works. Tunnels for dams are usually lined with cast in place concrete or welded steel. In some cases (usually in the past) tunnels have been constructed for dams without tunnel linings. This practice is not currently accepted for outlet tunnels located near embankment dams because of the potential for pressurized water to travel through joints in the rock and cause internal erosion of the embankment.

---

[2] Refer to "Conduits through Embankment Dams" a guideline developed by FEMA containing the design requirements for conduits through embankment dams. Final Draft dated February 2005.

3.4 Embankment Dam Failure Caused by Outlet Conduits

Outlet conduits have been found to be responsible for approximately 25 percent of embankment dam failures. Four possible failure modes associated with outlet conduits that can result in dam failure are shown in Figure 1. Two of the failure modes are caused by a structural failure of the outlet conduit, the other two failure modes is caused by preferential seepage paths through the embankment near the conduit. These failure modes are discussed in detail in the upcoming FEMA guideline for the design of outlet conduits.[3]

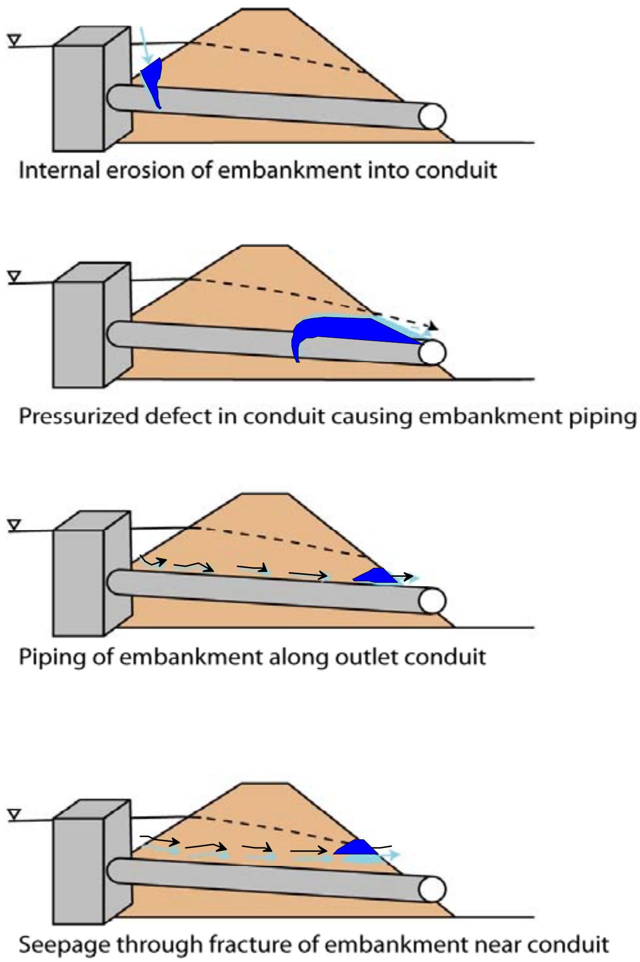


Figure 1 – Failure Modes for Conduits in Embankment Dams.

3.5 Failure Modes of Tunnel Outlet Works

Tunnel outlets works adequately separated from the embankment cannot cause the internal erosion of the embankment. However, tunnel outlet works constructed too close to a dam can result in internal erosion of a dam embankment. Internal erosion of an embankment caused by an outlet tunnel is rare but can occur. The outlet tunnel at Willow Creek Dam was constructed under the abutment of the dam. Erosion of embankment material through rock joints above the tunnel

[3] "Conduits through Embankment Dams," FEMA. Final Draft dated February 2005.

caused a sinkhole at the embankment and required significant repairs to the embankment and the tunnel.[4]

3.6 Methods of Preventing Failure of Conduits and Tunnels

Methods that can be used to reduce the potential for failure of outlet conduits through embankment include the following actions:

- Filter the dam embankment near the outlet conduit to prevent the internal erosion of the embankment along or near the conduit.[5]

- Construct outlet conduits on rock foundations whenever possible. Founding the outlet conduit upon a rock will provide several benefits and reduce the potential for settlement and cracking of the conduit and therefore reduced potential leakage of from the conduit to the embankment or from the embankment into the conduit. Conduits constructed directly upon rock foundations can also decrease the contact area between the embankment and the conduit and reduce the paths for seepage along the conduit. Constructing the conduit into the dam abutment can also reduce the potential for stress concentrations and for the embankment near the conduit as seen in Figure 2.[6]

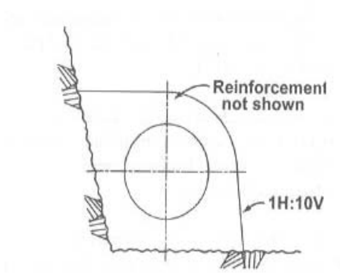


Figure 2 – Conduit Cast Against Excavated Rock

- Conduits can be designed with redundant methods to prevent seepage of water from the conduit to the embankment and embankment material from piping into the conduit. Redundant methods of seepage prevention can include the use of a cast in place concrete conduit with water-stopped joints and a welded structural steel liner. This redundant

---

[4] "Conduits through Embankment Dams," FEMA. Final Draft dated February 2005.
[5] Refer to the upcoming FEMA guideline on conduits through embankment dams for guidance on the design of filters for outlet conduits.
[6] Source: "Conduits through Embankment Dams – FEMA Final Draft dated February 2005.

design method has been used by the Bureau of Reclamation for pressurized conduits for higher head dams or outlets founded upon weak compressible foundation. HDPE pipe with welded joints and reinforced concrete encasement with water-stopped joints can also be used for a redundant outlet conduit design for lower head dams.

4.0 CONTROL STRUCTURES

4.1 The Function of Control Structures

For the purpose of this paper, the term 'control structures' is used to refer to the location where the discharge from the outlet works is controlled. The flow regulating gates for the dam are located at the control structure. The regulating can be located: at a valve house at the downstream toe of the dam, at an intake structure or at a gate chamber within the dam. Figure 3 shows these typical locations for control valves.[7]

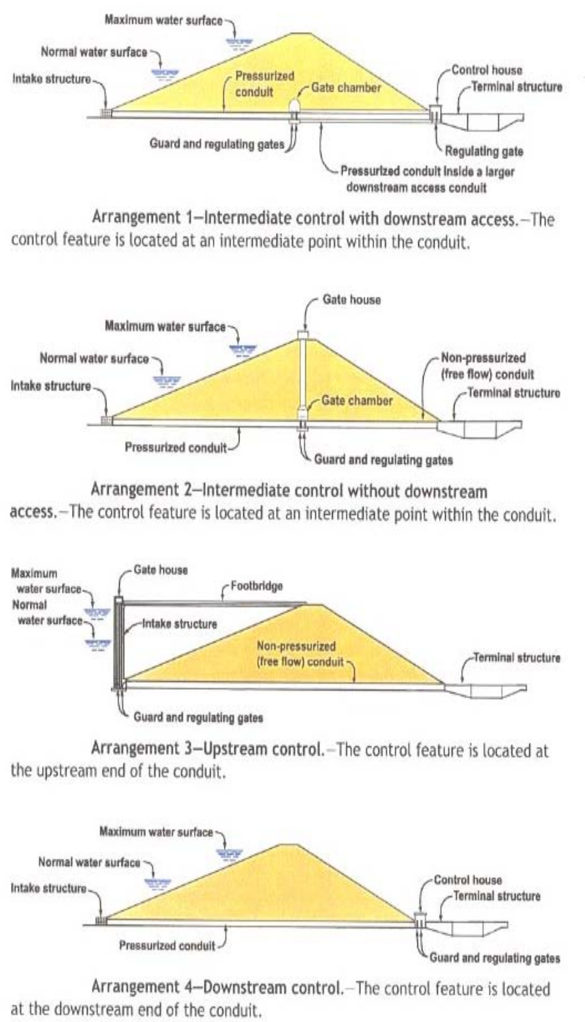


Figure 3 – Various Locations for Control Structures.

[7] Source: "Conduits through Embankment Dams – FEMA. Final Draft dated February 2005.

4.2 Control Valves for Outlet Works

The selection of the valve used to control flow is strongly influenced by the location of the control structure.

- Control Valves Located at Intake Structures- When control valves are located at the intake structure, the conduit through the dam is usually not pressurized; this type of design is commonly used by the Corps of Engineers for their flood control dams. Location for the control valve at the intake structure is also common for small dams where slide gates are located at the upstream face of the dam. Sluice gates or bonneted slide gates are commonly used to control flow from intake towers. The approach conditions for control gates located at intake towers are usually less than ideal; these poor approach conditions can affect the performance of the gate and can cause cavitation and vibration. When intake gates are used to control flows at heads above approximately 40 feet, care is required in the design of the intake and selection of the control gate.

- Control Valves Located in Gate Chambers- When control valves are located in gate chambers the flow upstream of the gate chamber is pressurized and the flow downstream of the gate chamber is not pressurized (open channel flow conditions.) This type is commonly used by the USBR for their outlet works. The approach flow to valves located in gate chamber is usually a pressurized conduit with a transition designed to streamline flow to the control valve. Conditions upstream of valves located in gate chambers are usually trouble free. However, because of the high velocities that can occur downstream of a control valve, cavitation can occur downstream of valves at higher head facilities. The bonneted slide gate is commonly selected for this application because they perform well under a wide range of operating heads and they produce a compact jet which is required to allow open channel conditions in the downstream conduit.

- Control Valves Located a Valve House at the Downstream Toe of the Dam. The entire length of the outlet conduit is pressurized when the control valves are located at the downstream toe of the dam. This type of design is often used when the outlet works is used to supply a pressurized pipeline or a hydroelectric power plant. This type of design is almost exclusively used when the head at the valve exceeds 200 feet. The types of valves commonly used for this application include the fixed cone valve, the jet flow gate, the bonneted slide gate and the sleeve valve.

4.3 Failure Modes of Control Structures

Failure modes of control structures are usually associated with the gates, valves, or gate operators and control systems. These types of failures do not usually jeopardize the safety of the dam, but can limit the ability of the dam to discharge water for normal or emergency releases. Photo 2 shows a valve stuck in the closed position because of lack of maintenance. Photo 3 shows poorly maintained and broken gate operators at an intake tower. Photo 4 shows a failed needle valve, this failure resulted in the death of the dam tender. Many of these failures are caused poor maintenance and the use of outdated (antique) equipment.

Photo 2 - Valve stuck in the closed position due to lack of maintenance.

Photo 3 – Broken Gate Operators at an Intake Tower.

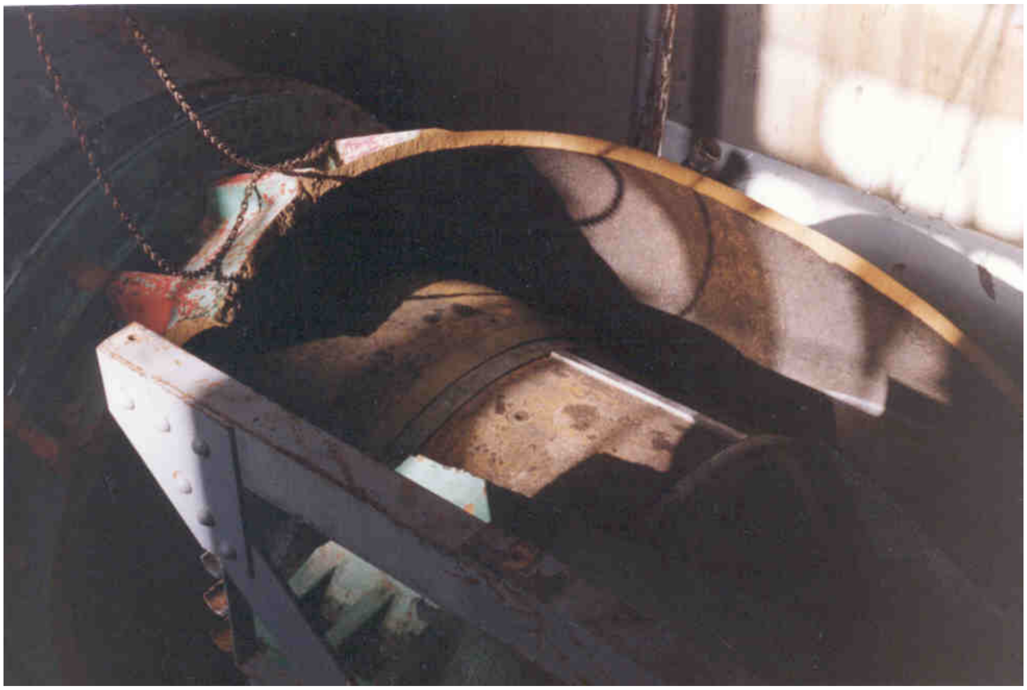


Photo 4 - Failed needle valve.

4.4 Methods to Prevent Failure of Control Structures

Methods that can be used to prevent failures of control structures include the following actions:

- Proper training of all operations and maintenance personnel
- Regular periodic exercise of all gates and valves to prevent buildup on seats and other moving parts that would inhibit operation (minimum of once per year, preferably 3 or 4 times per year).
- Note any unusual noises or vibration during operation of equipment, and investigate any new observations.
- Periodically measure electrical current or hydraulic pressure required for gate and valve operation. Compare readings with previous measurements to note any deviations
- When designing new outlet works or outlet works rehabilitations, use a mechanical engineer experienced with the design of gates, valves and mechanical systems for dam outlet works.
- Replace outdated and unreliable gates, valves and operators

5.0 ENERGY DISSIPATORS

5.1 Energy Dissipators and Their Function

Energy dissipators are used to reduce channel erosion downstream of outlet works. A more thorough discussion of the types of energy dissipators used for outlet work and their application can be found in the White Paper prepared for this workshop by Dr. Henry T. Falvey titled "White Paper on Energy Dissipators."

5.2 Types of Energy Dissipators

The more commonly used energy dissipators used for outlet works are:

- No energy dissipator is used and water discharges directly to the downstream channel. As seen in Photo 5 taken at Hubbart Dam a concentrated jet discharging directly to the channel downstream of the gate. Initial operation of the gate caused localized channel scour which eventually stabilized.

Photo 5 – Hubbart Dam gatehouse and stilling basin.

- Use a valve that produces a dispersed jet to reduce the potential for downstream channel erosion. Fixed cone valves are often used because the produce a dispersed jet that reduces the potential for downstream channel erosion. The spray produced by the fixed cone valve can result in maintenance problems in cold climates because of the icing that often occurs downstream of these valves.

- Energy dissipating valves - Energy dissipating valves such as the sleeve valve or Monovar valves are expensive but can eliminate the need for downstream energy dissipating structures.

- Conventional Concrete Stilling Basin Design- Some commonly reinforced concrete stilling basin designs include: the hydraulic jump basin, the Impact basin and the fixed cone valve dissipation chamber.

5.3 Failure Modes of Energy Dissipators

The principal failure mode for energy dissipators is uncontrolled erosion of the downstream channel.

5.4 Method to Prevent Failure of Energy Dissipators

The design of energy dissipators for outlet works can usually be accomplished using designs standardized by the USBR, USACE, and other large state and federal agencies. These designs should be used by the designer whenever possible.

6.0 CONCLUSIONS

In order to minimize the occurrence of outlet works failures the following guidelines should be followed:

- Well-trained, experienced engineers should design outlet works;
- Outlet structures should be located on rock foundations whenever possible;
- Standardized, reliable designs should be used;
- Unusual failure modes like those associated with vibration, ice loading, and air/water interactions, should be considered in outlet works design; and
- Redundancy should be built into the design of all critical elements of outlet works systems.

Failures of mechanical equipment can usually be traced to the following causes:

- Lack of exercise

- Lack of maintenance

- Deterioration due to erosion, corrosion, and/or cavitation

- Neglecting operating observed difficulties

- Operator error or lack of training

Attachment 5

DESIGN AND CONSTRUCTION OF OUTLET WORKS CONDUITS FOR EMBANKMENT DAMS

FEMA Outlet Works Workshop
May 25 – 27, 2004 – Denver, Colorado

By Sal Todaro, P.E.

1.0 Introduction

This paper addresses outlet works design for smaller dams owned and operated primarily by municipalities and private owners. These smaller dams account for most of the nation's jurisdictional dams. This group of outlet works provides greater design versatility than designs produced by federal design agencies and large experienced engineering firms.

There is no single nationally recognized standard for designing outlet works for dams, and inexperienced firms have a greater need for established design guidelines for outlet works. State dam safety officials are tasked with reviewing designs that can vary significantly in their design approach. On the other hand, outlet works designed by federal agencies and large engineering firms use similar designs and are often more consistent in their approach to design. For example, outlet works designed by the U.S. Bureau of Reclamation (USBR) are consistent within groupings of pressurized and non-pressurized outlet works.

Not all outlet works should be similarly designed; however, there should be consistent guidelines and criteria for preparing these designs. Design guidelines could include recommendations for pipe encasement, the need for redundancy, seepage control, methods for addressing compressible foundations, pipe selection, joint details, and criteria for reinforced concrete conduit design.

Consistent guidelines can direct design engineers to safe designs, thus providing state dam safety officials assistance in reviewing these designs. Designs developed using thorough, consistent standards would result in more consistency between projects and would result in safer, more reliable facilities.

Guidelines currently being prepared by the National Dam Safety Review Board (NSRB) can form a basis for design of smaller facilities. The NSRB is preparing a manual for the design, construction, maintenance, and repair of conduits for embankment dams. The NSRB manual is intended to be used for designing and maintaining outlet works for significant high-hazard dams and should be required reading for outlet works designers of both large and small dams.

2.0 Reducing Embankment Dam Failures Related to Outlet Works Conduits

Approximately 25 percent of embankment dam failures are related to embankment piping at or near the outlet works (Foster et al.)[1]. By reducing this failure mode, significant dam safety improvements would result. Primary embankment dam failures at or near outlet works can be attributed to structural defects of the conduit, resulting in piping embankment into or along the outside of the conduit (see Figure 1). Because of the extensive erosion that can occur from a failure, the exact cause is often difficult to determine. The above-referenced research also shows that dam failures associated with outlet works occur rapidly and usually do not provide adequate time to respond so that dam failure can be prevented.

Important improvements in outlet works design methods and construction procedures can be achieved by determining the best practice for designing and constructing outlet works, preparing nationally accepted standards, and by state and federal dam safety officials enforcing these standards.

3.0 Standards Presently Used for Design of Outlet Works

3.1 General

Outlet works are often designed using standards not specifically intended for use in designing pressurized outlet system for dams. For example, American Water Works Association (AWWA) pressure pipe standards were developed for water supply pipelines; these requirements may not be appropriate (without modifications) for the design and construction of outlet pipe under embankment dams.

Outlet pipes have different requirements than water supply pipelines, including long-term performance requirements and requirements for construction procedures compatible with the design and performance of the embankment dam. Some of the variations between water pipelines and outlet works include:

- Outlet pipe buried under an embankment dam are there for the life of the dam (which can be greater than 100 years), thus not allowing the accessibility for repairs as that of a water pipeline. The dam may need to be breached to replace an outlet conduit.
- Outlet pipes under dams are subjected to different foundation movements than waterlines; this is especially true during an earthquake.
- Because public safety issues are associated with dams, outlet works have redundancy requirements not required for water pipelines.
- The consequences from an outlet pipe leak through an embankment dam can be much more critical than a water supply pipeline leak.

[1] Foster, M., R. Fell, and M. Spannagle. 2000. *The statistics of embankment dam failures and accidents*. Canadian Geotechnical Journal. Volume 37, Number 5, pp. 1000-1024. October.

Engineers not experienced in designing dams and outlet works can inadvertently use inappropriate design standards. Examples of misapplication of outlet works design standards include:

- State highway department standard plans for culverts and culvert structures. These standard drawings are simply referred to in design documents to save the engineer from designing the outlet works. Culvert designs for highways were not intended for use in dams.
- Natural Resources Conservation Service (NRCS) standards for the structural design of flood control outlets have been used for designing high-hazard pressurized outlet facilities; however, these standards were not intended for such application.
- NRCS has also developed design standards for articulated outlet pipe design. These standards can also be used beyond NRCS' intended use. These design standards have been used for designing a pressurized outlet at a high-hazard municipal dam on a soft foundation. These particular standards should not be used for designing high-hazard pressurized outlet works.
- USBR Design of Small Dams. This may be the best general reference for designing reinforced concrete outlet conduits. The NRCS and Design of Small Dams show a precast concrete outlet pipe detail with partial encasement, which should not be used for pressurized outlet works for high-hazard dams (Figure 2). This detail allows embankments to be placed directly against the pipe surface, an area where leakage from the pipe joint has direct access to the embankment.
- Precast pipe under medium height to high embankments. For example, reinforced concrete pressure pipe is usually not a good selection for a pressurized outlet pipe under a medium height dam. An outlet pipe under a 100-foot-high dam can have more than 80 gasketed joints, each of which is a potential leakage source into the embankment.

3.2 Need for Design Guideline for the Design and Construction of Outlet Works Conduits

Nationally recognized design guidelines are needed for designing outlet works at small- and medium-sized dams. Dam safety officials could then require and enforce minimum standards for all new non-federal designs, and design engineer's tasks would be simplified by having a consistent standard for design, one they know review agencies will accept. Such guidelines would reduce the use of inappropriate design standards. The USBR and U.S. Army Corps of Engineers (USACE) design standards for outlet works combined with the forthcoming NSRB manual can form a basis for preparing a single design and construction standard for smaller dam outlet facilities.

4.0 Foundations for Outlet Works

Good foundations are important for all civil engineering structures, especially for dams and outlet works structures. Design engineers must use appropriate measures in determining the foundation and potential movements to help eliminate possible outlet works failures.

4.1 Outlets Constructed on Rigid Foundations

Outlet works structures should be founded on firm non-erodable foundations whenever possible. The alignment of an outlet conduit should be based upon the location of competent foundation for the conduit. Outlet works designs and construction specifications should allow for adjustments in the alignment during construction after the foundation in the areas of the outlet has been exposed. Final alignment adjustments to fit field conditions can improve foundations and help ensure that the outlet works structures are founded on firm, uniform foundations. Refining the outlet works alignment can also reduce the amount of required excavation or the amount of backfill concrete required. Figures 3, 4, and 5 show the construction of an outlet pipe excavated into the abutment of a dam.

Locating the outlet works on a firm rock foundation will decrease settlement and potential for structural distress, improve performance during seismic loads, and reduce seepage potential adjacent to the conduit.

4.2 Outlets Constructed on Compressible Foundations

Outlet works structures founded upon compressible foundation require more attention during design and construction, and provide more challenge to the designer and more risks to the dam owner than those on firm rock foundations. Outlet conduits on soft and erodable foundations are subject to foundation movement, thus incurring greater risks of embankment piping and structural distress of the conduit than outlet conduits founded on firm rock foundations. Foundation movements are especially dangerous for rigid outlet pipes with open gasketed joints; Figure 6 shows a photograph of a failed pipe.

Outlet conduit should be located on uniform foundations whenever possible to prevent abrupt changes in conduit settlement. Because geological condition variables can exist along a conduit alignment, uniform foundation is often not possible. Figures 7 and 8 show profiles of foundation settlements for cast-in-place outlet conduits at several USBR dams on compressible foundations. Soft foundations under embankment dams can settle vertically and spread horizontally. Figure 9 shows settlement profiles of a failed cast-in-place articulated pipe. Note that the settlement of the pipe joints is more abrupt than the cast-in-place conduit design. (The longitudinal reinforcement provided by cast-in-place conduits appears to have an effect of smoothing out the conduit settlements under the embankment.)

These figures are important information for engineers conducting outlet conduit settlement analyses. It is important to note that foundation settlement conditions can vary significantly along an outlet conduit, do not conform to more uniform settlements, and concentrated localized settlements can be more severe than predicted by analysis.

Engineers should question the precision or theoretical settlement analysis conducted to estimate the foundation movement of an outlet works. This is especially important if the outlet works has gasketed joints that can fail or open when subjected to movements larger than their design capacity. Figure 9 shows the estimated deflection and actual deflection of a reinforced concrete cylinder pipe that failed under a 100-foot-high embankment. This outlet pipe was designed using articulated joint design methods.

Work by Rutledge and Gould[2] has documented longitudinal movement of pipe joints on soft foundations. This work shows that settlement and the horizontal joint openings can be erratic and non-uniform. Large horizontal movements take place at random selected joints, rather than uniformly along the conduit. This type of concentrated movement can open joints of gasketed pipe that are not designed for large concentrated horizontal movements. The results of these field measurements show that dangerous movements can occur for gasketed pipe outlet works, even when the engineer may believe that the pipe has been designed to resist movement predicted by analysis.

Because of the unpredictable random movements that can occur under dam foundations, engineers should question the precision of theoretical settlement analysis estimates of outlet works conduits. This is especially important if the outlet works has gasketed joints that can fail or open when subjected to movements large than their design capacity.

Techniques historically used by USBR for designing outlet conduits on compressible foundations include:

- Over-excavating foundation and refill with compacted impervious earthfill,
- Positioning control gates upstream of impervious embankment,
- Avoiding pressure conduits through impervious embankments unless it is housed in a freestanding pipe,
- Providing steel lining for pressurized conduits,
- Avoiding pre-cast concrete pipe except for embankments of small heights (10 to 12 feet), and
- Protecting the foundation during construction.

Approaches to Design Outlet Conduits on Soft Foundations

1. Provide a Freestanding Pipe inside of a Reinforced Concrete Conduit. This is a classical outlet works design, which locates a freestanding pressurized outlet pipe inside of a cast-in-place reinforced concrete conduit. The conduit upstream of the embankment case is usually pressurized. The design prevents pressurized water from a leaking pipe from contacting the embankment.

2. Provide a Non-Pressurized Outlet Works System.

3. Welded Steel Outlet Pipe Encased in Reinforced Concrete. This design includes a welded steel pipe and reinforced concrete encasement. The theory of this design is that the welded steel pipe is ductile, will deform and maintain a watertight conduit, and will resist rupture when subjected to foundation movements. The reinforced concrete encasement provides a rigid beam to bridge over weak foundation to minimize concentrated deflections. The reinforced concrete also provides a redundant water passage, capable of resisting internal and external water loads. This design has been

[2] Rutledge, P.C., and Gould, J.P. 1973. Embankment-Dam Engineering. Casagrande Volume. John Wiley & Sons. New York City, New York.

successfully used by USBR and URS Corporation for new dams as well as retrofits for relining outlet works; however, there are no published design criteria for this design method. When possible, field joints for welded steel pipe on compressible foundations should be welded after embankment construction once the initial foundation settlement has occurred.

4. Articulated Joint Conduit Design. Another outlet design system on soft foundations is the use of articulated joints for the outlet conduit. Joint design for outlet work conduits is an important area where guidelines are needed, especially for pressurized outlet works on compressible foundations. The theory of this design is that the pipe joints are designed to deflect and accommodate for longitudinal and rotational deflections of the pipe joints. The pipe encasement concrete is provided with open joints to allow the movement of the pipe joints.

   There are two important dam safety concerns when an articulated pipe design is used for pressurized outlets at high-hazard dams. The first is that theoretically predicting deflections and longitudinal movement of joints may not be accurate, and the joints can be subjected to movements beyond their safe capacity. The second concern is that the encasement concrete at each pipe joint that can provide a leakage path directly to the embankment. A gasket or pipe bell failure from excessive settlement will allow pressurized flow from the conduit to the embankment.

5. Treatment of Foundation During Construction. Special construction procedures should be provided to protect the foundation integrity, which can degrade when exposed to air, moisture, and construction activity. Construction methods used to prepare conduit foundations include covering the exposed foundation with a concrete mud mat as soon as the excavation to final grade is exposed.

5.0 Pipe Material Used for Outlet Works Conduits

The following is a brief description of various pipe material that have been used at embankment dams for outlet conduits. The information is intended to form a basis of discussion by group members during the conference.

1. <u>Cast-in-Place Reinforced Concrete and Outlet Works Construction</u>. This design is typical construction for larger dam projects, especially projects designed by major federal agencies such as USBR and USACE. The design requirements and methods for cast-in-place conduits are well documented in USBR and USACE technical publications. These conduits are very versatile in their application and can be designed to fit specific project requirements and site conditions. Design alternatives for cast-in-place conduit include various standard circular and horseshoe shapes. Cast-in-place conduits can house freestanding outlet pipes and can also be steel lined when required for water tightness (see No. 2 below). This cast-in-place reinforced concrete conduit is often the best technical solution for an outlet works conduit, but is an expensive design alternative.

2. <u>Welded Steel Pipe Encased in Reinforced Concrete</u>. This alternative is similar to cast-in-place reinforced concrete construction. The primary difference between the two is that

steel-lined conduits are designed to be watertight. The encasement concrete is designed to resist embankment and foundation loadings, as well as internal and external water pressure. The steel liner is usually designed to resist both the internal and external water pressure loadings. This design can be used to provide a ductile and watertight conduit for compressible foundation conditions. This design has also been used with relatively thin non-structural steel linings whose function is to only provide water tightness.

3. High-Density Polyethylene Pipe. High-density polyethylene (HDPE) pipe has been successfully used for low-head water supply outlet works; however, its use for higher head and high-hazard dams needs further investigation. This design requires the HDPE pipe to be fully encased in concrete. The encasement allows compaction of embankment next to the conduit, fills the pipe haunch areas to eliminate this area of difficult compaction and potential seepage, prevents pipe deformation from embankment loadings, and can provide a redundant conduit system.

   HDPE pipe is a relatively new material to be used for outlet works conduits. Advantages of this material include: (1) it is relatively inert and not subject to erosion; (2) it has relatively good and because of the smooth wall, lack bond to the concrete and potential for radial thermal movement it has potential for; (3) it has fusion-welded joints and is seamless; (4) it is ductile and will not crack and act brittle when subjected to differential settlements; and (5) it is relatively inexpensive.

   Possible disadvantages include: (1) there is not a long record of its use; (2) it has a large expansion coefficient, and the design must account for radial and longitudinal expansion and contraction; (3) it has a smooth wall and will not bond to encasement concrete; (4) and because of the smooth wall, lack of bond to the concrete and potential for radial thermal movement, it has potential for seepage along the outside of the pipe lining, which is a design concern especially if large thermal changes can be expected; and (5) buckling and collapsing are important design concerns. HDPE pipe has a low modulus of elasticity and is relatively weak in buckling when subjected to external water pressure or vacuum loads.

4. Ductile Iron Pipe. Ductile iron pipe has been used for outlet conduits through embankment dams. Modern designers encase the pipe in reinforced concrete. Design concerns with the use of ductile iron pipe includes corrosion of the pipe and opening of the gasketed joints caused by foundation settlement.

5. Reinforced Concrete Pressure Pipe. RCP pipe is the most commonly used pipe for outlet works at small- and medium-head dams. RCP pipe is used for both pressure and non-pressure applications. This design when used for embankment dams requires either partial or full encasement in concrete. Design references for outlet works using RCP pipe include NRCS and USBR design references.

   A hard rock foundation is the best application for this pipe because RCP is relatively rigid. Large deflections can crack pipe joints or open gasketed joints. Abrupt settlement changes can occur under embankment dams, and this pipe can act brittle when subjected to concentrated vertical movements (refer to Figure 6).

The primary advantages of using RCP pipe for outlet conduits are that it is low cost, is commonly available, and requires low maintenance.

Disadvantages of using RCP pipe include:

- The pipe gasket is the only line of defense against direct seepage into the embankment unless the pipe is fully encased with waterstopped encasement joints.
- RCP pipe was developed for water supply pipelines; however, improved joints can be specified for dam use. Each joint is a potential source of leakage.
- RCP pipe sections are typically only 8 feet long, thus resulting in a large number of gasketed joints under the dam.
- RCP pipe sections provide little or no resistance to longitudinal pipeline movements that can result in openings of joints from foundation settlement and spreading joints.
- RCP outlet pipe under embankment dams can elongate as the dam settles.

6.0 Tunnel Outlet Works

Tunnel outlet works are often not considered for dams less than 150 feet high. In the past, tunnel outlet works were more common for embankment dams. For example, USBR used a tunnel outlet works at an 80-foot-high dam with soft ground tunneling conditions (see Figure 10 [Rye Patch Dam Outlet Tunnel]). Tunnels are not usually considered as a design alternative for conditions where soft ground conditions are encountered. However, tunnel outlet works have several technical advantages when compared to cut-and-cover outlet conduit designs, especially for pressurized outlets. These advantages include:

- A tunnel outlet works is not physically associated with the embankment. Using a tunnel outlet will eliminate embankment failure modes associated with conduit outlet works. This failure mode accounts for 25 percent of embankment dam failures.
- Tunnel outlet works often facilitates stream diversion around the dam site during construction.
- Tunnel outlet works construction can take place independently of embankment construction.
- The tunnel outlet works can allow embankment placement, unobstructed by the outlet conduit.
- Tunnel outlets eliminate special compaction requirements required for the conduit.
- Tunnel outlets eliminate the need for special filter placement and drainage requirement, which can also slow embankment construction.
- Tunnel outlets eliminate the conduit, a critical path item in constructing the embankment dam.

Disadvantages include:

- Tunnel outlet works are often more expensive than conduit outlet works, especially for smaller diameter outlet works.
- Tunnel construction typically involves more cost risk for overruns than a conduit outlet works.
- Few engineering firms maintain qualified staff for planning, design, and construction services for tunnel engineering.
- Design engineers may not have readily available costing information to compare costs of conduit and tunnel outlets.

6.1 Comparing Conduit and Tunnel Outlet Works

Tunnel outlet works are generally more expensive than conduit outlet works. However, outlet works for medium-size dams incorporating modern design methods and redundancy features can also be surprisingly expensive. This is especially true if the outlet works conduit is a pressurized system and the design incorporates a gate chamber under the dam with a freestanding discharge pipe. An important benefit of the tunnel outlet is that it eliminates the failure mode caused by the conduit passing through the embankment.

Cost curves for tunnel outlets based on outlet diameter would be helpful, allowing engineers the ability to compare costs for preliminary evaluations of tunnel and conduit outlets. Also, cost curves for outlet tunnels combined with design guidelines for tunnel outlet works design can provide a method for engineers to properly evaluate tunnels when planning the design of an outlet works.

7.0 Conclusions

- Outlet works are a significant cause of embankment dam failures. Approximately 25 percent of embankment dam failures are related to piping failures at or near the outlet works (Foster et al.). By reducing this failure mode, significant dam safety improvements would result.
- There is no single nationally recognized standard for designing outlet works for dams. Outlet works are often designed using standards not specifically intended for outlet works.
- Nationally recognized design guidelines are needed for outlet works at small- and medium-sized dams. Consistent guidelines can direct design engineers to safe designs and provide state dam safety officials guidelines for review. Designs developed using thorough, consistent standards would result in more consistency between projects and result in safer, more reliable facilities.

Attachment 6

WHITE PAPER ON GATES AND VALVES

FEMA Outlet Works Workshop, May 25 – 27, 2004 – Denver, Colorado

By Lee C. Gerbig, P.E.

This white paper is an attempt to present the current state of the art with regards to gates and valves for dam outlet works systems.

Introduction

The purpose of an outlet works system in a storage reservoir is to control the flow of water from the dam into a river, canal, or some other type of channel. The outlet works releases can be controlled to maintain river flows, provide irrigation water, provide water to a water treatment facility, provide water to an industrial user, lower the reservoir in an emergency, or any other of a multitude of options. The outlet works system must be capable of regulating the flow of water for the intended purpose, and must be very reliable to provide the necessary control whenever needed. In many facilities, the outlet works equipment is very reliable, requires very little maintenance, and is often taken for granted until something goes wrong.

This paper will discuss several types of gates and valves that can be used in outlet works, from the very basic to the more complex systems. The discussion will also include different methods of gate and valve operation and control.

The terms gate and valve are used interchangeably in many designs and existing structures. For the purpose here, a gate is a mechanical device with a sliding flat member within a square or rectangular framework or structure that controls the flow of water. A valve is usually a circular structure with a sliding member, flat or circular, that controls the flow of water.

This paper will be organized into several sections, including gate descriptions, types of operators, typical outlet designs, and current developments.

Gate and Valve Descriptions

The following are descriptions of the basic types of gates and valves found in current use on dams, and some descriptions of older equipment that may be found. First the discussion will cover the current gates and valves used.

1. Current Gates and Valves

A. **Slide Gates -** The most common type of gate used for dam outlet works is the basic slide gate, also referred to as a sluice gate. A slide gate has a movable leaf or disk, which slides against bearing surfaces in the frame. The frame is attached to a conduit or wall, which provides support against the water load of the gate. The gate leaf is moved by a gate stem, which is operated by a manual handwheel or crank, electric motor-operator, or hydraulic cylinder.

Slide gates have been used for throttling service on dams with up to 500 feet of head when the proper design is provided, and slide gates are often used as guard gates for outlet works with discharge valves at the downstream end of the conduit.

Slide gates can be of various types and designs as follows:

1) Cast Iron Slide Gate – The cast iron slide gate (also known as a cast iron sluice gate) has been used for over a century for controlling the flow of water. The square or rectangular gate leaf or disk and frame are constructed of cast iron (or in some instances, ductile iron or cast stainless steel). Reinforcing ribs are included on the gate leaf for required strength and a pocket for attaching the gate stem is provided. Bronze seats are attached to the downstream side of the leaf and the upstream side of the gate frame to provide a low-friction sliding surface, and to provide a metal-to-metal seating surface to reduce leakage. The gate stem is usually made of stainless steel, but older designs may use bronze or carbon steel. For longer length stems, guides with bronze bushings are provided to reduce the stresses due to column loading. Wedges are installed around the perimeter of the gate leaf to assist sealing when closed, by forcing the leaf against the seats. Gate leakage is usually very low (0.1 gal/min. per foot of leaf perimeter). These gates are usually very robust and can be used for throttling flow in excess of 90 feet of head, and used for guard service for heads in excess of 150 feet.

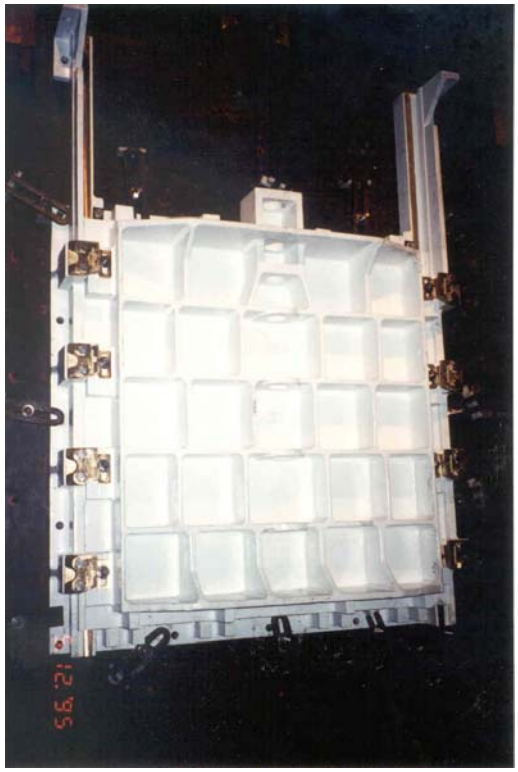


Photo 1
Typical Cast Iron Slide Gate

2) Fabricated Slide Gate – The fabricated slide gate can be made from a variety of materials including, steel, stainless steel, and aluminum. The fabricated gate uses welded construction for the gate leaf and frame, with reinforcing ribs where needed. The gate leaf uses the metal plate as a sliding surface against low friction material (UHMW or similar) attached to the frame. Neoprene J-type bulb seals are often attached to the perimeter of the leaf to provide additional sealing, eliminating the need for wedges. Gate stem design and construction is the same as for cast iron gates. Gate leakage is approximately ½ the leakage form cast iron slide gates.

   For higher head applications (above 100 feet of head), the slide gates can be provided with metal-to-metal seats, eliminating the bulb-type seals.

   a. Bonneted Slide Gate - For high head applications, usually greater than 100 feet, bonneted slide gates can be used. Bonneted slide gates are similar in design to fabricated slide gates, except that the body is fabricated to totally enclose the gate leaf. The gate leaf may be fabricated as a flat stainless steel plate without gate seats attached or a carbon steel plate with bronze or stainless steel seats to slide against bronze or stainless steel seats in the gate body. The flat stainless steel plate design will seal at the top at all gate openings; whereas the leaf design with seats attached will allow water to flow over the top of the leaf at partial gate openings. At higher operating heads, stainless steel/bronze seat combinations provide low friction, long wear, and cavitation resistant characteristics. The bonneted gates use a flush bottom design, with no offsets in the flow along the floor of the conduit, providing increased discharge capacity and reduced cavitation potential. The upstream side of the leaf is designed for reduced downpull and effective flow control at all gate openings.

The bonneted slide gate is usually embedded in reinforced concrete to provide additional structural reinforcement for the pressurized gate body.

b. Wheel Gate – Wheel gates are similar in design to slide gates, in that there is a square or rectangular leaf, moving vertically over an opening in the gate frame. Instead of the leaf sliding on machined bearing surfaces, the leaf is fitted with multiple wheels that ride on rails attached to the face of the structure. The rails support the water load of the gate leaf and frame, and must be installed in good alignment to provide a smooth operating surface. The operating loads are much lower for a wheel gate, since there is less friction in the wheels and axles than there is in the sliding contact on a slide gate. Wheel gates can be designed to close by gravity in an emergency if necessary. There is usually a bulb-type seal attached to the perimeter of the leaf to seal against the gate frame.

Installation of wheel gates is often difficult because the tracks and frame require critical alignment to achieve smooth operation and effective sealing.

Wheel gates can be operated by stem systems similar to the stem design for slide gates, and are usually operated by hydraulic cylinders, although there are many installations using a wire-rope hoist systems with an electric motor operator. Some multiple intake installations use a gantry crane that can install one gate in any one of several gate slots when needed.

Photo 2
Example of a Wheel Gate

c. Roller Gate – Roller gates are similar to wheel gates, but a roller train is used instead of wheels, when moving against the rails. Roller gates also have less friction than slide gates, and are capable of closure by gravity. Roller gates have fallen out of favor because the roller trains are susceptible to corrosion and buildup of deposits that increase friction and interfere with operation of the rollers and links.

   The operating systems for roller gates are similar to the systems used for wheel gates.

B. Butterfly Valves – Butterfly valves are commonly used at power plants and water facilities. A butterfly valve has a circular body with a circular disk in the fluidway that rotates around a shaft in the centerline of the valve, perpendicular to the flow. The valves may be installed with the shaft vertical, but the valves are usually installed with the shaft horizontal. Butterfly valves are relatively inexpensive to purchase and install, and as result, they are often used in installations that are questionable. The flow velocities through butterfly valves are usually limited to 25 to 30 feet per second, although high-performance butterfly valves can operate up top 50 feet per second. The flow around the disk in the fully open position creates eddies and flow disturbances that can be carried to downstream valves unless proper spacing is provided between valves. Butterfly valves can be provided with resilient seats for extremely tight shutoff capability.

Butterfly valves are sometimes used for controlling flow, but that has to be done with caution. The rotation of the disk does not provide good flow control throughout the operating range, resulting in most of the flow control in the mid-position of operation. It is also difficult to introduce air into the water flow immediately downstream of the valve to prevent cavitation.

Butterfly valve operating forces are very low, with very little friction and hydraulic effects. They may be operated manually, by electric motor-operators, or by hydraulic operation. Some butterfly valves are counterweighted to close upon loss of power in an emergency situation.

C. Gate Valve – A gate valve is a variation of a slide gate, with a circular body and disk. The disk is often wedged into tapered seats to provide tight shutoff. Gate valves are often used for guard gates upstream of regulating valves, or used for throttling flow in low-head applications. Flow through the valve is fairly unrestricted except for the slot around the disk seats. They are relatively inexpensive and easy to install, but the larger valves can become quite heavy.

Knife gates are often manually operated, but the larger sizes are often operated by electric motor-operators or hydraulic operation.

D. Knife Gate – A knife gate is another variation of a slide gate, but is not commonly used in the hydropower or dam industry. A knife gates has a circular opening in the gate body with a very thin disk that moves across the flow, resulting in a very thin valve, face to face. The wetted parts are often made of stainless steel to prevent corrosion, and resilient seats are often used for tight shutoff. Flow through the valve is fairly unrestricted, with just slight offsets in the flow at the seat area.

Another variation of the knife gate is a "Thru Port Knife Gate, which has a disk with a circular opening which matches the pipe diameter to provide an unobstructed flow through the valve, resulting in no flow losses or cavitation potential.

Knife gates may be operated manually, by electric motor-operators, or hydraulic operation.

E. Fixed-Cone Valve – A fixed-cone valve is commonly used for regulating the flow of water from an outlet works in a dam. A fixed-cone valve is a cylindrical valve with a sliding sleeve that covers the opening at the downstream end of the valve. A cone (usually 90 degrees) is installed at the end of the circular structure that disperses the flow radially through the opening between the valve body and the sleeve. Flow can be controlled very well at all but the smallest valve openings. Seals are provided between the valve body and sleeve to reduce leakage. Operating forces are low, since there is only the friction between the moving parts and the seals, with little hydraulic forces involved. The valves have a high coefficient of discharge, and do not dissipate much energy. They tend to produce considerable spray, as a result of the cone at the end.

Fixed-cone valves can be furnished with hoods attached to reduce the spray, while some other installations use an energy dissipation chamber to contain the spray and reduce the energy at the downstream end of the structure. Some attempts have been made to operate fixed-cone valves submerged, but that requires careful study and evaluation.

Fixed-cone valves can be operated manually or with an electric motor-operator through a miter-gear box and shafts or by hydraulic operation.

Photo 3
Fixed-Cone Valve with a Hood

F. Jet-Flow Gate – A jet-flow gate is a variation of a slide gate used as a free discharge gate. The gate has a circular opening with a sliding disk that moves over a floating, sloping orifice shaped opening. The sloping orifice concentrates the flow to help introduce air to prevent cavitation. There is very little energy dissipation, resulting in fairly high flow coefficient. Operating forces are high, due to the friction between the disk and the seats, and between the disk and the orifice.

Jet-flow gates have also been used in submerged applications, by expanding the downstream discharge pipe to three times the orifice diameter and keeping the discharge pipe very short to allow recirculation and prevent cavitation.

Jet-flow gates can be operated manually, by electric motor-operators or by hydraulic operation.

Photo 4
Motor-Operated Jet-Flow Gate

G. Sleeve Valve – Sleeve valves are used as energy dissipaters, both in-line and at the end of a conduit. Sleeve valves consist of a section of perforated pipe with small tapered holes and a sliding sleeve to uncover the ports required to provide the desired discharge. The sleeves are provided with seals to minimize leakage. The in-line type valves usually operate with the flow on the exterior of the perforated section, flowing inward to dissipate the energy and then the flow moves downstream within the conduit. The valves at the end of a conduit are usually installed in a vertical position, with the flow moving outward from inside the conduit into a stilling well to dissipate energy. Sleeve valves are very expensive to purchase, because the manufacturing process is difficult and the materials are usually stainless steel and other corrosion/cavitation resistant materials. Installation costs are nominal, since the valves are usually just connected to the conduit with appropriate flanges.

Sleeve valves are usually operated to provide precise flow control; they are usually operated by either electric motor-operators or hydraulic operation, with remote position sensing provided.

H. Clamshell Gate – The clamshell gate is a special design used by the U.S. Bureau of Reclamation. The clamshell gate consist of two leafs operating in an arc over the end of a conduit; machined to match the arc of the gate leafs. The leafs move in a symmetrical manner to provide uniform flow between the two leafs. There is very little energy dissipation, since the flow is much like the flow from an open pipe, so an energy dissipation basin or structure is required. Clamshell gates work very well in a submerged installation, providing excellent recirculation to prevent cavitation.

Clamshell gates are usually operated by electric motor-operators or hydraulically operated.

I. Radial Gate – Radial gates have been used for many installations at spillways, canal check structures, and canal turnouts. They have also been used occasionally for outlet works with a top-seal arrangement in a pressurized structure. A radial gate consists of a curved plate with reinforcing ribs, and arm structure to provide lateral support, and trunnion pins to allow rotation of the gate structure. Resilient seals are provided at the bottom and sides to reduce leakage, and smooth wall plates are often used to provide a good sealing and sliding surface.

Operation of radial gates is provided by wire-rope hoists using either manual operators or electric motor-operators, or by hydraulic cylinders attached to the gate structure.

Variations of radial gates with a top seal have been used for medium head (100 to 150 feet) outlet works regulation. The use of the top seal provides a sealing surface around the entire perimeter of the gate leaf. The top seals have been difficult to maintain, however, and leakage can be a problem.

Photo 5
Example of Radial Gate

J. **Hinged Crest Gate –** Hinged crest gates are used at the crest of a spillway, to allow flow overtopping the gate to regulate the reservoir or pool elevation. The gate consists of a flat or slightly curved plate structure, with a hinge system at the bottom to allow the gate to rotate from near vertical to horizontal. The crest gates are usually wide and short to provide regulation of long spillway structures.

The operation of crest gates varies considerably. Some gate use torque tube arrangement with a hydraulic operator or electric motor-operator at one end. Some other installations use hydraulic cylinders, mounted either underneath the panel or mounted above the gate on a deck. Still others use a pneumatic bladder arrangement under the panel to regulate the gate.

2. Older Equipment

A. **Needle Valves –** Needle valves have been used primarily as free discharge valves for outlet works, but on some occasions they have been used for guard valves for turbines in power plants. Needle valves are cylindrical valves with an inner plunger or needle, with a tapered nose, that moves back and forth to regulate flow through the valve. Most needle valves were operated by pressurizing the opening or closing chambers within the valve, with reservoir water from within the valve. A type of feedback control system was built-in to try to maintain the position of the needle. The needle valves were very troublesome, due to build-up of corrosion on closely fitting plungers and bodies, operating clearances that increased with usage and produced large internal leaks, and control systems with close tolerances that tended to plug up or corrode. Some needle valves have experienced catastrophic failure due to air entrapment that created large unbalanced forces in the opening and closing chambers. As a result, the valves slammed shut and ruptured the valve body or upstream piping due to water hammer.

Some needle valves are mechanically operated, and do not experienced the operating difficulty experienced with water-operated valves. Many needle valves have been replaced with more modern, trouble-free valves, with better flow characteristics. The needle valves also experienced problems with cavitation on the needles, due to sub-atmospheric pressure, and leakage past the seats due to erosion form high-velocity flow.

B. Hollow-Jet Valves – Hollow-jet valves have been used for many years by the U.S. Bureau of Reclamation and some other entities. The valves are designed as a type of reverse needle valve, with the seal at the upstream end of the needle instead of downstream, but they are operated either hydraulically or by electric motor-operator.

Hollow –jet valves provided higher discharge coefficients than needle valves, but they are very costly to fabricate because of the complex shapes used in the needle portion and upstream body. The hollow-jet valves experience seat erosion at small openings, and can have cavitation damage at any slight offsets in the downstream bodies.

Gate Operating Systems

There are several types of operating systems available to operate gates and valves. Principally, there are four basic types; manual operators, electric motor-operators, hydraulic operators, and pneumatic operators.

1. Manual Operation

Manual operation is usually accomplished with a crank or handwheel connected to the gate or valve operating mechanism with threaded stems or a gearbox arrangement. (Manual operation is also possible with hydraulic operators, and will be discussed under hydraulic operation).

a. Slide gates, gate valves, knife gates, jet-flow gates, and some sleeve valves and butterfly valves use a rising stem design, where an operating stem rises and lowers to open or close the gate or valve. The stem has threads machined onto the upper end, and a crank, handwheel, or gearbox is connected to the stem with an operating nut.

b. Fixed-cone valves, clamshell gates, and some sleeve valves and butterfly valves use rotary motion from the crank or handwheel and rotating shaft to convert to linear motion through a gearbox arrangement.

c. Radial gates, wheel gates, roller gates, and crest gates often use a wire – rope hoist design that can be manually operated with a crank or handwheel that turns the wire-rope hoist drums. Usually wheel gates and roller gates are too large to operate manually, in a practical sense.

The crank or handwheel should be sized to operate the equipment easily and provide sufficient force to operate the equipment. The handwheels should be at least 12 to 15 inches in diameter for ease of use. Equipment with cranks or handwheels is usually designed to operate with no more than 40 pounds of pull on the handle or handwheel rim, but the equipment must be designed for much more effort (80 to 120 pounds), since some operators can exert much more than 40 pounds effort if the equipment is stuck or difficult to operate.

The size of the equipment using manual operation should be carefully considered. Although some gates and valves can be operated manually, operation may be so slow that it is not practical, and if operation is too difficult, the equipment will not be exercised as it should.

Photo 6
Manual Operator

2. Electric Motor-Operators

Electric motor-operators are used in similar manners as the manual operators, that is, either linear motion with threaded stems or rotary motion converted to linear motion.

An electric motor-operator consists of a high-torque electric motor, gearbox for suitable gear reduction and operating speed, pushbuttons, limit switches to control stopping positions, torque switches to protect equipment from overloads, indicating lights, local position indicators, an in some instances, remote position indicators. The high torque electric motors are used to initially start equipment open or closed, and operate best on three-phase power due to the high current draw during initial operation. The motor-operators will function on single-phase power, but size and output is limited.

The electric motor-operators are usually designed for outdoor applications, with weatherproof enclosures. Submerged operation is usually not an option, except for extremely short duration.

Handwheels are usually provided on the units for manual operation if power is interrupted.

Photo 7
Electric motor-Operator

3. Hydraulic Operators

Hydraulic operation is most often used on large gates and valves operating at high head, but is becoming more common for small equipment at low heads for particular installations.

Hydraulic operation typically uses one or more hydraulic cylinders attached to the gate or valve, to provide linear motion. The hydraulic cylinder(s) are connected to a central hydraulic power unit, with rigid or flexible hydraulic lines. The hydraulic line connections should be welded where possible, to reduce the potential for leaks at the joints. The hydraulic cylinders can be made fairly compact, since high operating pressures are available (2,000 to 3,000 psi, with some systems approaching 5,000 psi). The hydraulic cylinders can be designed for submerged operation, and can be furnished with electronic sensors for remote gate or valve position sensing.

The hydraulic power units (HPUs) consist of an oil reservoir, one or more electric motor-driven hydraulic pumps, control valves, filters, pressure switches to control pump and valve operation, relief valves to limit operating pressure, and sometimes accumulators to store hydraulic pressure. HPUs can be designed to operate more than one gate and/or valve at a facility, by simply adding the required control valves, and can be located at fairly long distances from the equipment being operated.

Manual operation can be provided by using a hand pump system instead of an HPU. Also, a hand pump may be provided with an HPU for operation during electric power interruption. Hand pumps can provide slow operating speeds, but some pumps utilize a two-stage pump, with a larger output available at low pressure.

Accumulators provide operating flexibility when need by providing for limited operation during electric power interruption, or for modulating service without running the hydraulic pumps and motors frequently.

Improved hydraulic oils can provide better outdoor performance, and biodegradable oils are available where environmental concerns arise.

Some older gates and valves operated on hydraulic systems using water instead of hydraulic oil. The water is stored in tanks above the dam, or the pressure is built up by pumps. The principles are the same, but the water systems are usually manually operated by opening and closing control valves. The water systems have operated for many years, and some are still in service, but corrosion, worn and corroded seals, and leaky piping have made many of the systems lacking in reliability. Many of the water components, such as cylinders, are very large, since high pressure, produced in oil hydraulic systems, is not available. Most water systems operated in the range of several hundred psi, instead of several thousand for an oil hydraulic system.

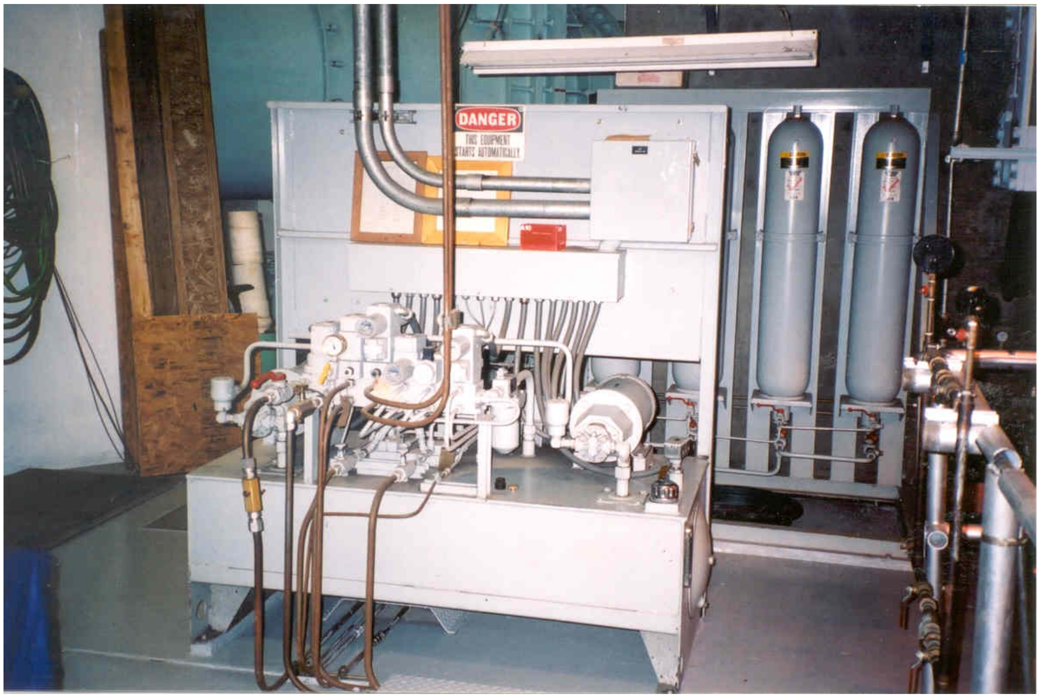


Photo 8
Hydraulic Power Unit with Accumulators

4. Pneumatic Operators

Pneumatic operators are rarely used for operating gates and valves; although one successful gate manufacturer currently designs and fabricates hinged crest gates using pneumatic bladders at low pressure (Approx. 20 psi).

The problem with pneumatic operation in typical gates and valves is that, with the air, being compressible, it is difficult to maintain a set position. If operating forces are high, pneumatic cylinders and control systems become quite large, since air pressure is limited to approximately 125 psi. Compressed air is also dangerous to work with, because the expansion of the air when released can cause great damage.

Moisture in the compressed air can also create problems at cold temperatures, and can cause corrosion to occur in pneumatic equipment.

5. Portable Operators

There are several types of portable operators available to work in conjunction with manual operators. The manual crank or handwheel operators can usually be provided with a square nut or fitting for adapting to a portable operator.

A. **Portable Drill –** A portable drill unit is available, which can be mounted on a tripod and attached to the crank or handwheel shaft on a manual operator.

Electric power must be available, and output is usually limited to approximately 80 lb. ft. of torque. The drill unit is usually comparable to a ½-inch heavy-duty drill.

B. Portable Hydraulic Operator – Portable hydraulic operators are available, which also connect to the shaft of the manual operator. The portable hydraulic operator usually uses a small (5 hp) gasoline engine, hydraulic pump, control valve, and a hydraulic motor with flexible hoses to clamp to the manual operator. These units are usually mounted on a cart that can be easily transported to where needed.

Photo 9
Portable Hydraulic Operator

Another type of portable hydraulic operator connects to a standard hydraulic system with quick-connect fittings or other connections, to power a hydraulic system or to take the place of the main HPU during an electric power interruption.

C. Chain Saw Operator – Chain saws have been modified to replace the cutting chain assembly with a chain-driven operating nut to attach to the shaft of a manual operator. These units are lightweight, but very noisy.

Trends

In the design of outlet works gates and valves, and outlet works arrangements, there are several trends that have been noted.

1. **Remote Operation –** More and more designs are being prepared with remote gate position sensing and remote or automated operation. The modern gate operating systems have reasonably inexpensive means of providing remote gate position sensing, and consequently remote control is more attractive. More precise control of water flow is provided by remote or automated control, since there is faster response to changing conditions. The remote operating systems have also become more reliable. Remote sensing is achieved by several means:

   A. **Electric Motor-Operators –** Electric motor-operators can be furnished with position transducers producing a 4 to 20 Ma signal that provides a continuous output signal of the gate or valve position. This signal can be transmitted by hard wire, optic cable, or radio signal to a control panel or computer many miles away. The transducers are built into the operators for integral operation, and can be easily modified to produce stepping functions or signals at certain openings.

   B. **Hydraulic Cylinders –** Hydraulic cylinders can be provided with linear position transducers also producing a 4 to 20 Ma signal, that function just as the transducers on the motor-operators. These transducers san be used on hydraulic cylinders submerged in the reservoir for underwater operation.

   C. **Inclinometers –** Some gates that operate with limited rotation, such as radial gates and crest gates, can use a transducer known as an inclinometer, which measures the angle of a gate member and converts that to gate position. These transducers also produce a 4 to 20 Ma signal that functions just as the other transducers.

2. **Hydraulic Operation –** There appears to be more acceptance on smaller projects for hydraulic operation of gates and valves. This practice is favorable for several reasons:

   A. **Submerged Operation –** Hydraulic operators can be designed for submerged operation, which may be preferable in some instances. Submerged hydraulic cylinders can eliminate long operating stems, and the resultant alignment problems. Some stem installations are difficult to design, considering access and maintenance issues.

   B. **Improved Hydraulic Fluids –** Developments in recent years have provide hydraulic fluids that are suitable for outdoor use, at most operating temperatures. Biodegradable hydraulic fluids are now available that reduce the problems with oil leakage in storage reservoirs.

C. **Better Seals –** Seals and pipe joint connections have improved to reduce leakage and oil spills. Welded pipe connections have virtually eliminated oil leaks, and tubing and fitting connections are improved.

D. **Automated Operation –** Hydraulic operation lends itself very well to automated operation. Where gates and valves are frequently operated for optimum flow control, there are no stem threads to wear out, and accumulators in the hydraulic systems can reduce pump starts and stops. The design of hydraulic cylinders allows for frequent operation without undue wear.

3. **Foreign Design and Manufacturing –** In recent years there has been a shift in gate and valve design and fabrication to foreign countries. Two large gate manufacturers, Hydro Gate and Waterman Industries, have gone through bankruptcy. Hydro Gate reorganized and was purchased by the Henry Pratt Company, and Waterman is trying to reorganize and scale back, eliminating much of their engineering staff.

   Asian countries, such as Korea and Japan, have been designing and/or fabricating gates and valves for many years. India is now trying to expand their expertise in gate and valve design and manufacturing. Some work is still produced in Europe, notably England and Sweden.

   There is a lack of gate designers in the U.S. now, with many steel fabricators trying to bid on work, but there are no designers to be found for jobs involving design-and-build. Many of the old gate and valve manufacturers have disappeared, such as Bingham-Willamette, Allis-Chalmers, Pelton, and Goslin-Birmingham, with no new companies arising to take their place.

4. **Reduced Government Involvement –** Most of the government agencies, such as the Bureau of Reclamation, Corps of Engineers, and Tennessee Valley Authority, have cut back on their dam design and construction phases of work, resulting in less research on new equipment and operation. The government agencies were in the forefront of new developments for many years, but that development has really decreased.

Attachment 7

White Paper on Energy Dissipators

FEMA Outlet Works Workshop, May 25 – 27, 2004 – Denver, Colorado

By

Henry T. Falvey[1]

INTRODUCTION

Water passes over or through a dam in a controlled manner through three possible paths. These paths are over the spillway, through the penstock, or through an outlet works. The purpose of the spillway is to pass flood events past the dam without overtopping the structure. Water passing through penstocks goes to hydroelectric turbines to generate electricity. Water passing through outlet works is used to control the water level in the reservoir and to provide water for irrigation, municipal, or minimum downstream flow requirements.

The outlet works conduit normally passes through the body of the dam. Upstream of the centerline of the dam, the pressure in the conduit is almost balanced by the external pressure from the water in the dam. However, in the section downstream of the dam centerline, the internal pressure can be much higher than the external pressure. A guard gate is often placed near the centerline of the dam to avoid the risk of cracks forming in the downstream conduit and washing out an earth dam. The conduit downstream of the guard gate is either a steel pipe located in a tunnel or it is a chute that forms a part of the tunnel. If the downstream conduit is a steel pipe in a tunnel, then the control gate structure is located near the downstream toe of the dam. However, if the downstream conduit is a chute, then the control gate is located immediately downstream of the emergency gate. With a concrete dam, the location of the guard and control gates is not critical. They can be found at the axis of the dam or at the downstream face.

Almost every outlet works requires an energy dissipator so that the high-energy flow from the reservoir does not damage the downstream channel or structures. Technically, energy is not dissipated in the process. The hydraulic energy is converted into heat energy. However, the heat rise in the conversion process is normally so low that it can be neglected. Therefore, hydraulic engineers normally refer to the energy conversion process as dissipation of the hydraulic energy. The conversion is accomplished by

- Creating fine grain turbulence, or
- Creating a loss through a change in momentum of the flow.

The different types of energy dissipators that have been used at outlet works include,

- Stilling basins,

[1] Henry T. Falvey & Associates, Inc, Conifer, CO 80433. Email: Falvey@members.asce.org. Tel & Fax: 303 808-4920

- Baffled Apron Drops,
- Stepped spillways,
- Impact basins,
- Stilling wells,
- Various types of valves,
- Sudden enlargements
- In-line orifices
- Flip buckets, and
- Plunge pools.

The selection of the type of energy dissipator that is used at an outlet works depends upon head, discharge, and economical considerations. Often the energy dissipator that is used for a specific installation consists of a combination of the types listed above.

The design of the stilling basins, impact basins, flip buckets, and baffled apron drops has been thoroughly discussed in USBR Engineering Monograph No. 25.[2] General guidelines for the design of outlet works can be found in the US Army Corps of Engineers Engineering Manual EM 1110-2-1602[3] and in the USBR publication "Design of Small Dams."[4] Many of the specialized types of dissipators are described in site-specific studies.

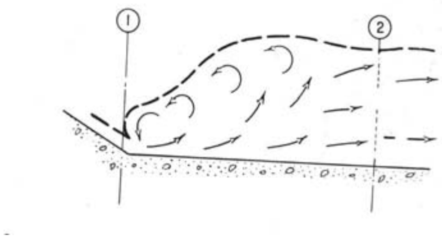
The purpose of this paper is to present a "state of the art" review of current energy dissipation devices with respect to their design and selection.

DESIGN FEATURES

Stilling basins. The USBR defines three types of stilling basins. The Type I Basin is simply a hydraulic jump on a horizontal apron, Figure 1. The energy dissipation is accomplished by turbulence within the jump. The Type II Basin contains blocks (chute blocks) at the end of the basin and a dentated end sill, Figure 2. The chute blocks create shear zones that generate fine grain turbulence. The purpose of the end sill is to prevent downstream erosion and does not contribute significantly to energy dissipation. The Type III Basin contains an additional set of blocks (baffle blocks) within the horizontal apron to create additional turbulence, Figure 3. Cavitation and transverse loads on the baffle blocks have required the development of special shapes for high head installations. The addition of the chute blocks and the baffle blocks permits the length of the stilling basin to be reduced. The energy dissipation for these structures is based on the change in momentum of the water through the structure.

---

[2] Peterka, A.J., 1978, "Hydraulic Design of Stilling Basins and Energy Dissipators." This monograph is available over the Internet at http://www.usbr.gov/pmts/hydraulics.lab/publications.html.
[3] This can be obtained on the Internet at http:/www.usace.army.mil/usace-docs/eng-manuals/em1110-2-1602.
[4] Hoffman, C.J., 1987, "Outlet Works," Chapter X of Design of Small Dams." Third Edition. This book is available over the Internet at http://www.usbr.gov/pmts/hydraulics.lab/publications.html.



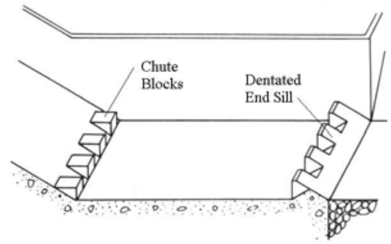


Figure 1. Type I Basin

Figure 2. Type II Basin

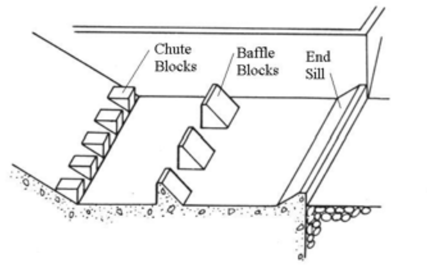


Figure 3. Type III Basin

Baffled Apron Drops. The baffled apron drop that is shown in Figure 4 is extremely useful in dissipating energy by exerting a force on the water that passes through the baffles. The drops are also useful in controlling the air content of the water. With approximately seven rows of baffles, the air content of the water becomes saturated. That is, if the water is supersaturated or if the water needs more air the baffled apron drop will either release air or entrain air to improve the water quality.

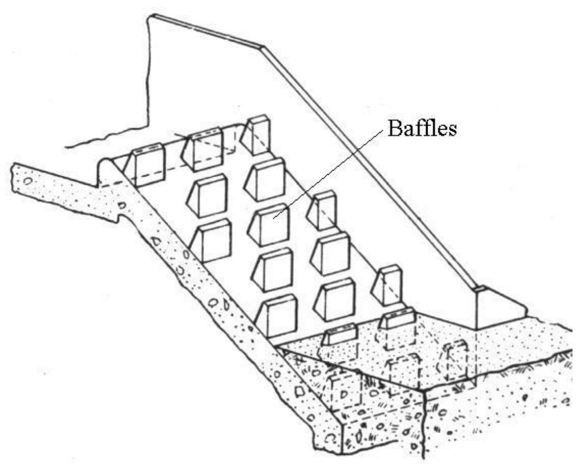


Figure 4. Baffled Apron Drop

Stepped Spillways. Methods to design a stepped spillway as shown in Figure 5 can be found in an excellent book edited by Minor and Hager.[5] Although the title indicates that the designs are for spillways, the methods outlined in the book can be applied equally well to the design of dissipators of outlet works. If the flow depth relative to the step height is less than about 0.8, then the energy dissipation is primarily due to changes in momentum. This regime is known as nappe flow. For greater depths, energy dissipation is primarily due to boundary shear. This regime is known as skimming flow. The exact value of the coefficient 0.8 depends upon the slope of the chute.

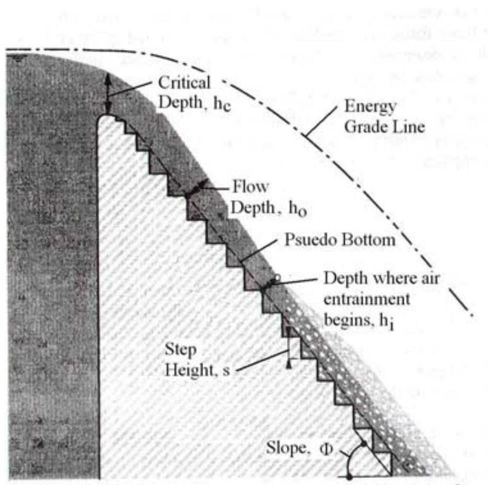


Figure 5. Stepped Spillway

Impact Basins. With an impact basin, the energy is dissipated by turbulence that is generated when a jet of water impacts against a vertical wall. After hitting the wall, the jet is deflected upward and downwards. A horizontal projection is provided on the top of the wall to increase the turbulence in the upstream pool. Although the USBR limits the dimensions and discharges to relatively low energy levels, the basins have been used successfully at much higher energy levels by scaling the recommended dimensions to the larger sizes. The USBR defines impact basins as Type VI Basins, Figure 6. The force that the baffle wall exerts on the incoming water jet changes its momentum and thus generates the loss.

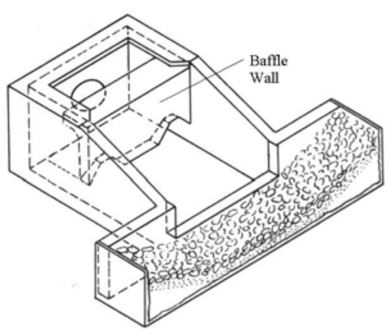


Figure 6. Type VI Basin

[5] Minor, H.E, and Hager, W.H., 2000, *Hydraulics of Stepped Spillways*, A.A. Balkema, Brookfield.

Stilling Wells. For low discharges for flows into canals, a stilling well as shown in Figure 7 is frequently used. The design of stilling wells has been outlined by Falvey[6] and Burgi[7]. The energy dissipation is achieved by the change in momentum between the water entering the well through the pipe with the diameter and the flow up the square well with a side length of width b. The corner fillets and the pedestal in the invert tend to maximize the circulation and energy dissipation in the lower portion of the well. The flow is controlled by changing the opening, a, using a sleeve valve on the bottom of the down comer pipe. Problems have been experienced with the valve operating mechanism due to the turbulence in the stilling well.

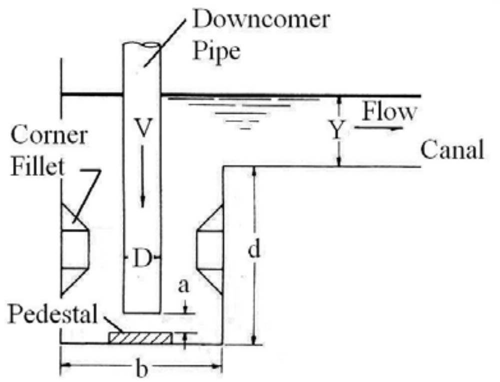


Figure 7. Stilling Well

Valves. With high-head and high flow applications, fixed-cone valves are normally used for energy dissipation. These valves use the principle of impinging jets and baffles to provide the energy dissipation as shown in Figure 8.[8] The ring deflector was damaged during operation of the energy dissipator because of a weld failure on the steel cladding.[9] Subsequent inspection found that a large void had been left in the concrete behind the steel liner when it was placed. Various modifications of this design concept have been developed including hoods on fixed-cone valves that discharge into the atmosphere as shown in Figure 9.[10] The distance between the end of the fixed cone valve and the hood is critical. Severe blowback has been experienced in prototype installations where this distance was off by only an inch or two.

---

[6] Falvey, H. T. 1962, “Hydraulic Model Studies of the Wanship Dam Vertical Stilling Wells, USBR Hydraulic Laboratory Report, HYD 481.
[7] Burgi, P.H., 1973, “Hydraulic Model Studies of Vertical Stilling Wells, USBR Hydraulic Laboratory Report, REC-ERC-73-3.
[8] Colgate, D., 1963, “Hydraulic Model Studies of the River Outlet Works at Oroville Dam,” USBR Hydraulic Laboratory Report, HYD 508.
[9] DeVries, J.J., Hameed. T., and Cheema, M.N., 1994, “Hydraulic Model Study of the Oroville Dam River Outlet Works,” Center for Water and Wildland Resouces, University of California, Davis.
[10] Beichley, G.L., 1970, “Hydraulic Model Studies of an Energy Dissipator for a Fixed Cone Valve at the Ute Dam Outlet Works,”“ USBR Hydraulic Laboratory Report, REC-ERC-70-11.

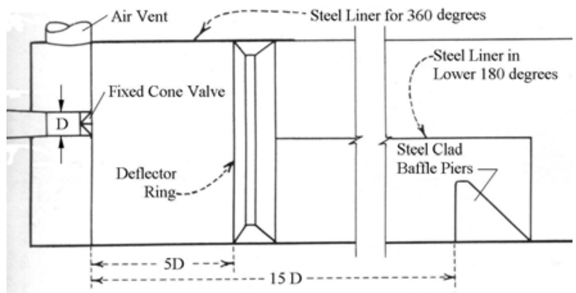


Figure 8. Fixed-cone valve installation

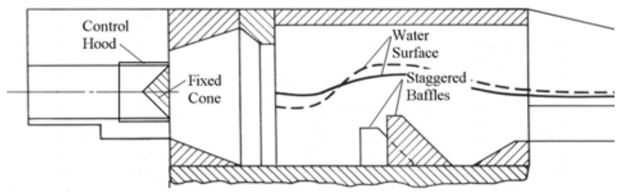


Figure 9. Hooded Installation of a Fixed-cone Valve

For high-head and low-flow requirements, the valves are designed on the principle of providing small orifices through which the water flows.[11, 12] The sudden expansion at the downstream side of the orifice is the mechanism that generates the energy dissipation. The valves are normally placed in-line as shown in Figures 10 and 11. However, a 40-inch Monovar™ valve was used at Terminus Dam in California. In this case, the valve discharged freely into the downstream pool.

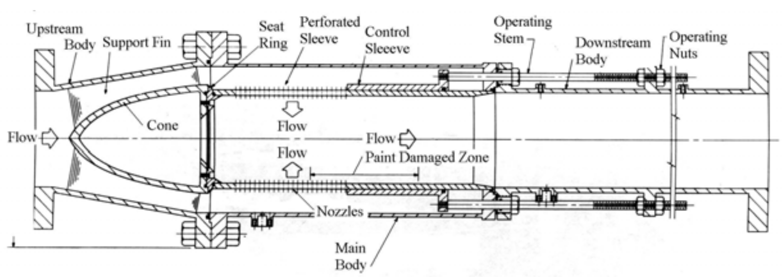


Figure 10. Orifice valve

[11] Burgi, P.H., 1977, "Hydraulic Tests and Development of Multijet Sleeve Valves," USBR Hydraulic Laboratory Report, REC-ERC-77-14.
[12] Frizell, K.W., "Laboratory Testing of an 8-inch Monovar™ Valve."

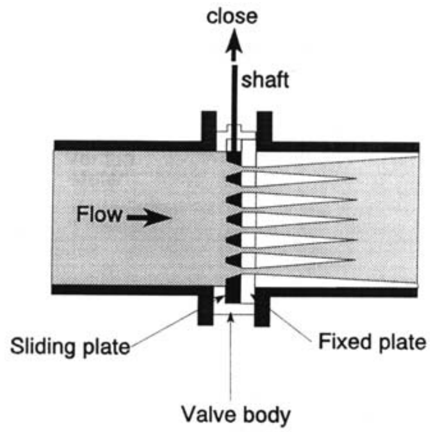


Figure 11. Monovar™ Valve

<u>Sudden Enlargements.</u> A sudden enlargement is a very effective method of dissipating energy. The sudden enlargement can occur within or at the end of a pipeline. Two examples of sudden enlargements are shown in Figures 12 and 13. The proportions shown in Figure 12 are those that minimize the formation of cavitation in the sudden enlargement.[13] Nevertheless, some ranges of operating conditions will still generate cavitation within the structure. The sudden enlargement at the end of the pipeline places all the cavitation formation in the downstream tailrace.[14] At the Crystal Dam outlet, long snake-like vapor filled cavities can be seen during operation. However, these cavitation vortices apparently do not generate any adverse effects.

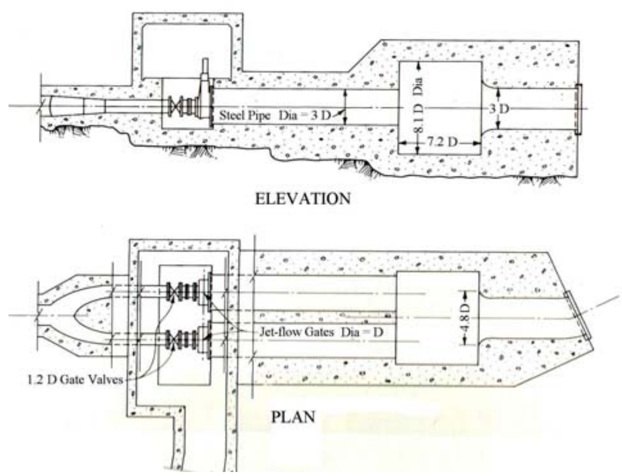


Figure 12. A sudden Enlargement in a Pipeline with Jet Flow Gates

[13] Isbester, T.J., 1974, "Hydraulic Model Studies of the Teton Canal Outlet Works Energy Dissipator,"" USBR Hydraulic Laboratory Report, REC-ERC-74-16.
[14] Burgi, P.H., and Fujimoto, S., 1973, "Hydraulic Model Studies of Crystal Dam Spillway and Outlet Works, Colorado River Storage Project," USBR Hydraulic Laboratory Report, REC-ERC-73-22.

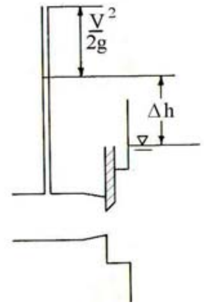


Figure 13. A Sudden Enlargement at the End of a Pipeline

In-line Orifices. Another example of the use of sudden enlargements to dissipate energy is the placement of a series of in-line orifices in a pipeline as shown in Figure 14.[15]

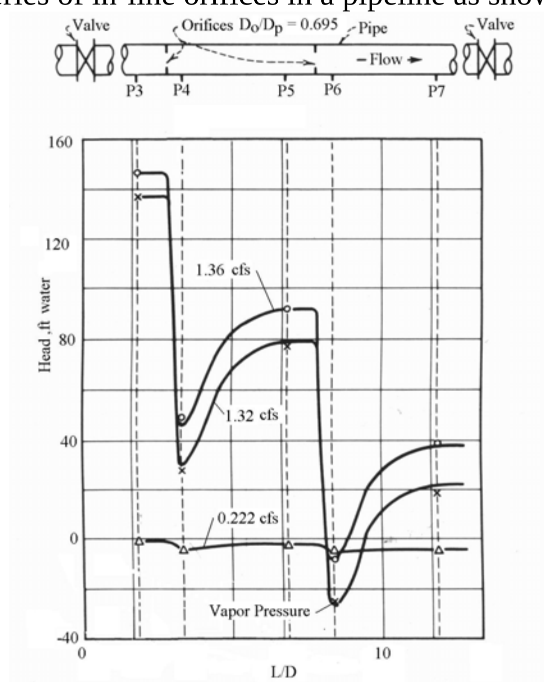


Figure 14. In-line orifices

This solution was used at Seven Oaks Dam outlet to provide low flows under a high head. Instead of a valve, the terminating structure was an impact basin. Detailed computations were necessary to determine the proper number and orifice diameters to provide the required energy dissipation under a wide range of reservoir heads without generating cavitation downstream of the orifices.

Elbow Dissipator (ECI Concept)

The energy loss for a 90-degree miter bend is approximately

$$\Delta H \approx 1.1\frac{V^2}{2g}$$

[15] Ball, J.W., 1963, "Progress Report on Hydraulic Characteristics of Pipeline Orifices and Sudden Enlargements used for Energy Dissipation,"" USBR Hydraulic Laboratory Report, HYD 519.

Placing several 90-degree miter bends in a concrete block, as shown in Figure 15, can dissipate relatively high heads. The concrete block must be designed to withstand the internal pressures and be massive enough to resist overturning from the uneven thrust produced as the pressure reduces at each elbow. To date, this concept has not been model tested or installed at any prototype location.

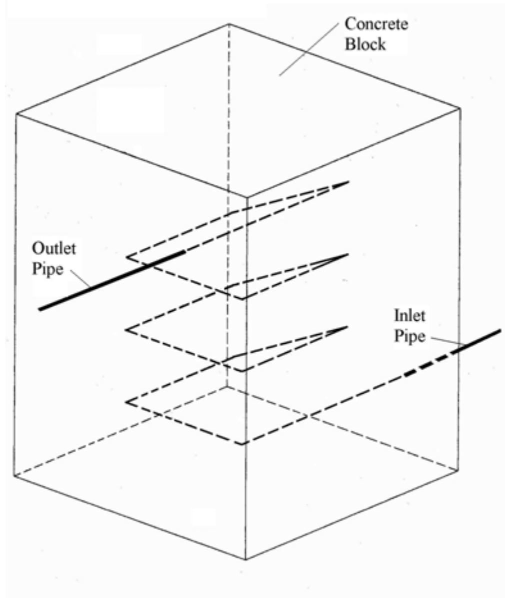


Figure 15. Elbow Energy Dissipator

Flip Buckets. A flip bucket is often used at the end of an outlet chute to throw the flow away from the toe of the dam. These are used in conjunction with plunge pools described below. Actually, the flip bucket is not an energy dissipation device although it is designated as one in the USBR Engineering Monograph No. 25, as shown in Figure 16. Dentates are frequently used to spread the compact jet as it enters the plunge pool as shown in Figure 17.[16] The literature frequently refers to the energy dissipation effects of the jet within the air due to the spreading jet. Actually, very little energy dissipation occurs because of the air-water interaction as the jet flies through the air. The principle effect of the dentates is to increase the area over which the jet enters the plunge pool. This decreases the energy per unit area over which the energy must be dissipated.

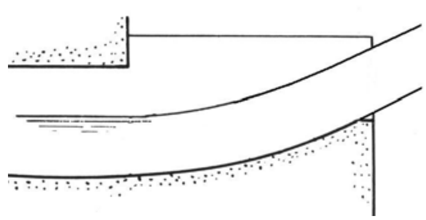


Figure 16. USBR Type X Basin

[16] Cooper, D.R., 1992, "Outlet Works for Seven Oaks Dam, Santa Ana River, San Bernardino, County, CA," US Army Corps of Engineers, Technical Report HL-92-14.

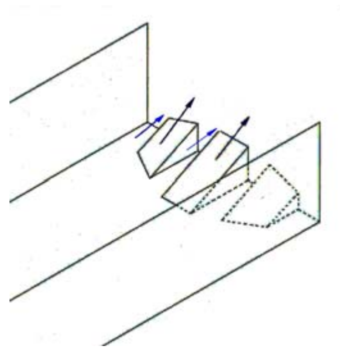


Figure 17. Dentates at the End of Chute

Plunge Pools. A typical plunge pool installation in connection with a flip bucket is shown in Figure 18. During the development of a plunge pool, the material that is excavated by the plunging jet can form a dam downstream of the plunge pool that will raise the tail water sufficiently to drown out the flip bucket. Therefore, many plunge pools are pre-excavated to alleviate this possibility. The depth and side slopes of this type of plunge pool are determined by the soil characteristics.

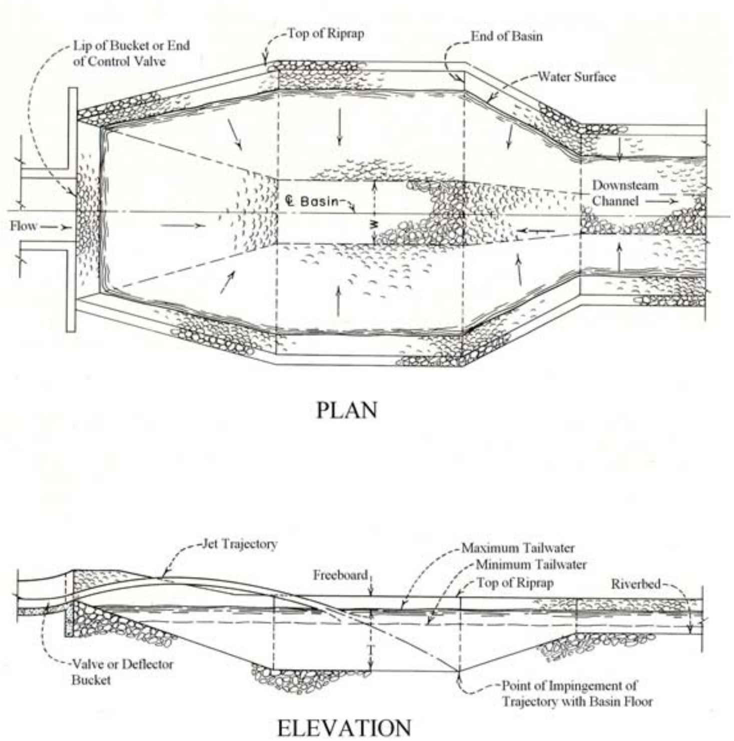


Figure 18. Plunge Pool in Connection with a Flip-Bucket

Another type of plunge pool is shown in Figure 19.[17] High-pressure fluctuations develop on the invert with this design. Sufficient anchorage and thickness of the floor slabs must be provided to prevent their loss during high flows.

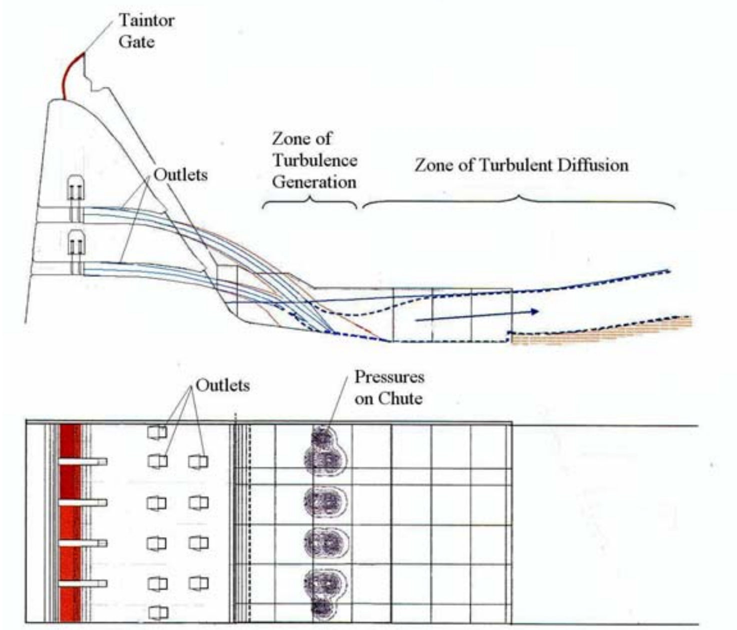


Figure 19. Plunge Pool for an Outlet in a Concrete Dam

CONCLUSIONS

Wide varieties of structures are available to designers for energy dissipation of high head flows from outlet works. Many of these are described in books and monographs. However, many designs have been developed for site-specific installations that have not appeared in the literature. Some of these designs have not been verified by either model or prototype tests.

[17] Bollaert, E., 2004, "Folsom Dam, Numerical Modeling of Hydrodynamic Forces on the Stilling Basin" , Aquavision Engineering, Lausanne, Switzerland

Attachment 8

White Paper on Rehabilitation of Pipe Conduit Spillways Through Dams

FEMA Outlet Works Workshop, May 25-27, 2004
Denver, Colorado

By James R. Crowder, P.E.
Schnabel Engineering

Included in the aging infrastructure of the Southeast United States are hundreds of dams in excess of thirty (30) years old. Many of these aging dams are earthfill embankments constructed with corrugated metal pipe (CMP) spillway conduits passing through the base/foundation of the embankment. Deterioration of the conduit may become a problem when a spillway conduit has reached or exceeded its design service life, which is generally considered to be 25 to 30 years for CMP. The deterioration generally consists of leaking joints, corrosion and holes in the pipe. Corrugated Metal Pipes (CMP) are the most susceptible to deterioration. Corrugated Metal Pipes were used extensively in small earthen embankment dams in the southeast, ranging in height from 10 to 50 feet, in the past 30 to 50 years. The main risk associated with the deterioration of these conduits is piping of the surrounding embankment soils into the conduit, which can lead to eventual failure of the earthen embankment.

This paper discusses the repair options that are available to address these deteriorated conduits. The options discussed below are based upon the experiences of the author in the Southeast United States and are mainly limited to CMP's in earthen dams having a maximum height of less than 50 feet. Included in the discussion of each of the options are advantages, disadvantages, and design considerations.

- Option 1 – Replacement (Cut and Cover)
- Option 2 - Slipline the Existing Conduit
- Option 3 – Grouting Along the Exterior of the Conduit

- Option 4 - Abandon the Existing Conduit
  - Construct Siphon Spillway
  - Construct “Short” Riser and New Outlet Conduit.

Option 1 - Replacement

Replacement, as the name suggests, consists of excavation of the earthen embankment, removal of the deteriorated conduit, installation or construction of a new conduit, and backfill of the excavation. The side slopes of the excavation through embankment dams are typically limited to two horizontal to one vertical (2:1) or flatter, in order to facilitate compaction of the replacement backfill against the existing embankment. On relatively high embankments in narrow valleys, the excavation required to remove the existing low-level conduit may necessitate the removal of nearly the entire dam.

The replacement option typically offers the greatest operational flexibility among the spillway rehabilitation options. Appurtenances with the ability to completely drain the lake can be provided, if desired. Spillway capacity can be increased, or in some cases, controlled to allow for flood control improvements or storm water management.

Removing and replacing the existing conduit typically offers the most thorough rehabilitation option for impaired conduits through dams, although this option can be cost-prohibitive.

The advantages of the replacement option include:

- Ability to inspect or observe the foundation of the dam
- Ability to repair areas that may have been damaged by the deteriorating spillway
- Ability to dramatically change the capacity of the principal spillway
- Ability to add or improve seepage control measures along the conduit.
- Capacity to fully drain lake can be provided

The disadvantages of the replacement option include:

- Potential high cost of excavating the existing embankment fill to remove the existing conduit
- The creation of potential seepage paths along the surface of the excavation if proper bonding of the replacement backfill is not achieved.

- The lake must be drained, and remain in a drained condition throughout construction. The draining of the lake may be detrimental to both surrounding property values, as well to the aquatic life that relies on the lake.
- Difficulty in diverting normal flows and flood flows during the construction operations
- Loss of the use of the crest of the dam for pedestrian or vehicular traffic
- Excavation through the dam may cause conflicts with existing utilities or seepage control measures that may be present in the dam

Option 2 - Sliplining

Sliplining a pipe consists of placing a new pipe with a smaller diameter inside the existing deteriorated conduit and grouting the annular space between the two pipes. The sliplining technique can be used in lieu of the replacement or cut and cover method for the rehabilitation of the existing outlet pipe.
Depending on the pipe used, sliplining may increase the hydraulic capacity of the outlet pipe, even when reducing the inside diameter of the original pipe. The reason the hydraulic capacity may be increased, even when the diameter of the pipe has been decreased, is due to the decrease in roughness of the pipe. Corrugated metal pipes have a relatively high roughness value as a result of the corrugations.

The liner will typically have a roughness value of approximately ½ of the corrugated metal pipe. When designed and installed properly, the slipline technique will add additional years of service life to the existing pipe conduit spillway. A sand diaphragm drain is typically installed around the downstream portion of the existing conduit to limit the potential for soil piping as the CMP eventually corrodes and deteriorates.

The advantages of sliplining are many when compared to Option 1. The advantages include:

- No excavation required through the dam. In cases when either pedestrian or vehicular traffic is common or required along the crest of a dam this advantage may be critical.
- In some cases, a lake can be maintained at or near full when sliplining. When rehabilitating a lake in a residential area or adjacent to a golf course green, aesthetics are commonly the controlling factor. Keeping a lake full of water during summer months, as opposed to having a mud flat, is attractive to many clients. In addition, the presence of a full pool allows for the maintenance of the existing aquatic habitat within the lake.

The disadvantages of sliplining can be project threatening. The common disadvantages include:

- Specialized contractors are required for the installation of the liner and grouting of the annular space. Specialized contractors may increase the construction cost.
- Complete annular space grouting can be a challenge in certain instances.
- Use of excessive pressure during the grouting of the annular space may cause failure or collapse of the liner. Failure of the liner could be critical and could require excavation and removal of the conduit system.
- Partial collapse, irregularities, offset joints or bends in the existing pipe conduit may prevent the installation of an adequately sized sliplined pipe.
- Inability to observe and address internal issues associated with the embankment dam.

Option 3 – Grouting along the Exterior of the Conduit

Conduits exhibiting seepage through joints or deteriorated portions of the pipe walls can be remediated by injecting materials through the walls of the pipe in an attempt to fill voids that may have been created and to plug openings in the pipe walls or joints. Cementitious or chemical grouts are typically utilized for the purpose. Injection of the materials can be performed either from the surface of the embankment or from the interior of the conduit. Selection of the approach to injecting the grout depends upon the availability of working room for grouting equipment and personnel (i.e. conduit size), the depth of the conduit below the embankment surface, and if the remediation is performed with the lake full.

Injection of the grout from the interior of the pipe typically offers a better opportunity to deliver the grout to specified areas. Drilling through the embankment to grout along the conduit is usually performed for small diameter conduits or when the pipe is very shallow within the embankment. The greater the depth of fill over the conduit, the less certainty the grouting procedures are impacting the targeted areas. Drilling through the embankment is not practicable for situations in which the lake cannot be drained and portions of the conduit within the upstream slope of the dam are to be grouted.

Although costs for this type of rehabilitation are typically lower than the cost of other options, this approach is generally considered somewhat of a temporary repair. This option does not extend the design life of the material of the conduit. If the damage to the conduit has created voids in the surrounding backfill, it is difficult to be certain that the grouting has filled all of the voids.

This option retains the stage/discharge relationship of the existing spillway, which maintains any flood control benefits downstream of the dam. However, if the existing spillway capacity is insufficient to meet current project requirements, there is no opportunity to alter the capacity of the existing conduit.

To summarize, the advantages to this remediation option include;

- Relatively low initial cost.
- Ability to make multiple repairs, if initial attempts are not completely successful
- Work can be performed without draining the lake, although flow through the conduit needs to be controlled when working on the interior of the conduit.
- Access along the top of the dam may not be impaired.

The disadvantages to grouting along the conduit exterior include:

- Inability to be certain that potential voids have been filled.
- Does not typically provide a permanent repair for an aged conduit.
- Inability to address spillway capacity issues.

Option 4 – Abandonment of Existing Conduit and Construction of a Siphon

Abandonment consists of grouting full the existing corrugated metal pipe with either a sand/cement grout or a gravel/sand/cement grout. In either scenario, an expansive chemical admixture is typically included in the grout mix to control or reduce shrinkage during curing of the grout. As with the sliplining option, a sand diaphragm drain is typically installed around the downstream portion of the existing conduit to limit the potential for soil piping as the CMP eventually corrodes and deteriorates.

Siphons, as the principal spillway for the rehabilitation of dams, have been used successfully in the southeast, but are generally limited to small drainage basins with relatively small peak inflows. Because the soil loading is relatively small, siphons can be constructed of flexible conduit such as PVC, HDPE, or Ductile Iron. Typically, siphon spillways in these applications do not exceed 12-inches in diameter. However, in some instances, siphons as large as 15 to 18 inches in diameter have been successfully utilized in small dams. Dam owners and surrounding property owners should be aware that the use of siphons, as opposed to the more traditional pipe-and-riser spillway systems, generally results in a lake that will fluctuate more as a result of the inherit inefficiency of the siphon until priming occurs. Siphons prime with a head or water surface elevation between 1 and 1-1/4 times the diameter of the siphon above the siphon invert. Once a siphon primes, there is very little increase in outflow as the lake surface rises.

The advantages of grouting full the existing corrugated metal pipe and installation of a siphon include:

- Lake does not have to be completely drained. Maintaining a partial pool allows for the maintenance of some of the aquatic habitat.
- Installation of siphons can be performed in a relatively short amount of time and are typically cost-effective.
- No visible outlet structure in the lake.
- Allows for the removal of relatively cool water from deeper areas within the lake to promote cold water fish habitat downstream. In areas where trout populations are threatened by increasing water temperature, the use of siphons can be used to combat the rise in stream temperature.
- Specialty contractors are not required if quality engineering oversight is available during construction.

The disadvantages of this option include:

- Some excavation of the dam is required. If the dam is utilized as either a pedestrian path or vehicular path, some interruption of service should be anticipated.
- Inefficient removal of water at heads below 1 to 1-1/4 times the diameter of the pipe, which causes excessive fluctuations in the water surface when compared to pipe and riser spillways.
- Not cost effective for large watersheds.
- Can be susceptible to vandalism, unless protective measures are taken.

- Limited ability to drain lake deeper than 20 to 25 feet.
- Inability to keep lakes drained
- Susceptible to blockage with ice unless special provisions are implemented during design and construction
- Some underwater work may be required

Option 4 – Abandonment of Existing Conduit and Construction of a Short Riser and Pipe Spillway

This option can be considered a modified version of the traditional pipe-and-riser spillway system or an economical hood inlet spillway system. The grouting procedure is the same as for option 3. The riser and pipe inverts for this option are set higher in the dam instead of being set along the fill/foundation interface. Usually, the riser invert is set a vertical distance below normal pool equal to 1/5 to ¼ of maximum water depth at the upstream toe of the dam. For example, if the lake depth were approximately 20 feet, the riser invert would be set 4 to 5 feet below normal pool. The limiting height of the riser is dictated by both pipe diameter and location of the upstream pipe invert (entrance to the pipe) relative to the hydraulic grade line. Subatmospheric pressure conditions, that can accompany entrance conditions for steep pipes should be avoided. Also, the conduit invert should be a minimum depth of 1.5 diameters below the pool elevation to avoid the capture of air due to surface water drawdown, and associated "slugging" under full flow conditions.

Installation requires excavation of the embankment below normal pool. This excavation depth is greater than that required for the installation of a siphon but significantly less than what would be required for the removal of the deteriorated conduit. Utilization of this system may require the use of bends or elbows along the conduit to allow for the discharge of water at or near the downstream toe. A gate is usually installed on the upstream edge of the riser to allow for partial draining of the lake. Complete draining of the lake is not feasible with this system.

The main advantage of this system is its ability to simulate the hydraulic characteristics and efficiencies of the traditional pipe-and-riser systems located through the base of the dam. Unlike the siphon, both the traditional pipe-and-riser system and this option can accommodate a wide variation in base flows into the lake without the corresponding large fluctuations in lake level.

Because soil loading is relatively moderate, flexible conduits such as ductile iron, PVC, and HDPE may be utilized.

The advantages of such a system include the following:

- Limited embankment excavation
- Limited lake level fluctuation, as compared to a siphon spillway.
- Can be installed without complete draining of the lake.
- Cost-effective in that the riser height is limited.

The system does have disadvantages, such as:

- Cannot be utilized to drain the lake below the invert elevation of the riser.
- Conduit bends/elbow can be expensive
- Riser location within the upstream slope allows for an increase chance for vandalism in that the riser is only located a short distance from shore
- Foundation soils for the riser base may be soft which can cause settlement problems or raise costs due to over-excavation
- The height of fall in the conduit is limited. Pipe or culvert spillways should not be used for drops, from riser invert to pipe outlet, greater than about 25 feet due to the danger of cavitation.

The owners of most old embankment dams with problem CMP conduits have a number of concerns or issues that will usually involve several of the options described above. The engineer should attempt to learn of these concerns or issues for each dam owner and present the advantages and disadvantages of each of the available repair options. In many instances, education of the owner by the engineer may be required to repair the dam in a manner consistent with good engineering practices that also meets the requirements or requests of the owner.

Attachment 9

White Paper on Outlet Works Inspection

Federal Emergency Management Agency
Outlet Works Workshop
Denver, Colorado

May 25 – 27, 2004

Prepared by Chuck R. Cooper[1]

Introduction

Outlet works are generally inspected as part of a thorough inspection of the dam and its features. Outlet works are typically either cut-and-cover or tunnels. This white paper will focus on the inspection of cut-and-cover outlet works. A cut-and-cover outlet works is typically comprised of the following components:

(1) Entrance channel
(2) Intake structure
(3) Conduit(s)
(4) Terminal structure
(5) Downstream channel

The purpose of an outlet works inspection program is to ensure that conduits through dams are safely and efficiently operated and maintained. Structural defects and deterioration develop progressively over time. A trained and experienced inspector can identify defects and potential problems before existing conditions in the dam and conduit become serious. This white paper will address the following specific topics relating to outlet works inspection:

- Frequency of inspection
- Systems, methods, and techniques used for inspection
- Design criteria to accommodate inspection

This white paper will not address the inspection of the entrance and downstream channels, since they rarely develop dam safety concerns.

Frequency of Inspection

Periodic inspection may reveal trends that indicate more serious problems are developing. Inspection intervals may vary depending on the overall conditions determined from previous inspections and the existence of any dam safety concerns. Periodic inspections can vary in scope and purpose and by the organization or personnel (damtender, agency/district level, etc.) performing the inspection.

[1] Civil Engineer, U.S. Bureau of Reclamation, P.O. Box 25007, Denver, Colorado 80225-0007

Types of inspections

Dam safety organizations and dam owners may employ a variety of inspections during the life of an outlet works. These inspections may include the following types (Reclamation, 1988a):

(1) Initial or formal. – Initial or formal inspections include an in depth review of all pertinent data available for the outlet works to be inspected. Design and construction data are evaluated relative to current state-of-the-art to identify potential dam safety problems or areas requiring particular attention. A thorough onsite inspection of all features is conducted, and an attempt is made to operate all mechanical equipment through their full operating range, if possible.

(2) Periodic or intermediate. – Periodic or intermediate inspections are conducted between formal inspections. An in depth review is made of all pertinent data available on the outlet works to be inspected. However, the data review focuses on the current status of the outlet works and the data are not evaluated relative to current state-of-the-art criteria. A thorough onsite inspection of all features is conducted. All mechanical equipment may not be tested during any one inspection. Some equipment may be operated at another time or during the next inspection.

(3) Routine. – Routine inspections are typically conducted by field or operating personnel. The primary focus is on current condition of the outlet works. Available data may not be reviewed and evaluated prior to the inspection, depending on the inspector's familiarity of the outlet works. Inspections may be scheduled on a regular basis or performed in conjunction with other routine tasks.

(4) Special. – A special inspection is conducted when a unique opportunity exists for inspection. For example, if low water conditions exist in a reservoir exposing a normally inundated structure, a special inspection may be arranged.

(5) Emergency. – An emergency inspection is performed when an immediate dam safety concern is present or in the event of an unusual or potentially adverse condition (e.g., immediately following an earthquake).

The actual terms and meanings used to define the types of inspection may vary between dam safety organizations and dam owners.

Factors influencing scheduling of inspections

Scheduling of periodic outlet works inspections may be influenced by (Reclamation, 1988b):

(1) Sufficient notice. – Dam owners and operators may need sufficient time to make necessary arrangements, such as pre-inspections associated with lockout/tagout and confined space entry, or special equipment or approval for unwatering conduits, terminal structures, or pools. This process could require several weeks or months depending on the facility.

(2) Scheduling access. – Access for the inspection should be scheduled when most or all of the major components of the outlet works system can be examined. Some features such as intake structures and upstream conduits are usually submerged and not accessible. Downstream conduits and terminal structures may or may not be able to be unwatered and made accessible for inspection. The dam owner or operator may be requested to provide notification when reservoir conditions permit or when the reservoir can be drawn down to allow the inspection to be performed. If the feature to be inspected is normally inundated and inaccessible, certain factors (Reclamation, 1985 and 2001) should be considered in determining the extent and frequency for inspection such as:

   a. Results of previous “hands on” inspection or evidence from the inspection of the normally accessible portions of the feature. Inspection of the normally accessible portion of a feature may provide information on the probable condition of the inaccessible portion.

      i. Condition of the concrete. – Cracking, joint separation, or significant deterioration.

      ii. Condition of the embankment and foundation. – Excessive post construction settlement or alignment distortion of the downstream conduit. Excessive embankment settlement or the existence of sinkholes on the upstream face along the alignment of the outlet works.

      iii. Observed seepage. – Seepage or wet areas observed at the downstream toe of the embankment.

      iv. Flow conditions. – Changes in the discharge capacity of the outlet works.

      v. Damage and deterioration. – Damage or deterioration of gates and metalwork.

      vi. Water quality. – Water quality known to be detrimental to concrete, conduit linings, or waterstops. Excessive amounts of sand or other material transported by the discharge.

   b. Operational history and performance of the feature, since its previous inspection.

c. Relative costs for providing access for inspection of the feature, including costs associated with lost water and power revenues.

d. Age of the feature.

e. Design and construction considerations.

   i. Changes in standards or guidelines. – Design criteria, construction techniques, and/or quality of material at the time of construction fail to meet current standards or guidelines.

   ii. Foundation conditions. – The conduit was constructed on foundation of varying compressibility where there is a potential for differential settlement. This may result in cracking of the conduit or excessive opening of joints. Differential settlement is also possible between the conduit and gate chamber.

   iii. Foundation faults. – The conduit crosses a foundation fault where there is the potential for movement or disruption.

   iv. Unfavorable stresses. – The conduit located where conditions are conducive to arching and resulting in unfavorable stresses in the embankment and/or conduit. These stresses could be conducive to hydraulic fracturing of the embankment or stress concentrations on the conduit.

   v. Filters. – Lack of adequate filters and drainage material around the conduit downstream from the impervious zone of the embankment to safely convey seepage or leakage along the conduit to an exit point.

f. Critical function of the feature.

g. Any site conditions which exist that may compromise the safety of the feature.

(3) Operation. – Certain problems may not normally appear when the feature is dry that appear when the feature is being operated. Also, when a feature is operating during a period of higher than normal releases may provide information that may not have been available to previous inspections.

The opportunity to optimize both access and operation during a single inspection typically is not possible. Inspection objectives may have to alternate from one inspection to the next. This may necessitate the need for scheduling “special” inspections during unusual conditions, in addition to regular inspections to provide a comprehensive view of the outlet works safety. Special inspections may be required after floods, seismic activity, or other unusual events.

Periodic inspections by selected organizations

The frequency of periodic inspections varies between organization and dam owners. Emergency situations may require much more frequent inspections, such as daily or hourly. Situations can arise suddenly that cause serious damage in a short period of time. Examples of these problems are operations at full discharge capacity, seismic activity, or other special conditions. The need for special inspections should be evaluated after occurrence of any of these situations.

A sampling of periodic inspections as required by selected organizations:

The Bureau of Reclamation employs the following process (Reclamation, 2001) to monitor its significant and high hazard dams and attempt to detect any potential dam safety deficiencies:

- Annually. - Annual inspections are performed by inspectors who are generalist (as opposed to specialist) engineers very familiar with the dam and its operations, and can readily distinguish changes from year to year. All inspectors attend regular training in dam safety inspections.

- Periodic. - On a 6-year cycle (alternating with the comprehensive facility review (CFR), each dam is examined by a team originating in a Reclamation Regional Office, including the regional examination specialist. This examination is referred to as a Periodic Facility Review (PFR) and includes a rather thorough review and reporting of all past dam safety and operation and maintenance recommendations.

- Comprehensive. - On a 6-year cycle (alternating with the PFR), each dam is examined/evaluated by a team of specialists from Reclamation's Technical Service Center that includes an Instrumentation Engineer, an Examination Specialist, Mechanical Engineer, and a Senior Dam Engineer. This examination is referred to as a CFR and includes not only the PFR activities, but also includes technical evaluation of all design, construction, and analysis of the dam.

The Natural Resource Conservation Service (NRCS) requires the sponsor/owner to be responsible for making inspections after they are turned over to the sponsors/owners (NRCS, 2003). Special, annual, and formal (once every 5 years) inspections are performed by personnel trained in conducting the inspections. If requested by the sponsor/owner, NRCS may participate in inspections; provide training to ensure that the sponsor/owner understands inspection techniques and the importance of completing corrective action; and provide technical assistance to address specific O&M needs. If an inspection reveals an imminent threat to life or property, the sponsor/owner shall immediately notify all emergency management authorities.

The U.S. Army Corps of Engineers (USACE) performs periodic, intermediate, and informal inspections on the basis of project size, importance, or potential hazard (USACE, 2004):

- Initial periodic inspection. – The first periodic inspection and evaluation of a new earth or rockfill dam is carried out immediately after topping out of the embankment prior to impoundment of the pool.

- Second periodic inspection. – The second periodic inspection for new dams is performed no later than one year after impoundment is initiated.

- Subsequent periodic inspection. – Subsequent periodic inspections are performed at one-year intervals for the next two years. The next two inspections are performed at two-year intervals and then extended to a maximum interval of five years. More frequent inspection intervals are scheduled, if conditions warrant.

- Intermediate inspection. – For projects on a five-year inspection cycle, an intermediate inspection of all or some of the features may be scheduled, if warranted. Selection is based on consequences of failure, age, degree of routine observation, a natural event (e.g. earthquake), performance record and history of remedial measures. Intermediate inspections are also made of any portion of a project exposed during dewatering that could not be accomplished during scheduled periodic inspection.

- Informal inspection. – Frequent informal inspections are performed by appropriate employees at the project. The purpose of informal inspection is to identify and report abnormal conditions and evidence of distress.

Systems, Methods, and Techniques Used for Inspection

The success of an inspection will be dependent upon good preparation and planning. Any inspection should consider:

- Selection of the inspection team. – The members of the inspection team will vary depending on the needs and resources of the organization or dam owner, type of the inspection, results of the data review, and any special requirements.

- Review of project data. – The amount of available data may vary greatly from outlet works to outlet works. The extent of project data review and evaluation depends on the type of inspection to be conducted.

- Preparation of an inspection plan. – A detailed inspection plan should be prepared to identify all features to be inspected, problem areas, and areas of potential problems. The inspection plan will also identify special logistics, access, or equipment requirements. An inspection checklist is typically prepared as part of an inspection plan. The checklist is used to identify specific inspection objectives and is also useful in developing the final inspection report.

Methods used for the inspection of the various features of an outlet works are mainly dependent upon accessibility. Factors influencing accessibility include:

- Inundation. – Reservoir operations and water levels may make some features unavailable for normal inspection and require specialized inspection services (e.g., dive team, remotely operated vehicles).

- Confined space. – Certain features may require Occupational Safety and Health Administration (OSHA) confined space permitting for man-entry, lockout/tagout procedures, and preparation of a job hazard analysis (JHA). An alternative to man-entry is the use of specialized inspection services (e.g., closed circuit television).

- Size constraints. – Limitations in size may prevent man-entry and require specialized inspection services (e.g., closed circuit television).

Inspection of intake structures

In most cases, due to the intake structure's location in the reservoir, it is either partially or fully inundated. If the intake structure is partially inundated, inspection of the structure above the water level will be fairly straight forward. However, inspection of the portion of the structure below the water level such as the entrance, trashracks, fish screens, ice prevention systems, gates/valves, stoplogs, and bulkheads will require specialized inspection services. If the intake structure is a tower, it may have a wet well or some other access to the control mechanism. Closure of a guard gate or bulkhead may provide the ability for inspection of the interior of the tower.

Problems common to intake structures include deterioration, damage, and misalignment. Description of more specific problems related to trashracks, fish screens, ice prevention systems, gates/valves, stoplogs, bulkeads, and bridges are beyond the scope of this white paper.

Inspection of conduits

Generally, outlet works conduits with diameters 36 inches or larger can be inspected by man-entry, if proper OSHA precautions are taken. Conduits with diameters smaller than 36 inches are inaccessible for man-entry and require specialized inspection services.

Problems common to conduits include obstructions, defective joints, cracking, deterioration, and mechanical equipment operation. Signs of these types of problems include: water ponding on the invert of the conduit which could be an indication of settlement-related problems in certain reaches of the conduit, metallic corrosion of pipe or exposed reinforcement, discoloration or staining of concrete surfaces, damaged protective coatings, deformation of the conduit circumference, chemical deterioration of concrete, joint separation, leakage into or out of the conduit, misalignment of conduit sections, plugged drain holes, voids behind the concrete near any observed cracks, joint separations, or misalignments, spalled concrete from compression, reinforcement corrosion, drummy or hollow-sounding concrete, erosion, abrasion, or damage in concrete downstream of gates, offsets, and/or changes in slope, cavitation damage, and binding of mechanical equipment.

Inspection of terminal structures

The terminal structure may be dry or partially inundated depending on the time of year and the schedule of releases through the outlet works. If the terminal structure is partially inundated, inspection of the structure above the water level will be fairly straight forward. However, inspection of the portion of the structure below the water level such as the basin, chute blocks, baffle blocks, or end sill will require specialized inspection services.

Problems common to terminal structures include deterioration, damage, obstructions, misalignment, backfill and foundation deficiencies.

Specialized inspection

Specialized inspection includes the use of a dive team, climbing team, remotely operated vehicle (ROV), or closed circuit television (CCTV).

(1) Dive team

Certain factors should be evaluated when considering a dive inspection:

a. Depth. - As the depth below the water surface increases, the difficulty of performing the dive increases. Divers have a limited amount of time on a given dive, and that time decreases with the increased pressures on deeper dives. Also, as the dive becomes deeper, more of the allowable dive time is spent descending. Allowable dive times can be increased by means such as using mixed gas, or diving in a pressurized “newt suit.” This increased dive time at depth comes at an increased cost due to requirements for items like larger dive crews, more specialized equipment, and a limited number of companies that can actually do the work.

b. Altitude. - The altitude of the feature to be inspected can greatly affect the viability of a dive inspection. This could really be considered a subfactor of the depth factor. Due to the lower atmospheric pressure at higher altitudes, a diver has an even more limited dive time associated with a given depth of dive.

c. Access. - Often the entrances to a feature are equipped with trashracks on the inlet side. The ability to remove enough of the trashrack bars to allow easy entry and egress is important. Since divers in such an environment will be utilizing some type of surface-supplied breathing gas, it is important that the access point be such that the hoses will be able to be fed into the conduit without hanging up.

d. Leakage and currents. - Leakage of downstream gates or valves within a conduit is a safety factor that can affect whether a dive inspection can be safely performed. Any inspection of this type should be performed such that the diver enters the conduit against any current and then exits with the current. For an outlet works, a submerged conduit will more than likely need to be entered from the upstream end. Therefore, the condition of the gates and how much amount of leakage is critical with respect to the viability of a dive inspection.

e. Visibility. - The distance a diver can see is important to whether a dive inspection is advisable. In the event of zero visibility, little reason would exist to pursue a dive inspection, as the shear magnitude of the entire surface of a feature would be extremely difficult to inspect by feel. Also, in a circular conduit a diver does not have a real edge or other reference point to keep track of any findings. If a dive inspection is planned for a conduit, consideration should be given to making a large release prior to the inspection as a means of flushing sediments from the conduit and then allowing some amount of time for the water to settle out prior to diver entry. This time will depend on the type of sediments in the water, but could vary from a day to a week.

f. Size. - A conduit should be large enough, so the diver can turn around inside and exit head first. The diameter required for inspection would depend on the size of the individual diver and also the type of dive equipment required.

g. Length. - As with depth, the conduit length becomes a factor relating to the amount of time the diver has available at depth. If the conduit is extremely long, it can take much more time to inspect than the diver has available. The available dive time for a long conduit can be increased, but this can be costly and have extreme safety concerns since the diver does not have a direct path to the surface.

(2) Climbing team

Although not often required, a climbing team may be utilized to perform inspection of the inaccessible portions of intake towers and the walls of terminal structures.

(3) Remotely operated vehicle

Inspection using an ROV is a good alternative to dive inspection when conditions such as depth, diameter, or length become prohibitive. The ROV can be used to inspect the submerged portions of intake structures, conduits, and terminal structures. Divers can be used to assist with upstream access by opening trashracks and/or guiding the ROV through the racks. Access is also possible from downstream conduit, if the section of conduit between the upstream guard gate and downstream regulating gate can be unwatered and the ROV placed inside. Cables can be threaded through a special manhole bulkhead and the conduit can be rewatered, so the ROV can travel upstream and perform the inspection.

Some of the limitations of an ROV inspection include visibility and the size of the conduit. If the conduit diameter is large, the ROV inspection is much more likely to be limited to one small path along the conduit, where as a diver can cover a much larger path or wider swath as the diver moves down the conduit. Because the diver can use their sense of feel, in a limited visibility situation they are able to possibly locate more items of interest and then focus in on them with their other senses. With an ROV in a limited visibility situation, the only area inspected is the small area directly in front of the camera, basically whatever the ROV is bumping into. Sometimes, it can be difficult with the ROV to tell exactly where the view seen on the monitor is within the conduit, and since ROV’s often rely upon a compass, the steel in the conduit lining and/or concrete reinforcement can affect the navigation. If CCTV equipment is used in lieu of an ROV, the length of cable tether can be measured to determine the location within the conduit.

(4) Closed circuit television

CCTV can be used to inspect the submerged portions of intake structures, conduits, and terminal structures. CCTV inspection can also be used in structures or conduits where confined space entry issues may require permitting prior to physical entry. The OSHA regulations define a confined space as having limited access and egress, and not being designed for continuous human habitation. This would include not only small conduits, but also larger diameter conduits where risks, costs, or system complexity may make remote inspection more advantageous.

CCTV inspection equipment consists of a video camera attached to a self-propelled transport vehicle (crawler). The transport vehicle and camera are commonly referred to as a camera-crawler. An operator remotely controls both the transport vehicle and camera. The camera can provide both longitudinal and circumferential views of the interior of the feature. Video images are transmitted from the camera to a television monitor, from which the operator can view the conditions within the conduit. The video images are recorded onto videotape, compact disc, or digital versatile disc (DVD) for future evaluation and documentation. The operator can add voice narrative and alphanumeric captions or notations as the inspection progresses.

Depending on the model, camera-crawlers used in conduits with smaller diameters (generally about 4 to 14 inches) have cameras with some pan, tilt, and zoom capabilities, a wide range of tether pulling capacity (200 to 1,000 feet), and some steering capabilities. Camera-crawlers used in conduits with diameters of 15 inches or larger are steerable, have a greater cable tether pulling capacity (500 to 1,500 feet), and have cameras that can provide a wider array of optical capabilities, including pan, tilt, and zoom. Actual tether limits obtainable in the field, vary greatly depending upon a number of factors such as conduit diameter, bends, invert slopes, and existing invert conditions.

In large diameter conduits, the video camera can be attached to a scissor mechanism mounted to the transport vehicle. The scissor mechanism, controlled by the operator, can raise or lower the video camera as needed for inspection. In addition, the video camera usually has a high powered zoom, which can be used to provide closeup views of areas that might be difficult for the transport vehicle to get near. These features allow examination of very large conduits with diameters as large as 40 or 50 feet.

If required, some models of camera-crawlers allow for the attachment of retrieval tools such as alligator clamps, grippers, and magnets. These tools can be used to remove light debris or damage. The attachment of any type of retrieval tool will require additional clearance within the conduit to operate the retrieval tool. Some models of crawlers have robotic cutters attached to them. These cutters can be used to remove debris or protrusions in concrete, steel, or reinforcement.
Sometimes the conduit is so small that a transport vehicle cannot be used, or obstructions/invert conditions exist that prevent the transport vehicle from traversing the conduit. For these types of situations, small color video cameras (1.5 to 3 inches in diameter) can be attached to metal or poly-vinyl chloride (PVC) poles and manually pushed up the conduit. Push poles are normally used for straight sections of conduit. The use of poles for advancement is generally limited to about 400 feet. If bends exist in the conduit, a flexible snake device (spring steel wire, coiled wire, or flexible polypropylene-jacketed fiberglass push rod) can be used instead of the push poles. The color cameras are connected to a video cassette recorder and to a television monitor. The snake devices are generally limited to about 75 to 200 feet.

Design Criteria to Accommodate Inspection

Intake structures

Locating submerged intake structures can be very difficult and time consuming. On a large dam where the structure is a fair distance from the shore, it is advantageous to have some reference points to line up on from two directions. Ideally, if these are permanent then they can be used to triangulate in on. For intake structures on small dams where the structure is closer to shore, a series of permanent markers can be utilized as a center point and a measured length of rope can be used to locate the structure in a radial search using the marker as the center point. The series of markers would allow ease of use with several water surface elevations. With either of these methods, good documentation is needed, so the same points can be used each time. Another possible method is the use of an embedded air line which can be used to supply bubbles which can be used to locate it. This, of course, requires a compressor, but a small compressor can typically be brought on site. Another alternative for locating intake structures involves the use of the Global Positioning System (GPS). GPS is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these satellites as reference points to calculate positions to a high degree of accuracy.

Access entry locations (e.g., trashracks) should be in an easily locatable position, such as the corner next to the tower. Also, the entry location should be oriented, so it can easily be found from inside the structure. If a hatch is near a concrete column, then the column can be used for reference. If the hatch is located in the center of the structure it is difficult for the diver to determine where the hatch located in the trashracks. The size of the hatch or opening provided in the trashracks is recommended to be about 3.5- by 3.0 feet. The larger hatch size also is beneficial if divers are inserting an ROV.

The trashracks used for entry locations need to be easily opened or removable by the diver.

Conduits

If a conduit is going to require inspection by a diver the diameter shouldn't be less than 48 inches, so the diver can turn around in the conduit.

The Bureau of Reclamation performed a series of tests in 2002 to evaluate the performance capabilities using camera-crawlers in double walled high density polyethylene (HDPE) pipe. The results of these performance tests are generally applicable for other conduit materials. The following is a summary of those tests:

(1) Diameter. - The minimum recommended conduit diameter to successfully accommodate camera-crawlers is 8 inches. Although camera-crawlers are available for conduits smaller than 8 inches, they can be very limited in cable tether pulling capacity and generally do not have sufficient traction for use in conduit inspection. In addition, the cameras typically only have a fixed lens and the transport vehicle is not steerable. Camera-crawlers used in conduits with diameters between 8 and 12 inches generally have cameras with some pan, tilt, and zoom capabilities, but generally are not steerable. Camera-crawlers used in conduits with diameters of 15 inches or larger are steerable, have a greater cable tether pulling capacity, and have cameras which can provide a wider array of optical capabilities including pan, tilt, and zoom. Where practical, the use of conduits with diameters 15 inches or larger is strongly encouraged. This allows for the use of more powerful and versatile camera-crawlers.

(2) Bends. - The maximum recommended bend angle to successfully accommodate CCTV inspection equipment is 22.5 degrees. In conduits with diameters of 8 and 10 inches, the camera-crawler cannot be navigated around bends greater than 45 degrees, since the camera cannot clear the conduit crown as it travels through the bend. If sharper bends are required in conduits with diameters of 8 and 10 inches, a series of 22.5-degree bends are recommended. Each bend should be connected to a minimum 5-foot length of conduit to allow the camera-crawler to navigate around the bend segment and provide adequate crown clearance. Conduits with diameters of 12 inches or larger can have bends that exceed 22.5 degrees, but drag friction then reduces the cable tether pulling capacity by as much as 75 percent.

(3) Invert slope inclination. - The maximum recommended invert slope inclination to successfully accommodate camera-crawlers is 5 degrees. The difference in invert slope inclination between flat and 10 degrees can reduce cable tether pulling capacity by as much as 70 percent depending upon the conduit diameter, degree of conduit bend, and the invert condition. Flat to 5-degree invert slopes would appear to be the most reasonable inclination. Slopes with inclinations greater than 10 degrees are not recommended, due to the significant loss of traction that occurs when camera-crawlers are pulling long cable tethers. If slopes greater than 5 degrees are required, upstream access locations should be provided within the conduit.

(4) Distance between access entry locations. - The maximum distance between access entry locations can range between 500 and 2,000 feet, but highly depends upon the conduit diameter, bends, invert slopes, and invert conditions. The designer will need to take these limitations into account when selecting the appropriate distance between access entry locations. In conduits with diameters of 8, 10, and 12 inches, the maximum distance should not exceed about 1,000 feet. This assumes that access is available on both ends of the conduit. If access will only be available on the downstream end of the conduit, then the maximum distance should be limited to about 500 feet. In conduits with diameters of 15 and 18 inches, the maximum distance should not exceed about 2,000 feet. This assumes that access is available on both ends of the conduit. If access will only be available on the downstream end of the conduit, then the maximum distance should be limited to about 1,000 feet.

Terminal structures

Often the most difficult aspect for dive inspection of terminal structures is accessing the water. Carrying all of the heavy dive equipment down a riprap slope is a difficult and often dangerous task. Providing some means for more easily crossing the riprap such as stairs or a narrow concrete section would be useful. Fluctuation of the water level in the terminal structure may cause this “path” to become green with algae and result in a very slick surface.

Other innovative technologies

Other innovations in inspection systems are currently under development for sewer pipelines and for the oil and gas industry. These systems may eventually prove applicable to outlet works inspection. These systems involve state-of-the-art lasers scanners (digital imaging) and gyroscope technology. Laser scanner systems allow the operator to see the total conduit surface with color-coding of conduit defects on a digital computer image. Data processing and report preparation are completed using a manufacturer's proprietary software. Currently, laser scanners are not readily adaptable for conduit inspection, since they have some difficulties identifying infiltration, corrosion, and conduit ovality. Laser scanners also are limited to conduits in the range of 8 to 24 inches in diameter. Costs are generally 50 to 75 percent higher than for CCTV. However, the major benefit of laser scanners is the ability to produce a digital record, which reduces the subjective interpretation of results. Computerized assessment will gain wider acceptance as a reliable inspection and evaluation tool as further technological advancements are made (Civil Engineering Research Foundation, 2001, .

There also are a number of geophysical and non destructive testing (NDT) technologies that could have application for the inspection of outlet works. These technologies include: acoustic and ultrasonic testing, seismic tomography, sonar, electrical resistivity, ground penetrating radar, mechanical and sonar calipers, hydro-acoustic surveys, and radiography.

References

Bureau of Reclamation, Assistant Commissioner – Engineering and Research Center, Technical Memorandum No. 6, *Guidelines for Determining Whether Normally Inundated Outlet-Works Features Should be Examined*, 1985.

Bureau of Reclamation, Training Aids for Dam Safety Module, *Inspection of Spillway and Outlet* Works, 1988a.

Bureau of Reclamation, Training Aids for Dam Safety Module, *Preparing to Conduct a Dam Safety Inspection*, 1988b.

Bureau of Reclamation, Directives and Standards FAC 01-07, *Review/Examination Program for High- and Significant-Hazard Dams*, 2001.

Civil Engineering Research Foundation, CERF Report No. 40551, *Evaluation of SSET: The Sewer Scanner and Evaluation Technology*, 2001.

Natural Resource Conservation Service, *National Operation and Maintenance Manual*, 2003.

U.S. Army Corps of Engineers, EC 1110-2-1156, *Draft Safety of Dams – Policy and Procedures*, 2004.