WATER OPERATION AND MAINTENANCE BULLETIN

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photograph**: Photo taken during the original construction of the Grassy Lake Dam spillway.*

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NONDESTRUCTIVE TESTING OF RECLAMATION STRUCTURES

by William F. Kepler, P.E., Ph.D.[1]

Introduction

For nearly 100 years, the Bureau of Reclamation (Reclamation) was an organization dedicated to providing water and power to the arid West. Recently, its priorities have shifted from building new features to maintaining existing structures. As Reclamation's infrastructure continues to age, it will become more important to determine where best to spend its limited funding. Our work, under Reclamation's Science and Technology Program, uses state-of-the-art technology to evaluate the condition of its unique structures.

Reclamation has very large infrastructures within its jurisdiction. There are 348 storage dams, 250 diversion dams, 1,607 miles of canals, 1,460 miles of pipelines, 280 miles of tunnels, 37,495 miles of laterals, 28 pumping plants larger than 1,000 horsepower, and 58 powerplants producing over 42 billion kilowatthours of electricity each year. Unfortunately, many of these structures have exceeded their design life.

Condition assessment has not changed dramatically in the past 50 years. However, there are a number of new nondestructive testing (NDT) techniques that have been developed in the past 10 years that should be used by Reclamation to evaluate its structures. As Reclamation facilities continue to age, more efficient methods to determine their condition are needed.

Reclamation's Science and Technology Program has put together a program to evaluate various NDT techniques that can be used to perform condition assessments on hydraulic structures. In order to implement state-of-the-art NDT on Reclamation structures and to disseminate these techniques throughout Reclamation, this program performs small-scale nondestructive evaluation and assessments throughout the various regions. The cost of the assessments is carried by both the research program and the receiving area office.

The results of each evaluation and assessment are reported to Reclamation in one of the various agency publications, ensuring that we are not only solving specific field problems but we also are educating the entire staff of Reclamation in the possibilities of NDT. Over the life of the program, about three specific NDT assessments will be performed.

Reclamation, like most of the civil engineering community, has been reluctant to adapt these new techniques to solve infrastructure problems. It is difficult to change the way a conservative engineering organization thinks about nondestructive testing, but this is not

[1] Materials Engineering and Research Laboratory, D-8180, Bureau of Reclamation, Denver, Colorado 80225; (303) 445-2386.

necessarily a bad thing. There are a number of NDT methods being touted that have a reliability level equivalent to chance. This reliability level is one reason this research program is so important. The Science and Technology Program is providing the means to (1) determine which NDT methods are best suited for Reclamation structures, (2) evaluate those methods, (3) educate our organization, and, to some degree (4) expand the knowledge in this area. This program will not find the cure for cancer, but we have been able to solve specific problems and raise the awareness of what can be done throughout Reclamation.

In the Beginning

In research, it is always important to begin by learning what has already been done. It is very embarrassing to work long and hard only to find out that someone else already invented your great idea 30 years ago. Most of Reclamation's structures can fit into one or more of four broad categories: metal, concrete, soil, and electrical mechanical controls. So, to this end, in 1998, Tom Johnson, Bill McStraw, and I read every article and book describing the NDT of concrete and steel we could get our hands on. We then wrote a paper describing and comparing all the possible NDT techniques that can be used to evaluate concrete and metal.

We concluded that Reclamation needs to begin using some of the new NDT techniques to evaluate metal and concrete structures. There are a number of industry-proven techniques that can easily be transferred to fulfill Reclamation's needs. However, we need to be careful; there are a few NDT techniques which are the equivalent of a modern dowsing stick.

Test Methods

To evaluate concrete, we depend on a combination of four techniques to do most of our condition assessment—visual examination, the Schmidt hammer, the chain drag, and impact-echo testing. The equipment is inexpensive, easy to use, and accurate. While more advanced methods exist, we have found that the additional expense does not provide significantly more information about the causes of deterioration.

Visual examination is the foundation for our examinations. Reclamation is fortunate in that we have a number of people who understand the mechanisms that cause concrete deterioration and can provide an accurate assessment of a structure.

To complement this, we use ASTM C 805, "Standard Test Method for Rebound Number of Hardened Concrete," also known as the Schmidt hammer, to get an idea of concrete strength. The Schmidt hammer is a simple test to perform, and it provides a lot of information, even though it can only give relative strength values.

ASTM D 4580, "Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding," is also known as the "chain drag" test. Very simply, you drag a chain along the concrete and listen for changes in tone. It is easy to use and remarkably accurate in finding delaminations in concrete slabs (figure 1).

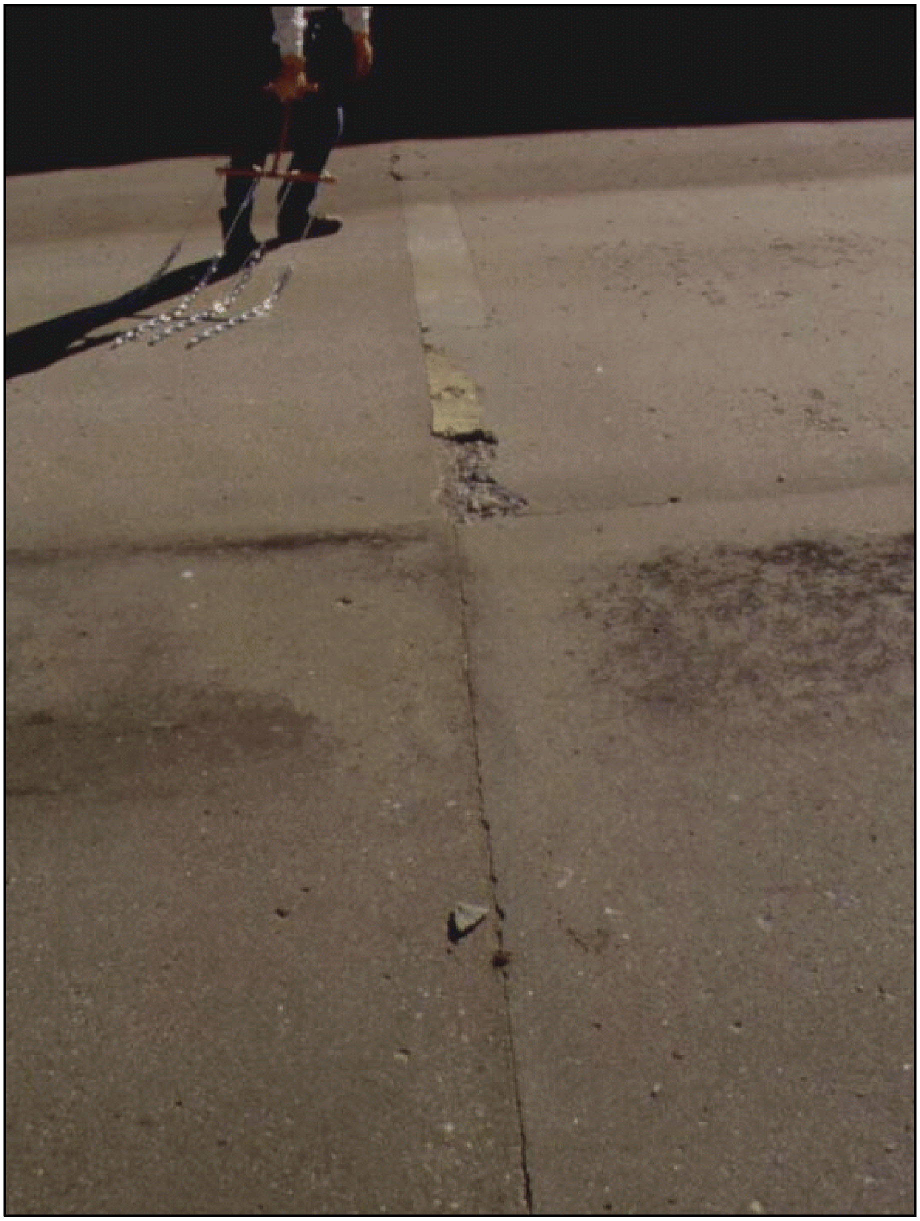

Figure 1.—The "chain drag" test in an excellent method for finding delaminated areas on a concrete slab.

Impact-echo testing is done in accordance with ASTM C 1383, "Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method." This test has a lot of promise. First, tap the concrete with a small hammer, then measure the time it takes to hear the echo from the bottom of the slab. Knowing the wave velocity, we can calculate the thickness of the slab. However, we need additional field testing to fine tune the procedures to ensure accurate test results (figure 2).

Figure 2.—The "impact-echo" test can determine the depth of cracks and the thickness of the concrete.

Green Mountain Dam Spillway, Colorado

In 1998, as part of this program, we provided a condition assessment of the spillway at Green Mountain Dam, Colorado, for the Eastern Colorado Area Office. This assessment was a combination of traditional and nondestructive evaluation methods.

Green Mountain Dam is located on the Blue River, 14 miles southeast of Kremmling, Colorado. The dam and powerplant are part of the Colorado Big Thompson Project. Built in 1943, the dam itself is an earth fill structure, 309 feet high, with a crest length of 1,150 feet. The reservoir has a capacity of 154,600 acre-feet. The spillway is a concrete-lined open channel located in the left abutment of the dam. It is approximately 1,056 feet long and has a vertical drop of 228 feet. The spillway runs approximately north, receiving very little sunlight during the winter months. Although the orientation of the spillway, climate, and lack of entrained air in concrete would suggest that freeze-thaw deterioration would be a significant problem, there is very little evidence of this (figure 3).

Figure 3.—Photo taken during the original construction of the spillway at Green Mountain Dam.

The spillway was inspected using four techniques—visual inspection, strength testing in accordance with ASTM C 805, "Standard Test Method for Rebound Number of Hardened Concrete," acoustic testing in accordance with ASTM D 4580, "Standard Practice for Measuring Delimitations in Concrete Bridge Decks by Sounding," and impact-echo testing, in accordance with ASTM C 1383, "Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method."

Overall, the spillway at Green Mountain Dam is in pretty good condition. However, there are a number of areas that need to be repaired. Some of the previous repairs have failed and need to be replaced. There are a few areas that have major delaminations that will require coring to determine exactly how bad things are and what needs to be done. However, most of the minor damage, including undercut joints, delaminations, cracks, and deteriorated surfaces can be repaired by Reclamation forces in accordance with USBR M-47, "Standard Specifications for Repair of Concrete" (figure 4).

Figure 4.—Photo showing some of the areas of the Green Mountain Dam spillway that need repair.

Grassy Lake Dam Spillway, Wyoming

We also evaluated the spillway at Grassy Lake Dam, Wyoming, for the Dam Safety Office.

Built in 1939, Grassy Lake Dam is a 118-foot-tall earth fill storage dam near the southern boundary of Yellowstone National Park. The reservoir has a capacity of 15,500 acre-feet. The spillway is an uncontrolled, concrete-lined, closed channel located in the left abutment of the dam. The spillway runs approximately north (figure 5).

Figure 5.—Photo taken during the original construction of the Grassy Lake Dam spillway.

The spillway at Grassy Lake Dam has experienced numerous problems over the years. During the initial construction, violent thunderstorms eroded away the fill that was to be underneath the lower spillway section (figure 6). This lost fill was replaced with a silty soil. In 1940, less than 1 year after completion of construction, there were signs of distress in the concrete. By 1950, there was severe deflection in the spillway walls as well as signs of alkali-silica reaction. The spillway was originally open, but later a concrete roof was added, which was then covered with soil to reduce freeze-thaw damage. The general consensus is that the problems seen at Grassy Lake Dam are due to frost heave in the silty soil underneath the spillway floor.

Figure 6.—Grassy Lake Dam spillway after a thunderstorm had washed out the foundation.

We evaluated the spillway at Grassy Lake Dam using a combination of visual inspection, the "chain drag" test, the Schmidt hammer, and impact-echo testing.

We determined that the primary problem at the Grassy Lake Dam Spillway is not voids under the concrete floor slab but the extreme heaving along the centerline (figure 7). Six of the 15 slabs have severe heaving problems. In one area, the concrete has moved up over 1 foot in elevation from the original grade. There is no evidence of voids directly beneath the concrete in these areas, although we expect to find poorly compacted soil with the possibility of ice lenses. The type of soil under the spillway, as well as the location and the history of the structure, indicate that the heaving is probably due to frost action.

Figure 7.—Photo showing a large crack down the centerline of the spillway at Grassy Lake Dam.

Now What?

Currently, we are writing a manual entitled, *Guide to Condition Assessment of Concrete Structures*. It is written to help the nonexpert determine what causes concrete to deteriorate and to help rank the severity.

As always, we are looking for more structures to appraise. We have some new equipment to evaluate and some old equipment that needs work. So, if you know of a structure that needs some attention, please call me.

Conclusions

Reclamation is focusing more and more on maintenance of existing structures. Because of this, nondestructive testing is going to be more important, and more common, in the future. The goal of our program is to educate Reclamation staff about the strengths and weaknesses of nondestructive testing as well as making it as easy to use and as intuitive as a tape measure.

MODERN MATERIALS FOR REPAIR AND MAINTENANCE OF RECLAMATION FACILITIES

by Kurt F. von Fay[1]

One goal of the Science and Technology Program of the Bureau of Reclamation (Reclamation) is to find modern materials to use in two broad areas: (1) extending the service life of concrete structures and (2) protecting structures with the use of modern protective coatings. The Materials Engineering and Research Laboratory Group (MERL) in Denver is responsible for program administration and accomplishments.

Reclamation's infrastructure is aging, with much of it now exceeding its original design life. At the time of design and construction, Reclamation's dams, powerplants, canals, and appurtenant structures used state-of-the-art materials-engineering technology. However, just as new state-of-the-art earthquake and flood loading criteria were emerging for design, physical deterioration mechanisms affecting long-term durability were also being discovered. As these deterioration mechanisms were discovered, new materials and mixtures were formulated to prevent damage in newer structures. Unfortunately, there are many Reclamation structures that have older technology materials that need improvement and enhancement to remain viable resources.

New environmental regulations have forced the reduction or elimination of certain products (especially protective coatings) that once worked well but now pose hazards. In many cases, very little is known about the medium- to long-term performance of new products in exposure conditions typical for Reclamation facilities; therefore, the search for new materials is a critical component to maintain, protect, and repair Reclamation's infrastructure.

A coordinated program was developed to evaluate the newest repair and protection systems and materials. There has been a relative "explosion" of repair and protection systems and materials over the recent years to address problems with older infrastructure in the United States. Some of these new repair and protection systems and materials may provide cost-effective improvements over existing Reclamation methods.

Concrete Repair and Maintenance

Repairs to concrete have a poor track record. Although there are numerous products on the market that claim to offer exceptional performance as a repair material, the reality is that very few ever perform as claimed. In many cases, the repair materials appear to be working well for a year or so, but then quickly deteriorate. In a worst-case scenario, the repair material

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appears to be working very well, but due to the nature of the material and its service conditions, the deterioration of the existing concrete accelerates and goes unnoticed until significant damage has occurred.

The difficulty of achieving successful concrete repairs is due partly to the age of much of Reclamation's concrete infrastructure, the exposure conditions (hot and cold weather, water exposure, etc.), and a poor understanding of the physical and chemical properties that a repair material needs. In the past, these were not big issues since repairs were generally a small part of most budgets. However, as the infrastructure ages, the failure rate and associated costs of these repairs is becoming much more important.

MERL has taken several significant steps that will hopefully enable us to identify better repair materials. We will perform tests for the Confederated Tribes of the Warm Springs Reservation of Oregon. These tribes helped develop a magnesium oxy-phosphate repair material for thin repairs to concrete. The repair material has been used several times on a variety of structures, and the results were favorable. In addition, through an agreement with the Civil Engineering Research Foundation, we have agreed to evaluate a similar repair material that incorporates waste by-products from a number of industries. This material may have a double advantage—providing a viable repair material and reducing industrial wastes.

In addition to the above-mentioned tests, MERL has entered into an agreement with the Eastern Colorado Area Office to test favorable thin repair materials at Green Mountain Dam in Summit County, Colorado. Exposure conditions at this site have been very harsh, with many cycles of freezing and thawing weather and large temperature swings, particularly on south-facing slopes. Starting in May of this year, we will test three to five repair materials at Green Mountain Dam. Newly developed tests will be used to evaluate these materials. MERL's improved ability to evaluate thin repair materials is a direct result of involvement with the Concrete Repair Engineering Experimental Program (CREEP) (Reclamation is a founding member and is on the steering committee of this program). CREEP is directed by a select group of Federal Government agencies, universities, and private enterprises (Reclamation; Corps of Engineers; University of Laval; Structural Preservation Systems, Inc.; Simpson Gumpertz & Heger, Inc.; Sika; U.S. Naval Facilities; and ConProCo), with support from the American Concrete Institute and International Concrete Repair Institute.

Protective Coatings

The other major area of study for CREEP is protective paints and coatings. For many structures, these two items comprise the first line of defense in a deleterious or corrosive environment. Many of Reclamation's structures are exposed to environments that will rapidly corrode metal and other materials if they are not properly protected. As such, a strong protective coating will help prevent the infrastructure from premature deterioration.

In the past, Reclamation was one of the leaders in developing and applying protective coatings. Several products were identified that provided excellent protective capabilities for materials exposed to corrosive environments. However, there has been a revolution in the formulation of protective coatings, driven by existing and planned environmental regulations. This "revolution" will continue as coatings are developed to meet newer, even more restrictive regulations.

Many of the new formulations have not been tested and do not have long track records. Many require much different and more complex surface preparation techniques before they are applied. For these materials to be successful, and to meet new environmental regulations, the interrelationships between the chemistry and formulation process, application techniques, and surface preparation procedures have become extremely complex.

The new requirements have had a profound impact on Reclamation's protective coatings program because many of the products traditionally used are no longer available. In some cases, products that were used must be removed or covered using special processes to contain them and to keep them from contaminating the environment. Unfortunately, many of Reclamation's standards and guidelines are based on data and products that were developed and written in the 1970s and early 1980s, and some of this information relates to products that we can no longer use.

Because of the relative suddenness of the impacts of some of these changes, MERL needed a coatings strategy to rapidly move us back to the forefront of coatings technology. We recently took a big step towards realizing that goal by proposing a partnership with the Metropolitan Water District of Southern California (MWD). MWD has one of the most extensive paint and coatings evaluation facilities in the world. Through this partnership, MERL will also be working with several other public agencies on issues related to coatings.

MWD will test and provide data on coatings they have tested or will test. MERL will use that data to select modern coatings and application procedures for use on Reclamation facilities and to update the standard guides and specifications. MWD has also agreed to conduct joint training programs with us for Reclamation personnel on current protective coatings topics such as coating inspection, selection of products, surface preparation techniques, and approved coatings application procedures.

In addition to working with MWD, MERL has drafted a document entitled, *Guide to Protective Coatings: Inspection and Maintenance.* This report should be available later this year. The guide will focus on coatings issues that are specific to Reclamation needs. Information will be provided on, but not limited to, the types of coatings to use, inspection methods, coating quality assessment tools, and repair methods.

Recently, Reclamation was asked by the Environmental Protection Agency to help design a concrete chamber to test instrumentation to detect hazardous waste plumes and their movement in aquifers. The Modern Materials Program assisted by helping to locate a coating system that would work on concrete and stand up to hazardous chemicals. Findings from that study are documented in *Coatings Systems for Use on Concrete Tanks Containing Hazardous Chemicals.* This report will also be available later this year.

NEW METHODS OF FENCE POST MOUNTING

In the past, fence posts were secured to the top of a concrete wall by coring a hole, setting the fence post, and pouring lead around the post. For many years, it served us well as our fence post detail.

When we learned that lead was a hazardous material, we had to find another material to fill around the post. We tried various cementitious and epoxy grout materials in our search for a good way to set fence posts in the top of walls. None of these products gave us the seal and the strength that lead could give. Making two different materials, such as steel and concrete, form a strong bond presented a challenge.

Recently, construction began on a project in Avoca Borough, Luzerne County, that involves approximately 7,000 feet of concrete channel. The project will require 14,000 feet of fence and approximately 1,400 fence posts.

Each fence post will be welded to a nine by nine inch metal plate that contains four holes for mounting purposes. This unit will be treated to prevent corrosion through a process of hot-dipped galvanizing and then mounted to the back face of the wall with four stainless steel bolts approximately one foot below the top of the wall. The bottom of the post will be left open to drain any water that collects.

In Milesburg, Centre County, we fabricated a unit that welded a fence post to a U-shaped metal plate that contained two holes, one on each vertical leg of the U. After being hot-dipped to prevent corrosion, the unit was placed on the concrete wall so that a leg of the U straddled the wall like a saddle. A hole was drilled through the wall, and a bolt held the unit in place.

At the Lindy and Keyser Creeks Project in Scranton, Lackawanna County, a 9" plate was welded perpendicular to the fence post. This unit was then bolted vertically to the top of the wall.

As you can see, we are looking at new and innovative methods of installing fence posts on our projects. We encourage sponsors to look into new mounting details for fence posts and to share their ideas with everyone.

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RECLAMATION'S DESIGN PROCESS OF EARLY WARNING SYSTEMS FOR DAM SAFETY

by David B. Fisher[1]

Abstract

This paper discusses the Bureau of Reclamation's process for designing the detection and decisionmaking components of an Early Warning System (EWS) for dams with hydrologic deficiencies. The design of an EWS is a site-specific activity, with the final goal of the system being the successful evacuation of the population at risk located downstream of the dam. EWS designs consider meteorological and hydrological data in developing flood detection and decisionmaking elements of the system.

Introduction

The Bureau of Reclamation (Reclamation) and the Bureau of Indian Affairs (BIA) of the Department of the Interior are using Early Warning Systems (EWSs) as a nonstructural mitigation to the loss of life from hydrologically induced dam failure. Reclamation dams that have a "clear-day" failure potential (failure of the structure due to seismic activity or foundation seepage) are evaluated and modified as necessary under the Safety of Dams program. Generally, for the "clear-day" failure, the ability to detect the failure, without constant monitoring, may not be possible; therefore, to protect the population at risk (PAR), structural corrective actions are necessary. EWSs can provide information regarding the increased outflow from a dam as an interim measure until the modification is undertaken. Dams with hydrologic deficiencies (i.e., dams which could fail from embankment overtopping caused by floods up to the probable maximum flood) are candidates for an EWS because hydrologic events are detectible and the response of the dam is predictable. This paper provides an overview of Reclamation's design process for the detection and decisionmaking components of EWSs as an alternative to the structural modification of existing dams.

Background

The high priority given to the Dam Safety Program within Reclamation was a direct result of the rash of dam failures in the early to mid-1970's, including the failure of Teton Dam in Idaho in 1976. This failure generated a keen interest in the public safety aspect of dam ownership. The Reclamation Safety of Dams Act of 1978 provided nonreimbursable funding for the repair of Reclamation dams. The amendment to the Reclamation Safety of Dams Act

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in 1984 provided additional funding for dam safety but placed a 15 percent reimbursement requirement from the project beneficiaries. As repair of specific dams progressed, it was apparent that the cost to modify all Reclamation dams with identified deficiencies would be a major burden on the national budget. Many stakeholders and participants in the public process have had an influence in establishing Reclamation's policy to seek alternatives to the structural modification of all dams with hydrologic deficiencies.

An analysis of the warning time versus loss of life was undertaken by Brown and Graham (1988) for historic dam failures and floods. This study suggested that warning times to the PAR greater than 90 minutes could greatly reduce or eliminate the loss of life. The EWS concept was the solution developed that would provide for enhanced public safety at a reduced cost to the Federal Government. Structural modifications may also be used alone or in combination with EWSs to increase warning times and to minimize overtopping potential.

Early Warning System Components

All EWS designs for Reclamation and BIA dams are site specific. The EWSs are comprised of the following components:

(1) A method for detecting flood events.

(2) A decisionmaking process.

(3) A means of communicating warnings between operating personnel and local public safety officials.

(4) A means for local public safety officials to effectively communicate the warnings to the public and carry out a successful evacuation of the threatened PAR.

All of these components must be in place to have a successful EWS. An effective evacuation requires that public safety officials downstream of the dam be notified by the dam owner of specific areas to be evacuated. This information is detailed in the dam failure inundation maps and the Emergency Action Plan (EAP) or Emergency Preparedness Plan (EPP) located in the Standing Operating Procedures (SOP) document. The EAP/EPP is required for all Department of the Interior dams with a high or significant hazard classification. The design of an EWS includes updating the EAP/EPP with specific decision criteria and current notification procedures.

The public warning and evacuation process is the role of the emergency response officials located downstream of the dam, not that of Reclamation. However, with some BIA dams, the BIA has direct warning and evacuation responsibility for the PAR located downstream of the dam. Reclamation does provide inundation maps, including the travel times to the PAR, and also some assistance to the local officials in preparing the EAP/EPP.

Design Process for the Detection Component

The EWS design process for the detection system that is currently used in Reclamation's Denver Office is based on the design storm concept developed for probable maximum flood (PMF) determination. The PMF design was based on centering the probable maximum precipitation (PMP) storm over the drainage basin in such a way as to maximize either the peak or volume of the inflow into the reservoir. The typical storm arrangement (Cudworth, 1989, pp 58-61) is to locate the peak incremental precipitation value at two-thirds of the storm duration (i.e., hour 4 of a 6-hour local storm and hour 48 of a 72-hour general storm). This is usually the most critical arrangement for traditional structural considerations but may not be the most critical arrangement of the storm event for warning purposes (warning critical event), especially for dams that are overtopped by small percentages of the PMF. The goal of the warning critical event is to determine the storm event that will produce the minimum time from detection of the event to overtopping of the dam. Because of this, the potential for other arrangements that may be more critical from a warning perspective are evaluated. The considerations include locating the peak incremental precipitation value earlier in the event (front end loaded storm), such as in the first hour or first 6-hour period, moving the storm center location closer to the dam, or combinations of the above. The justification for a rearranged temporal distribution is based on an analysis of historical storm events (Corps of Engineers, U.S. Army, 1945), (Schwarz, 1986), (Vogel et al., 1990). Most of Reclamation's EWS designs are for dams with small drainage basins.

After the hydrologic analysis is completed, a detection system must be designed to provide the warning time necessary to evacuate the PAR. The goal of this process is to minimize the hardware necessary to detect the event but still include enough redundancy to assure effective detection of an event. The range of hardware includes reservoir elevation monitoring systems to full basin rainfall monitoring systems with real-time rainfall-runoff modeling. The types of data communication systems in use include manual observation by a dam tender, GOES satellite telemetry, UHF/VHF polling radio systems, and ALERT format radio systems.

Although ensuring public safety in the event of dam failure is the goal of this program, an EWS must be designed to provide warning as needed during large operational discharges as well. Most hydrologically induced dam failures will involve life-threatening discharges early in the event. If the EWS is not used on a regular basis for floods, it will most likely not function effectively when needed for a major overtopping event which may cause a dam failure. The development of decision criteria must take into account both the notification for potential frequent flood events as well as rare extreme flood events, which may pose a threat to the safety of the dam.

Design Process for the Decisionmaking Component

The goal of the decisionmaking design is to establish realistic notification thresholds that interface with the response actions of the local officials. The definition of adequate warning time for this process is the time needed for the local officials to successfully evacuate the PAR downstream of the dam. This may be 90 minutes at one dam and 10 hours at another. Again, each EWS must be designed as a site-specific system. The goal of the evaluation is to minimize the frequency of false alarms (evacuation without a severe event), maximize the notification time, and eliminate any potential missed events (undetected flood events). At dams with large reservoir routing times between the design maximum water surface (MWS) and the dam crest, decision criteria can be established based on the rate of rise of the reservoir, exceedance of a threshold elevation (MWS, spillway crest elevation, or other elevation), or a combination of the two. These decision criteria must be presented in a format that the decisionmaker can easily understand, such as a reservoir rule curve or a table of elevations and corresponding actions.

For dams that reservoir monitoring alone does not provide adequate warning time, alarms based on exceedance of stage or flow thresholds at an existing or potential upstream stream gauge location are evaluated. Factors considered in the use of these criteria include estimating the travel time from the upstream stream gauge to the reservoir and determining the size and potential effect of runoff from the contributing drainage basin located downstream of the gauge. Again, the potential notification time that this approach provides is compared with the warning time required to determine if streamflow and reservoir elevation monitoring will satisfy the requirements of the detection system.

Basin rainfall monitoring combined with streamflow and reservoir monitoring may be required to provide adequate warning time at sites when more time is required. Precipitation gauge networks are designed based on meteorological judgment in conjunction with an analysis of warning critical storm events. Some considerations include the determination of the spatial distribution of the PMP or smaller storms, wind effects, adequate exposure, and representative catchment.

Due to the severity of the storms these systems are designed to detect, redundancy in both the gauges and communication paths are needed. Potential rainfall decision criteria include exceedance of a threshold such as a 100-year, 1 - or 3-hour point precipitation reduced for representative area size. An analysis of the warning time available for these and other thresholds are evaluated. On basins with available rainfall and streamflow data, rainfall runoff models may be calibrated to provide a real-time forecast of inflow into the reservoir. The limitations of these models is the need for qualified personnel to interpret the results, which may not be available at most Reclamation and BIA dam sites. An alternative to runoff modeling for locations without data or expertise for small drainage basins is a simple volumetric approach in which the precipitation at the various gauge locations is converted to an equivalent volume of runoff after a minimum loss is subtracted. The volume is totaled for the basin and compared to the available storage in the reservoir. This allows for a variable decision criteria based on current reservoir storage. This logic is easily programmed in the ALERT software and will be implemented at the sites employing this technology.

Summary

Reclamation is designing EWSs to provide enhanced public safety to populations located downstream of Reclamation and BIA dams. Meteorological considerations include the analysis of standard arrangement and front end loaded storms and alternate storm center locations to determine the storms that cause the least amount of detection time available between the storm onset and the ensuing dam overtopping. Hydrologic considerations include reasonable runoff modeling of the storm events and determination of the maximum warning time available based on selection of appropriate detection technology. It is anticipated that in the future most Reclamation and BIA dams will have an associated EWS. These systems will include an enhanced emergency action plan.

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Mission

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Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

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