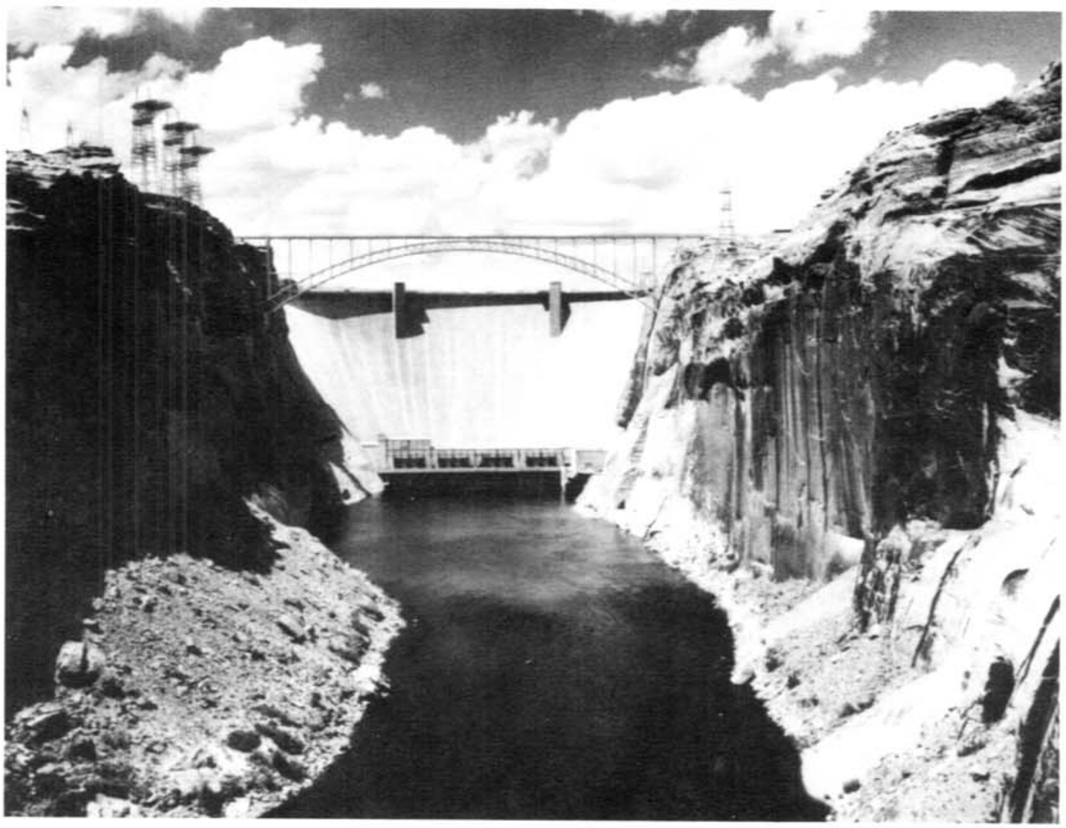
WATER OPERATION AND MAINTENANCE

BULLETIN NO. 143

March 1988



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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The Water Operation and Maintenance Bulletin is a technical publication prepared by the Bureau of Reclamation for use by its personnel and water and user groups for maintaining project facilities. The principal purpose of the bulletin is to provide guidance to water operating entities through the dissemination of Reclamation standards, criteria, and directives on acceptable operation and maintenance practices for storage and diversion dams or structures, conveyance facilities, and other appurtenant works.

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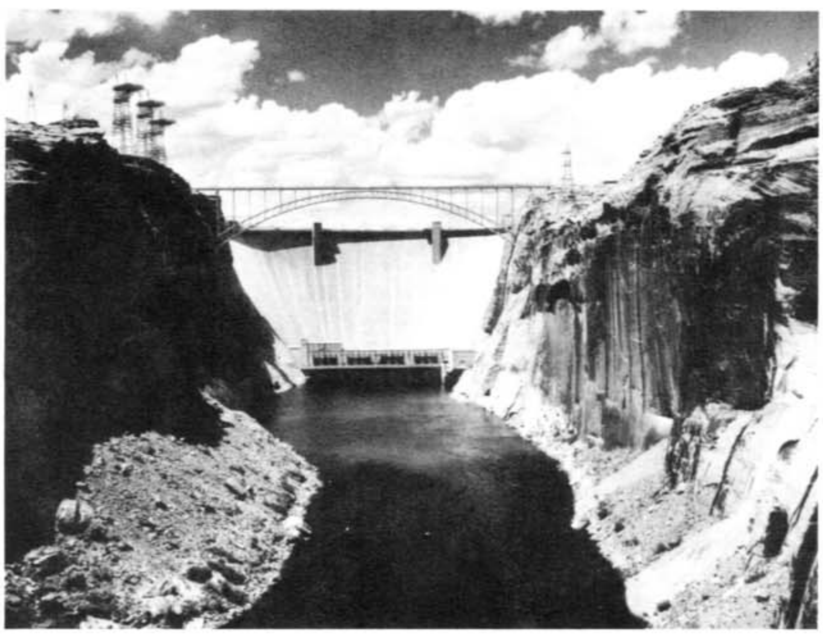

Cover photograph:

Aerial view of Glen Canyon Dam and Powerplant, Utah-Arizona. Lake Powell in the background.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

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REDUCING MAINTENANCE COSTS OF IRRIGATION SYSTEMS[1]

by Franklin E. Dimick[2]

Reducing the costs of maintaining an irrigation water delivery system is becoming more important as the financial problems of the irrigators become more critical. The maintenance costs can be significantly reduced by taking one or more actions such as rehabilitation of the project, proper selection of equipment, proper selection of methods, preventative maintenance, and training of personnel.

Introduction

Maintenance costs of an irrigation delivery system are a significant portion of the overall cost of water delivered to the farm. These costs vary widely, depending on such things as the age of the system, whether it is open canals or closed pipe, the location, the environment, and the interest and ability of the managers. Generally speaking, large systems tend to be better maintained than small-to-medium systems. Exact costs for maintenance of all systems are hard to obtain since accurate records are not usually kept by smaller projects. The maintenance costs are generally combined with operational costs since the same person may do both jobs. A study of these combined operation and maintenance costs, however, will give a good indication of maintenance costs.

Estimates of the average costs for all projects indicate that over 50 percent of the annual costs are for operation and maintenance. These costs continue to increase each year. The Bureau of Reclamation prepares an index of operation and maintenance costs for irrigation delivery systems. Their report shows that the cost index has risen from 1.00 in 1977 to 1.812 in 1985. This means that operation and maintenance costs have almost doubled in an 8-year period. From these figures, it is apparent that steps must be taken to reduce the maintenance cost in order for farmers receiving the water to survive in the present financial environment. There are several actions that can be taken to reduce maintenance costs.

Rehabilitation

Rehabilitation of irrigation delivery systems to bring them up to current standards is one method of reducing long-term maintenance costs. Rehabilitation is usually most effective on older systems. Since many of the systems in the United States are more than 40 years old, this approach may be beneficial to many water users.

Rehabilitating a delivery system provides the owner an opportunity to install state-of-the-art equipment, reduce losses, and increase efficiency. Installing new equipment will significantly reduce maintenance costs because the newer equipment is designed to be relatively maintenance free. Open bearings with grease cups are replaced with sealed bearings. Enclosed gear boxes replace the older open gears. New metal alloys replace ordinary steel, and sulfate-resistant concrete replaces regular concrete. These types of improvements will reduce the system's maintenance time.

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[1] Reprinted with permission of the ASCE (American Society of Civil Engineers) from Proceedings of Symposium in Portland, Oregon, July 28-30, 1987.
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Reducing water losses and increasing efficiencies will not reduce maintenance costs but they will reduce the ratio of maintenance costs to the amount of water delivered and the cost of that water. The Greenfield Irrigation District which supplies water to approximately 83,000 acres of land in Montana recently invested $8.3 million in a rehabilitation project. The work done included lining of canals, replacing some open canals with pipelines, replacing old structures, etc. The completed work saves 50,000 acre-feet of water each year and increased the efficiency of the system from 46 to 76 percent. Part of the efficiency increase was due to operational changes rather than structural improvements. The new facilities have reduced the maintenance costs for the district by a significant amount.

Rehabilitation of a project will require a large capital investment, but during the life of the project the savings in maintenance costs may repay much of those costs.

Proper Selection of Materials

The type of materials selected for maintaining or repairing a water delivery system can have an impact on the maintenance costs. From the selection of the proper lubricant for a gearbox to the proper concrete mix design for a structure, maintenance costs are dependent upon the ability of the materials selected to perform their task. All too often, maintenance personnel select materials based upon costs or availability rather than a true evaluation of which material would be best. Sometimes a material is selected just because it was used the last time. In order for materials to perform their best, they must be carefully selected and properly used. Individuals making the selections should be familiar with industry standards and national standards such as ASTM so that they can select good quality materials. They should also consult with other people who have had a similar problem or who have used the type of material being considered. Next, they should consider the environment the material will be used in. This is particularly true of coatings such as paints and epoxies. It is a serious mistake to buy one type of paint and expect it to satisfy all of your coating needs.

Selecting the proper coating involves a process of matching material characteristics to the requirements of the situation. As with any material, the elements in the environment that will cause the paint to deteriorate must be identified. The next condition to be evaluated is the condition and location of the object to be coated. A different coating might be selected if an object can be removed from the field and taken inside to paint than if it must be painted in place. The qualifications of the applicator must be evaluated when selecting a coating. Other items to be considered are the cost of the coating, equipment available for application, allowable curing periods, etc. These considerations are then matched against the characteristics of the various coatings and a selection is made. The Bureau of Reclamation has published a book entitled Paint Manual which covers this subject well and will provide valuable assistance in selecting and using the proper coatings.

Maintenance personnel must be willing to try different materials if the material they are now using is not performing satisfactorily. Loyalty to a specific product may result in higher maintenance costs. The A&B Irrigation District in Idaho had problems maintaining the pumps in their system due to wear on the shafts. Each year they had to remove the pump and rebuild the shaft where it went through the packing box. The district then tried a new type of packing material in the pump. The pumps were placed into service and have run up to 16 years with no significant wear on the shaft. This simple act resulted in a major reduction of maintenance costs on the pumps.

Finally, the health hazards of a material must be considered before obtaining and using it. A material may allow a significant reduction in maintenance costs but may be hazardous to the health of the people using it or to others. This concept is particularly applicable to chemicals used for pest control. The same concepts listed above would be used in selecting pesticides, but special attention should be paid to the health hazards and environmental impact each chemical may have.

Proper Selection of Equipment

The use of the right tool for the job is an important aspect of reducing maintenance costs. This includes all equipment from hand tools to emergency generators. The selection of equipment is sometimes based on capital costs rather than on its ability to perform the job. This results in higher maintenance costs because a machine is required to perform beyond its limits or in a manner that it was not designed for. This causes high maintenance costs on the equipment and added time in completing the task. A typical example of this is buying a truck that is too small for the loads it will carry. The truck will be frequently overloaded with resultant high maintenance on transmission, clutch, motor, and suspension system. When selecting a motor vehicle, it is very important that the projected use for the vehicle be balanced against the abilities of the vehicles available. Common sense would tell you not to buy a light sedan for a ditchrider who will use the vehicle primarily on gravel and dirt roads. What about using a compact pickup for that job? The experience of utility companies and water districts has shown that a compact may be suitable for an operator or supervisory personnel but is not an economic choice for maintenance personnel. Where a vehicle is to be used for maintenance purposes or for both operation and maintenance, the 1/2-ton and 3/4-ton sizes are more economical because of reduced maintenance costs. The motor selected for a vehicle will impact maintenance costs also. The diesel engine gained popularity among water users a few years ago. However, experience gained during recent years has indicated that diesel engines must be selected for specific purposes just as propane engines are selected for specific purposes. Diesel engines, for example, are not usually cost efficient for lighter vehicles driven less than 40,000 miles a year. Maintenance cost of vehicles can also be reduced by matching the wants of the operator with the vehicle. The Weber Basin Water Conservancy District in northern Utah has found that an operator will take much better care of a vehicle he likes than one he does not. An operator may actually abuse a vehicle he does not like in hopes of getting one he does like sooner than scheduled.

When selecting equipment of any kind, it is important that all factors be considered before buying the equipment. It should be remembered that bigger is not necessarily better, and smaller is not necessarily more economical.

Proper Selection of Methods

Although selecting a method of repair may be determined somewhat by the equipment and materials available, some alternatives are usually available. Keeping abreast of new developments in maintenance procedures and using your imagination will provide the opportunity to select the best alternative.

This concept can best be described by the experience of an irrigation district in eastern Utah. The rapid growth of grasses and weeds in a canal prism in the early spring was making it impossible to get the volume of water needed down the clogged canal in the late summer. The maintenance personnel had been informed earlier that they could not use any pesticides in the canal water to clear the grass; therefore, they began using a backhoe to remove the grass and weeds. This was a slow process that was costing about $2,500 per mile. Realizing the scope of their problem, they began making inquiries of others who were experiencing the same problem. They found that there were chemicals that could be used to solve their problem. They purchased and applied the chemical, and for less than $1,500 were able to treat several miles of canal sufficiently to allow full delivery of water for the rest of the season.

Another example is the repair of the Gateway Canal lining on the Weber Basin Project in northern Utah. The reinforced concrete lining was being broken up in a section of the canal that runs through unstable ground. The district found that since the lining had to be removed and replaced on a recurring basis, leaving the reinforcing steel out of the new lining made it much easier to remove later.

The Roy Water Subconservancy District in Roy, Utah, found that by adding an orifice plate on the end of a pressurized pipe that released water into an irrigation canal eliminated the cavitation in a butterfly valve used to control the releases. This simple act eliminated the need to repair or replace the valve on an annual basis.

Preventative Maintenance

Establishing and using a preventative maintenance program is one of the best actions a water user can take to reduce maintenance costs. The principle behind this action is to spend a little money now to prevent large repair bills in the future. All too often our attitude toward maintenance is to not take any actions, until the system fails. When we have that attitude, we fail to realize that it is less expensive to grease a motor bearing once a month than it is to replace the bearing and maybe even the motor. Painting a steel outlet works pipe is much less costly than replacing the pipe when corrosion has damaged it beyond repair. Although simple in theory, this is one of the hardest programs to implement, particularly on smaller systems, because people think they are spending money when they really do not need to.

A good preventative maintenance program provides better deliveries because of fewer failures, safer working conditions and better safety to the public, and reduction or elimination of emergency repairs; and it allows for setting of maintenance standards and for planned repairs and replacement of equipment with subsequent savings. The Bureau of Reclamation has developed a preventative maintenance program for some of its smaller irrigation systems. The system is described in the "Water Operation and Maintenance Bulletin No. 138," dated December 1986, published by the U.S. Department of the Interior, Bureau of Reclamation. The bulletin describes an MMS (Manual Maintenance System) that can be utilized by any water user to reduce maintenance costs. The MMS can be readily adapted to a micro computer for easier handling if desired. The MMS has proven to reduce maintenance costs on all projects which have used it. Other systems can be developed for individual projects but the basic idea is the same - pay a little now or a lot later.

According to an article in the September 11, 1980, issue of the Engineering News Record, the TVA (Tennessee Valley Authority) conducted a study of its coal-fired powerplants in 1978 and found that the equivalent of one large generating plant was being wasted because of system-wide neglect of repairs and the lack of a formal maintenance program. Two years later after spending $79 million to make repairs and initiate a maintenance program, the reliability of its plants had been boosted by 2.7 percent, which saves the TVA customers $47 million per year. This same concept can be applied to irrigation delivery systems.

Training Personnel

The method of reducing maintenance costs that is most often overlooked, especially on smaller systems, is the training of both operations and maintenance personnel. It is essential that operators know how to properly operate a system to reduce damages. The simple act of setting a check too high in a canal can cause the canal to overtop and require thousands of dollars to repair. The same thing can happen if a trashrack is not cleaned. Operators who are not well trained may try to force a gate to move when it is hung up and cause damage to the operating mechanism. Being well trained on how to properly operate a system and handle emergency procedures may significantly reduce maintenance costs.

Proper training of maintenance personnel will help them determine better alternatives for repairs and keep them abreast of "state-of-the-art" methods. They will be more willing to adopt and utilize a preventative maintenance program.

Summary

Owners and operators of an irrigation water delivery system can reduce maintenance expenses if they will adopt a goal of good preventative maintenance and take a few basic actions to achieve their goal. The savings in maintenance costs can be passed on to the water users or can be used to improve the system.

YAKIMA-TIETON IRRIGATION DISTRICT REHABILITATION PROGRAM[1]

by Karl Ames[2]

Abstract

The YTID (Yakima-Tieton Irrigation District) obtained funding from the USBR (U.S. Bureau of Reclamation) and the State of Washington to replace an open canal and lateral irrigation delivery system with a gravity pressure pipeline system. The conversion will eliminate the need for on-farm pumping, allow hydropower production, reduce operation and maintenance costs, provide a low cost alternative for frost control, allow significant water savings, increase the water delivery rate, and enhance public safety.

District Background

The YTID, organized in 1918, evolved from the Tieton Water User's Association which was created in 1906 to contract with U.S. Reclamation Service (now the Bureau of Reclamation) for the construction and operation of the Tieton Division of the Yakima Project. Construction began in 1906 and water was first delivered in 1910. The YTID has the distinction of being the first irrigation district to repay its original construction charge obligation back to the Federal Treasury.

The YTID includes approximately 27,000 acres of land lying west of the city of Yakima between the Naches River and Ahtanum Creek (fig. 1). Approximately 80 percent of the land is in orchard production, primarily apples, with the remaining in pasture or miscellaneous crops. By contract with the USBR, the district is entitled to a maximum of 114,000 acre-feet of water annually from Rimrock Lake (impounded by Tieton Dam). The water is diverted from the Tieton River by the Tieton Diversion Dam, located 8 miles downstream from Tieton Dam. The diversions are carried to the district boundary by the 12-mile-long Tieton Canal. Prior to the rehabilitation program, the water was distributed to the lands with a system consisting of 240 miles of open canals and laterals and 80 miles of low-head pipe.

In 1977, YTID began an evaluation of its irrigation system because of rapidly escalating costs of maintenance on the aging structures. The district engaged the engineering consultant firm of a CH2M Hill to do a comprehensive study of the irrigation system. The study concluded that the diversion works and the Tieton Canal were structurally sound and would perform adequately with continued maintenance, however the remaining system was obsolete because of age and changes in the method of irrigating in fruit orchard areas. Also seepage and evaporation losses in the system reduced the water supply below the consumptive demand during July and August.

In 1979, the district applied for a loan under the R&B (Rehabilitation and Betterment) Act, administered by the USBR. Construction was initiated in 1983. The rehabilitation replaced the original open canal and lateral system with a closed conduit pressurized

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[1] Reprinted with permission of ASCE from Proceedings of Symposium in Portland, Oregon, July 28-30, 1987.
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IRRIGATION WATER DELIVERY SYSTEM

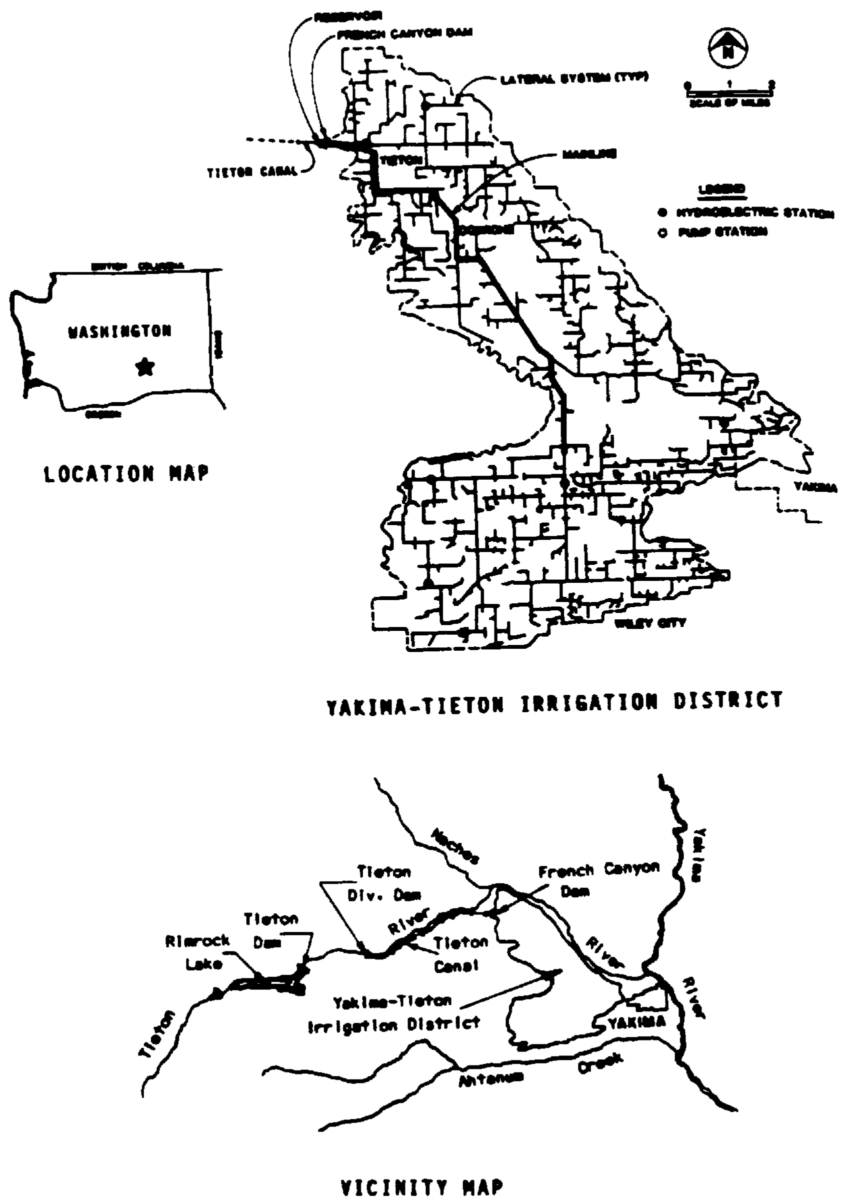

Figure 1. Yakima-Tieton Irrigation District, Washington

system. Approximately 210 miles of pressure pipe, ranging in size from 90 inches to 4 inches in diameter, was installed. Since there is topographically about 900 feet elevation differential between the upper and lower limits of the district area, approximately 85 percent of the area receives deliveries with sprinkler pressure furnished by gravity through the pipe system. To provide equitable service, the other 15 percent of the project area is provided sprinkler pressure through the use of booster pumps. In-line conduit hydroelectric generating stations were installed at two locations on the system that had excess pressure. The stations generate more power than is required by the booster pumping plants. French Canyon Dam, an earthfill dam, was constructed at the head of the distribution system to form a 540-acre-foot regulating reservoir used to control system fluctuations. The flow from the Tieton Canal discharges directly into the reservoir. The project was essentially complete in the fall of 1986.

R&B Program Background

The R&B Program was authorized by the R&B Act of October 7, 1949, as amended on March 3, 1950, and on October 3, 1975. The Program is administered by the Secretary of the Interior through the Bureau of Reclamation to facilitate the R&B of irrigation systems on projects governed by Federal Reclamation law and projects constructed under the Small Reclamation Projects Act. Federal funds are made available for the repair, replacement, or improvement of irrigation structures and systems which have deteriorated or become obsolete to the extent that the cost of the work is more than can be funded by the water user organization, except as a long-term obligation.

Benefits that can be derived from an R&B Program include better use of the project water supply, improved water distribution through modern control structures and measuring devices, reduction in frequent and expensive maintenance, improved safety for operating personnel and the public, and environmental enhancement.

Since the Program began, 108 programs have been approved.

R&B Program Process

a. The water user entity advises the Regional Director of its interest in the R&B Program or is advised by the Regional Director that the entity's project facilities are in need of rehabilitation and/or betterment.

b. Bureau of Reclamation and water user entity representatives conduct a joint examination of the system to evaluate the need for and extent of the work that should be considered.

c. An engineering and financial study is made, and a report is prepared to describe the need for the work, the proposed engineering plan, cost estimate, benefits to be derived, repayment ability, repayment schedule, and the environmental impact of the proposed work.

d. The findings of the study and contents of the report are reviewed and agreed upon by the Regional Director and the water user entity.

e. Copies of the report in draft form are submitted to the Commissioner of Reclamation and the E&R (Engineering and Research) Center for review and comment.

f. When the comments from the Commissioner and the E&R Center have been received, the Regional Director revises the report and prints and distributes it in final form.

g. The Regional Director requests the Commissioner's approval for contract negotiations based upon the repayment data in the final report.

h. When contract negotiations have been approved, a contract is prepared in draft form by the Regional Director for approval by the water user entity's board of directors.

i. A copy of the proposed contract is submitted to the Commissioner by the Regional Director.

j. The Commissioner reviews the proposed contract and, if he approves, recommends it for Secretarial approval.

k. If the Secretary concurs, he approves the form of the contract and signs letters to the Senate Committee on Energy and Natural Resources and the House Committee on Interior and Insular Affairs discussing the proposed program and his determination that the repayment terms are consistent with the R&B Act.

l. Following expiration of the 60-day review period, or earlier committee approval, the Commissioner notifies the Regional Director to proceed with contract execution.

m. The entity must then comply with State statutes regarding contract approval by the entity's electorate; the Regional Director and the entity's representative execute the contract; and confirmation is secured, if required.

n. The design and construction of the R&B work may begin after program funds have been appropriated.

Project Justification

In 1977, the YTID began an evaluation of its irrigation system because of rapidly escalating costs of maintenance on the aging structures. Due to the deteriorating condition of the distribution system, there was a high possibility of a system failure, such as a canal break, which would result in significant damage and a prolonged shutdown. Because of significant seepage losses due to aging of the system, the district was unable to adequately supply water to meet crop demands during the peak growing season. In addition, most of the irrigators served by the YTID have converted from gravity flow methods of irrigating crops, used when the distribution system was constructed, to sprinklers. The individual irrigator must pump water from the open canal or lateral to pressurize it for their sprinkler system, resulting in an overall average pumping power demand of 14 million kWh annually. Some rehabilitation of the system was considered to be necessary or serious restriction of water delivery would result.

It was estimated that rehabilitating the system in kind would cost the water users approximately $72.20 per acre per year, including on-farm power costs. Replacing the system with a pressure pipeline system was estimated, at that time, to cost $66.10 per acre per year.

Project Financing

The district applied for a loan under the R&B Act, administered by the USBR, in 1979 to replace the original open canal and lateral system with a closed conduit pressurized system. The project was approved in February 1981, and a repayment contract executed in October 1981. The total project cost was estimated to be $66,271,000. The R&B loan was for $62,133,000 and the remainder $4,138,000 was funded by a grant from the State of Washington, Department of Ecology, under the Agricultural Water Supply Program which was established by the 1979 session of the State Legislature (SB 2504), which in effect appropriated some $16 million that has been provided for drought relief in 1977. The amount of funding that will be a grant and terms on any portion that is to be a loan are an administrative decision which is made by the Director of the Department of Ecology with approval by the Governor.

The R&B loan was to be repaid to the United States by annual installments of $1,518,625 plus a power privilege charge equivalent to $34,700, or 50 percent of the annual net power revenues for the preceding year, whichever is greater. The loan would be repaid in 40 years or less.

Due to many factors, the district experienced a shortage of funding during construction to finish the project. The contributing factors cited are as follows.

a. Inflation and funding delays.–Project cost estimates were made in August 1979, and assumed initiation of construction in October 1980, and project completion in March 1983. Construction actually started in February 1983, and was completed in 1986. One item mentioned as causing delay is NEPA (National Environmental Protection Agency) compliance. Project construction was delayed at least 8 months because the Bureau required the preparation and public review of the environmental assessment before issuing a Finding of No Significant Impact. The lack of full-capability funding during construction is cited as lengthening the construction period.

b. Frost protection and pressure reduction.–The capacity of the lateral system was increased to provide additional frost protection capability. A decision was also made to include pressure-reducing valves in each turnout rather than clusters.

c. Design changes at French Canyon Dam.–French Canyon Dam is different than originally conceived. The spillway capacity required by the Bureau is 23,000 ft^3/s instead of the 4,000 originally contemplated. The Bureau also required changes in the design of both dam abutments after construction had started due to concerns relating to structural stability.

d. Increased powerplant capacity.–The district decided to increase the size of the power-generating facilities to take advantage of what appeared to be an advantageous financial opportunity. The power facilities were constructed with grant and load funds from the State of Washington. Since then, power demand declined substantially and

YTID was not able to negotiate the favorable power sales agreement it had expected. The change in the economics of the power facilities was significant because the district planned to use the power revenues to repay the increased construction costs.

e. State sales tax.–The district was surprised that the State sought to collect sales tax on the project. This matter was litigated, and the State's right to collect sales tax on materials was upheld.

The effect of the above changes is summarized below.

Original total project cost		$66,271,000
Inflation and funding delays	$ 2.3	
Frost protection & pressure reduction	1.4	
Design changes at French Canyon Dam	2.6	
Addition to powerplant	2.3	
Sales tax	2.7	
Total increased costs	$11.3	
Revised total project cost		$77,600,000

The district obtained grants and loans from the State of Washington and utilized its reserve fund to make up the shortfall. The sources of funding obtained are as follows:

R&B loan	$62,133,000
State grant (1981)	4,138,000
State grant (1984)	4,530,000
State loan (9.5%)	4,140,000
District reserve fund	400,000
State grant (1985)	125,671
State loan (10.5%)	2,134,000
Total	$77,600,671

The district obtained a 4-1/2-year deferment in the initiation of the repayment of the R&B loan, so that all irrigation repayment could be diverted to repay the $6.3 million in interest-bearing loans from the State of Washington.

The contract was amended to allow the 4-1/2-year deferment with $700,693 available for R&B repayment in year 5. The only repayment that would be made on the R&B loan during the first years would be the $34,700/year minimum power privilege charge. As soon as the interest-bearing loans are repaid, YTID would repay the R&B loan by annual installments of $1,518,625 plus three-fourths of net power revenues instead of one-half as stipulated in the original repayment contract. The minimum power privilege charge would be $34,700 in years I through 5, $80,000 in years 6 and 7, and $240,816 thereafter to the end of repayment. The increased power privilege charge will insure that the loan can still be paid off within 40 years.

Based on 28,271 assessable acres, the annual water user assessments would amount to $86.40 per acre - $53.72 for loan repayment - and $32.68 for operation and maintenance expenses.

Project Benefits

The benefits of replacing the open system with a pressure pipeline system include the elimination of the need for on-farm pumping, power-generating revenues, reduced operation and maintenance costs, low-cost alternative for frost control, water savings, increased delivery rate, and reduced liability.

Since water is delivered under pressure, the water users no longer require their own private pumps and motors to provide sprinkler pressure, resulting in considerable savings in power costs. Approximately 1,200 privately owned pumps totaling 8,700 hp, with an average annual usage of 14 million kWh can be removed. It was estimated that the 1983 average project farm pumping cost was $25.80 per acre irrigated.

The new system will require about 3,400,000 kWh of pumping energy for the booster pumping plants. The turbine-generators installed at two sites will produce a total of 10 million kWh per year through three generating units. Power and energy produced in surplus to the amount needed for the operation of the pumps will be sold to Pacific Power & Light Company. (Financing for the generating facilities was with State of Washington funds, no R&B funds were used.)

It is projected that the annual operation and maintenance costs of the district will be reduced by approximately 15 percent as a result of the project. With an operation and maintenance budget of $950,000, a savings of $140,000 may be anticipated - reduced expenses for weed and moss control chemicals, repairs and maintenance, and labor. The design of the system incorporated several features to minimize operating costs. (These features were presented by Roger W. Beieler, CH2M Hill, in a paper titled "Design Considerations for Reducing Operating Costs," at the 1983 ASCE, Irrigation and Drainage Division, Specialty Conference held in Jackson, Wyoming.) These features include labor savings by allowing water users to control their own rate of delivery, automatic flow regulating devices to limit the rate of delivery, and location of turnout boxes adjacent to public roads. Also, operation of the system will be easier by use of bypass lines around the isolation valves and system telemetry.

The project also offers the option of providing water for frost control to growers who elect to pay for the additional service. Over-tree frost sprinkler systems are considered to be an effective frost control method, eliminating the need for orchard heaters using fossil fuels resulting in environmental benefits. The severe spring frost conditions in the district in 1985 caused at least a 46 percent drop in fruit production due to frost damage. It is estimated that the gross dollar value of the fruit that could have been saved if the new system had been operational with its frost control capacity is $4.7 million.

There are other benefits of the project to the district and its water users. Distribution system conveyance efficiencies are expected to increase from 78 percent to 98 percent. Annual water savings of about 21,800 acre-feet previously lost to seepage and evaporation will be available for productive use. The district average delivery rate will be increased from 5.3 gal/min to 6.8 gal/min per acre. This increase will come closer to meeting crop needs since the previous water supply was marginal at best. Crop yields should improve as a result. Continuous delivery will not be necessary, thus reducing farm labor costs and giving greater convenience to the grower. Underground pipe will allow many growers to increase their land utilization. District and grower liability, associated with open canals and laterals, will be reduced and public safety enhanced.

The rehabilitation of the aging distribution system, reducing operation and maintenance costs, eliminating the need for on-farm pumping, power-generating revenues, and providing a low cost alternative for frost control, will have a continuing beneficial effect to the individual water user, the district, and the economy of the area in general for years to come, especially considering future rising energy costs.

References

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2. Bureau of Reclamation, "Contract Between the United States of America and the Yakima-Tieton Irrigation District for Rehabilitation and Betterment," dated October 13, 1981.

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CONCRETE DETERIORATION[1]

Automatic Wasteway Structure No. 3
Gravity Main Canal – Gila Project, Arizona

By Harry Uyeda[2]

Automatic Wasteway Structure No. 3 was constructed in 1939. A 1986 RO&M inspection disclosed severe spalling of the concrete and severe corrosion of the exposed steel (figure 1) such that the stability of the structure was questioned. Sometime during the period between construction and the 1986 inspection, the Wellton-Mohawk Irrigation District performed some repairs (judged as being primarily cosmetic) around the wasteway gates pivots (figure 2).

The current deterioration (figures 3a. and 3b.) appears to be isolated to the outside walls of the structure floatwells with no effect on the canalside surfaces of the structure. The areas of spalled concrete and subsequently exposed steel reinforcement generally follow the backfill grade which is 5 to 6 feet above normal canal water surface. The ground water reportedly is high at this location.

Subsequently, the Yuma Projects Office submitted concrete spall fragments and cores, backfill soil, and canal water samples for evaluation to determine the cause for the distress.

Fragmented samples contained abnormally high levels of chloride and substantially more chloride than core No. 4 (figure 4), which was removed from the middle of a 14-inch-thick wall. The gradient of chloride content, from lower concentration at the surface to higher concentration in the interior of both fragment samples, would suggest that the critical chlorides were mixed into the concrete initially and leached out by years of exposure. However, if this were the case, severe distress of waterside concrete, particularly near the normal water surface elevation, would have been expected soon after exposure. Therefore, it is likely that core No. 4 reflects the chloride originally incorporated in the concrete mix. Thus, it appears that the critical chlorides were derived from the exposure conditions, either the canal water or the soil backfill, and that the high levels and the reverse gradients were due to concentrating effects and accumulations after cracking, respectively.

If the water were the source for the critical chlorides, again waterside surfaces of the structure (particularly adjacent to the normal water surface elevation) would have shown distress at an early age.

The only remaining source for chlorides, consistent with the nature of the distress, is the backfill soil. The concentrated attack about the backfill grade and the high water table are both consistent with this conclusion. Near grade, cyclic wetting and drying, and an ample supply of oxygen are available to concentrate the chlorides and to support the corrosion reaction, respectively. Since corrosion products of steel are more voluminous

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1 Condensed for bulletin. Full report with chemical analyses is available from the author.

2 Harry Uyeda is a Technical Specialist employed at the Engineering and Research Center, Bureau of Reclamation, PO Box 25007, Denver CO 80225.

than the alloy itself, the corrosion activity can exert tremendous tensile stresses and strains on concrete. Since concrete cannot accommodate tensile strain, it cracks and spalls. After cracking, the chlorides are able to enter the interior concrete freely resulting in the anomalous chloride concentration gradients.

Conclusions

1. The distress of the concrete at Wasteway Structure No. 3 is the result of chloride-induced corrosion of the embedded steel.

2. The source of the critical chlorides is likely the backfill soil.

3. The structure should be repaired with high-quality concrete.

4. To minimize the potential for chloride intrusion from the soil, the concrete surfaces within 2 feet of the backfill grade should be coated with a waterproofing membrane for longer life.

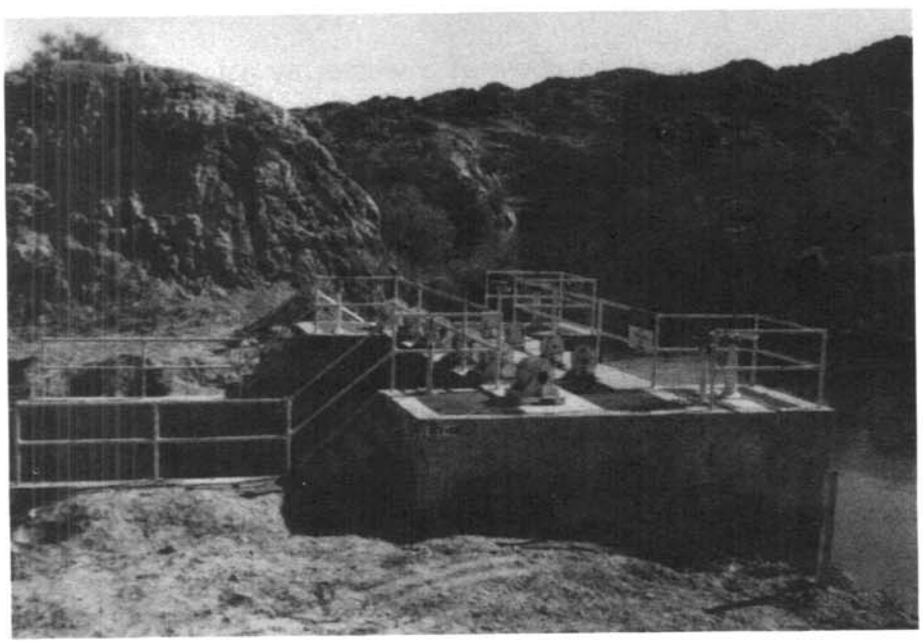


Figure 1. View of downstream side of Automatic Wasteway Structure No. 3 after excavation of backfill from outside wall of the downstream floatwell.

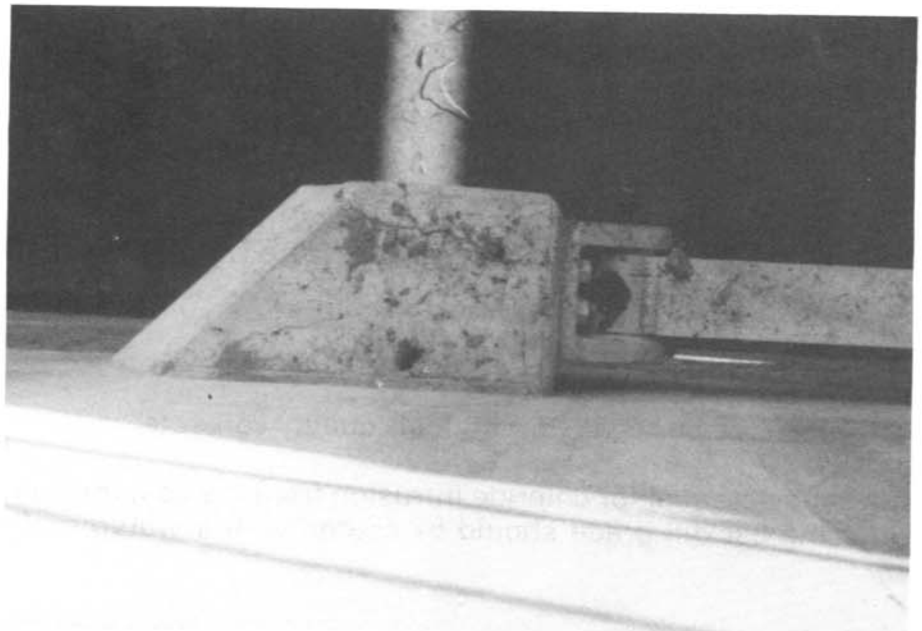


Figure 2. View looking down at a wasteway gate pivot where repairs, primarily cosmetic, were previously made.

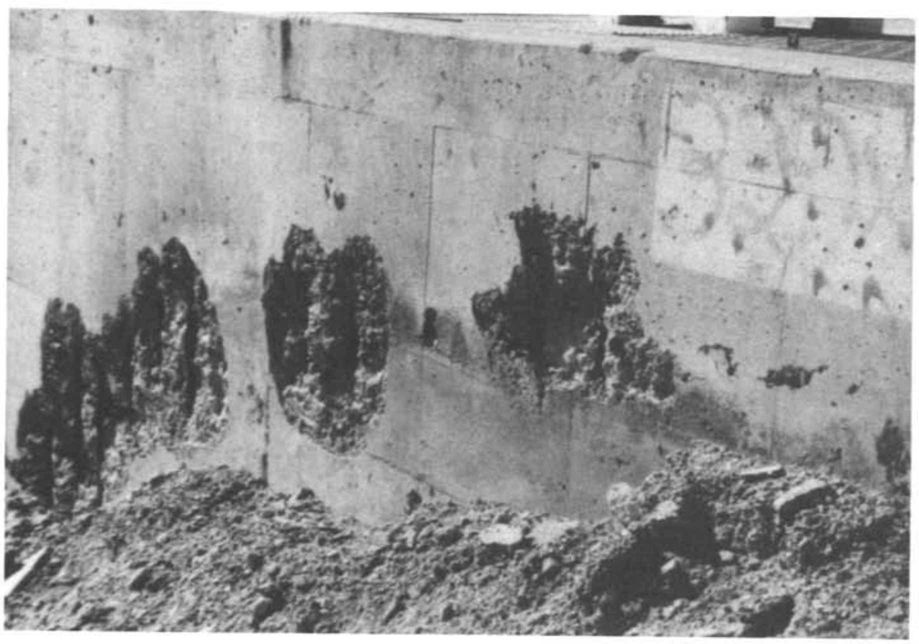


Figure 3a. Outside wall of upstream floatwell.

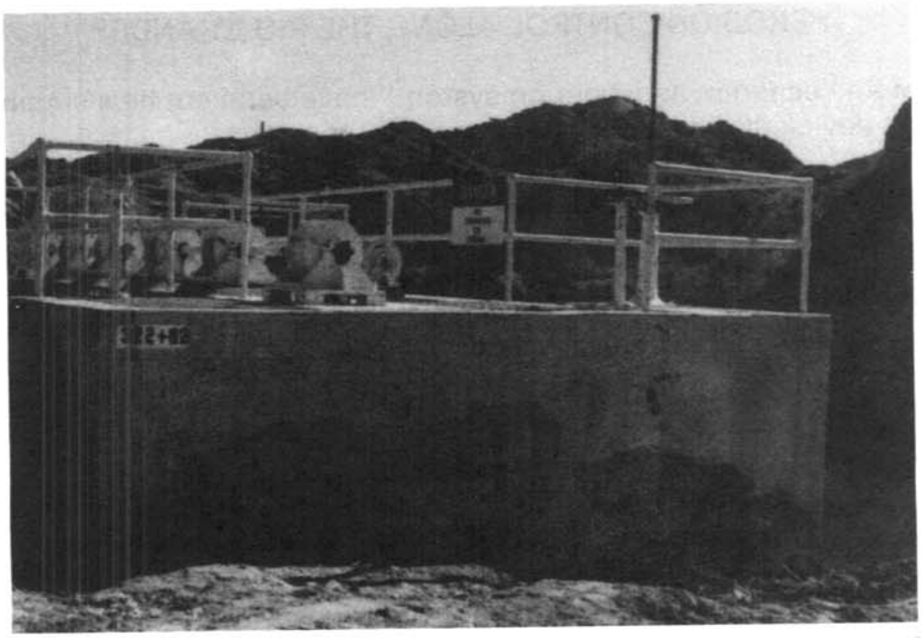


Figure 3b. Outside wall of downstream floatwell. Note that severe damage is isolated to surfaces adjacent to original grade.

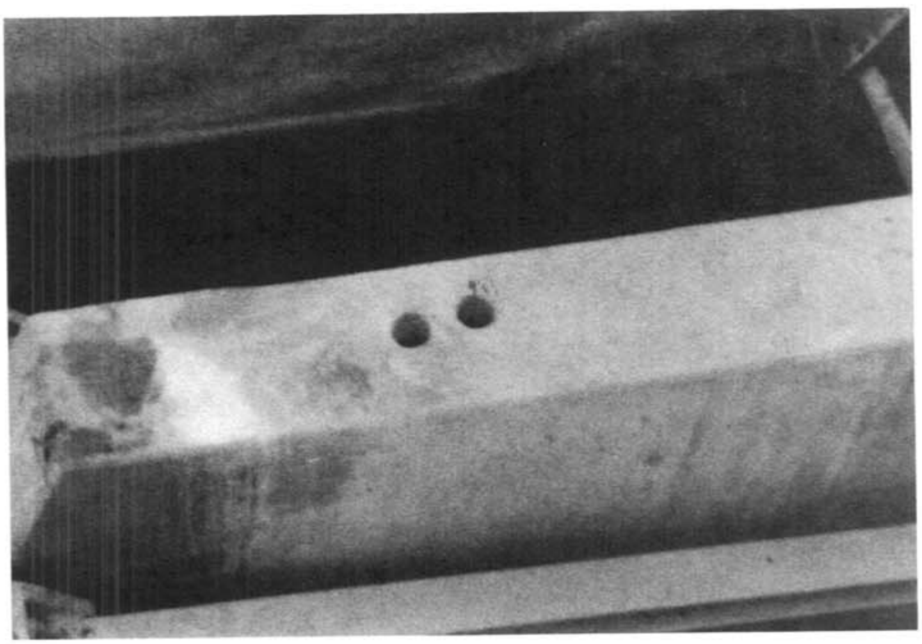


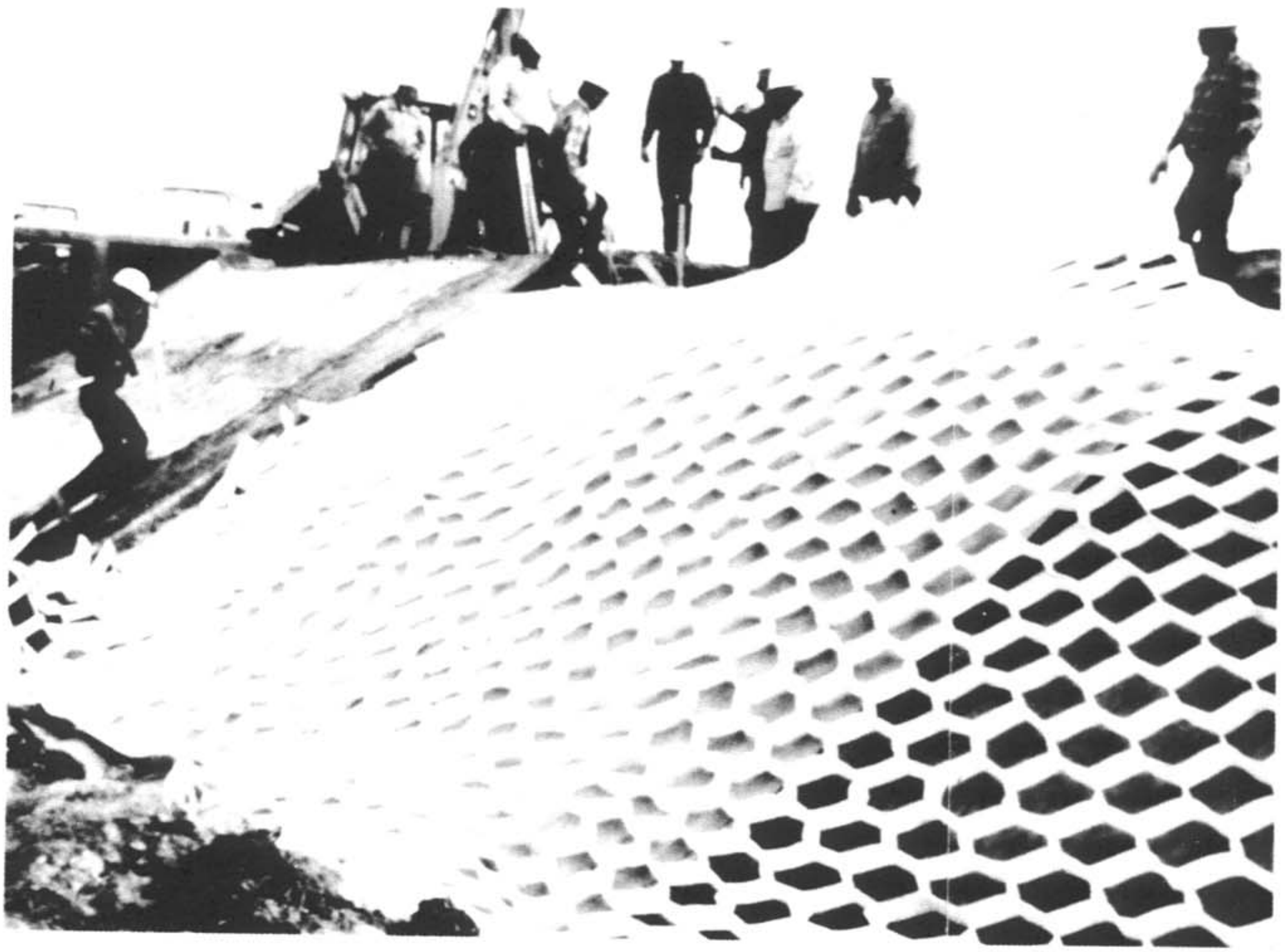
Figure 4. View of center wall from which core No. 4 was removed. Wall is 14 inches thick.

EROSION CONTROL ALONG THE RIO GRANDE[1]

The ravages of an "ocean in an irrigation system" have been cut by a simple but effective erosion-control device. It did not happen a moment too soon.

Ask Gary Esslinger. He maintains a complex irrigation system down around Las Cruces, New Mexico, and to say that his erosion-control problem is widespread is an understatement. The system consists of hundreds of miles of aging earthen ditches and canals, designed to get water from the Rio Grande River to thousands of farmers in the area.

Esslinger is maintenance chief for the Elephant Butte Irrigation District. It is a part of the New Mexico portion of the Rio Grande Project, which furnishes irrigation water for about 200,000 acres of land, as well as providing electrical power for communities and industries in south-central New Mexico and West Texas.



The Armater was spread out and anchored across a 2- to 4-foot flat ledge and down the slope.

[1] Reprinted with permission from the Editor of Irrigation Journal, March/April 1987 issue.

The project includes two large storage dams, six smaller diversion dams, 139 miles of canal, 457 miles of irrigation laterals off the main canals, 465 miles of drains, and a hydroelectric powerplant.

It helps irrigate approximately 5,000 farms and provides municipal water service for about 450,000 people.

"The part of the project I maintain consists of 327 miles of canals and laterals, and 200 miles of drains," Esslinger said recently.

"The system is old. The major dams and canals were constructed in the early 1900's. Most of the laterals and ditches were built in the 1920's. Almost the entire system consists of earthen canals, laterals, and ditches."

The Elephant Butte irrigation system consists almost entirely of earthen canals, laterals, and ditches.

"We are continually rebuilding eroded sections. Last summer we rebuilt 14 areas. In each case, we had to bring in between 2,000 and 6,000 yd^3 of dirt. We currently have 96 more areas where we anticipate doing erosion-control work this winter."

Esslinger has turned to a newcomer, an erosion-control product called Armater, in hopes of alleviating his problems. Successfully used in Europe for over a decade, it was recently introduced in the United States by Geomatrix Systems, Enka, North Carolina, a division of BASF Corporation Fibers Division.

He learned about the product while he was searching for a cost-effective method of dealing with erosion, Esslinger recalled. "The cost of lining hundreds of miles of canals with concrete was prohibitive. I approached a local distributor who deals in erosion-control products, and he sold me on the merits of trying Armater. I understand this is the first application of the product in the United States."

Armater is a three-dimensional, semi-rigid geomatrix made of nonwoven, polyester fabric. It is permeable, lightweight and rot-proof, and provides virtually permanent erosion control, the manufacturer promises.

The hexagons that make up Armater's honeycomb design are 4 inches deep with 8-inch sides. After it has been placed on a surface, it can be filled with native soils, sand, gravel, pea gravel, or other aggregate. Surface-water flow is impeded and slowed by the raised edges of the hexagons.

The Rio Grande Project has thousands of control gates. They are used to hold water and then release it as necessary for irrigation. Water to be used for winter power generation is released from a dam near Truth or Consequences, New Mexico, then held in a reservoir 25 miles downstream, and eventually released for irrigation use during the summer. The control gates in the irrigation system are supported by concrete structures.

During the summer growing season, the water is continually rising behind the control gates and being released. Esslinger noted.

"The water drops rapidly as it rushes out of the concrete control gates, and when it hits the earthen canals and laterals it causes erosion," he explained.

"Our situation is not unlike what you have on an ocean beach, with the continuous rise and fall of the tide."

Esslinger tried Armater earlier this year in one of the laterals where he was having erosion problems.

"We installed 280 yd^2 - two panels - in January 1986, when the system was drained because the growing season was over," Esslinger recalled. "The Armater was spread out and anchored across a 2- to 4-foot flat ledge and down the slope. All that is needed to join a series of panels is a commercial stapler.

"We filled the honeycombs in the Armater with a mixture of rock fine, consisting of baseball- to football-size rocks, and soil to keep the banks stable. The Armater was installed quickly and with a minimum of labor. It is inexpensive when compared to the alternatives of installing concrete or riprap."

About 2 weeks after the erosion-control material was installed, the system was filled with water again for the growing season. The material was under water for about 9 months until the water was drained for the winter in mid-October. In November, Esslinger was asked how he thought the first installation of Armater had performed.

"The Armater seemed to perform well while it was under water," Esslinger said. "When we drained the system, it looked just like it had when we put it down. It was not stretched or deformed. There was even some bermudagrass growing on the slope, which indicates that the Armater anchored everything down like it is supposed to do."

The maintenance chief continued, "Overall, I am very pleased with the results. There was only one small area where we had a minor problem, and that was because we were not as careful as we might have been in anchoring the Armater when we installed it."

This February the product was installed in a different application, where it would be exposed to a much greater capacity of water – 380 to 400 ft^3/s, as opposed to 80 ft^3/s for the first two panels. This time the installation was in the main channel. The high-velocity area was designed to put the product to the supreme test.

Esslinger was interviewed again in March to learn the results of the new installation of Armater in the main channel.

He explained, "This year we put in four test plots. All of them were different applications for the product. One of the test plots failed completely, but the other three are holding their own - which means five of the six panels we have installed have been successful."

The one panel that failed "was just downstream of a structure where there was a section of concrete lining that had been washed away," said Esslinger, "and we tried the product in place of the concrete lining. But the velocity and turbulence on the downstream side of the structure was too great for the product to withstand."

The honeycombs of the Armater were filled with a mixture of rock fine, consisting of baseball- to football-size rocks, and soil to keep the banks stable.

In the other three new applications, the Armater panels were placed on a curve where the velocity of the water is about 50 ft^3/s. Although they take the brunt of the water because they are on an exposed curve, there has not been any erosion yet.

Esslinger revealed, "I have talked to the people who sell the product, and they have another product that they can put on top of the Armater as a screen. We might try that next year in the same location (where the panel failed), to keep the material inside the honeycomb."

He explained, "When the Armater is spread out it forms a honeycomb. We fill it with dirt and rock to hold it to the side of the slope. The rocks range in size from the size of a fist to the size of a football. On top of that mixture they are talking of putting a screen that would keep the rock and dirt from washing out."

Esslinger is not critical of the Armater for the one failure. He explains, "There was so much turbulence and water interaction against the rock mixture that first the dirt was extracted, then the rock was put in a stress area and started to break the cones of the fabric, so that eventually the fabric started tearing away."

"We have always had a concrete lining in that place to protect the banks from erosion and turbulence. I do not know if it was a fair application of the product, because where we used it the water was running around 400 ft^3/s when it failed. We have the same amount of material in another test plot in a similar canal that averages 200 ft^3/s every day, and it remains untouched - no problem. The product could have reached its limits at 400 ft^3/s. It was the first usage in a canal, so we were experimenting."

Nevertheless, he says of the Armater, "We are impressed with it at this point. It goes in real fast, and we learned a lot by our experiences with it. There are places where we might improve our installation of the product. One thing we might do next time is use that screen over it in high-turbulence areas."

"For our type of work, it costs about $5 per foot to install. That is not too bad. We would probably be able to reduce the cost, once we got more experienced in how to put it in and what to do with the product. At $870 a panel, the Armater is relatively cheap and by improving our installation methods, we can cut costs even further."

Esslinger declared, "I think, overall, the product would better fit mountain slopes and highway use. But we thought we would try it in the canal, and I would say the success rate so far is about 80 to 90 percent in our favor. We have just had one failure out of five, so that is not too bad. We plan to order some more for our next season in October, when we can install it again."

He concluded, "I foresee the day when most of our areas which are susceptible to erosion are covered with Armater."

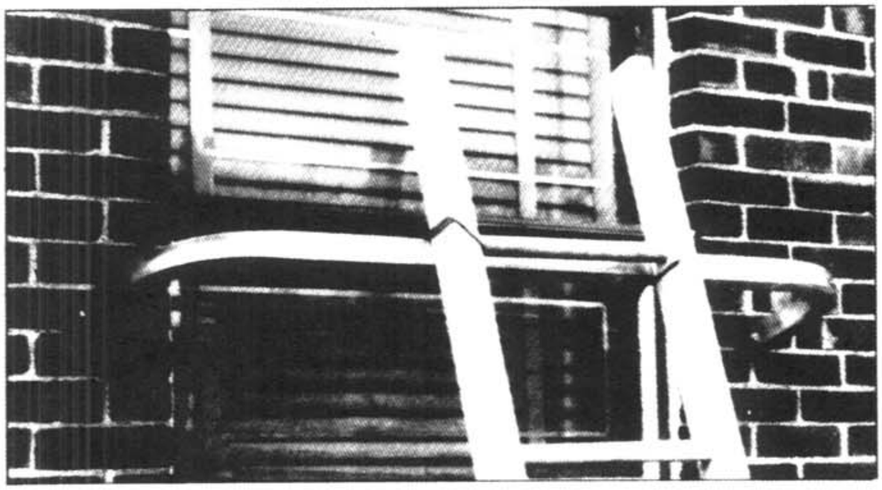
KEEP FALL COSTS DOWN[1]

Falls from elevated places occur less frequent than the slip or trip fall, but almost every fall from an elevated position poses a higher risk of producing either greater physical damage to the fall victim, or resulting in a fatality.

Engineering controls must be considered wherever a fall hazard exists. Very often, a fall hazard is an indication that safety standards are not up to minimum requirements. The safety professional needs to be thoroughly familiar with ANSI (American National Standards Institute) and OSHAct (Occupational Safety and Health Act) standards, and adhere to those guidelines.

Slips from grease, oil, and other contaminants can be as much of a problem on ladders, scaffolds, and catwalks as on floors and other walking surfaces. Ladders are particularly dangerous. A number of slip-resistant cleats are available for fixed ladders, but workers must be reminded to keep cleats and side rails as clean as possible. Remind workers to hold the rails when climbing ladders, rather than the rungs. This helps prevent the transfer of any slippery contaminants from ladder rungs to workers hands or gloves.

Too often falls result from single-instance or nonrepetitive jobs that require work at elevations where suitable fixed ladders and platforms have not been constructed. Under these circumstances, a job hazard analysis should be performed to identify what personal protective equipment must be used. Do not forget to allow time to train the workers on the proper use of the selected personal protective equipment.



Ladders are a major contributor to industrial fall injuries. This metal bracket allows workers access to all points of this window without having to reach too far or extend the individual's center of gravity too far left or right.

[1] Reprinted with permission from the Editor from the April 1987 issue of Safety and Health.

Using equipment incorrectly, even the right equipment for the job, is a common fall hazard. A ladder may be set too close or too far from the building or structure that supports it. Using a tall ladder alone, and setting the ladder on loose or uneven ground, are other hazards. A second person should be positioned at the base of tall ladders to steady the ladder whenever someone is using it. Standing on top of a stepladder, or using an extension ladder that is too short, is an invitation to a serious fall.

Follow the one-to-four rule when using an extension ladder. Set the ladder's base 1 foot out from its supporting structure for every 4 feet of working ladder height. (The working height is the vertical distance from the ground to where the ladder hits its support.)

Extend an extension ladder 3 feet beyond its contact with its support. Never use the top three rungs of an extension ladder or top two steps of a stepladder.

The worker's belt buckle should never extend beyond the side of the ladder or it will be unstable. The worker should have both hands free to hold the ladder's rails when climbing and descending. Workers should carry only small tools and work implements on a belt. It is a better choice to raise and lower tools and equipment with a rope. Never raise or lower power tools by their power cords (the rope should be tied to the body of the tool, not to its power cord), and always unplug power tools before raising or lowering them.

Workers will sometimes be tempted to use whatever is handy to build a makeshift ladder. Standing on top of a barrel or chair to reach something, or making a small ladder bigger by putting a box on top are common hazards.

Makeshift ladders are never acceptable. They often cause a further hazard by making the worker reach beyond his center of balance thereby inviting a fall.

When a worker is found using a makeshift ladder, he should be called in, along with his supervisor, for a detailed review of ladder safety procedures.

Construction of permanent ladders and platforms should be considered. But when it is necessary to work with temporary ladders, movable platforms, and all types of scaffolds, follow the basic safety rules:

Be certain the scaffold or ladder is firmly seated and, if on the ground, will not tip if it sinks into soft soil.

Be sure all rungs have flat steps or that rungs are treated with an abrasive coating, or that they are rigid and are free from oil, mud, and other contaminants.

Always use both hands when climbing or descending a ladder. Both hands must be free to hold the ladder.

Use the proper type of ladder when working near electricity and stay clear of overhead wires. Be sure personal protective equipment, especially the helmet, is suitable for working around electricity.

Never over-reach from a ladder or work platform.

Do not invent climbing equipment.

Always inspect a ladder before using it. If the ladder is found to be damaged, do not use it.

Never paint a wooden ladder.

Supervisors should allow adequate time during scheduled safety meetings to review the proper use of ladders. Workers should be instructed to check with their supervisors if there is any question as to what climbing equipment is proper for the job.

In addition to ladders and catwalks, loading docks are primary candidates for slips and falls. Loading docks are often heavy traffic areas. And moisture is a major contributor to accidents around the loading dock.

Dock plates or gangplanks are used to bridge the gap between the loading platform and the highway truck, trailer, or railroad car. The typical gangplank is made of wood, steel, or one of the lighter metals such as aluminum or magnesium. Whatever the material, it must be strong enough to carry heavy loads.

Worn or improper surfaces, or surfaces that become slippery when wet, should be attended to immediately. These surfaces can be coated with one of several commercially available nonslip coatings. Dock seals will keep snow and rain out. If dock seals are not practical, consider some form of overhead shelter to protect high-traffic areas.

In addition to slippery surfaces, falls may result from workers tripping on raised edges of bent dock plates or on dock plates left lying on platforms and ramps. Bent dock plates should be removed from service until repaired. Dock plates left lying on platforms and ramps should be stored properly.

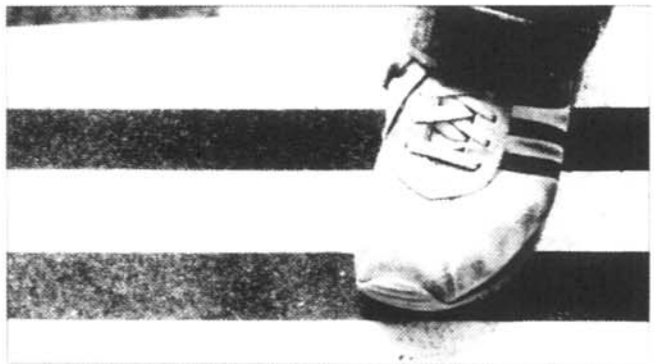
Gangplanks and ramps should be of the least slope practical and should have an abrasive coating or pressure-sensitive adhesive strips attached to help insure safe footing.

There are abrasive coatings and materials available for most applications including specially formulated coatings for application on surfaces of concrete, metal, and wood. They take the form of epoxies and enamels, and usually contain gritty compounds that are held in suspension.

Many of these products were designed to be applied by brush, roller, spray, or trowel. If there is any doubt as to the correct or acceptable application method, contact the coating manufacturer or the manufacturer's representative for detailed instructions.

Coatings of a high or low profile may be created through various application techniques. These coatings may have been specially formulated to resist grease and oil, water, metal filings, and a wide range of chemicals. When making a selection, be sure the coating offers good skid resistance.

Primary targets for the application of these materials in and around the work place are aisles, stairs, walkways, ramps, and loading docks. And do not forget to coat worker shower and locker room areas. There are special formulations available that meet strict Federal regulations and have been approved for use in food handling, and meat and other food processing plants.



Adhesive-backed, anti-slip strips like these can be obtained in general purpose and conformance configurations. Thus, they are useful for reducing slip hazards on rungs, plant floors, shower rooms, and office-walking surfaces. (Photo courtesy of Direct Safety Company.)

A number of manufacturers offer a selection of strips and rolls of skid-resistant surfacing mounted on pressure-sensitive backings, or supplied with special mastic, that were designed to permit easy application to stair treads, gangplanks, and other potentially hazardous walking surfaces.

Many falls are caused by loose footing on stairs and steps. Buckling stair treads and broken floorboards are trip hazards that invite serious injury. Loose or worn carpeting on stairs is a major fall hazard. Make sure all carpeting on stairs is secured, and replace any areas of worn carpeting. Repair treads that are loose or buckling. Double check all handrails to make certain they are secure.

All employees should be instructed to report hazardous walking areas, including uneven surfaces on walkways, defective stairways, torn mats and runners, and potholes in the parking lot. Warning signs should be posted, or barricades should be erected cautioning pedestrians, and repairs should be made immediately.

Keep the work area well lighted and clean. Have light bulbs replaced as soon as they burn out.

Adequate lighting is necessary wherever employees walk or work. It is especially important where workers must climb or work on elevated levels such as catwalks, gangplanks, and loading dock areas. Lights left off and burned-out bulbs can interfere with the workers' ability to see and identify possible hazards ahead.

In operations and industries where workers are expected to climb and descend a lot and work from elevated positions, the safety professional should review the company's fall protection program on a regular basis. If no fall protection program exists, manufacturers offer a wide range of products and information to help the safety professional establish or upgrade a company fall protection program.

For any fall protection system to work successfully, employees and management must work together to make sure the equipment selected suits the application, that the workers are properly trained in the equipment's use, and that the system is maintained in good working order.

For a fall protection system to provide maximum safety, it is important that the correct equipment be chosen per industry standards and guidelines as well as specific worker needs.

The fall protection program can be divided into two categories including lifeline systems and climbing protection systems.

It is important to note that selecting and purchasing appropriate safety equipment is not the same as having a fall protection program. An effective fall protection program depends on well placed and secure anchorage points and, equally important, proper equipment inspection and maintenance procedures must not be overlooked.

When purchasing fall protection equipment, it is recommended that a complete system be purchased from a reputable safety equipment manufacturer or authorized distributor. This should include the fall protection device and all accessories, service, repair, and comprehensive instructions required for proper use.

No components of the fall protection system should be substituted unless approved by a qualified engineer or the equipment manufacturer. Many times commodity grade rope is selected in an effort to hold costs down. If commodity grade rope is selected as a lifeline, it must meet rigid manufacturing standards before it can be considered safe for use with a specific fall protection device.

Finally, workers must be trained in the proper use of the fall protection equipment. Knowing how to use the equipment is as important as having it. And workers must be properly supervised to ensure that they are using the equipment as it was designed to be used. As in all successful safety programs, training and supervision are an ongoing process.

Principal fall protection systems require the worker to wear a body belt or harness that is attached to either the lifeline system or the climbing protection system.

Safety belts, also known as body belts, are often made of nylon or polyester webbing for durability. Safety belts were designed to be worn around the waist and may be 2, 4, or more inches wide. A body harness is more elaborate and will distribute the force of an arrested fall over the torso and possibly thighs rather than just the worker's mid-section.

The simplest lifeline system would connect a 6-foot lanyard to the worker's safety belt or harness with the other end tied off at the work station.

Vertical rope-grab lifeline systems feature a mechanical device that moves up and down a vertical drop line. The device locks on the rope (compression) when a fall is sensed.

Similar devices that roll freely along the rope without requiring the worker's constant attention reduce frustration and promote adherence to the fall protection program. This system is particularly well suited to workers operating from scaffolding. A shock-absorbing lanyard can be substituted for the 6-foot lanyard to maintain mobility and dramatically reduce the shock of arresting forces to the body.

Other devices such as retracting lifelines eliminate dangerous slack that can develop with static lines or long lanyards. A retracting lifeline can arrest free-fall in just a few inches. Horizontal lifelines may be permanent or temporary depending on the duration of protection need for a worker moving horizontally.

Climbing protection systems limit accidental free-fall during climbs. This type of system is especially suited for tall ladders, derricks, bridges, poles, chimneys, and antenna towers.

In operation, a taut synthetic or wire cable (or rigid rail) runs parallel to, or in the center of, the climbing structure. The safety belt or body harness is attached to the cable or rail by a climbing safety sleeve that moves freely as the worker climbs or descends. The sleeve locks securely the instant a fall is sensed.

A very similar system uses a rail that runs parallel to, or in the center of, the ladder. This flat-rail system offers several advantages over synthetic or wire cables. The rail is easier to inspect and maintenance costs are low. In addition, the rail will allow several workers to climb or descend at the same time.

SPOTLIGHT ON GLEN CANYON DAM

Wedged into a deep sandstone gorge on the Colorado River, Glen Canyon Dam impounds water for more than 180 miles to form beautiful Lake Powell. Each year, millions of visitors are drawn to the lake, but recreation provides only a small part of the benefits offered by the lake and the dam which formed it. Lake Powell's dependable supply of water for irrigation, municipal and industrial use, and hydropower generation benefits millions of people far from its spectacular shores.

How the Site for Glen Canyon Was Selected

The lower section of Glen Canyon was first considered for a damsite in the early 1920's. The final site for Glen Canyon Dam was carefully examined and selected by a group of Bureau of Reclamation engineers and geologists working from 1946 to 1948. There were three main criteria in choosing this particular site:

1. The area forming the reservoir basin could contain an immense amount of water.

2. The canyon walls and bedrock foundation were strong and stable enough to safely support a high dam.

3. A large source of good rock and sand for making concrete aggregate to build the dam was close by on Wahweap Creek just 5 miles from the construction site.

Construction History

Glen Canyon Dam was authorized by the U.S. Congress in April 1956. The first blast occurred on October 15 that same year, signaling the start of construction.

In April 1957, the prime construction contract to build Glen Canyon Dam was awarded to Merritt-Chapman and Scott Corporation. Until June 1960, the emphasis was on rerouting the river and excavating – drilling tunnels, blasting to bedrock for the foundation, and carving into the canyon walls for the abutments of the dam. The canyon was actually shaped to fit the dam.

Concrete placement began in the summer of 1960 and continued day and night until September 1963, when the final "bucket" was dumped. The "bucket" used was a huge container holding 24 tons of damp concrete. In all, it took over 400,000 buckets of concrete to build Glen Canyon Dam.

Glen Canyon Dam is a concrete arch structure. It has a structural height of 710 feet and a crest length of 1,560 feet.

The turbines and generators that produce the hydroelectric power were installed between 1963 and 1966. Glen Canyon Dam was dedicated on September 22, 1966.

The spillway tunnels at Glen Canyon Dam were not used continuously until the 1983 floods on the Colorado River. With discharges of approximately 30,000 ft^3/s, severe cavitation and erosion damages occurred in both tunnels. The majority of the damage was located in the elbow areas after a drop of 500 feet from the spillway crest. Aeration slots were provided to eliminate future cavitation damage. In 1984, over 16,500 yd^3 of concrete were used to repair the tunnels (see figure 1).

Glen Canyon Dam, Lake Powell, and the Navajo Reservation

Glen Canyon Dam, Lake Powell, new paved highways, and the incorporated town of Page have remarkably transformed a large area of the Utah-Arizona canyon lands.

Before 1956, the land near the future damsite was virtually inaccessible. When the Glen Canyon Dam construction crews arrived, they found they had to drive 200 miles to cross from one side of the canyon to another.

Glen Canyon Bridge was completed in 1959 and, together with the connecting highways, permitted trucks by the thousands to deliver equipment and materials for the dam and for the new town of Page.

Nearby Navajo Indians, who pastured livestock on meager desert grass in the area, suddenly found themselves near stores, schools, and medical care. Many Navajos worked on the construction of Glen Canyon Dam.

Land for the town of Page and the south side of Lake Powell, formerly a part of the Navajo Indian Reservation, was exchanged by the Tribe for equivalent land in southeastern Utah. The town is carved from the desert and was first designed as home base for the thousands of men and women and their families associated with the construction and operation of Glen Canyon Dam. At the peak of Glen Canyon Dam construction, Page had about 7,500 residents. The town was incorporated under the laws of the State of Arizona in March 1975 and has a population of about 6,000.

The Canyon, the Lake, and the Dam

From the concrete barrier of Glen Canyon Dam, upstream for more than 180 miles, Lake Powell's blue waters lap at cliffs, buttes, and gentle sands. Hour by hour, earth-tone colors change as shadows creep through the canyon.

Rain and wind sometimes sweep across the lake, but are quickly gone. This is desert and the sun dominates.

Lake Powell is awesome, vast, overwhelming — it is ever changing, always sublime.

Lake Powell

Glen Canyon Dam backs Colorado River water through Glen Canyon to form Lake Powell, one of the most scenic lakes in the world. When full at 3,700 feet above sea level, Lake Powell is 186 miles long. The shoreline distance - backing in and out of numerous side canyons - is an incredible 1,960 miles.

Lake Powell started filling on March 13, 1963, when diversion tunnel gates were partially closed. Although the filling rate varied because of erratic precipitation, the lake usually peaked a little higher each year. In 1980, it was completely full and water flowed over the spillway. A test spill was allowed; however, operators at the dam now try to avoid the waste of spilling from a full reservoir without producing hydroelectric power.

To meet its intended purpose, Lake Powell must fluctuate. During spring runoff, May through July, the lake normally rises. During the remainder of the year, the lake declines. How much or how fast it drops depends on both the water surface and elevation, how much water is carried over from the previous year, and how much runoff water flows into Lake Powell from the Colorado River system. During a series of low-water years, Lake Powell could drop more than 200 feet below its maximum elevation, but that would be highly unusual.

Rainbow Bridge

A star attraction of the Glen Canyon National Recreation Area is Rainbow Bridge. This wonder is the largest natural bridge on earth. The Navajos call it "Nonnoshoshi" or "the rainbow turned to stone."

Rainbow Bridge is 290 feet above the bottom of the streambed. It has a span of 278 feet and a minimum thickness at the top of 42 feet across. When full, Lake Powell's waters are 48 feet deep directly beneath the arch, but the water surface is still 21 feet below the lowest part of the bridge abutments.

When Lake Powell began to fill, there was some concern that the stability of Rainbow Bridge would be threatened by the rising water. Precise surveys conducted semiannually since Lake Powell entered Rainbow Bridge National Monument grounds show no discernible movement or change that can be attributed to the presence of standing water beneath the arch. In other words, Lake Powell apparently has no significant effect on the structural integrity of Rainbow Bridge.

The Colorado River Below the Dam

Before Glen Canyon Dam was built, the Colorado River ran warm and muddy red. Now it is clear and cold. Today, stocked rainbow trout thrive in the cold water, often reaching trophy size.

The riverflow fluctuates not as much seasonally as it does daily and weekly in response to power demands from distant towns. During the recreation season, water releases through the dam are no lower than 3,000 ft^3/s. To maintain good boating through the Grand Canyon, maximum water releases are limited to about 32,000 ft^3/s.

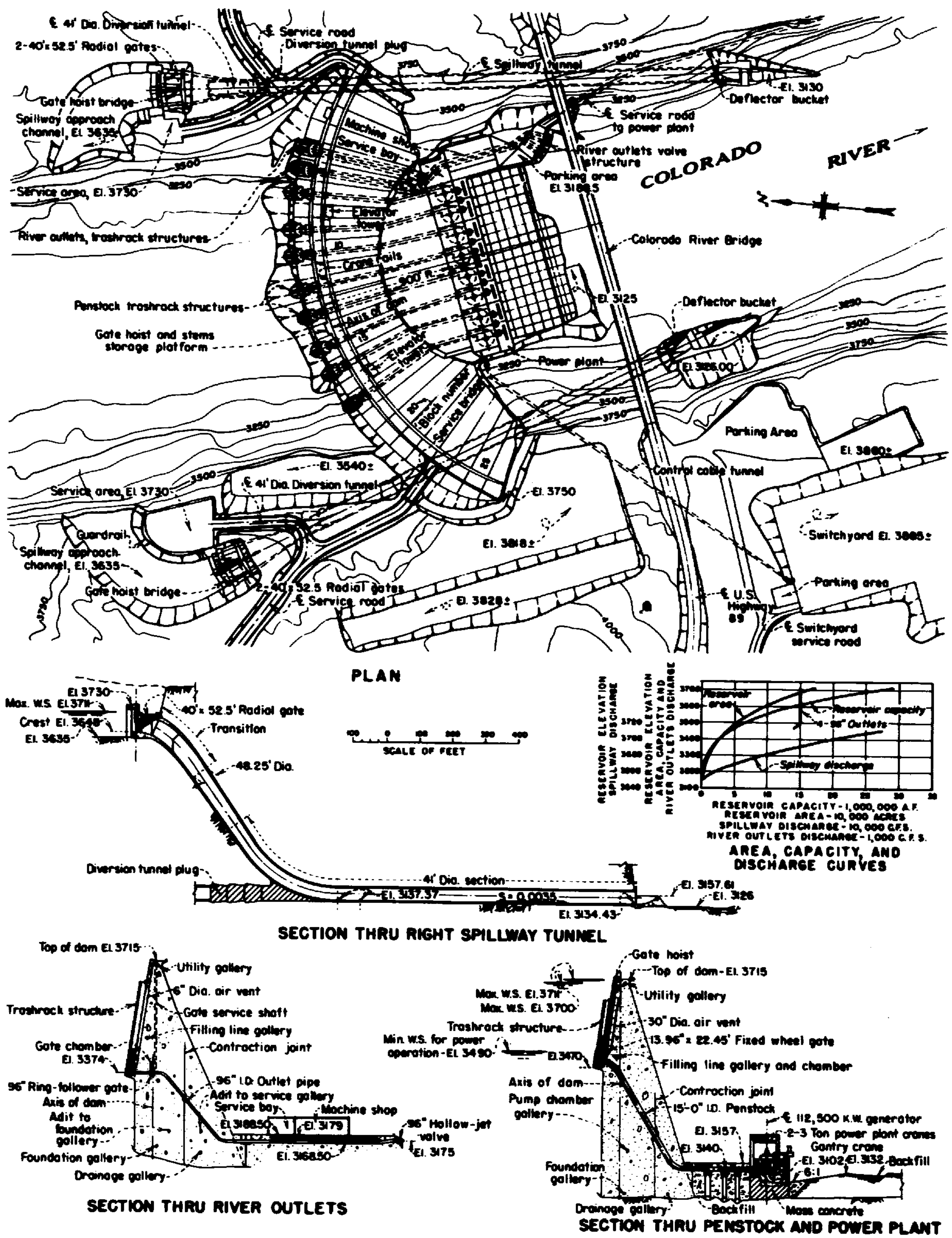
Since water releases from the Glen Canyon Powerplant are usually greater during the day than at night, boaters and campers along the river must take precautions to prevent boats from being grounded as the riverflows decrease.

Glen Canyon Dam and the CRSP (Colorado River Storage Project)

Glen Canyon Dam is the key storage unit in a far-reaching water development plan called the CRSP. The annual flow of the Colorado River is highly erratic, with spring floods that dry to a trickle in the summer and fall. When Glen Canyon was completed and Lake Powell was formed, the irregular flows were brought under control. The now steady flow from the dam and Lake Powell makes water developments possible throughout the Upper Colorado River Basin and provides a regulated supply of water to meet downstream commitments.

To help pay for the construction of Glen Canyon Dam and other Upper Basin water developments, hydroelectric power is produced at the powerplant located at the toe of the dam. At peak load, the powerplant generates more than 1 million kW of hydropower that is sold to public and private power companies.

Other storage units in the CRSP include Flaming Gorge in Utah; Navajo in New Mexico; as well as Blue Mesa, Crystal, and Morrow Point Dams in Colorado.



Glen Canyon Dam and Powerplant, Plan and Sections

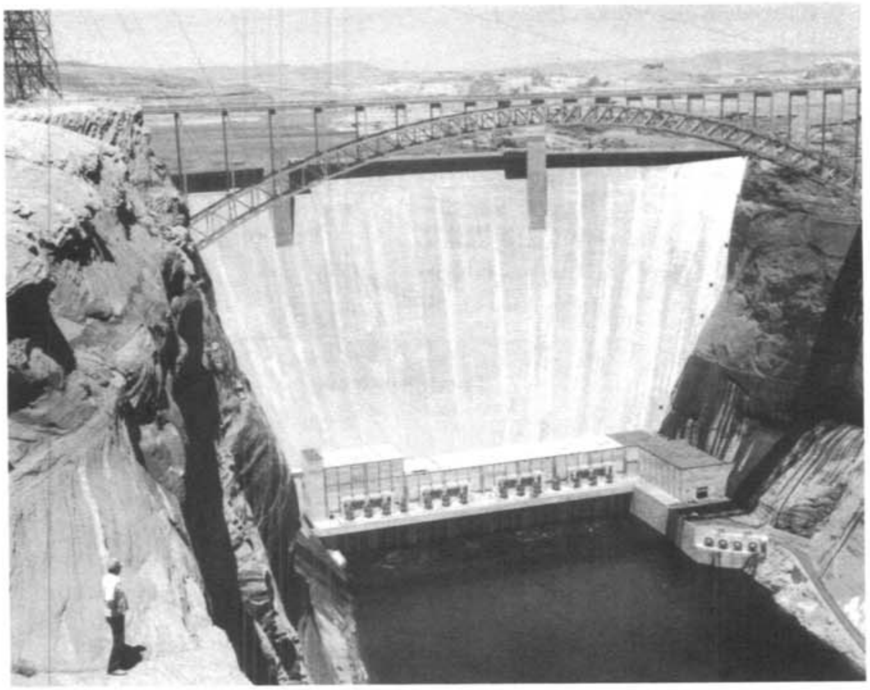


Photo 1. Glen Canyon Dam.

Aerial view looking up stream showing dam and bridge. 5/13/56

Photo 2. Glen Canyon Dam.

Aerial view looking north over town of Page, Arizona. 8/25/66

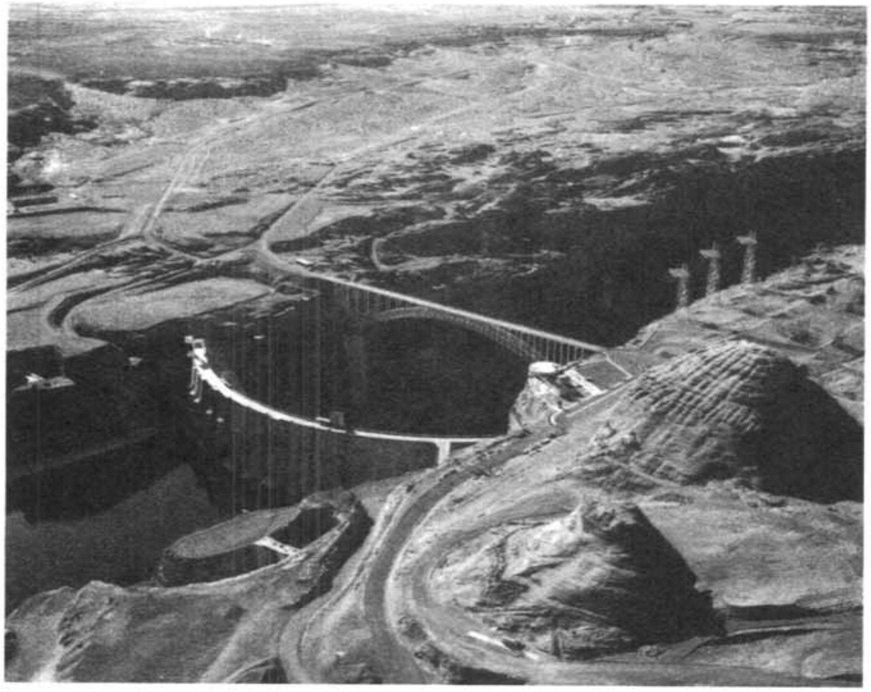


Photo 3. Glen Canyon Dam.

Aerial view showing dam and bridge. Vistors' Center is almost completed on rim of canyon. 5/7/67

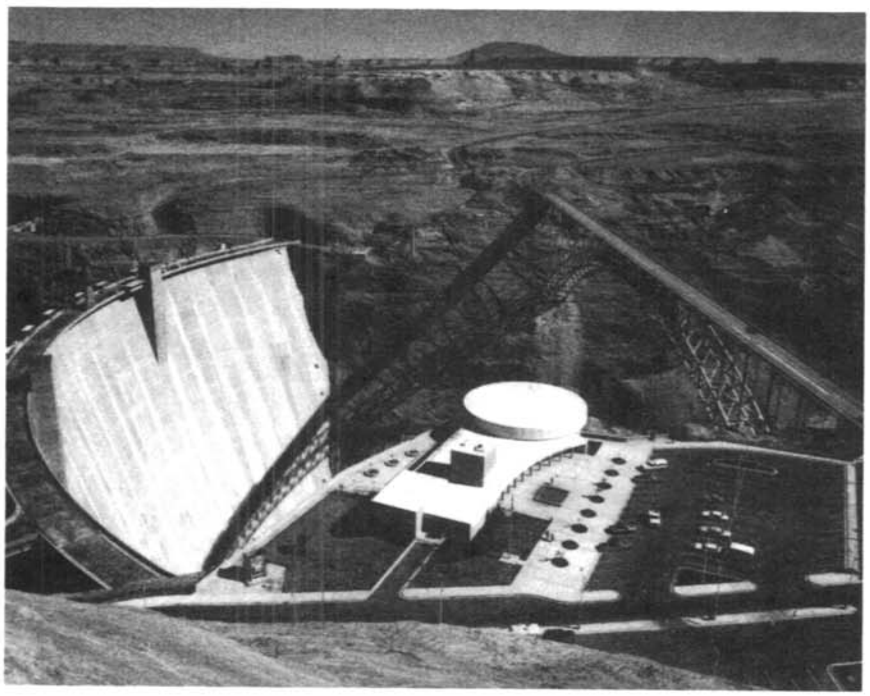


Photo 4. Glen Canyon Dam.

Aerial view of Visitors' Center. Dam and bridge in background. 10/29/70

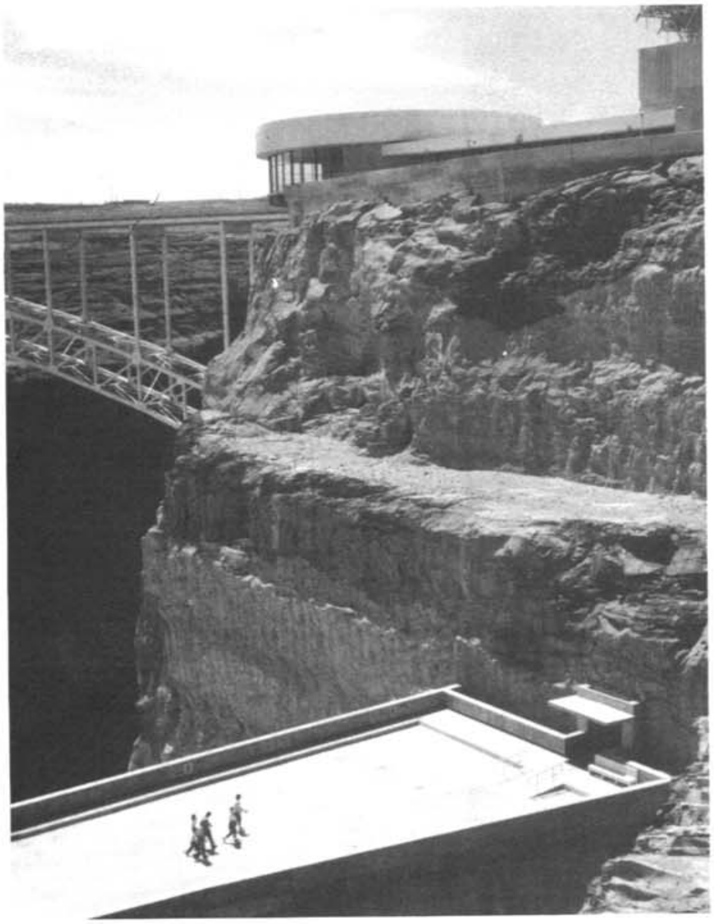


Photo 5. Glen Canyon Dam.

Aerial view showing visitors returning from tour of dam and powerplant. Approaching tunnel to the elevator which will take them 100 vertical feet to Visitors' Center at top of photo. 5/29/68

Photo 6. Glen Canyon Dam.

Aerial view looking downstream to dam, showing Lake Powell in foreground. 9/29/65

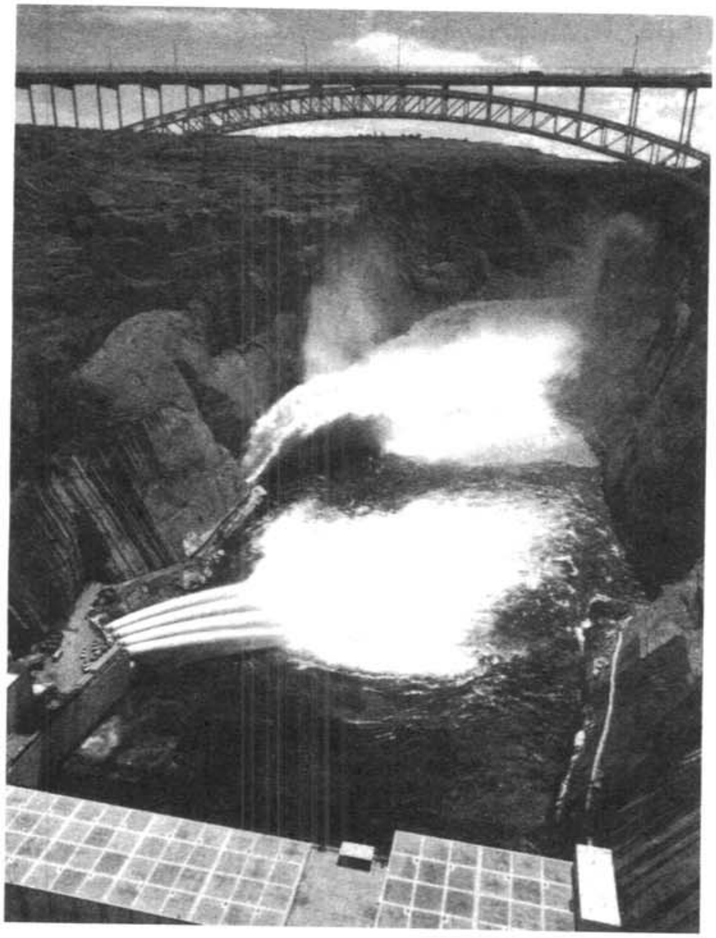


Photo 7. Glen Canyon Dam.

Aerial view of left spillway and hollow-jet valves in operation. 8/12/84

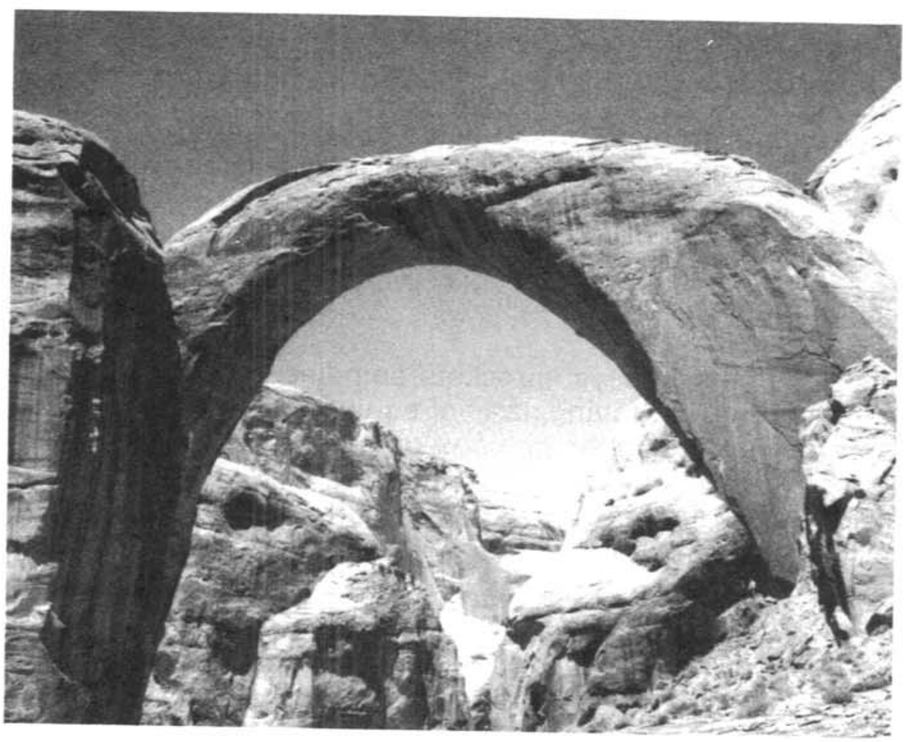


Photo 8. Rainbow Bridge.

A great natural stone arch at the foot of Navajo Mountain near Lake Powell in Utah. 5/8/65

POLICY FOR SAFETY RECOMMENDATIONS[1]

During RO&M (Review of Operation and Maintenance) Examinations

During RO&M reviews, the examiner should identify any safety-related deficiencies which could cause personal injury to operating personnel and/or the general public. Examples of such deficiencies include improper electrical wiring, broken handrails, and lack of protective screens over chain- or belt-driven motorized equipment. Depending on the severity of the safety concern, a category I or 2 recommendation should be issued and reported in the associated RO&M report.

Extracts from the Bureau's Construction Safety Standards are quoted below. These excerpts and the accompanying photographs are typical of safety deficiencies which should be reported.

Electric Wiring and Apparatus

12.1.1. "Code Requirement.–Electrical installations, temporary or permanent, shall comply with the applicable provisions of the National Electrical Safety Code, National Electric Code, and applicable State codes, unless otherwise provided by regulations or this section." This includes any exposed electrical wiring which is a code violation.

Wall Openings

15.2.1. "Requirement.–Wall openings, from which there is a drop of more than 4 feet and the bottom of the opening is less than 3 feet above the working surface, shall be guarded with a standard guardrail or guardrail components to afford protection to a height of 42 inches above the working surface. A standard toeboard shall be provided where the bottom of the wall opening is less than 4 inches above the working surface."

15.2.2. "Extension platforms.–Extension platforms, outside of wall openings, erected to provide access for materials, equipment, or personnel, shall be protected on exposed sides by a standard guardrail and toeboard." This includes broken or missing handrails, damaged walkways, etc.

Unscreened Reciprocating Equipment

19.14.2. "Guarding.–Belts, gears, shafts, pulleys, sprockets, spindles, drums, flywheels, chains, or other reciprocating, rotating, or moving parts of equipment shall be guarded or isolated in order that they do not endanger persons or property. Guarding shall comply with the standards set forth in the current edition of ANSI B15.1, 'Safety Standard for Mechanical Power Transmission Apparatus.'" This includes any unscreened motor-driven equipment operators whether part of the original design or a postconstruction modification.

[1] This policy for safety recommendations was developed to create a greater consciousness among examiners of facilities in operational status and to ensure any deficiencies which could cause injury or death to facility operators are corrected by the operating entity.

In addition to the above safety matters, the RO&M examiner will report instances of poor housekeeping since this can adversely affect the safe working environment of operating personnel. Facilities should have an overall appearance of orderliness and operating buildings and yards should be clean, neat, and free of strewn or discarded material, parts, or equipment.

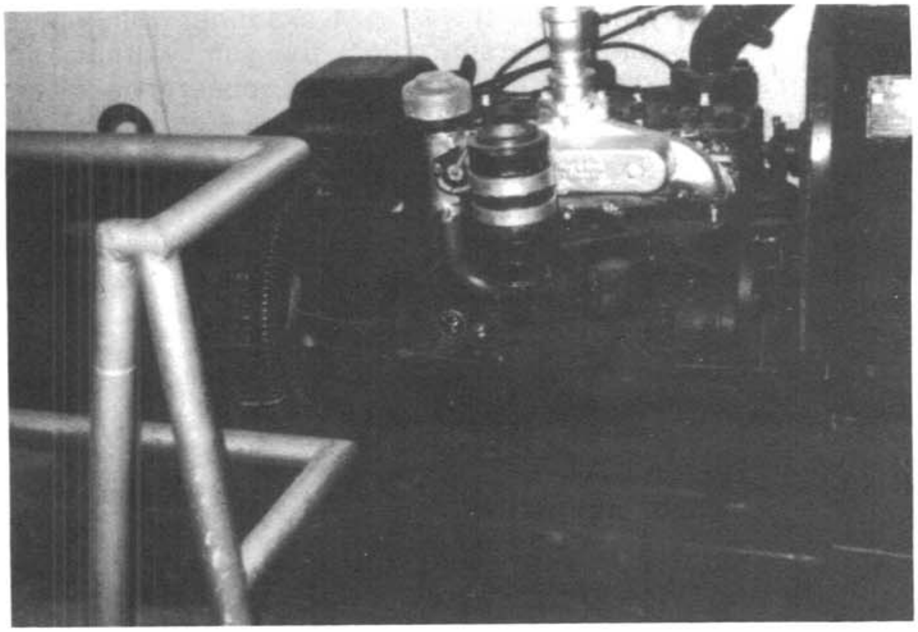


Photo 1. - Potential for gasoline fire or explosion. Carburetor is inoperable and replacement parts are no longer available. Gasoline is poured into engine in order to operate.

Photo 2. Potentially hazaardous intake tower. A safety buoy line should be installed to prevent swimmers and boaters from drifting into intake tower. A sign should also be posted warning recreationists of high-velocity flows.

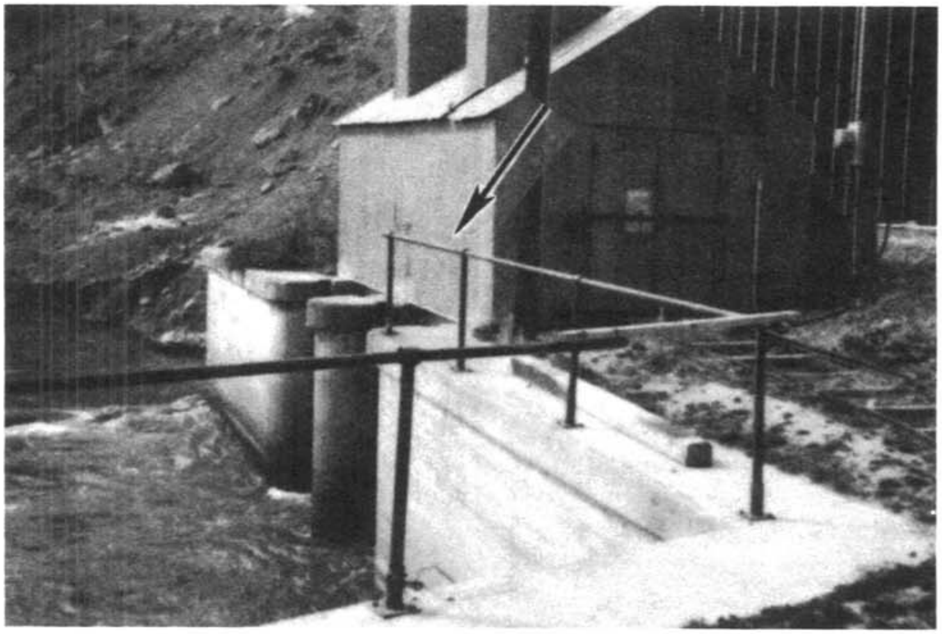


Photo 3. - Broken guardrail has been patched with a timber board and should be replaced with a pipe of original design. Also, the guardrail should be extended to the equipment house to prevent anyone from falling through the opening.

Photo 4. - Closeup view of above photo showing opening.

Photo 5. - Grab bars are needed to allow operating personnel to climb safely through the roof hatch.

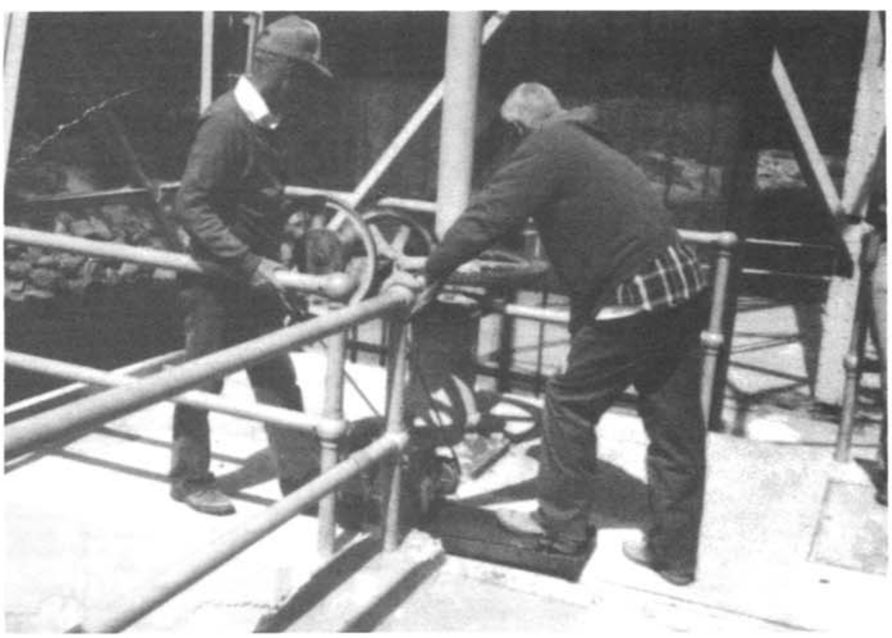


Photo 6. - Unscreened motor-driven gate operator. A rubber fan belt is connected between a 3-hp gasoline engine and a 14-inch-diameter pulley on the handcrank shaft. Tension in the belt is maintained by foot pressure against the engine base. The equipment should be screened because serious injury can result.

Photo 7. The safety screens around the motor-operated gears can protect operators from serious injury.

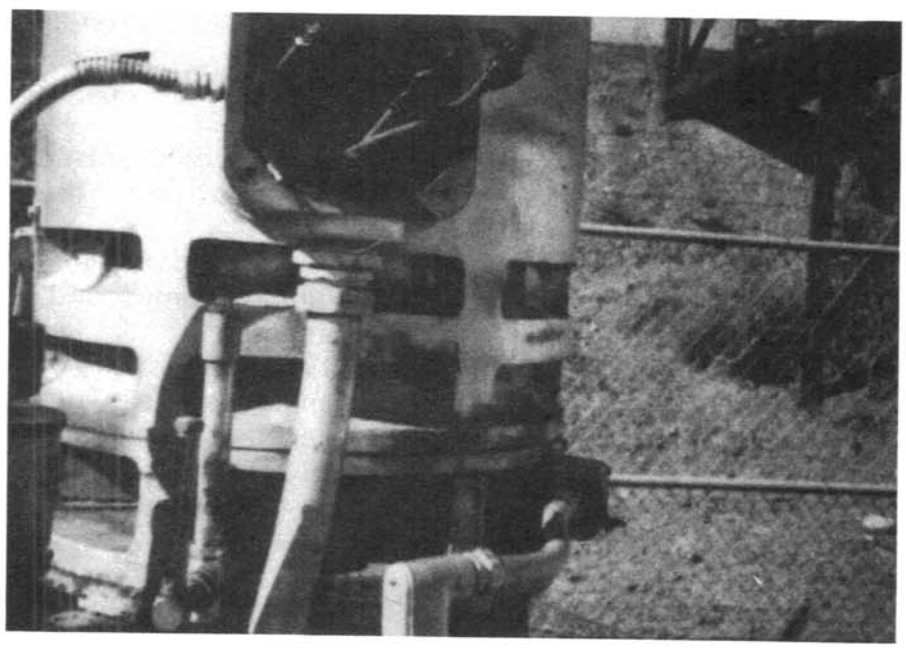


Photo 8. The missing faceplate should be replaced. Exposed electrical wiring on the motor junction box can cause serious injury to operating personnel.

CRITERIA[1] FOR THE REMOVAL OF TREES, OTHER VEGETATIVE GROWTH, AND RODENT BURROWS FROM EARTH DAMS, DIKES, AND CONVEYANCE FEATURES (1987)

Proper maintenance of dams, dikes, water conveyance features, and appurtenant structures requires the periodic removal of all undesirable vegetation within a defined area around these features. If not removed, the effect of this growth may be detrimental to the safe operation of the features and can also lead to structural failure. Properly maintained natural or planted grass cover on or about these structures is the exception to the above.

Tree growth on or near embankment dams, dikes, and water conveyance structures is undesirable. Uprooted or decaying trees may lead to the establishment of voids, shortened seepage paths, a weakness in the embankment, and/or damage to nearby structures. Mature trees on or near these structures also provide seed stock that can result in establishment of new growth as well as create a continuous maintenance problem.

Other than the natural or planted grasses, shallow-rooted chaparrals should also be removed because they can inhibit proper examination and monitoring of conditions such as seepage, settlement, cracking, etc. This vegetation may also encourage rodent activity by providing a food source for the burrowing animals as well as shelter against predators. These animals can also detrimentally affect embankment dams and other structures by burrowing and intercepting the phreatic surface in these dams and structures.

The following criteria are to be used for all Bureau embankment dams and major diversion dams, dikes, conveyance features, and appurtenant structures (refer to the attached sketch and photos).

1. All trees and other deep-rooted growth, including stumps and associated root systems, are to be removed from earth dam embankments and dikes. Upstream and downstream groin areas are to be free of trees and other woody growth within 25 feet beyond each contact for conifers[2] and 50 feet for deciduous trees. The old root systems should be removed and the excavated volume replaced and compacted with material similar in character to the surrounding area to prevent the development of piping action. Seedlings are to be removed at the first opportunity to minimuze future maintenance, expense, and damage to the embankment.

2. Except for grass cover, unlined spillway inlet and outlet channels are to be free of vegetation which may significantly impede waterflow. Similarly, and to prevent damage to concrete sidewalls and floors, or riprap sideslopes, woody growth is to be removed within 25 feet of the outside edge of these structures for conifers and 50 feet for deciduous.

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[1] These criteria were developed by the Bureau's water operations staff and supersedes the vegetative growth removal guidelines published in Water Operation and Maintenance Bulletin No. 131. The revised criteria established clear zones to better view changing conditions at Bureau dams, dikes, and conveyance features.

[2] Conifers are cone-bearing evergreen trees or shrubs which include pines, firs, and spruce. Deciduous trees and shrubs are those which shed their leaves annually.

3. Properly maintained grass cover is acceptable on the downstream face of dams and dikes to prevent erosion damage, control weeds, and to enable the structure to be routinely examined and monitored.

4. For open canals, laterals, drains, and other minor facilities, the above criteria apply except that the minimum distance from the outside edge of the prism should be 15 feet for conifers and 30 feet for deciduous. For embankments supporting these structures, the 15- and 30-foot distances shall be measured from the toe of the fill.

5. To provide access and prevent root encroachment in pressure conduit conveyance systems, the clearance distance should be 15 feet from the outside edges of the pipeline for conifers and 30 feet for deciduous.

6. Burrowing rodents are to be prevented from establishing habitats in and around facilities in accordance with the above clearance distances. Associated rodent burrows are to be backfilled and compacted with material similar to that of the surrounding area to prevent the development of piping action.

As discussed above, the removal of trees and brush on or near structures is necessary to prevent deterioration and allow proper surveillance. However, excavations into or near these structures can be hazardous in some situations. Because of this danger, such removal must be carefully planned and executed, and should be approved by an engineer experienced in the design and construction of the pertinent structure.

The above minimum distances should be increased if suspected or known problems exist at the facility. This increase applies to groin areas, slope cuts, abutments, fills, areas upstream or downstream from a dam, and elsewhere as appropriate. As an example, a damp or ponded area 120 feet below the toe of a dam that is partially concealed by vegetation should be examined and, as necessary, cleared of vegetation to permit surveillance of the area, construction of drains and monitoring equipment (piezometers, weirs, etc.), or access to the area.

These criteria apply to concrete dams as well; however, variances may apply due to geologic conditions, topography such as steepness of abutments, and other factors.

The above criteria may need to be modified for specific instances in which rights-of-way, the National Environmental Protection Act, the presence of endangered species, landscaping, or other constraints exist. However, it is the responsibility of the examiner to make recommendations enforcing the above criteria; and then, the appropriate administering office will determine if these constraints apply and the extent to which the recommendation(s) can be completed.

The following sketch and photographs illustrate these criteria. Also included is a summary of vegetation root systems which were the basis for establishment of the clearance distances. Your attention is called to the radial extent of root growth of cottonwoods and the need to increase the above clearance distances for mature trees of this type.

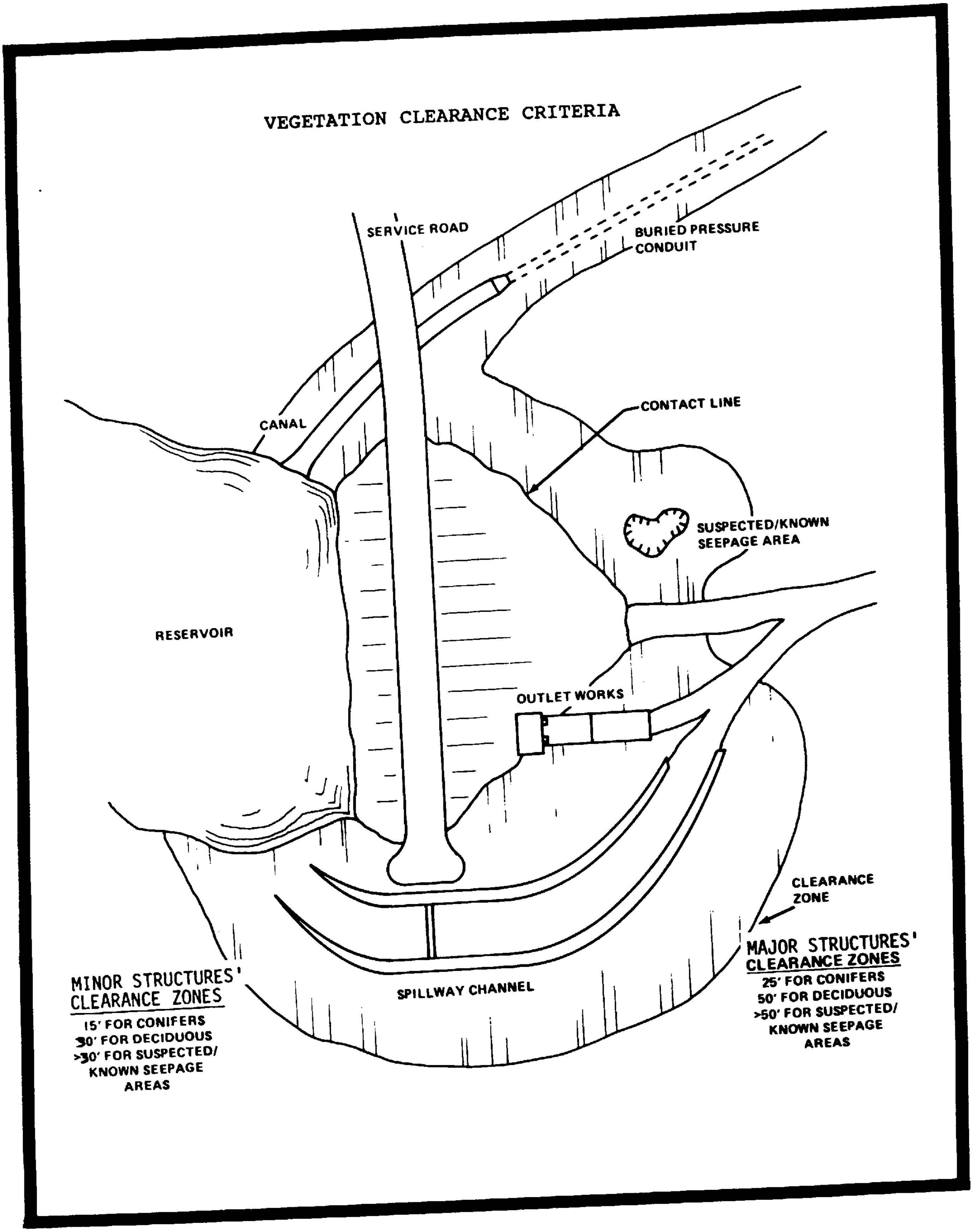
VEGETATION CLEARANCE CRITERIA
SERVICE ROAD
BURIED PRESSURE CONDUIT
CANAL
CONTACT LINE
SUSPECTED/KNOWN SEEPAGE AREA
RESERVOIR
OUTLET WORKS
CLEARANCE ZONE
MAJOR STRUCTURES' CLEARANCE ZONES
25' FOR CONIFERS
50' FOR DECIDUOUS
>50' FOR SUSPECTED/ KNOWN SEEPAGE AREAS
MINOR STRUCTURES' CLEARANCE ZONES
15' FOR CONIFERS
30' FOR DECIDUOUS
>30' FOR SUSPECTED/ KNOWN SEEPAGE AREAS
SPILLWAY CHANNEL

Photo 1. - The dense conifer stand has been allowed to grow in the lower end of an unlined spillway and will adversely affect and impede flood flows.

Photo 2. - Conifers and deciduous trees are established in a large area immediately upstream of the dam (arrow) and need to be removed to permit surveillance of any problems such as reservoir seepage which is known to exist.

Photo 3. - Conifers have established themselves in the seepage area to the right of the valve house (arrow). They should be removed because they are partially concealing the seepage area and any evidence of adverse changes that may occur.

Photo 4. - The vegetation clearance zone and natural grasses on the embankment satisfy the criteria.

Photo 5. - The mature conifers (arrows) can provide seed stock for the emerging juvenile conifers located on the abutment contact.

Photo 6. - Apron downstream of the toe of the embankment. The conifers on the apron are masking the stilling basin and any evidence of problems that may exist in these areas.

Photo 7. - The soil around the root system of the mature conifer (arrow) has been eroded by fluctuating reservoir levels and wave action. This conifer needs to be removed because it can fall and destroy the access bridge or equipment on the intake tower.

Photo 8. - Exposed root system of conifer in above photo.

Photo 9. - The chaparral-type growth on the outside slope of the canal fill is concealing exit points of subsurface seepage channels. Material eroded from the fill has been deposited at the toe of this slope (arrow).

Photo 10. - Conifers have established themselves on the downstream face of this saddle dike and can conceal evidence of any problems in this area.

Photo 11. - Mature conifers have established themselves on both the upstream and downstream faces of this low saddle dam. Surveillance of rodent habitats and structural problems is difficult to perform.

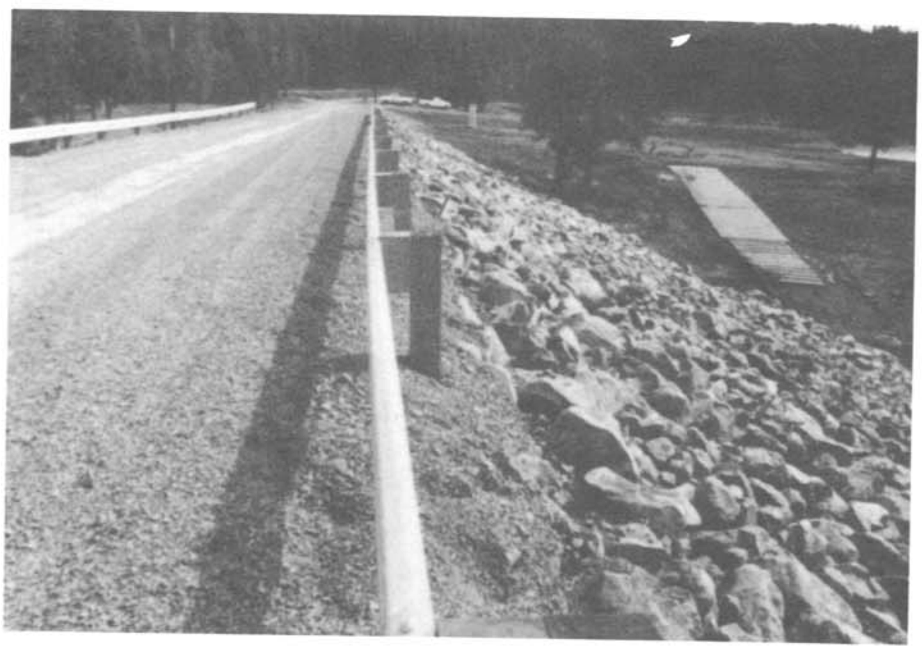

Photo 12. - The two conifers near the right upstream abutment can provide annual seed stock for more conifers and result in the spread of undesirable growth in this area.

ROOT CHARACTERISTICS OF COMMON WOODY VEGETATION IN THE WESTERN UNITED STATES

ROOT SYSTEMS - TREES

Basic Information:

Generally speaking, trees throughout the world do not have well-defined taproot systems. Their root systems are shallow. The depth of the roots is influenced by the their location and conditions present (light, oxygen within the soil, soil type, tree age, abundance or lack of moisture in the environment, etc.). As a rule of thumb, the major roots (greater than 1-inch diameter) are located within 2 to 3 feet of the surface.

Martin H. Zimmermann and Claud L. Brown in their book, Trees–Structure and Function (pp. 55-56), do an excellent job in summarizing the form and extent of roots:

> "Many woody plants possess a characteristic pattern of root development even if grown under different environmental conditions. Inherent differences in patterns of root development are especially noticeable during early seedling growth; but root systems often become greatly modified in later years by environmental influences such as soil texture, water availability, and overall nutrition. For these reasons the depth and extent of lateral roots is highly variable even within the same species. Contrary to what many laymen believe, the bulk of the root system of most trees growing on medium textured soils (loams and clay-loams) is within 3 feet of the surface. The majority of the smaller absorbing roots lie in the upper 6 inches of the forest soil. Density of spacing or competition among individual trees has a pronounced effect on the extension of lateral roots; therefore, generalized statements on the extent of lateral root development have little meaning. In open-grown trees, it is common to find lateral roots extending out 2 to 3 times beyond the radius of the crown, although the majority of the absorbing roots may lie within the area circumscribed by the periphery of the crown. More specific data on the form and extent of root systems in trees are found in Kramer and Kozlowski (1960), Toumey (1929), and Busgen and Munch (1929)."

Spruce: This tree has an extremely shallow root system. The width of the lateral radial spread of the roots can be as much as the height of the tree.

Ponderosa: The taproot, although not well defined, may reach 8 to 10 feet deep. (This would be an extremely large tree to have roots this deep.) The width of the lateral radial spread of the roots can be as much as the height of the tree and beyond.

Lodgepole: The taproot, although not well defined, may reach 10 feet deep. (Again, this would be an extremely large tree to have roots this deep.) The width of the lateral roots may be as much as the height of the tree and beyond.

Englemann Spruce - Subalpine Fir: Both these root systems are shallow and spreading. Tree growth is extremely slow.

Aspen: Fairly shallow root system - no taproot. Aspen can reproduce by root suckers or seedlings. Aspens do not like to grow in areas where the soil has been disturbed.

Cottonwood: Cottonwoods do not have a taproot but do have sinker roots which are similar to taproots. Sinker roots are roots that extend straight down from a lateral root and usually follow a crack in the ground. These roots may extend 3 or 4 feet in depth. Their major function is water and food storage as are the taproots. Lateral roots nearly always extend past the width of the limbs and can easily extend for 150 feet or more. This tree is extremely sensitive to even minor water drawdown.

Russian Olive: Russian Olive trees have a shallow root system and their lateral spread is usually 3 to 4 feet or more beyond their limb width.

Willow: Willows do not have a large taproot although sinker roots can be quite deep (6 to 8 feet deep).

Chinese Elm: Chinese Elms may have roots that extend 4 feet down into the ground. The lateral width of their roots usually extends well beyond the width of their limbs.

ROOT SYSTEMS - BUSHES

Sagebrush: Average size sagebrush generally has a taproot 4 to 6 feet deep. Larger sagebrush may have taproots 15 feet deep with lateral roots 10 to 16 feet long.

Fourwing Saltbush: Taproots up to 20 feet deep.

CONTACTS:

Information obtained from the offices of the U.S. Forest Service, the Bureau of Land Management, and the Denver City Forester, Denver, Colorado; Colorado State University Horticulture Department, and the Rocky Mountain Station, Fort Collins, Colorado.

CASE STUDY

LEMON DAM–CONCRETE SPILLWAY INLET WALL FAILURE

Dam:	Lemon
Project:	Florida
State:	Colorado
Type:	Zoned earthfill
Completed:	1963
Functions:	Irrigation, flood control, recreation
Crest length:	1,360 feet
Hydraulic height:	215 feet
Active capacity:	39,030 acre-feet
Surface area:	622 feet

Design Characteristics: Lemon Dam is a zoned earthfill structure with a structural height of 284 feet and a crest length of 1,360 feet. The spillway is on the right abutment of the dam and consists of an approach channel, concrete inlet structure, concrete ogee crest section, open concrete chute, concrete stilling basin, and outlet channel discharging into the Florida River.

Evidence: The first sign of a problem with the spillway concrete wall was in July 1966, when minor deflections were noted. Additional deflection occurred during the winter of 1966-1967. During the winter of 1971, an additional I to 1-1/2 inches of deflection occurred, with the total deflection now being 4-1/2 inches on the right wall and 5-1/2 inches on the left wall. Some rupturing was also noted at the base of the right inlet wall. During April 1973, at the request of the Acting Regional Director, the Director of Design and Construction at the E&R Center conducted a special examination of the spillway entrance walls. Total deflections had now reached up to 12 inches, and repair was recommended within the year.

Incident: Beginning in 1966, progressive deflections were noted in both concrete spillway inlet walls. By 1973, deflections as much as 12 inches were apparent; and on May 14, 1973, the left wall failed and fell into the spillway. The incident did not cause any operational problems.

Causes: Lemon Dam receives significant snowfall and experiences large variations in surrounding temperatures with extremely low temperatures. In 1967, it was believed that due to the temperature variations, surface water was entering between the concrete walls and the backfill; and subsequent freezing action was causing the walls to deflect.

Upon examination of the exposed reinforcement at the base of the wall stems during the reconstruction, it was discovered that only one-third of the required face wall movement reinforcement extended into the footings. In addition, for the left face wall that had overturned, only stubs of moment reinforcing bars protruded above the footing, and only two or three of these showed the characteristics of tension failure. It appeared that most of the bars did not extend continuously into the face wall, and two-thirds of the bars did not extend into the wall footing. Lack of proper reinforcement was probably the major cause of the failure of the spillway entrance walls.

Remedy: Since it was determined the deflections were caused by freezing action in the impervious soil blanket behind the concrete walls, a portion of the backfill was excavated and a pervious blanket of soil was placed beneath a layer of impervious soil. Several pipe drains extending to the base of the wall penetrated the pervious backfill. Insulation board, 1-1/2 inches thick, was placed between the back face of the walls and the pervious backfill. Seepage wells to collect the pipe drainage and heaters were installed at the base of the walls to allow drains to operate through the winter months. The curved inlet walls were replaced with adequate reinforcement anchoring the walls to the footings.

Conclusion: Although above-normal runoff was expected when the wall failed in 1973, sufficient storage capacity and outlet works capacity existed to avoid using the spillway. Both inlet walls were replaced and no major interruption of service was experienced. The replacement walls have experienced no problems.

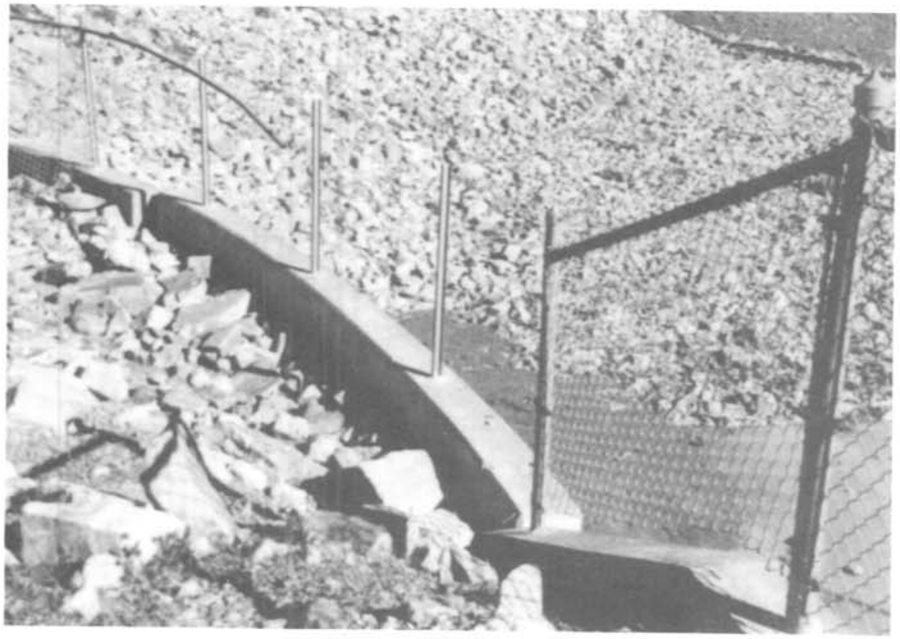

Photo No. 1. - Lemon Dam

Right wall of spillway approach channel. Deflection of the wall damaged the fence.

9/17/73

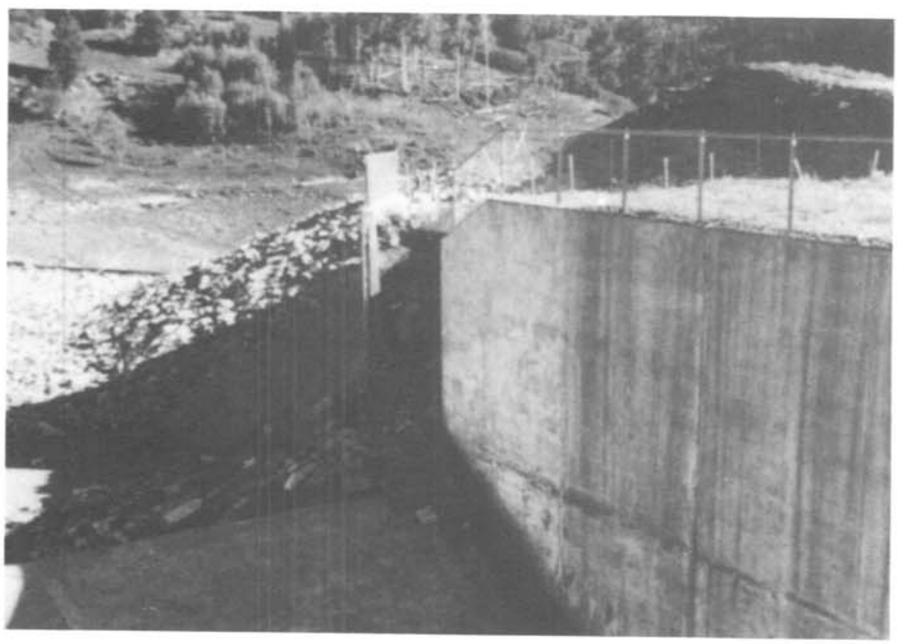

Photo No. 2. - Lemon Dam

Left wall of spillway approach channel. Failure was result of repeated cycles of frost action on saturated fill.

9/17/73