WATER OPERATION AND MAINTENANCE

BULLETIN NO. 141

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IN THIS ISSUE

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The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging operation and maintenance information. It is hoped that the reports herein concerning laborsaving devices and less costly equipment and procedures will result in improved efficiency and reduced costs of the systems for those operators adapting these ideas to their needs.

To assure proper recognition of those individuals whose suggestions are published in the bulletins, the suggestion number as well as the person's name is given. All Bureau offices are reminded to notify their Suggestions Award Committee when a suggestion is adopted.

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Division of Water and
Land Technical Services
Engineering and Research Center
P O Box 25007
Denver CO 80225

Cover photograph:

Aerial view of Owyhee Dam, southwest of Adrian, Oregon. Owyhee Project is the subject of our "Spotlight" this issue.

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THE INTEGRATED APPROACH TO AQUATIC AND DITCHBANK WEED CONTROL

By John C. Pringle*

INTRODUCTION

Management of undesirable vegetation on Federal lands and waterways is a formidable task with ever increasing problems. This is due to a combination of rising expectations and increasing disturbance of the ecosystem, including introduction of exotic plant species. Aquatic and ditchbank weeds in and on water storage, conveyance, and distribution systems are a threat to irrigated agriculture and to other essential water uses, including municipal and industrial water supplies, water-based recreation, and fish and wildlife habitats.

Irrigated agriculture is almost totally dependent on an adequate, high-quality, and timely supply of water for crop and livestock production and for the entire food, feed, and fiber production system in arid regions. If aquatic weeds are not controlled, they damage water conveyance and storage systems, prevent timely delivery of water, and reduce the supply and quality of water leading to reduced agricultural production efficiency.

INTEGRATED WEED MANAGEMENT SYSTEMS

With increased restriction on traditional aquatic weed control methods, IWMS (Integrated Weed Management Systems) is receiving greater emphasis. An integrated weed management system is a planned attempt to maintain growth of undesirable vegetation at acceptable levels. Such systems emphasize a balanced and combined use of all appropriate control methods to minimize adverse effects on the environment. The integration of various weed control strategies is already a reality on many aquatic sites but the majority of such strategies employ herbicides. Because of the formidable costs of providing data required to register aquatic herbicides and ever increasing environmental concerns, new products are very rare. Many long-established materials, such as 2,4-D, are coming under increased scrutiny and may not be available for aquatic site weed control much longer. Therefore, future aquatic site managers will be ever more dependent on alternative control methods, including biological, mechanical, ecological, and physiological methods, integrated to achieve the desired objectives.

MAJOR WEED PROBLEMS ON FEDERAL AQUATIC SITES

The major problem aquatic weeds have been categorized into traditional ecological classifications as follows:

a. *Floating aquatic weeds (general distribution).–*

Alligatorweed (in both floating and emersed categories)
Duckweed
Waterhyacinth

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* John C. Pringle is Supervisory Coordinator of the Aquatic Site Pest Management Research Group, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

b. *Emersed and marginal aquatic weeds.*–

Alligatorweed	Pickerelweed
Arrowhead	Sedges
Bulrushes	Smartweed
Cattails	Spatterdock
Common reed	Waterprimrose
Lotus	Willow
Perennial grasses	White waterlily

c. *Submersed aquatic weeds.*–

Benthic & filamentous algae	Elodea
Bladderwort	Fanwort
Chara	Hydrilla
Coontail	Naiad
	Watermilfoil

PRESENT FEDERALLY FUNDED RESEARCH ON IWMS FOR AQUATIC WEEDS

Federally funded research on aquatic weeds is primarily conducted by the Bureau of Reclamation, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, the Tennessee Valley Authority, and the U.S. Fish and Wildlife Service. In-house and extramural research is sponsored by these agencies. The Department of Agriculture is primarily responsible for basic research while the Bureau, the Corps of Engineers, and the Tennessee Valley Authority are more applied in their research approach. The Fish and Wildlife Service is involved primarily in studying effects of weed control practices on fishery resources. Major areas of research, target weeds, and the objectives of this research are as follows:

a. *Chemical control.*–Target weeds are floating aquatic weeds, pondweeds, watermilfoil, hydrilla, elodea, and algae. The objectives are (1) to study the uptake and movement of herbicides through the plant; (2) to determine the fate of herbicides related to their dissipation, degradation, and accumulation in the aquatic ecosystem; (3) to develop new and more efficient methods of applying herbicides to water; (4) to investigate new methods for formulating herbicides, especially controlled release granules; and (5) to evaluate new herbicides for their potential as aquatic weed killers. Potential benefits of this research include development of new, more effective and safer aquatic herbicides and more efficient use of present herbicides. The newest, fully Environmental Protection Agency-registered product for aquatic use, is Elanco Chemical Company's Fluridone marketed under the trade name "Sonar."

b. *Biological control.*–Included in this category are insects, plant pathogens, herbivorous fish, and competitive plants. Target weeds are waterhyacinth, alligatorweed, eurasian watermilfoil, hydrilla, pondweeds, and filamentous algae. The major objectives are (1) to develop methods for implementation and utilization of natural enemies of aquatic weeds, (2) to conduct surveys to identify organisms with potential value as biocontrol agents for aquatic weeds, and (3) to investigate the mode of action, environmental requirements, and the impact of introduced natural enemies of aquatic weeds on the aquatic environment. The Corps of Engineers' Aquatic Plant Control

Research Program has conducted extensive overseas searches for natural enemies of waterhyacinth, alligatorweed, and hydrilla. Their searches have taken them to Africa, India, Australia, Pakistan, Panama, and South America. They are also working with genetically engineered microorganisms where gene splicing is used to custom design an organism capable of controlling a noxious aquatic plant. Before exotic organisms may be released in the United States, an Environmental Assessment must be filed with the Environmental Protection Agency.

Considerable research has been conducted on the use of herbivorous fish, specifically the grass carp to control algae and vascular weeds. The Bureau of Reclamation, in cooperation with the California Department of Food and Agriculture and the Imperial Irrigation District in Imperial, California, has developed a program for utilizing sterile grass carp to eliminate hydrilla in the All-American Canal system. This program moved from experimental phase to full-scale implementation in only 7 years - a very rapid response to a serious problem. A 3-year Bureau study to evaluate grass carp use for weed control in a cold water Colorado irrigation canal has recently been completed, and the fish have again proven themselves to be an effective management tool. There is still some bias against introduction of non-native herbivorous fish because of possible detrimental effects on native fisheries. However, development of the sterile grass carp will likely eliminate much of the objection.

One of the most notable competitive plants is spikerush. This plant has been shown to eliminate stands of larger and more troublesome species of vascular aquatic weeds through competition and chemical interaction. The Bureau is currently evaluating spikerush for dust abatement and erosion control in reservoir drawdown areas.

c. *Mechanical control.*-Target weeds for mechanical control are hydrilla, pondweeds, elodea, watermilfoil, filamentous algae, and floating weeds such as waterhyacinth. Objectives are to determine the optimum time for harvest and to determine whether the products of the harvest can be developed into something useful for livestock feed, mulch, or other beneficial substances. Mechanical methods for aquatic weed control were used before herbicides became commonly available. In some aquatic sites, mechanical methods are still the only acceptable means of control. Optimum time of removal may reduce the rate of plant regrowth or stress the plants to inhibit the development of reproductive structures and thereby reduce later weed infestations.

d. *Control through recognition of nutritional and ecological requirements.*-Target weeds are all aquatic vascular plants that are pests. The major objectives of this type of study are (1) to investigate environmental stress factors as related to the growth and development of aquatic weeds, (2) to learn why and how weed problems occur, (3) to study ecological relationships among aquatic plants in mixed communities, and (4) to determine relationships between environmental factors and the control of aquatic weeds. Research of this type, which is being conducted with close coordination by the Bureau, the Corps of Engineers, and the Department of Agriculture, is useful not only in developing control strategies but in predicting where problem aquatic weed stands are likely to develop.

e. *Control related to aquatic plant physiology.*-Target weeds are pondweeds, hydrilla, watermilfoil, filamentous algae, and alligatorweed. The objectives of this type of research are (1) to determine interrelationships of weed control and vegetative reproduction, (2) to determine environmental influences on development of reproductive structures, and (3) to study the role of natural plant growth regulators in controlling production of reproductive structures. The Bureau and the Department of Agriculture are currently conducting this type of research.

TECHNICAL CONSTRAINTS TO THE USE OF IWMS ON AQUATIC SITES

One of the major constraints to the use of IWMS on Federal aquatic sites is the multiple use of the water and the conflict generated by those varying interests. When water is being used for recreation, for irrigation, and for domestic home uses, the aquatic site manager must be very cautious about treatments applied to control weeds. A treatment suitable when water is used for fishing might preclude use of the water for livestock.

Another constraint that has caused problems in the registration and regulation of aquatic weed control systems is the lack of techniques for comprehensively monitoring effects of control methods on the myriad non-target organisms that exist in complex aquatic ecosystems. Model ecosystems that are reliable for predictive purposes must be developed for determining the effects of various aquatic weed control techniques.

One constraint to the use of mechanical methods of weed control is the difficulty in developing economical uses of products from harvesting aquatic weeds. In general, in order for these products to be profitable, the aquatic weeds will have to be managed much like terrestrial crops and maximum productivity encouraged. This approach is counter to the need to keep aquatic weeds under control in aquatic sites. As energy costs accelerate; however, the use of any and all biomass for energy could become an important consideration in the management of all vegetation, terrestrial and aquatic.

COATINGS PERFORMANCE

John S. Baker*

A study was undertaken to gather and evaluate information on the actual performance of Bureau coatings. Rapid changes have taken place in the coatings field, many of them accelerated by environmental and safety regulations at Federal, State, and local Government levels.

The most durable coating which the Bureau is currently specifying is coal-tar enamel. It is the only coating which, when properly specified and applied, and properly maintained, has a proven capability of giving 50 years or more of satisfactory service. The expression "properly specified and applied, and properly maintained" is a necessary qualifier in evaluating <u>any</u> coating system. Environmental, safety, and application considerations have caused the usage of this coating to decline in recent years. It is believed by some people in the coatings industry that the usage of coatings containing coal-tar may be banned at some point in the future.

Coal-tar epoxy is used in much the same kind of applications as is coal-tar enamel. It has not been in actual service long enough to determine its useful life span. At present, based on this study and other observations, a useful life span in excess of 10 years can be reasonably predicted for this coating system. It is expected that this system may perform as well as the coal-tar enamel in many applications.

The Bureau's VR-3 and VR-6 vinyl systems have become "standards" of the coatings industry. They are, however, more sensitive to surface preparation and applications conditions and techniques than are some other coatings. An expected useful life span in excess of 30 years has been reported for the vinyl coatings in some applications. There have also been other instances where the conditions of applications were not correct for these types of coatings, and the useful life was limited to 6 years.

Performance of the alkyd coatings, both conventional and silicone modified, has been up to expected levels for these types of coatings. They are exhibiting useful service lives of 5 to 15 years or more. The broad variations in durability exhibited by alkyds are due to differences in severity of exposure, surface preparation, and application.

CA-50 coal-tar cutback coatings have exhibited wide ranges of durability. Where they have failed, the failures have been more spectacular than those of most competing coatings. For example, they may come off in "sheets" in some areas. This coating is no longer specified by the Bureau, although it was once widely used and has been very successful in some applications. It is likely that this coating will be seldom, if at all, used in the future because of the same factors mentioned in connection with coal-tar enamel.

Red lead primers, either as a base for other coatings or as complete multicoat systems, have given very satisfactory service in Bureau applications. In varied atmospheric exposures, TT-P-86G, type IV, red lead primer topcoated with phenolic aluminum, has

* John S. Baker is a Materials Engineer for the Bureau of Reclamation at the Engineering and Research Center, Denver, Colorado.

proven to be a very reliable coating system. Acceptable protection of metal structures for as long as 40 years has been achieved in some applications of this coating system. Environmental and safety considerations have forced plans to be made to eliminate TT-P-86G, type IV, red lead primer. It is scheduled to disappear from Bureau specifications as soon as laboratory investigations, now in progress, are completed and specifications for a lead- and chromate-free primer can be made available. Phenolic and other aluminum coatings will continue to be available. Environmental considerations (their visual appearance) have caused their usage to decline in recent years.

The following table shows the commonly used Bureau coatings and their possible replacement or alternative coatings.

Commonly used Bureau coatings and their possible replacement or alternative coatings

Item	Present coating column 1	Advantages column 2	Disadvantages column 3	Repl. or alt. coatings column 4	Advantages column 5	Disadvantages column 6
1	Coal-tar enamel	Proven exceptionally long, useful life span.	Acute health and safety problems and must be hot applied. Specialized application technique required.	Coal-tar epoxy.	Fewer acute health and safety problems, cold applied, although 2-package materials.	Relatively long curing times, mandatory short maximum recoating times, cannot be applied at low temperatures (below 50 °F).
2	Coal-tar epoxy	Bureau has had reasonably satisfactory experience with this coating.	See column 6, item 1.	Hi-solids, 100% solids, or faster curing epoxies.	Shorter downtimes, and longer critical recoating times with many of these types. No solvent problems with 100% types.	Lack of extensive Bureau experience with these types of coatings. Special application equipment may be required. Low temperature limitations.
3	Coal-tar enamel and Coal-tar epoxy	See column 2, items 1 and 2.	See column 3, items 1 and 2.	Elastomeric coatings, Hi-solids and 100% solids.	Same as column 5, items 1 and 2, plus high dry film thicknesses and good abrasion and erosion resistance. No solvent problems with 100% types. Aliphatic polyurethane types weather well.	Same as column 6, item 2, plus possible potential of "sheeting" off if adhesion is lost. Aromatic polyurethane types do not weather well.
4	VR-3 and VR-6 Vinyls	Equally suitable for immersion or atomospheric exposure, long useful life span with good surface preparation and application. May be applied under <u>relatively</u> low temperature conditions.	Multiple coats required (labor intensive), sensitive to surface preparation and application conditions.	Conventional epoxies	Fewer coats required (less labor intensive), slightly less sensitive to surface preparation and application conditions, and shorter downtimes.	Chalk when exposed to sunlight, and cannot be applied at low temperatures (below approximately 50 °F - 55 °F).

Commonly used Bureau coatings and their
possible replacement or alternative coatings

Item	Present coating column 1	Advantages column 2	Disadvantages column 3	Repl. or alt. coatings column 4	Advantages column 5	Disadvantages column 6
5	VR-3 and VR-6 Vinyls	See column 2, item 4.	See column 3, item 4.	Hl-solids, 100% solids, or faster curing epoxies.	Same as column 5, item 2, plus appreciably shorter application and downtimes. May be topcoated with aliphatic polyurethane to prevent chalking and improve long-term appearance and durability. Topcoating will reduce a portion of the savings in application and downtimes.	Same as column 6, item 2 for these coatings and conventional epoxies.
6	VR-3 and VR-6 Vinyls	See column 2, item 4.	See column 3, item 4.	Elastomeric coatings, Hl-solids and 100% solids	Same as column 5, item 3, for these coatings plus shorter downtimes.	Same as column 6, item 3, above these for coatings.
7	Coal-tar enamel Coal-tar epoxy VR-3 and VR-6 Vinyls	See column 2, items 1, 2, and 4.	See column 3, items 1, 2, and 4.	Metallizing	Very short downtime without an organic topcoat, relatively short downtime with an organic topcoat. Expected long useful life span.	Surface preparation and application very critical, relatively high initial cost. Requires experienced applicators.

Commonly used Bureau coatings and their possible replacement or alternative coatings

Item	Present coating column 1	Advantages column 2	Disadvantages column 3	Repl. or alt. coatings column 4	Advantages column 5	Disadvantages column 6
8	1/ TT-P-86G, type IV, red lead primer	Proven, usually long, useful life span. Suitable for applications where there is heavy condensation.	Acute health and safety problems.	2/ Lead and chromate free anticorrosive primers.	No acute health and safety problems, some types can be used with a relatively broad spectrum of topcoats. It is almost a "universal" alkyd or oil-based primer for steel.	Use of these primers on Bureau features as alternative coatings has begun so recently that no long-term data are available.
9	TT-P-636D Alkyd oxide - chromate primer	Proven satisfactory useful life span, widely available from coatings suppliers.	Contains chromate which is sometimes "under fire" for health and environmental reasons, not suitable for applications where there is heavy condensations.	2/ Lead and chromate free anticorrosive primers.	See column 5, item 8.	See column 6, item 8.
10	TT-E-490E Silicone alkyd semi-gloss enamel	Good weathering properties, easy field application.	Solvent-borne coating, may streak if there is overflow from a water tank.	3/ Acrylic emulsion.	Good weathering properties and ultraviolet resistance, water-borne coating.	Cannot be applied at low (below approximately 40 °F) temperatures. Limited Bureau experience with these coatings on metal.

1/ TT-P-86G, type IV, Red Lead Primer is in the process of being phased out of Bureau specifications for health and safety reasons. Removal of old red lead coatings is posing an expensive problem in some areas, at present, because of safety and environmental considerations. Presently available alternatives for TT-P-86G, type IV, Red Lead Primer are discussed in footnote 2/.

2/ The Materials Science Section, D-1521, of the E&R Center is currently completing a testing program which will result in the deletion of TT-P-86G, type IV, Red Lead Primer from Bureau specifications. The two alternative coatings which are currently available are Coroband No. 167, stock No. 391-N-167, produced by the Cook Paint and Varnish Company, and Chromox Primer 13-R-28, produced by the Valspar Corporation. These primers are lead and chromate free. Their performance has been equal to or better than that of TT-P-86G, type IV, Red Lead Primer in untopcoated water immersion tests. When testing has been completed, a new coating specification for lead- and chromate-free primer will be written or adopted. Because this primer will also be an alternative for TT-P-636D Alkyd Oxide - Chromate Primer, economics will be able to determine whether this primer becomes our "universal" alkyd or oil-based primer for steel. Also, we will be completely prepared if the use of chromates in coatings is banned in the future.

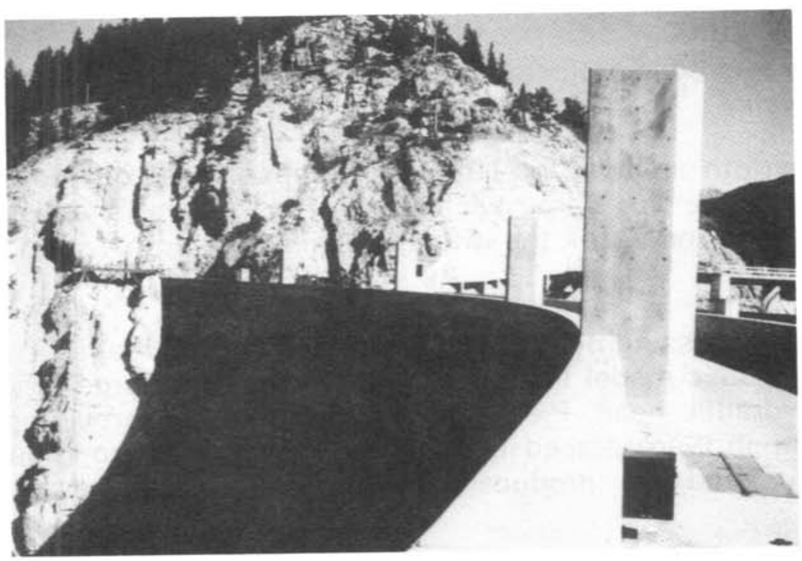
3/ There are new acrylic emulsion coatings which have shown promise as coatings for architectural steel. The Bureau is quite interested in these coatings, particularly if water-borne primers can be used with these coatings to form a completely water-borne system. The U.S. Navy is currently investigating the possibility of replacing silicone alkyd coatings with acrylic emulsion coatings on the superstructures of naval vessels. A planned investigation of acrylic emulsion versus silicone alkyd coating systems is on the research agenda of the Materials Science Section of the E&R Center.

NEW APPROACHES TO REHABBING OLD DAMS*

by Neil Parrett[1]

How can old dams be rebuilt to meet new standards for maximum flooding? How can spillway crest length be increased without changing overall spillway width? What is the most cost-effective way to reinforce an aging earth dam, and are new materials adequate for dam and spillway rehab? The Bureau of Reclamation has taken a look at some innovative answers to these questions, and has for the first time applied these methods to reconstruct several old dams.

Gibson Dam, located in a narrow gorge of the Sun River about 70 miles west of Great Falls, Montana, was the scene of one of the agency's projects. When a 1964 storm overtopped the 199-foot-high dam for 20 hours with about 3.2 feet of flow over the top of the parapet wall, no substantial damage to the then 37-year-old concrete-arch dam was detected. A reevaluation of the PMF (probable maximum flood) raised the peak discharge from 60,000 to 155,000 ft^3/s.



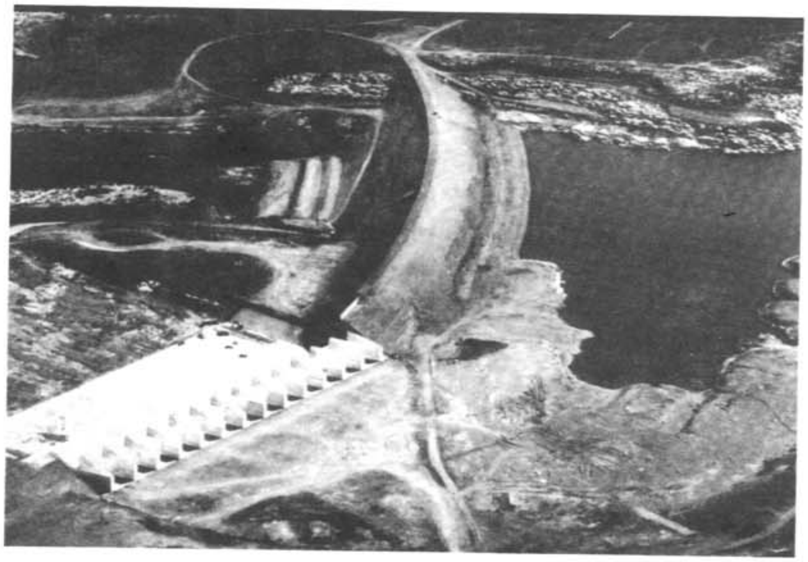
Splitter piers built on Gibson Dam's crest divide the flow over the dam, and provide for aeration beneath the overtopping flow.

BuRec's choice for the 1980-82 rehab would allow overtopping and meet a new PMF 5-day volume of 365,000 acre-feet. Overtopping during this maximum flood would be 12 feet.

Rock bolts and concrete caps were installed on portions of the downstream rock abutments to prevent plucking erosion. And piers were constructed on the dam's crest to divide the flow over the dam and provide for aeration beneath the nappe or overtopping flow. Each pier, spaced at 100-foot intervals, extends 12 feet above the top of the parapet

* Reprinted with permission from the Editor from the June 1986 issue of Civil Engineering, American Society of Civil Engineers.

[1] Neil Parrett is Chief, Division of Dam and Waterway Design, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.



Ute Dam's labyrinth spillway increases the effective spillway length within given length of the dam crest.

wall with the upstream edge projected into the roadway and the downstream edge flush with the parapet wall.

BuRec built a labyrinth spillway in 1985 to increase reservoir storage and spillway discharge capacity at the Ute Dam near Logan, New Mexico. The zigzag configuration of this type of spillway increases the effective spillway length within the given length of the dam crest.

Though the discharge passing over the labyrinth spillway increases in direct proportion to crest length, hydraulic model tests demonstrate that discharge efficiency decreases with increasing hydraulic head. Piers splitting the flow and providing for air to enter under the flow nappe were placed along the spillway crest to reduce oscillation in atmospheric pressure and noise produced when the spillway operates under low hydraulic head.

Labyrinth spillway geometry is sensitive to reservoir approach flow conditions. An approach flow parallel to the spillway centerline will produce the most uniform flow distribution.

One Season

Building a new spillway at Montana's Lake Sherburne Dam would have been costly because abutment slopes were unstable. So BuRec decided to raise the 85-foot earthfill structure to increase storage capacity.

Using patented Reinforced Earth retaining walls to raise the dam's crest cut construction time to one 5-month season. Conventional methods would have required restricting reservoir operation during two irrigation seasons.

After excavating the upper 6 feet of embankment to provide an adequate foundation, the required height of the wall for retaining the design flood, wave setup and runup, was 20 feet. The design was controlled by the dynamic loading from a design earthquake of 7 on the Richter scale at a 20-mile epicentral distance. When the reinforcing strip density or wall geometry is changed to obtain the desired factor of safety, the design analysis must be repeated with the new wall stiffness.

The strips were covered with an electrostatically applied epoxy coating, rather than traditional galvanizing. A water barrier sealing all joints on the inside wall of the upstream retaining wall was installed to prevent seepage, and fill material was placed within the structure. The fill, mainly processed sand and gravel, was placed so that a narrow zone of gravel and cobbles went against the downstream retaining wall.

The first row of precast panels was installed and braced while backfill and reinforcing strips were placed. Succeeding rows of panels were held in place by clamping and wedging against the previously placed row.

The walls are located entirely above the normal operating elevations of the reservoir. Since their November 1982 construction, the 48,000 ft^2 of retaining walls have not been inundated.

Raising Embankments

At Pactola Dam near Rapid City, South Dakota, construction is underway to raise the dam embankment 15 feet and widen the spillway from 250 feet to 435 feet. Rehabbing the 30-year-old dam will assure its capability for increased peak flows from 68,600 ft^3/s to 321,200 ft^3/s. And usually a geomembrane as an impermeable barrier for the embankment will reduce costs $1 million and will allow traffic on the highway across the top of the dam to continue during construction.

A rock-fines zone was placed over the downstream section of the crest and the upper portion of the downstream slope. At the upstream toe of this rock-fines zone is an excavation to reach the impervious zone.

The geomembrane, underlain with a nonwoven geotextile, is anchored in a 3-foot-deep vertical-walled trench into the impermeable zone and laid against the 45° upstream slope of the downstream rock-fines zone. The anchorage trench is backfilled with concrete, and the top of the geomembrane and geotextile linings are anchored in a 2-foot-deep trench backfilled with earth. As the upstream rock-fines zone is raised over the geomembrane, 1 foot of sand is laid against it. The zones upstream and downstream of the rock-fines zones at the embankment crest are rockfill.

Where the lower portion of the fabrics is not anchored on the existing embankment, the geomembrane is laid on a neoprene layer and bolted to a concrete footing below. At the anchorage footing, the geotextile underlayment is folded back under the downstream rock-fines fill.

Emergency Spillways

Last year, BuRec used flexible membranes to replace an aging spillway at Cottonwood Dam No. 5, a 20-foot-high dam near Grand Junction, Colorado. The liner was installed with grade sills at the upstream end to prevent piping and at the downstream end to protect against head cutting. The lining is attached to the concrete grade sills with redwood furring strips and nails in an attempt to prevent separation and distribute load evenly across the sheets.

Each sheet of lining was placed in a slackened condition, overlapping the adjacent downstream sheet by about 5 feet. They are anchored along the edges and at its upstream end in trenches with compacted backfill. The entire lined area is covered with 6 inches of granular material providing protection against puncture from animal and vehicle traffic.

Rehab Studies

BuRec has also researched the use of auxiliary spillways with fuse plugs as a cost-efficient alternative for passing flows from large floods that have a remote chance of occurring. The auxiliary spillway channel design width can be narrow because the fuse plug can be designed to remain stable to a selected reservoir elevation and to fail in a predictable manner.

A fuse plug embankment is designed as a zoned earthfill. The impervious core in a fuse plug embankment is inclined so that pieces of the core break off from bending, not erosion, as the downstream shell is washed away.

Thus, the rate of washout is a function of the embankment materials and not the erosion resistance of impermeable core materials. The core is protected with filter zones as a stopgap against premature failure due to desiccation and piping.

An overtopping of the entire fuse plug would eliminate predictability. A low spot, called a pilot channel, should be provided at a selected elevation to control the breach formation. A pilot channel about 3 feet lower than the remaining fuse plug crest contributes to a predictable erosion rate. The highly erodible particles, which come from the central and downstream shell zone will breach rapidly, and the remainder of the fuse plug embankment will wash out laterally at a predictable rate without overtopping.

BuRec studied auxiliary spillways with fuse plugs at Foss Dam, Oklahoma, and Twin Buttes Dam, Texas. To date, however, the agency has not built fuse plug auxiliary spillways.

METRICS

Metric or SI equivalents of English units of measurement used in this article are

1 foot	=	0.305 m
1 ft^3/s	=	0.028 m^3/s
1 mile	=	1.61 km
1 square foot	=	0.093 m^2
1 inch	=	25.4 mm

ICE PREVENTION AT INTAKES: A REVIEW OF DESIGN AND OPERATIONAL CONSIDERATIONS*

by Michael Pill[1]

In freezing climates, ice prevention can be a very serious problem. Trashracks clogged with "frazil" and "anchor" ice can prevent plant operation for days or weeks. Aside from manually chipping away ice blocking the trashracks, the only remedy is to await the spring thaw.

Once a trashrack is blocked, the operator may have no choice but to stay up all night with a hammer and chisel. One New Hampshire site operator has to stay up all night two or three times each week during very cold weather, breaking up the ice with a chisel and removing it by hand.

During those periods he goes on night shift, coming to work at 10 p.m. The ice starts forming just after midnight and persists until 9 a.m. when morning sunlight reaches the surface of the intake canal.

Icing occurs at this northern New England site whenever the air temperature reaches minus 10 to minus 15 °F. Rakes that will remove ordinary debris are generally ineffective because ice sticks to the trashracks, according to the plant operator.

Ice Varieties

There are different types of ice. These vary widely in the extent to which they can threaten winter hydroplant operation. The variables which create these different types of ice are air and water temperature, water depth and velocity, and river channel characteristics.

Frazil ice consists of small crystals or needles of ice. It most often forms when the water surface is not covered by a sheet of ice. An ice sheet cover will help insulate the underlying body of water from subfreezing air temperatures, and can help prevent the formation of frazil ice.

Frazil ice occurs when the water temperature is at or near 32 °F and the river or stream is flowing so fast the water is prevented from freezing solid (e.g., rapids).

Frazil ice needles generally form when the water temperature sinks from 32.11 to 32.09 °F. Formation continues as long as the temperature remains at or below this point. In local whirls, these ice needles have a tendency to clump together and these clumps will then unite with other clumps to form large clumps of ice needles measuring several cubic yards in volume. These ice crystals will melt when the water temperature again rises above the critical temperature of 32.11 °F. (1)[2]

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*Reprinted with permission from the Editor from the Winter 1986 issue of Hydro Review.

[1] Michael Pill, 71 North Pleasant Street, Amherst MA 01002, is a lawyer who holds a master's degree in Urban and Regional Planning and a Ph.D. in Economics. He is a principal in NEEDS – Hydrolec, Inc., a hydroelectric equipment supply and consulting company.

[2] Numbers in parentheses refer to References at end of article.

Water is called "sub-cooled" or "super-cooled" when its temperature is at or below the freezing point. It remains liquid as long as it is is still moving at a sufficient velocity. This is the reason why frazil ice can form almost instantly when the sub-cooled water reaches a trashrack. The low velocity required to minimize head loss at the trashrack actually encourages ice formation.

> "A New York developer tells horror stories of frazil ice so thick that a crane is required to lift the ice out of the forebay."

Frazil ice will stick to metal or other surfaces that are at or below 32 °F. If the trashracks themselves are partially above the headwater level, they take on the surrounding air temperature, which in winter may be far colder than the freezing point of water. Under these conditions, the trashrack bars may cool the water even more, by transferring the cold temperature from the colder winter air.

Last winter, a New Hampshire operator tried building an enclosure around his troublesome trashracks. The enclosure was a simple tent made of plywood and plastic. A kerosene heater inside the tent was connected to a timer so that it would start at midnight during cold periods when icing was expected.

This system prevented icing by warming the rack to the point where ice did not stick to the bars.

A developer in New York state tells horror stories about frazil ice so thick that a crane is required to physically lift the ice out of the forebay once or twice each winter.

This particular site is beset with the classic combination of conditions to promote serious frazil ice:

Rapids just upstream from the forebay, creating sub-cooled water.

The site has a small, shallow forebay with intake velocities too high for sheet ice to form.

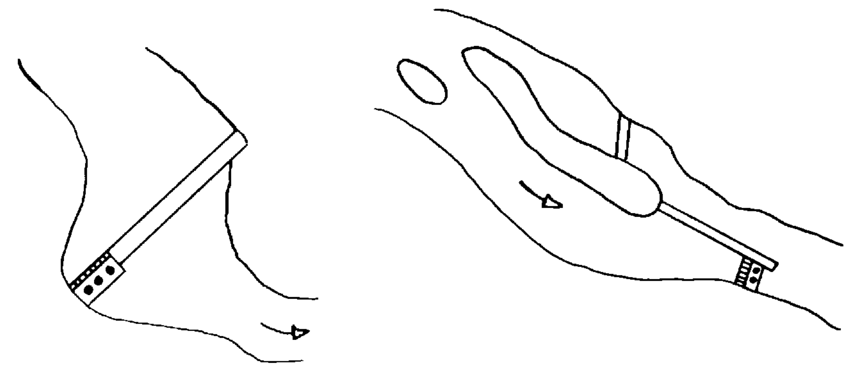
The very small sluice gate in the forebay is inadequate to pass a significant volume of ice.

The developer has decided to install a new gate to dump ice through the dam before it reaches the forebay. This decision illustrates how expensive ice problems can be if major structural modifications are required.

Preventive Designs

For many years, hydro engineers have understood that ice prevention begins with proper design. Certain configurations of river channel, dam, and intake works will promote ice problems, while other design approaches will help prevent them.

A good design takes into account the inverse relationship between the amount of sheet ice and the likelihood of frazil ice. This is because the more ice-covered the river becomes,



These layouts invite trouble from floating ice. On the left, a low head, shallow intake, and the absence of a boom or skimmer wall attracts ice to the intakes. At right, funneling of the river toward the powerhouse tends to choke the narrow intake stream with ice.

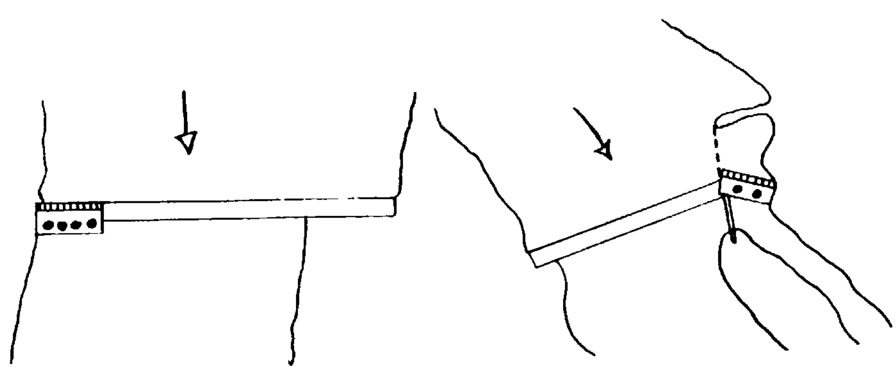
the less subject it is to the cooling effects of air, and the less trouble there will be with frazil ice.

Civil designs least likely to create ice problems are those which foster the formation of sheet ice on the surface, or which provide some means for disposing of unwanted ice, or both.

One engineering text summed up the crucial elements this way:

> "When the powerhouse is located in the dam and a pond of considerable size lies above the dam, there is seldom serious trouble for frazil or anchor ice. Similarly, little or no trouble need be expected when the approach to the powerhouse intake is through a long, deep canal at a velocity low enough to permit the ice sheet to form readily. On the other hand, when conditions are such that water is brought to or near the intake at a relatively high velocity, which tends to prevent the formation of an ice sheet, a great deal of frazil and anchor ice is likely to be formed." (2)

Trashrack blockage also can be caused by "anchor ice," an ice formation that consists of small ice needles which form at the bottom of fairly quiet, shallow bodies of open water or water covered by a thin transparent ice sheet.



These layouts minimize floating ice troubles. On the left, a large size pool with a deep intake. At right, a moderate size pool with a shallow intake will require a skimmer wall or a substantial boom.

This type of ice generally forms during clear freezing nights and drifts downstream the next day. It can clog trashracks much like frazil ice.

An earlier study by R. C. Beardsley agrees on the importance of forming a solid sheet of ice in the forebay. Beardsley noted in his studies that narrow channels, when parallel with the dams and head work, were seldom troubled with ice. Plants having short mill ponds ending in rapids, or long shallow ponds ending in rapids, were invariably troubled with anchor ice.

Beardsley observed that, in ponds which were frozen over to a good depth, the anchor ice lost its form before it reached the racks. Tailraces which were not protected were frozen over and clogged, unless they were deep enough to take care of the water. Turbines running in unprotected steel flumes were, in some cases, so bothered by water freezing in the flumes that a housing had to be built around the flume and fires kept burning.(3)

Diversion Tactics

What happens if, despite all design precautions, frazil ice still clogs the forebay? The ice can be diverted by providing ice chutes from the forebay toward the tailrace. The crest of these should be of the same elevation as the crest of the main spillway.

The experience of modern developers shows that an undersized gate is as bad as none at all. The gate must be large enough to clear the entire forebay of ice or other debris. Project design can be modified after construction, in some cases, by the addition of a wing wall or log boom to help keep ice away from the trashracks.

While a wing wall or log boom will obstruct only frazil ice floating on or near the surface, it may promote the formation of beneficial sheet ice in the forebay by decreasing the velocity of the surface water.

Where a boom cannot be used, a sluice gate of sufficient size may help create enough current alongside the trashracks to carry away the ice.

Operational Deterrents

In addition to site design, project operation may be helpful in ice prevention. Temporarily shutting down the turbines reduces water velocity in the forebay, thereby assisting in the formation of a sheet of surface ice which can prevent frazil and anchor ice from clogging the trashracks.

In years past, when pond level control was a manual operation, there was more likely to be someone present at the site to observe ice conditions. Today, with the tendency toward remote monitoring and automatic equipment operation at many smaller plants, there may not be an operator on hand to shut down the turbines when necessary.

If the project is far enough north, an effort can be made to create a sheet of ice that will hopefully last all winter.

Sometimes the physical characteristics of the site make it impossible to create a protective sheet of ice. One engineer describes two recently developed sites in upstate New York.

The projects are within a few miles of each other on the same river. The upper one has an intake about 19 feet deep while the lower site's intake is only 13 feet deep.

The engineer has observed that the upper site consistently develops a sheet of ice over the intake, right up to the trashracks. Once the ice sheet forms, there is generally no further problem with frazil ice.

At the lower site, however, frazil ice is a constant concern. A shallow spot just upstream from the intake only exacerbates the problem. The shallower forebay of the lower site has a somewhat higher intake velocity that prevents the formation of sheet ice.

There are 5-inch spaces between the trashrack bars, but once the frazil ice begins accumulating, it can fill that entire space in a short time. Then the ice must be physically knocked off the rack, or removed with steam heat.

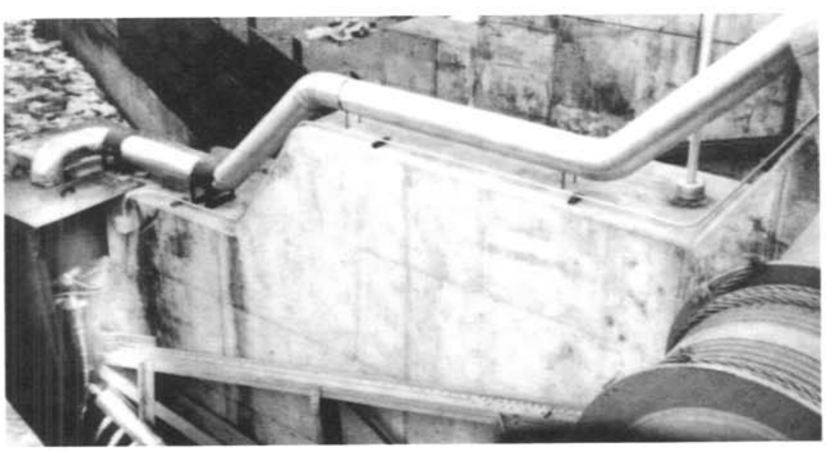
Fortunately, process steam from an adjacent paper mill is readily available.

Very few hydro sites have the luxury of readily available steam heat. At other projects, bubblers and electric heating elements have been used to deal with ice problems.

Bubblers

More than 30 years ago the U.S. Bureau of Reclamation concluded that compressed air systems lend themselves best to the prevention of ice along the upstream faces of dams, and also at trashracks and gates. The Bureau concluded that the electrical heating systems are best used primarily for the prevention of ice along the seats and seals of drum, radial, and slidegates. (4)

In the United States, use of bubbler systems dates back at least to the winter of 1917-1918, when a compressed air de-icing system was installed at the Keokuk Dam in Iowa on the Mississippi River.



An air line extends down the top of a spillway pier. The compressed air is distributed along the downstream side of a tainter gate. Photo courtesy of Mead and Hunt, Inc., Madison WI.

A similar system has worked successfully at the Grand Coulee Dam and the Black Canyon Diversion Dam, both operated by the U.S. Bureau of Reclamation.

Today, in the upper midwestern United States, compressed air bubbler systems are commonly used to thin out or prevent ice growth. Such devices will not destroy an ice pack, but they will usually prevent an ice formation from clogging trashracks or gates.

A bubbler system takes advantage of two sources of heat. The primary source is the warmer water located near the bottom of a forebay. Since frazil ice is attributed to cold air temperatures, the bubbling action causes a circular flow. The warmer water at the bottom is carried upward as the bubbles rise. This will help melt existing ice and prevent further icing.

A secondary source of heat comes from aerating the water. The bubbling increases the water's dissolved oxygen content, much as the bubbler in an aquarium.

An increase in the dissolved oxygen level in turn slightly lowers the freezing temperature of the water. As discussed earlier, a very small increase in water temperature may be enough to prevent formation of frazil ice.

The key variables in any bubbler system are:

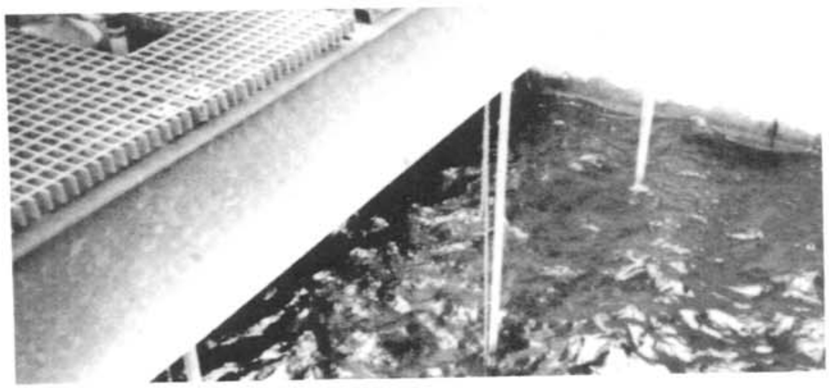
Depth of the intake
Amount of waterflow
The amount of air required

A detail view of the connection of the compressed air header pipe on the pier wall and the header on the gate arm. Flexible hosing connects the two headers and, in this application, the hosing is wrapped with heat tape. Photo courtesy of Mead and Hunt, Inc., Madison WI.

The main components are an air compressor or blower, piping, and valves. If the water is deep enough that the pressure is more than 12 lb/in^2, then a compressor, rather than a blower, must be used.

Piping may be embedded in concrete around the intake, or hoses with weighted ends may be hung in the water. The embedded pipe will not be knocked away by ice, debris, or water pressure. However, its maintenance is much more difficult because, if a problem occurs, the pipe may have to be abandoned.

Air from the blower or compressor is discharged upstream of the trashrack. The exact distance of the discharge from the trashrack is a function of pipe depth. One rule of thumb is to locate the system about 3 feet upstream from the trashrack, depending on how much clear area is needed.



Three hose lines drop from a header pipe into the headwater around the inlet. The light chains are used for elevation adjustment and stability. Photo courtesy of Mead and Hunt, Inc., Madison WI.

The danger is that if the hoses are placed too far upstream, they may be carried away by ice. Since ice conditions are site specific, one cannot generalize about the location of the bubbler's air nozzle and the arrangement of piping. An analysis of each site is necessary.

The cost of a bubbler system is very modest, especially when compared to costs of ice removal and the potential for lost revenue. At one 500-kW site in northern Wisconsin, a bubbler system was designed, built, and installed for less than $10,000. Only a small amount of electricity is needed to run the blower or compressor in such a system.

In conclusion, the bubbler system appears to offer the most cost efficient solution to ice problems at many hydroelectric sites. It has been in use continuously for many years, and with satisfactory results.

This solution to ice problems represents one example of the value of historical research and open exchange of technical data in an industry that is still in the process of re-learning old lessons.

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3. Beardsley, R. C., "Design and Construction of Hydroelectric Plants," McGraw Publishing Company, New York, 1907, p. 56.

4. Bier, P. J., "Ice Prevention at Hydraulic Structures," Water Power and Dam Construction, Vol. 6, Nos. 4 and 5, April, May 1954, p. 136.

WEEDBURNER*

A weedburner built and used by the Falls Irrigation District in American Falls, Idaho, is doing an excellent job of controlling aquatic and broad leaf plant growth. The truck-mounted weedburner is a very useful piece of equipment which can burn large amounts of weeds in a short period of time.

After the growing season is over, the burner is removed from the flat-bed truck, and the truck can be used for other maintenance jobs.

The following is a list of the main items required to build your own weedburner:

Item	Approximate cost
Two 3-1/2-inch x 20-foot-long aluminum channels for a 3-1/2-inch x 3-1/2-inch x 1/4-inch x 20-foot boom	$141.00
15 feet of 2-1/2-inch steel pipe for boom carriers	34.15
One 8-ton hydraulic jack	113.00
4-foot x 4-foot expanded metal for stand tray	20.20
One 8-inch- to 10-inch-wide burner head	21.00
40-foot rubber propane gasline	40.00
35-foot x 1/4-inch cable	18.20
2-foot x 2-foot x 1-inch plate steel for base of burner	77.00
Truck axle and brake cylinder (this would depend on person purchasing – can be purchased from wrecking yard)	Undetermined
Seat (this can also be from a wrecking yard or from old farm equipment)	Undetermined

This particular burner can be installed on and removed from almost any flat-bed truck with four bolts through the bed of the truck. The burner shown in the following pictures uses 2-1/2 gallons of propane per mile with the truck speed of approximately 3 to 5 miles per hour.

* Information and pictures courtesy of the District Manager of the Falls Irrigation District, Route No. 1, Box 203A, 310 Valdez Street, American Falls ID 83211.

Photo 1. Weedburner mounted on truck and being used in ditch alongside of road.

Spring of 1987

Photo 2. Weedburner mounted on truck and being used in ditch alongside of road.

Spring of 1987

Photo 3. View of weedburner being used alongside of road.

Spring of 1987

Photo 4. View of weedburner being used alongside of road.

Spring of 1987

Photo 5. Closer view of weedburner in use.

Spring of 1987

Photo 6. Closer view of weedburner in use.

Spring of 1987

Photo 7. View of weedburner when not in use.

Spring of 1987

Photo 8. View of weedburner when not in use.

Spring of 1987

CASE STUDIES

WHISKEYTOWN DAM - GATE VALVE FAILURE

Dam:	Whiskeytown
Project:	Central Valley
State:	California
Type:	Zoned earthfill
Completed:	1963
Functions:	Irrigation, flood control, recreation
Crest length:	4,000 feet
Hydraulic height:	262.5 feet
Active capacity:	213,550 acre-feet
Surface area:	3,220 acres

Design Characteristics: Two 45-inch-diameter outlet pipes convey water through the construction-period diversion tunnel in the left abutment of the dam. Two 2-foot 9-inch by 3-foot 9-inch outlet-type regulating gates are located in the control house at the downstream toe of the dam. A 12-inch bypass pipe, containing a 10-inch jet-flow gate and a 12-inch gate valve, is connected to the No. 2 outlet pipe in the control house.

Evidence: No visible prefailure symptoms.

Incident: On January 28, 1983, the 12-inch gate valve ruptured. The operator had started to adjust the regulating gates so that the 100 percent flow would exit through gate No. 1 and partial flow through gate No. 2. From the control cabinet, the operator initiated the hydraulic system to close gate No. 2, made a visual inspection to verify that the gate was closing, and then started back to the control cabinet. At this time, the 12-inch gate valve failed, forcing out a 10-square-inch piece of the valve bonnet.

The valve halves separated by one-half inch, creating a water discharge which blew the operator against the far east wall of the regulating chamber and began filling the chamber within seconds. The operator escaped unharmed up the 10-foot-high chamber access ladder. Increasing static water pressure within the chamber collapsed the steel door separating the chamber from the penstock tunnel and water began to fill the tunnel. The operator immediately initiated an emergency closure of all guard gates by using the remote control panel at ground level above the tunnel. Eighteen minutes after the failure, the operator reported both guard gates were closed and waterflow had ceased.

Causes: The probable cause of failure was the result of a combination of fatigue and embrittlement due to crystallization of the metal. In this particular installation, a coupling was not provided between the 12-inch cast iron guard gate and downstream jet-flow gate. This may have caused additional stress on the gate valve that could have been cushioned by a coupling.

Remedy: The damaged guard gates were replaced with a 12-inch cast steel guard gate. It was recommended that a high-water alarm be placed within the penstock tunnel, in the unlikely event of another failure.

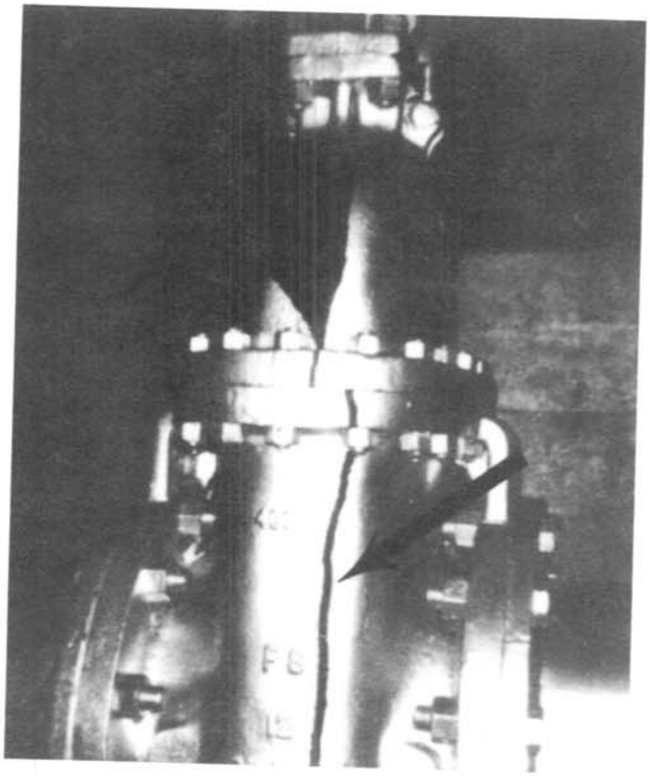

Photo 1.
Whiskeytown Dam

Fractured 12-inch gate valve.

1/28/83

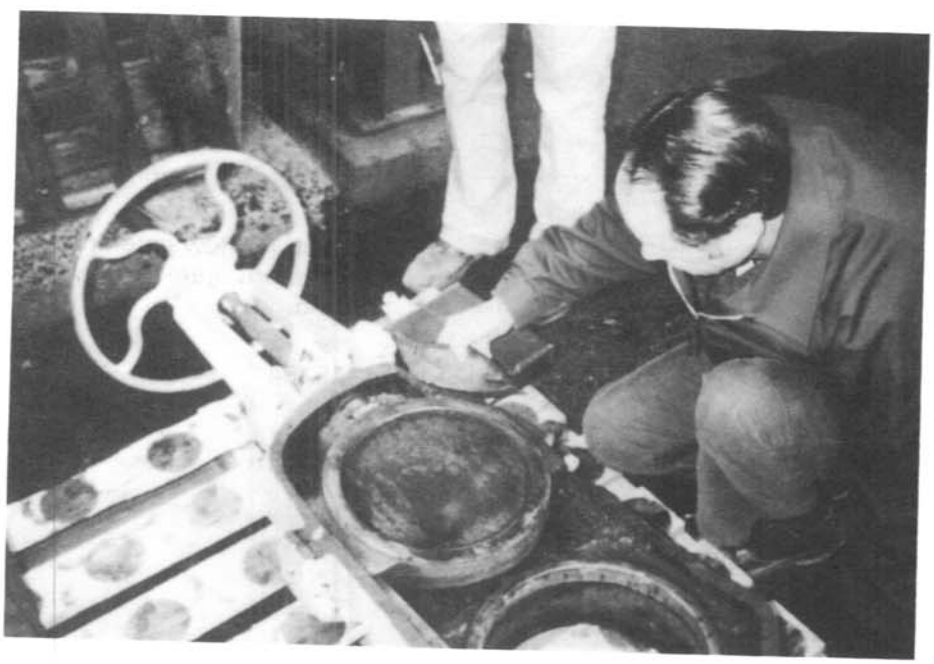

Photo 2.
Whiskeytown Dam

Fractured 12-inch gate valve.

1/28/83

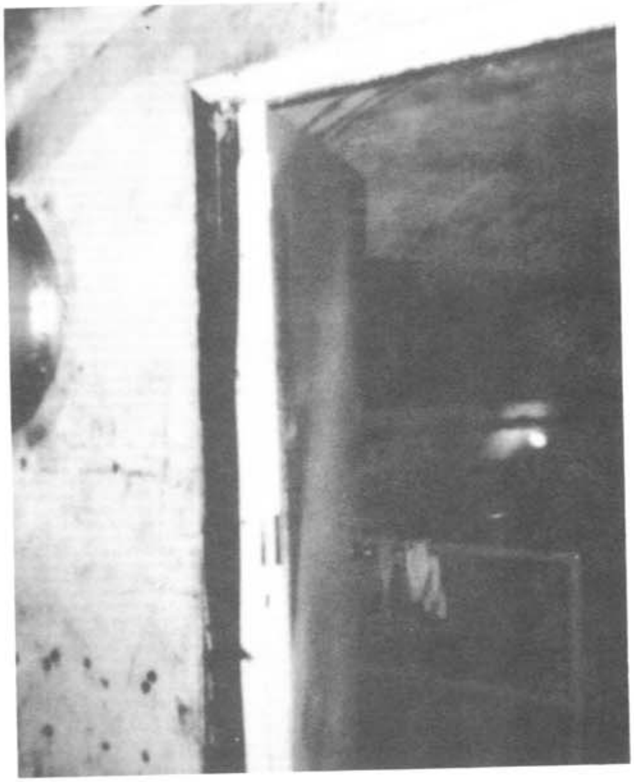

Photo 3.
Whiskeytown Dam

Collapsed door to penstock tunnel.

1/28/83

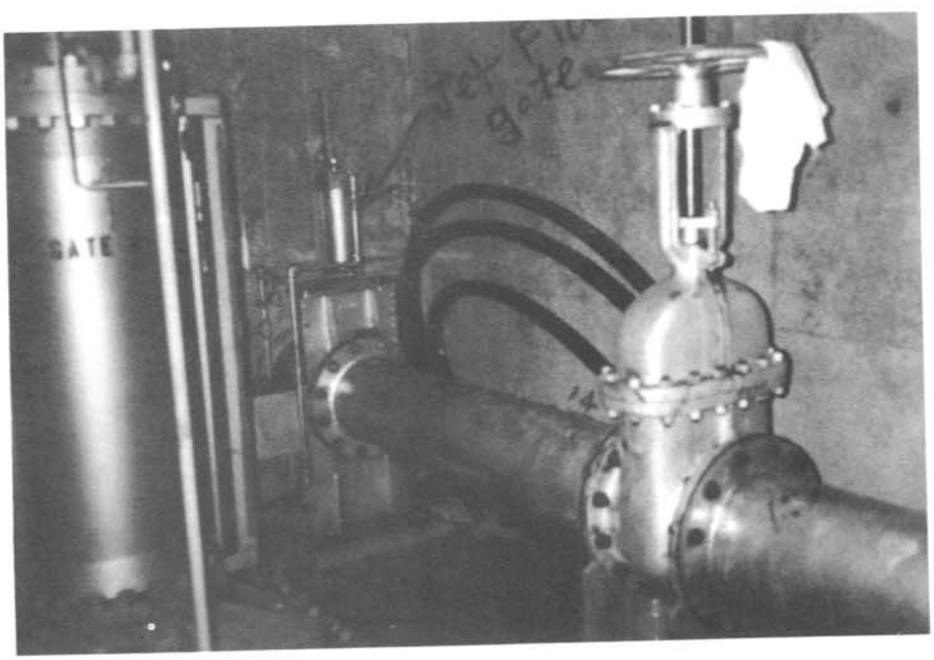

Photo 4.
Whiskeytown Dam

10-inch jet-flow gate and 12-inch guard gate on bypass system.

4/25/84

SPOTLIGHT ON OWYHEE PROJECT

Southeastern Oregon is mostly a high, warped plateau formed by lava flows from volcanic cones in the Cascade Range. Locally known as "Rimrock Country," the area is noted for its stark, colorful canyons. The major drainage system is the Owyhee River, a tributary of the Snake River. "Owyhee" is a phonetic spelling of the name young Hawaiians gave to the area while working for the Hudson Bay Company in the early 18th century.

Geographically known as the Malheur-Owyhee Upland, this area, which also includes part of southwestern Idaho, is a semiarid, climatically harsh desert. The region's annual precipitation varies between 8 and 13 inches, most of which occurs during the winter months. Hot, sunny summers and brisk winters with wide ranging temperatures are also characteristic.

Irrigated agriculture is the region's primary industry. The Owyhee Project, constructed by the Bureau of Reclamation, harnesses the unpredictable Owyhee River to provide water to the fertile soils of the Owyhee and Central Snake River Valleys.

History

Eastern and southern Oregon were held in low repute by the early explorers and settlers traveling to Oregon Territory. Emigrants journeying west along the Oregon Trail forded the Snake River south of the present town of Nyssa, and pressed on toward Vale. Here they rested, then proceeded to the Willamette Valley – the State's major agricultural area. Until about 1860, the inhabitants of the Owyhee and Central Snake River Valleys were mostly cattle ranchers and sheepmen.

In the 1860's, wheat farmers began to settle in the region, and farming began to replace ranching as the area's main industry. Because of the arid climate, the farmers diverted water from the river to nourish their crops, their livestock, and themselves. By the beginning of the 20th century, individuals and private concerns were irrigating about 6,000 acres by diverting water from the Owyhee and Snake Rivers and nearby Succor Creek. As the acreage under irrigation continued to increase, people began to consider developing storage facilities to provide water for late season use and to irrigate the higher benchlands of the valleys.

Seeking suitable storage sites, individuals and private organizations investigated several possible dam locations, and considered various irrigation plans. They soon discovered that gaining access to potential sites in the rugged canyon country would make construction costs prohibitive. About this time the Bureau of Reclamation (then called the Reclamation Service) was established.

From 1903 to 1905, the new agency conducted topographic surveys of the Owyhee River Basin to determine possible reservoir sites and irrigable lands, but no project was recommeded. Still, private development continued, and by 1923 over 32,000 acres were under irrigation.

In 1925, after studying various reports and plans made by Government engineers, State cooperative boards, and private companies, and after conducting further investigations of its own, the Bureau issued a feasibility report recommending construction of the

Owyhee Project. Work began on the storage dam and canal system in 1928, and the first water was delivered to project lands in 1935. By 1939, the lateral system had reached the last irrigation area.

The Owyhee Project was designed to supply water to the entire project area by gravity flow from Owyhee Reservoir. But because the Owyhee River's flow is frequently too low to supply the necessary water, privately constructed pumping plants provide Snake River water to lower-lying project lands. These plants are operated under a 1936 contract between the Bureau of Reclamation and several irrigation districts.

The completed Owyhee Project lies west of the Snake River in Malheur County, Oregon, and Owyhee County, Idaho. The project provides a full irrigation water supply to 105,249 acres, and a supplemental supply to 13,000 acres. Of the 118,249-acre total, 71 percent is in Oregon, the remainder in Idaho. The project area encompasses 1,831 farm units and 8 towns.

Facilities

Owyhee Dam, on the Owyhee River about 11 miles southwest of Adrian, Oregon, is the key feature of the Owyhee Project. The world's highest dam when completed in 1932, Owyhee is a concrete thick-arch structure 417 feet high with a crest length of 833 feet.

Owyhee acts as both a storage and diversion dam. Its impoundment, Owyhee Reservoir, has a total storage capacity of 1,120,000 acre-feet, with an active storage capacity of 715,000 acre-feet, a surface area of 13,900 acres, and a shoreline of 150 miles. From the reservoir, water is released through a 3-1/2-mile tunnel to Tunnel Canyon. The North and South Canals then distribute the water to the project's North and South Divisions.

Supplemental water for project lands is pumped from the Snake River by the Gem, Ontario-Nyssa, Owyhee Ditch, and Dead Ox Pumping Plants.

Project works also include 102 miles of main canals and 447 miles of farm distribution canals that were constructed by Reclamation. Facilities constructed by other organizations and operated as part of the project include three diversion dams, 58 miles of main canals, and 97 miles of farm distribution laterals.

Benefits

Irrigation is the primary purpose of the Owyhee Project. The assured water supply, combined with the fertile soil and 160-day growing season, produces bountiful alfalfa, pasture, cereal grain, sugar beet, potato, onion, and alfalfa seed crops. The project is also a major supplier of the Nation's sweet corn seed crop. Apples, plums, and other small fruits are also grown successfully on project lands.

Recreation is also an important project benefit. Owyhee Reservoir, which penetrates the heart of the wild Mahogany Mountains, is an oasis in a desert wilderness. The 52-mile-long reservoir attracts over 63,000 visitors annually.

Because of the difficulty in gaining access to much of the lake, most of the recreation facilities are located within 4 miles of Owyhee Dam. Picnicking, swimming, camping, and boat launching facilities, constructed by Reclamation and the Oregon State Parks and Recreation Branch, are located in Owyhee Lake State Park above the dam. A privately operated marina facility is located near the State Park.

Two recreational areas have been provided away from the dam. Downstream, the irrigation districts and the Bureau have provided access for stream fishing and have developed a picnic area. Approximately 30 miles up the reservoir, in Leslie Gulch, the Bureau of Land Management operates and administers a campground.

The public recreation areas are administered by Reclamation and the Oregon Highway Commission.

Waterskiing, boating, fishing, sailing, camping, picnicking, hiking, and rock collecting are favorite recreational pursuits in the project area. Anglers pit their skills against the smallmouth and largemouth bass which inhabit the reservoir's depths. Crappie, coho salmon, and several species of trout also challenge fishermen. Hikers and boaters in Owyhee Canyon find serenity among the sheer cliffs of the 1,000-foot-deep chasm. Many-hued walls and basaltic canyons with colorful volcanic rock formations carved and honeycombed by erosion provide spectacular scenic delights. And, rockhounds visit the project area in search of thundereggs, jasper, and agate.

Wildlife is also plentiful along the reservoir, and on project lands. Sharp-eyed visitors may catch a glimpse of California bighorn sheep, wild horses, or antelope along the canyon walls. Chukar, Chinese pheasant, quail, geese, and ducks offer small game hunters ample opportunity to test their skills.

A third benefit provided by the Owyhee Project is flood control. For those rare times when the river flows high and wild, Owyhee Dam and Reservoir serve as a catchment for the water, and protect the lower valley lands.

Photo 1. Aerial view of Owyhee Dam and reservoir looking upstream. "Glory hole" spillway stands dry above the waterline.

9/22/77

Photo 2. Aerial view of Owyhee Dam and reservoir showing the high water level following heavy spring rains.

4/28/78

Photo 3. Aerial view of Owyhee Dam and reservoir showing the high water level following heavy spring rains. Note "glory hole" spillway in foreground.

4/28/78

Photo 4. Aerial view of Owyhee Dam looking across the face of dam.

6/15/78

Weiser
Dead Ox
Pumping Plant
Project Lands
Payette River
Ontario
Malheur River
Malheur Siphon
Vale
Owyhee Canal
North Canal
Ontario-Nyssa Canal
Nyssa
Owyhee Ditch and
Ontario-Nyssa
Pumping Plants
Owyhee River
Boise River
Adrian
Tunnels
Owyhee Dam
Owyhee Lake
State Park
Tunnel
Homedale
Snake River
South Canal
Marsing
Lake
Owyhee
Gem
Pumping
Plant
Oregon
Idaho
MALHEUR COUNTY
OWYHEE COUNTY
Leslie Gulch
Campground