WATER OPERATION AND MAINTENANCE

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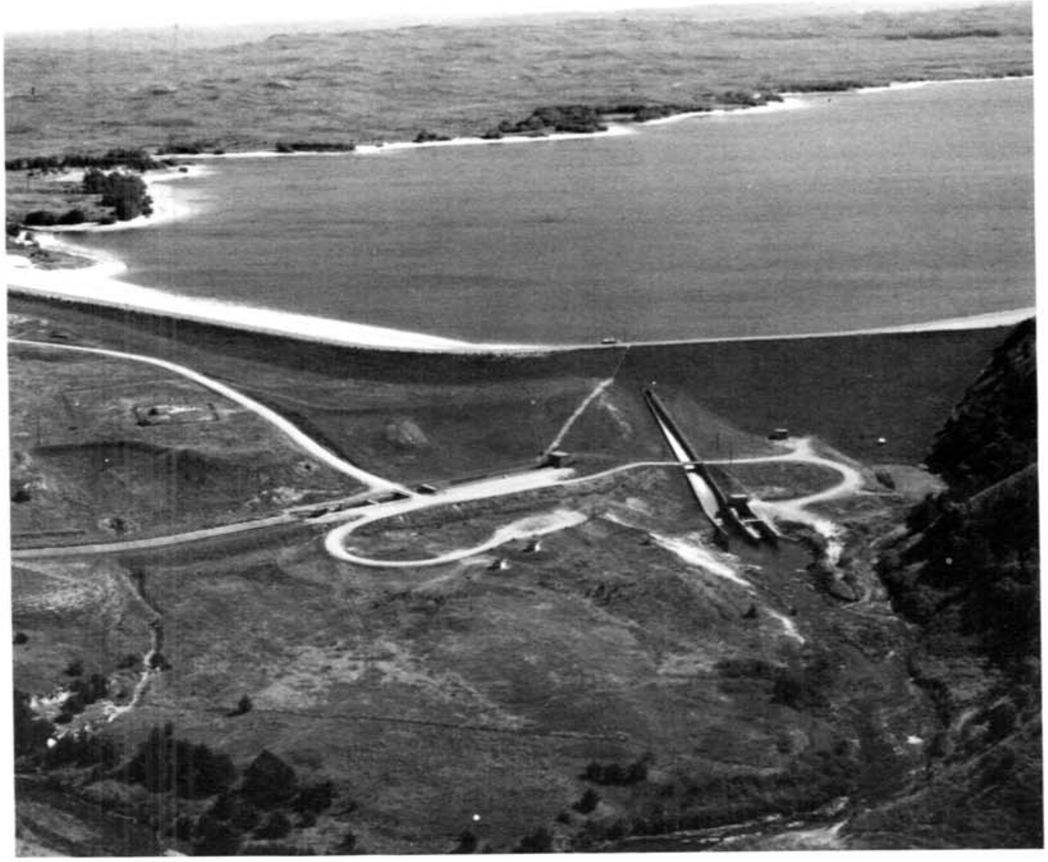

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

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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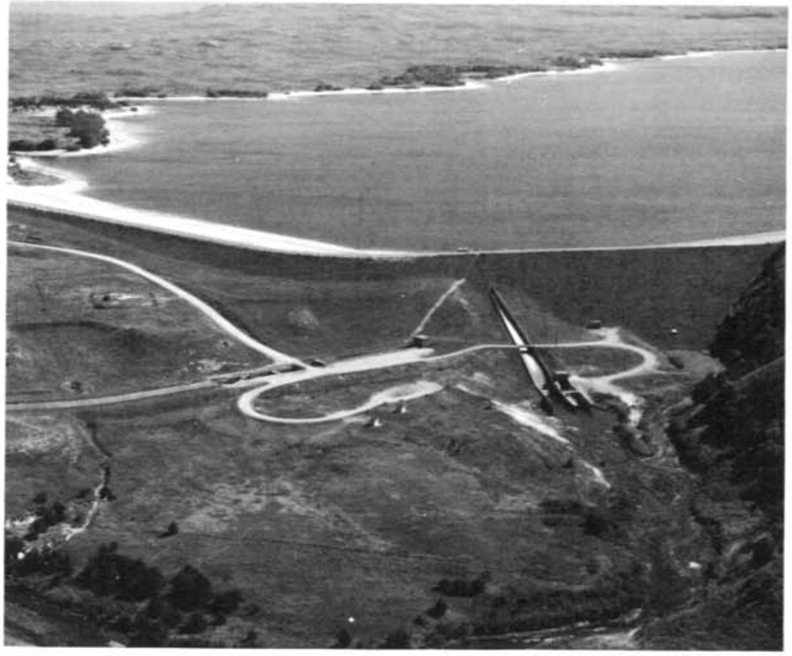

Cover photograph:

Merritt Dam, Ainsworth Unit, P-SMBP, is the spotlight of this issue.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

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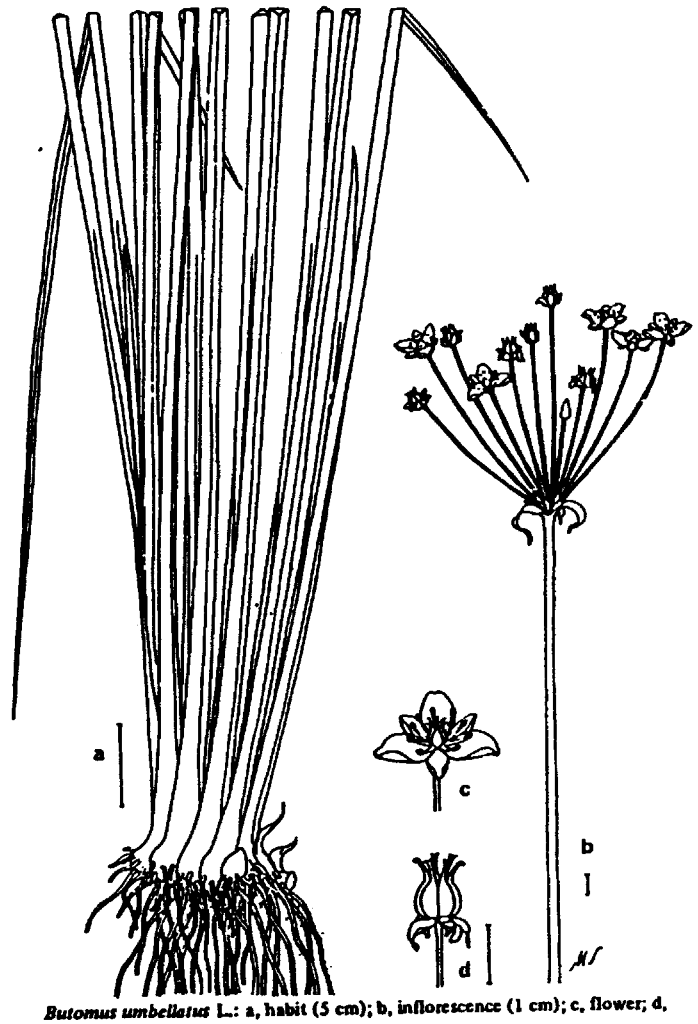
Aquatic Weed Alert

An agressive exotic weed, which has proven difficult to control in the eastern North American Continent, has been found growing in the 12-mile segment of the Aberdeen-Springfield Main Canal near Burley, Idaho. The weed, flowering rush, *Butomus umbellatus L.*, is resistant to conventional herbicides and other control methods. The water district resorted to mechanical removal which is costly and provides only limited control of the weed. The average depth of the infestation is from the wetted perimeter to 5 feet with some stands growing to 11 feet deep.

Flowering rush, a perennial weed, grows in two forms, a submersed form and an emersed form approximately 3 feet high. The plant reproduces by seeds and rhizomes with bulbous storage structures. These attributes, in addition to the plant's ability to live in deep water, make it difficult to eradicate.

The Bureau of Reclamation's Environmental Sciences Section staff will investigate the situation more thoroughly and make recommendations for its control. It is hoped that this weed can be controlled before it spreads further and causes additional problems for other water users.



***Butomus umbellatus* L.: a, habit (5 cm); b, inflorescence (1 cm); c, flower; d, fruit (1 cm).**

CLEANING IRRIGATION SYSTEMS: WHEN "PIGGING OUT" PAYS OFF[1]

By Mike Landes[2]

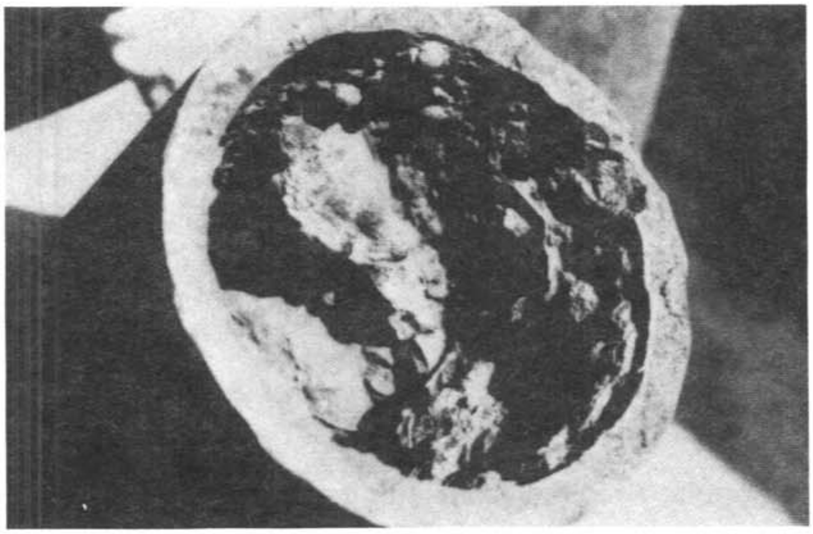
Whoever coined the phrase "dirt cheap" did not know the first thing about irrigation costs. Dirt can cost plenty when it coats the inside of an irrigation pipe.

That is why, for today's irrigation farmer, it is becoming increasingly important to maintain clean internal surfaces in water-distribution pipelines. Water deliveries remain the farmer's primary goal. However, the cost of pumping that water has grown into a major concern.

Since 1965, we have seen the cost of a kilowatt-hour in the United States triple. In Texas, for example, it has gone from 2 cents to 7 cents in many areas.

While that figure is in line with inflation, it hurts when it is your own pocket that feels the pinch. However, it also offers an inflated chance to extract big savings as well.

When hard encrustations such as iron oxide and calcium carbonate build up in water-distribution pipelines, profits are cut down — because such buildups can greatly increase pumping costs.



Pipe containing irregular buildup of iron tuberculation.

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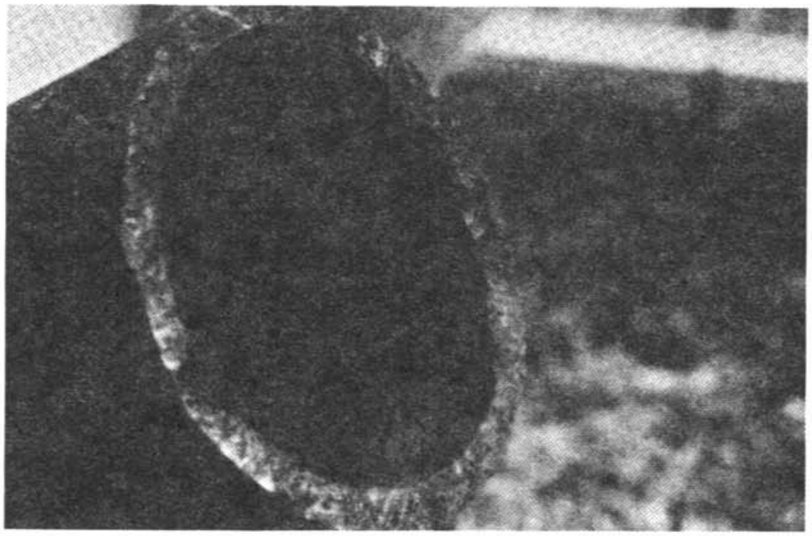
[1] Reprinted with permission from the Editor from the November/December 1986 issue of Irrigation Journal.

[2] Mike Landes is president of Girard Industries, Inc., Houston, Texas.



The same pipe following a cleaning.

In the municipal industry, the efficiency of waterflow is measured by the Hazen Williams formula — or, as it is commonly called, the "C"-factor formula.

A typical new cast-iron water main, for example, would have a "C" value of 140. As irregular buildups form in the pipe, "C" values begin to decline — and there is nothing irregular about that. They go straight down.

Often the buildups may seem slight — but their irregularity, which seems inherent in such buildups, causes the flow to descend from laminar (that is engineers' lingo for regular and continuous) to turbulent. A rating too far below the original "C" level can literally drown profits.

There is a simple formula for calculating horsepower increases and ultimate energy costs if "C" values are known.

$$\underset{\text{(horsepower)}}{\text{HP}} = \frac{\text{New ``C''}}{\text{Present ``C''}}\ 1.85$$

An example might be as follows (assuming a present "C" value of 70).

$$\text{HP} = \frac{140}{70}\ 1.85 = 3.7 \text{ times original horsepower}$$

By determining the number of horsepower being used and what a horsepower costs in an area, we can get to hard dollars.

There are many methods available today for cleaning water pipelines, such as chemical cleaning, water blasting, drag lining, rodding, and mechanical pigging. The most-used method, however, is the hydraulically propelled polyurethane foam pig.

This product is often referred to in the trade as aqua-pigs or polly-pigs. Aqua-pigs are basically comprised of an "open-cell" polyurethane flexible-foam body and are usually molded in the shape of a "bullet" (length two x diameter). Sizes range from 1 inch up to 9 feet in diameter.

They are generally grouped into three basic types — three little pigs: bare, coated, and coated with abrasives. The bare units have a flexible polyurethane coating on the tail to serve as a drive seal. The coated versions usually have a flexible polyurethane crisscross or crosshatch design applied to the outer surface.

The crisscross design actually tries to expand when pressure is applied to the rear of the unit, causing this type to act as a hydraulic ram in the line. The coated-with-abrasives type is manufactured the same as the crisscross version, with an addition of wire-brush or silicon-carbide strap embedded in the coating. This unit is designed to remove hard encrustations in waterlines, such as iron oxide and calcium carbonate.

Ever try to catch a greased pig? These plastic pigs are equally nimble. All models are flexible enough to negotiate 90° ells and T sections, and can pass reductions up to 35 percent cross-sectionally. Usually, when cleaning water pipes, a "progressive pigging method" is used.

This simply means that the "true" pipe opening is determined, and cleaning units that will fit snugly are pumped through the line and increased in diameters until the pipe is clean. The wire-brush types are usually applied toward the end of a cleaning job.

A typical cleaning job was done recently at Sunheaven Farms in Prosser, Washington. Two water-distribution lines were involved: a 4,000-foot section of 8-inch cast iron and a 3,000-foot section of 10-inch cast iron.

The 8-inch line had a before "C" value of 77. Flowline Services Northwest was contacted and subsequently ran a series of 6-, 7-, and 8-inch aqua-pigs. (No, they cannot swim.) The result was a new "C" value of 108. The annual energy savings, based on 7 cents per kilowatt-hour, will be $1,685.

The 10-inch section had a before "C" value of 78. It was brought up to 103 following "pigging." The annual energy savings on this line should be $940 — enough to "pig out" on pizza for a year.

In another case, 18-inch and 20-inch lines were cleaned with the aqua-pig method in a large farming operation in the Central Valley of California. These distribution lines irrigate 60,000 acres of cotton, wheat, and milo. They were scaled so badly that sprinkler units on the mobile laterals were becoming clogged.

Introducing the "pig" into the irrigation line.

Flowline Services of Long Beach, California, was called in to assist. In this case, a total of five aqua-pigs was run. The first unit was a 20-inch (2-lb/ft^3 density) bare type. Two 20-inch (5-lb/ft^3 density) crisscross were pumped one at a time, followed by two 20-inch (5-lb/ft^3 density) crisscross wire-brush types.

This pigging job, while successfully removing the scale problem, proved to be even more successful in saving pumping costs. Prior to cleaning, the pumping rate was 3,000 gal/min at 115.5 HD FT pressure. After cleaning, the line produced 3,000 gal/min at 57.75 HD FT pressure.

To determine energy statistics on this job, the following formula may be used.

FORMULA

$$\text{Cost per 1,000 gallons pumped} = \frac{.189^{*} \times \text{cost per kWh} \times \text{HD FT}}{\text{pump EFF} \times \text{motor EFF} \times \text{60 min}}$$

Assuming: (Actual, in this case, energy cost = .07¢/kWh)
Motor efficiency = 80%
Pump efficiency = 80%

THEREFORE:

Cost before cleaning: $$\frac{.189^{*} \times .07\text{¢} \times 115.5}{.80 \times .80 \times 60\text{ min}} = .0398\text{¢}/1{,}000\text{ gal}$$

Cost after cleaning: $$\frac{.189^{*} \times .07\text{¢} \times 57.75}{.80 \times .80 \times 60\text{ min}} = .0199\text{¢}/1{,}000\text{ gal}$$

This represents a savings of .0199 cents per 1,000 gallons pumped.

At a normal pumping rate of 4,320 Mgal/d x 200 days per year, this amounts to an annual savings in energy costs of $17,194 due to the reduction in head, at the pumps, of 57.75 HD FT.

While cleaning waterlines with polyurethane foam pigs is relatively simple, it is suggested that experienced assistance be retained for that initial job. It is inexpensive insurance that should yield maximum results.

History shows that the price of energy will continue to rise, so the irrigation farmer must look to new ideas such as internal pipeline "pigging" to keep his operating costs to a minimum.

"Pigging out" your pipes can produce savings that would make anyone — pig or person — squeal with delight!

FIELD EVALUATION OF SOIL-APPLIED AND SELECTIVE HERBICIDES

By Victor S. Miyahara[3]

INTRODUCTION

This is the third year of a study initiated in 1983 to screen soil-applied herbicides that are used in Bureau of Reclamation noncrop areas such as irrigation rights-of-way, power switching stations, and drainage ditchbanks. In addition to the study at the Denver Federal Center, a study was set up at an area by the Marias River in northern Montana, using selective herbicides to control broadleaf weeds such as leafy spurge (*Euphorbia esula*), Russian knapweed (*Centaures repens*), and Canadian Thistle (*Circium arvense*). The purpose of the study is to update the list of soil-applied herbicides that can be recommended for use in Bureau of Reclamation noncrop areas and to test selective herbicides for broadleaf weed control to reclaim rangeland in Montana.

METHODS AND MATERIALS

The test sites for this study are on the Denver Federal Center and an area by the Marias River in Montana. The plots on the Center are approximately 0.0065 acre with an undisturbed 6-1/2-foot border on all sides (fig. 1). The herbicide plots set up at Marias River were on both grazed and ungrazed rangeland.

Herbicide	Grazed	Ungrazed
Picloram	7.64 acres	9.24 acres
Picloram & 2,4-D	9.80 acres	12.70 acres
Dicamba & 2,4-D	7.45 acres	8.45 acres

Table 1 lists the soil-applied herbicides evaluated at the Denver Federal Center and the selective herbicides applied at the Marias River. The herbicides evaluated at Marias River were used alone and in combination with 2,4-D.

Application rates recommended by the manufacturers are in terms of pounds per acre of formulated product and are listed this way in table 2. At the Denver Federal Center, herbicides were applied at three rates in 1983 and two rates in 1984. The herbicides that were evaluated in Montana were applied at one rate per herbicide or combination of herbicides in 1984 and 1985. In 1986, the plots that were treated in 1985 on grazed and ungrazed rangeland were retreated at half the rate of the initial treatment.

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[3] Victor S. Miyahara is a botanist in the Division of Research and Laboratory Services, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

At the Denver Federal Center, the granular and pelleted herbicides were applied with a rotary vane-type herbicide applicator. The wettable powders and liquids were applied with 5 gallons of water per plot, using a garden sprinkling can. In Montana, the liquids were applied with a truck-mounted sprayer. This sprayer has a 300-gallon-capacity tank with a 42-foot boom.

The vegetation found in the Denver Federal Center site was mainly broadleaf annuals with a few perennials and grasses. At the Marias River site, the vegetation was annual and perennial grasses and broadleaf weeds. There were 25 quadrat vegetation samples collected randomly from each plot at the Montana site. The samples were collected before retreatment and 90-day posttreatment. Biological evaluations for types and density of vegetation in each plot were made at each sampling date.

RESULTS AND DISCUSSIONS

The plots at the Denver Federal Center were evaluated in late April and August. Results are as follows:

Herbicide 1. — There is still complete control of the vegetation at all three rates with a very slight lateral movement beyond the area reached last year (fig. 2).

Herbicide 2. — There was still very good control of all vegetation in the medium- and high-rate plots. Vegetation was starting to move back in the low-rate plot in August. The herbicide moved very little beyond the area reached last year (fig. 3).

Herbicide 3. — In April, only the high-rate plot showed some effect in controlling weeds; however, by August, even the high rate showed little effect on the weeds. As with the other herbicide plots, the herbicide moved very little beyond the area reached last year (fig. 4).

Herbicide 4. — There was a dense stand of thistle in all the plots, including the high rate; but in late August, the thistle showed some injury (fig. 5).

Herbicide 5. — Only the high-rate plots showed good control in April; but by August, some regrowth was observed (fig. 6).

Herbicide 6. — The high-rate plots showed very good control of the vegetation with some broadleaf weeds starting to reinvade plots in August. The herbicide is, apparently, staying within the treated area with very little lateral movement (fig. 7).

Herbicides 7 and 9. — There seemed to be very little weed control. A dense stand of kochia (*Kochia scoparia*) seemed to be slowing down the invasion of other weeds.

Herbicides 8 and 9. — There seemed to be little or no vegetation control as evidenced by a dense stand of kochia (*Kochia scoparia*).

The plots in the area around Marias River that were treated in 1985 and retreated in 1986 were reevaluated, and pre- and posttreatment vegetation samples were collected from each plot. Results are as follows:

Herbicide 10. — This herbicide was applied in 1984 to control leafy spurge (*Euphorbia esula*). Spring of 1985 evaluation showed a very high percent regrowth of this perennial weed; therefore, we did not reevaluate the plot in 1986.

Herbicides 8, 8 and 11, 11 and 12. — From the posttreatment vegetative samples collected from these plots in 1986, there was no significant difference in total production from the control and the treated plots. However, in the control plots, approximately 446 lb/acre of the total production was forbs; and in the treated plots, all but a trace of the vegetation collected was grasses. This appears to indicate that the grasses are reinvading areas vacated by the broadleaf weeds.

CONCLUSIONS

After 3 years of the soil-sterilant study at the Denver Federal Center, the following information was obtained:

Herbicides 1 and 2 are still giving good control at all rates tested, and herbicide 6 only at the high rate.

The herbicides did move from the treated area, but not to the extremes that would be of concern if used in the field under similar conditions.

Reported lateral movement of soil-sterilants in the field was a major concern, especially with herbicide 1. This was not, however, a major problem in this study, leading to the conclusion that soil type, treatment rates, and application methods interact to cause lateral movement of the herbicides from treated areas in some field locations.

The treatments in Montana in the area by the Marias River with herbicides 8, and 11 and 12 are in the second year of a 3-year evaluation. The efficacy of these treatments in inhibiting regrowth of the noxious broadleaf weeds is good. If the results of the treatments continue on schedule with a 50 percent regrowth inhibition the first year and 75 percent at the end of the second year; by the end of the third year, there should be over 90 percent control. Another good sign is that desirable grasses are reinvading the areas once occupied by broadleaf weeds.

Table 1. – Identification and composition of soil-applied herbicides

Herbicide No.	Common name	Chemical name and percent ai (active ingredient)	Formulation
1	Pramitol 5PS	2-methoxy-4, 6-bis (isopropylamino)-s-triazine 5.0 percent ai	Pellets
2	Spike	N-[5(1,1-dimethylethyl)-1,3,4-thiadiaxol-2-yl]-N-N dimethylurea 1.0 percent ai	Granules
3	Krovar I	Bromacil [5-bromo-3-sec-butyl-6-methyluracil] Diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea] 80.0 percent ai	Wettable powder
4	Oust	Methyl 2-[(4,6-dimethyl-2-pyrimidinyl) amino[-carbonyl] sulfonyl] benzoate 75.0 percent ai	Wettable powder
5	Tanzene	Simazine: 2-chloro-4,6-bis (ethylamino)-s-triazine Karbutilate: tert-butylcarbamic acid, ester with 3-(m-hydroxyphenyl) -1,1-dimethylurea 79.9 percent ai	Wettable powder
6	Atratol 90	Atrazine: 2-chloro-4-ethylamino -6-isopropylamino-s-triazine 90.0 percent ai	Wettable powder
7	Tordon 101	Picloram: 4-amino-3,5,6-trichloropicolinic acid 2,4-D: 2,4-Dichlorophenoxyacetic acid	Liquid
8	Tordon K	Picloram: 4-amino-3,5,6-trichloropicolinic acid	Liquid
9	Garlon 4	Triclopyr: (3,5,6-trichloro-2-pyridinyloxyacetic), butoxethyl ester	Liquid
10	Krenite	Ammonium salt of fosamine [ethyl hydrogen (aminocarbonyl) phosphonate]	Liquid
11	2.4-D	2,4-Dichlorophenoxyacetic acid	Liquid
12	Banvel	Dicamba: 3,6-Dichloro-O-anisic acid	Liquid

Table 2. – Application rates of soil-applied herbicides

Herbicide No.	Total formulation (lb/acre or oz/acre) (low, medium, and high ratio)	Formulation
1	217 lb 434 lb 868 lb	Pellet
2	400 lb 800 lb 1,600 lb	Granular
3	4 lb 8 lb 19 lb	Wettable powder
4	3 oz 6 oz 12 oz	Wettable powder
5	6 lb 12 lb 24 lb	Wettable powder
6	11 lb 22 lb 44 lb	Wettable powder
7 & 9 (mixture)	2.5 lb & 2.0 lb 5.0 lb & 4.0 lb	Liquid
8 & 9 (mixture)	1.0 lb & 2.0 lb 2.0 lb & 4.0 lb	Liquid
4 (low rate)	0.5 oz 1.0 oz 2.0 oz	Wettable powder
10	160 lb	Liquid
8	0.5 lb	Liquid
8 & 11 (mixture)	0.25 lb & 1.0 lb	Liquid
11 & 12 (mixture)	2.5 lb & 1.25 lb	Liquid

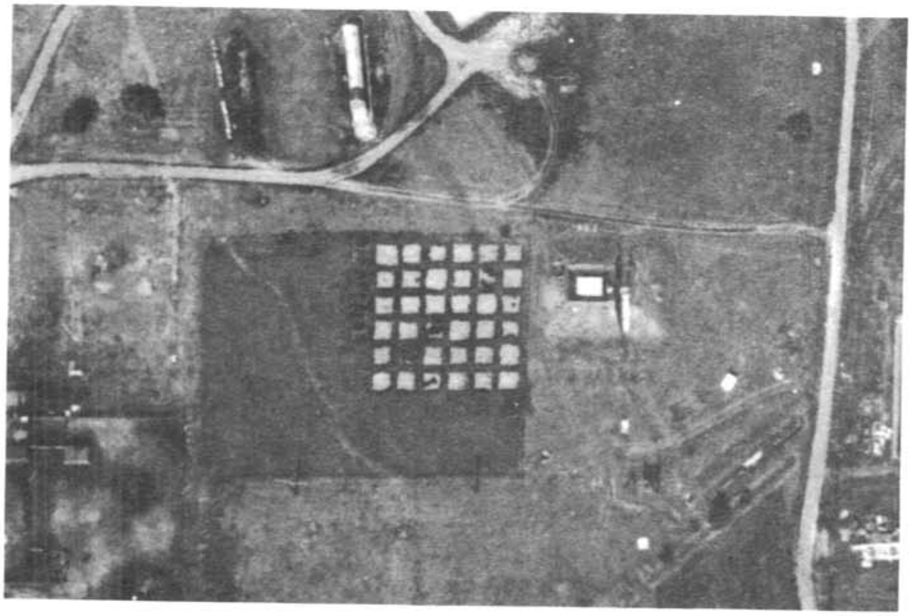

Figure 1. - Overview of plots at Denver Federal Center.

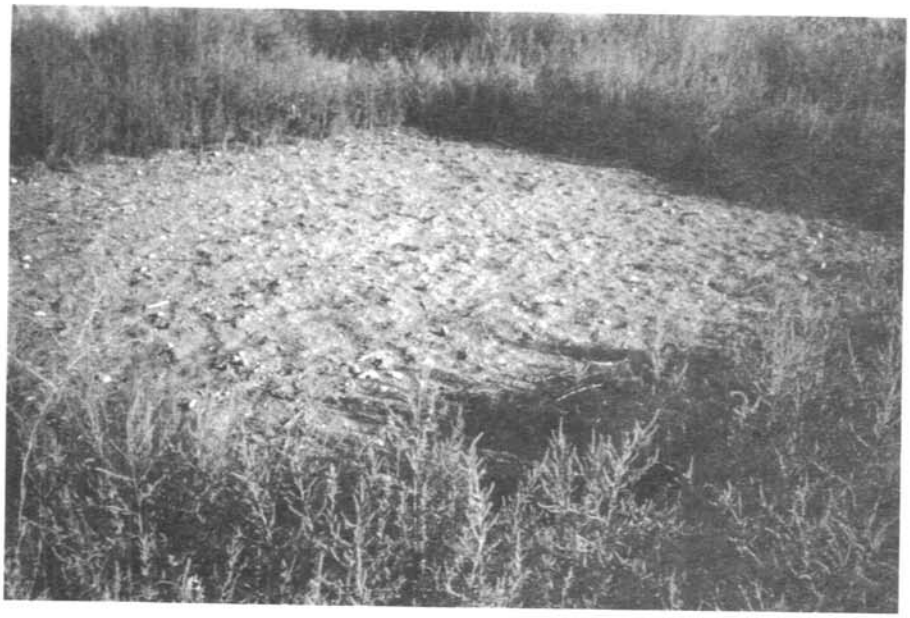

Figure 2. - Herbicide 1 treated in 1983.

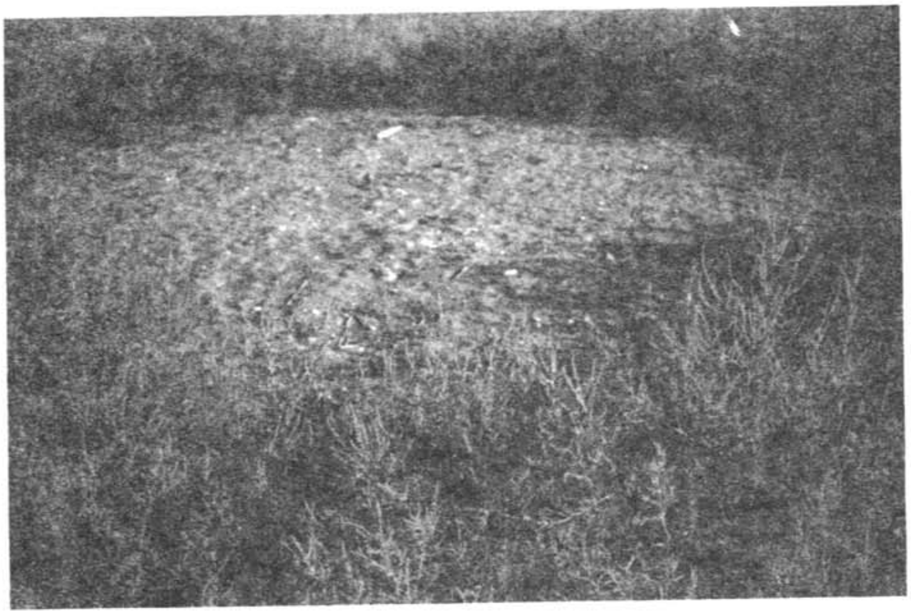

Figure 3. - Herbicide 2 treated in 1983.

Figure 4. - Herbicide 3 treated in 1983.

Figure 5. - Herbicide 4 treated in 1983.

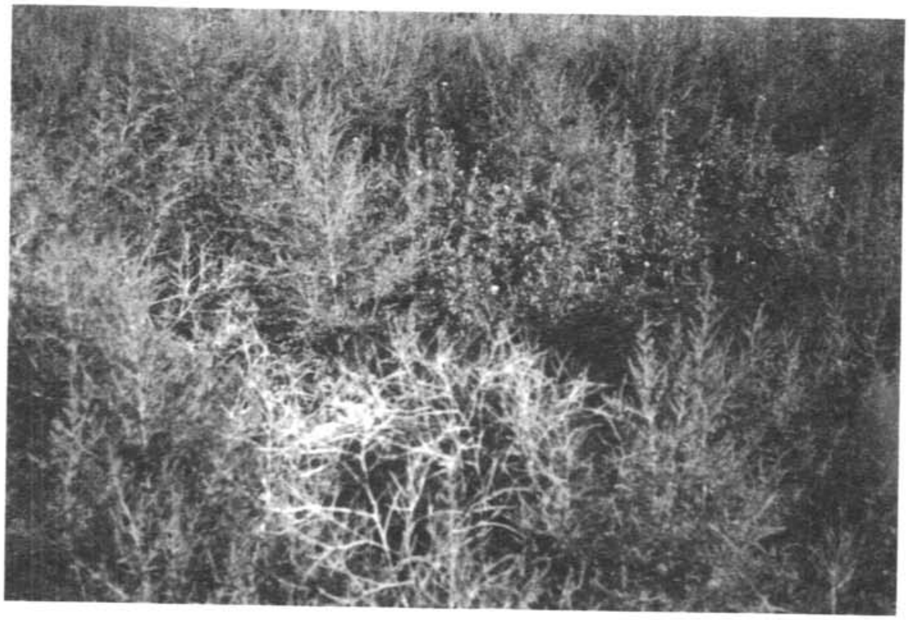

Figure 6. - Herbicide 5 treated in 1983.

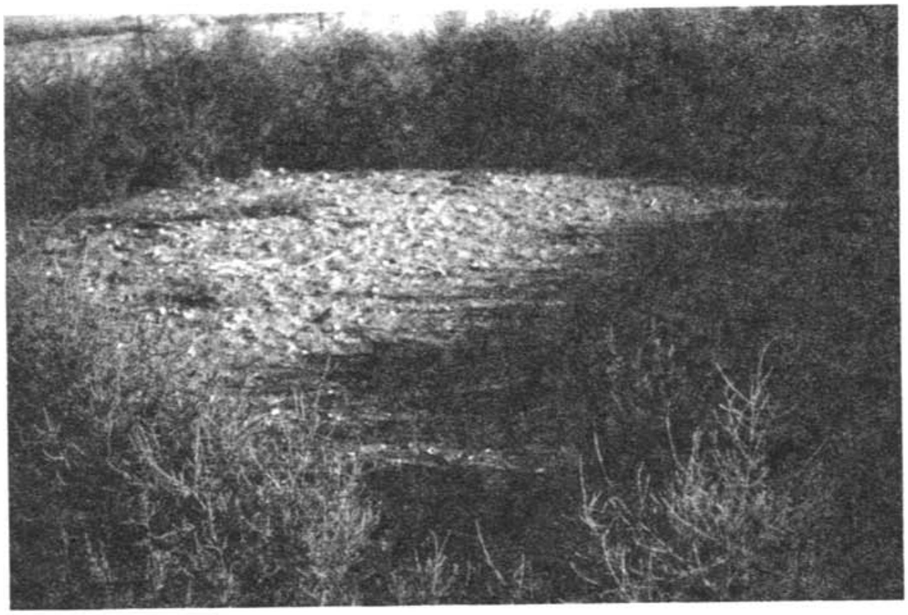

Figure 7. – Herbicide 6 treated in 1983.

FOUNDATION TREATMENT USING PNEUMATICALLY APPLIED CONCRETE

By Forrest R. Schall and Ted H. Bruce[4]

INTRODUCTION

The use of dental concrete as a foundation treatment is not new. This report discusses the various ways it can be applied on the rock foundation of a dam embankment and describes the specific methods used by the Bureau of Reclamation on the rock foundation of Sugar Pine Dam.

Sugar Pine Dam, a part of the Auburn-Folsom Project, is located in Shirttail Canyon, 25 miles northeast of Auburn, California. The dam is a central core rockfill embankment 185 feet high with a crest length of 689 feet at elevation 3650 feet. An ogee section spillway located on the left abutment is designed for the future installation of a 26-foot radial gate. No facilities for power generation were constructed.

Dental concrete is used to fill voids or to form a leveling course that provides a more uniform area for application of additional pneumatically applied concrete or earthfill.

Some 2,781 yd^3 of dental concrete were placed in the foundation: 1,988 yd^3 as pneumatically applied concrete, 569 yd^3 by crane and bucket, and 224 yd^3 behind forms. The engineer's estimate for the job was 2,616 yd^3; the overrun was 6.3 percent. The total area on the foundation cutoff covered with dental concrete was 50 percent.

CONCLUSIONS

Dental concrete, applied pneumatically, is a fast and efficient way of treating geologic discontinuities and irregularities exposed in a foundation. In the four areas at Sugar Pine Dam where the dental concrete to rock contact surface was exposed for inspection, the bond was found to be excellent, even where the concrete was placed against decomposed to intensely weathered material in a shear zone.

The methods and procedures used are thought to be reasonable. Placing dental concrete pneumatically expedited all phases of the dam embankment construction. No delays resulted from waiting for major areas to be formed or for concrete to be placed. The quantity of the concrete placed would have been much higher if it had to be formed.

The use of a truck-mounted concrete pump with an articulated placing boom was the most efficient way of transporting concrete to any part of the dam foundation. This equipment had the flexibility to pump into formed areas or into unformed irregularities. It was also able to shoot concrete over or into thin or restricted areas where protection against weathering was required. Using the concrete boom truck is an economical way of placing dental concrete, whether it be pumped or pneumatically applied.

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[4] Forrest R. Schall and Ted H. Bruce were employed by the Bureau of Reclamation in the Mid-Pacific Region at the time of this study.

CONSTRUCTION CRITERIA FOR FOUNDATION AND ABUTMENT SURFACE TREATMENT

After completion of the dam foundation excavation, additional foundation treatment was required under the impervious core and filter zones. The major purposes of this additional treatment were (1) to develop a uniform shape to the foundation that would reduce near verticals and overhangs to slopes no steeper than 1/2:1, (2) to prevent or reduce seepage along and adjacent to the contact between the core and the foundation, and (3) to improve the bond between the embankment and the foundation by proper shaping.

Where rock is exposed to form the foundation in the abutments and valley bottom, substantial treatment is normally required. It is general practice to provide more treatment beneath the impervious core section than beneath the upstream and downstream shells. In addition, the foundation beneath the embankment filter zones frequently receives the same treatment as the area beneath the core. The amount of treatment required depends primarily on the condition of the exposed rock and on the number of defects at the surface.

At Sugar Pine Dam, dental concrete was applied to the foundation surface at the contact between zones 1A and 2 for foundation shaping and treating geologic discontinuities and irregularities (fig. 1). The general construction for the treatment of the foundation was performed to eliminate vertical faces more than 1 foot high or steeper than a 1/2:1 slope so that there would be minimal differential settlement or tensile cracking of the embankment.

All cracks, joints, and shear zones were treated. Treatment consisted of cleaning each opening by air and/or water jet, air spading, and barring it to a depth three times its width and refilling with concrete. The shear zones were treated to eliminate the contact path of permeability between them and zone 1A and to protect against piping of embankment into the foundation or loss of fines from the foundation into the embankment filter zones. All features, even of the narrowest, that extend upstream to downstream across the cone and filter zone contact require special attention.

Foundation Preparation

The difference in the quality of acceptable foundation between the impervious zone and the remainder of the dam foundation is reflected in the cleanup required. Before embankment material is placed on any rock foundation within the impervious zone, the rock surface should be cleaned to remove loose and objectionable materials. In portions of the foundation outside the central contact area, cleanup by construction equipment usually achieved adequate results.

The cutoff trench was cleaned adequately with air and water as the original excavation progressed to allow geologic mapping (fig. 2). Before embankment placement, the foundation was marked for shaping and fault treatment. Only an adequate amount was marked to stay ahead of the contractor's operations.

General Geology at Sugar Pine Dam

The rock in the foundation is a fine-grained, dense amphibolite derived from low-grade metamorphism of volcanic flows and tuffs. The amphibolite rock is fractured with various types of geologic discontinuities, and two areas located in the upper left abutment contain intensely weathered and intensely fractured amphibolite. These two areas were treated with a thin 3-inch blanket of pneumatically applied concrete. The most prominent geologic features in the foundation are the joints and the shear zones associated with joints. These joints were assigned letters during the preconstruction investigation. Listed below in order of importance with reference to pneumatically applied concrete are the joints with their attitudes.

Joints	Range in strike	Range in dip
A	N. 70° E. to E.-W.	45° to 65° N.W.
B	N. 70° W. to N. 87° W.	45° to 70° S.W.
F	N. 55° E. to N. 70° E.	35° to 42° S.E.
D	N. 15° E. to N. 45° E.	12° to 30° N.W.
C	N. 55° E. to N. 70° E.	16° to 30° S.W.
Foliation planes	N.-S. to N. 30° W.	65° to 85° N.E.

Foundation Shaping Treatment

The A-joints strike nearly normal to the dam axis and dip steeply out of the left abutment into the right abutment. They predominate upstream of the dam axis in the lower left abutment and in the lower to mid-right abutment. The A-joints commonly created overhang irregularities ranging in height from 1 to 5 feet. These overhangs were treated with pneumatically applied concrete for foundation shaping (fig. 3).

Occasional A-joint faces on the left abutment are steeper than 1/2:1 (63-1/2°) (fig. 4). In such a situation, a bulkhead was constructed in an effort to hold the dental concrete. After dental concrete was applied to these faces, the slope was flatter than 1/2:1.

The B-joints dip steeply out of the right abutment into the left abutment. These joints are predominantly exposed on the right abutment downstream of the dam axis. As in the case of the A-joints, the B-joints create a similar problem with occasional faces steeper than 1/2:1. Consequently, these joint faces required a bulkhead and dental concrete flatter than 1/2:1. The B-joints created no problems on the left abutment.

The F-joints have similar attitudes to the B-joints but a flatter dip. These joints are generally exposed on the right abutment but do not pose any problems on the left abutment. The F-joints only required dental concrete treatment when they were combined with foliation planes. On these few occasions, a bulkhead was necessary to shape the slope.

Although D-joints were very prominent on the left abutment, they seldom required dental concrete treatment. These joints dipped out of the left abutment at a low angle and controlled most of the slope excavation. Only in combination with A-joints did any D-joints need treatment.

Foliation planes commonly created overhangs in the upstream 2:1 cut slope of the left abutment. In some cases, the overhangs exceeded 10 feet vertically and required construction of a bulkhead (fig. 5). Occasionally, overhangs created by foliation planes were treated on the downstream portion of the right abutment.

Shear Zone Treatment

Most shear zones treated in the foundation cutoff area were sheared joints that had the same joint letter designation. Decomposed to intensely weathered material within the shear zones was removed to a depth of three times the thickness by air spading (fig. 6). After removal of the weathered material, dental concrete was applied as treatment.

A-joint shears are predominant in the lower left abutment and in the lower to mid-right abutment. Two predominant A-joint shears exposed in the right abutment were continuous from upstream to downstream (fig. 7).

A few D-joint and C-joint shear zones were treated on both the left and right abutment. One D-joint shear zone exposed in the lower right abutment is continuous from upstream to downstream.

One prominent shear zone, termed S-1, traverses diagonally from downstream to upstream in the left abutment. The strike of S-1 ranges from 30° N. to 50° W. and dips 25° to 35° NE. or upstream and into the left abutment. Because of a special near vertical treatment excavation for S-1, bulkheads were required to hold the dental concrete.

Blanket Weathering Treatments

Two areas in the upper left abutment were treated with a thin 3-inch blanket of dental concrete. In both these areas, the amphibolite was intensely weathered and intensely fractured. One area is located in the downstream portion of the left abutment below the spillway structure, and the other area is located left of the spillway.

These blanket treatments were placed to protect the amphibolite from excessive moisture and freeze-thaw conditions. Exposure of the two areas to these weather conditions would cause further breakdown and excessive raveling of the rock (fig. 8).

Where the catch point was nonexistent or limited, forming of concrete was required. Forms were placed on a 3/4:1 to 1/2:1 slope with space between the rock to allow access behind the forms to consolidate the concrete with a vibrator. Concrete was then pumped behind the forms using the pump without air pressure and nozzle.

Forming materials consisted of 4- by 6-inch whalers, 2- by 12-inch form material, she-bolts to hold whalers, and coil ties embedded in the rock.

One area in particular, on the right abutment, had a large bench that needed to be filled with concrete. A crane and bucket (fig. 9) were used to place a low slump, three-fourths inch, concrete. The depth of the concrete ranged from 1 to 8 feet. In this instance, it was more practical and economical to use the crane because the area was not formed, and the concrete was placed to a depth of 8 feet (fig. 9).

Another method of placing dental concrete was by end dumping directly from the transit mixer into large holes in the river bottom where access was available. The concrete was then consolidated using a 3-inch vibrator (fig. 10).

PNEUMATICALLY APPLIED CONCRETE

A Thomsen 875 concrete pump was used to pneumatically place the 3/4-inch, maximum-size aggregate mix into the cracks and crevices (fig. 11) of all faults. A properly operating air compressor of ample capacity is essential to a satisfactory shotcrete operation. The compressor should maintain a supply of clean, dry air adequate for maintaining sufficient nozzle velocity for all parts of work while simultaneously operating a blow pipe for clearing away rebound. A 1-inch air line was attached to the 3-1/2-inch nozzle, and a constant pressure of 100 lb/in^2 was used. This proved to be the most effective pressure for achieving a good bond with less than 3 percent rebound.

Rebound is aggregate and cement paste that ricochet off the surface during the application of shotcrete because of the collision with the hard surface or with the aggregate particles themselves. The amount of rebound varies with the position of the work, air pressure, cement content, water content, maximum size and grading of aggregate, and thickness of layer.

Initially, the percentage of rebound is large, but it becomes less after a plastic cushion has been built up. Rebound is much leaner and coarser than the original mix. The cement content of the inplace shotcrete is, therefore, higher because of rebound; this increases the strength but also increases the tendency toward shrinkage cracking.

Rebound should not be worked back into the construction by the nozzleman nor salvaged and included in later batches because of the danger of contamination and of variability in the cement content, in the state of hydration, and in the grading of the aggregate.

The Thomsen 875 concrete pumper has a fully articulating boom capable of rotating 360°. It is capable of pumping 125 yd^3/h; however, an average of only 23.5 yd^3/h was attained because of difficult accessibility, the small size of the areas treated, and the fact that the truck had to move frequently because it could not reach beyond 80 feet.

The slump of the concrete was a maximum of 6 inches at the pump. This was reduced to approximately 1-3/4 to 2 inches by the loss of entrained air as a result of impact, the friction of the pumpline, and the blast of air at the nozzle. The resulting 2-inch slump was found to be ideal for placing concrete on the rock foundation. Air temperature is a very important variable in determining the slump needed for the placement. When the wet shotcrete was placed, the air temperature was ± 91 °F. As the air temperature during placing increased, an increase in slump was needed at the pump. Wet fogging of the surface rock is important before placing shotcrete, because it provides a better bond between rock and concrete.

One advantage of using the shotcrete method was that the full range of treatment required for filling cracks, openings, and excavated shears, and for shaping the foundation could be performed at this time. All sharp changes in the slope were reduced by placing the shotcrete as a filler.

The final rock surface should have smooth contours against which soil can be compacted by heavy equipment. In more extensive areas where there were large overhangs, multistage application was necessary to eliminate sagging of the shotcrete. This resulted in a void beneath the overhang. The ideal way of placing wet shotcrete beneath overhangs is to build it up in 6- to 8-inch lifts, then let it set or stiffen sufficiently before applying another lift. Satisfactory results were achieved with varying depths up to 3.28 feet in thickness. There was excellent penetration into cracks and crevices and excellent bonding to the rock foundation. This was verified by an NX core sample taken on the left abutment beneath a large rock overhang (fig. 12).

After the wet shotcrete was placed, it was important to blow off with air or to sweep away with a stiff-bristled broom all rebound or loose material. This was done before applying curing compound to reduce the amount of compound required. This procedure provides a bonding surface free of unconsolidated concrete that, otherwise, could create percolation paths. It results in surfaces rough enough to provide adequate bonding of the earth materials.

Wet shotcrete was used for blanket treatment on highly weathered rock on the left abutment to prevent deterioration over prolonged exposure. This eliminated further weathering of the rock. A thickness of ± 2 to 3 inches was applied to this area with excellent results.

Concrete Control

The pneumatically applied concrete mix was tested both before pumping and after being discharged from the nozzle. Concrete cylinders (6 by 12 inches) were cast from the batch before pumping for the purpose of testing compressive strength. At that time, tests for slump, unit weight, and percent of entrained air were performed. Four-inch cubes were also made.

All the slump, unit weight, and percent entrained air tests were performed according to procedures in the *Concrete Manual*.[1].[5] The average results are shown in the following table.

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[5] Numbers in brackets refer to entries in the bibliography

Test results of pneumatically applied concrete*
(averages of 10 test batches)

	Before going into pump	Coming out of nozzle	Percent loss
Slump	4-3/4 inches	1-1/2 inches	69.4
Percent air (gravimetric)	5.4	1.6	70.4
Percent air (air meter)	6.9	3.4	50.7
W/CP	0.71	-	-
Unit weight	3,791.93 lb/yd^3	3,950.93 lb/yd^3	-

* Concrete mix consisted of 615 pounds of cement, 65 percent sand, and 35 percent 3/4-inch maximum-size aggregate per 1.3 yd^3.

Four-inch cubes. — The shotcrete cubes were made in plywood forms with a 4- by 4-inch opening and a 4-inch depth. One form was used for 16 cubes. The shotcrete nozzle was held between 2.5 to 3 feet away from and perpendicular to the box and moved back and forth across the box until all the cells were filled. The concrete was then struck off level with the box and allowed to set up for 24 hours. The cubes were then stripped from the box and stored according to designation 29, paragraph 4(b), page 567, of the *Concrete Manual*: "(b) Specimens made in the field at the site of placement should be kept, as nearly as practicable, at 73.4 °F and protected from the sun and from moisture loss." These cubes were tested in compression at 2, 4, 7, and 28 days. The average strength of the 4-inch cubes is plotted on figure 13. At 90 days (not plotted), the cubes had a strength of 4,022 lb/in^2.

Six- by twelve-inch cylinders. — The cylinders were made according to designation 29 of the *Concrete Manual*. Average strengths are plotted on figure 13.

Observations

The size of the orifice on the discharge nozzle is very important. Experimentation was performed reducing the nozzle diameter (fig. 14) from 3-1/2 inches to 2-1/2 inches. The same shotcrete mix and slump were used, but the shotcrete was wetter when discharged through the smaller opening because of the greater pressure. The nozzle diameter was changed back to 3-1/2 inches. Through more experimentation, it was observed that the drier the concrete at discharge, the better bond to the rock surface. Furthermore, the shotcrete mix must have a higher slump at the pump hopper than at the nozzle. This higher consistency allows a more uniform flow from the pump through the hose and nozzle. Because of the lack of control of the flow at the nozzle, the pump operator regulates the flow. The person applying the shotcrete must maintain visual contact with the pump operator to instruct him when to start and stop the flow.

The pumpline became easily blocked with oversized aggregate, causing downtime of up to 1 hour to clear the line. Material used for shotcrete mix must be properly graded to alleviate this problem.

Suggestions for Applying Wet Shotcrete

1. Apply normal to the surface, less rebound will occur.

2. A good distance from the nozzle to the rock surface is 1 to 3 feet.

3. Apply beneath overhangs slowly enough to reduce or eliminate sagging.

4. Apply curing compound as soon as possible after placement. This will help reduce shrinkage cracks.

5. Before placing the embankment, slush grout shrinkage cracks in the same manner that other cracks are treated.

6. Keep lifelines ahead of placing to ensure some continuity on steep slopes. Lifelines are necessary on steep slopes for the laborer to be able to handle the nozzle.

7. Provide sufficient air pressure at the nozzle. This is important because proper air pressure reduces slump and sag in the concrete.

8. In open cracks, put the nozzle in the hole to ensure filling without voids.

9. Start at the bottom of the area to be treated with shotcrete and work up. This will eliminate the collection of rebound in depressions and cracks below the placement.

Inspection

The pneumatically applied concrete operation should be continuously inspected by a qualified inspector who should check materials, forms, reinforcing, ground wires, application equipment, application of material, curing, and protection against freezing. Each layer of shotcrete placed should be systematically sounded with a hammer to check for drummy areas. Cores should be taken from the structure as required to verify the quality of material in place, especially for structural shotcrete; such cores should be taken as early in the job as practicable so that the data obtained can be used to improve the later work.

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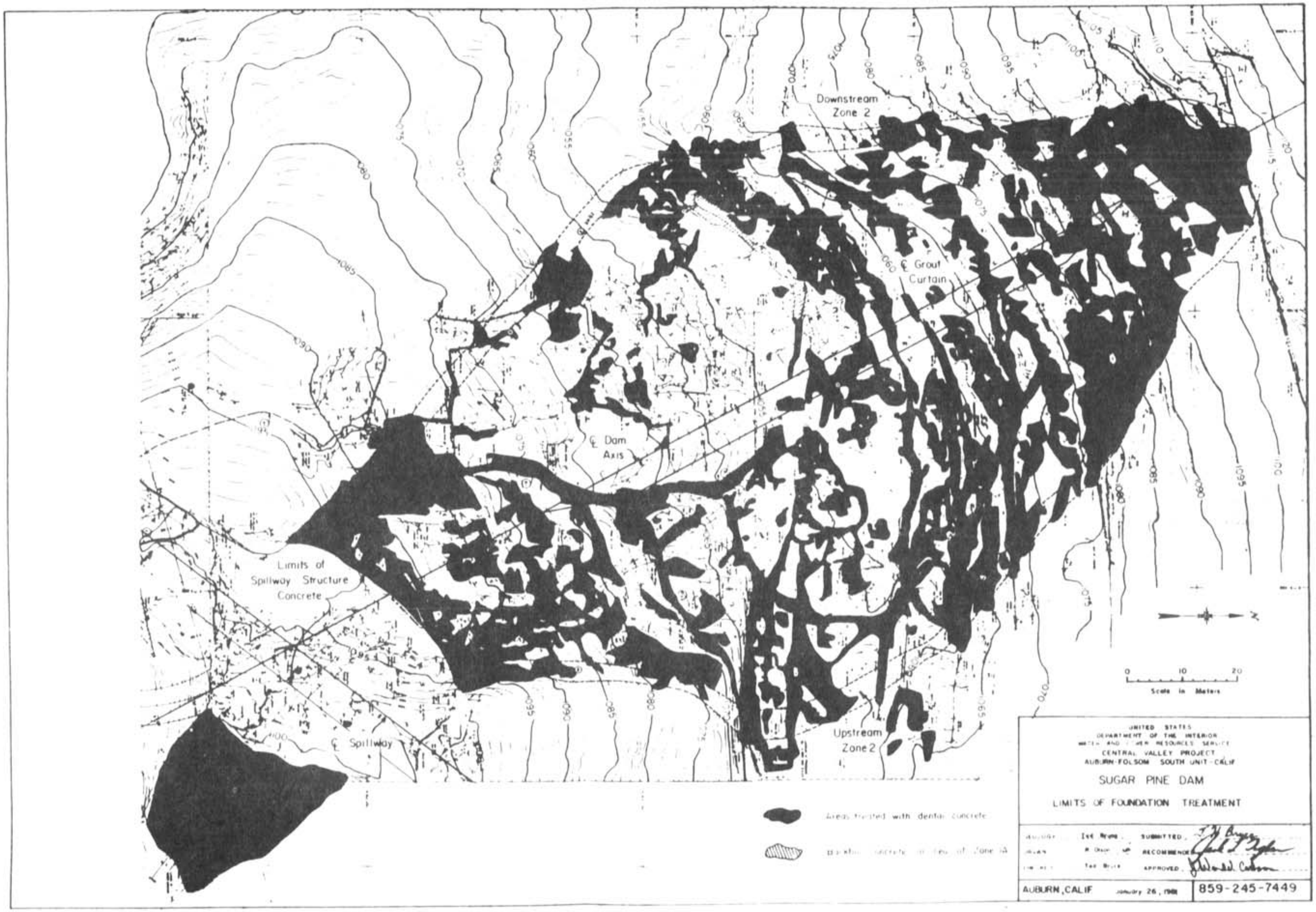

Figure 1   Limits of foundation treatment at Sugar Pine Dam. Darkened areas were treated with dental concrete. 859-245-7449

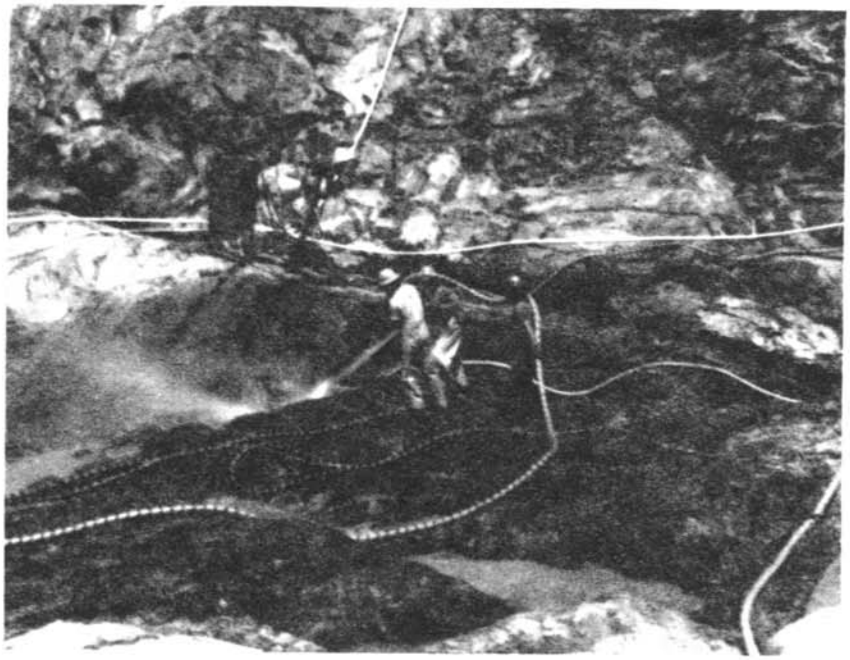

Figure 2. - Cleaning the cutoff trench foundation with air and water before geologic mapping.

Figure 3. - Overhangs treated with pneumatically applied concrete for foundation shaping.