Reclamation Research in The Seventies— First Progress Report

A Water Resources Technical Publication

RESEARCH REPORT NO. 26

United States Department of the

INTERIOR

Bureau of Reclamation

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for the wise use and conservation of our land and water, energy and minerals, fish and wildlife, and park and recreation resources. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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PREFACE

The goal of research in the Bureau of Reclamation is to achieve the high degree of knowledge and proficiency needed to:

Improve techniques for more efficient water management, conservation, salvage, and reuse throughout the hydrologic cycle.

Improve the reliability and efficiency of hydroelectric power generation and transmission.

Identify and develop means for measuring and describing the social, economic, and environmental impacts of water and related resources development.

Determine economic, social, and environmental situations which can be enhanced by water resources development and establish how this can best be achieved.

Determine ecological and water quality impacts of water resources development, how deleterious effects can be mitigated, and how beneficial effects can be enhanced.

Improve project planning concepts and procedures.

Advance engineering design concepts and procedures.

Improve construction materials, methods and techniques.

This report summarizes the Bureau's Congressionally-funded water resources research programs. Unlike past editions, this first progress report for the Seventies includes the major research activities of the seven regional offices of the Bureau, as well as those of the Engineering and Research Center in Denver.

The format of this edition also differs from previous ones. The material, with the exception of Project Skywater, is organized and presented under subject categories established by the Committee for Water Resources Research (COWRR) of the Federal Council for Science and Technology. These categories are widely accepted among Federally-funded water resources research institutions.

The Bureau's research, except for Project Skywater, lies within five of the COWRR research categories. Each of the five is described at the beginning of the section dealing with that subject, and subdivisions within each of the categories are also described. Each subcategory is further composed of one or more individual research projects. Project Skywater, which includes studies within several COWRR categories, is presented as a single program.

The report presents the work of many Bureau engineers and scientists in the numerous disciplines involved in water resources development, conservation, and utilization. Some of the projects discussed are long-term studies of physical properties and behavior of materials, some are continuing studies of basic physical problems facing all water resources development organizations, and many are new studies of social, economic, ecological, and environmental concepts.

In keeping with national policy, the unique, unusual, or expensive-to-duplicate facilities in the Bureau's research laboratories are made available to the national scientific community to the maximum extent practicable considering the Bureau's own work requirements. Most of the Bureau's facilities are described or pictured in this report. If qualified scientific and technical personnel, and particularly academic personnel, wish to use specific facilities in pursuing their work, inquiry should be made to: Chief, Division of General Research, Bureau of Reclamation, P.O. Box 25007, Denver Federal Center, Denver, Colo., 80225.

This report covers significant progress made on the full range of Bureau research programs. Certain continuing routine studies not listed here may be found in previous reports covering the years 1965, 1966, 1967, 1968, and 1969.

Other water resources technical publications which may be of interest are listed on the inside back cover.

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PROJECT SKYWATER

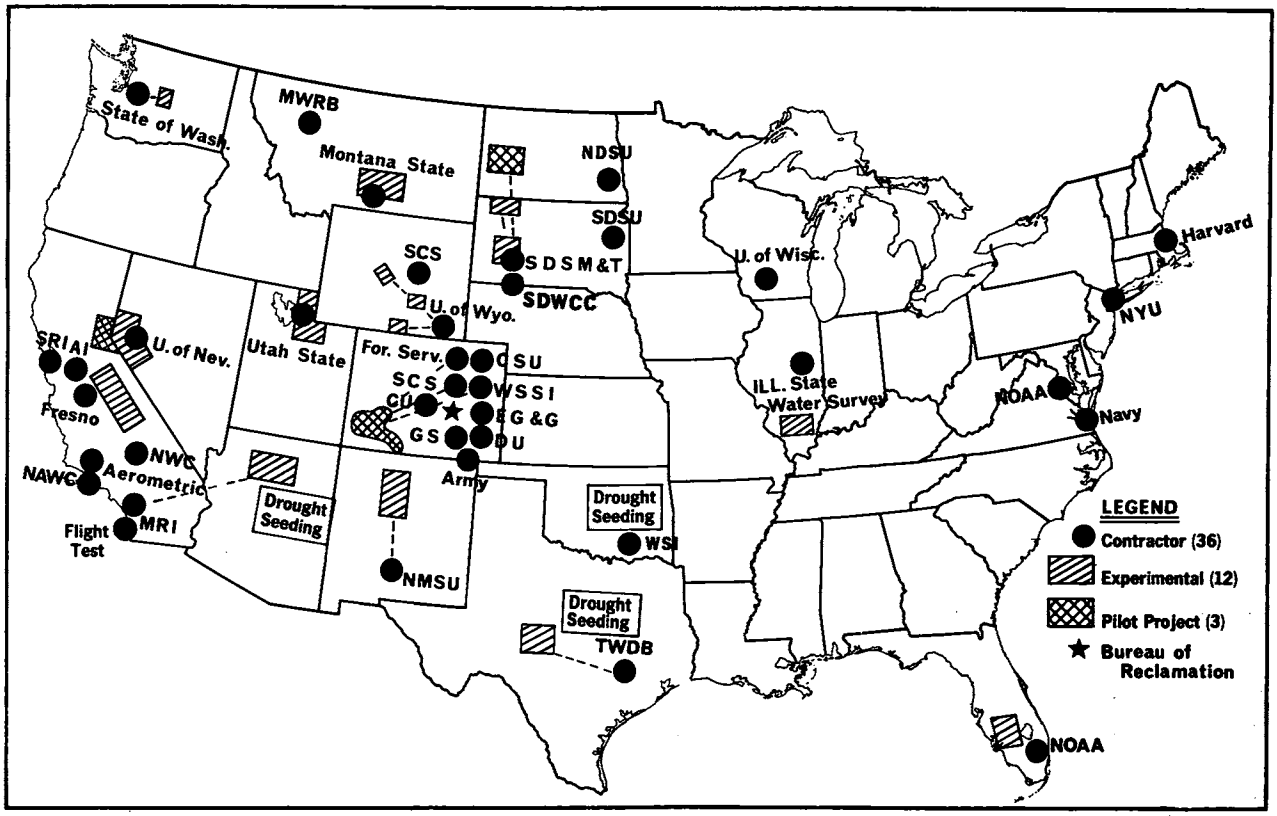
The 87th Congress in 1961 directed the Bureau of Reclamation to conduct research on increasing precipitation by cloud-seeding. This was the origin of the Bureau's Project Skywater.

Project Skywater is a coordinated effort of meteorologists, engineers, physicists, chemists biologists, mathematicians, lawyers, economists—in short, specialists in all fields related to weather modification. The goal is to tap the rivers in the sky and put together systems to manage—to the extent Nature will allow—the amount and distribution of precipitation in an efficient, economic, and socially acceptable manner. The program is described in the annual Bureau of Reclamation brochures entitled "Project Skywater."

About 90 percent of Project Skywater activities is conducted through contracts with colleges and universities, private organizations, State agencies, and other Federal agencies. The Division of Atmospheric Water Resources Management of the Denver Engineering and Research Center provides overall direction and coordination for the large variety of field and nonfield efforts that make up Project Skywater.

PROJECT SKYWATER CONTRACTORS—FY 1972–73

Aerometric Research, Inc.
Atmospherics, Inc.
Colorado State University
EG&G, Inc.



Project Skywater activities, FY 1972–73.

Flight Test Research, Inc.
Fresno State College Foundation
Harvard University
Meterology Research, Inc.
Montana Department of Natural Resources (formerly Montana Water Resources Board)
Montana State University
Naval Weapons Center
Navy Weather Research Facility
New Mexico State University
New York University
North American Weather Consultants
North Dakota State University
South Dakota School of Mines and Technology
South Dakota State University
South Dakota Weather Control Commission
Stanford Research Institute
State of Washington
Texas Water Development Board
U.S. Army
U.S. Forest Service
U.S. Geological Survey
U.S. National Oceanic and Atmospheric Administration
U.S. Soil Conservation Service
University of Colorado
University of Denver
University of Illinois (Illinois State Water Survey)
University of Nevada (Desert Research Institute)
University of Oklahoma
University of Wisconsin
University of Wyoming
Utah State University
Weather Science, Inc.
Western Scientific Services, Inc.

ACCOMPLISHMENTS—PROJECT SKYWATER

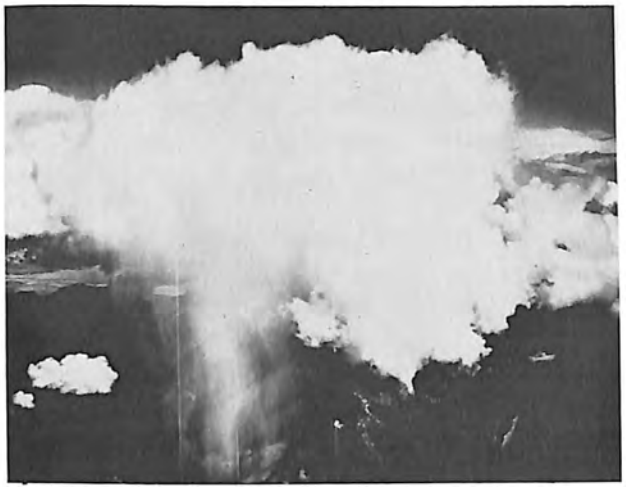
System Testing—Pilot Projects

Advances in cloud seeding technology during the 1960's led to the establishment of several pilot projects in water-short river basins. The first of these (though not the first to begin actual seeding operations) was the Upper Colorado River Basin Pilot Project. Located in the San Juan Mountains of southwestern Colorado, the target area was selected so that potential inconvenience and damage to the public were minimized. After several years of equipment and instrumentation installation and testing, seeding operations began in the 1970–71 winter season. Seeding will continue for four winter seasons.

The precipitation management system used in the Upper Colorado River Basin Pilot Project consists of a number of ground-based silver iodide generators arranged so that a fixed area can be targeted. Clouds that form when moist air is lifted over the massive mountain barrier in winter are the subject of this system. Wind direction, wind speed, and the temperature of the cloud tops are important criteria in deciding whether or not an approaching storm can be seeded effectively. Seeding when cloud-top temperatures are between about –14° C and –23° C is associated with precipitation increases. When the cloud-top temperature is colder than –23° C, precipitation decreases are to be expected.

This temperature dependency is explained by the threshold of activity of natural precipitation initiators. Natural nuclei do not become

seeding opportunities were maximized, and active in large numbers until the temperature is below some value, about –23° C in the Colorado Rockies. When artificial nuclei, active at higher temperatures, are introduced into the warmer clouds, the precipitation process can be enhanced.



The left half of this cloud was seeded and is precipitating, while the unseeded right half is not.

Because an operational precipitation management system includes consideration of nonmeteorological effects, several other studies are associated with the Upper Colorado River Basin Pilot Project. In 1970 a preliminary ecological study was completed. Its objective was to identify those elements of the San Juan ecosystem that would be affected by a change in the winter season precipitation and whose study over the 4-year period of the project would result in meaningful conclusions. The follow-on field study was begun in the fall of 1970 to examine elements of both forest and alpine ecosystems.

To identify the relationship that might exist between precipitation management and avalanches, the Bureau began a study in the San Juan area. Seismometers were installed to gather data that, hopefully, can be used to warn of impending slides and provide for further precipitation management research.

The first pilot project to begin seeding operations was in western North Dakota. Here, airborne generators dispensing silver iodide

A resident of the area services a precipitation gage in the Colorado River Basin Pilot Project area.

Ecologists make a careful study of alpine plants in an attempt to detect the environmental effects of the Colorado River Basin Pilot Project.

are used to seed summer convective clouds of the Northern Great Plains. The project began

its third season of seeding in the spring of 1971. Although five summers of operation are needed for a reliable statistical analysis, examination of the existing data suggests precipitation decreases on seed days when using this particular seeding system.

The newest pilot project is located at the headwaters of the Truckee River, which drains into Pyramid Lake. The Pyramid Lake Project uses ground-based silver iodide generators to seed winter clouds that form over the Sierra Nevada. The precipitation management system here is similar to that used in the Upper Colorado River Basin Pilot Project, but much of the equipment (generators and mountain-top radar) is remotely controlled from the project headquarters. While some seeding operations were conducted in 1970, the first year, the project was primarily concerned with installation and testing of system components. As in all systems, the components of a precipitation management system must be attuned to the particular situation at hand.

System Development—Laboratory and Field Experiments

Each component of the precipitation management systems tested in the pilot projects—be it a technique or hardware item—was previously developed in one or more laboratory or field experiments. The largest number of accomplishments of Project Skywater comes from these sources. For convenience, discussion of system development will be divided into four parts: seeding techniques, instrumentation, modeling, and socioeconomic and environmental implications.

Seeding Techniques.—The cloud-top temperature criterion mentioned in discussion of the Upper Colorado River Basin Pilot Project was first identified in a National Science Foundation (NSF) study conducted in Colorado. Since then, several Project Skywater contractors have stratified their data by temperature and have found a similar temperature dependency. The NSF study actually used the temperature at a specific pressure level in the atmosphere—500 millibars (about 18,000 feet)—because this was about the height of the cloud tops in that experiment. Project Skywater scientists found that the mean height of cloud tops varied so much from area to area that use of a single standard level for all projects was inadequate. Most of the field projects have now developed techniques to obtain the cloud-top temperatures.

The seeding system used in the North Dakota Pilot Project came from an earlier field experiment in South Dakota. Results from the South Dakota experiment for the 1969 and 1970 summer seasons also indicated a general decrease in precipitation on days when clouds were seeded as compared with nonseeded days. Further analysis of the data suggested that, by chance, the nonseeded days were just naturally wetter than those randomly selected as seed days.

A second South Dakota experiment is comparing silver iodide seeding and salt seeding with no seeding. Both the silver iodide and the salt are dispensed from aircraft. In this phase of development, radar is used to evaluate the results of the seedings. Advanced concepts of tying radar data to computer processing are being applied to yield the maximum amount of information while the experiment is in progress and still preserve the information for more leisurely analysis at a later time. Although insufficient data are available for firm conclusions, early results indicate that precipitation is initiated at higher temperatures in clouds seeded with salt than in those seeded with silver iodide, and both salt and silver iodide cases showed precipitation echoes at higher temperatures than unseeded cases.

Salt and silver affect the physics of clouds in quite different ways. Salt affects the coalescence process, while silver iodide affects the nucleation process. An outgrowth of the South Dakota Project, not yet tested, is the hypothesis that seeding appropriate clouds with both salt and silver iodide will maximize the total seeding effect.

A study of warm clouds (clouds whose temperatures are everywhere higher than 0° C) over Texas showed that the natural precipitation processes in these warm clouds tend to suppress subsequent cloud development. As soon as the coalescence process has produced droplets large enough to fall, the downdrafts associated with the falling droplets begin to dissipate the cloud. The study found evidence that substantial cloud growth existed only

when there was a clustering of clouds, permitting new updrafts to take over from the dissipating cells.

Studies of convective clouds over Arizona led to a greater understanding of precipitation physics, including the behavior of natural and artificial nuclei. This information is being used to improve numerical models of cloud development and precipitation processes.

A field experiment in northern Utah is comparing airborne and ground-based seeding techniques for treating winter orographic clouds. After two seasons, results show precipitation increases from both airborne and ground-based seeding. The target for the airborne seeding was much smaller than that for the ground-based seeding, and one of the tests was to see whether such a precise target area in mountainous terrain could be affected. Preliminary evidence indicates that precipitation in the target area was increased, while that in the control areas was not. Both airborne and ground seeding modes used an 8-hour test period, with seeding in either the first or the second 4-hour block. However, evaluation of the ground-based experiment indicates that a 24-hour experimental period is more suitable for the kinds of storms that occur over the Wasatch Mountains. There is, as yet, no evidence showing that one seeding mode is clearly superior to the other. A hoped-for outcome of this experiment is an indication of how the two modes can be used together to optimize the treatment of winter orographic storms.

Studies over the past decade have shown that many materials are as good as, or better than, silver iodide for seeding clouds. In 1970 and 1971, several of these materials were studied in laboratories and in the field. Liquid propane and metaldehyde were successfully field tested, though neither is completely ready for operational use.

Staff scientists at the Bureau's Engineering and Research Center are working on several other techniques, including the use of compressed air as a seeding agent. As the compressed air is released, it expands and thereby rapidly cools to well below 0° C. The water vapor changes to tiny ice crystals, which then act as natural nuclei in the precipitation process. The obvious advantages of essentially unlimited supplies of the material and its non-

A helicopter delivers material to a remote mountain-top site for construction of an instrumentation station.

contamination of the environment make compressed air seeding an attractive alternative, though many problems must be overcome.

Progress has been made in understanding

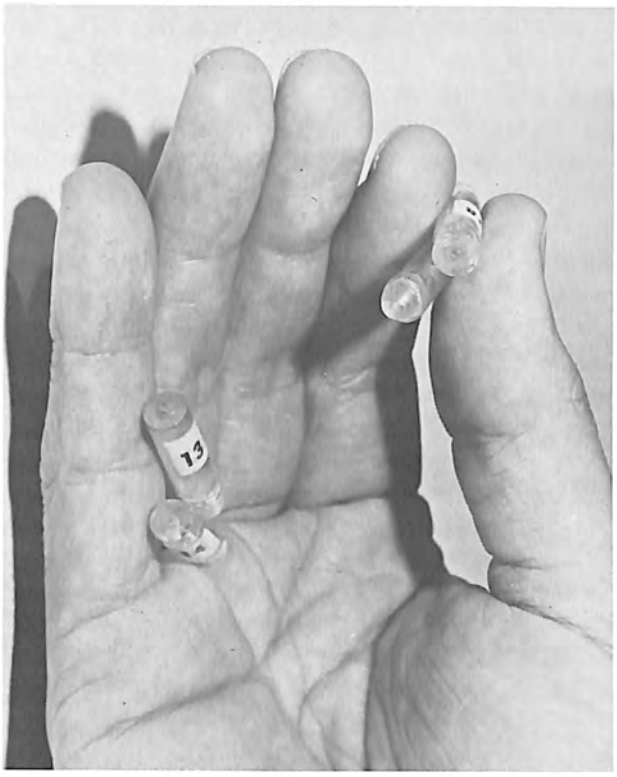
A typical instrumentation station used in Project Skywater.

the precipitation processes in both natural and seeded clouds. The significance of any given element of this progress is almost impossible to assess until all the other elements are in place.

Development of Nozzles for Seeding.— Cloud seeding technology has advanced to a point where the physics of clouds is relatively well understood. However, it has become very desirable to develop new equipment for efficient cloud seeding. Research began in 1970 for development of nozzles for two specific applications: (1) spraying liquids for seeding warm weather clouds, and (2) supersonic nozzles for generating ice embryos to act as seeding nuclei for cold weather clouds. The study is being accomplished by an interdisciplinary team at the Engineering and Research Center, with the experimental work being done in the engineering laboratories.

Patents have been reviewed and commercial devices obtained and tested in the laboratory. A ground-based seeding rig utilizing a commercial nozzle was fabricated, assembled, tested, and shipped to Texas for use in spraying hygroscopic materials into warm cumulus clouds. Work is underway to investigate the basic characteristics of nozzles to develop improved designs.

Spray issuing from a commercial "Sonicore" nozzle, which was investigated for seeding warm clouds with hygroscopic solutions.



Miniature supersonic air nozzles developed for producing ice nuclei for seeding supercooled clouds.

Several different configurations of supersonic nozzles have been fabricated and tested by injecting the nozzle output into a supercooled fog in a cold room. The tests, guided by theoretical predictions, have shown conclusively that very large numbers of ice nuclei can be produced in this way. Attempts are being made to develop nozzles which are efficient in ambient air temperatures only slightly below freezing. Formation of seeding nuclei from water vapor has a pronounced economic advantage and eliminates any possible tendencies to chemical pollution.

Instrumentation.—A most important element of a precipitation management system is the hardware used to recognize, treat, and evaluate a seedable event. While most of the hardware are off-the-shelf items, many new and sophisticated instrumentation systems are required. For example, a special laser radar was developed and given initial field testing. This instrument measures the amount of

water vapor in the air below the clouds, an important factor in seedability.

An elaborate airborne data system was put together by Project Skywater scientists. Mounted in a B-26 aircraft, the radar plots cloud data and also tracks the position of the aircraft. In addition, data are recorded on magnetic tape for subsequent analysis. The radar display is always north-oriented, regardless of the position of the aircraft. Some improved cloud physics instrumentation has also been developed.

Counting the number of natural nuclei present in the air is a major problem in weather modification efforts. The problem is complicated because of the several ways the materials can nucleate. Sublimation nuclei grow ice crystals from the vapor state. Other nuclei, imbedded in tiny cloud particles, convert supercooled liquid (liquid state at temperatures below 0° C) to ice as their activation temperature is reached. Still other nuclei convert supercooled liquid droplets to ice on contact. Several nuclei counters have been designed and tested by Project Skywater scientists and engineers, each of them considering a different aspect of the nuclei-counting problem. One contractor began work on a new counter that considers all three nucleation mechanisms.

Because of the problems in obtaining reliable wind measurements from mountain-top sites in winter, an instrument was developed that will operate under extreme conditions of wind and icing. The rotating cups are enclosed in a housing that lifts on radio command for 5 minutes each hour to obtain a reading. A device mounted on one of the cups is used to obtain wind direction, replacing the usual wind vane. Field tests of the instrument have begun.

Modeling.—The role of numerical modeling in weather modification, as in virtually every area of scientific inquiry, is expanding as fast as computer technology will allow. Numerical models are used in Project Skywater as fundamental research tools, for operational decision making, and for applicable tasks in between. A considerable effort has gone into surveying the vast array of models already developed, and modifying them for the particular needs of weather modification. Special attention was paid to developing models that would run on the moderate-size computers available on time-share systems and give the field operator information useful for real-time decision making regarding which clouds to seed.

Current weather data from a network of National Weather Service observing stations, supplemented by data from Project Skywater field sites, are entered into the time-share computer system. A series of computer programs processes these data and stores them in individual files. Contractors in the field can then reach these files, via their own remote computer terminals, and run any of seven models that further process the specific data files of interest. The results can be displayed in a manner that gives the field decision maker maximum information with minimum effort.

Most field contractors have developed special models for their particular areas, and also models that process data not available over the time-share system. One contractor developed a new model for mountain cumulus clouds. The numerical simulation included such effects as surface heating and evaporation, environmental airflow, the formation of the cloud, the effects of cloud shadow on surface factors, and a rain process. Although this model is too large for the present real-time information system, it is useful for research purposes. It is expected that, as computer capabilities improve, a version of this model will be available for real-time use.

Socioeconomic and Environmental Implications.—The socioeconomic and environmental implications of operational weather modification have received considerable attention in recent years.

A study of the attitudes of the general public toward weather modification was made by a California contractor. The results included the following: (1) attitudes favorable to weather modification are based on a combination of forces, one of which is financial dependence on weather; (2) there is a positive correlation between level of education and favorability of weather modification; (3) increased importance of conservation is the most clear-cut determinant of favorable attitudes; (4) no identifiable patterns could be established with regard to political affiliations; and (5) a program of education about weather modification would increase public approval.

An economic study of the effects of weather

modification on agriculture in Illinois, while not complete, indicated that cloud seeding would lead to increased yields of corn and soybeans. An additional bushel per acre could be obtained on the average, with a low probability that an overall crop decrease would result from seeding. The average added income would be on the order of $2 to $3 per acre. The actual economic benefits vary from area to area, so much so that no one value can be considered as even roughly applicable to all areas.

The effects of weather modification on the environment will be difficult to assess. Several ecological studies are underway, but a number of years of data gathering and study will be needed for anything like definitive results. All evidence thus far assembled does indicate that increased precipitation will not result in any catastrophic changes in the ecosystem, including its human component.

The legal problems of weather modification continue to receive attention. A model statute was prepared by a university contractor. However, it appears that most of the legal issues of weather modification are likely to be resolved by court action rather than by legislation.

WATER SUPPLY AUGMENTATION AND CONSERVATION

Research in water supply augmentation and conservation is undertaken to improve our water supply situation by increasing the supply available and by conserving that which we have.

WATER YIELD IMPROVEMENT

Research in water yield improvement is performed to reduce water losses which occur through nonbeneficial evaporation and transpiration. Current studies are concentrated on control of deep-rooted, water-wasting plants called phreatophytes.

Vegetation Management

Phreatophytes, plants that use underground water, occupy extensive areas, transpire large quantities of water, and frequently prevent more beneficial use of the land. Vegetation management research is conducted in two phases: (1) developing methods of controlling phreatophyte vegetation, studying revegetation species and techniques, and evaluating hydrological and ecological parameters; and (2) evapotranspiration investigations to develop accurate and rapid methods of measuring water losses to determine the potential amount of water which might be salvaged by phreatophyte removal.

Seventy-two herbicides and combinations have been evaluated by foliar treatment of greenhouse-cultivated saltcedar plants. Six herbicides were evaluated in soil-applied tests on greenhouse-cultivated saltcedar plants. Thirteen herbicides were evaluated in outdoor saltcedar plots*. Finac shows promise as an effective foliar-applied herbicide. A 2,4-D polymer and MSMA (Monosodium Methanearsenate) were completely ineffective.

*"Annual Report of Phreatophyte Activities—1968," Bureau of Reclamation Report No. REC-OCE-70-27 (1970).

An abstract bibliography of evapotranspiration prepared under contract by the U.S. Forest Service was completed and will be published by the Department of Agriculture. A long path hygrometer was developed under a contract with the University of Denver. The instrument was calibrated and its potential was determined for measuring water losses due to phreatophytes. Initial results showed that additional refinement and testing will be needed.

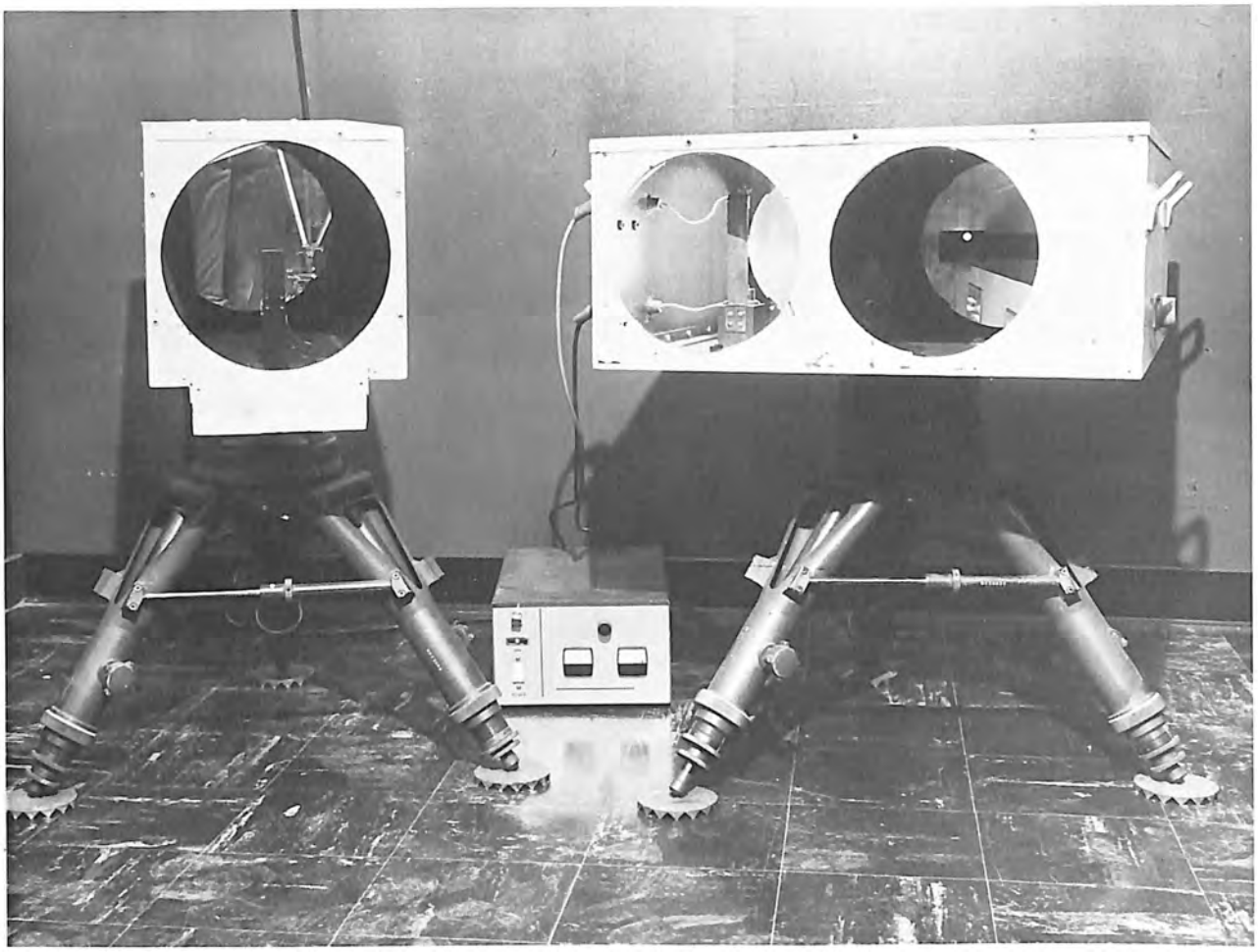
Under contract with the University of Nevada, based on mutual interest in controlling phreatophytes, a research program was begun to determine effective and practical methods to control phreatophytes (such as saltcedar, cottonwoods, willows). The program seeks to evaluate effectiveness of various control measures to determine economically feasible methods of obtaining desirable results. Various strengths and combinations of several different herbicides were tested on sample plots of phreatophyte growth. Mowing, spraying herbicides in water and oil reagents, and application of soil sterilants were among the methods of treatment.

The best herbicide on a cost-effective basis is Silvex used alone. Other herbicides and mixtures were somewhat less desirable on a cost-effective basis.

In addition to systemic herbicides, trials also made with soil sterilants indicated that bromacil was the only material (of four tested) that showed any promise. However, the long-term persistence of this herbicide may be undesirable.

Phreatophyte Water Use Studies

A research program conducted by the Bureau of Reclamation jointly with the U.S. Geological Survey and the Nevada Department of Conservation and Natural Resources covers the



A long path hygrometer developed by the Denver University Research Institute under contract with the Bureau.

study of water use in lysimeter tanks containing various phreatophytes found in the Humboldt Basin, Nevada. The objective is to relate the evapotranspiration rate of saltcedar to the depth of the water table.

Another study is underway near Bernardo, N. Mex. Here, nine large rubber-lined tanks 12 feet deep with a surface area of 1,000 square feet and a number of barrel-size tanks are installed. Water supplied for plant use or evaporation is measured with a water meter. The depth to the water table is automatically controlled. Six of these large tanks were originally planted to saltcedar. The initial phase of the project—determination of consumptive use and relationships with vegetative density and depth to ground water—was completed at the end of the 1968 growing season. Phase II is now underway to determine: (1) consumptive use of water by Russian olive; (2) the effects of salinity on the consumptive use of water by saltcedars; (3) the change in consumptive use rate of saltcedars after the depth to ground water has been rapidly increased (simulating the effect of taking the water away from the plants by drainage); (4) consumptive use rate of one of the natural replacement vegetations, saltgrass; and (5) the effects of gravel barriers placed above the water table to interrupt the capillary flow of water on consumptive use and evaporation.

CONSERVATION IN AGRICULTURE

Research in this subcategory involves techniques to save water after delivery for irrigation purposes. The Bureau's research is main-

ly directed toward developing a reliable method of determining irrigation efficiency and lower investment costs, and to develop an economical irrigation management service to increase crop yields while lowering water use.

Use of Water—Data Collection and Analysis

Analysis of water use on over 5,000 acres at 17 locations in 11 Western States was made to identify means of improving on-farm irrigation efficiency. It was found that an average of 44 percent of the water delivered was made available for use by crops through storage in the root zone. This low efficiency was primarily due to lack of correlation between water deliveries and soil moisture already available. It was also correlated with abundance and low cost of water.

The average efficiency can be increased with additional labor and proper management. Efficiencies of 70 to 90 percent are achievable but are dependent upon improvements in farm irrigation facilities. To help achieve and to demonstrate these higher efficiencies, an Irrigation Management Services Program was initiated.

Irrigation Management Services

The Irrigation Management Services Program is designed to improve farm irrigation efficiencies through scientific prediction of the timing and amount of water application required. Predictions are based upon computer analysis of data on climate, soils, crops, and soil moisture. In the 1972 irrigation season, this service was provided for 96,000 acres in 11 irrigation districts.

The research identifies and demonstrates the extent to which actual farm irrigation efficiencies can be increased with better water management, additional farm labor, and improved farm delivery systems. With proper timing the number of irrigations can be reduced, saving labor and fertilizer costs and increasing crop yields. Improved efficiencies can also reduce the salt burden of return flows. The higher level of water management will result in water savings, reduced drainage requirements, economies in design and construction, and improved operation and maintenance. The Bureau plans to extend this service wherever possible to demonstrate and to measure benefits to the farmers, and hopes to eventually cover all projects which receive Bureau irrigation water. The ultimate aim is to convince the farmers of the benefits of better irrigation management and have them provide their own management services.

WATER QUANTITY MANAGEMENT AND CONTROL

Research in water quantity management and control is directed to improving the management of water on and beneath the land surface.

CONTROL OF WATER ON THE SURFACE

Studies of control of water on the surface are made to determine effects of control programs and devices on the stage and timing of streamflow and reservoir storage, and on the control of noxious weeds and objectionable plants in surface channels.

Aquatic Pest Control

Aquatic organisms representing both plants and animals rapidly invade manmade water conveyance systems and develop populations that reduce the carrying capacity of the channels. The most serious aquatic pests are submersed aquatic weeds, which include both rooted higher plants and attached algae. More than one-half of all irrigation and multiple-use water channels in the 17 Western States have aquatic weed infestations. The cost of controlling the aquatic vegetation amounts to as much as 40 percent of the annual operation and maintenance expenditure. This vegetation must be controlled to allow for the normal operation of conveyance channels.[1]

In cooperative programs the Bureau of Reclamation, Agricultural Research Service (ARS), and the Bureau of Sport Fisheries and Wildlife are working on research to develop new, improved, and less costly methods of aquatic plant pest control. There is mounting pressure for the best possible use of waters delivered to an increasingly wide range of users, and such deliveries must be without contaminates that might be harmful to crops, humans, livestock, industrial processes, fish, and wildlife. Some herbicides presently used for aquatic weed control in water-conveyance systems may be unsuitable for use in multiple-use systems because of harmful effects on some nontarget organisms. Research is needed to develop aquatic plant pest control techniques that affect only target organisms.

A weed control process using copper sulfate crystals measures the rate at which crystals dissolve at different water temperatures and flow velocities.

[1] Numbers refer to "References" at end of chapter.

Among new candidate compounds, some exhibit potential effectiveness in greenhouse studies.[2] The herbicide MCPA (Methyl Chlorophenoxyacetic Acid) was the only material active when applied to the aquatic soil. Allylidene diacetate and two new amine formulations of endothall were promising when applied to the total water volume.

Combinations of older herbicidal compounds were tested to determine whether efficacy could be improved. None showed significant improvement.

A number of the new experimental herbicides and combinations of older materials were subjected to preliminary field evaluation. Only one material, allylidene diacetate, was sufficiently promising to be tested in an operating irrigation canal. The test showed some weed control, but results were not conclusive. The herbicide manufacturer declined further development at the time because of other commitments.

Laboratory evaluation of new experimental algaecides for filamentous green algae and mat-producing blue-green algae revealed one compound that was very active on green algae and one that exhibited selectivity on blue-green algae. Algaecidal tests on over 90 compounds representing many classes of chemicals have not produced any chemical that will completely control the troublesome, mat-producing blue-green algae.[3] Growth suppression from copper sulfate treatments continues to be the only method of practical management of these algae in operating irrigation canals.

A number of preliminary algaecidal field tests were conducted. Results indicate that copper sulfate produced as much toxicity as combinations of copper sulfate-surfactants and copper-ammonia-chlorine mixtures. These combinations might be useful in alkaline waters where copper sulfate is rapidly precipitated to insoluble copper carbonates.

Laboratory studies are continuing under controlled environmental conditions to determine mineral nutrition requirements of pondweeds and to determine effects of mineral enrichment on growth and productivity of sago and American pondweeds. These tests suggest that these pondweeds may obtain necessary mineral ions more through root than through foliar absorption. In addition, there were no

Facilities for feeding copper sulfate into canals include an adjustable-rate feeder with copper sulfate crystals in the hopper and a shelter house to protect the feeder and copper sulfate from weather.

significant data that suggested that aqueous enrichment with inorganic minerals produces an increase in pondweed productivity.[3] Subsequent studies using these pondweed species demonstrated that carbon availability caused a greater response in pondweed biomass production than any other enrichment. These data appear to support a hypothesis that carbon availability could be a limiting factor to pondweed productivity rather than the more popular phosphorous limiting theories.

Residues of herbicides used for plant control are being intensively studied in water, soils, crops, and fish, and are reported herein under "Water Quality Management and Protection."

Field studies performed by the Mid-Pacific Regional Office include:

1. Developing slender spikerush as a biological method of controlling aquatic weed growth. This low-growing rush has proved effective in crowding out larger aquatic plants which impede canal flows. It is anticipated that as many test plantings of spikerush as possible will be made in coming seasons to determine the value of spikerush as a plant competitor and possible replacement for part of the chemical control methods.

Environmental growth chamber used to culture filamentous green algae utilized in algaecidal studies.

2. Developing diquat and copper sulfate for aquatic weed control. In combination, the chemicals are more effective at lower concentrations than when used separately, and are relatively harmless to fish and to potable water. This combination for control of aquatics will be applied in the Tehama-Colusa Canal.

3. Developing and refining the use of Hydrothol 191 for control of many submersed aquatic weeds in the Corning Canal. This is now an operational application on the Corning Canal and provides excellent results.

Siltation in the Delta-Mendota Canal

The Bureau has been conducting periodic data-gathering on siltation and organic life in the Delta-Mendota Canal since the 1960-61 dewatering. A significant advance in the study occurred recently when regional personnel established the importance of Asiatic clams in precipitations of what appear to be inorganic deposits on the canal bottom ("Journal of Sedimentary Petrology," vol. 39, No. 3, pp. 891–901.) Calculations indicate that a single clam in one year may produce 5.5 grams of particles, which act as a "glue" to hold fine sands and mineral particles which otherwise would be flushed through the canal. Data collected during the 1969-70 dewatering of the canal indicate a spectacular increase of clams and a similar increase of sedimentation rate in the canal. Both changes were predicted and were related to additional water deliveries for the San Luis Unit.

A paper describing canal biota and sedimentation was presented at the National Symposium on Hydrobiology in Miami Beach, in June 1970, and appears in the proceedings of the Symposium.

Advanced Hydrology Techniques

A mathematical model was developed in cooperation with Colorado State University to statistically analyze available hydrologic time series data, such as streamflow data, and generate additional sequences of data. Results of this work will be published in the University's Hydrology Paper Series. Procedures will also be developed to program reservoir releases on the basis of consumptive use, to delineate temperature profiles in reservoirs for multilevel outlet operation, and to incorporate optimization and systems analyses in Reclamation studies of water utilization.

Shasta-Trinity Pilot Model

The increased complexity of meeting multipurpose demands of the Central Valley Project (CVP), California, required development of a decision-advising tool to increase operational effectiveness and check project efficiency.

A mathematical model of the CVP was decided upon. Output of the model would be

optimum Trinity and Shasta reservoir storage levels with corresponding water quantity releases, diversions, and power production at the various facilities.

The modeling project was started in December 1970 and, by the end of April 1971, an operational program had been formulated. The purpose of developing a "pilot model" was twofold: to give personnel experience in mathematical modeling, and to develop a program which could be expanded to a larger model. The model optimizes the operations of Trinity and Shasta reservoirs on a daily basis for 30 days. It operates Whiskeytown Lake according to a rule curve and accepts Folsom Lake operations as input for a check on power contract requirements.

The pilot model is now being field tested by the Water Control Branch of the Central Valley Operations Office to verify the model operation and point out any areas in need of improvement. Future plans call for developing a prototype model which will optimize the operations of Shasta, Trinity, Folsom, and San Luis reservoirs each month for up to 18 months. Eventually, a mathematical model will be developed to aid in operations of the entire Central Valley Project on an hourly basis.

Mathematical Model of the Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Rivers Delta comprises 740,000 acres of low-lying, rich farmland at the drainage outlet of the Central Valley, California. More than 700 miles of meandering Delta waterways are open to ocean salinity intrusion and are subject to tides. The channels serve as a water supply, a waste disposal system, a transportation network, a recreational area, and a fish and wildlife habitat.

The Central Valley Project and the California State Water Project pump water from the southern end of the Delta to areas further south. These are diversions of water previously released from storage reservoirs and surplus runoff from Central Valley drainage areas. Since 1944, the Bureau has prevented excessive ocean salinity intrusion into the Delta by maintaining a hydraulic barrier with these surplus flows at the Delta's western outlet to San Francisco Bay and the ocean.

Presently, the Delta is undergoing considerable change. With the rapid buildup in water development and use, large quantities of water will no longer be available from the Central Valley to maintain a large flow for a hydraulic barrier.

To predict salinity levels in the estuary under different future conditions, anticipated project effects (such as the proposed Peripheral Canal), and various levels of outflow from the Delta, the Bureau is using a mathematical model of the Delta and San Francisco Bay.

The model consists of two separate programs, a hydraulic model and a tidal quality model. The hydraulic model represents both the Bay and Delta as a network of one-dimensional channels. Each channel is designated by a numerical description of length, width, hydraulic radius, friction factor, and head. The flow in each channel is calculated over regular time intervals, and the hydraulic head at the junction or nodal point of each channel is updated at each time interval by summing the flow into and out of each junction. Boundary conditions include a tidal height input at the Ocean (Golden Gate) node, stream and drainage inflows, diversions and exports, and other factors, from appropriate junctions in the model.

The tidal quality model routes a constituent through the channels for each time increment according to the flow in each channel. Inflows into the model, such as ocean exchange and stream discharges, are assigned appropriate concentrations of the constituent being considered. A diversion is assumed to have the constituent concentration of the junction from which it is diverted. A mass balance is calculated for each junction at the end of each time interval. The quality model can be run for as many tidal cycles as desired, reusing the same tidal hydraulics or calling for a different hydraulic input as appropriate.

The original model has been refined to accurately reproduce historical salinities recorded in the Delta. Although the model still has limitations because it is an over-simplification of the very complex Delta System, it was not intended to predict exact quality values for a given station for a given condition. It has

proven its value in estimating changes in water quality over a region of the Delta or Bay in response to physical or operational modifications of the system.

Hybrid Computer Model for River Drainage

The complex nature of Upper Jordan River Drainage and Utah Lake operation and its relation to features of the Bonneville Unit of the Central Utah Project required new techniques for studying the system. The Bonneville Unit Plan includes: (1) diking of Utah Lake to salvage water presently lost to evaporation by reducing surface area, (2) exchange of the salvaged water and water imported from the Uinta Basin to existing and future upstream reservoirs, and (3) delivery of project water on a variable demand to Salt Lake, Utah, and Juab Counties. Because ground water contributes to Utah Lake, the effect of additional well development on the future yield of Utah Lake must be assessed. Control of water quality in the system is also necessary.

The study is being made in cooperation with the State of Utah, which has the required background and experience at the Utah Water Research Laboratory, and a hybrid computer.

The objectives of the study are to:

1. Formulate and verify a model for Utah Lake.
2. Formulate and verify a model for the Provo River System.
3. Formulate and verify a model for the ground water system of Utah Valley.
4. Combine the above models to yield a model of the complete Upper Jordan River Drainage, which will be used in determining the interrelation mentioned above.

Objectives 1 and 2 are essentially complete. From the Utah Lake model a new relationship between pan evaporation and Lake evaporation has been defined using the theory of energy balance. Results of this relationship are now being studied. Preliminary sizing studies for the Jordanelle Reservoir are being contemplated in connection with objective 2, and work has begun on objective 3.

Flood Hydrology Investigations

Reliable estimates of design flood potential are important in specifying optimum investments in dams and spillways. Records of large floods are being analyzed to verify and improve procedures for estimating retention loss rates, lag times, unit hydrographs, routing, frequency, and runoff from snowmelt. Studies are being made of convergence effects and the relation of elevation to intensity and frequency of precipitation, and on the separation of runoff into interflow and overland flow.

Sediment Transport and Channel Degradation Studies

Sediment problems in canals and erosion (degradation) in unlined canals or streams can be minimized by proper design of structures and channels. In a study made to check the validity of a procedure currently used, data from three river channels (Niobrara River near Cody, Nebr.; Middle Loup River near Dunning, Nebr.; and Middle Rio Grande Conveyance Channel at San Acacia and San Marcial, N. Mex.) were used to compute total transport for all sand-sized fractions greater than 62 microns. Total load sampling stations located on these channels provided data to check the computational procedure. A technical paper[4] was published on the findings.

Settling basins are sometimes constructed in the heading area or entryway to an irrigation

San Marcial conveyance channel, New Mexico.

canal system. Their purpose is to remove as much sediment as possible from waters delivered to the canal. In studies of the behavior of fine sediments carried by flows in suspension over gravel beds, Dr. H. A. Einstein developed a procedure for estimating sediment deposition. A Bureau technical guide[5] based on Dr. Einstein's work describes procedures for determining the volume of sediments deposited in basins, necessary dimensions of settling basins, and trap efficiencies.

Culbertson settling basin, Nebraska.

In channel stability studies, data were collected at four sites along Turkey Creek near Farwell, Nebr. The creek channel bed and banks were composed primarily of silty clays and silty clay loams. The studies showed that unconfined compressive strength of the soils and width-depth ratios of the channels offered the best measures of channel stability. Additional data are needed to check the stability of the test channels under higher discharges. A report[6] is available on results of this research to date.

Sediment Deposition in Reservoirs

Improved methods for collection and analysis of reservoir sedimentation data are required to provide accurate information on reservoir and capacity. Research in this area involves developing and testing new techniques and equipment on Bureau reservoirs. A report[7] on the 1963-64 Lake Mead survey was published. The survey was run at the time of closure of Glen Canyon Dam on the Colorado River, 370 miles upstream from Hoover Dam. Analyses were made of the geodetic and hydrographic survey results.

Sonic sounding, photogrammetry, and cross sectional profiling methods were used to run the hydrographic survey. Reservoir area and capacity tables were generated using a computer. The present lake capacity is 29.8 million acre-feet, and sediments have accumulated to a volume of 2.72 million acre-feet in the lake since 1935. Samples of the reservoir deposits at various locations were taken with a piston core sampler. A gamma probe was used to measure in situ wet bulk densities. Special sampling with a drill rig was made in Pierce Basin to study the physical properties of sediments that have built up in the reservoir delta area. Undisturbed samples of the delta sediment deposits taken from a hole drilled 207 feet deep in Pierce Basin showed a variety of changes in physical properties with depth. The reservoir trap efficiency was judged to be 100 percent. The life of Lake Mead is estimated to be increased to 500 years following the closure of Glen Canyon Dam.

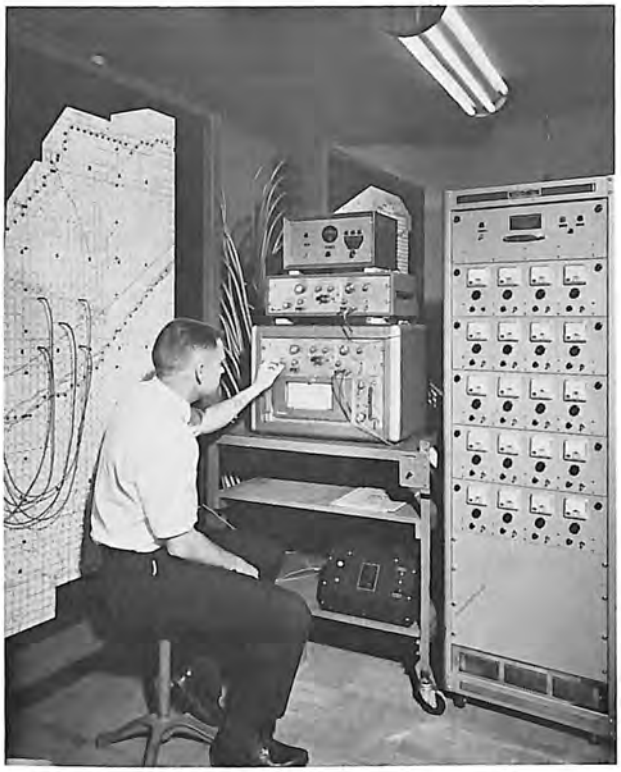
A similar study using a gravity core sampler, a gamma probe, and a sonic sounder was used for surveying sediments in Guernsey Reservoir in Nebraska.[8]

GROUND WATER MANAGEMENT

Ground water management research consists of development of pilot programs to determine the feasibility of ground water recharge and to establish computerized techniques for ground water measurement.

Ground Water Analysis by Computer

Present analytical methods for analyzing ground water aquifers using electric analogs have not been found satisfactory for areas larger than 2,500 square miles. However, it appears that procedures can be developed which will satisfactorily treat areas up to 2,500 square miles by use of digital computers. Work has been initiated on these procedures to study declining water tables, to forecast



Electrical analog analyzes ground water aquifers.

aquifer depletion, and to analyze effects of new sources of water which might be put into aquifers at specific locations. The required data have been obtained and the computer program is being developed and tested.

WATERSHED PROTECTION

Watershed protection studies aim to improve the management of watershed areas to increase the available yield of surface runoff water.

Studies in Watershed Management

The increase and control of runoff from watershed areas by such practices as timber thinning, snow evaporation reduction, snowmelt acceleration, and conversion of lodgepole pine forest to herbaceous vegetation have been the subject of a study being conducted by contract with Colorado State University. The site of the field work is an area west of Fort Collins in the Colorado mountains.

Equipment and techniques have been developed for the continuous gaging of streamflow in remote and unattended areas by a dye dilution method. Plot studies of vegetative conversion are underway, with snow measurements being taken on all plots. A model has been completed for predicting shortwave reflectivity on lodgepole pine plots, and a computer model has been completed for analysis of soil moisture data. A simulation model of snowmelt on a snowfield was constructed based on previous plot studies and existing climatic and streamflow data, and results suggest that substantial water yield increases could be obtained by treating the snowfield surface with albedo-reducing (darkening) materials.

In consultation with the U.S. Forest Service and Colorado State University, plans were made for removing timber on the lodgepole pine plot and disposal of the slash. Also planned are additional combined soil moisture and snow water equivalent measurements, the sampling of rain and snowfalls, and the completion of an analysis of pretreatment snow and soil moisture data. Yet to be evaluated are the different kinds of herbaceous species and sedges with respect to their adaptability to conversions, their relative demands on water, and their utility for protection and recreational use of forest land.

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Water Quantity Management and Control

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WATER QUALITY MANAGEMENT AND PROTECTION

Research in water quality management and protection is directed to finding ways to protect the quality of reclamation water resources.

IDENTIFICATION AND SOURCES OF POLLUTANTS

This research is conducted to develop techniques for identifying physical, chemical, and biological pollutants, and to locate the sources and determine the nature of pollutants in water.

Wastewater Reclamation Opportunities

The collection, treatment, and reuse of reclaimable wastewater is an important aspect of improving the efficiency of water use. The objectives of research in this area are to determine the location, amounts, and characteristics of wastewater in the 17 Western States; to identify opportunities for its use; to develop needed new technology; and to design and construct wastewater reuse facilities.

The first phase of the research, which is now underway, is an inventory of wastewater reclamation resources and opportunities. Later phases will depend on the results of the inventory. Wastewater reclamation is included in studies of the Ventura County Water Management Project on the central coast of California.

Salinity Surveillance Program—Parker Dam to Imperial Dam

In 1968 and 1969, the day-to-day variations in the salinity of Colorado River waters at Imperial Dam became quite pronounced. There was much speculation concerning the cause and origin of these "salt surges." The outgrowth of this speculation was the beginning, in February 1970, of an intense sampling program at the 11 stations which comprise the major inputs and outputs in the reach of the river between Parker and Imperial Dams. From February 1, 1970, through February 1, 1971, this program consisted of taking daily electrical conductivities, weekly residue determinations, and monthly constituent analyses. These data were digitized and maintained on file in a time-sharing computer system.

Statistical analyses performed on data accumulated through November 1970 indicated that there was considerable variation in the sampling frequency required to maintain a uniform confidence at the various stations. Accordingly, beginning February 1, 1971, sampling intervals were adjusted so that the deviation from actual tonnages caused by sampling intervals would be less than 5 percent, 95 percent of the time. The data are being analyzed to obtain an understanding of the lower Colorado River salt-loading dynamics.

WASTE TREATMENT PROCESSES

Research in waste treatment processes will help develop new techniques and methods for treating and reclaiming project wastewater.

Nutrient Removal and Beneficial Use of Agricultural Wastewaters

Since 1967 the Bureau has cooperated in studies with the California State Department

of Water Resources and the Environmental Protection Agency to determine the source of nitrates in San Luis and San Joaquin Valley drain waters. These studies include methods for reducing nitrate at the source, and treating the effluent to reduce nitrate concentrations. From lysimeter studies of representative west side soils, the Bureau found that only small amounts of fertilizer moved into drain effluent in the slowly permeable soils typical of the poorly drained areas during 2 years of irrigated cropping. From lysimeter data and soil chemical information a prediction model was developed which is now being used to estimate changes in the nitrate concentration of the drain effluent during early and later stages and development of the San Luis Project.

Studies on removal of nitrates from drainage effluent were made by a research team at the Firebaugh Interagency Agricultural Wastewater Treatment Center (IAWTC), and in field studies carried out or sponsored by the Bureau. Three different methods of removing nitrogen studied and found to be technically feasible include: algae stripping, bacteriological denitrification in ponds and filters, and a symbiotic process (a bacterial-photosynthetic process).

Algae Stripping.—The basic theory of algae stripping for nutrient removal involves: (a) growth of algae, which utilizes the nutrients in their cell structure, and (b) removing the algae from the water—thus removing the nutrients. The algae stripping study was divided into the three basic phases of growth, separation, and disposal, each with specific problems. While technically feasible, this process was found to be economically unattractive.

Bacteriological Denitrification.—Bacteriological denitrification is accomplished through the use of microorganisms which, in the absence of dissolved oxygen, oxidize organic matter and reduce the nitrate-nitrogen to nitrogen gas. One advantage of this system is that there is no by-product. In the agricultural wastewater of the valley, it is necessary to supply the microorganisms with an appropriate quantity of suitable organic material which serves as an energy source. Methanol was used at the IAWTC.

Two process configurations of the anaerobic system were evaluated at the E&R Center—deep ponds and filters. In deep ponds, methanol was mixed with the influent tile drainage, and the developing bacterial culture was either free-floating or attached to the sides of the container.

In the filter configuration, methanol mixed with tile drainage flowed upward through an enclosure or reactor filled with inert gravel media, which provided a substrate to which the bacteria could attach. Thus, the water to be treated could pass through at a higher velocity without washing out the bacteria. Both processes were found to be technically feasible but costly.

Symbiotic Process.—A "symbiotic" process was also investigated by the Study Group but not to the extent of the methods previously discussed. The term "symbiotic," as used in the project, describes an environment in which biological groups function in mutually supporting relationships. In the particular case of nitrogen removal from wastewaters, this type of environment is thought to be composed of two mutually dependent biological groups: bacterial and photosynthetic. Results of independent experiments have shown that the symbiotic process has technical and economic merit. The Bureau has completed a 2-year investigation into denitrification of agricultural drainage water in grass plots, using a 6-acre diked area planted with a water grass. Data obtained by this study indicated that wastewater containing 16 mg/1 nitrate-nitrogen was reduced to 2 mg/1 as the water flowed over the acreage. The estimated costs of treatment of drainage water by the symbiotic process is one-third to one-half the cost estimated for the two previously discussed processes. Based on the preliminary evaluation, a 2-year study is planned to further evaluate the symbiotic process under controlled conditions. Studies will be made to find grasses or other plants which can adapt to the saline conditions and which might provide pasture or waterfowl benefits to offset some of the operation costs.

WATER QUALITY CONTROL

Water quality control studies consist of research to control surface and ground water

quality by all methods (except waste treatment), including: evaluating the potential effects of herbicide residues; reservoir and river reaeration; and management of ground waters, impoundments, and streams to improve water quality.

Herbicide Residues

This project, conducted in cooperation with the Agricultural Research Service (ARS) and the Environmental Protection Agency (EPA), involves measurement of herbicide residues in water, soils, and plants, following applications for control of aquatic and ditchbank weeds in irrigation systems. Data on herbicide residues and their dissipation rates are needed to support petitions for registration for use of the materials, establish safe tolerances, improve the efficacy of herbicide use, and establish safety in herbicide applications.

The quantity of 2,4–D getting into irrigation water as a result of weed control measures on ditchbanks was determined on 18 field treatments on the Columbia Basin Project.[1] In 16 treatments, the maximum 2,4–D concentration in the water samples was well below 100 ppb (parts per billion) ; in two cases the maximum level slightly exceeded 100 ppb. In general, the quantity of 2,4–D which entered the irrigation water was very low. The specific residue data were included in a petition presented to the EPA for registration of 2,4–D for use on canal banks.

Twenty-one acrolein treatments of canals on the Columbia Basin Project were monitored for the levels of acrolein in the water at sampling stations downstream from the application site. The results showed that acrolein will move many miles downstream with a slow rate of dissipation.

Determination of residues of copper in water, hydrosoils, and aquatic weeds, resulting from continuous and intermittent daily applications of copper sulfate to operating irrigation canals, has continued. This information is valuable in designing improved techniques of application for aquatic weed control and for supporting petitions that may be needed for registration.

The quantity of arsenic in irrigation water

Determining arsenic content of water collected downstream in several canals after ditchbank treatment.

following treatment of a dewatered ditchbank with organic arsenical herbicides was determined in several canals on the Rio Grande Project. The maximum quantity of arsenic found in waters collected at the downstream end of the treated section ranged from 0 to 0.6 parts per million (ppm). These data were used to support a petition for registration of the organic arsenicals for this type of use.

Reaeration

The assimilation of waste and maintenance of fish life in streams, lakes, and reservoirs require adequate levels of dissolved oxygen. Biological degradation of waste materials often results in lowering the level of dissolved oxygen to a point which no longer meets water quality criteria as set by law. Many methods and devices for reoxygenation have been developed for application to treatment of municipal and industrial wastes. A review of about 500 references on this subject[2] showed that, in general, the technology developed for waste treatment has not been widely applied to problems of reaeration in streams, lakes, and reservoirs. The state-of-the-art review resulted in recommendations for Bureau research to determine the application of existing technology and to develop new technology for application to the problem of reaerating large water bodies and large flows.

Late in 1970 an interdisciplinary team was formed for the purpose of formulating a re-

search program. A tentative program was outlined and a recommendation was made for formation of a permanent interdisciplinary team for management of the program. This team became active in 1972, and a detailed plan for research in reaeration has been formulated. Preliminary field studies have been initiated at Arbuckle Reservoir in Oklahoma and at Flaming Gorge Dam in Utah.

Reservoir Temperature Prediction

Most Bureau projects include downstream fisheries as a beneficial feature and many even include fish hatchery facilities at some point downstream from the dam. Control of the temperature of reservoir releases, therefore, is an important consideration in the design and operation of reservoir outlet works. Prediction of reservoir temperatures in both proposed and existing impoundments can provide useful criteria for the design and operation of outlets for downstream temperature control.

The Bureau is currently evaluating two computerized mathematical models which predict temperature distribution within reservoirs. One model was developed by a private engineering firm and the other by the Corps of Engineers. Both models generate reservoir depth versus temperature profiles throughout the year. The required input data include discharges and temperature of all inflows to the reservoir, area-capacity data, discharges and levels of releases, and various climatological data such as solar radiation, cloud cover, air temperature, relative humidity, and wind speed.

The first model is the more mathematically sophisticated of the two and, thus, would be better for prediction of daily temperature variations. The Corps' model, however, requires less input data and would be preferable for average monthly predictions over several years of record and in cases where daily records are unavailable. Unlike the Corps' model, the other is applicable to partially or completely mixed reservoirs in addition to the deep, fully stratified reservoirs.

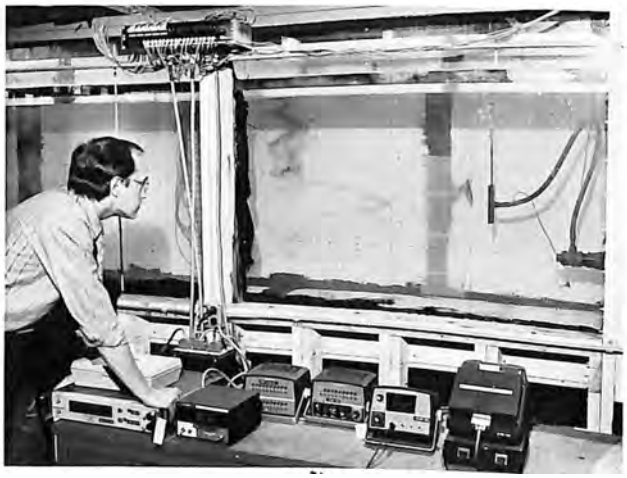
Verification tests of both reservoir temperature prediction models were applied to Folsom Reservoir in California. They demonstrated that the two models are equally capable of predicting reservoir temperatures with an accuracy of about ±5° F. The Bureau is presently utilizing the prediction models on Shasta and Trinity Reservoirs in California. These prediction studies will provide project operating criteria necessary to release water of desirable year-round temperatures to downstream fisheries, as well as to the Tehama-Colusa Canal fish spawning channel near Red Bluff, Calif.

Water Quality as Affected by Stratified Flow

Water quality in streams, lakes, and reservoirs is related to the phenomenon of density stratification. Knowledge of the stratification pattern and the mechanics of stratified flow affect the design of structures for the control of water quality. The stratification pattern can be predicted with mathematical models, and the mechanics of stratified flow are determined with physical models and prototype measurements.

The past few years have seen important gains in the field of stratified flow; however, some questions of similitude in physical modeling remain unresolved and mathematical models still contain important deficiencies.

Flume studies, as part of the present research, have contributed to understanding of selective withdrawal for water quality control. The data have shown general agreement with prototype experience.[3] Measurement of velocity distribution in withdrawal layers will essentially complete this phase of the research.



Velocity distribution in a selective withdrawal layer is measured in a temperature-stratified laboratory flume.

Mathematical models are presently being investigated and verified by comparing predicted and measured temperatures in existing reservoirs. A selected model can now be used, with some reservations, for predicting temperatures in reservoirs to be built in the future.

Predicting Nutrient and Salt Loads

Information on return flows can be used to assess the environmental impact of irrigation projects and predict changes which take place in soil and water due to application of irrigation water. Technical Bulletin 196 of the Agricultural Experiment Station, University of Arizona, on a "Computer Simulation Model of Dynamic Bio-Physicochemical Processes in Soils," Tucson, October 1972, is an example of contract research aimed at predicting total salts and the concentration of major cations and anions in irrigation return flows. This bulletin presents a digital computer model to simulate nonsteady-state changes in the unsaturated soil matrix and percolating water. It incorporates processes of infiltration and redistribution of soil water, evapotranspiration, nitrogen transformations, changes in the solute concentration of soil water, and nitrogen uptake by crops. It predicts the distribution and concentration of the constituents over time.

Another publication, "Results of Water Quality Return Flow Model," by Richard W. Ribbens, was prepared in connection with a report for the Souris Loop area of the Garrison Diversion Unit. This model incorporates and extends the Arizona research to simulate the total irrigation system, including the saturated zone, extending the flow to tile drains. Surface water applications are computed by irrigation water scheduling techniques. Return flow quantities and qualities and the positions of the fluctuating water table are predicted over time.

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WATER RESOURCES PLANNING

Research in water resources planning primarily emphasizes improvements in the planning and decision making process and is devoted to determining the best way to plan, the appropriate criteria for planning, and the nature of the economic, legal, and social aspects of water management.

TECHNIQUES OF PLANNING

This research covers the application of modern methods of economic and systems analysis to project planning, including techniques for optimizing the plans for water resources developments, and meeting population dispersal objectives.

Reclamation Program Objectives

To assure that Bureau programs adapt and change to meet changing national needs and priorities, studies related to program objectives are funded in organizations outside the Bureau.

The dynamic nature of the Reclamation program is illustrated by Colorado State University's contract research report[1] on a century of changes in public land and water policy since the Civil War. "Foundations of Federal Reclamation Policies: An Historical Review of Changing Goals and Objectives" relates national value concepts of what is right or good to policy objectives and program goals in response to changing conditions and needs.

EVALUATION PROCESS

Studies of the evaluation process are directed to developing methods for evaluating benefits and costs of water projects, as well as techniques for making economic, social, and technological projections. Research is also undertaken on methods of calculating repayment, the techniques of cost allocation, the socioeconomic impact of cost sharing, and pricing and repayment policy.

Improvement in Benefit Analysis

The report "A Guide to Using Interest Factors in Economic Analysis of Water Projects" and a contract with the University of California at Davis provide improvement of methods to evaluate nonsocial benefits from municipal and industrial water service. Research contracted with Utah State University will develop methods of analysis for social benefits from water projects.

Correlation of Economic and Physical Factors In Selecting Irrigable Lands

This research is designed to improve land classification and economic analysis by combining conceptual models, field research, and existing data in estimating crop yields, payment capacity, and design of project facilities. The research is being conducted by contract with Iowa State University. A report on "The Production Function and Imputation of the Economic Value of Irrigation Water" was published in 1969[3] and a report on "Programming Models of Irrigation Development" was published in 1971.[4] Two seminars in linear programming for Reclamation economists were conducted at the Engineering and Research Center. An extensive data base was

developed from over 50 field experiments in six States to develop crop response functions to irrigation water, fertilizer, and other factors of production in different soils and climates. A final report of the research is in preparation.

The Iowa research was supplemented through a contract with the University of California at Davis. The report on "Water Production Functions and Irrigation Programming for Greater Economy in System Design and Increased Efficiency in Water Use"[5] deals with the adaptability of production functions from one location for general use in other situations.

Economic Survey of Beaverhead County, Montana

In order to assess the economic impact of irrigation development, an economic study of Beaverhead County, Montana, was made in 1964 prior to construction of Reclamation's East Bench Unit project. This project will ultimately provide full irrigation services for 21,800 acres of land not previously irrigated, and supplemental water for 28,000 acres under irrigation before construction of the project.

An interim study of secondary data was performed in 1972, using data from the 1969 Census of Agriculture and the 1970 Population Census. A final study and evaluation to measure the effects of the irrigation project on Beaverhead County and surrounding trade centers will be conducted in 1975 and 1976. This will represent a 10-year time span essentially coinciding with the end of the development period and will also permit full utilization of 1974 Census of Agriculture data.

Economics of Water Conservation Practices

To illustrate the benefits of more efficient use of irrigation water and to identify areas where the Bureau can initiate water conservation techniques, a study was conducted for the Bureau by Oregon State University. A report[6] was prepared which identifies legal, institutional, operational, and economic factors which influence on-farm and irrigation district investment and use of water facilities in three irrigated areas of Oregon. Five water conservation practices were evaluated: canal lining, water pricing, reservoir storage holdover, irrigated acreage increase, and sprinkler irrigation.

LAND CLASSIFICATION

Land classification studies are made to improve techniques for classifying land for irrigation suitability, and to develop reliable means for classifying suburban lands for suitability for purposes other than irrigation.

Predicting Changes in Soil Chemistry and Water Quality

An important aspect of land classification is the ability to predict changes in soils and water resulting from application of irrigation water to previously arid land. In some cases, these changes affect the soil productivity and create water quality problems. A computer program is being developed to predict changes that occur as water percolates through various soil and salinity conditions into ground-water aquifers. This information will allow a more realistic economic evaluation of irrigation project feasibility.

Studies in Soils and Agronomic Practices

As part of the Bureau's continuing effort to improve its irrigation projects by assisting irrigation districts and individual farmers, studies are constantly underway to solve problems encountered in the field. An example of such assistance is the current study of management factors necessary to improve the productivity of the Christianberg soil series, a saline soil in the Shoshone, Wyo., area with a poor production record. Test plot studies are underway to determine the effects of gypsum and manure on certain properties of the soil and on crop yields and quality. The value of trace elements with and without gypsum and manure is being determined. Adequate levels of nitrogen, phosphorus, and potassium are maintained in all plots to assure that these factors do not influence the results.

Boron Leaching

Boron salts are essential to normal plant growth, but the concentration required is small and if exceeded may cause plant injury. Species vary both in boron requirements and in tolerance to excess boron. Normally, soils with less than 2 ppm of boron satisfy the need of most plants. If this amount is doubled, few plants will tolerate the excess.

In the more humid regions of California, boron deficiencies have been found and, in arid regions, toxic concentrations were found in both the soil and the irrigation water. The presence of excess soluble boron in arid lands is usually attributed to the weathering of boron-containing soils, or the application of irrigation water containing boron.

In the Hollister area of the San Felipe Project, boron in irrigation water has been concentrated in the soils to the point of reducing yields of fruit and grape crops. With the importation of better quality water it is expected that leaching will take place and yields should improve.

To better understand the leaching process, field testing was carried out by Reclamation personnel in cooperation with the County Agricultural Extension Service. Plots were leached with San Luis Reservoir waters, and laboratory analysis of the boron movement in the soil profile followed. Although the results are not complete, it appears that boron was not removed as rapidly as hoped. This indicates that in certain areas near Hollister, good production of tree fruits may require long periods of leaching. In some cases it may be more profitable to grow more tolerant crops.

As part of this research, soil leaching characteristics are determined to see if any of the known leaching equations can be used to predict boron removal.

ECOLOGICAL IMPACT OF WATER DEVELOPMENT

Research of the ecological impact of water development covers the effects of water projects and water management operations on the overall ecology of the area. Such research includes the environmental impacts of electric power transmission facilities, ecological considerations in project planning, and environmental effects of the construction and operation of wastewater reclamation projects.

Ecology and Water Quality Research

A comprehensive research program is being conducted to determine the effect of construction and operation of water resource projects upon the ecology, limnology, water quality, and other pertinent environmental parameters of Western reservoirs and rivers.

Consideration is also given to the effect of domestic, industrial, and agricultural pollutants upon these waters and projects. Studies are being made of possible corrective action to prevent, eliminate, or reduce undesirable conditions and to enhance water quality. The results of these research studies will be used for planning, designing, and operating water resource projects to meet the national environmental, social, and economic goals.

General Water Quality Investigations

A symposium concerning the ecological impact of water resource projects, cosponsored by the Bureau and the American Institute of Biological Sciences (AIBS), was held in 1971 during the annual AIBS meeting at Colorado State University. It was unique in that engineers, ecologists, water resource planners, and others met to discuss common problems and goals. The symposium included a panel of scientists and engineers, who discussed agricultural, waste, and ecological aspects of water resource management. A session of technical papers on examples and needs of biological information in engineering and a series of workshops explored such subjects as construction and operational impacts, recreational use of reservoirs, reservoir ecology, ecological effects of coal-fired powerplants, weather modification, impact on wildlife, and the ecological information necessary for water resource planning.

The Division of General Research hosted the Bureau's first Ecology and Water Quality Review Meeting in 1971. Representatives from all regions, the E&R Center, and the Commis-

sioner's office gathered for a comprehensive review and plan formulation concerning Bureau needs and its role in meeting national environmental objectives.

A review of literature concerning the state-of-the-art and research needs in reaeration was conducted and a seminar on reaeration for Denver office engineers and scientists was presented by Vanderbilt University and the Georgia Institute of Technology.

A research review team was formed and specific goals for research and a research program were developed to:

1. Determine the reaeration capabilities of conventional hydraulic works.
2. Develop new methods and devices to achieve reaeration of reservoirs, reservoir releases, and streams; establish related design and operating characteristics.
3. Evaluate environmental and biological effects of reaeration.
4. Determine the relative performances of various methods and devices at various locations in a river-reservoir system.
5. Establish standard procedures for rating the reaeration efficiency and cost effectiveness of methods and devices.
6. Develop basic information and procedures for use in planning and design for determining the needs, selecting optimum methods and devices, estimating the costs, and predicting the effects of reaeration.

The research program concerns:

1. Environmental and ecological effects of reaeration.
2. Development of standard methods of economic comparison.
3. Methods and devices for reaeration.
4. Reaeration requirements.
5. Field pilot studies.

A Reaeration Program Management Team* to direct the above research has been formed. The team has initiated an updating of the literature review, the development of a standard method for determining reaeration effectiveness, and a survey of field problems.

Field surveys were made with the mobile chemistry laboratory at the Aquatic Weed Test Station at Twin Lakes Reservoir. The laboratory is self-contained and includes an electric

*Also see "Reaeration" under "Water Quality Management and Protection."

Mobile chemistry laboratory for water quality studies.

generator, raw and distilled water supply, microscope, balance, flame photometer, furnace, air, and gas. Comprehensive chemical analyses of water and biological factors are possible with the unit.

Instrumentation in mobile chemistry laboratory.

Impoundment Studies

Research work was completed and a report published concerning the effects of effluent from Las Vegas Wash, Nevada, on the water quality in Lake Mead.[7] The study concluded that effluents from the Wash contributed to the eutrophication of the Lake. This was due to the high amounts of total dissolved solids and algae-supporting nutrients entering Lake Mead from Las Vegas Wash.

Field work was conducted on the ecological impact of a pump-back storage project at Twin Lakes Reservoir, the site of the Mt. Elbert Pumped-storage Powerplant. The existing Twin Lakes Reservoir will be enlarged by con-

struction of an earth dam, and the powerplant will be located on the north shore of the enlarged reservoir. The study is being performed in cooperation with the Colorado Department of Game, Fish, and Parks.

Collecting benthic fauna from bottom muds of Twin Lakes Reservoir.

Twin Lakes provides one of the best lake trout fisheries in the western United States. One of the principal reasons for the success of the fishery is the presence of the mysis shrimp, an essential item in the food of young fish. A key environmental factor is the cold water temperatures favorable to trout and shrimp. If construction or operation of the powerplant and dam should be detrimental to either the trout or shrimp, a valuable and unique regional fishery would be lost.

The study will determine the effect of construction and operation of the Mt. Elbert Pumped-storage Powerplant and Twin Lakes Dam upon the ecology, water quality, and limnology of Twin Lakes Reservoir. Preliminary data have been used for input to the Environmental Impact Statement for Mt. Elbert Pumped-storage Powerplant.

Data from the study will also be used to evaluate temperature prediction models for reservoirs. The necessary limnological and meteorological data for evaluation of temperature prediction models were obtained from Flaming Gorge and Horsetooth Reservoirs. However, due to lack of synoptic data for key parameters, the evaluation was not as precise as desired. Therefore, the Twin Lakes data collection program will emphasize synoptic measurements.

Collecting water samples for dissolved oxygen analysis at Twin Lakes Reservoir.

The research study on the effect of impoundment on water quality in Cheney Reservoir was issued as a Water Resources Technical Publication.[8] This reservoir was constructed by the Bureau to provide water to the city of Wichita. A multiple outlet structure was included in the dam for selective withdrawal. Water quality data were collected to document the changes in a new plains-type reservoir and the effectiveness of multiple outlets for water quality control.

Due to wind mixing, the reservoir did not stratify so the effectiveness of the multiple outlets could not be fully determined, although at one time they were used to avoid turbid water. The data showed an increase in salinity as a result of 42 percent of the total inflow being lost by evaporation.

Ecological Evaluation

For some time, the Bureau of Reclamation has recognized the need for a procedure which could be used in all planning offices to evaluate the environmental impacts of the Bureau's water development projects. In June 1970, Battelle Memorial Institute was awarded a contract to develop such a system. The system was field tested, then refined, and published in a report.[9]

The Battelle system ranks project plans in terms of their effects upon four major environmental categories: ecology, esthetics, pollution, and human interest. These categories are divided into 18 component subcategories, which contain 78 measurable parameters. The parameter measurements are converted to commensurate environmental impact units, showing total scores with and without the proposed project. "Red flag" warnings of sensitive topics requiring further consideration are revealed by the evaluation system.

Reservoir Shoreline Vegetation

The Bureau's Mid-Pacific Region began a 5-year program in 1971 to evaluate and select known tree, shrub, and ground cover material types which could be planted and could survive on the flooded perimeters of manmade California reservoirs. Such perimeters to date have lacked native vegetation for various reasons, including periodic flooding due to water level fluctuations.

The Bureau has executed a primary agreement with the U.S. Forest Service, Pacific S.W. Experimental Station at Berkeley, Calif., which in turn has a secondary agreement for the research and research sites with the University of California, Environmental Horticulture Department, at Davis, Calif.

A research site with provisions for controlled flooding has been established at the Davis campus. Reclamation will furnish field sites for test or demonstration facilities at Folsom Reservoir and later at the proposed Auburn Reservoir area, both on the American River.

Klamath Project—Nematode Control

In 1965, infestations of a barley rootworm (nematode) were discovered on the public lease lands of the Klamath Project near Tule Lake, Calif. Little was known about control of this rootworm since it had been found in only a few locations in the United States, but it was known to reduce yields of barley, a major source of project income and revenue. Together with the U.S. Bureau of Sport Fisheries and Wildlife, the Bureau sponsored research by the University of California to determine the most effective and economical control.

Findings to date indicate that this nematode is a serious threat to such important host crops as barley and wheat, but it does not affect other important crops such as potatoes, onions, or certain varieties of alfalfa. It is spread by harvesting potatoes and onions, and by grazing, farm equipment, and other soil carriers. Control by fumigation is difficult and uneconomical in the organic soils of Tule Lake, and flooding or fallowing provide only temporary reduction in soil nematode population. The most economical control found to date is crop rotation so that host crops are not grown in successive years.

Lessees are now required to rotate crops so that host crops will not be grown in successive years in nematode-infested areas. Grazing on lease lands has been prohibited, and improved washing facilities for farm equipment have been installed.

Estuary Studies

Reclamation activities can affect water quality in estuaries by reducing fresh water inflow and by changing the seasonal pattern of inflow. Flow reductions may affect turbidity levels and nutrient concentrations which play vital roles in the estuary's level of aquatic productivity. Agricultural return flows containing nutrients and other biostimulants may increase an estuary's productivity to undesirable levels.

The San Francisco Bay-Delta estuary in California is at the crossroads of the Bureau's Central Valley Project. A portion of the water from the north, which once flowed unchecked to the Pacific Ocean, is now diverted to irrigate crop lands in the San Joaquin Valley. In the

future, greater diversions will be made by the Bureau and the California Department of Water Resources for agricultural, municipal, and industrial uses south of the Delta.

The Mid-Pacific Region of the Bureau is conducting an extensive water quality surveillance program in the Bay-Delta estuary. This program is conducted to gather and analyze water quality data to ensure that the environment of the estuary will be protected or enhanced through the proper planning and operation of Bureau facilities. Chemical, physical, and biological data are obtained on a regular basis to determine present conditions in the estuary, and to provide input to verify a mathematical model being developed by the California Department of Water Resources to predict future levels of biological productivity in the estuary.

Studies of biological productivity are also being conducted to assess the impact of the San Luis Drain, which will carry return flows from the Bureau's San Luis service area. Monthly measurements of primary productivity, chlorophyll, phytoplankton, algal growth potential, chemical constituents, temperature, light intensity, and turbidity are conducted using highly sophisticated equipment and instrumentation. Data from the study will aid in establishing operational criteria for the Drain, and will be used to determine whether treatment of the drainage water is necessary.

Dredged Backwater Areas

Little is known of the ecological effects that dredging has on backwater areas. To gain knowledge in this area, the Lower Colorado Region of the Bureau has contracted with the U.S. Bureau of Sport Fisheries and Wildlife, and the Arizona Cooperative Fisheries Unit, University of Arizona, to investigate over the next 2½ years, four dredged backwater areas in the Palo Verde Division of the Colorado River. The study will provide data which will assist Reclamation in the future development of backwaters and improvement of river channels under the lower Colorado River channelization program. The major parameters to be measured in the backwaters and adjacent river sections are various fish concentrations, exchanges in the aquatic organisms essential to fish life, and related water quality values. The study will be completed in 1973.

Lake Mead Mathematical Model and Micronutrient-Biological Relationships

The biological relationships of phytoplankton, zooplankton, and biological productivity to chemical and physical variables in the Lake Mead ecosystem are largely unknown. The Lower Colorado Region of the Bureau is currently conducting research into these relationships in Lake Mead under a contract with the University of Arizona.

The objectives of the study are to: (1) determine trace metal concentrations at different locations in Lake Mead; (2) measure biological productivity and conduct plankton population counts at each sampling location; (3) derive functions relating biological productivity to trace metal concentrations, suspended sediments, and the physical variables of temperature, light, and solar radiations; and (4) develop a mathematical simulation model of chemical-biological interaction in the Lake Mead ecosystem.

Field samples are being taken during critical times of the year at eight selected points on the Lake. After analysis of the data, a digital simulation model of the chemical-biological interaction in Lake Mead will be developed.

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ENGINEERING WORKS

Research in engineering works is directed toward improving the design of water storage, control, and transmission facilities; hydropower and pumping facilities; and electrical generation and transmission facilities. It encompasses research on the materials used in these facilities, on instrumentation, and on improved methods of construction, operation, and maintenance. The goal is to improve the economy, efficiency, and safety of the Bureau's water resource projects.

STRUCTURES

Research in structures is conducted to improve design and construction criteria and techniques for all structures associated with the Bureau's development of water resources. Included are investigation of earthquake and dynamic loads on structures and foundations, development of more efficient shapes for dams, measurement of in-situ stresses in structures and foundations, more effective use of materials, improved pipeline structural design and use, and improved analysis techniques.

Response of Concrete Dams to Dynamic Forces

To obtain information on earthquake loadings for concrete dams, the Bureau has made forced-vibration tests on two structures. The first arch dam tested in this manner was Monticello Dam in California. Following this, similar forced-vibration tests were made on Morrow Point Dam with low reservoir water, and then in 1972 with high reservoir water. The report on this investigation will include comparisons between measured and computed natural frequencies, mode shapes, and deflections.

Methods were developed for analyzing concrete gravity dams for earthquake loadings. These methods were used to make stability studies of Grand Coulee Dam and the adjoining Forebay Dam, now under construction. This work was prompted by a request from the Atomic Energy Commission, which wanted to know what the maximum discharge downstream would be if the two structures were subjected to a Modified Mercalli Intensity VII earthquake.

Response of Intake Towers to Dynamic Forces

Forced-vibration tests of the San Luis Dam intake towers were completed for low and high reservoir water conditions. The final report on this work will include comparisons between computed and measured data.

Using methods based on the above investigation, the Toa Vaca Dam intake tower and the downstream intake tower at Hoover Dam were analyzed for three earthquake loadings of varying intensities. Design earthquake loadings and dynamic response for the towers were determined from the results of analysis.

Response of Earth Dams to Dynamic Forces

Subsurface nuclear blasts such as Project Rulison produce manmade earthquakes at known times and intensities. When structures are located near such blasts, information on their response to earthquake-type ground vibrations can be obtained by field measurements. Experiments of this kind have been

made on three Bureau dams during two subsurface nuclear blasts: Navajo Dam during the Gasbuggy event, and Vega and Rifle Gap Dams during the Rulison event.

Comparisons between measured and computed data have been made for all three dams. The results of the studies for Navajo and Vega Dams have been published.[1,2] During these investigations, the Bureau worked with the National Oceanic and Atmospheric Administration (NOAA) and the Corps of Engineers.

Seismic Activity Due to Formation of Lakes

There are conflicting opinions on whether the weight of reservoirs on the earth's crust triggers earthquakes. The Bureau has been investigating this problem for more than 30 years. Recent studies on the seismic activity near reservoirs impounded by Flaming Gorge, Glen Canyon, and San Luis Dams indicate that these particular bodies of water have not caused local earthquakes. The data on which the investigations were based were obtained from seismograms recorded at Bureau seismograph stations near the reservoirs. A report was prepared on the results of the San Luis Reservoir seismic activity study.[3]

Plans were prepared for installing a short-period seismograph near the Auburn damsite in California to obtain data on the local seismicity before and after filling of the reservoir.

Dynamic Tests of Structural Members

The vibration testing laboratory at the Bureau's Denver Engineering and Research Center was used to test reinforced concrete beam-column connections under earthquake loads. The laboratory equipment includes a 50,000–pound force ram, capable of a 10–inch stroke with a 30–inch–per–second velocity and a 100–cycle–per–second frequency. Electronic instrumentation to control test sequences and obtain and analyze data is also available.

Nine reinforced beam-column connections were tested. Each specimen consisted of a 12–inch by 15–inch by 13.5–foot column with a 12–inch by 18–inch by 6–foot beam jointed to the column center.

The testing program included loading the specimen with a small static load, dynamic loads simulating the El Centro 1940 earthquake scaled by a time factor of one-fifth, and a test loading at the natural frequency. Other dynamic tests were performed at low stress levels to obtain natural frequency and damping values.

Mass concrete beams, 16 inches square, 12 feet long, and cast with 3–inch–maximum size aggregate, are also being tested to determine their performance under earthquake-type loads. They are axially loaded to prestress the concrete to 1,000 pounds per square inch. A bending load is dynamically applied at approximately the third points with a 10–foot simple span. Variables consist of the axial and bending stress level and the frequency of the dynamic load.

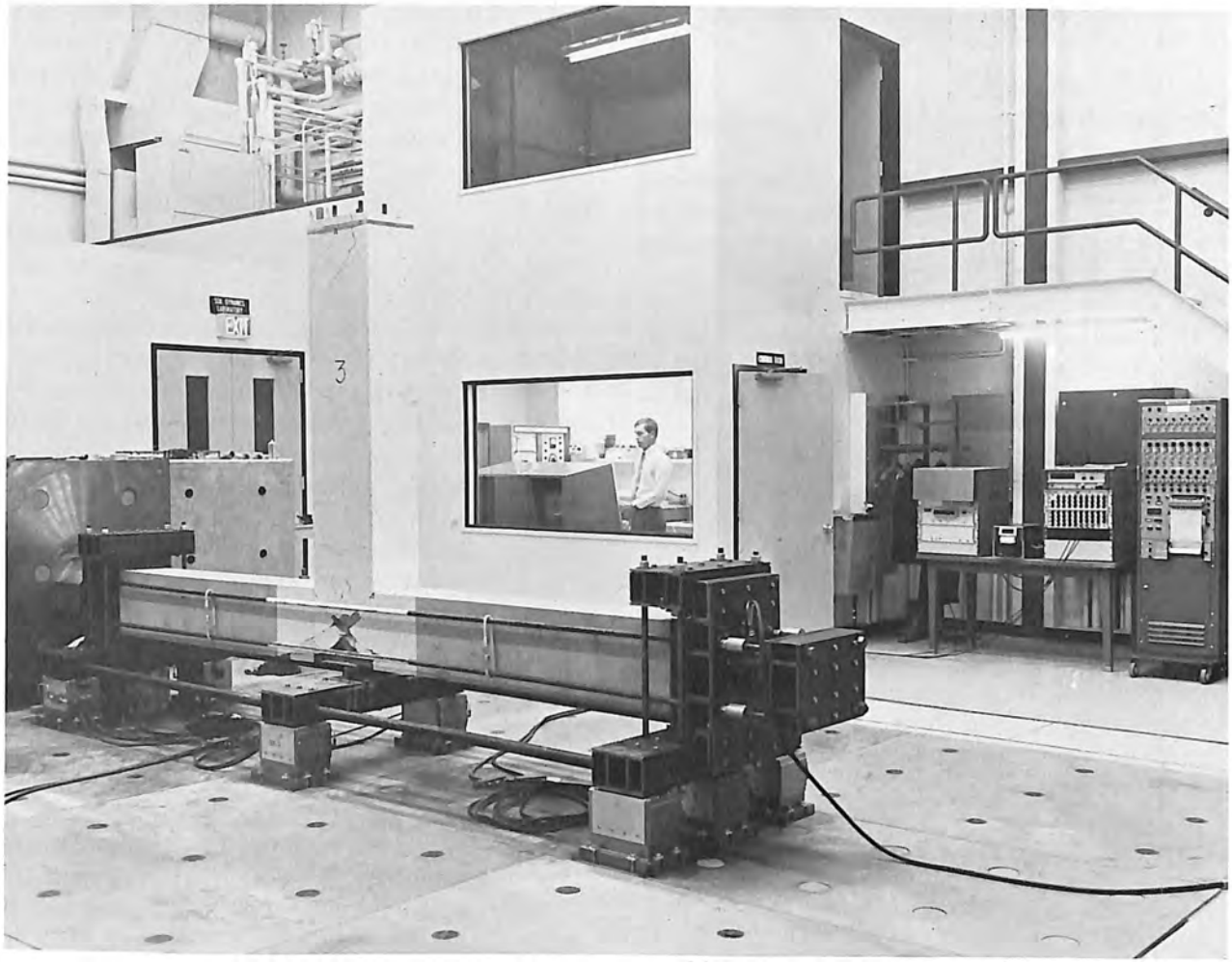
Three-dimensional Finite Element Analysis of Arch Dams

A contract with the University of California was established with the objective of developing a program for three-dimensional finite element analysis of arch dams. The program will accurately model the dam and foundation and analyze their behavior as a monolith due to the applied loads. The analysis of Morrow Point Dam will be included as part of the work to demonstrate the accuracy and applicability of the work, and results will be checked with dynamic responses obtained in prototype vibration studies.

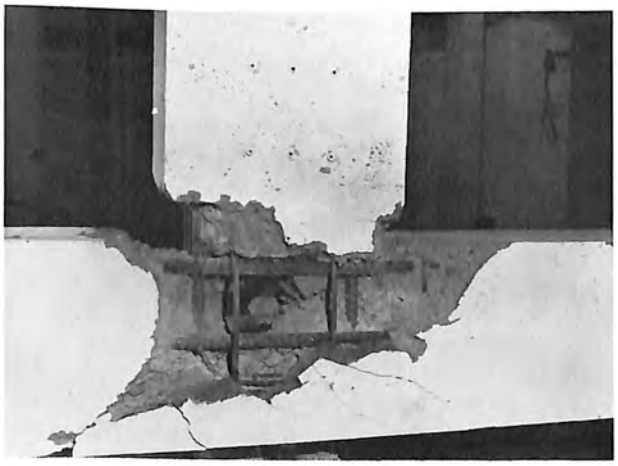
Arch Dam Foundation Analysis

The Arch Dam Stress Analysis System (ADSAS), a computerized version of the trial-load analysis method, uses an approximate procedure for predicting the deformations of the foundations of arch dams. The deformations are then used in analysis of the dams. Research is now producing analytical systems to replace this approximate procedure with a more exact method.

The first step in the research was to develop a procedure using a three-dimensional finite element analysis to compute foundation deformations so they could be compared to those presently used. The comparison showed that sig-



Reinforced concrete beam-column connection tested under earthquake load.



Reinforced concrete beam-column showing specimen cracking pattern, following dynamic loading with scaled El Centro earthquake.

nificant differences occur betwen the two methods. It was noted that the key assumption of the approximate procedure, which states that the abutments of individual arches and cantilevers are independent of adjacent effects, is a major contributor to the difference in the results of the two methods. For significant improvement to take place in the determination of the foundation deformations, it is necessary to abandon the concept of the present approximate procedure. This procedure would be replaced by one using the three-dimensional finite element representation to develop unit foundation material that would treat the foundation as a monolith. It is the goal of the second phase of the research to develop this unit foundation material for a specific dam, incorporate

its use into ADSAS, and determine the effect of the change on indicated stresses.

Structural Models of Underground Openings

A model study was started to supplement field, analytical, and other laboratory studies to gain a better understanding of underground openings in rock. Operations research techniques were used to develop a program for this study, and mix investigations were made to select material for the model. Since similitude relations are critical in model studies, a library research program was conducted on available literature, and results of this study have been condensed in a report.

Experimental Transmission Line Towers

In 1964, the Bureau energized the 230–kv Glen Canyon-Shiprock transmission line. This line included a 7–mile experimental tower section, composed of four each of seven different supporting structures. The structures were either guyed or self-supporting, steel or aluminum, tubular, lattice welded, or bolted construction. Except for one structure which proved most expensive, all structures had a horizontal conductor configuration with two ground wires.

Although most tower construction was accomplished by crane, sufficient erection was accomplished by helicopter to prove that this method could be used. The cost analysis indicated that conventional steel lattice structures were the least costly and that, where possible, crane erection was least expensive. The experimental section has performed satisfactorily since the line was energized, with no adverse reports from maintenance personnel. A report on these experimental transmission towers is available.[4]

Indeterminate Structural Analysis

The use of finite elements for bending analysis of thick plates and axisymmetrical solids has been incorporated into the Indeterminate Structural Analysis computer program. Mindlin's higher order plate theory and variational principles were used for the plate bending elements. Stiffness equations have been developed for both rectangular and triangular elements. Both elements produce solutions for thick plate problems that rapidly converge to the theoretical answer as the element mesh size decreases.

A triangular-shaped element is used for the axially symmetrical stress distribution problem. Equations were developed for a typical element and for elements with one or two nodes on the symmetric axis.

Analysis can now be performed on a wide variety of structures, ranging from simple frames to complex powerplant structures, by the use of straight members, rigid arms, plate bending elements, plane stress elements, plane strain elements, and axisymmetrical elements. This technique provides a much faster, more accurate, and economical design for the many structures required in water resource projects.

Structural Problems Associated with Concrete Pipe

In the development of water resource projects, large amounts of concrete pipe are used. In the search for less expensive installations, monolithic pipe continues to be competitive for larger diameters. Present studies consist of developing and establishing design criteria for both noncylinder and steel cylinder monolithic pipe and developing standard designs for low head noncylinder monolithic pipe.

Tentative criteria for the design of cylinder and noncylinder monolithic pipe have been developed, with full consideration given to existing criteria; e. g., higher allowable stresses for concrete, reinforcement, and steel; existing and proposed codes; previous design and research studies; and current construction requirements and practices. Standard designs for low head noncylinder and monolithic pipe were developed based on the tentative design criteria.

Three-dimensional Photoelasticity

Three-dimensional photoelasticity provides a means for experimental stress analysis solutions to previously unsolvable three-dimensional structural analysis problems through the use of birefringent epoxy resin models. In addi-

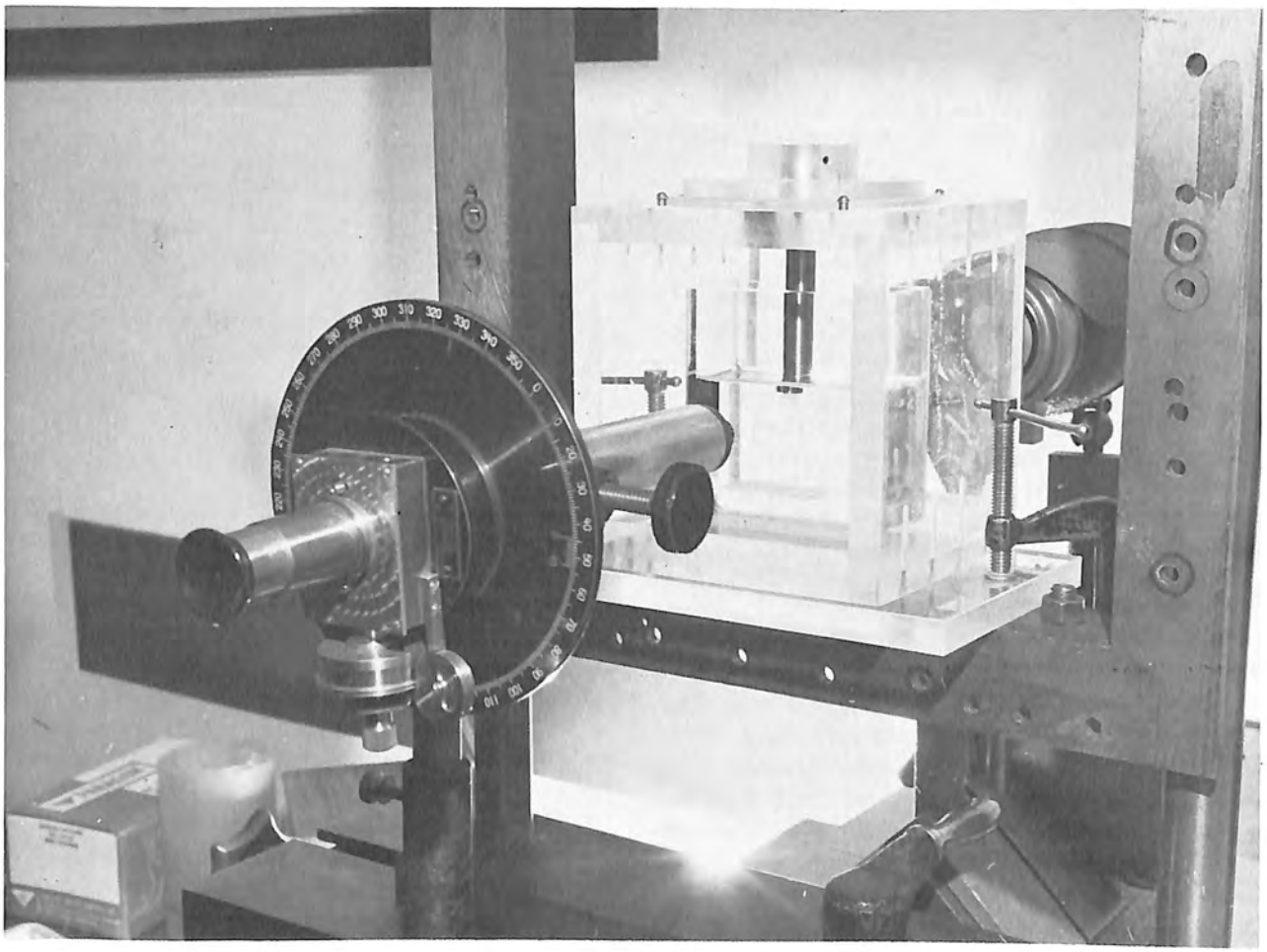
tion, it can provide an excellent check on certain approximate mathematical methods.

The core method of three-dimensional photoelasticity is a technique that allows determination of boundary stresses by analyzing small cores photoelastically. The cores are removed from three-dimensional models in which the state of stress has been fixed (frozen). This technique will provide great savings in time and effort when boundary stresses are of interest.

The exterior boundary stresses of a thick-walled cylindrical pressure vessel have been determined using the core method. The results obtained along the transverse centerline were compared with the analytical values and excellent agreement was obtained. The practicality of this technique is enhanced by using a small diamond core drill to obtain the cores.

By removing slices from a three-dimensional model in the "frozen stress" mode, and using a technique such as the shear difference method, the complete state of stress may be determined at interior as well as boundary points in a three-dimensional structure. (The core method yields boundary stresses only.) A photoelastic polariscope, with the necessary auxiliary equipment to allow the use of the shear difference technique, has been acquired.

An assessment of the core method, based on the ability to rehabilitate dull core drills, as a practical tool for three-dimensional photoelastic stress analysis will be made. The optics of the new polariscope will be checked for alinement and accuracy. The analysis of the thick-walled pressure vessel will be continued using both the core method and the slicing technique.



Optical set-up for analyzing cores, using the core method of three-dimensional photoelasticity.

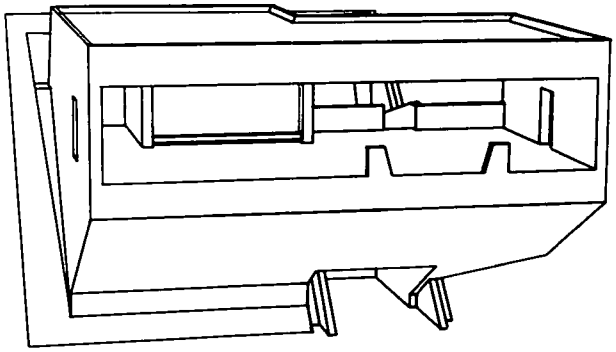
Analyzing frozen stress pattern in new photoelastic polariscope.

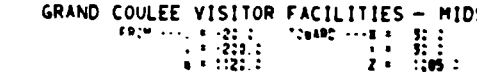
Interactive Computer Graphics

The solution of structural analysis and design problems by computer methods has exposed a communication problem between man and machine. The communication of input data by punched cards and of output by the printed page is a significant constraint to the efficient utilization of the computer. Interactive computer graphic methods offer improvements in both the speed and effectiveness of the structural analysis and design process.

Two interactive graphics programs have been developed that demonstrate the advantages of this method of communication. The first program computes concrete and steel stresses in a reinforced concrete member subjected to a combination of axial force and biaxial bending moments using an elastic stress distribution. The interactive feature of the program allows the designer to revise any portion of the problem description at the keyboard and receive immediate pictorial results on the console screen. The capability to instantaneously plot a member cross section, with the neutral axis and material stresses for a given load, greatly improves the process of checking and correcting input data, evaluating results, and selecting alternative designs. The analysis and design of a structural member can be accomplished with a minimum of human effort and in a much shorter time span than when done by conventional means.

The second is a general purpose three-dimensional graphics program which is useful in improving visualization of complex solid objects. Top, front, and side projection views, isometric views, and true perspective views from any viewpoint can be produced. The interactive feature allows revisions to the data base or new view requests at the keyboard. One unique feature of this program is the capability of determining which lines or parts of lines are visible from the chosen viewpoint.





A computer graphics simulation of a structure in the Grand Coulee visitor facility.

In these developments, an interactive graphics package was produced that will greatly aid in the development of future programs. A method of interactive simulation was also developed which overcame part of the difficulty of debugging the programs without having a graphics console available locally.

HYDRAULICS AND SEDIMENTATION

Research in hydraulics and sedimentation is conducted to solve the wide variety of design, operational, and maintenance problems associated with water control facilities. Studies are conducted on automatic and remote control of water conveyance systems, high velocity flows, protection of facilities from these flows, energy dissipation, surging in turbine draft tubes, water measurement, pipeline and tunnel hydraulics, ice effects, sedimentation, and drains.

Automatic and Remote Flow Regulation in Canals

Considerable progress has been made in the development and implementation of the Hydraulic Filter Level Offset (HyFLO) method of automatic downstream control of canal check gates.

The need exists to modernize traditional methods of operating irrigation canal systems that maintain a unity load factor; that is, canals that operate at essentially the same flow day and night. Automated farm distribution systems, the relation of soil moisture and weather factors in determining the amount of applied water, and the possibility that distribution system pumps and their control systems may suffer power outages result in unscheduled variations in turnout demands. More sophisticated methods of control than those realized by conventional means are required if the canal system is to respond actively to prevent wastage or shortage of water.

The automatic downstream control of canal check gates by the HyFLO method is one means that can meet these unscheduled demands. Changes in water surface levels caused by canalside turnout demands are used to control check gates upstream and thus the flow throughout the system. With the HyFLO method the upstream gate openings are made proportional to the difference between the actual and the target water surface elevation (offset) at the lower end of each reach. Together with techniques incorporated to prevent instabilities, this results in a stable, self-regulating control system which maintains a reasonably constant water level in all reaches and should be useful in many canal installations.

In March 1969, the HyFLO method was tested on the Corning Canal, Central Valley Project, California, for the first time. Results

General view looking downstream at the Coyote Creek Check No. 1, Corning Canal. The white cabinet houses the HyFLO controller, which regulates the adjacent check No. 1 gate opening. The primary control signal is received from the hydraulic filter well, located downstream immediately above the next check, a distance of 1.5 miles.

Laboratory studies of the HyFLO water-level sensor and signal generator developed by the Mid-Pacific Region were conducted at the E&R Center.

of the test program confirmed the theory of the HyFLO method and also showed the importance of having reliable control equipment. The primary problem encountered was the pickup of extraneous "noise" signals within the electronics.

Laboratory studies at the E&R Center have determined modifications for the equipment to correct the trouble. In February 1971, the HyFLO method, with modified equipment, was reinstalled on the Corning Canal for control of the first check structure. The results of initial tests showed that establishment of a reliable control system is well on the way. Reliability is very important if new systems, such as the HyFLO method, are to be used successfully. Field tests on the Corning Canal are being conducted to determine and demonstrate reliability.

On the horizon is a more refined concept, called the Smith method, which consists of two independent controllers: (1) the "Smith Linear Predictor," and (2) a controller to eliminate reflected surges. The predictor controller basically eliminates dead time from the controlled processes and incorporates an analog model of the canal reach being controlled so that input remains unchanged when the surge (created by the change of the upstream gate opening) arrives at the sensor location downstream. The reflection controller operates in parallel with the Smith Linear Predictor controller, using the same input to control the same upstream gate. It eliminates reflected surges which travel upstream from the sensing device and are reflected below the controlled gate.

The Smith method, because of its capability of immediate response, has the potential of replacing the need for remote supervisory control of canal check gates on canals such as the Delta-Mendota Canal. At present, the Smith method is an analytical study and it has not yet been developed and tested on a prototype basis.

The analytical investigation for the HyFLO and Smith methods was completed through a research and development contract with the University of California sponsored by the Bureau of Reclamation. The final report, which includes a step-by-step process to develop the control parameters, is in its final stages of preparation.

The E&R Center is also investigating an automatic turnout controller. There are many instances where flows in distribution system laterals depend on the maintenance of a constant water level in the main canal at the head of the lateral turnout. Such dependence causes the main canal to lose much of its flexibility of operation and could have an effect on efficiently meeting variations of turnout delivery for other distribution systems. The automatic turnout controller will have the capability to maintain a constant turnout delivery (preset) when the canal water level changes. Therefore, the main canal will regain its flexibility of operation and automatic downstream control by such methods as HyFLO, thus enhancing the total system efficiency.

Prevention of Cavitation Damage to Flow Surfaces

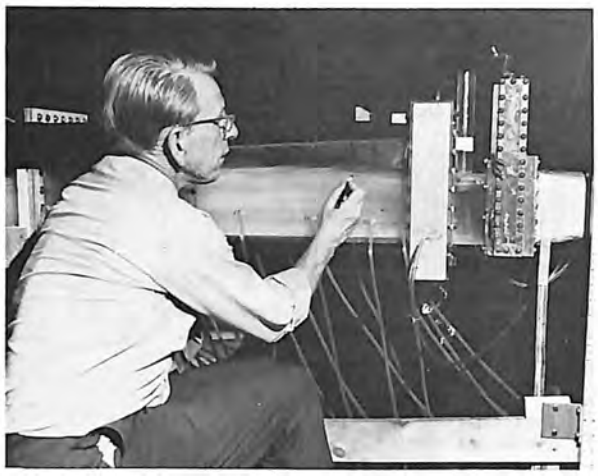
Flow surfaces of hydraulic conveyance structures such as spillways have on several occasions been damaged by cavitation during high-velocity flows. Proper flow passage configuration and surface finishes reduce the tendency for cavitation pressure to form, and the admission of air into the stream will cushion the damaging forces of cavitation.

Current research includes laboratory and field tests for the design of air slots and deflectors, or offsets away from the flow surface, for admission of air. An aeration slot installed in the Yellowtail Dam tunnel spillway proved successful in prototype tests completed in 1970.[5,6] A different configuration for installation in a proposed tunnel spillway was developed with a hydraulic model.

Design details for aeration offsets immediately downstream from high-pressure slide gates were developed for six separate installations. General studies were used to formulate design recommendations for both new and existing structures. A report is being prepared on results of this research.

Energy Dissipators

The dissipation of energy in high-velocity flow is a major consideration in the design of



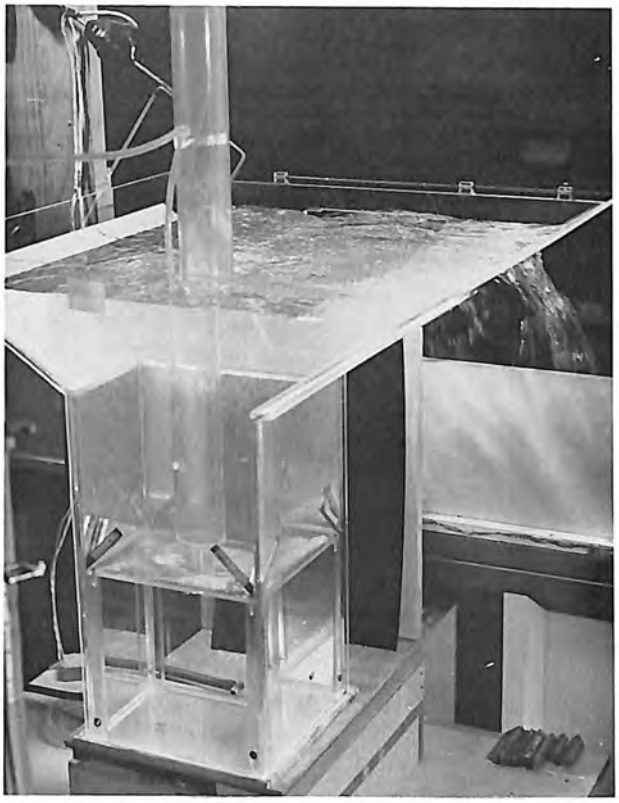
1:10.1 scale model used for developing a deflector and aeration slots for the Navajo Dam auxiliary outlet works.

water conveyance systems. Various types of conventional energy dissipators, particularly hydraulic jump stilling basins, have been developed during the past several decades.

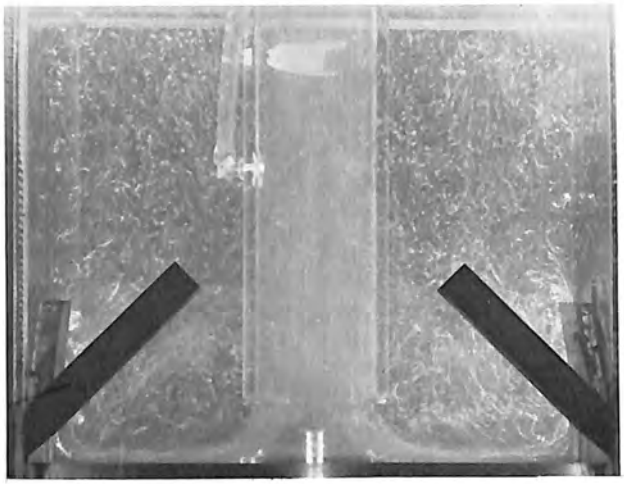
The current research program is directed toward development of special-purpose energy dissipators to augment or provide an alternative to the conventional types. Special purpose dissipators can result in lower construction cost, higher efficiency, and reduced maintenance and repair costs.

Vertical stilling wells offer an efficient and compact means of dissipating high energy flows in lieu of an outlet works stilling basin of conventional design. A small-scale plexiglass model was used to obtain the optimum size and internal configuration of vertical stilling wells for high head discharges from sleeve valves. The data have been verified with a larger model.

Work is underway to develop design criteria for plunge pools for dissipating the energy of outlet works discharges. A small model is being used to relate scour patterns in a movable bed to parameters such as head, gate size, gate inclination, etc. The results will be verified with a larger model.



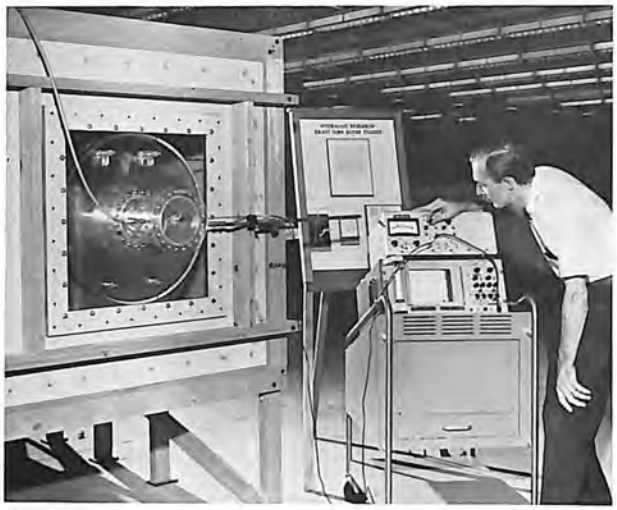
9-inch-square plexiglass model of the vertical stilling well and sleeve valve.



Side view—air was injected into pipe flow to illustrate flow pattern around the corner angle-iron baffles.

Draft Tube Surges

Studies of hydraulic turbine draft tube surging continue, using the air model test facility. The investigations have been directed toward determining the effect of draft tube shape on surging characteristics. A model of a standard draft tube, as well as simplified shapes such as cylinders, expanding cones, pipe elbows, and combinations thereof, were studied. The re-



Studies on surging in turbine draft tubes are economically performed using air.

sults show that the draft tube expansion angle and length-to-diameter ratio strongly influence the surge frequency and amplitude. Other features, such as gradual bends and entrance edge rounding, have little influence.

The results of the air model study have been used to predict the frequency of surges in hydraulic turbine model tests, resulting in good comparison with measured frequencies.

The computer program used to compute characteristic dimensionless parameters from the model data was expanded and routines were added to utilize a cathode-ray tube plotter on line with the computer. The resulting plots are photographed on 35-mm microfilm for later use in comparisons and analyses and for convenient storage.

A report[7] presenting analytical studies, model description, and results of initial testing was published. Two papers,[8,9] based in part on the air model studies, were also published.

A model turbine test facility has been assembled at Estes Powerplant in Colorado, where an operating head of 355 feet will be used to further investigate draft tube surges and remedial actions. Ranges of head, turbine gate opening, and draft tube submergence will be used to define parameters that can cause surging. These will provide a basis for investigation of actions necessary to minimize rough turbine operation. An analog/digital data acquisition, computation, and X-Y plotter system is used to obtain test results.

Water Measurement

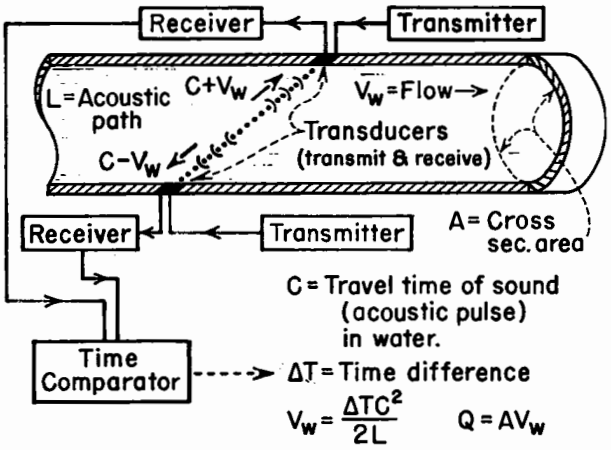
Increased use of our limited water resources and the trend towards increased automation and control require improved water measuring methods, increased measuring accuracy, and information availability to the people concerned with measuring water and automating delivery systems. Newer distribution systems demand greater knowledge of older, established devices and newer, more complex devices to account for and control water in pipelines and canals. Studies are directed toward increased accuracy for continuously indicated flow rates and totalized flows, and for increased knowledge of how the devices will respond in automated systems.

Studies on the use of radioisotope tracers for measuring flow through high head pumps and turbines were completed. The method consists of injecting radioisotopes into pipelines and timing their passage or determining their concentration after mixing with the flow. The studies investigated the preparation and handling of isotopes, injection techniques, required mixing with the flow, sampling methods, and radiation counting techniques. Field tests were made at Flatiron and Pole Hill Powerplants, Colorado, where accuracies of 1.5 percent were attained. The studies are summarized in a report[10] and a paper.[11]

Ultrasonic flow measuring devices generate pulses and measure the time it takes them to travel through the flowing water. Average velocities are determined and converted into discharge, or rate of flow. Laboratory tests were conducted to determine the feasibility of using strap-on pulse transmitters and receivers (transducers) on thick-walled pipe such as those made of concrete or asbestos cement. Results of tests indicated that thickness of wall and transducer-wall-contact variation produced poor accuracy. Strap-on transducers were accurate for thin-walled steel pipe, but for thick-walled materials the transducers should be in contact with the flowing water. A thesis[12] concerning these tests with the ultrasonic flowmeter was written.

Further analyses of laboratory data obtained with 10–, 12–, and 14–inch flowmeter/controllers were made in preparation for a report. These devices combine the capability of

This long penstock leading to Flatiron Powerplant provided an excellent test site for evaluating radioisotopes to measure flow rates in pipelines.



Schematic diagram of ultrasonic flow measuring system.

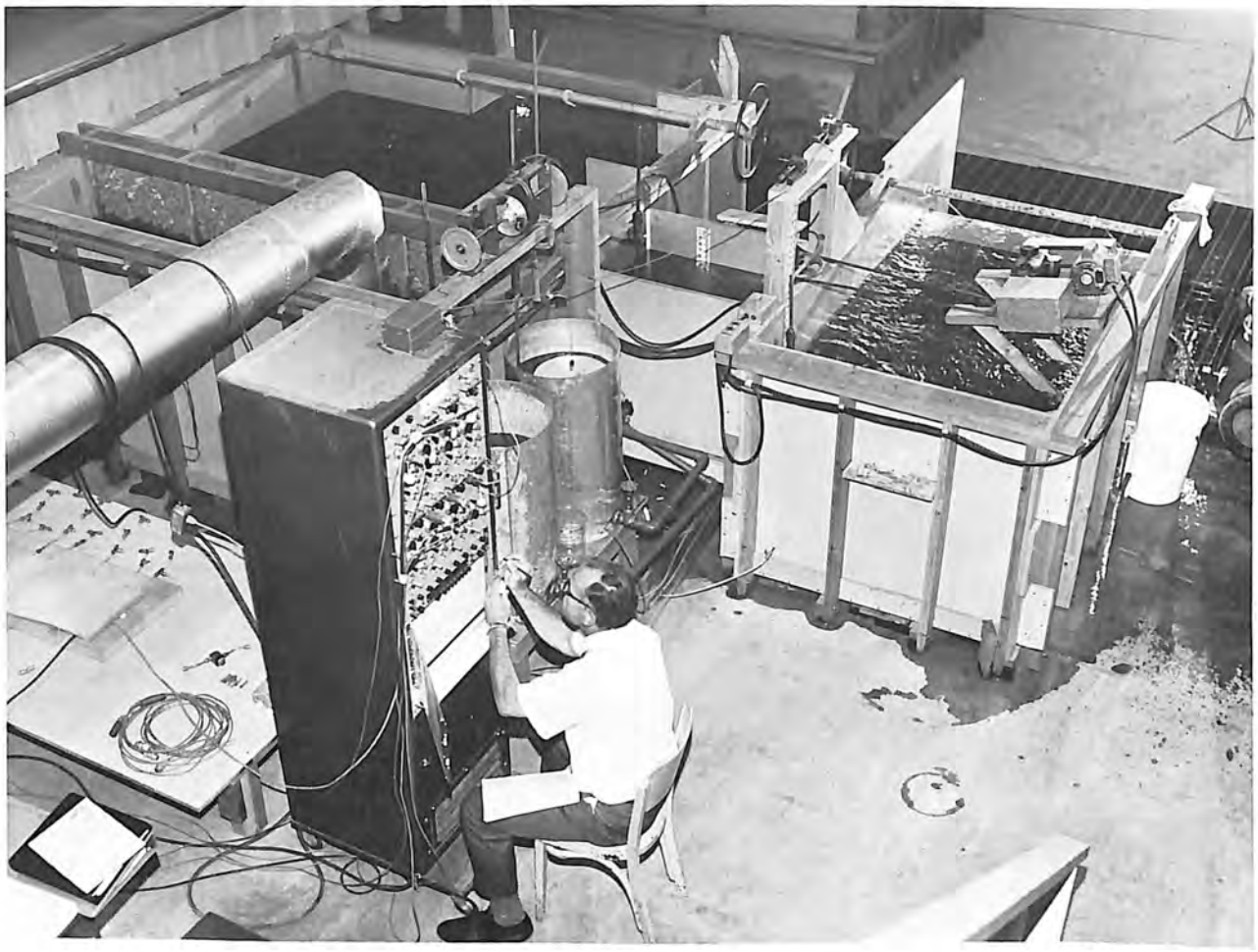
measuring flow, returning delivery flow back to set amounts after large pressure changes in supply lines, and shutoff of main flow by means of a ½–inch hand valve. The latest analyses were mostly concerned with the response of the controllers to large pressure increase and their subsequent temporary overdelivery of flow.

A water measurement publication was revised and printed for use in the Bureau's Irrigation Operators' Workshop.[13] This publication was also furnished for use in a similar joint workshop with the Department of Water Resources of California, and a Utah State University workshop. Assistance was also given by teaching and moderating water measurement procedure sessions for all three workshops.

Measuring delivery of water through a constant-head orifice turnout depends upon knowing the opening of one gate and maintaining a constant differential of water surfaces between each side of this gate by means of another downstream control gate. Often the water level in the supply canal changes enough to cause variation from the set differential, requiring the constant attention of operating personnel to deliver a constant discharge. A turnout was automated in the laboratory to aid in developing design data and methods and to provide stable systems that will adequately accommodate themselves to expected water supply canal water surface changes. Tests and studies are continuing that will determine the interrelationship of changes of water levels, gate characteristics, water surface lag in and around the turnout and the float wells, mechanical lag of floats and switches, and gate speed. Documentation will also be provided for checking future mathematical models of the complete system.

Salmon Spawning Beds

The new Tehama-Colusa fish facilities near Red Bluff, Calif., will have a monitoring system to determine the velocity of water flowing through the spawning gravels and to determine the amount of dissolved oxygen in the water. The salt velocity method will be used to determine water velocity. A salt solution is injected into the gravel through a piping system and the change in conductivity on monitoring probes is indicated on a recorder through an electrical system. To determine oxygen content, samples of water are extracted from the spawning gravels through a piping system, and



An automatic constant-head orifice turnout being developed to provide constant water flow regardless of variation in canal level.

oxygen content is determined with an appropriate analyzer. Both monitoring systems were developed and tested in the hydraulics laboratories prior to being installed in the field.

It is necessary to monitor the water flowing through the spawning gravels to determine when fine sediments entering the spawning channels will have to be cleaned from the gravels. A mathematical model is being developed to simulate sediment concentrations in the canal during cleaning of the gravels and flushing of the sediments into the Sacramento River. The model will be programmed on the computer and will incorporate theory and equations developed at the University of California, Berkeley. The model will be used to optimize the operation of the gravel cleaning machine and to predict turbidity of the flushing flows entering the Sacramento River. If turbidity is likely to be higher than water quality regulations allow, the model will be used to analyze schemes for meeting those requirements.

Instrumentation for Fluid Mechanics

Studies of the state-of-the-art of instrumentation are necessary in order to continually improve research in the Hydraulics Branch. The increased complexity of fluid mechanics studies requires rapid and detailed measurements. Progress made in computer techniques, programs, and applications needs to be monitored to provide efficient means of acquiring and analyzing data from research investigations.

Preparing the data acquisition system for use with the turbine model test facility.

Information from these studies led to the purchase of a digital data acquisition system for a turbine model test facility. A laser system was applied to a shadowgraph and considered for hologram photography of dispersed water particles and ice crystals in an air jet. Flow line tracing was improved by the use of hydrogen bubble and tellurium dye production apparatus. Bubbles were used in an idealized model of a reservoir stratification and dye in an atmospheric simulation using stratified liquid.

Pipeline and Tunnel Hydraulics

The cost and size of water conveyances depend to a large extent on the accuracy with which surface roughness and attendant friction head losses can be predicted. Prototype measurements of friction heads in existing and future systems provide the necessary correlation betwen theoretical and experimental values of surface resistance head losses.

The program to provide prototype test facilities for future measurement of friction heads in large pipelines and tunnels has been continued. Facilities have been constructed in three tunnels of the Fryingpan-Arkansas Project and have been included in designs of tunnels along the Strawberry Aqueduct, Central Utah Project.

Canal Capacity Studies

The capability to accurately predict resistance to flow in hydraulic channels is necessary for appropriate design of the structures. In many cases the bed shape resulting from water-transported sediment is the most important single factor affecting resistance to flow. Research on this problem has been underway for some time and now has been completed. A technical report, "Hydraulic Performance of Non-cohesive Channels," is being prepared on results of this research. This report establishes criteria for predicting sediment movement and the resultant bed shape, from which realistic hydraulic resistance coefficients may be selected.

Control of Ice on Water Resource Projects

A survey of ice problems on Bureau projects, a review of the literature, and a review of Bureau experience[14] showed icing problems to be a serious and widespread concern. The survey and review were followed by formation of an interdisciplinary team, which studied many facets of ice problems in natural channels, water conveyance systems, and hydraulic structures. Concurrently, a hydraulic model study was made of an ice jam problem which occurs annually on the North Platte River in Wyoming. Plastic chips, having almost the same specific gravity as ice, were used to simulate flow and jamming of floating ice. A report of this research is being prepared.

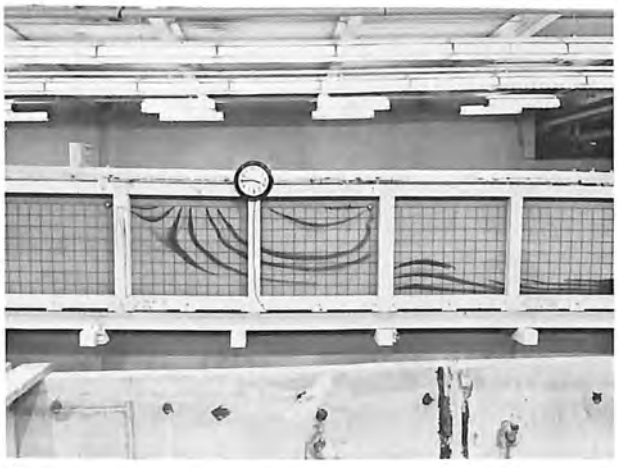
Floating plastic chips simulate an ice jam in a 1:24 scale model of an ice control structure on the North Platte River near Casper, Wyo.

Recommendations for future research on ice problems and for formation of a new followup interdisciplinary team to manage the research were made. The new team has been formed, and plans for future research are being assembled.

Drains on Level and Sloping Land

Research using a 60-foot-long, 2-foot-wide, and 2½-foot-deep tilting flume has shown that drain spacing formulas developed for level land can be used for spacing midslope drains on sloping land with a shallow, impermeable barrier. The upslope end drains can be spaced wider than the midslope drains and the downslope end drains should be spaced more closely.

Sloping 60-foot-long flume for pipe drainage tests.



Dye tracers photographed in a sand tank flume with the ground surface sloping 2½ percent.

Dye tracers photographed to show flow lines for steady-state flow conditions on sloping land were used to assist in analyzing the ground water draining research problem. The flow lines for irrigation water being applied uniformly to sloping land with pipe drains placed close to the ground surface and the spacing between the drains equal to 6 feet were also portrayed. Computer programs were developed to quickly determine pipe drain spacing from basic data for steady-state flow conditions.

HYDRAULIC MACHINERY

Hydraulic machinery investigations are made to improve the design and performance of the Bureau's hydraulic turbines, draft tubes, pumps, gates, valves, and other mechanical facilities.

Turbine and Pump Testing

A continuing study is maintained on methods for improving all phases of testing turbines and pumps, including test equipment, test methods, and computer programming. Included are more accurate, practical ways of measuring water flows; better methods of detecting and measuring vibrations, surging, and deflections in the systems; and methods of quickly and accurately analyzing data to optimize the testing sequences.

Gates and Valves

Investigations are underway to develop new analytical techniques and fabrication procedures for radial gates using a thin skinplate with no stiffeners. This design is being checked by model tests. The new and simpler design is expected to reduce fabrication and maintenance costs, and provide better drainage of the structural members.

Design studies and model tests have also been started for new water passage contours for butterfly valves used in turbine intakes. The new water passage shape gives uniform acceleration of flow from the valve intake to the centerline of the trunnions and a constant flow velocity from the trunnion centerline to

the valve outlet. This will result in smaller body and leaf diameters with a savings in material and cost, and less resistance to water flow.

ELECTRIC POWER

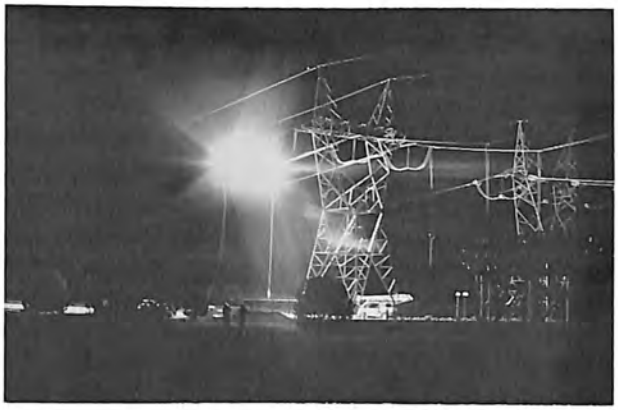
Research in electric power is conducted to improve the efficiency and reliability of electrical power generation, transmission, and control.

High-voltage Line and Series Capacitor Tests

The Bureau's double-circuit, 238–mile, 345–kv, series-compensated Glen Canyon-Flagstaff-Pinnacle Peak lines in Arizona are a vital part of the transmission system triangle supplying loads in the Phoenix area. This power system triangle also includes the Bureau's 230–kv Glen Canyon-Shiprock line, the short 230–kv interconnection between Shiprock and Four Corners, and the Arizona Public Service Co.'s two series-compensated 345–kv Four Corners-Pinnacle Peak lines. The Bureau's Glen Canyon-Pinnacle Peak lines were 60-percent compensated to achieve system stability and to provide balanced loading on the triangle. Compensation was designed so the two lines together would ultimately deliver 1,000 megawatts of power to Pinnacle Peak Substation. The Flagstaff and Pinnacle Peak series capacitor installations, new to the Bureau's system, were somewhat similar to series capacitor installations on the Bonneville Power Administration (BPA) system. During recent field tests, BPA had identified a number of problems requiring correction and it was considered prudent to test the slightly different design of the Bureau's installation.

Series capacitor installation at Flagstaff for the two 345-kv Glen Canyon-Flagstaff lines, Colorado River Storage Project. The power system mobile laboratory is in the foreground.

Two series of tests were conducted in 1970. The initial tests demonstrated that the capacitor banks were not reinserting against load current following a fault because of improper bank lockout. Some bank relay and vibration problems were identified as probable sources of trouble. Individual capacitor fuses in use at that time required lower than normal gap settings to assure proper coordination problems and the line relaying operated in accordance with design requirements for all faults that were applied.



Line-to-line fault staged for Glen Canyon-Flagstaff line relay coordination checks, Colorado River Storage Project.

Subsequent tests were scheduled after the manufacturer had been given an opportunity to study the problems at the factory. As a result the manufacturer made several bank modifications before the Government conducted another series of tests. This final test series demonstrated that the series capacitor banks, as modified, would operate satisfactorily. There were no lockout or fuse coordination problems during the tests. In addition, the trip line relaying still operated in accordance with design requirements with the higher gap settings. A relay polarizing problem at Glen Canyon was identified and corrected during the test series. The tests also demonstrated that if high-speed (26-cycle) reclosing on the Flagstaff-Pinnacle

Peak lines is ever required, means will have to be incorporated to discharge the trapped charge.[15]

Induced Transients in Control Circuits

False tripping of three 345–kv circuit breakers at Grand Island Substation was traced to induced voltages in control circuits resulting from transients generated by operating switchyard disconnect switches. On one occasion, the a-c station service supply of one breaker arced to ground. On another occasion, a breaker trip coil was burned out, and during exploratory tests a set of three trip coils of yet another breaker was damaged. Shortcomings were traced to the 345–kv breaker local cable installation.

Substation switching transients were simulated in the laboratory high-voltage cage by an impulse generator feeding a simulated high-voltage bus.

The problem was studied and some simulation switching tests were made in the laboratory and on the actual field installation. False tripping was eliminated by replacing breaker local control cables with direct buried shielded cables, eliminating loop circuits in the controls, and improving the grounding of the breaker parts and local cables. The original trouble-some cables were unshielded and routed on overhead trays between the breaker parts. Full voltage field tests were made to evaluate the transient magnitudes after corrective modifications were completed. Transients of only 5 to 75 volts were measured on switchyard control circuits in the control house. Measurements on a dummy cable, unshielded and routed over-

head as in the original faulty system, indicated that induced transients on the original breaker local cables were in the order of 5,000 to 6,000 volts even though the circuits were only about 25 feet long. Very small exposures of unprotected control circuits to EHV switchyard transients may be hazardous.

Power System Stabilizer

As the Western power system grid has continued to grow, power oscillations or swings have become detrimental to reliable operation. Efforts to alleviate the oscillations were continued by further development of the basic power system stabilizer (supplementary excitation control) designed in 1967.[16,17] As commercial versions of the stabilizer became available, assistance in alinement procedures for various private and public utilities was requested.

During 1970, several serious oscillations occurred in the Western systems. As one of several relief measures, the Western Systems Coordinating Council (WSCC) recommended that power system stabilizers be installed on all suitable generators larger than 75 megawatts. To aid in implementing this recommendation, the Bureau's research team participated in a seminar for private and public utility engineers to acquaint them with power system stabilizers. In cooperation with the Public Service Co. of Colorado, a demonstration of alinement procedures on a large in-service steam turbogenerator at the Cherokee Powerplant in Denver was included in the seminar.

Advancements in design of the power system stabilizer included development of a frequency transducer,[18] a voltage transducer, a method for obtaining generator shaft speed from terminal frequency, and application of state-of-the-art advances in microcircuit technology.

Installations of power system stabilizers were made at Judge Francis Carr Powerplant, California, and at Hungry Horse Powerplant, Montana. Commercial equipment was evaluated and commissioned at Yellowtail Powerplant, Montana. Each installation provided new information and allowed new techniques to be developed. Realinement of the equipment at Glen Canyon Powerplant, Arizona, provided a testing ground for alinement procedures now being used by Western utilities.

Other Government agencies were assisted in installation problems. Alinement of equipment at Hanford No. 1 Nuclear Powerplant, Washington, was undertaken in coordination with the Bonneville Power Administration. Installation and alinement of equipment at Oahe Powerplant was made at the request of the Corps of Engineers.

As a support to the various installations and in an effort to continually improve the quality of power system stabilizer applications, analog computer studies were made. These studies included application to the high initial response static excitation systems now available. Because the techniques applied to the older rotating exciter systems were inadequate for the static systems, new alinement techniques were developed.

A second training seminar was conducted by the Bureau, at the request of the Western Systems Coordinating Council, for private and public utility engineers. The second seminar on power system stabilizers extended alinement procedures for conventional excitation systems and dealt also with the new type of high initial response systems now coming into use. Analog computer simulations of generating units were used as training tools.

Frequency Deviation Transducer

Need for a fast response deviation transducer was indicated early in the undertaking

A versatile power system stabilizer was designed and assembled in the laboratory for use in simulation studies and for demonstrating alinement procedures.

of control applications to improve power system dynamics. Commercially available frequency transducers were examined and it was found that improvements were required.

A novel transducer was designed which aimed at ultimate performance expectations. Performance was checked first by analog simulation, followed by testing of an experimental laboratory model. Results were gratifying. A fail-safe feature is incorporated which gradually shifts the output to nominal (zero deviation) when the input voltage is drastically reduced or fails completely. Solid-state circuitry is used to achieve a reliable, low-power dissipation, convenient, and compact transducer.

As need for this device developed in power system stabilizers used on excitation systems, for special rate relays such as the acceleration relay, and for monitoring schemes for power system dynamic performance, further effort was devoted to simplify and improve the transducer. A number of power system applications have been made in both the private and public sectors. Applications have been aided by the research report[18] which explains the principles utilized, circuitry and characteristics, and also provides alinement, calibration, and trouble-shooting information.

Typical signal waveforms of the frequency transducer were monitored and photographed in the laboratory for use in the alinement instructions.

Rate Relays

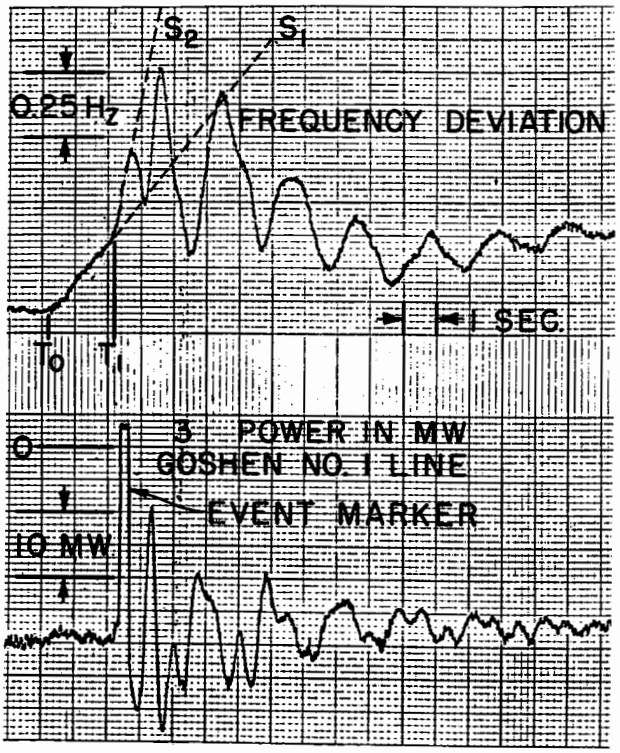
Two solid-state relays have recently been added to the Bureau's family of rate relays. An acceleration (rate of change of frequency) relay was designed to detect and operate upon power system accelerations of preselected values over a wide range, and a power rate relay was designed to operate on a combination of power and rate of change of power.

The acceleration relay was initially used in conjunction with a two-channel tape recorder to gather dynamic system performance data. These devices were installed at Palisades Powerplant, Grand Coulee Powerplant, and Tracy Pumping Plant to record system disturbances. The recording scheme provided pre-event data which proved most useful in system evaluation.

Acceleration relay and tape recorder used for acquisition of dynamic system performance data.

Early in the summer of 1971, system disturbances both in Canada and in the United States were producing adverse effects through the Winnipeg-Grand Forks interconnection. A joint effort on the part of investor-owned utilities, Canada, and the Bureau, prompted installation of a recent model of the power rate relay at Laverendrye Substation, Winnipeg, Canada. The relay was initially operated in a monitoring mode for about 2 weeks; then, as system demands increased, it was committed to tripping service. The relay detects and operates on system disturbances for which the overall system stability is best served by opening the intertie.

Rate relays are presently being investigated in conjunction with a generator dropping scheme to increase system stability. As shown in the accompanying illustration, an initial acceleration, S_1, followed a loss of the Pacific Intertie at T_0. At T_1, the eastern side of the WSCC transmission "donut" separated, producing acceleration S_2. The acceleration relay operated as shown by the event marker when the acceleration exceeded its setting.



System parameters recorded at Palisades Powerplant during September 29, 1969, disturbance.

Reactor Fault Relay

Failure of several of Reclamation's air-core shunt reactors used to compensate the line-charging currents associated with long, high-voltage transmission lines prompted development of a high-speed reactor relay. Irreparable reactor damage had resulted from the arcing which accompanied interlayer faults before being detected by conventional relaying.

The relay developed for reactor protection affords the speed and sensitivity to detect these interlayer faults and remove the reactor from service before extensive damage is done.

Field tests of a prototype reactor relay were conducted at Shiprock Substation in early 1970. The relay detected simulated faults on the reactor in 1 to 2 cycles, about 17 to 33 milliseconds. Performance of the relay was so encouraging during the tests that it was subsequently placed in permanent service at Shiprock Substation. Ten to twenty other applications are being considered in the Bureau.

Prototype reactor relay assembled in the E&R Center laboratory.

Surge Level Detectors

Surge level detectors were placed in service on the Blue Mesa three-phase transformer from October 1969 to October 1971. Three detectors were installed to determine whether the 115–kv bushing spacing for this transformer, equivalent to the minimum spacing recommended for sea level, is satisfactory at the 7,190–foot altitude of this station. Data accumulated on a statistical basis over an 18-month period have shown that the highest phase-to-phase surge levels between transformer bushings are modest, not exceeding 3.2 per unit and well below the 4.0 per unit level which can be tolerated. Phase-to-ground surge levels at 1.63 per unit were well under the 2.6 per unit protection provided by the lightning arrestors. It was concluded from this investigation that the 115–kv bushing spacing on this transformer is satisfactory for the service conditions at Blue Mesa.

Transformer Fault Current Monitor

Following failure of the Tyndall Substation's three-phase autotransformer in 1969, the Bureau has been concerned over the increased exposure and probability of line-to-ground faults on the customers' 69–kv line resulting from removal of overhead ground wires from all but the first one-half mile from the station. Current monitoring equipment was developed and

installed in the transformer neutral as a statistical check on the number, magnitude, and severity of line-to-ground faults on the transformer. The monitoring equipment includes a counter with four digital displays to record the most severe line-to-neutral fault currents at the transformer, in the range of 750 to 1,500 amperes. During 1970, four faults were recorded, two of which were in the range of 960 to 1,190 amperes.

Dielectrics

A considerable number of generators in the Bureau's system have been in service from 10 to 20 years. Since the normal life expectancy of stator generator insulation is in the order of 10 to 20 years, replacement of some of these stator windings is to be expected. Recently an epoxy-resin-insulated test coil, from replacement coils furnished for a a Grand Coulee stator winding, was dissected and evaluated in the Denver laboratory. The coil was one of several which had been rejected with questionable turn-to-turn insulation during preinstallation tests. The turn-to-turn failure was confirmed in the laboratory and the exact location of the fault was identified.

Thyristor Voltage Regulators

For over two decades, rheostat-type voltage regulators have served the eighteen 108-megawatt generators at Grand Coulee Powerplant, Washington. As the Western power system continued to grow, more precise and convenient control of voltage was needed. To provide the required control, a d-c, solid-state thyristor voltage regulator was developed to replace the motor-operated rheostat and contactor system. Although thyristor regulators which operate from an alternating-current source are rather common, this type of regulator for operation from a direct current was not commercially available.

The thyristor regulator contains unique circuitry to control by rapidly switching the exciter main-field voltage, using the existing d-c pilot exciter as a source. To switch direct current with thyristors (silicon-controlled rectifiers), momentary energy storage in a commutating capacitor is necessary. A fail-safe lockup detector and a restart scheme was developed to restore the commutating charge if it should ever be lost and to assure the high reliability needed. Other features include solid-state control circuitry, a voltage killer for internal machine faults, and a power system stabilizer (supplementary control). A complete description is given in references 19 and 20.

Two pilot models of the regulator accumulated 3 unit-years of successful service before installation of equipment for the remaining units, assembled by a commercial supplier, began in late 1971. Benefits include accurate, smooth and quick control of voltage, low cost of conversion compatibility with present and future automatic control schemes, and very little maintenance.

Electric Governor Conversion

Previous experience with the electric conversion of Grand Coulee Powerplant Unit G-17 and the more recent conversion of Unit G-15 with a newer, more advanced design has prompted the decision to equip all 18 of the original Grand Coulee units with identical conversion packages. Bids were invited and a contract for manufacture of the apparatus was awarded.

The conversion of the Grand Coulee units will provide the type of governor characteristics needed to comply with the requirements of modern interconnection problems, namely: improved response to tieline control signals, reduction of transient speed deviations for given load changes, and a more effective influence for damping system swings.

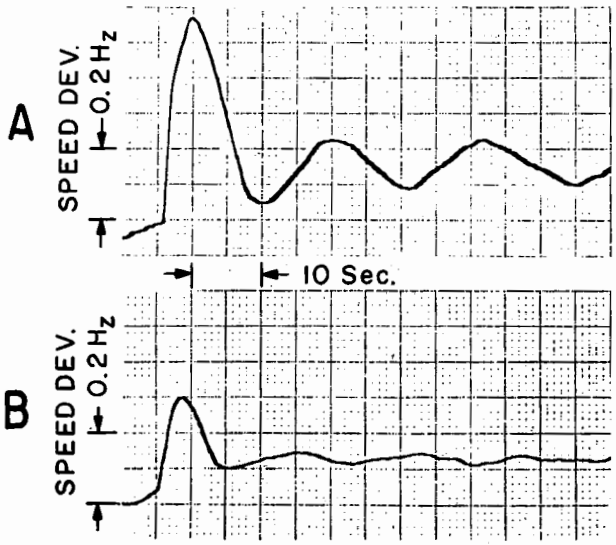
Governor Characteristics for Large Hydraulic Turbines

In considering appropriate parameters for large hydropower generating units, such as those for the Grand Coulee Third Powerplant, control characteristics to satisfy power system needs strongly influence economics of the design. Parameters fundamental to control characteristics, such as the penstock water starting time and the mechanical inertia or flywheel effect, are subject to control by the designer but if abnormal values are required the increase is obtainable at appreciable cost.

Calibration and operational check of final version of electric governor conversion package by analog simulation of the machine and power system.

To aid the designers with a basis for the most economical combination of the parameters to satisfy the requirements, an analysis of the requirements and their interrelation was undertaken.

On the basis of a conventional temporary droop-type governor, and to meet the required overall control characteristics, the flywheel effect and water starting time of the units were excessive.



Field test of governor systems on a Grand Coulee Powerplant unit. Shown in A is the large speed transient of a conventional governor for a 3-percent load change, and in B the much smaller transient and more stable response of the same machine with a refined governor.

Through the use of analog and digital computer studies and field tests, a refined governor system was developed to provide the control with less restrictions on water starting time and mechanical inertia. Some guides for proportioning parameters were defined. The system departs in several respects from conventional practice; consequently, the studies and results are recorded in a report.[21]

Auxiliary Pump Start Governor

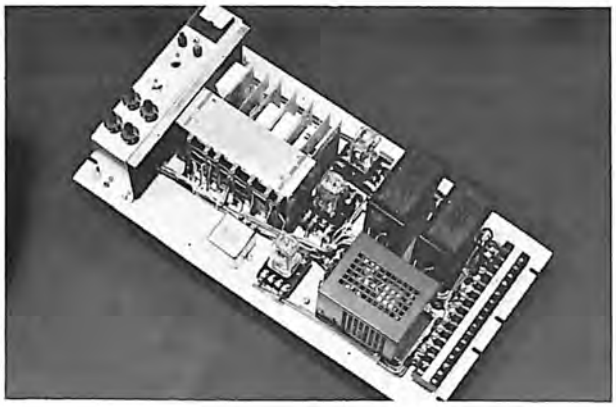
The Coulee pumping units, the largest in the world at the time of their design, were conservatively planned for starting by the full synchronous system, which required a rather long delay prior to starting for bringing the driving units to standstill to initiate the starting sequence.

Subsequent study and tests evolved the semisynchronous starting procedure, which saves time in that the driving unit need only be brought down to half normal speed. Water delivery starts at about 80 percent speed and tends to increase rapidly near full speed. Consequently, acceleration in the vicinity of full speed must be very slow to avoid generation of a bore wave in the feeder canal from the pump discharge to the balancing reservoir. A bore wave generated when the canal is already nearly full could be disastrous. Consequently, the starting process under manual control is critical.

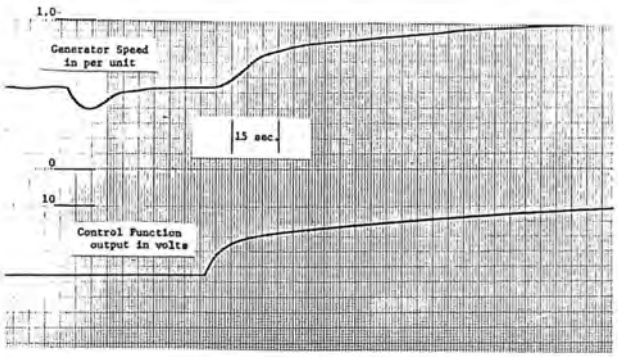
Increasing demand for irrigation water, installation of additional pumping units, relegation of pumping load to daily off-peak hours, and need to reduce operating labor, all combine in an urgent need for automation of the pump starting process.

The auxiliary programmable governor for pump starting was especially developed to fulfill the need for automatic control. It is a special-purpose system for automatically controlling speed and acceleration of its generating unit according to a program for starting and loading either one or both large motor-driven pumping units which can be directly connected. In the semisynchronous pump start method, the motors and generator are synchronized. The combination, still under control of the auxiliary governor, is accelerated toward

normal speed, rapidly at first but more slowly near 80 percent of normal speed as water delivery starts, and finally very slowly as full water delivery and rated speed are approached. The normal governor takes control when the unit is essentially up to full speed and capacity.



The auxiliary programmable governor for automatic pump starting.



Generator response for a two-pump start, showing performance of the auxiliary governor.

Transmission Line Hardware

Wind-created vibrations in transmission lines, while reasonably well understood, are difficult to control. The vibrations have caused concern about presently-used vibration damper efficiencies and bundle conductor spacer performance. The two parallel 345-kv transmission lines on the Colorado River Storage Project in an area 20 miles north of Flagstaff, Ariz., are being used to test the effectiveness of different vibration damper and conductor spacer schemes.

The test site was inspected in November 1969, and again in June 1970. Data were obtained on conductor wear at spacer attachment points and on bolt torques for the various types of bolted spacers. A special washer appears best of the various locking devices in maintaining torque value at acceptable levels.

Three other types of hardware were installed in 1970: spacer dampers, armor grip spacers, and vibration dampers of a new design consisting of a concrete ball mounted on a dash-pot mechanism. Performance of these items will be monitored in future tests and inspections at the test site. A new damper was also installed for test in a 115–kv line in North Dakota, and vibration recorders were placed on the line in March 1971. Data from the recorder tapes are being analyzed to determine the effectiveness of the damper.

Tentative plans include a test and inspection period of from 2 to 4 weeks at the test site in Arizona. Various manufacturers will participate in obtaining vibration data. A wind recording instrument will be installed to obtain data on wind velocities to correlate with the data obtained with the vibration recorders.

High-voltage Direct-current Circuit Breakers

Direct-current transmission at high voltages and extra high voltages promises substantial benefits over a-c transmission for long distances and large blocks of power. Direct-current transmission by cable circuits is also attractive, even for relatively short distances. To utilize the full potential and economy of d-c transmission, it will be necessary to expand its use from the present limited application in point-to-point transmission to d-c networks similar to those used in a-c transmission. This will require the development of d-c circuit breakers, presently unavailable. The special features required for d-c circuit breakers may also have some applications to future a-c systems.

The Bureau and Bonneville Power Administration are participating with the Edison Electric Institute in a d-c circuit breaker development program proposed by an aircraft manufacturer and sponsored by the Electric Research Council. The first phase of this program is to establish engineering and economic feasibility of the firm's sequential switching concept in a 30-month study completed in 1971.

The d-c circuit breaker concept utilizes interrupters for circuit switching, with linear resistors or silicon carbide nonlinear resistors for energy absorption. Laboratory prototype interrupters have been developed and tested for switching up to 100 kv and 1,000 amperes. Higher values are to be attained by the end of the program, and feasibility designs will be made for larger interrupter ratings required for high capacity d-c breakers. Experiments are being made on the series operation of four small-size interrupters with voltage control networks. A prototype high-speed mechanical, current-transfer switch has been developed and is being tested. Energy absorption requirements and performance of silicon carbide resistors have been evaluated. Preliminary design and cost evaluations of a d-c breaker have been made. Simulator studies are being made to model the interaction of the d-c breaker with the d-c system.

The aircraft company proposed a follow-on program to develop d-c breaker field prototype components for testing on the West Coast d-c intertie. This program has been accepted by the Electric Research Council and work is in progress. The work is reviewed and guided by a Bureau steering committee, which meets every 6 months at the company's research laboratories.

SOIL MECHANICS

Soil mechanics investigations are conducted to improve the economy, safety, and performance of foundations, canals, pipelines, earth dams, and other structures. Research is performed on the effects of overburden and soil pressures on steel, concrete, and plastic pipe; on transmission tower footings; and on new methods of reinforcing earth and rockfill dams.

Soil Pressures and Deflection of Flexible Pipe

With today's emphasis on placing water conveyance systems underground, the Bureau is constructing hundreds of miles of pipeline each year. A small savings in the design and construction of pipe per unit length would total millions of dollars. Laboratory and field tests are being conducted to supply data for reexamining old methods of flexible pipe design and improving applications of new types of plastic pipe.

The laboratory tests consist of applying loads on 18– to 30–inch-diameter pipe of various thicknesses buried in soil placed at 90 and 100 percent Proctor density to measure: (1) soil pressures on the pipe, (2) deflections and strain in the pipe, and (3) deformation of surrounding soil. The completion of a series of laboratory tests on 18– to 30–inch–diameter steel pipe has essentially confirmed current methods of design for this type of pipe.[22,23] Initial tests on reinforced plastic mortar pipe show that existing flexible pipe design methods based on steel pipe need modification because the plastic pipe acts differently under buried soil conditions.

Measurement of horizontal deflections of test pipe at the E&R Center. The cylindrical projections contain cells for soil pressure measurement.

Recently, Bureau designers became interested in comparing the deflections of various types of flexible pipe under identical field conditions. Therefore, 160 feet each of 48–inch–diameter steel, reinforced plastic mortar, and pretensioned concrete pipe were installed under 15 feet of fill in a drainage channel at the Denver Federal Center. To show the effects of cohesive and cohesionless types of side support, half of the pipe length was bedded in clay and half in sand. Instrumentation was provided to measure soil pressures on the pipe and the soil deformations. Pipe deflections can

be measured for as many years as required. These long-term field tests will be valuable in determining time factors to supplement the 1–day laboratory tests on the steel and reinforced plastic mortar pipe.

Test section of 48-inch-diameter steel, reinforced plastic mortar and pretensioned concrete pipe under 15 feet of soil backfill at the E&R Center to determine pipe deflections over a period of years.

Model Tests on Transmission Tower Footings

To prevent overturning of transmission line towers by high winds and possible line breakage, the tower footings must resist uplift forces tending to pull them out of the ground. In soils sufficiently cohesive so that auger holes can be drilled without casing, auger-type footings have been extensively used by the Bureau. For this type of footing, a steel reinforcement cage is placed in the auger hole and concrete is placed to form an embedded footing. For additional uplift resistance, the auger hole is often enlarged near the bottom to form a flared end or "bell."

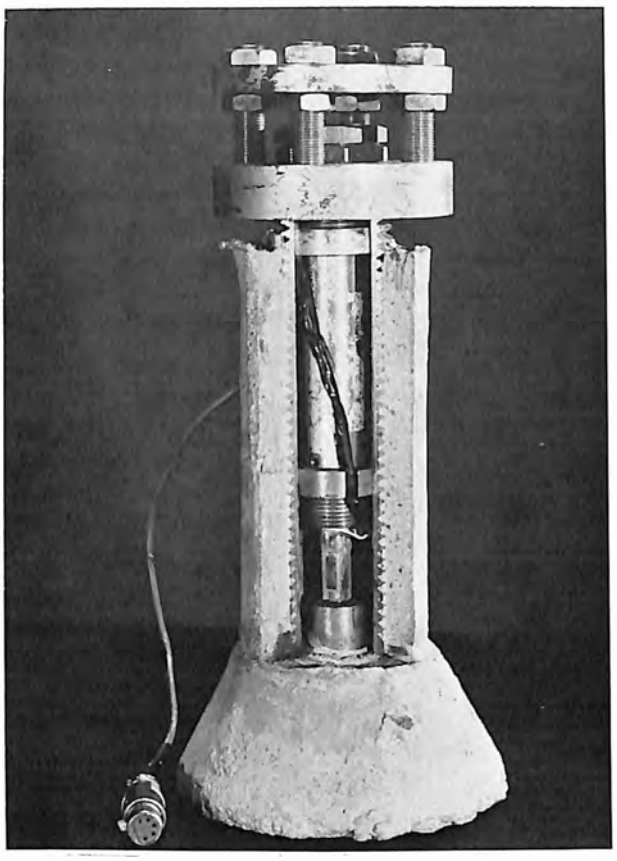
Following several full-scale field tests on auger footings,[24,25,26] laboratory model tests at about one-sixth field scale were started using silty soil. The purpose is to learn, under controlled laboratory conditions, more about how the strength and other characteristics of the soil affect the upward movement of the footing under load; this information is particularly needed within the movement limit range (about ½ inch) for allowable stresses in metal members of the towers.

Failure shape formed by uplift loads on 1/6-scale model of belled auger transmission tower footing.

The first series of model footing tests has been completed. The footings were pulled vertically to obtain basic relationships in the simplest directional mode. Footings of various lengths, both with and without bells, were tested. The footings were instrumented for the measurement of load and displacement. The tests showed that the use of a bell on an auger footing improved the load resistance about 50 percent over that for a straight auger footing. The belled footings also take more movement than a straight auger footing before pullout occurs. The tests generally showed that by using properties of the soil surrounding the concrete footing, the load characteristics of the footing could be predicted more accurately than by present cone-of-earth methods often used in design.

A second series of model tests now underway is similar to the first series, including the vertical footing installation, except that upward forces are being applied at various angles. This is representative of the more complex conditions actually encountered in prototype footings where the forces from the tower are not usually in the vertical direction.

The ultimate goal of the model tests is to develop an improved footing design method which involves the properties of the soil at the tower site and a finite element procedure of analysis. With this method it will be possible to design more economical footings which will withstand the forces imposed on them.



Cut-away version of a model transmission tower footing with a 10.5-inch length. With the strain-gage instrumented interior, the loads on the bell and on the shaft are determined separately when the footing is buried in soil and uplift forces are applied.

Ground Motions from Vibratory Rollers

Vibratory rollers have not been allowed on Bureau earth dams for the compaction of cohesive soil (clay) zones because not enough is known about the properties of the resulting soils with regard to their effectiveness as water barriers. To determine these properties, a field test section was included in a highway embankment near Cawker City, Kans. The variables investigated included moisture content, number of roller passes, and lift thicknesses.[27]

In addition, the velocities, amplitudes, and accelerations of ground motions in the embankment caused by the roller were determined. This produced important data on the vibratory action occurring in the soil and the resulting changes in the soil properties that were measured.[28] For dams, density and permeability are of particular concern. Measurements with accelerometers were obtained over horizontal distances of 0 to 50 feet and depths ranging from about 2.0 to 22.5 feet. Results indicated that: (1) relatively high ground motions were produced in the immediate vicinity of the roller, with accelerations exceeding 1 force-of-gravity to a depth and distance of 5 feet from the roller; (2) vibrations were directional, with the vertical components to the front of the roller being two to three times greater than those to the side; (3) higher ground motions were produced by the vibratory roller when stationary than when moving; (4) the magnitude of the ground motions appeared to depend on the moisture content of the soil directly beneath the roller; (5) the phenomenon of "beating" occurred when two rollers were operated near each other; (6) based on available damage criteria, the risk of damage should be considered when the roller is operated near structures; and (7) the ground motions were such that they could not be adequately duplicated in laboratory specimens because of the difference in boundary conditions.

Earth Dams

Special studies, based on results of a grouting test program at Teton Dam, were made to determine the most economical method of sealing dam foundation material to prevent leakage. Open cut or cement grouting or a combination are normally used. This study showed that 75 feet of soft rock could be excavated for the same cost as a grout curtain through the area. Since in general most of the grout is placed in the uppermost portions of a foundation, similar test studies at other sites may show economies that warrant a heavy cut approach in preference to grouting the uppermost groutable rock.

Another study was made to determine whether providing a grouting tunnel for supplemental grouting or doing the supplemental grouting from the surface with closed holes through the fill would be cheaper. This study showed that it would be less costly to drill through the fill and, in addition, if supplemental grouting is not needed the fixed cost of a tunnel could be saved. This study also indi-

cated that it is desirable to do a thorough grout job when the foundation is open to avoid either extra cost.

Studies were made for two dam foundation cutoffs by comparing open cuts and slurry cutoffs. In both cases for relatively small volume open cut cutoffs, the cost of slurry trenches was found to be greater.

A special study was completed on uplift in outlet works and spillway stilling basins. A special study has also been made comparing flip bucket and stilling basin energy dissipators that shows very favorable cost benefits for flip bucket construction where foundation conditions are suitable. A model test is being made to confirm or permit modification of the design assumptions used.

A series of stress analyses for oblong conduits of variable thickness and height-to-width ratios was made for use in dams. From these, the relative advantages of oblong, circular, horseshoe, and flat-bottomed conduits were considered. The study includes a tabulation of coefficients for the oblong conduit shapes investigated for determining moment, thrust, and shear for various loading conditions.

Improvement of Soil Mechanics Test Procedures and Analysis of Results

Since soil mechanics is a relatively new and rapidly changing field, it is necessary to continually develop and improve testing equipment and procedures. Such research is directed toward obtaining test results for design that will better represent soil characteristics under field conditions.

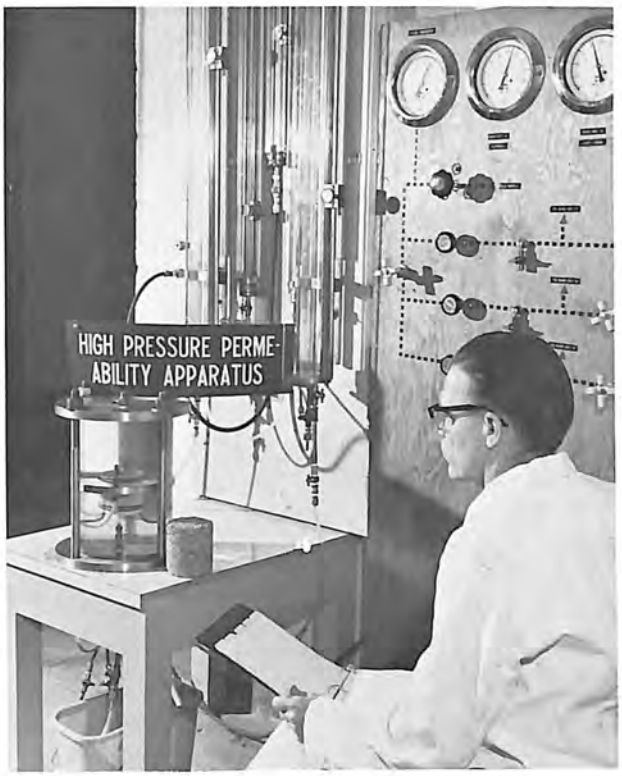
Large high-pressure triaxial-shear testing equipment for gravelly soils.

A progress report[29] was published on Bureau efforts to improve soil sampling and soil testing. The report included methods of advancing drill holes; use of drilling fluids, including air; comparisons of drill hammers and drill rods for penetration-resistance testing; and comparisons of performance of various samplers. One of the most significant advances was use of double-tube samplers with spring-loaded inner barrel; with this, difficult soils such as the variable clays at Grand Coulee Third Powerplant could be successfully sampled.

Another project was a cooperative testing program by 14 Bureau laboratories to determine reproducibility of results by the current relative density test.[30] This is the standard test used for controlling the placement density of sandy and gravelly soils during construction. This work, together with participation in a cooperative program in The American Society For Testing and Materials (ASTM) on relative density testing, is expected to lead to improvement in this important area of soils testing.

By contract with the University of Colorado, a computer graphics system for solving slope stability problems was developed.[31] In this system, data input can be from cards or a keyboard, and results are visible on a graphics display console. Any change in the input will be reflected immediately on the display. This graphic method affords a rapid solution to soil mechanics problems and will handle slope stability analysis methods used by the Bureau, as well as methods used by others.

In connection with problems of determining the anticipated flow of water through fault zones in the foundation of Auburn Dam, special equipment was developed and successfully used. This involved the design and fabrication of field permeability-type equipment capable of producing and withstanding water pressures about twice those normally used. This equipment has proven to be very helpful in obtaining exit gradient and permeability data for design of the dam.



To determine soil permeability a high-pressure permeability apparatus is used at the E&R Center. A cylindrical sample of the material to be tested is clamped in the device, and water is forced through under pressure.

Polymer Soil-cement

In view of the anticipated benefits from the development of polymer concrete, a small laboratory program was conducted on polymer soil-cement.[32] The purpose was to determine any beneficial effects on the properties of soil-cement as used in Bureau construction.

Tests were conducted on soil-cement specimens made from soils classified as silty sand and silt treated with the monomer methylmethacrylate (MMA). Some specimens were preformed, then impregnated with MMA and polymerized with gamma radiation from Cobalt 60. Other specimens were premixed, using 3 or 6 percent MMA with 1 percent benzoyl peroxide as a catalyst incorporated during specimen preparation; polymerization was by heat. The compressive strength of the preformed specimens containing silty sand was increased about 3.4 times that of specimens without MMA, but the premix specimens did not increase in strength. Results of freeze-thaw tests did not show conclusive trends, but there were indications of improvement with the addition of MMA. The MMA reduced signifi-

cantly the permeability of the silty sand specimens. Petrographic examinations showed that the MMA penetrated and filled the voids of portions of the silty sand specimens, but the voids in the silt specimens were nearly empty.

This research has shown that polymer-soil has potential for special applications in Bureau work and the potential will increase if costs of polymer and processing methods can be reduced by development of new techniques and materials.

Evaluation of Nuclear Moisture-density Gauges

With the rapid development of earth construction equipment it is difficult on large jobs to obtain adequate numbers of moisture and density tests by older methods for good earthwork embankment control. This is true even with the adoption of a rapid compaction control method which has reduced the effort required for field compaction tests.

The newer, faster moisture-density method involves a gauge with a nuclear source and a detector which, when set on the soil surface, provides a measure of the soil density; the higher the density the fewer the number of electrons scattered from the source reaching the detector, as shown by a digital display of count rate. This is simpler than the older sand-replacement method, which requires excavating a hole in the soil and computations involving weight and volume measurements of soil removed and of replaced sand.

In the early 1960's the Bureau conducted laboratory and field tests on some of the first nuclear moisture-density gauges to be manufactured. At that time the results were too inaccurate and the operation of the gauges was unreliable, particularly under field conditions. These instruments have been greatly improved, and now tests are being conducted on one of the current models. Laboratory tests comparing results of the nuclear and conventional density and moisture tests have been completed. These show variations within generally acceptable limits ($\pm$ 2 pounds per cubic foot).

Plans have been made to use the nuclear gauge under typical field conditions during construction of Pueblo Dam in Colorado. If performance of the gauge is satisfactory here, and possibly at other field construction sites, use of the gauge can become general and provide a much improved soil compaction control system.

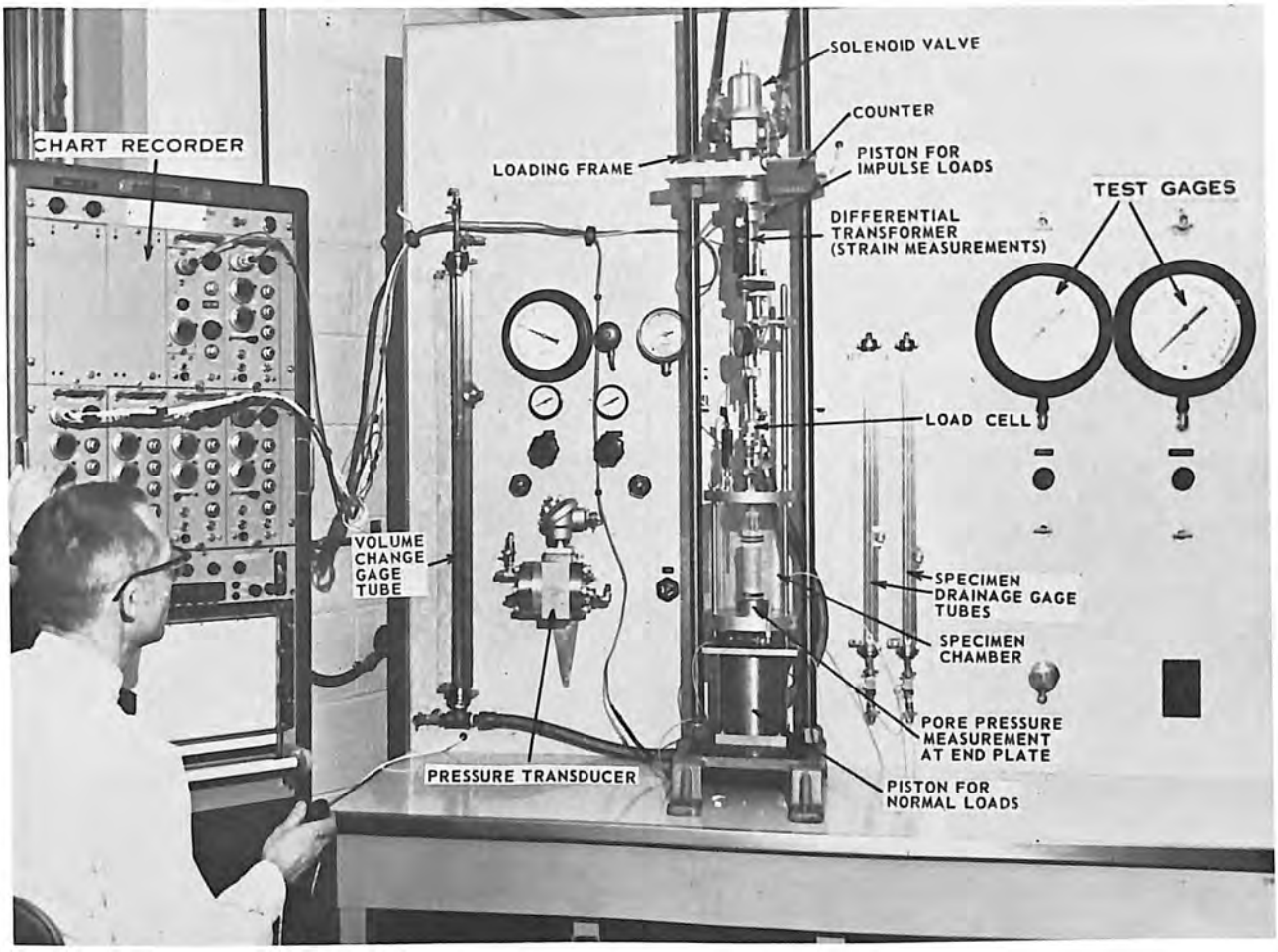
Measurement of soil moisture and density with a nuclear-type gauge.

Earthquake Engineering for Soils

The failure of soil foundations has been a major cause of loss of life and property during earthquakes. Investigations to delineate soil types and in-place conditions that are susceptible to liquefaction and resulting collapse have been continued by a contract with the University of New Mexico.[33] Saturated fine sands, considered to be the most unstable, so far have received the most attention. Research on the sands has shown that liquefaction is largely the result of the interaction of: (1) soil gradation, (2) soil density, and (3) ratio of stress from the earthquake vibrations to stress existing on the soil prior to the vibrations. The stability of the sand depends a great deal upon the density (the greater the density the greater the number of vibrations before collapse) and the stress history of the soil, particularly as to whether the soil had previously been subjected to vibrations.

This research has been conducted in the laboratory, where soil specimens are placed at controlled density, moisture, and surrounding

pressure conditions, and are subjected to pulsating loads simulating earthquakes. Additional new laboratory equipment for determining the effects of natural and manmade seismic effects on soils has been obtained. This is a resonant column apparatus which determines resonant frequency, wave velocity, and damping characteristics of column-shaped soil specimens. Besides being important in research on earthquake engineering, this equipment will be valuable in connection with proposed excavation of canals.



Testing equipment for simulating earthquake (impulse) loads on soils.

All of this laboratory test equipment is being used to extend knowledge of the effects of earthquakes on soil types ranging from sands to cohesive silts and clays. At present, tests are being conducted on silty soils with varying moisture conditions and upon which negative pore pressures have first been determined.

Soil density is also the principal property that practicing engineers can examine and use to judge the quality of a sand foundation. Several years ago, the Bureau established a criterion to predict density from the standard penetration resistance test. This criterion has gained prominence throughout the world as a result of renewed interest in earthquake engineering, particularly for such structures as nuclear powerplants. The numerous earthquakes and critical foundation conditions in Japan have provided the opportunity to field check this criterion and prove its validity.

The Bureau's representation on the Panel on Wind and Seismic Effects, United States-Japan Cooperative Program on Natural Resources Development (UJNR),[34,35,36] has been of unique research value since it has provided the opportunity to compare results with Jap-

anese findings where failures occurred and where foundations have resisted failure. As a result, guidelines have been developed on density conditions that are critical with respect to varying depth.

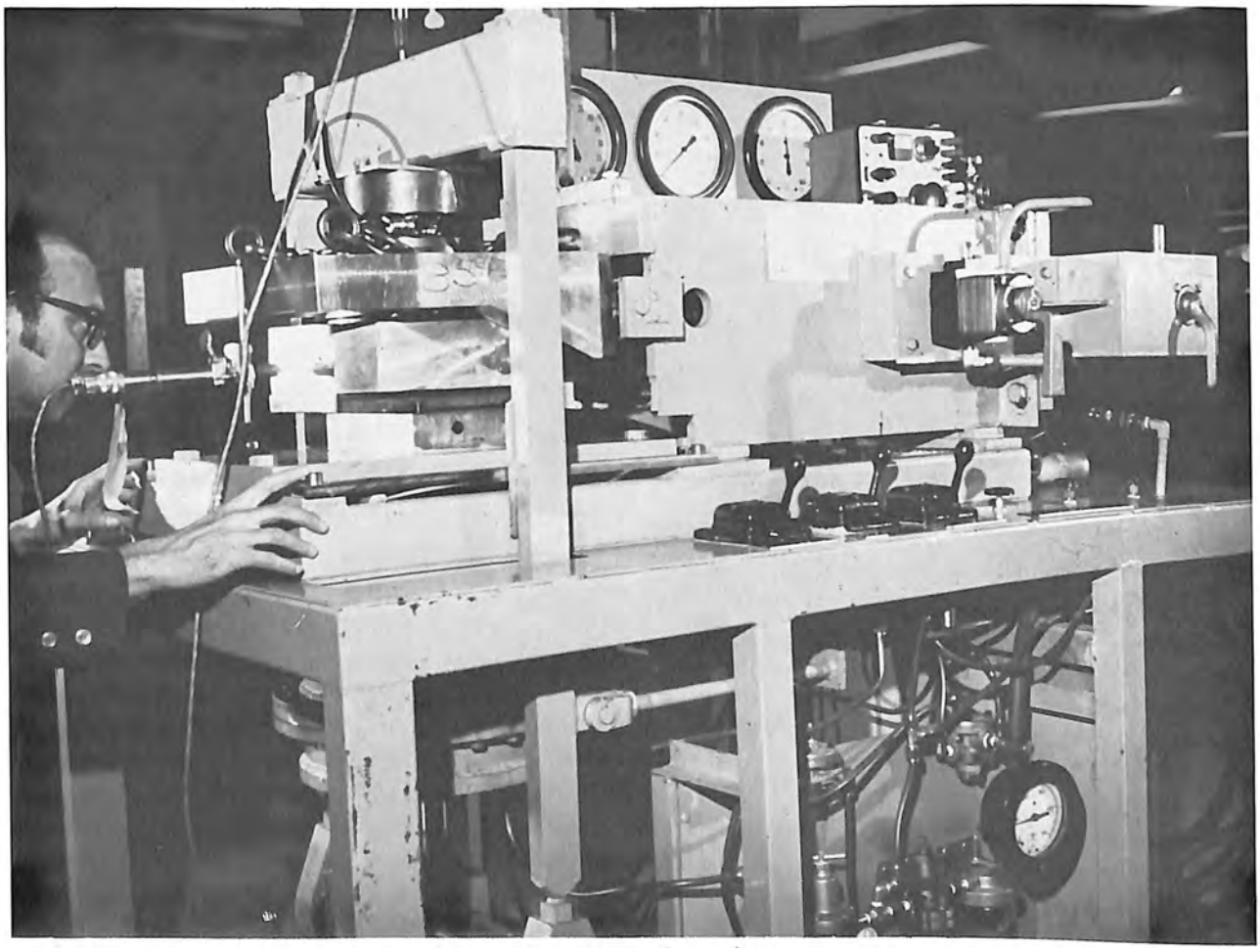
ROCK MECHANICS

Research in rock mechanics and geology is conducted to improve the safety and economy of Reclamation structures to be built on or in rock by obtaining more accurate data on the behavior of rock masses, and on design techniques. These studies provide more realistic criteria for designing underground powerplants, pressure tunnels, dam foundations, and stable rock slopes.

Strength of Rock Discontinuities

The physical properties and structural behavior of rock masses, which include geologic discontinuities such as joints, bedding planes, shears, and other features, are imperfectly known. Test equipment and procedures are being developed that will allow cores from rock masses and cores containing discontinuities to be loaded in the same manner and at the same intensity as loads from the proposed structure.

A recently fabricated testing machine was utilized for this purpose to investigate shear strengths of foundation rock at Grand Coulee Third Powerplant and at Auburn Dam. NX cores (2⅛ inch diameter) were tested for direct shear strength (rock or joint failure) and sliding friction resistance, and 6–inch-diameter cores were tested for sliding friction resistance only. The shear machine, incorporating the best features of equipment developed throughout the world, can apply a 10,000–pound nor-



Shear testing machine for rock cores.

mal load and 20,000–pound shear load to the specimen. It has the capability of increasing the applied load at a constant rate, or of sliding the specimen at a constant velocity.

The requirement for larger, more representative samples containing key features for testing has led to the design of a new shear machine. It has all the desirable features of the existing equipment, and has the capability of testing samples up to 10 inches in diameter with total loads of 100,000 pounds normal and 300,000 pounds shear. Results obtained with this larger equipment will provide more realistic data for design criteria and safety factors.

Rock Stress Measurements

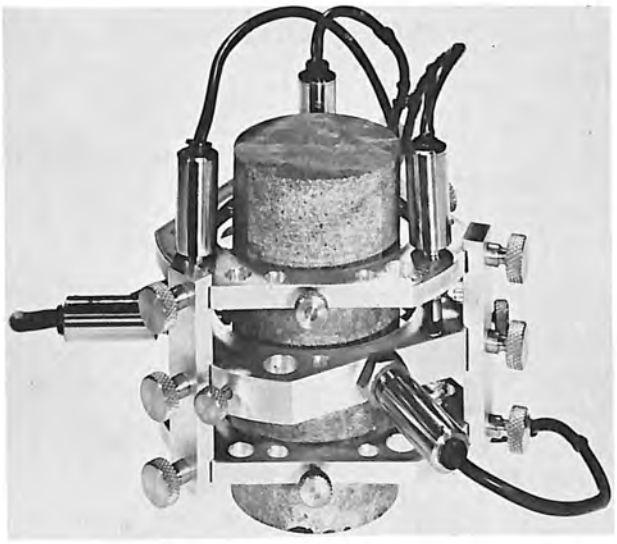
The Bureau's three-directional borehole deformation gauge has been used successfully for determining in-situ stresses in hard rock foundations.[37] The most recent application was at the proposed Raccoon Mountain Underground Powerplant (TVA). The present method requires three nonparallel boreholes for a three-dimensional stress analysis. This is somewhat costly and time consuming. Therefore, the development of a new gauge is in progress. This gauge will measure absolute longitudinal displacements in addition to changes in borehole diameter, and thus make it possible to obtain three-dimensional, in-situ stresses using only one borehole.

Physical characteristics of the present gauge do not permit in-situ measurements in relatively soft rock such as shale. Initial studies for development of an instrument capable of meeting these demands have been started. Preliminary testing of an inclusion gauge, cubical in shape, met with little success. A finite element study is being conducted to determine the optimum elastic modulus of the inclusion instrument.

Mechanical Properties of Rock

An important phase of preconstruction investigations is the determination of such mechanical properties as compressive strength and modulus of elasticity of foundation rock. Equipment has been developed that will significantly reduce the time required to conduct these laboratory tests, and at the same time improve the accuracy and reliability of results. This equipment consists of a special lightweight circular frame that attaches to the rock core specimen and holds a series of electronic differential transducers which measure rock deformation as the specimen is subjected to a series of axial loads. The applied loads and resulting displacements are recorded automatically by a digital recorder. The new test system provides an accurate, high-speed technique for rock core testing programs, free of human recording errors.

Measuring component for a three-directional borehole gauge.



Frame with transducers for measuring rock deformation.

Stability of Rock Slopes

Failure of cuts and slopes in rock is a problem frequently encountered in heavy construction. Continuing research is underway to improve and extend methods of analysis and design procedures for stability of rock slopes.

A contract with the University of California for development of a three-dimensional analysis of jointed rock slopes was completed. By this contract, a computer program was developed to examine the behavior of jointed rock slopes under initial, body, and boundary loads.[38] A second contract with the University of California to develop design procedures for high cuts in jointed hard rocks is nearing completion. In this contract, the procedural steps needed to formulate a problem and design a solution are to be defined. Spillway cuts at Auburn Dam are to be a typical application of the derived design procedure.

Existing computer programs written by the Bureau for analysis of the stability of rock blocks by the rigid block method are being improved and extended to enable consideration of rotational-sliding instability. Other efforts are directed to advancing planar finite element solutions of rock slopes subjected to excessive lateral stress conditions. These additional techniques and procedures will give engineers improved methods to formulate, analyze, and design solutions to anticipated or known rock slope stability problems.

Rock Stabilization at Morrow Point Powerplant

During excavation of the underground Morrow Point Powerplant, an extensive rock monitoring system detected inward movement along a longitudinal rock face of the powerplant chamber. The movement was associated with a large rock block, which was formed in part by two intersecting faults and the powerplant rock wall. Investigations indicated further movement was possible, necessitating installation of a permanent restraint system. Anchor bars, long rock bolts, post-stressed tendons, and flat jacks were selected to provide the required support. The rock restraining system is fully effective in maintaining stability of the rock block. No movement of the rock has taken place since the installations were completed.

Drill Performance Monitor

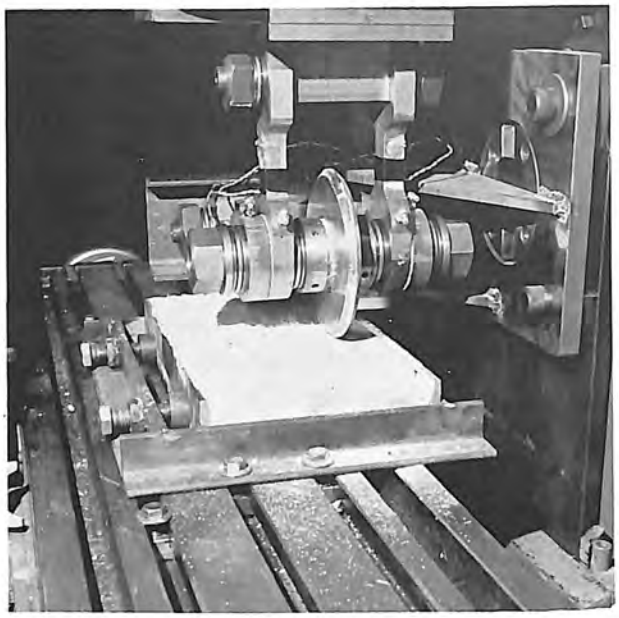
This research involves development of a device for measuring various aspects encountered during drilling operations. In oil well drilling, continuous "downhole" measurements are customary. Small-scale equivalents of such instruments are needed for foundation exploration drilling. Continuous records of controlled drilling would provide a means of defining the true in situ conditions of the foundation rock. For example, accurate recording of the variations in drilling fluid loss might indicate open joints, and the amount of loss would be an indication of the extent of the fractures.

Devices to measure downhole permeability have been constructed and are being tested in the field. Conceptual drawings have been prepared on other phases of the program.

Engineering Geologic Properties of Rock

Current and anticipated design and planning problems require more comprehensive and exacting engineering geologic data on actual subsurface rock conditions. New and improved investigation techniques are required to provide more definite data for predicting the behavior and influence of geologic structures and rock materials. Stress and hydrogeologic conditions change when deep rock cuts, underground openings, and foundations are excavated, supported, and loaded. These investigations will yield criteria for judging the need for tunnel supports, foundation and reservoir seepage rates, stability of natural earth and rock masses, and faulting and structural patterns.

A contract with the Colorado School of Mines for developing equipment and test procedures for evaluating the practicability of tunneling by "mole" methods has been completed and reported.[39] Petrographic studies by the Bureau's Chemistry and Physics Section on companion rock samples were completed as part of a study on varying hardness in geologically similar rock. A linear cutter device was fabricated and will be used to determine the "boreability" of rock from proposed tunnel sites.



Linear cutter equipment used as an aid for determining boreability of rock.

Earthquake and Active Faults Associated with Hydro Projects

The program objective is to obtain knowledge of the crustal strain at the surface and at depth along active faults. Such information will direct efforts toward the critical and important matter of controlling or avoiding disastrous damage to hydro projects by earthquakes. A 5–year cooperative program with the U.S. Geological Survey and the National Oceanic and Atmospheric Administration has been initiated. The program consists of recording low-magnitude earthquakes and measuring earth displacements and strains associated with three very active geologic faults—the San Andreas, Sargent, and Calaveras—in the Hollister Valley of central California. This program will obtain fault creep, earth movement, and seismic design data that can be used in the design of the canals of the Bureau's San Felipe Division. The canals will cross these faults several times.

CONCRETE RESEARCH

Concrete research helps develop new methods of producing better, more economical concrete with predictable longtime performance that will lead to safer, more economical water resource structures. Studies include those on polymer concretes, special-purpose cements and admixtures, and the evaluation of factors that make concrete products more resistant to deterioration.

Concrete-polymer Materials

The Bureau is cooperating with the Brookhaven National Laboratory in developing concrete-polymers for use as a new construction material. The program is jointly sponsored by the Atomic Energy Commission, the Office of Saline Water, and the Bureau of Reclamation.

The program is developing methods for incorporating polymers in concrete to produce new concrete materials having greatly improved durability and strength compared to conventional concrete. Studies in progress include developing process technology for economical production of a uniform material having exceptionally high strength and durability; investigating physical, chemical, mechanical properties, and fundamental nature of the materials; and translating laboratory technology into potential full-scale applications.

A number of potential applications are emerging. Concrete-polymer materials are under investigation for saline water distillation plants, as tunnel liners and supports, in pipelines, and for structural elements. Other applications include bridge decks, piers and wharfs, piles, utility line poles, break-away luminaires, underwater installations, and housing.

Three distinct types of materials are under investigation: (1) polymer-impregnated concrete (PIC), i.e., precast portland cement concrete impregnated by a monomer system, which is subsequently polymerized in situ; (2) polymer-cement concrete (PCC), i.e., a premixed combination of portland cement, aggregate, water and monomer, in which the monomer is added during conventional concrete mixing and polymerized after placing; and (3) polymer-concrete (PC), i.e., a composite material formed by polymerizing a monomer

and aggregate mixture. The monomers are polymerized (changed to another form) by heat and catalysts or by gamma radiation.

Investigations indicate that the most successful concrete-polymer material for construction is PIC, which is now receiving the major emphasis in the program. Investigations are continuing with PCC and PC because these materials will have many potential applications if feasible fabrication methods and suitable properties can be developed.

All monomer systems under test have produced improvements in the properties of concrete. Tests show compressive strengths over 25,000 psi and tensile strengths of 1,700 psi (increases of 400 percent over untreated concrete). Durability tests still in progress show improvements of 1,000 percent or more in resistance to 15 percent hydrochloric acid and to freezing and thawing, and a 200-percent increase in resistance to sulfate attack.

Developmental work in process technology includes studies on the effects of concrete mix design parameters and concrete curing conditions on the properties of polymer-impregnated concrete, as well as studies to improve specimen fabrication and polymerization techniques. The fabrication technique may be improved by eliminating a wrapping step, by polymerizing underwater, or by using live steam for thermal-catalytic polymerization inside an impregnation vessel.

Investigations on PIC for normal temperature applications include evaluation of six monomer systems currently under test. New monomers are being surveyed to select other promising systems.

Studies on PIC for use in saline water distillation plants include evaluating high temperature structural properties and resistance to deterioration in exposure to brine and distilled water at elevated temperatures. Two monomer systems were selected for testing. One had good high temperature structural properties, but was found to undergo deterioration when exposed to hot brine. A new monomer system has been selected and is currently under test.

Work on PC and PCC has been limited, but the results obtained so far look promising. PC specimens have been made with compressive strengths of over 17,000 psi. A new specimen fabrication technique, based on mechanical packing of selected sized aggregate, has reduced monomer requirements for PC specimens from up to 25 percent by weight to between 5 and 6 percent. PCC studies are in very preliminary stages. Test results on PCC made with epoxy resin indicate possibilities of producing a high-strength concrete. Further work is to include investigations on incorporating acrylic monomer and polymer emulsions, emulsified epoxies, and furfural-aniline polymers in the concrete mix.

A large scale impregnation-polymerization facility has been constructed and is now operational. The facility can produce PIC specimens up to 4 feet in diameter and 6 feet long. Polymerization is by thermal-catalytic methods using steam. Both impregnation and polymerization are done in the same vessel.

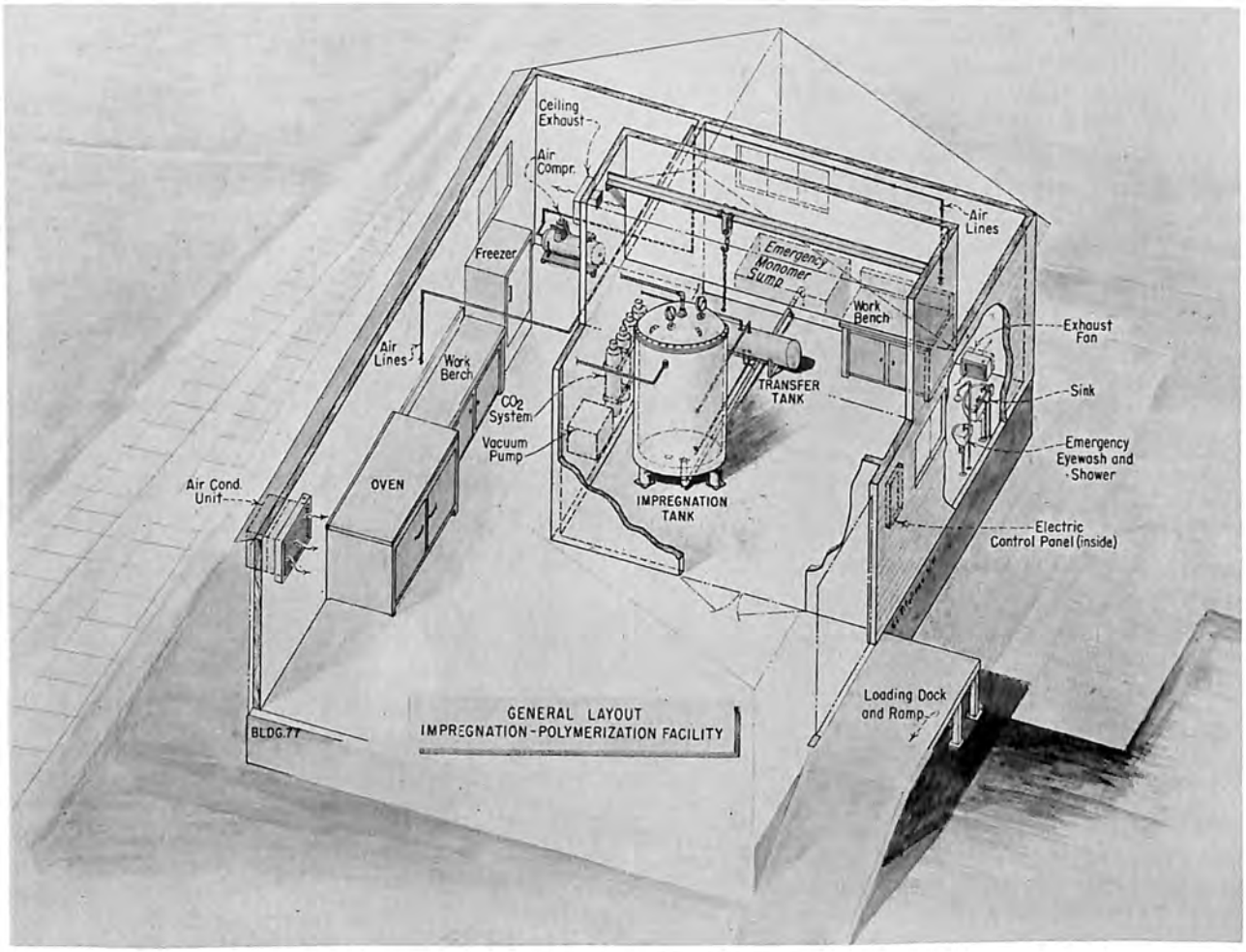
Polymer-impregnated Concrete Pipe Research Program

The testing and evaluation of concrete and polymer-impregnated concrete (PIC) pipe is a cooperative effort sponsored by the American Concrete Pipe Association, the Atomic Energy Commission/Division of Isotopes Development, Brookhaven National Laboratory, and the Bureau. Both three-edge bearing and hydrostatic pressure tests have been conducted on 12– and 24–inch internal diameter unreinforced pipes having two different wall thicknesses. Half of the pipe specimens were impregnated with t-butyl-styrene monomer and radiation polymerized. The other half were used as control specimens. A sufficient improvement in strength of the PIC was found to warrant further investigation.

The next step in the investigation of PIC pipe is to compare reinforced and unreinforced PIC pipe. The objectives are to yield complete design information, service requirements, manufacturing techniques, and evaluation of the economic benefits of PIC pipe.

Improved Concreting Techniques

Several important advances in concrete technology have been developed at the Bureau's research center. One which will have wide application in concrete construction is computer-



Impregnation-polymerization facility.

ized programming for concrete control, mix design, and mix adjustments; another is the establishment of procedures for use of a special epoxy compound to repair damaged concrete in permanently wet areas.

In construction involving large quantities of concrete, good control is laborious and time-consuming. Usually a series of established mixes is used throughout the job. Changing aggregate moistures and gradations, however, makes frequent adjustment of scale weights necessary to achieve uniformity in the concrete. Test batches are taken and yield quantities must be calculated and voluminous records kept. Several hours each day are spent performing and checking the calculations—hours that could be more profitably used at other tasks.

By using a desk model teletype connected to normal telephone lines at the mixing plant or in the laboratory, a computer can make these routine calculations using a program developed by the Bureau. Moisture and gradation corrections can be made and scale weights adjusted in a small fraction of the time now required, which means more exact concrete control. A batch plant technician can be taught to use the technique in a few hours.

The practicality of using computer capabilities in concrete control has been demonstrated on a Bureau project. Additional programs are being written for use in concrete control and in other fields.

In the repair of the Yellowtail Dam spillway tunnel, following flood damage in 1967, special techniques were necessary as water seeping from behind the concrete lining kept the repair area continuously wet. A damp or wet

Hydrostatic testing of polymer-impregnated concrete pipe.

Mix designs for best economy and desired performance are made in the laboratory using project aggregate, cements, and admixtures.

condition is unsuitable for installing epoxy repairs by conventional methods. Laboratory research, consisting of trial repair using seven different commercial epoxy-base compounds and many different application techniques, was required before a suitable repair system evolved. As a result, following installation of several hundred epoxy patches, a detailed procedure for successful use of a proprietary epoxy that cures at low temperatures and under moist conditions has been outlined to accomplish similar difficult concrete repairs in the future.

Repair epoxy mortar is being compacted using a "plastic-head" hammer.

Modified Cements for Improving Bureau Concrete

Abnormal setting of cements with admixtures, resulting in poor workability of concrete, is a frequently encountered problem. Admixtures can improve quality and reduce costs of concrete. Yet, only 35 percent of ready-mixed concrete (National Ready Mix Concrete Association data) in the United States is currently made with admixtures, largely because of unpredictable effects ranging from harmful to highly beneficial. A research program has shown that abnormal setting is caused by gypsum recrystallization (previously known), ettringite precipitation, and thixotropy, the latter two being new findings. Subsequent to issuance of a report on this research,[40] an instrument was invented and patented to evaluate thixotropy. The continuing investigation also revealed why cements and admixtures may be incompatible. A tentative laboratory method for overcoming this problem is described in the report and confirmed by tests.

Expansive cements have gained widespread

use in recent years, largely to compensate for shrinkage of the hardened concrete. A laboratory investigation of three of these cements has been completed and is described in a report.[41] The results indicate some adverse effects on curing temperatures, calcium lignosulfonate, and fly ash. Precautions are mentioned which should be considered in using these cements on Bureau jobs.

Development and Evaluation Tests for Concrete

To properly design concrete mixes, it is necessary to know the fundamental relationships of water-cement ratio, compressive strength, and water requirement. The Bureau's widely used *Concrete Manual* describes these relationships for ordinary air-entrained concretes; however, the increasing use of water-reducing, set-controlling admixtures (WRA) has resulted in a need for mix design guides to obtain the full benefits of these admixtures. As a result of an extensive research investigation, a future edition of the *Concrete Manual* will contain basic mix design information for use with WRA. The new data give average values for water requirements and the compressive strength versus water-cement ratio relationships for various dosages of WRA.

Concrete for Longtime Service in Sulfate Environment

The results of long-term comprehensive Bureau research on sulfate-resistant concrete, beginning some 30 years ago and evaluated in 1971, permit two highly significant conclusions. Eighty-four percent of high-quality concretes made with Types II and V cements showed life expectancies of less than 50 years (a few, much less). This observation is in agreement with durability of sulfate-resistant concretes placed in sulfate-bearing soil in Canada subsequent to about 1935. Some of these concretes have failed. The second conclusion is that certain pozzolans, including fly ash, in 33 percent of concrete tested showed a life expectancy in the 100– to 200–year range. The use of a high-quality pozzolan and Types II or V cement provides the solution to a difficult problem for which no theory was available to guide applied research. Long-term testing has been necessary to provide data on the durability of many types of cement and pozzolans.

Durability of Pressure-saturated Concrete

The resistance of concrete to cycles of freezing and thawing normally is increased by entraining tiny air bubbles in the concrete when it is mixed. It is possible, however, that with sufficient water pressure these small air bubbles could fill with water and make the concrete more vulnerable to freeze-thaw deterioration. These conditions may exist in hydraulic structures where concrete is under deep water and then exposed when the water level is lowered.

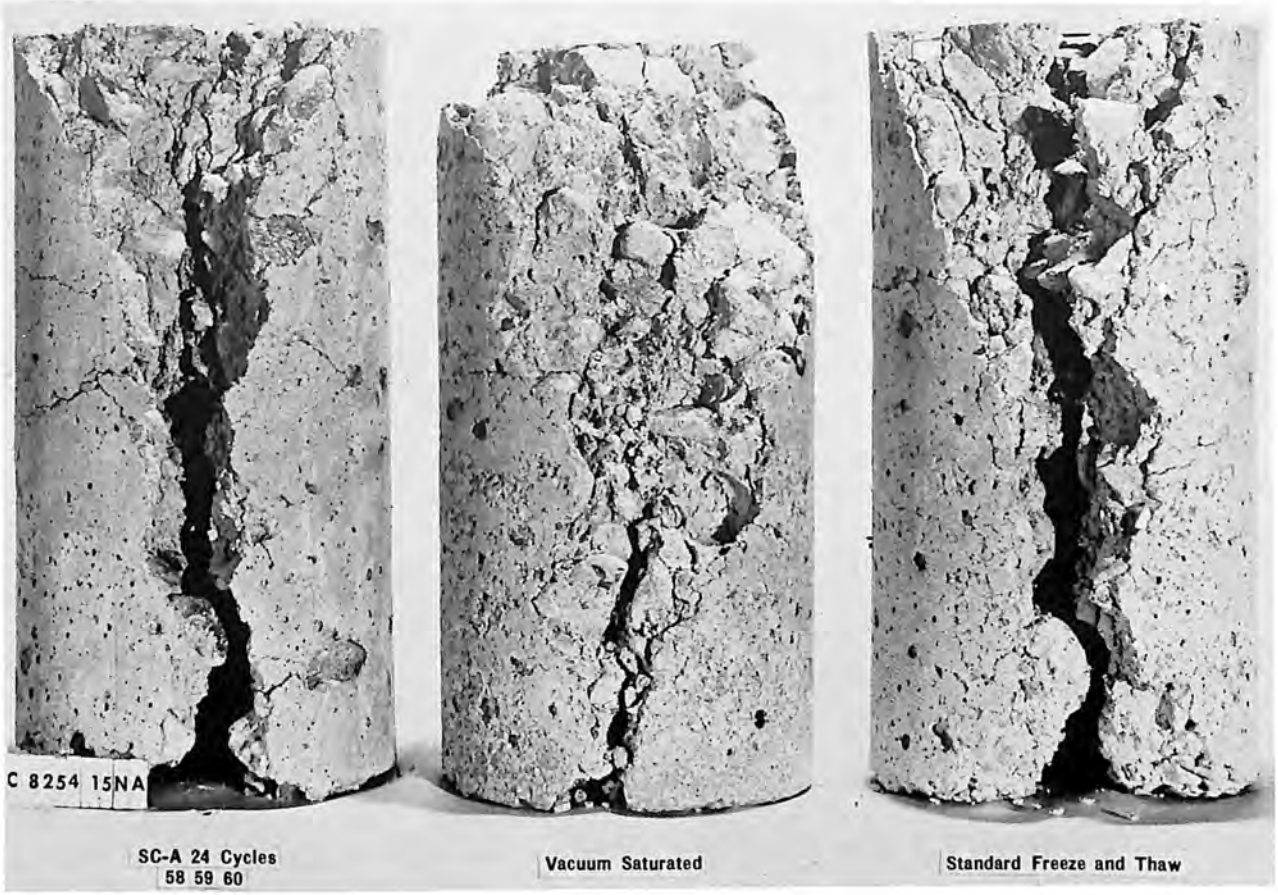
By soaking concrete in water in a vacuum chamber, enough air voids can be filled with water to cause concrete failure after a few cycles of freezing and thawing. Soaking concrete in water under pressure has a similar but less severe effect. Research is now in progress to determine whether pressures present in hydraulic structures are sufficient to reduce the freeze-thaw resistance of air-entrained concrete. Concrete specimens saturated under different conditions are under test.

Preliminary results indicate that the durability of air-entrained concrete saturated at 50 psi may be reduced as much as 50 percent.

The concrete, however, is still four times more resistant to freezing and thawing damage than nonair-entrained concrete similarly saturated.

Studies of Internal Stresses in Concrete Dams

To better understand and predict the structural behavior of existing and future concrete dams, studies are being conducted to determine the effects of different types of load application, and changes in temperature and moisture on stresses produced in concrete. A report[42] was published covering the results of the initial tests concerning actual stresses in concrete. Stress, strength, and deformation variations in concrete masses produced by drying and wetting conditions and temperature changes are discussed in the report. The performance of meters and instruments embedded in the concrete mass to provide stress data is also described.



Air-entrained concrete saturated in a vacuum chamber has failed after only 24 cycles of freezing and thawing. Soaking concrete in water under pressure has a similar but less severe effect.

OTHER MATERIALS AND INSTRUMENTATION

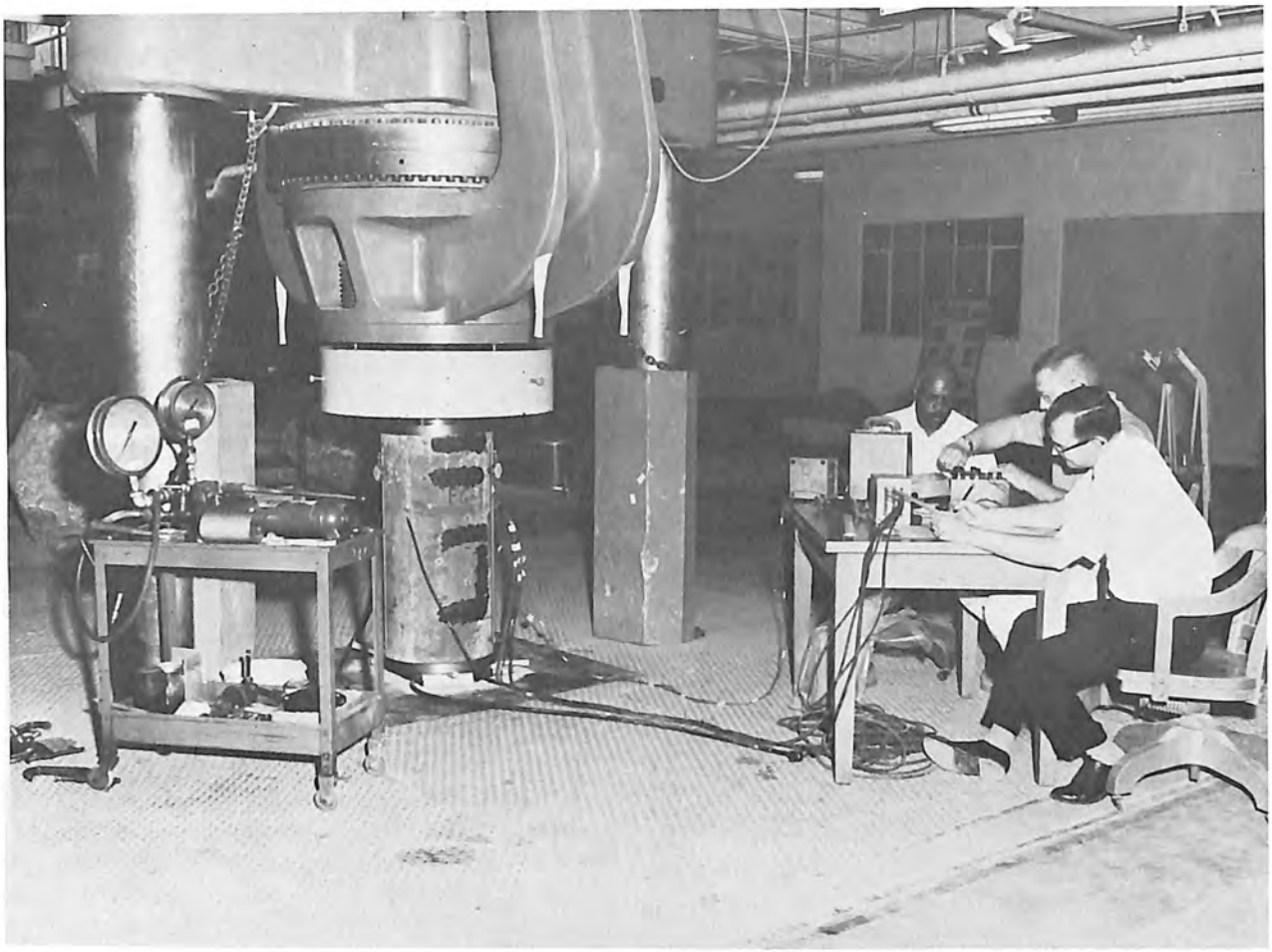
Research in other materials and instrumentation is performed to develop and evaluate the wide variety of materials other than soil, rock, and concrete necessary for the safety, economy, and long life of Bureau structures. Studies in bituminous materials, chemical materials, metals, paints, corrosion and plastics are included. Studies are also made to select, improve, and develop instrumention used in Bureau research.

Open and Closed Conduit Systems

Synthetic Rubber Linings.—A number of synthetic rubber materials especially compounded for use as waterproofing membranes are now available. They have a variety of thicknesses and can be shop-fabricated into large sizes for quick and easy installation in canals and reservoirs. Rubber membranes are weather-resistant and can be used as exposed liners. A report[43] was published summarizing laboratory and field investigations made on synthetic rubber linings over the past 10 years.

Specifications for EPT and EPDM Rubber Linings.—The Bureau has developed tentative specifications for new butyl-rubber lining made of ethylene-propylene terpolymer (EPT) and ethylene-propylene diene monomer (EPDM). These new materials appear to have advantages over the present butyl-rubber lining for certain applications, and appropriate studies are being made and monitored. Specifications for the EPT and EPDM rubber linings are needed to facilitate purchase and use of the best possible formulated materials.

Through cooperation with the rubber industry and analysis of laboratory test data, drafts of specifications were prepared for unreinforced and nylon-reinforced EPDM lining. The



Load tests of a concrete cylinder containing external and embedded instruments for recording stresses and deformations in the concrete.

Bureau laboratories are participating in meetings sponsored by ASTM Committee D–8, Task Group XIX, for finalizing ASTM specifications of rubber lining materials, including EPDM rubber.

Covers for Open Structures and Reservoirs.—The Bureau has constructed several projects to deliver municipal and industrial water. A water quality problem has arisen on some of the uncovered (open) forebays at pumping plants and regulating reservoirs on the Canadian River Project in Texas, and the Arbuckle and Norman Projects in Oklahoma. The water in these structures experiences areas of low velocity and when exposed to sunlight the algae grow rapidly, with associated odor and taste problems. Concern also exists about contamination of the water in the open structures by drift of pesticides applied by aerial spraying and windblown sediment, weeds, or other debris.

Studies are underway to develop a floating cover with adequate buoyancy and adequate resistance to damage from high winds. One or more floating roofs will be field tested to obtain information on installation requirements, economics, and durability. For possible future installations the feasibility of using air-inflated covers in lieu of floating covers will be explored.

Reinforced Resin Linings.—There is an increased interest in the petrochemicals industry in development of sprayed and extruded liquid plastic materials for waterproofing applications. These materials may be reinforced with fiberglass and other products to produce thin,

strong, tough nonrigid layers which have potential as lining for canals.

Laminate material for a test lining in a canal is easily installed and is temporarily held in place with steel pins.

As part of the Upper Colorado Region program, a field test installation was made of glass-fiber reinforced polyester lining in the Willard Canal laterals, Weber Basin Project. Laboratory personnel assisted in the work and obtained information on manufacturing and installation techniques. Samples of the lining, both precast and cast-in-place, were obtained from the field test sections and evaluated in the laboratory. Generally, it was found that the lining as installed was not satisfactory due to flaw areas which were structurally weak and allowed water leakage. However, the process of producing reinforced plastic lining on the job appears to have merit and it is reasonable to assume that, with more experience, the system can be perfected. A report covering the laboratory evaluation of the field lining samples was prepared.[44]

Plastic Drain Pipe.—During the spring of 1970, 29,500 feet of 4–inch–diameter, slotted,

Chopped roving and resin were sprayed on prepared earth canal sections to desired thicknesses, then surface rolled with paint rollers to press the fiberglass into the polyester resin. Seepage losses through this lining were higher than desired.

corrugated plastic pipe was experimentally installed as spaced drains on the Columbia Basin Project. Overall costs for this installation under normal construction conditions were estimated to be $0.85 per linear foot, as compared with $2.22 for concrete pipe. On this project about 22 percent of the total pipe is 4 inch diameter and 69 percent is 6 inch or less. If larger sizes can be installed, considerable savings in the $5–6 million annual Bureau drain construction program can be realized. A report of the installation and cost data was drafted.

Data on water table fluctuations between the installed lines is being collected and analyzed. It is expected that small sections of the tubing will be removed after about 5 years of in-place service and sent to the Denver laboratories for appropriate testing.

Approximately 4,440 feet of corrugated plastic drain tubing were installed on the Garrison Diversion Unit. The drain is in coarse sand, and part of the drain in North Dakota is installed without a gravel envelope. The purpose of the installation was to evaluate: (1) practicality of installing drains with modern high-speed drain installation machinery in the Oakes area of North Dakota; (2) performance of drains installed without gravel envelopes in sandy soils; (3) estimated construction costs

of drains designed to utilize corrugated plastic drainage tubing and modern high-speed drain installation machinery; and (4) deflections of in-place drainage tubing over a period of years.

Reinforced Plastic Mortar Pipe Research.—To perfect methods of installation and to evaluate field performance of reinforced plastic mortar (RPM) pipe, a research program was begun in the Yuma area to determine the deformation of the pipe under various trench conditions. Two 660–foot sections of 30–inch–diameter, 100–psi pipe were installed in a predominately silty-sand soil both above and below water table level. During installation the deflection of the pipe was recorded for various degrees of bedding compaction, ranging from uncompacted to fully compacted. Pipe deflections are being measured over a long period of time to determine how the pipe reacts with time to the various trench conditions. A report of the construction and test results has been drafted and a report on the overall evaluation of RPM pipe is available.[54] Additional RPM pipe studies are discussed later in this publication.

Yuma Project employees laying 30-inch inside-diameter plastic mortar pipe in 20-foot lengths with 3/10-inch wall thickness and bell- and spigot-joints.

Economics of Pipe Irrigation Distribution Systems.—The research objective was to investigate and evaluate factors which influence selection of closed conduit systems over open channel water conveyance systems. This was done by a study of operation and maintenance costs of various types of systems and development of predictive models of irrigation system costs.

Heavy blocks on a 36-square-foot wooden platform 5 feet above the plastic mortar pipe on compacted backfill produced deflections in the pipe which were measured as part of the installation test program.

Data obtained from several operating projects were not sufficient to meet all objectives because of differences in costing procedures and accounting details.

Refinement work continues under contract with the University of Idaho. Data have been collected from 10 additional systems and are being analyzed. The final phase will be employment of a stepwise multiple regression analysis of data from all 31 districts using parameters found significant.

Field Drainage Plots.—In the latter part of 1966, 18 experimental on-farm drain lines were installed on a farm field in the Westlands Water District in California. The system was installed as part of a cooperative investigation among 13 individual groups, including private corporations, State and Federal agencies, and local drainage and water districts.

Objectives of the on-going investigation are: (1) to provide a field test plot to compare the performance of some of the newly developed drainage materials and construction techniques with presently accepted materials and construction; (2) to provide an on-farm drainage demonstration plot to develop drain design criteria and encourage tile drainage by landowners with such problems; and (3) to pro-

vide a field plot where various reclamation and salinity studies can be carried out in a highly saline and fine-textured soil environment.

Water level data, soil salinity, and tile performance data have been gathered for 5 years and results are presented in annual progress reports. Samples of various pipe materials were removed after service of 3 years and tested at the Denver laboratories. Pipe types included reinforced plastic mortar (RPM) and polymer-impregnated concrete. Data will continue to be gathered for 5 more years to finalize and substantiate results.

Cleaning Canals in Service.—The problem of preserving canal capacity without shutdown where the water carries sediment, debris and weed and algal growth, has not been solved. Development of special equipment to clean large concrete-lined operating canals is therefore being studied.

The current concept involves a dredge discharging into a portable clarifier that will separate unwanted materials from the discharged water, deposit these on the banks or in trucks, and return clarified water to the canal. The problem is complicated by the various size canals, the many over-crossings, the nature of the water conveyed (clear vs. turbid), the amount of debris to be removed, manpower required, and similar considerations. A solution being developed for the Delta-Mendota Canal includes a lightweight hydraulic track-mounted dredge on the berm or a track-mounted submarine dredge that moves along the canal bottom. Clarification may be accomplished by discharging over a small-mesh vibrating screen and repumping the underflow through hydraulic cyclones. Removal of solids of significant density down to –300 mesh has been accomplished in laboratory mockups of prototype equipment.

New Synthetic Materials for Roofing Systems

More durable and maintenance-free roofs are desired on Bureau structures such as powerplants. As new and improved materials and systems are introduced by industry, their applications to Bureau needs must be determined. Studies are underway on sprayed-in-place urethane, a foam roof insulation, for use as the roofing system on concrete, metal, and wood roof decks. Urethane was selected because of its high initial insulation value, good retention of insulation value, reduced structural requirements due to light weight of the foam, and more rapid construction time. Evaluations of vapor-barrier coatings on the substrate and protective coatings on the urethane foam are included in the studies.

Outdoor exposure test areas are used for investigating various roofing systems.

Studies involve both laboratory-accelerated aging and outdoor exposure tests of foam sprayed on precast twin-tee concrete roof slabs. The outdoor exposure tests also provide an opportunity to evaluate the various installation techniques necessary in developing satisfactory construction specifications.

After the vapor-barrier coating has dried on the concrete roof deck, urethane foam will be spray-applied to form a watertight, insulated roofing system.

An inspection was made of eight structures on the Southern Nevada Water Project where a new butyl-rubber roofing bonded to styrofoam insulation was used. Earlier research led

to the development of this completely bonded roofing system (without mechanical attachments) for use on concrete roof decks. The roofing installations on the eight structures appeared to be in satisfactory condition.

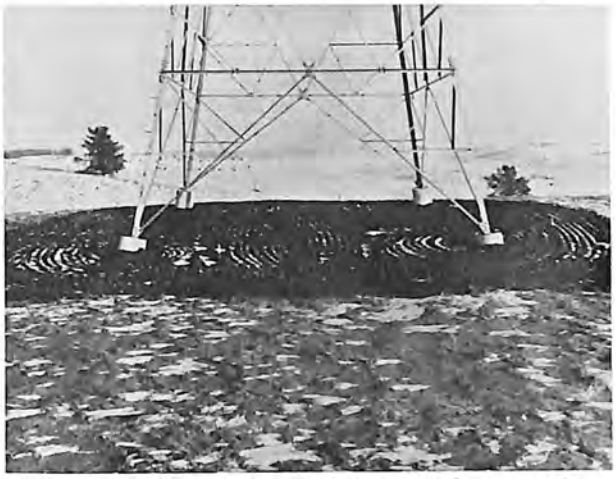
Petrochemicals for Erosion Control, Stabilization, Grouting, and Linings

Unstable or erosive soils are often encountered in Bureau construction. Economical stabilization of these soils is highly desirable and often requires petrochemical materials for applications such as dust abatement on construction projects; sealing shales and clays in slope or tunnel excavations to prevent air slaking; and waterproofing soils to improve foundation conditions, stabilize embankments, and prevent erosion.

Laboratory and field evaluations of several petrochemical liquid soil stabilizers were conducted and reported.[45] Laboratory tests indicated that a sprayable liquid vinyl polymer has excellent properties for stabilizing sandy soil. Field observations, after 1 year of service, showed that a deep penetrating liquid cutback asphalt was performing satisfactorily in stabilizing dune sand around transmission tower sites along the Fort Thompson-Grand Island 345–kv transmission line. Field evaluation showed that none of five different protective coatings applied to shale seams in a highway excavated slope at Paonia Dam in Colorado were effective in reducing air-slaking.

A preliminary study was made on an elastomeric emulsion to stabilize gravel for use as a substitute for riprap. The stabilized gravel will be used for erosion protection on a roadway embankment slope, which will also serve as a temporary dike during the construction of Mt. Elbert Powerplant. Erosion protection of the dike is necessary to prevent fines from being washed into Twin Lakes and causing a muddy water condition.

Laboratory tests were completed on two gelatinous grouting materials for possible use in stabilizing problem soils. The materials were a polyphenolic polymer formulation which, when dissolved in water, will produce weak to extremely stiff gels, and a modified sodium silicate grouting mixture. Penetration characteristics, strength development, and effect of water immersion were determined. Tests indicated that the modified sodium silicate had satisfactory characteristics for Bureau grouting applications. The polyphenolic polymer grouting material had satisfactory gelling characteristics. Grouted soil samples subjected to water immersion, however, lost strength and became soft and somewhat spongy.



Forty-seven tower sites along the Fort Thompson-Grand Island 345-kv transmission line were treated with a deep-penetrating, liquid asphalt for protection against wind erosion and animal traffic.

Laboratory tests were conducted to determine the setting time for asphalt emulsion triggered by a hydrated lime water slurry. The asphalt emulsion-hydrated lime combination had been selected as a grouting agent for use at Morrow Point Dam.[46] Under full reservoir head, leakage was occurring through the left abutment. Although the leakage was not considered critical from volume or dam safety viewpoints, it was desirable to reduce the flows through the abutment to keep the underground powerplant walls as dry as possible. Since reduction of the leakage could not be accomplished with standard cement grout, the asphalt emulsion-hydrated lime system was selected.

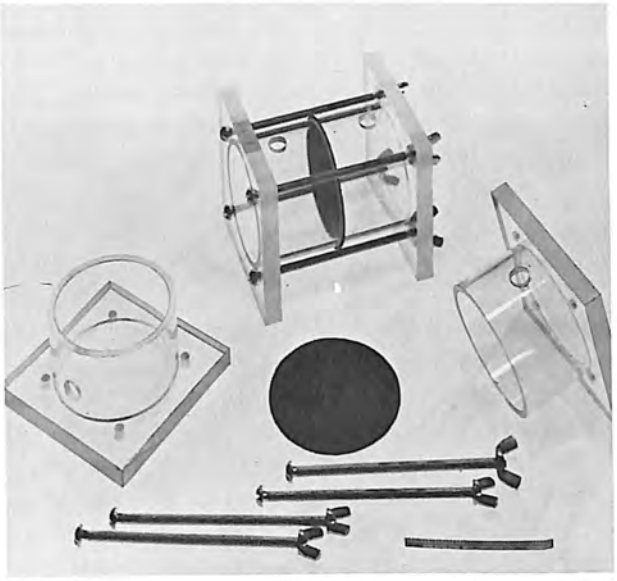
Laboratory tests were made with a sample of Morrow Point water cooled to 38° F., the temperature of the water encountered during grouting. Test results showed a satisfactory setting time of 12 to 15 minutes using ½–pound of hydrated lime to 1 gallon of asphalt emulsion.

Field grouting with 10,000 gallons of as-

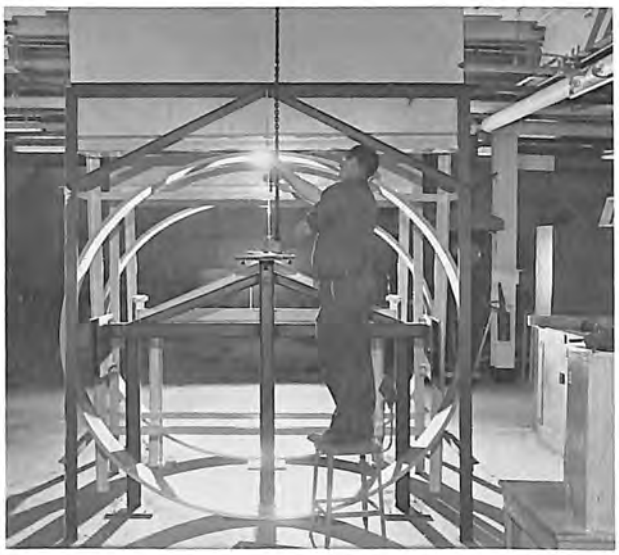
phalt emulsion reduced the leakage approximately 65 percent. With this reduced leakage, standard cement grout was used to establish a permanent grout curtain. The combination of the asphalt and cement grouts reduced flows from 429 gpm before treatment to 37 gpm after.

To guide future designs and field control for better asphaltic construction, laboratory and field studies were used to evaluate asphaltic concrete dam facings and pavement installation of varying service ages.[47] Samples from both the better and poorer installations were evaluated to determine adequacy of current specifications and construction methods. The study showed the need for the development of better slip-form compaction equipment for use in small canals or laterals to obtain satisfactory density and durability. This study also showed that asphaltic concrete resurfacing of approximately 2–inch thickness when properly applied over old concrete canal lining is an effective rehabilitation method.

The increased interest in use of lining materials for water conservation, pollution control, and in covering reservoirs to prevent loss and contamination is encouraging industry to develop new lining materials. Two types of materials being introduced for this purpose are nylon-supported and unsupported rubber sheeting. A laboratory study was conducted to determine the physical properties of these materials, with particular emphasis on water absorption of the nylon-supported rubber sheeting, and resistance to shrinkage for the unsupported sheeting.[48]



Water absorption test cell with test sample assembled (at top) and disassembled (at bottom).



Fiberglass reinforced plastic pipe under longtime load test.

Longtime Load Investigations of a New Fiberglass Reinforced Plastic Pipe

To determine the expected performance and life of a new lightweight plastic pipe and for the preparation of specifications for the new product in Bureau pipelines, longtime sustained load studies are underway on 8–foot–diameter sections of the pipe. The pipe is indicated to be very sound and durable for Bureau use, and should be cheaper to handle and install than comparable concrete pipe by virtue of its light weight and toughness.

Petroleum Products for Electrical Equipment

Research is needed to improve existing test procedures and specifications for quality control of electrical insulating oils and synthetic liquids such as polybutene cable oil. Divergent opinions exist between producers and users over an acceptable test for sludge formation; consequently, a reliable standard test method must be developed to predict oxidation stability or resistance to sludge formation. In addition, ecological and environmental legislation

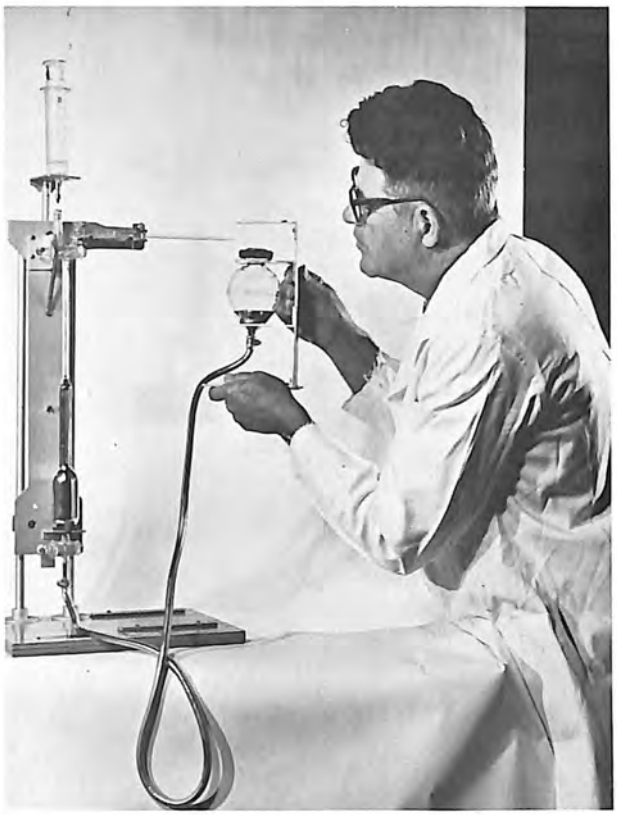
makes disposal of oil difficult and means must be found to reclaim the oils by isolating, identifying, and removing contaminants responsible for their degradation.

Physical and chemical properties data were obtained on 15 samples of the Bureau's in-service insulating oils. Subsequently, these oils were treated with fuller's earth and retested. The results indicated the feasibility of reclaiming the oil. To further study the feasibility of reclaiming oils, a mobile insulating oil reclaiming unit was built and technical assistance was provided during its initial operation at Phoenix, Ariz., in November 1969. The unit was designed to remove free and dissolved water, gas, mineral and organic acids, normal oxidation products, and contaminants such as glycols, varnishes, and other foreign matter.

The unit was also designed to operate without requiring transformer shutdown. Modifications were made after initial tests at Phoenix, and the unit has been successfully used at the Glendo and Seminole Powerplants in Wyoming.

New instruments were purchased, calibrated, and placed in service to determine the gas content of oil in new transformers for compliance with specifications and for employing the "Karl Fischer Method" for determining water content. A laboratory report was drafted on the use of interfacial tension as an end point for Test Procedure ASTM: D 1904. Field test procedures for interfacial tension, polar contaminants, and acidity are being reviewed and updated.

A need exists for developing operation and maintenance procedures to quickly determine the quality of in-service lubricating oil to insure proper lubrication of hydropower machinery. This involves developing test methods and establishing value limits. There is also a need to upgrade existing specifications to assure obtaining the best oils. Current test methods are being evaluated and literature is being reviewed to achieve these goals.



Portable apparatus for determining the dissolved gas content of electrical oils used in transformers and Pirelli-type cables.

Investigation of Groove and Crack Sealing Materials

Permanent, economical, and effective sealing of joints and cracks in all types of structures is the goal of this research. In recent years, emphasis has been given to sealing joints and cracks in concrete canal linings to save water and maintain the integrity of the linings and their subgrades. Plastic joint forming and sealing strips for installation in fresh concrete and, to a lesser extent, cured-in-place, polysulfide sealers for application in grooves of hardened concrete have generally replaced rubberized asphalt mastics for sealing contraction joints in concrete canal linings. Although promising in laboratory tests, field application of the polysulfide sealer in fresh concrete has not yet been made on a large scale. Due to problems associated with such a placement, the economies promised by this one-shot canal lining and sealer application have not been realized.

Current emphasis is on slower-setting sealers suitable for both hand and machine application on both small and large jobs. Consideration will also be given to effective seals for construction joints in dams, powerplants, pumping plants, and other structures.

Screening tests continued on new canal sealants for conformance to the new rubberized mastic and slow-set polysulfide canal sealers specifications. The new specifications developed are entitled "Specifications for Canal Joint Sealer" (covers two classes of polysulfide sealants, rapid set and slow set), dated April 1, 1971, and "Specifications for Mastic Sealer, Rubberized, Cold Application, Ready Mixed, for Joints in Concrete Canal Lining," dated March 1, 1971.

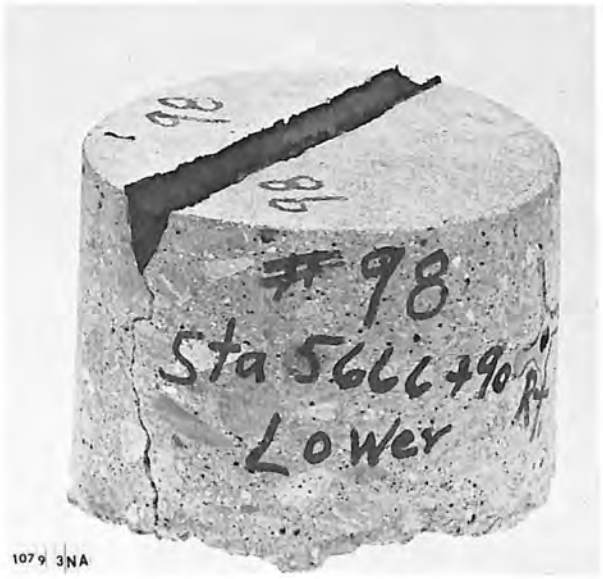
A temperature cycling test chamber was installed to more nearly simulate prototype movements and conditions in canal and building joints. Creep and cycling loading tests of plastic sealing strips were continued. Laboratory tests showed the detrimental effect of early water immersion on polysulfide extruded into joint forming grooves in fresh concrete linings.[49] This study indicated that sealer-concrete bond is a function of the cure time prior to immersion. Although 1-day cure time was found to be the minimum acceptable in these tests, several days' curing before immersion improved performance significantly.

Evaluation of 26 cores from the San Luis Drain[50] revealed the excellent joint forming and sealing provided by plastic sealing strips (longitudinal joints) and preformed polysulfide strips (transverse joints). The latter were found to be superior to polysulfide extruded into formed grooves in 3–day–old concrete.

Evaluation of similar cores from the Tehama-Colusa Canal emphasized the need for rigorous control of the sealing strip installation operation. While sealing was estimated to be effective, the PVC strips used in both transverse and longitudinal contraction joints were believed to have been in some instances excessively tilted or buried too deep for optimum performance. Intersections posed particularly difficult problems.

A paper[51] presented to the March 1971 American Concrete Institute (ACI) Convention traced the progress of joint and crack sealing research and construction methods for concrete-lined canals through Reclamation history. The paper emphasized current polysulfide cap seals and asphalt mastic tape seals recommended for cracks, plastic sealing strips, and preformed and extruded polysulfide groove sealers for canal contraction joints. Many materials, including asphalt mastics, silicones, neoprene hypalons, and polyurethanes, in addition to the polysulfide sealant and PVC plastic finally employed, were investigated in the laboratory and in field tests at several locations.

A concrete core removed from a large canal contains two PVC preformed sealing strips; the one on the left for transverse joints and the one on the right for longitudinal joints.



Canal core containing the intersection of PVC strip (right) with preformed polysulfide strip (top).

A laboratory study was initiated on the effect of low (40° F.) temperatures on the application of polysulfide sealer in fresh concrete. An inspection was made of the crack and joint sealing materials installed in the St. Vrain Supply Canal, Colorado-Big Thompson Project, and a short test section of a coal-tar polysulfide crack sealant furnished as a preformed tape was installed in the canal. Field studies at the St. Vrain Supply Canal were initially under the Open and Closed Conduit Systems (OCCS) Program and have been shifted to this program in an effort to consolidate related studies.

Concrete Curing Membranes

Water curing of concrete disrupts other construction activities and produces unsightly stains. Wax-base curing compounds are not suitable for some surfaces. Both water-cured and wax-base compound-cured concrete must be cleaned or primed, or both, to obtain bond of subsequent treatments or to obtain normal concrete appearance.

Special resin base compounds offer superior durability and are readily topcoated, or in clear versions will present a near normal concrete appearance. Particular compounds promise a satisfactory bond at construction joints. Composite sheet membranes appear to be suitable for performing three functions in some applications: curing, waterproofing, and joint sealing.

Evaluation after exposure of pigmented and clear resin-base, compound-coated panels to natural and accelerated weathering continued. Laboratory tests were made to determine the effect of flatting the gloss of pigmented compounds. Compatibility of the clear compound with use of other construction materials, for example, decorative and protective coatings, caulking compounds and foamed-in-place urethane insulation, was determined. Specifications for the pigmented compound for curing were updated, and bonding test requirements were established for instances in which the compound would also serve as a bond coat. A test program was initiated to determine the effect of form oil on appearance of clear compound-coated concrete, and to upgrade application characteristics of the clear compound.

The application of a pigmented compound at Parker Dam was inspected, and initial applications were observed of the pigmented resin-base curing compound on the Auburn Foresthill Bridge substructure. The first field use of the essentially clear material at Grand Coulee Dam's Third Powerplant and Forebay Dam was closely monitored. Specifications were modified because of the poor application characteristics of pigmented compounds in initial field uses.

Field test application of pigmented resin base curing-and-bonding compound to a horizontal construction joint surface at Grand Coulee Forebay Dam.

Protective Coatings Technology and Research

Investigation of new methods and materials developed and marketed by the coatings industry comprises the primary effort under this program. Developments in materials and application methods for coating resins and polymers are expected to yield better service and to offer increased economy and flexibility in the Bureau's corrosion control program. New materials are continually screened by exposure to several standardized laboratory test environments and are evaluated for particular usages as warranted. Maintenance painting often proceeds under adverse conditions and stringent time limitations, and materials and methods are tested under adverse conditions such as high humidity, low temperatures, short curing periods, and less-than-optimum surface preparation. Contacts with research organiza-

tions of industry, government, and technical groups are maintained to keep abreast of developments and to keep industry apprised of Bureau needs.

Black, red, and aluminum-pigmented coal-tar epoxy coatings were applied and tested, showing satisfactory bond between coats but also showing that the aluminum topcoat discolored markedly in atmospheric exposure. A survey of current coal-tar enamel pipe linings showed that they provided excellent protection through the first few years' immersion exposure on Bureau projects. Accordingly, use of this lining material was recommended to designers as an alternative to cement mortar specified for municipal and industrial water piping in which coating maintenance can be performed only infrequently, if at all. Screening tests were continued and the exposed panels were examined periodically. Exposure and periodic examinations were continued on special proprietary paints for electrical equipment and on underwater epoxies and other repair coatings.

The improvement of bond produced by four different metal conditioners, used with several types of coatings over sandblasted and unblasted steel, aluminum, galvanize, copper, and brass, was found to vary considerably. The metal conditioners generally improved bond and are considered desirable. However, light blasting generally produced even greater bond and should be used in conjunction with the metal conditioner for nonferrous metals whenever feasible.

The bond of coatings applied to small panels show how well metal conditioners enhance coating adhesion to nonferrous metals.

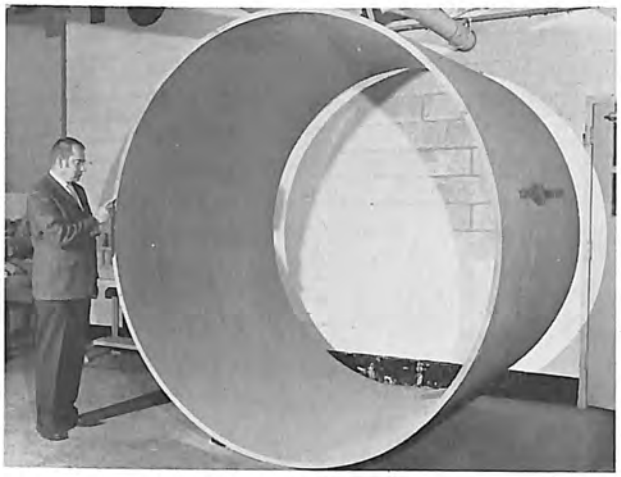
A progress report[52] was published on cavitation testing of potential protective coating materials that can be field-applied to steel and concrete surfaces. Performance of 71 coated specimens representing 21 classes of materials was evaluated in a venturi-type cavitation apparatus which produces a mild to moderate cavitation environment. A proprietary neoprene paint outperformed other materials by a wide margin; thus, this neoprene paint is recommended when need exists.

On the Southside Canal, Collbran Project, Colorado, 36 lining systems in siphon piping are being compared to coal-tar enamel for fresh water immersion resistance. An inspection showed that 25 of the 36 systems remain without defects after 10 years' exposure. A report on the test at Collbran was drafted. In other field tests, a neoprene paint reportedly has sharply reduced maintenance on pump turbine runners in an erosion exposure at Chandler Pumping-Generating Plant, Washington, and has shown the best resistance to high velocity flows of selected coatings being tested in outlets at Grand Coulee Dam.

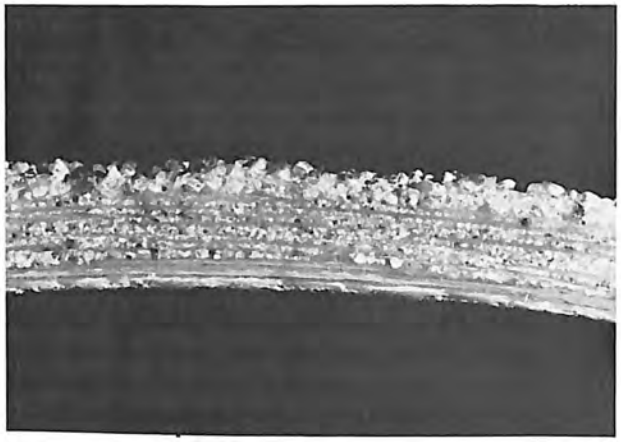
Plastic Pipe and Tubing

Plastic pipe continues to show advantages over conventional pipe for certain applications. Reinforced plastic mortar (RPM) pipe is commercially available in sizes through 48 inches, and is economically competitive with concrete and asbestos-cement pipe. A few questions on limitations of RPM pipe remain to be answered through laboratory and field tests. Developments in thermoplastic pipe, both polyethylene and polyvinyl chloride, for irrigation and drainpipe are being evaluated.

The major portion of the work was accomplished in conjunction with the OCCS Program and the Government-Industry Cooperative Study to evaluate RPM pipe, and progress and final reports were published.[53,54] Laboratory exposure tests to determine creep behavior and environmental durability of RPM pipe are continuing. Two papers on RPM pipe were presented at the 1971 AWWA conference and tentative Bureau specifications for RPM pipe were prepared. A cooperative 1-year study with ASTM on the chemical resistance of a



96-inch-diameter reinforced plastic mortar (RPM) pipe showing its characteristic thin walls.



Cross section of RPM pipe showing its laminated or layered structure; 4X magnification.

variety of reinforced plastic pipe is also underway.

Corrosion of Steel in Polymer Concrete

Steel embedded in conventional concrete is frequently vulnerable to corrosion promoted by chlorides from sea or brackish water, deicing salts, naturally occurring salt deposits, as well as stray current corrosion from cathodic protection systems. Use of polymer-impregnated concrete pipe in lieu of present concrete piping may eliminate the need for installation of corrosion mitigation measures on Bureau concrete pipelines. However, testing will be required to assure the superiority of polymer-impregnated concrete over normal concrete with regard to exclusion of chlorides and stray currents for embedded steel.

The following properties of a polymer-impregnated concrete relating to corrosion were investigated: permeability to sea water; chloride retention; soluble calcium hydroxide content; and electrical conductivity of air-dried, vacuum-dried, and undried submerged polymer-impregnated concrete. Test results showed that polymer-impregnated concrete is low in permeability to sea water and consequently to chlorides; that free calcium hydroxide is present in approximately one-half the concentration found in normal concrete; and that resistivity is so high as to virtually preclude passage of usual stray electrical currents.

Engineering Applications of Polymeric Materials

In this research, developments in polymer construction materials and techniques are evaluated through review of technical publications and by contacts with research and development segments of industry. Physical characteristics and use records of items such as plastic siding and structural elements, prefabricated panels, insulating material, and sheeting for waterproofing are investigated. Proven techniques and materials will be recommended for implementation and use.

A report was prepared and published[55] on epoxy repairs made to the concrete spillway tunnel at Yellowtail Dam, Montana. New specifications, guide paragraphs, and instructions for concrete repair, including expanded epoxy repair sections, were issued. A study of the performance of reinforced plastics in a denitrification system for treatment of sewage was completed.

Analytical Chemistry—Methods Research

Three areas being investigated are: (1) a water quality mobile laboratory, (2) ecology and water quality parameters, and (3) engineering materials.

To increase accuracy; reduce water quality changes induced by shipping, handling, and storing; and allow field personnel to adapt quickly to changing and unusual conditions, a

water quality mobile laboratory has been designed and equipped to perform field-site water analyses. The mobile laboratory is a self-contained trailer unit, permitting field personnel to perform many of the normal water analyses currently performed in the central laboratory. Included in the instrumentation is an atomic absorption spectrophotometer which can be used for determining many metallic elements in solution, allowing for the rapid performance of on-site analyses especially needed for ecology and water quality research. The mobile laboratory is currently being field tested and extensive use of it will be made in water quality field research projects.

The ecology and water quality parameters project was undertaken to improve rapidity, sensitivity, and accuracy of present standard methods and to develop new methods of analyses for nitrates, phosphates, heavy metals, and other pollutants in water. Experiments were made to find an effective preservative for nitrates in water so samples could be taken in the field, a preservative added, and the nitrate content determined at a later date.

Infrared (IR) spectroscopy is being used to investigate the following engineering materials: concrete-polymer, protective paint coatings, and electrical insulating oils. In concrete-polymer studies, IR spectrometry has provided useful information from: (a) examining aged specimens exposed to various environmental conditions; (b) determining the amount of monomer versus polymer in various systems (especially the excess and reusable monomer from past polymer impregnations), and (c) determining the rate of polymerization in polymer-concrete systems.

In paint coatings studies, IR investigations are being refined not only to detect types and amounts of desirable constituents, but also to identify contaminants.

Basic Petrographic Techniques and Investigations

Petrographic techniques which investigate the microstructure, composition, and physical properties of material are used in solving many engineering material problems, in developing uses for new substances, and in gaining understanding of the engineering behavior of materials. Petrography is especially important in the study of rocks and soils and can be a powerful approach in the investigation of any crystalline material or where microstructure is significant. New laboratory techniques which show promise but require further development will be investigated in future research programs.

A report summarizing research under this subject was published.[56] The following techniques and investigations were discussed: (1) applying X-ray spectrograph and infrared absorptions to petrographic problems; (2) reviewing sealed moist-storage and Conrow cycle mortar bar expansion tests; (3) freezing fresh concrete; (4) testing assorted rocks for alkali-carbonate reaction using the sodium hydroxide test; (5) solubility of sedimentary rock materials; (6) emission spectrographic methods for semiquantitative estimation of elements; (7) investigating a microscopic method for determining the size ranges of subsieve (0.074 mm) particles; (8) multiple-mount thin sections of fine-grained rocks for grain-size measurement; (9) dye staining tests for detecting microfractures; and (10) investigations of concrete deterioration from various causes.

The ASTM Tentative Method of Test for Potential Alkali Reactivity of Carbonate Aggregate was evaluated and demonstrated to be a valuable test for detecting expansive properties of certain carbonate rocks. Impact hammer and petrographic tests (with several strength tests) were used to determine the extent of deterioration in old concrete.

Basic Rock Physics

By the observation, petrographic classification, description, and laboratory testing of a wide variety of rocks, the physical properties and engineering performance characteristics of various rock types can be more firmly established. Values from physical observations and variations from these values can be studied and related to the petrographic characteristics of individual samples for each group. With the knowledge of which properties are characteristic, it may be possible to quantitatively assess the effects of weathering, fracturing, and other alteration of rock as related to petrograph-

ic features. Physical testing methods include impact hammer, sonic velocity, and other such tests that appear feasible. The program has three phases: (1) determining physical properties, (2) developing laboratory procedures, and (3) determining petrographic and microstructural features of rock types.

In the investigation of foundation rock at Morrow Point Dam, Colorado, rock cores were petrographically described and classified for structural tests. A report on this investigation was published.[57] Methods (articulation, model analysis, photometer method, and chemical analysis) for determining petrographic and strength characteristics of rock are described.

The Mobile Nuclear Laboratory is equipped to perform the wide variety of radioisotope field tests envisioned in the Bureau's work.

Interior view of the Mobile Nuclear Laboratory.

Radioisotope Applications

Research is performed in a broad program for the use of radioisotope sealed sources and tracers in the solution of engineering problems. The program is separated into three phases: (1) surface water investigations to improve methodology and accuracy of discharge measurements in both open and closed conveyance systems; (2) ground water investigations to develop equipment and techniques for determining the origin, velocity, and direction of flow of ground waters; and (3) environmental investigations to develop techniques for the measurement of natural tritium in ground water to distinguish ancient from juvenile sources and to assist in measuring photosynthesis of carbon (C–14) in reservoir eutrophication studies.

A research program, jointly financed by the Bureau and the Atomic Energy Commission, was directed toward perfecting a precise and relatively simple method of measuring flows in large turbines and pumps by using radioisotopes. Field tests of prototype injection and sampling systems were conducted at Flatiron Power and Pumping Plant, Colorado-Big Thompson Project, using the Bureau's mobile test equipment.

Several series of measurements compared the relative accuracy of the radioisotope velocity, integrated sample, dilution, and a total count method of measuring 300 cubic feet per second in a 6,000–foot–long penstock having diameters ranging from 6 to 7 feet.

A critical study was made of procedures that could cause the deviations of discharge as measured by the radioisotope methods. The investigations included a review of counting systems calibrations, preparation of calibration quantities and use at the field site, reliability of voltage and frequency control where com-

mercial powerlines are not available, temperature control of counting systems, and methods of minimizing or eliminating externally generated electrical noise that could appear as radioactive count. A demonstration discharge measurement series was performed at Pole Hill Powerplant, Colorado-Big Thompson Project. Three methods of discharge were used: total count, integrated sample, and dilution; the results of each are similar. A final report[58] was published which included a total program evaluation. A procedure manual was started which outlines the recommended procedures and equipment, and defines the limitations and expected accuracies of the method.

A series of discharge measurements were made on the St. Vrain Supply Canal, Colorado-Big Thompson Project. Results showed a repeatability within ½ percent and an error in accuracy of less than 1 percent. A new method of monitoring radioactivity in an open canal was demonstrated using a floating radiation detector, and new methods of calibration were successfully used. A progress report on the study is being prepared.

A dissolved oxygen probe was designed and built for use in small-diameter drill holes. It is basically a modification of an instrument commonly used in lakes. The probe is contained in a 1-5/16-inch-diameter case and mated to the drill hole logging cable in the mobile nuclear laboratory.

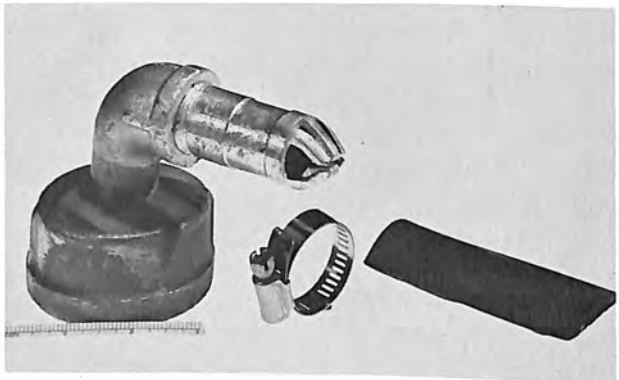
Special Studies in Applied Physics, Chemistry, and Materials

Under the Special Studies Program, four investigations were made of the application of new technology in physics, chemistry, and materials:

Infrared Detection of Reservoir Leakage.—Leakage at Anchor Reservoir has been associated with large sinkholes (underground cavities) and possibly solution-opened joints. It has been proposed that such features could be detected by their influence on the surface temperature. Imagery made from instruments in aircraft sensitive to thermal infrared shows effective ground temperatures, which are a combination of the character of the surface and its temperature. Investigations of this approach were made by obtaining infrared imagery at three different elevations, three different wave length bands, and pre-sunrise and post-sunset. Analysis of the imagery to date shows several cool thermal anomalies which are likely areas for seepage.

Use of Strain Energy for Evaluation of Cavitation Resistance of Protective Coatings.—Studies by Bureau investigators and others have shown that cavitation resistance of metals can be related to the elastic and plastic properties of the metal. Using these concepts, an investigation has been initiated to develop a rapid, quantitative rating of the ability of coatings to protect against cavitation damage. The investigation includes the relative performance of coatings in cavitation environments, a comparison of coatings as determined in laboratory and field tests with stress/strain diagrams, and specially adapted quick-test methods to measure strain energy. Results to date show encouraging correlation between cavitation exposure results and strain energy related measurements.

Development of a Low Cost Weep Valve for Canal Linings.—Hydrostatic back pressures on dewatered concrete canal linings can cause severe damage if not relieved. Mechanical weep valves installed in the lining have been used for this purpose, but are expensive and subject to malfunction when clogged with sediment and debris.



Simple components make up the raspberry flap valve used to vent back pressures under canal linings.

A simple weep valve, called a raspberry flap valve because of its similarity to a child's noise maker, was devised, tested, and six valves installed for field testing. The laboratory tests show the valve will flow under a very low head, but will not allow reverse flow. Field tests are not yet completed.

Assembled raspberry flap valves.

Use of Fiberglass-reinforced Plastic as Construction Material in Denitrification.—Anaerobic denitrification has recently been shown to be a possible method for removal of nitrogen nutrients from waste waters. Use of the method, particularly in small plants such as sewage treatment facilities at Reclamation installations, requires a tank for holding the anaerobic bacteria and supporting media. The tank must be constructed of materials not attacked by the bacteria.

Evaluation of fiberglass-reinforced, thermosetting plastics (FRP) is being conducted with the aid of optical and electron microscopy. The study is designed to determine whether bacteria in a relatively short period of time can cause microscopically small attacks which, after years of service, would result in major problems. Specimens which have been photographed have been subjected to exposure to laboratory cultures and in an operating plant. Results to date show very good resistance to biological attack and no inhibition of the desired action of the bacteria.

Electronic River Bank Hydraulic Pressure Monitoring System

Completion of the Bureau's Third Coulee Powerplant will result in large changes in the downstream river water surface and changing hydraulic pressures in the riverbanks. These pressures must be monitored and the results analyzed to determine the possibility of landslides. The data and analysis must be immediately available to permit corrective action if necessary.

To rapidly obtain and analyze data, an electronic computer-controlled interrogation and data acquisition system will be used. The computer-controlled central station will interrogate, by radio, different locations along several miles of river channel. Each location will involve several transducers, and the information from each transducer will be changed to digital values and sent to the central station. The central station will record the value for analysis by computer.

Electronic parts to test a pilot system have been ordered. These include transducers, pressure transfer equipment, multiplexers, analog-to-digital converters, radios, a computer and an input/output device. Transducers will be calibrated in the laboratory, programs for the computer will be prepared, a pilot system installed, and a report prepared on the system.

Electronic Computer Application to Sensor-based Laboratory Data Acquisition System

To provide for more efficient use of personnel and permit larger amounts of data to be obtained and rapidly analyzed, research is being conducted on the problems of connecting a minicomputer directly to data transducers. A small minicomputer with 8,000 words of memory has been obtained and interfaced with various data acquisition equipment, including a typewriter with paper tape read/punch capabilities. The typewriter is used for the input/output console, and the digital magnetic tape will be used for collecting large volumes of data at high speed.

The system has been assembled and several programs to check the minicomputer functions have been written and debugged. The operation of each unit of the system with the minicomputer has been checked. The system is being programmed to obtain data from and provide automatic control for a small model canal.

Long-line, Low-voltage Data Transfer Studies

In the past, difficulties have resulted in transferring low-voltage data information-

over long lines. As a result, much transmitted data have lacked the resolution desired and, at times, were not usable. Research is being conducted to develop simple and reliable techniques for such data transfer. Constant current circuits using field effect transistors have been developed. Tests of these circuits for data transfer under various line conditions and temperatures are planned. These circuits have been used to construct active legs for a bridge where high resolution in readout is desired for obtaining data from tunnels. A report covering the bridge circuit is being prepared.

Television Equipment Used in Research

To take advantage of features offered by modern television equipment, a small, inexpensive, and versatile system has been obtained. The system has two television cameras, monitors to permit the information obtained by each camera to be viewed, a special effects generator to permit the information from the cameras to be combined in any way desired, and tape recorders to store the information. The system has been used for several problems. Some notable examples of use where this equipment provided capabilities not available in a movie camera include: (1) comparing, on the same picture, approach conditions in a hydraulic model with vortex formation; (2) recording, on the same picture, both sides of a concrete beam as it failed; (3) recording a beam failing and the instrument readings at failure on the same frame; and (4) using the capabilities of a wide band amplifier to record electrical transients.

Besides being versatile the system is proving economical in two ways: (1) recording tapes may be used hundreds of times; and (2)

TV research monitoring system.

a production is completed rapidly. There is no need to wait for developed film to be returned and edited. The information that is placed on tape is immediately available and can be edited electronically as it is being recorded so that a production is immediately available for presentation.

RAPID EXCAVATION

Rapid excavation research develops mechanical, chemical, and explosive techniques and equipment for rapidly excavating and moving large volumes of earth or rock, with particular emphasis on rapid tunnel excavation in the construction of water resources projects.

Stillwater Tunnel Research Program

In 1971, the Bureau proposed a research program for rapid underground construction at the Stillwater Tunnel, Bonneville Unit, Central Utah Project.[59] The principal objective of the proposed program was to undertake research studies in various areas of tunneling technology in order to reduce the cost and increase the speed of tunnel construction.

Emphasis of the Stillwater Tunnel Research Program was to be on the use of advanced tunneling machines, waste removal systems such as slurry, pneumatic, and conveyor belts, and tunnel lining and support systems. This program would also involve research into geologic and geophysical exploration techniques, studies of occupational health and safety, and environmental considerations.

The Stillwater Tunnel Research Program, originally planned to start in 1973, was postponed due to budget readjustments in the Bureau's construction and research programs.

Geologic and Geophysical Investigative Techniques

This research concerns development of techniques to accurately define at construction sites those geologic features which affect the speed of tunnel construction, cost of excavation, and integrity of the tunnel. Items in the research effort are: (1) detailed geologic mapping, both surface and underground; (2) deep drilling on the tunnel alinement to provide oriented core for laboratory tests and petrographic analysis, and information on ground-water conditions and permeability of the rock; (3) development of new geophysical techniques or the adaptation of existing techniques, either surface, borehole, or in-tunnel; and (4) development of an integrated system of continuous exploratory drilling preceding the cutterhead. Studies have been made and data analyzed for preparation of prototype specifications for deep drill hole investigation of tunnel alinements.

Rapid Excavation of Soil and Soft Rock

Occasionally, tunnels constructed by the Bureau include regions of soft shale, as well as fault zones. Although the volume of this material may be relatively small, the problems of support and stabilization in soft and squeezing ground make these zones especially important to the overall construction program.

Plans are being made to study the shales and evaluate expansive potential, swell pressures, stress relief, and strength loss as a result of water content and possible increase of water volume. Results of tests to determine these properties will provide a basis for evaluating the requirements for protection between the time of excavation and lining, and the probability of changing dimensions after excavation.

In regard to rapid surface excavation, planning has continued in the selection and design of a test reach of canal to be excavated by the use of conventional high explosives. Liaison has been maintained with private industry and the Corps of Engineers on the latest explosive excavation methods. Bureau representatives witnessed explosive excavation demonstrations and attended a seminar on the subject conducted by the Corps of Engineers.

Tunnel Lining, Supports, and Reinforcement

The determination of tunnel lining requirements and possible necessity for reinforcement that may require large expenditures is a matter of continuing concern to planners and designers of water development projects.

Recent developments and use of underground

boring machines have presented the possibility of using thinner tunnel linings. Therefore, it is important to determine the minimum practical and safe requirements for lining so the economic benefits of using boring machines may be fully realized. Such studies are underway and will continue as performance data for machines now in use become available and behavior data from tunnel instrumentation are obtained. The studies include the finite element method of analysis for predicting stresses and displacements in the rock around a tunnel. Instrumentation for monitoring tunnel behavior is being installed in several existing tunnels to provide means of verifying design assumptions.

Studies are also being made to establish guidelines for selecting the most suitable type of support system for the particular sections of tunnel where poor foundation conditions exist. Newer types of supports such as shotcrete, shotcrete with perforated metal plate, and precast concrete are among systems being evaluated.

Work on the photographic-computer method for determining areas of cross sections in underground excavations continues. The method uses a photograph taken in the tunnel or underground opening and a computer-digitizer program to evaluate the area at a given section. The program shows the area at each section, cumulative volume of excavation, and average deviation from prescribed lines. Its use is also being investigated for determining hydraulic properties of unlined tunnels.

Shotcrete Tunnel Support and Lining

Shotcrete is concrete or mortar that is applied pneumatically through a hose and nozzle. It is increasingly being used by itself for primary tunnel support, rather than just as a protective coating in conjunction with steel sets or rock bolts. Added chemical accelerators cause shotcrete to begin hardening immediately after application.

Use of shotcrete for primary support requires close attention to economy and safety. Information is needed on: (1) lower cost accelerators of high quality because the cost of presently used accelerators varies from $15 to $18 per cubic yard of shotcrete in place; and (2) methods to determine accurately the quality of the in-place shotcrete at an early age to insure safety and economy.

Shotcrete is applied to laboratory test panels to determine rate of set and strength characteristics.

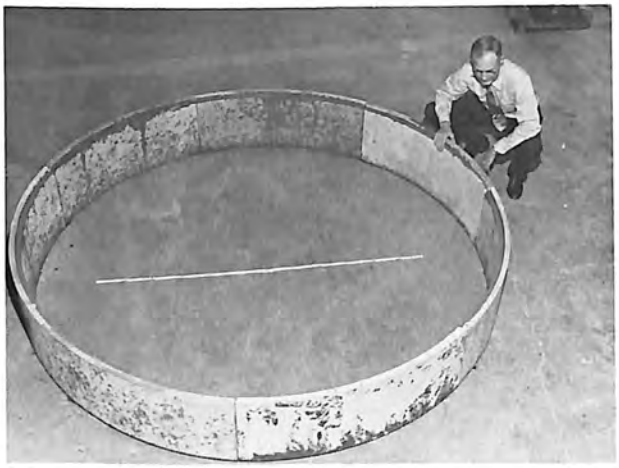
A research program to solve both problem areas is underway. Laboratory investigations will establish the most promising cement-accelerator combinations and the most promising quality control methods. These methods will then be used in tunnel construction as a final test of their usefulness.

Polymer Concrete Tunnel Support and Lining

The objectives of the program are to develop and test a low-cost, high-strength precast concrete tunnel support and lining system which uses the unique characteristics of polymer-impregnated concrete to best advantage. The support and lining system will have to be competitive with other systems and adaptable to commercial applications both as to manufacture and to its placement in tunnels. Immediate goals of the program are to develop

techniques for fabricating segments, evaluating their physical and mechanical properties, assembling them into the tunnel support and lining system, loading and testing full-scale systems, evaluating specific applications, and developing design criteria and construction procedures.

A series of segments has been fabricated and placed together to form an 8–foot internal diameter circular cross-section tunnel support and lining system. A number of segment tests have been performed to determine the mechanical properties of single segments. Technical analyses have been made on the full-scale tunnel support and lining system to determine its behavior.



Cylindrical precast concrete segments form an 8-foot-internal-diameter support and lining system.

Rock Indices for Rapid Excavation

Three areas of investigation are thought to be useful in predicting the boreability of rock: uniaxial compressive strength, linear cutter tests to determine specific energy for rock removal, and button indentation tests.

Results indicate a correlation between specific energy and uniaxial compressive strength of rock. For this reason, studies will continue using both the linear cutter and compressive strength as the basis for development of the boreability index. In addition, an investigation into the possible use of nondestructive testing methods for providing a more economical evaluation of drilling strength has been initiated.

As part of the program, samples of various rock types from Bureau projects will be tested to determine the range of energy requirements for removing a specific volume. Tunnel boring machine performance in various types of rock will be documented.

Reliable rock indices for drilling will be of great benefit to the construction industry in estimating costs. In addition, information useful in selecting the type of cutter bits best suited to particular rock types can result in more efficient construction equipment and reduced costs of tunnel construction.

Testing a single precast polymer concrete tunnel support and lining system.

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