Colorado River Storage Project
See also "Glen Canyon Dam"
SERVICE RECEIVES RECOGNITION

August 20, 1980

Dear Commissioner Higginson:

It is a pleasure to extend my personal congratulations along with that of the National Safety Council to the Water and Power Resources Service and all its employees for the outstanding safety performance that has earned you the Council's Award of Honor.

The Award of Honor is the highest recognition presented by the National Safety Council for outstanding occupational safety performance. In winning this award the Water and Power Resources Service, Washington, DC stands as a safety model for its industry. The Council has found that exemplary safety performance is achieved by management making a commitment to preventing accidents and occupational illnesses and then following through so that supervisors and all members of the work force understand that safety and health are priority concerns.

Your achievement in safety excellence can be credited to a sincere dedication to safety and to the enthusiastic cooperation of all concerned.

Please express my appreciation to all members of your staff for the maximum effort for safety. Your leadership in this significant accomplishment is very much appreciated.

I wish the Water and Power Resources Service and all its members continued success in seeking safety excellence and future awards.

Sincerely,

Vincent L. Tofany
President
National Safety Council

NITINOL ENGINE EXCITES ENGINEERS

Demonstration of a water-splashing "heat engine" in the middle of Commissioner Higginson's hour-long leadoff speech at the American Society of Civil Engineers meeting in Chicago August 7 considerably lightened up the event, Mr. Higginson said upon his return. Speaking on "Creativity, Innovation and Solutions: A Challenge to the Profession," Commissioner Higginson emphasized the potentials of alternative, renewable resources as they are being approached by Water and Power. The small Nitinol engine demonstration was one of several potentials mentioned.

The toy-sized engine was mounted for the demonstration on two plastic containers containing, respectively, hot and cold water. Whirling with much force, the little device splashed water all over the table, to the amusement of See NITINOL, Page 3.
LAKE POWELL
FINAL FILL CELEBRATED

Commissioner Higginson was keynote speaker in July at the occasion commemorating the final filling of Lake Powell to 3,700 feet surface elevation above sea level. The task of filling the Lake was begun in March 1963 after the Service completed building Glen Canyon Dam.

During his remarks, the Commissioner said, "About 93 percent of the Federal investment costs of this project will be repaid. And what were those costs? Here is where we learn a lesson about the value of far-sighted investments such as this.

"Glen Canyon Dam and Powerplant were built at a cost of $260 million, during the period from 1956 to 1964. In terms of today's dollars, the cost would be over $800 million. I take some comfort in that fact in the seemingly endless battle to justify investments such as this when history has shown time and again to far outstrip the benefits anticipated when those projects were being planned."

Also, the Commissioner pointed out that storage in Lake Powell is a key in satisfying terms of the Colorado River Compact, among the several States, as well as help the United States meet its commitments to Mexico.

Present and former Service employees, officials, dignitaries, and local citizens attended the event.

The event was sponsored by the Page, Arizona, Chamber of Commerce.

See Lake Powell, Page 4
EMPLOYEES ACCEPTED FOR TRAINING PROGRAM

Donahue

Linke

James F. Donahue and Deborah M. Linke were recently selected for the 1980-81 Departmental Executive and Manager Development Program.

They will begin the 10-month long program on October 20, 1980.

Donahue works in the Division of Program Coordination and Finance in Washington, D.C., and Linke works in the Regional Environmental Office in Salt Lake City, Utah.

During the training period, they will be exposed to all aspects of management and administration, including the Legislative/Executive branch interface, bureau-bureau interface, departmental policy role, and Service headquarters activity.

After completion of the program it is expected that the graduates will assume greater responsibilities in supervision and management for the Service.

PEDDE SELECTED PROJECT HEAD

Pedde

Kenneth R. Pedde of El Paso, Tex., has been named Project Superintendent for the Service's Rio Grande Project. He replaces Jim Kirby who retired in July.

The Rio Grande Project, with headquarters in El Paso, furnishes irrigation water to about 150,000 acres of land, generates electric power for communities and industry in the area, and provides water for delivery to Mexico under the 1906 Treaty. Project lands occupy the river bottom land of the Rio Grande Valley in south-central New Mexico and west Texas.

Pedde has a bachelors degree in civil engineering and is a registered professional engineer in Colorado and Texas.

He recently completed the Department's Manager Development Program, a 10-month training program designed to provide candidates for top level career management positions.

NITONOL, From Page 1

the engineers.

The Commissioner said Nitinol engines can operate at many levels of temperature differential, and can be used to pump water at reservoirs (with the warm water on top and cool water below) for irrigation or cooling purposes.

Nitinol—a nickel-titanium alloy developed by the Navy—has a "memory" causing it to deform and return to its original shape depending on the temperature. This cycle can be repeated indefinitely. Nitinol exerts about 50,000 pounds per square inch in this movement.
### Statistics on Glen Canyon Dam and Lake Powell

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Authorized</td>
<td>April 11, 1956</td>
</tr>
<tr>
<td>First Construction</td>
<td></td>
</tr>
<tr>
<td>Contract Awarded (Right</td>
<td>October 1, 1956</td>
</tr>
<tr>
<td>Diversion Tunnel Excavation)</td>
<td></td>
</tr>
<tr>
<td>Diversion of Colorado</td>
<td></td>
</tr>
<tr>
<td>River Around Damsite</td>
<td>February 11, 1959</td>
</tr>
<tr>
<td>First Bucket of Concrete</td>
<td>June 17, 1960</td>
</tr>
<tr>
<td>Last Bucket of Concrete</td>
<td>September 13, 1963</td>
</tr>
<tr>
<td>First Power Generation</td>
<td>September 4, 1964</td>
</tr>
<tr>
<td>Dedication by Mrs. Lyndon B. Johnson</td>
<td>September 22, 1966</td>
</tr>
<tr>
<td>Dedication of John Wesley Powell Museum in</td>
<td>August 1, 1969</td>
</tr>
<tr>
<td>Page</td>
<td></td>
</tr>
</tbody>
</table>

#### Glen Canyon Dam
- Height Above Bedrock: 710 feet
- Height Above Original River: 638 feet
- Volume of Concrete: 4,901,000 cubic yards
- Powerplant and Miscellaneous: 469,000 cubic yards
- Total Concrete: 5,370,000 cubic yards
- Cost of Dam: $155,000,000
- Cost of Powerplant: $70,000,000
- Cost of Dam, Powerplant Switchyard, Town of Page, Associated Facilities, etc.: $272,000,000
- (93% will be repaid U.S. Treasury from sale of power, 76% of total with interest)
- Recreation Facilities: $10,000,000
- Generating Units: 8
- Peak Power Production to Date (6/23/80): 1,124,000 KW
- Plant Capability at Rated Head: 1,021,250 KW

#### Lake Powell
- Start of Storage: March 13, 1963
- Completion of Initial Filling: June 22, 1980
- Capacity When Full: 27,000,000 acre feet
- Depth of Water at Dam When Full: 560 feet
- Shoreline Distance When Full: 1,960 miles

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**To Place An Article in the Washington Report Please Contact the editor, Darlene Harrod, in Room 7642 or Call her at 343-4662.**

**Kelly Passes Bar**

On September 3, 1980, Richard L. Kelley of the Operation and Maintenance Policy Staff was notified that he had passed the Virginia Bar Examination and was being licensed to practice law in Virginia.

The notice came about two weeks after Kelley graduated from the George Mason University School of Law in Virginia being awarded the degree of juris doctor.

Kelley works for Code 460, which deals primarily with policy regarding operations and maintenance of the Service’s power facilities. He handles matters relating to the procurement and frequency assignments for power communication facilities and processes certain power contracts for the sale of project-use power. He works generally with the operation and maintenance of the Service's 50 powerplants and other power facilities.

Kelley, a native of Washington, D.C., graduated from Maryland University in 1963 with a bachelors degree in electrical engineering.

He has worked with several government agencies and has completed 21 years of Federal service, including 2 years with the Navy.

Kelley plans to continue his government career, and in the future plans to practice law at night and on weekends involving out-of-court activities such as preparing wills and tax returns, corporation formations, contract negotiations, and real estate settlements.

Kelley and his wife Bo live with their two children in Annandale, Va.
Comparison of Analytical and Structural Behavior Results for Flaming Gorge Dam
Comparison of Analytical and Structural Behavior Results for Flaming Gorge Dam

Dams Branch
Division of Design
Office of Chief Engineer
In its assigned function as the Nation's principal natural resource agency, the Department of the Interior bears a special obligation to assure that our expendable resources are conserved, that renewable resources are managed to produce optimum yields, and that all resources contribute their full measure to the progress, prosperity, and security of America, now and in the future.

First Printing: 1968
Preface

Engineers concerned with the safety of concrete arch dams should be reasonably certain that the structure will behave during operation as predicted by the analysis. For more than 30 years the Bureau of Reclamation has instrumented large concrete arch dams.

The two principal reasons for instrumentation are: (1) to obtain information which can be used to detect abnormal behavior of the structure, and (2) to obtain measurements which can be used to evaluate the effectiveness of the analysis method and the reliability of assumptions.

In line with the second reason, the purpose of the investigation reported in this publication is to demonstrate the efficacy of the trial-load method and the reliability of assumptions used for the design of Flaming Gorge Dam. Comparisons were made between measured and computed data. Changes in concrete stresses and deflections of the dam were compared for conditions at two periods of time.

The initial period, from October 9, 1963, to March 26, 1964, was used for the comparison of deflections and stresses due to seasonal temperature variation. Since reservoir and tailwater elevations did not change appreciably during this period, results show the effects of seasonal temperature variation alone. This permits an evaluation of the temperature assumptions used in the trial-load analysis, as well as the effects of temperature on movements and stresses in the dam.

The differences in structural behavior results for the second period, from March 26, 1964, to March 6, 1966, indicate the deflection and stress changes due to reservoir water level fluctuations. The tailwater elevation remained constant during this period. Differences in temperature of the concrete between the two dates were small.

Because of the length of time covered by this study, the effects of concrete creep were introduced into the trial-load analysis by reducing the modulus of elasticity for the concrete. This study, which shows the effects of reservoir water level fluctuation on movement and stresses in the dam, gives an indication that the assumption made to include the effects of concrete creep is reasonably accurate.

Good agreement was obtained between the results from the trial-load analysis and those obtained from structural behavior measurements.

This report was prepared by Milton A. Kramer and Louis H. Roehm under the general direction of L. R. Scriver and G. C. Rouse. These structural engineers are on the staff of the Chief Engineer, Bureau of Reclamation, Denver, Colo. Drawings were prepared by F. L. Dockhorn.

Included in this publication is an informative abstract and list of descriptors, or key words, and “identifiers.” The abstract was prepared as part of the Bureau of Reclamation’s program of indexing and retrieving the literature of water resources development. The descriptors were selected from the Thesaurus of Descriptors, which is the Bureau’s standard for listing of key words.

Other recently published Water Resources Technical Publications are listed on the inside back cover of this report.
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Introduction

This report presents comparisons of results from trial-load analyses and structural behavior measurements for two loading conditions on Flaming Gorge Dam. Stresses and deflections from the analytical studies are compared with the results of measured data for each loading condition.

Flaming Gorge Dam is a concrete arch structure with an axis radius of 650 feet. The height of the dam above the lowest excavation for the foundation is 502 feet. The length of the crest is approximately 1,180 feet. A plan, elevation, and sections of Flaming Gorge Dam are shown on figure 1. The dam is on the Green River near Dutch John, Utah.

During the year, the dam is subjected to both daily and seasonal temperature variations. The period from October 9, 1963, to March 26, 1964, was selected for the investigation of the effects of seasonal temperature change. The reservoir water surface and tailwater surface remained very nearly constant at elevations 5932 and 5600, respectively. This loading condition permits an investigation of temperature effects on the dam.

The period from March 26, 1964, to March 6, 1966, was selected to investigate the effect of a rise in reservoir water level from elevation 5932 to elevation 6000. Although the change in water surface elevation occurred during the early part of the 2-year period, the later date was selected to eliminate as nearly as possible the effects of temperature change of concrete from the study. The tailwater surface remained constant at elevation 5600 throughout this period.
Figure 1.—Flaming Gorge Dam—Plan, elevation, and sections.
Data for Trial-Load Analyses

Data used in the trial-load analyses of Flaming Gorge Dam are as follows:

a. Top of dam, elevation 6047.
b. Base of dam, elevation 5555.
c. Reservoir water surface assumed constant at elevation 5932 for the period of October 9, 1963, through March 26, 1964.
d. Reservoir water surface raised to elevation 6000 during the early part of the 2-year period after March 26, 1964, and maintained at that elevation through March 6, 1966.
e. Modulus of elasticity for short-time loading of concrete, \(4.0 \times 10^6\) pounds per square inch.
f. Modulus of elasticity for concrete under a sustained loading for the 2-year period March 26, 1964, to March 6, 1966, \(3.0 \times 10^6\) pounds per square inch.
g. Sustained modulus of elasticity for abutment rock on the left side, \(2.0 \times 10^6\) pounds per square inch.
h. Sustained modulus of elasticity for abutment rock on the right side and at the base of the dam, \(1.0 \times 10^6\) pounds per square inch.
i. Poisson’s ratio for concrete, 0.20.
j. Poisson’s ratio for abutment rock, 0.04.
k. Coefficient of thermal expansion for concrete, \(5.0 \times 10^{-6}\) per degree Fahrenheit.
l. Unit weight of concrete, 150 pounds per cubic foot.
m. Unit weight of water, 62.5 pounds per cubic foot.
n. Tailwater surface remained constant at elevation 5600 throughout the period covered by these studies.
o. Effects of silt, ice load, and earthquake are not included.
p. Contraction joints grouted to elevation 6047. Two joints, one near each abutment, remain open above elevation 6000.
q. Temperatures used in the analyses were recorded at strain meter and stress meter locations for each of the three dates selected.

Previous studies indicate a lower modulus of elasticity for the abutment rock on the right side of the dam. Bureau laboratory tests indicate an average value of about \(1.5 \times 10^6\) pounds per square inch for all rock specimens tested. However, values for the modulus of elasticity in approximately the directions of resultant forces were not obtainable for many of the specimens on the right side of the dam and those available are, in general, lower than the values for the left side specimens. The values obtained near the base of the dam are also lower. Therefore, moduli of elasticity of \(2.0 \times 10^6\) pounds per square inch for the left abutment rock and \(1.0 \times 10^6\) pounds per square inch for the right abutment and base rock were assumed. Bureau laboratory results show that a modulus of elasticity of approximately \(4.0 \times 10^6\) pounds per square inch might be expected for the concrete over a relatively short loading period such as exists between October 9, 1963 and March 26, 1964. However, tests of Flaming Gorge Dam concrete, for sustained loading over a 2-year period, table I, show a modulus of approximately \(3.0 \times 10^6\) pounds per square inch. Thus, the change in deflections and stresses between March 26, 1964 and March 6, 1966, reflects not only a rise in the reservoir water level but also a change in the modulus of elasticity due to the effects of concrete creep for concrete under sustained loading.

Table I.—MODULUS OF ELASTICITY FOR CONCRETE UNDER SUSTAINED LOAD

<table>
<thead>
<tr>
<th>Age of concrete (1) (days)</th>
<th>Loaded age (days)</th>
<th>Modulus of elasticity (\times 10^6) psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>367</td>
<td>2</td>
<td>4.6</td>
</tr>
<tr>
<td>375</td>
<td>10</td>
<td>4.0</td>
</tr>
<tr>
<td>430</td>
<td>65</td>
<td>3.7</td>
</tr>
<tr>
<td>585</td>
<td>120</td>
<td>3.4</td>
</tr>
<tr>
<td>745</td>
<td>280</td>
<td>3.3</td>
</tr>
<tr>
<td>802</td>
<td>437</td>
<td>3.2</td>
</tr>
<tr>
<td>968</td>
<td>603</td>
<td>3.1</td>
</tr>
<tr>
<td>1, 122</td>
<td>757</td>
<td>3.1</td>
</tr>
</tbody>
</table>

\(^1\) Age of concrete at the time of initial loading was 1 year.

\(^1\) Numbers designate literature cited in the “Bibliography” at the end of this report.
Trial-Load Analyses

The trial-load method of analysis \(^2\) assumes the dam to be divided into a system of horizontal and vertical elements, each system occupying the entire volume of the dam and independent of the other. The loads applied to the dam are divided between these elements in such a way that geometrical continuity is attained throughout. Three displacements and three rotations may be satisfied in steps called adjustments. The radial deflections of the elements are brought into agreement by a radial adjustment. The tangential adjustment accounts for the tangential movements and may include vertical displacements and rotation about the radius. Rotations about the tangential and vertical axes are accounted for in the twist adjustment. The effects of vertical displacements and rotation about the radius are usually found to be small and were not included in these studies.

Tangential and rotational agreements are accomplished by introducing internal self-balancing tangential and twist loads at points common to the horizontal and vertical elements. The effects of foundation movement caused by the loaded dam are included.

The trial-load method is limited to a linear temperature variation from upstream to downstream face. Therefore, the measured temperatures, which may not vary linearly, must be represented by an equivalent linear temperature gradient. Stresses in these analyses are corrected for the variations of the recorded temperatures from the assumed gradient.

An electronic computer was used to perform the trial-load analyses of Flaming Gorge Dam for loading conditions which existed on each of the three dates selected.

Stresses and deflections were determined for seasonal temperature variations by using the temperature differences between October 9, 1963, and March 26, 1964. The results represent the effects of a temperature change from seasonal maximum to seasonal minimum.

Stresses and deflections for the rise in reservoir water level are changes from March 26, 1964, to March 6, 1966.
Instrumentation

To study the effects of loads, instruments of various types have been installed in concrete dams. Flaming Gorge Dam has been instrumented to provide structural behavior information.

Location of Instruments

Field measurements at Flaming Gorge were made using six types of structural behavior apparatus: strain meters, stress meters, joint meters, resistance thermometers, plumblines, and triangulation targets. Locations of this equipment are shown in figures 2 and 3.

The instruments embedded in Flaming Gorge Dam are: 912 strain meters, 61 stress meters, 116 joint meters, and 32 thermometers. Strain meter groups are embedded in 10 cantilever elements located in Blocks 3, 5, 7, 9, 10, 13, 16, 17, 19, and 22, respectively. "No-stress" strain meters used to measure autogeneous growth of the concrete are also located in the same 10 cantilever elements.

Thermometers were installed in a grid pattern in Block 13. The spacing is about 50 feet vertically by about 20 feet horizontally.

At elevation 5670, Block 13, 6 stress meters were embedded around strain meter Group 12, 2 meters each in Directions 1, 2, and 3, as shown in figure 4. At elevation 5880, 20 stress meters were embedded in the axial direction, 5 meters each in Blocks 7, 10, 16, and 19. At elevation 6000, 35 stress meters were embedded in the axial direction, 5 meters each in Blocks 3, 7, 10, 13, 16, 19, and 22.

Joint meters were embedded across contraction joints at all elevations where strain meters or stress meters are located. At elevation 5760 and below, 3 joint meters were installed across each joint. At elevations 5880 and 6000, 2 joint meters were installed across each joint.

Two systems for measuring deflections were provided. The first consists of three plumblines located in 12-inch-diameter wells extending from the top of the dam to near the foundation in Blocks 8, 14, and 18 (see figure 2).

The second system consists of a grid of 42 targets located on the downstream face of the dam. Triangulation measurements were made on the targets from four piers. No triangulation measurements were made on October 9, 1963, and March 6, 1966; therefore, only deflection measurements obtained from plumblines are reported.

Reading of Instruments

Readings from strain meters, stress meters, joint meters, and thermometers were begun immediately following their embedment and were continued on an increasing time scale until readings were taken biweekly. Plumbline readings were taken weekly. During the period of this study, all instruments were read on a weekly or biweekly schedule.

At each scheduled reading, a test set which is basically a Wheatstone bridge, is used to obtain values of resistance ratio, reverse ratio, and resistance sum for each strain meter, stress meter, and joint meter. Resistance thermometers require only a resistance sum reading.

Plumbline deflections were obtained using a 20-power microscope. A micrometer slide is attached to the microscope. Four readings are taken for each mounting position, two each for the target and for the plumbline. Graduation of the lead screw knob provides for micrometer readings to the nearest 0.0001 inch.

Analysis of Data

Before a comparison between measured and analytical results can be made, the measured data must be reduced to values of temperature, stress, and deflection. The methods and computer programs used to reduce the instrument data to temperature, stress, and deflection are completely described. These programs can be used to reduce these types of data for any structural behavior installation.

The calculation of stress from strain in concrete involves the concept of the "creep surface." Concrete is a material which exhibits changing elastic properties with increasing age and deformation of the concrete under constant load. The Bureau of Reclamation laboratory has been making creep tests on concrete for over 20 years. To describe the changing elastic properties of concrete, an equation was developed using
Figure 2.—Layout of structural behavior instruments—Blocks 10 and 13.
data obtained from Bureau of Reclamation laboratory tests. A detailed description of the equation is given in Reference 5.

The following table shows the modulus of elasticity and some of the creep data obtained from laboratory tests on Flaming Gorge concrete. Creep strain is assumed to be directly proportional to stress. The maximum stress applied to the test cylinders was 600 psi.

<table>
<thead>
<tr>
<th>Concrete age at loading time (days)</th>
<th>Modulus of elasticity $\times 10^6$ psi at loading time</th>
<th>Creep strain $\times 10^{-4}$ in./in./psi loaded for 200 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2.8</td>
<td>0.31</td>
</tr>
<tr>
<td>28</td>
<td>3.5</td>
<td>0.15</td>
</tr>
<tr>
<td>90</td>
<td>3.9</td>
<td>0.09</td>
</tr>
<tr>
<td>367</td>
<td>4.6</td>
<td>0.07</td>
</tr>
<tr>
<td>730</td>
<td>4.6</td>
<td>(t)</td>
</tr>
</tbody>
</table>

1 No creep tests for this age of concrete.

A computer program was written to compute the best fit surface using the elastic and creep data from laboratory tests.\(^1\)\(^5\) The equation expresses the laboratory data in a form which can be used by the computer to calculate stress from strain meter data.

Bureau laboratory tests indicated a Poisson's ratio of approximately 0.20 for Flaming Gorge concrete.
Comparison of Analytical and Measured Data

**Seasonal Temperature Change**

Radial deflection changes due to the seasonal temperature variation are shown graphically in figure 5. Deflections from the trial-load study and measured deflections are shown at the plumbline locations.

Agreement between radial deflections for the trial-load study and measured deflections is good. The maximum difference between the radial deflections from the analytical study and measured radial deflections is approximately 0.11 inch. The comparison indicates the moduli of elasticity for abutment rock and concrete are correct and the linear temperature assumption used in the trial-load study does not appreciably affect the radial deflections.

Table III lists the measured and computed radial deflections at the top of the dam, elevation 6047 and elevation 6000. The maximum radial deflection is 0.88 inch for the measured data and 0.91 inch for the trial-load study.

**Table III.** — SEASONAL TEMPERATURE CHANGE—COMPARISON OF TRIAL-LOAD ANALYSIS RADIAL DEFLECTIONS AND MEASURED RADIAL DEFLECTIONS

<table>
<thead>
<tr>
<th>Block</th>
<th>Elevation</th>
<th>Radial deflections (inches)</th>
<th>Trial-load</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>6047</td>
<td>0.60</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>6047</td>
<td>0.91</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>6047</td>
<td>0.68</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>6000</td>
<td>0.49</td>
<td>^0.62</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>6000</td>
<td>0.76</td>
<td>^0.83</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>6000</td>
<td>0.55</td>
<td>^0.60</td>
<td></td>
</tr>
</tbody>
</table>

^ Measured deflections are at elevation 6015.

Measured tangential movement changes are toward the left abutment. The trial-load study indicates movement toward the left abutment in Block 8 and toward the right abutment in Block 18. Although the tangential movements are small, the differences between analytical results and measured data shown in figure 5 indicate a movement of the abutments toward the left in the lower part of the dam. This may have been caused by a movement of foundation jointing as a temperature drop caused the dam to deflect downstream for the first time. Later measurements show tangential movements consistent with trial-load results.

Horizontal and vertical stress changes are shown in figures 6, 7, and 8. Stress distributions from the structural behavior measurements are represented by solid lines and those from the analytical study are shown as dashed lines. Stresses from the trial-load study were corrected for the deviations of measured temperatures from the assumed linear temperature gradient. A modulus of elasticity for concrete of $4.0 \times 10^6$ pounds per square inch and an assumed 100-percent restraint were used for this correction. A representative linear stress distribution for the analytical study is shown with the corrected stresses at elevation 5880 on Block 19 in figure 6. The seasonal temperature changes, along with the assumed linear temperature distributions, are shown adjacent to the meter locations.

Horizontal arch stresses are shown in figures 6 and 7 at meter locations along the horizontal arch elements. The comparison between measured arch stresses and the trial-load analysis stresses is good. At elevation 5670 near the downstream face, the measured data indicate stress changes of 340 psi, 310 psi, and 280 psi. At the same locations, the trial-load analysis indicated stress changes of 340 psi, 375 psi, and 305 psi. The maximum measured arch stress change at elevation 5760 was 320 psi in Blocks 13 and 16 near the downstream face. The trial-load analysis indicated stress changes of 340 psi and 350 psi, respectively. At elevation 5880, the measured data indicated stress changes of 230 psi increase to 300 psi decrease. The trial-load analysis indicated stress changes of 275 psi increase to 300 psi decrease at elevation 5880.

As shown in figure 8, the comparison between many of the measured vertical stresses and similar trial-load analysis stresses is good. At elevation 5670 near the downstream face, the measured data shows stress
Figure 6.—Arch stress change and concrete temperature change—Elevations 5880 and 6000—October 9, 1963, to March 26, 1964.
Figure 7.—Arch stress change and concrete temperature change—Elevations 5595, 5670, and 5760—October 9, 1963, to March 26, 1964.
Figure 8. — Vertical stress change and concrete temperature change—October 9, 1963, to March 26, 1964.
changes of 190 psi, 200 psi, and 230 psi, at Blocks 9, 13, and 17, respectively. The trial-load analysis indicates stress changes of 190 psi, 175 psi, and 220 psi at the same locations. Stress changes indicated by the analytical study and the measured data are not in good agreement in some instances, particularly in the vertical elements.

The assumption of 100-percent restraint for the temperature correction of the vertical stresses from the trial-load analysis appears to be high for the points located in the interior of the dam. As may be noted in the figures, some of the meters were indicating erratic data.

Reservoir Water Level Fluctuation
Radial deflection changes for a variation in reservoir water level are shown in figure 9. Deflections from the trial-load study and measured deflections are compared at the plumbline locations.

Agreement between deflections for analytical results and measured data is very close. The maximum difference between computed and measured radial deflections is 0.07 inch. The comparison indicates the moduli of elasticity for concrete and abutment rock used in this analysis are approximately correct.

Table IV shows the measured and computed radial deflections at elevations 6047 and 6000. The maximum measured radial deflection is 0.74 inch and the maximum computed radial deflection is 0.69 inch.

The comparisons of tangential deflection changes are shown at plumbline locations in figure 9. Unlike the previous comparison of tangential deflections, the analytical results and measured data are very close. The maximum difference between the tangential deflections for the trial-load study and measured deflections is 0.06 inch.

Horizontal and vertical stress changes are shown in figures 10, 11, and 12. As for the previously discussed study, the stresses from the trial-load analysis were corrected for the variations of measured temperatures from the linear temperature gradients, assuming 100-percent restraint. A modulus of elasticity for concrete of $4.0 \times 10^6$ pounds per square inch was used because of the relatively short period over which temperature changes occur. The changes of measured temperatures and assumed linear temperature distributions are shown adjacent to the meter locations.

Horizontal arch stresses are shown at meter locations on the horizontal arch elements in figures 10 and 11.

The comparison between measured and computed arch stresses is good. At elevation 5670 near the downstream face, the measured data indicate stress changes of 80 psi and 130 psi at Blocks 17 and 9 respectively. The trial-load analysis indicates stress changes of 41 psi and 100 psi at the same locations. At elevation 5760, the measured arch stress changes vary from 260 psi increase to 20 psi decrease. The trial-load analysis indicated stress changes of 143 psi increase to 6 psi increase. At elevation 5880, measured arch stress changes vary from 290 psi to 20 psi. The trial-load analysis indicated stress changes of 245 psi to 69 psi.

Vertical cantilever stress changes are shown at the locations of meters on the vertical cantilever elements in figure 12. The comparison between analytical results and measured data is good. At elevation 5670 near the downstream face, the measured data show stress changes of 110 psi at Blocks 9 and 17. Trial-load results indicate stress changes of 94 psi at Block 9 and 65 psi at Block 17.

In general, the agreement between stress changes from the trial-load study and the measured data is not as close for this loading condition as it was for the seasonal temperature change. However, the longer period covered by this loading condition may allow the effect of concrete creep on stresses existing prior to October 9, 1963, to influence the stress changes indicated by the measured data. This effect was not included in the trial-load analysis.
Figure 9.—Deflection change at plumblines—March 26, 1964, to March 6, 1966.
Figure 10.—Arch stress change and concrete temperature change—Elevations 5880 and 6000—March 26, 1964, to March 6, 1966.

NOTES
Change in concrete temperature from March 26, 1964 to March 6, 1966, plotted below arch section.
C indicates arctic date.
Stress results from strain gage groups in section 1.13 and 2 plotted above arch section.
—T—Tethered analysis corrected for temperature variation.
Structural behavior study.
Figure 11.—Arch stress change and concrete temperature change—Elevations 5595, 5670, and 5760—March 26, 1964, to March 6, 1966.
Figure 12.—Vertical stress change and concrete temperature change—March 26, 1964, to March 6, 1966.
Conclusions

The following conclusions were reached as a result of the comparison of structural behavior data and the trial-load analyses for the two loading conditions:

1. The linear temperature variation assumed for the trial-load analyses gives excellent deflection agreement. The resulting linear stress distributions from the trial-load analyses must be corrected for the differences between linear temperature distributions and measured temperatures. The comparison indicates that the assumption of 100-percent restraint was reasonable for horizontal stresses but high for the correction of vertical stresses.

2. The excellent agreement between the trial-load radial deflections and measured radial deflections for both loading conditions indicates the ratio of the assumed moduli of elasticity for abutment rock to the modulus of elasticity for concrete was correct. The radial deflection agreement for the 2-year period indicates the sustained modulus of elasticity for concrete including the effect of concrete creep is correct.

3. Measured tangential deflections indicate greater movements than the trial-load analysis for October 9, 1963, to March 26, 1964. Tangential deflection agreement for the change between March 26, 1964, and March 6, 1966, is very good. Between October 9, 1963, and March 26, 1964, the dam deflected downstream for the first time. These results indicate inelastic behavior of the abutment rock during this period.

4. As shown in figures 5 and 9, seasonal temperature changes produce slightly greater deflections of Flaming Gorge Dam than the change of reservoir water surface from elevation 5932 to elevation 6000. The trial-load studies show 0.91 inch and 0.69 inch, respectively. Measured results show 0.88 inch and 0.74 inch.
Bibliography

1. Roehm, L. H., *Investigation of Temperature Stresses and Deflections in Flaming Gorge Dam*, a thesis submitted to the faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the Degree of Master of Science, Department of Civil Engineering, 1967. (See also Bureau of Reclamation Technical Memorandum 667, March 1967.)


Abstract

Efficacy of the trial-load method and reliability of assumptions used in the design and analysis of concrete arch dams can best be demonstrated by comparison of analytical results with deflections and stresses from structural behavior measurements for an actual dam. Instruments that indicate length change, temperature, and deflection were installed in Flaming Gorge Dam. Readings from these instruments were recorded at scheduled intervals. An electronic computer was used to reduce the data to stresses, temperatures, and deflections. Stress and deflection changes were determined for two incremental loadings. Changes from October 9, 1963 to March 26, 1964, show the effects of seasonal temperature variation. Reservoir water and tailwater levels remained essentially constant during this period. The changes from March 26, 1964 to March 6, 1966, are the effects of a rise in reservoir water level. Average concrete temperatures were approximately the same for both dates and the tailwater level remained constant over the entire period. Using an electronic computer, trial-load analyses were made for the same incremental loadings. Comparisons of stress changes and deflection changes for each loading increment are presented. Agreement between analytical studies by the trial-load method and structural behavior results is very close.


IDENTIFIERS—Flaming Gorge Dam, Utah/ Utah/ trial-load method.
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Trinity River Division Features of the Central Valley Project
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Report to
U. S. Department of the Interior
Bureau of Reclamation

Colorado River Storage Project
FLAMING GORGE DAM
DESIGN AND CONSTRUCTION PROBLEMS

by
Board of Consultants

Raymond E. Davis           John J. Hammond
John W. Vanderwilt         Edward B. Burwell, Jr.
Julian Hinds, Chairman

Dutch John, Utah           October 16, 1961
October 16, 1961

Mr. Grant Bloodgood
Assistant Commissioner & Chief Engineer
U. S. Bureau of Reclamation
Denver Federal Center
Denver 25, Colorado

Dear Mr. Bloodgood:

To begin the assignment outlined in your letter of August 25, 1961
the members of the Board of Consultants for Flaming Gorge Dam assembled
at Dutch John, Utah late Thursday afternoon October 12, 1961. The
following four days were devoted to field inspections and analysis of
information contained in the book of technical data, furnished by your
office, pertaining to the items listed on the sheet enclosed with your
letter and an additional item presented by Mr. O. L. Rice to the Board.

Several members of the Bureau staff assisted in the course of the work
by providing information and supplementing data requested by the Board.
They included among others:

O. L. Rice, Acting Chief Designing Engineer, Denver, Colorado
C. H. Carter, Assistant Regional Director, Region 4, Salt Lake
    City, Utah
E. R. Schultz, Head, Concrete Dams Section, Denver, Colorado
J. R. Walton, Project Construction Engineer, Flaming Gorge Unit,
    Dutch John, Utah
F. S. Dallon, Assistant Project Construction Engineer,  
Dutch John, Utah

W. A. Behling, Office Engineer, Dutch John, Utah

R. C. Borden, Chief, Civil Engineering Division, Dutch John, Utah

G. Wongwai, Project Geologist, Dutch John, Utah

S. J. Turley, Engineer, Head, Laboratory & Aggregate Plant Branch,  
Dutch John, Utah

After a short meeting with Mr. Walton, in his office, Thursday afternoon, it was decided to postpone briefing until Friday morning in favor of a quick trip to the dam site for general orientation and to observe the stage of construction.

Friday morning, October 13, the Board members convened in the Project Construction Engineer's office. Mr. Walton outlined the status of construction progress and Mr. Rice gave a brief resume of the design and related studies of the Flaming Gorge Dam project. The items of the work assignment were reviewed and original item two was subdivided for clarity making a total of eight items to be considered.

Following the briefing, the Board proceeded to the right abutment to inspect the location of the proposed concrete retaining wall designed
to buttress the overhang of the cliff and protect shale bed 6R from further weathering; to observe the cutoff concrete backfills along this shale bed in the abutment; and to study the parking area and switchyard where a grout curtain is planned. In the afternoon the Board inspected the cutoff drifts along shale bed 9R in the right abutment; observed mass concrete placement and compaction practices; and inspected the completed excavations and rock bolting for the thrust block and spillway intake structure.

On Saturday morning inspections were made of the aggregate processing plant, the recently placed concrete lining in the spillway outlet tunnel, and the rock formation exposed in the tunnel beyond the lined section. Also the powerplant structure was visited. Board member Davis also inspected the batching and mixing plant.

Sunday morning a cableway skip was provided for a close view and inspection of both abutments. The skip was slowly lowered or raised, close to each abutment and as requested stopped to allow for more detailed observation and discussion of the features being observed. Special attention was given to the right abutment, above shale bed 9R. These observations from the skip provided a far better perspective of rock structures in relation to the dam abutments than would have been possible had work been limited to inspections from the ground.
The balance of the time, Saturday afternoon, Sunday and Monday, October 14, 15 and 16, was devoted to discussion of features observed, review of technical data furnished by the Bureau, and in preparation of this report.

The eight items upon which the Board's views are presented, after the revision and addition referred to above are as follows:

1. Examine the completed foundations for the thrust block and the spillway intake structure and appraise their adequacy.

2. Examine the abutments of the dam and appraise their adequacy.

3. Examine the area upstream of the right abutment in the vicinity of the parking area and switchyard and comment on the adequacy of the proposed extended grout curtain.

4. Review the foundation treatment program for the dam and appraise its adequacy.

5. Review the results of the latest trial-load analysis of the dam.

6. Review concrete test results of interior mass concrete to date.
7. Comment on compaction practices for mass concrete.

8. Review temperature history of mass concrete placed during this construction season and comment on methods now being used for thermal control of concrete.
ITEM 1

Examine the completed foundations for the thrust block and the spillway intake structure and appraise their adequacy.

The Board considers the completed foundations for the left abutment thrust block and the spillway intake structure as satisfactory. The anchorage which has been installed to stabilize the upstream-dipping massive slabs of rock in the areas above and on the left side of the spillway intake should effectively overcome the tendency for these slabs to slide on the shale seams that underlie them. There still remains a mass of fractured rock, resting on a thin upstream dipping seam of shale, located in the canyon wall above and immediately downstream of the spillway gate structure. As a slide or large rock fall at this location would endanger the gate structure, it would be prudent to install some anchorage in the questionable mass.

ITEM 2

Examine the abutments of the dam and appraise their adequacy.

In its report of June 8, 1960 the Board made specific mention of the relatively thin mass of rock that will provide the arch support in the right abutment above shale bed 6R at approximate elevation 5945 and emphasized the importance of making a careful analysis to determine its stability under conditions of maximum loading including earthquake. Subsequently, the magnitude of the arch thrust on the abutment rock above shale bed 6R was reduced substantially by the omission of the
the grouting in the end joint above elevation 6000.

Unfortunately, because of the difficulty of obtaining suitable samples for testing, the values of shear strength for 6R and other thinner beds of shale that lie above 6R were not obtained. The stability analysis which was made was based on assumed values of cohesion and tangent $\phi$ for the shale in 6R of 500 psi and 0.8 respectively. The results gave a safety factor of 24 for the condition of failure up the dip of the shale and 32 for the condition of failure along a horizontal plane cutting both shale and sandstone. The values of cohesion and tangent $\phi$ used in the analysis are considered much too high. Therefore, the Board requested that an analysis be made assuming values of cohesion and tangent $\phi$ of 200 psi and 0.5 respectively. Such an analysis was made while the Board was at Dutch John and it was found that, for the condition of failure in the shale up-dip the factor of safety, neglecting side shear, is 10 and for failure on a horizontal plane 13. While the assumed values of cohesion and tangent $\phi$ suggested by the Board may be on the high side, taking into account the fractured condition of the rock, any reasonable reduction in these values would result in a safety factor substantially in excess of 4. Therefore the Board is of the opinion that the rock mass in question is capable of resisting the arch thrust.
The Board concurs in the Bureau's proposal to stabilize the overhanging cliff of sandstone above shale zone 6R downstream of the toe of the dam and to protect this shale from future weathering by the construction of a concrete retaining wall.

The remainder of the right abutment is generally satisfactory although the bench and high abrupt step that exists in the keyway excavation at shale bed 9R is very objectionable. This condition will induce cracking and should, in the opinion of the Board, be rectified by the placement of a plug or fillet of concrete, which would be cooled and then considered as a part of the arch foundation.

Generally good conditions also exist in the left abutment and the dimensions of rock mass downstream of the keyway are quite adequate at all elevations. There does exist, however, at elevation 5900 a bench and abrupt step in the foundation that should be treated in the same manner as suggested for the bench at shale bed R9 in the right abutment to improve the symmetry of the keyway and avoid objectionable cracking.
ITEM 3

Examine the area upstream of the right abutment in the vicinity of the parking area and switchyard and comment on the adequacy of the proposed extended grout curtain.

The proposed extension of the grout curtain beyond the right end of the dam to provide a barrier against the possibility of reservoir leakage through the narrow saddle of the Uinta formation adjacent to and upstream of the switchyard area meets with the Board’s approval. However, the curtain line in the narrow part of the ridge as now located is too close to the canyon rim and should be moved back to about the center-line of the ridge. While the Tertiary Browns Park formation which overlies the Uinta west of the narrow saddle appears to have a low permeability, the upper part of the Uinta in this area may have a relatively high permeability, taking into account its fractured condition and the fact that it has an unconformable contact with the Browns Park formation. Should this be found to be the case, as demonstrated by the grout takes along the proposed 300-foot extension of the curtain into the area overlain by the Browns Park formation, it may be found desirable to continue the curtain farther to the west to protect the switchyard. It may also be found necessary to grout to greater depths below the Browns Park-Uinta contact than now proposed.
ITEM 4

Review the foundation treatment program for the dam and appraise its adequacy.

The program of consolidation and curtain grouting outlined in the Book of Technical Data under the heading "Foundation Treatment" meets with the approval of the Board. In view of the fractured condition of the rock disclosed in the upper part of the keyways, the Bureau's proposal to deepen both the "A" hole grout curtain and the drainage curtain in the upper elevations of the abutments is considered desirable.

The depths of the shale cutoffs at the heel and toe of the dam are in accordance with those previously recommended by the Board and are considered satisfactory.
ITEM 5

Review the results of the latest trial-load analysis of the dam.

Trial-load analyses for Flaming Gorge Dam are shown in the data book for the following conditions:

(a) Asymmetrical structure, rock modulus of 2,000,000 psi, including earthquake forces, contours for actual excavation.

(b) Symmetrical structure, based on contours and data furnished the Consulting Board in June, 1960, with earthquake forces, rock modulus of 1,000,000 psi.

These duplicate analyses resulted from a suggestion by the Consulting Board, Dutch John, Utah, June 8, 1960 as follows:

"The Board desires to call attention to the fact that the value of the rock modulus of elasticity used in computing the arch stresses was 2,000,000 psi. Although this value was approved by the Board in its report of October 23, 1958, it is now of the opinion that this value is too high. In view of the conditions disclosed by the keyway excavations, the Board is of the opinion that the modulus of elasticity might well be as low as 1,000,000 psi."

This opinion of the Board was based on a belief that the considerable fracturing of the otherwise excellent rock at Flaming Gorge might cause yielding that would reduce the modulus below the values obtained in the laboratory.
After careful consideration Bureau personnel doubts the justification of lowering the design modulus to a value of 1,000,000 psi and favor retaining the original value of 2,000,000 psi. They have, however prepared stress computations for both these limits and have made other investigations of the effect of the reduced modulus on stresses.

These studies show that changing the design modulus from 2,000,000 psi to 1,000,000 psi would affect the computed stresses as follows:

(a) The computed principal stresses at the downstream abutment would be lowered, which is favorable, but not important, as values for both moduli are within safe limits.

(b) The computed upstream principal abutment stresses would be slightly increased, eliminating the small tensile stresses found for the 2,000,000 psi modulus. This is favorable but unimportant, as these computed stresses are safe in either case.

(c) The computed concrete stresses in the arch would be somewhat increased, but still within allowable limits.

Since all computed stresses for either assumption are within safe limits it is unimportant whether the computed stresses are based on a modulus of 1,000,000 psi or 2,000,000 psi, or some intermediate value. The safety factors of the structure cover this possible variation in modulus.

Consequently, the Board approves the adequacy of the design as shown by the two trial-load analyses presented.
ITEM 6

Review concrete test results of interior mass concrete to date.

The statements which follow are based upon consideration of (1) the section entitled "Summary of Strength Data for Concrete Containing 6-inch Maximum Size Aggregate, Flaming Gorge Dam and Powerplant", as given in the Book of Technical Data for Use of Board of Consultants, Flaming Gorge Dam, September 15, 1961; (2) inspection of aggregate processing plant and batching and mixing plant, and examination of stock piles at these two locations; (3) observation of the operations of mixing, placing, and compacting interior and exterior mass concrete; (4) review of test records and monthly reports of the U.S.B.R. Concrete Division at Flaming Gorge; and (5) statements by members of the U.S.B.R. personnel at Flaming Gorge.

There is presently being employed an interior mass concrete mix containing 188 pounds of cement and 85 pounds of pozzolan. The sand-aggregate ratio is 21 percent and cobbles are being employed in the amount of 30 percent of the total coarse aggregate. This mix was first suggested in a letter from the Assistant Commissioner and Chief Engineer dated March 27, 1961. Until recently there has been employed a mix containing 188 pounds of cement and 94 pounds of pozzolan per cubic yard. For this mix the sand-aggregate ratio was 20 percent and the cobble content of the coarse aggregate was about 30 percent.
The average 28-day compressive strength of 6- by 12-inch wet screened test cylinders for the interior mass mix earlier employed was 3280 psi. Based on the 180-day compressive strength of 18- by 36-inch mass cured cylinders, it was computed that an average 28-day strength of wet screened 6- by 12-inch cylinders of 3215 psi would be required to assure a 1-year mass concrete compressive strength of 4000 psi which was assumed in design. From these data a reduction in the pozzolan content from 94 to 85 pounds per cubic yard appears to have been justified though as yet the number of 28-day test results on the new mix is insufficient to justify drawing conclusions in this regard. From the study of records and information obtained from U.S.B.R. personnel, it appears that for the interior mass mix and with materials presently being supplied to the batch plant, no further reduction in cement or pozzolan is possible.

While in general the coefficient of variation of 28-day compressive strengths of 6- by 12-inch cylinders has been in the order of 12 percent, at times this coefficient has been substantially greater and at other times substantially less than this figure. In attempting to learn the reasons for undesirably large values of the coefficient of variation, the records reveals that at times the variation in moisture content of the sand as batched has been much greater than those permitted by specifications, which provide that the maximum abrupt change shall
not exceed 0.5 percentile point and that during any period of four hours the maximum moisture variation shall not exceed 1.0 percentile point. The August 1961 monthly report of the Concrete Division at Flaming Gorge states:

"Sudden changes in the moisture content of the sand entering the mixing plant has been the greatest problem in concrete manufacture. Variations of 3 percent in sand moisture during the time required to mix 24 cubic yards of concrete were not uncommon."

Again in the September, 1961 monthly report it is stated:

"The sudden change in sand moisture content have continued with little sign of improvement."

No factor in concreting operations contributes more to lack of quality control than sudden changes in moisture content of the sand. The Board believes that before the next construction season the contractor should be required to remedy this condition.

One other condition is also believed to be a major contributor to lack of uniformity in concrete strengths. In the final screening plant above the batching bins wet screening is employed. This results in a large quantity of water in the coarse aggregate sizes as deposited in the batching bins. More particularly this is true in the No. 4 to 3/4-inch and 3/4- to 1 1/2-inch sizes. This condition contributes to lack of proper control of the mixing water requirement. The Board believes that the improvement in concrete quality that would be brought about by performing the final washing operation
at the ground level (perhaps in a location near the bottom of the conveyor leading to the batching plant), so that coarse aggregate in the No. 4 to 3/4-inch and the 3/4- to 1 1/2-inch sizes would be well drained before deposition of the batching bins, justifies giving careful consideration to changes in the present final screening operation before the next construction season.

Based on the experiences of this past summer, when the temperature of mass concrete as placed in the dam at times was in excess of 70°F, and in some locations after placement the temperatures during hardening were in excess of 100°F, it seems obvious that every possible means should be exercised to reduce the cement and pozzolan content of the interior mass mix to a minimum consistent with producing a concrete which at the later ages will provide a strength equal to that assumed in design. After having observed the favorable affects of employing a water reducing admixture at Glen Canyon, including a reduction in cement and pozzolan content of the interior mass mix, the Board is of the opinion that the Bureau, if it has not already done so, should conduct such investigations as are necessary to determine if similar favorable effects might not be achieved through the use of an approved water reducing admixture in concrete at Flaming Gorge. If results were favorable, the Board would approve the use of a water reducing admixture and a reduction in cement and pozzolan content of the interior mass mix as it has already done in its October 11 report on DESIGN AND CONSTRUCTION PROBLEMS OF GLEN CANYON DAM.
Judged by observations of the concrete placing operations at both Glen Canyon and Flaming Gorge, the use of a proper water reducing agent at Glen Canyon has greatly improved the workability of mass concrete. At Glen Canyon where there was used a water reducing admixture of the lignin type, interior mass concrete of 2-inch slump delivered to the work in 12-cubic-yard buckets was compacted very completely by 3 one-man vibrators at the rate of 80 to 100 cubic yards per vibrator man-hour. In fact, the time required by 3 vibrator men to compact 12 cubic yards on the average was not more than 2 minutes, the vibrator men being idle the remainder of the period between concrete deliveries to the work. On the other hand, at Flaming Gorge, while the concrete was of a satisfactory workability as judged by the usual standards, four vibrator men using one-man vibrators are required to compact interior mass concrete delivered in 8-cubic-yard buckets at a rate of 40 to 50 cubic yards per vibrator man-hour, and the vibrators are usually being operated during the entire time between concrete deliveries. While ease of placement and compaction in the case of Flaming Gorge may not be of importance to the Bureau, it certainly is of importance in the matter of labor costs to the contractor.

The Board wishes to express its hearty approval of the excellence of the processing plant for fine and coarse aggregate. The heavy media
separation plant, judged by records and statements of Bureau personnel is being operated in a highly efficient manner so as to provide beneficiated aggregate in sizes No. 8 to 1\(\frac{1}{2}\)-inch for which the content of particles of specific gravity lower than 2.5 is on the average much less than the 2 percent permitted by the specifications. The sand and coarse aggregate in each of the 4 sizes was in general well graded, meeting specification requirements. At times, however, the breakage in handling the coarse aggregate has been excessively high.
ITEM 7

Comments on compaction practices for mass concrete. During the time of the Board's visit to the work, mass concrete in the dam was being transported by 8-cubic yard bucket and was being placed by a crew of 7 men (sometimes 8 men), 4 of whom were using one-man Malin vibrators. The concrete was of approximate 2-inch slump and by the usual standards was regarded as of satisfactory workability. Normally the four vibrator men were working during the entire time from the discharge of one bucket to the arrival of the next. Sometimes a fifth vibrator man was employed in topping out the lift. The one-man vibrators were being operated in an efficient manner and it seemed evident that the compaction was thorough, though as compared with Glen Canyon mass concrete, the labor required to bring about thorough compaction was much greater. The rate of placement (40 to 50 cubic yards per vibrator man-hour) was considered by the Board to be about normal for this type of construction. The specifications require that 2-man vibrators be used. In the opinion of the Board, there is no good reason why this requirement should be enforced if Malin vibrators are employed.

Bureau personnel have at times expressed interest in the possibility of using very dry mass mixes such as have been employed on a number of jobs in Europe and in Japan. Batches are spread by a small
bulldozer and compaction is by a gang vibrator mounted on a small
caterpillar tractor. In the opinion of the members of the Board who
have witnessed this operation, the compaction achieved with such
equipment and such dry mixes is likely to be less thorough than that
obtained in Bureau work where manually operated vibrators are employed
to compact air-entrained mass concrete of about 2-inch slump. The
Board is of the opinion that generally the present practices of the
Bureau not only lead to more complete compaction, but to lower overall
costs than would be the case for very dry mixes of much larger cement
content such as have been placed and compacted by bulldozer and gang
vibrator in some countries abroad.
ITEM 8

Review temperature history of mass concrete placed during this construction season and comment on methods now being used for thermal control of concrete.

Temperature records of the current construction season indicate that when the temperature of fresh concrete was in the order of 70 to 75°F, and though cooling was started immediately, the maximum temperature of concrete during the hardening period at a number of locations was in excess of 100°F and in one location a temperature of 113°F was reached. The specifications permit a minimum placing temperature of 80°F. There were periods when the temperatures of the river water used for cooling during the first 12 days was in excess of 70°F, which records for the years 1959-61 indicate as being not unusual. The high temperature of the water used for cooling appears to be a major contributing factor to the undesirably high temperatures of concrete during the hardening period.

Another condition which contributed to high temperatures during the hardening period was the excessive thickness of the exterior or face concrete. The specifications provide that this concrete at both the upstream and downstream faces be not less than 5 feet and no more than 10 feet thick. During the first few months of the current construction season, it appears that generally the maximum permissible thickness of 10 feet was greatly exceeded and in some cases extended from the face into the mass as much as 40 feet. The exterior mass concrete at the downstream face contained $3\frac{1}{2}$ sacks of portland cement per cubic
yard and the exterior concrete at the upstream face contained three sacks of cement plus one sack of pozzolan per cubic yard. The interior mass concrete mix contained only two sacks of portland cement and one sack of pozzolan per cubic yard. The reason for the very high temperature rises (a maximum of 40° F in one location and more than 30° F in a number of locations) is obvious.

Specifications require that prior to grouting contraction joints the concrete mass within each grouting lift be cooled to a low temperature of 38° F through the use of river water during the winter season when its temperature will be nearly freezing. This would mean a decrease in temperature, from the maximum values observed in various locations in the concrete placed during the 1961 construction season, of 45° to 60° F. Where there is restraint as along the foundations and abutments it seems certain that any such decrease in temperatures would be accompanied by cracking and in some of the blocks this cracking would probably cause stresses under waterload that would be considerably different from those assumed in design.

For reasons just discussed, it appears desirable that the minimum cooling temperatures at and near foundation rock should be considerably greater than the specified minimum of 38° F assumed in design. Before the concrete placed during the current construction season is cooled and grouted a study should be made to determine for several degrees of cooling and cooling patterns in areas adjacent to the foundations, the stresses
within the dam after waterload is applied. On the basis of such studies a program of cooling that would be favorable to minimum cracking tendency and at the same time prevent stresses within the dam from becoming excessively high under waterload, should be undertaken.

Concerning concrete to be placed during 1962 construction season, the Board recommends that studies be made to determine the feasibility of cooling both the mixing water and the cooling water by artificial means during periods of peak river water temperatures so that maximum temperature of fresh concrete as placed will not exceed about 65° F, and the maximum temperature of cooling water will not exceed about 60° F. Perhaps this could be done economically through the use of a cooling tower if during the hot weather the humidities are sufficiently low.

In an earlier report it was suggested that some beneficial cooling might be achieved through evaporation by sprinkling or fog spraying stockpiles. To determine what might be the effect, comprehensive trials were carried out at Flaming Gorge using various combinations of sprinkling and fog spraying of stockpiles at the aggregate plant and of surge piles of aggregate at the batching plant. The results show no appreciable lowering of temperatures and the reason is obvious. Due to cooling during the processing operation, followed by the evaporation of moisture in the stockpiles, the temperatures of the
aggregates in stock piles are naturally as low as can be obtained by evaporation and any extra water spraying does no good. During periods of hot weather observations reveal that temperatures of aggregate in stock piles are usually somewhat less than the temperatures of river water.

While it does not seem desirable that the cement content of exposed concrete should be less than that being employed, the Board believes that effort should be directed toward keeping the thickness of face concrete to be placed during the 1962 construction season to as nearly specified minimum of 5 feet as possible; and certainly the maximum of 10 feet should not be exceeded. As a matter of fact, only a thin shell of the richer exposed concrete is necessary to provide adequate protection against freezing and thawing and if it could be done so economically, considering the lesser heat of hydration of the mass as a whole, a minimum thickness of two feet would be more desirable than the minimum thickness of 5 feet presently specified. For the interior mass concrete the Board would look with favor upon a reduction in cement and pozzolan below that presently employed, as may be possible through the use of a water reducing agent, provided the concrete strengths with the lowered cement content were adequate. Under Item 6 the possibility of a modest reduction through the use of a water reducing admixture as has been done in Glen Canyon was discussed.
In any case, the Board believes that appropriate steps should be
taken to insure placing temperatures and maximum hardening temper-
atures of concrete placed during the 1962 construction season well
below the peak temperatures of concrete placed during the current
season.

Respectfully submitted,

Raymond E. Davis

John J. Hammond

John W. Vanderwilt

Edward B. Durwell, Jr.

Julian Hinds, Chairman

APPROVED: OCT 20 1961
(date)

Assistant Commissioner

and Chief Engineer
FLAMING GORGE DAM

Colorado River Storage Project

BUREAU OF RECLAMATION
REGION 4
FLAMING GORGE STORAGE UNIT

The Flaming Gorge Unit on the Green River in Utah and Wyoming is one of the four storage units now authorized for construction in the Upper Colorado River Basin. The Storage Unit includes the Flaming Gorge Dam, Reservoir, and powerplant.

Flaming Gorge Dam will be a concrete arch dam rising about 490 feet above bedrock. The cover photograph shows the artist’s view of what the dam will look like when completed.

The reservoir will extend upstream for 91 miles to within a few miles of the city of Green River, Wyoming. When filled to the maximum normal water surface elevation of 6040 feet, the reservoir will store nearly 3,800,000 acre-feet of water. (1 acre-foot = 325,851 gallons, or enough water to cover 1 acre of land 1 foot deep.)

The powerplant at the foot of the dam will accommodate three generating units. The installed capacity of each unit will be 36,000 kilowatts, or a total of 108,000 kw, for the powerplant. As a rough indication, the Flaming Gorge powerplant would produce enough energy to supply the needs of an average American city of 180,000 population.

UPPER COLORADO RIVER DEVELOPMENT

A basinwide program for development and use of the water resources of the Upper Colorado River was authorized by the Congress in 1956. Initially authorized for construction are four storage units and 11 participating projects. Additional storage units and participating projects are planned for later development.

Two basic functions will be performed by the storage units. First, by providing storage capacity on the Colorado River and major tributaries, control and regulation of stream flows will be achieved. The 35 million acre-feet of capacity in the initial storage units will permit releases each year to meet downstream rights to Colorado River water in the Lower Colorado River Basin. With this ability to meet downstream rights, even in years of lowest run-off, increased beneficial consumptive use of water is possible on the participating projects in the Upper Basin.

And second, revenues from the sale of hydroelectric power produced at the storage dams not only will return the costs of the storage units, but also will help to repay the construction costs of the participating projects. Power produced by the storage units is needed to help meet the pyramiding demands for power in the states of the Intermountain West.

Direct uses — beneficial uses which consume water — will be made of Colorado River waters on the participating projects to be built. These uses include irrigation of farm land, and supply of water for growing cities and industries.

On the 11 participating projects authorized for construction, supplemental water will be supplied for about 230,000 acres of irrigated land which suffer from shortage of water and restricted crop production. A full water supply will be provided for about 130,000 acres of new land. About 49,000 acre-feet of water will be made available for municipal and industrial uses.
LOCATION

Flaming Gorge Dam site is located on the Green River in northeastern Utah about 6 miles south of the Utah-Wyoming State line. The nearest towns are Green River and Rock Springs, Wyoming, and Vernal, Utah. The railhead for Flaming Gorge Dam is at Green River, Wyo. — 60 miles from the dam site.

The 490-foot concrete arch dam will be built in the canyon cut by the Green River into the north flanks of the beautiful Uinta Mountains. At Red Canyon, the gorge of the Green River is more than 1500 feet deep. Pine forests, cold mountain trout streams, and abundant wildlife are found in the vicinity of the dam and lower portion of the reservoir.

With proper development, the reservoir and surrounding areas will become a major recreational area attracting visitors from all states of the Nation.

DISTANCES TO FLAMING GORGE DAM FROM:

- Green River, Wyoming ............................................. 60 miles
- Rock Springs, Wyoming ........................................... 75 miles
- Vernal, Utah (via Manila, Utah) .................................. 89 miles
- Salt Lake City, Utah (via U. S. 40) ............................. 264 miles
- Salt Lake City, Utah (via U. S. 30) ............................. 234 miles
- Cheyenne, Wyoming (via U. S. 30) ............................. 346 miles
- Denver, Colorado (via U. S. 40) ............................... 424 miles

ACCESS ROADS

Paved State Highway 530 extends south from Green River, Wyo., to Linwood and Manila in Utah. An excellent Forest Service highway reaches north from Vernal for 30 miles. From this point, a dirt and gravel road, easily traveled in good weather, crosses the Uinta Mountains and turns west to Sheep Creek and Manila. The road is highly scenic and may be improved in the near future.

The Bureau of Reclamation has built a temporary 17-mile access road to the new town of Dutch John, Utah, located 2 miles from the dam site. Part of this road will be flooded when the reservoir fills. It is expected that the states of Utah and Wyoming will cooperate in building a permanent highway which will cross the Green River on the crest of Flaming Gorge Dam.
Flaming Gorge Dam will be an arch-type concrete dam. It will rise about 490 feet above bedrock, and the crest will be 445 feet above the present river level. The crest of the dam will be a sweeping curve 1180 feet long between the rock abutments which are about 1000 feet apart on a straight line. The elevation of the top of the dam will be 6047 feet. A two-lane roadway will cross the top of the dam.

The concrete of the dam will be about 150 feet thick at the base and taper to a minimum thickness of 20 feet about 5 feet below the 27-foot roadway on the crest.

A single concrete-lined diversion tunnel will carry the flow of Green River round the damsite during construction. The tunnel, which will be about 1100 feet long and 23 feet in diameter, will be drilled through the right abutment. (Left and right are directions determined as you face downstream.) The diversion tunnel will carry up to 18,000 cubic feet of water per second.

The dam will be built upward from bedrock by placing a series of concrete blocks. These blocks will be 50 feet wide, about 5 feet high, each extending from the upstream face to the downstream face.

A tunnel-type spillway will be drilled through the left abutment. Gates high on the abutment will control the flow of water into the spillway tunnel. The tunnel will slope abruptly downward at a 55 degree angle and become horizontal at river level. The diameter of the spillway tunnel will vary from 26½ to 18 feet.

Water for the three generating units will be carried in steel tubes embedded in the concrete of the dam. These tubes are called penstocks. They will be 10 feet in diameter. One penstock will be placed for each of the generator turbines.

The 36,000 kw. generators will be of the vertical type and turned directly by a shaft connected to the Francis type turbines (waterwheels).

Trashracks will be placed on the upstream face of the dam to prevent debris from entering the penstocks and damaging the turbines.

Two outlet tubes will be embedded in the concrete of the dam to release water from the reservoir which is not needed for the operation of the generating units. (The diversion tunnel will be plugged and not used after construction of the dam.) These outlet tubes will be 6 feet in diameter. Flow of water through the outlet tubes will be controlled by hollow jet valves at the downstream ends of the outlet tubes.

About 5 years will be required to complete construction of the dam and powerplant.
PHYSICAL DATA—FLAMING GORGE STORAGE UNIT

DAM:
Type: arch-type concrete
Height above river bed: 450 ft.
Height above lowest point in foundation: 490 ft.
Crest length: 1,180 ft.
Crest width (width of roadway): 27 ft.
Crest elevation: 6,047 ft.
Base width: about 150 ft.
Volume of concrete in dam: 922,000 cu. yds.
Maximum spillway discharge: 29,000 cu. ft./sec.

RESERVOIR:
Capacity: 3,800,000 ac. ft.
Area: 66 sq. mi.
Length: 91 mi.
Maximum normal water surface elevation: 6,040 ft.

POWERPLANT:
Capacity: 108,000 kw.
Number of units: 3
Capacity of each generator: 36,000 kw.
Capacity of each turbine: 50,000 hp.
Collection title:
   Papers of Robert E. Glover

Collection code:
   WREG

Description of item(s) separated:
   1 black-and-white 8x10 photo of Flaming Gorge Dam

Old location:
   Series II, Colorado River Storage Project

New location:
   Photograph series

Name of processor: [Handwritten]

Date: [Handwritten]
COMPARISON OF ANALYTICAL AND STRUCTURAL BEHAVIOR RESULTS FOR MORROW POINT DAM

Milton A. Kramer
Keith Jones
Engineering and Research Center
Bureau of Reclamation

March 1972
COMPARISON OF ANALYTICAL AND STRUCTURAL BEHAVIOR RESULTS FOR MORROW POINT DAM

by
Milton A. Kramer
Keith Jones

March 1972
ACKNOWLEDGMENT

Analytical results are from studies conducted by Milton A. Kramer.

Carl W. Jones and Fred Dockhorn assisted in the preparation of data for the analytical studies.

Structural behavior results are from a comprehensive study by Keith Jones and Richard M. Griffith. Others who contributed to the behavior measurement program are Joe T. Richardson, J. A. Stables, and D. J. Helstrom.

Drawings of deflection and stress comparisons were prepared by Fred Dockhorn.

This report was prepared under the general direction of L. M. Christiansen and G. C. Rouse.

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INTRODUCTION

Comparisons of results from analytical studies and structural behavior measurements due to four different loading condition changes on Morrow Point Dam are presented in this report. Computed stress and deflection changes are compared with the results from measured data.

Morrow Point Dam is a thin double-curvature concrete arch structure with an axial radius of 375 feet (H). The height of the dam above the lowest foundation excavation is about 465 ft. The crest length is approximately 780 ft. A plan, profile, and sections for Morrow Point Dam are shown in Figure 1. The dam, a feature of the Colorado River Storage Project, is on the Gunnison River near Cimarron in the southwestern part of Colorado.

Comparisons of measured and analytical results of these studies for Morrow Point Dam provide the first opportunities to demonstrate the effectiveness of the Arch Dam Stress Analysis System (ADAS) for the study of double-curvature arch dams. Several earlier comparison studies demonstrate the effectiveness of the method for dams having less complicated geometrical configurations.

The first loading condition to be studied was the reservoir water loading. The period from January 24, 1969, with the reservoir empty, to February 2, 1969, with the reservoir water level at approximately elevation (el) 7150, was selected for this study. Although the reservoir water level had reached the higher elevation earlier, the February 2, 1969 date was selected to eliminate, as nearly as possible, the effects of the seasonal temperature fluctuations. The tailwater level was raised from el 6700 to el 6750 during this same period.

In addition to the reservoir loading, Morrow Point Dam will be subjected to daily and seasonal temperature cycles throughout its useful life. The period from February 2 to July 25, 1969, was selected for the study of seasonal temperature change. The reservoir water and tailwater levels remained nearly constant for the entire period; thus, the changes in deflections and stresses were due almost entirely to the temperature change. This study presents an opportunity to compare the computed effects of the temperature change with the measured effects.

Significant disagreements between measured and computed deflections were found in each of the two comparison studies during the first loading cycle for the dam. The nature of the disagreements for both radial and tangential deflections indicates that the abutment movements which occurred were larger than those computed in the analytical studies. Investigation of geological studies indicates that these differences may be due to inelastic foundation movements. The closure of joints in the rock during this initial loading period could produce sufficient deformation of the foundation to cause the disagreement. Two similar loading condition changes which occurred during the second loading cycle were selected for additional studies.

These studies were made to determine to what extent the foundation deformations were increased by the inelastic behavior and whether these movements have continued after the first load cycle.

The period from January 5 to November 23, 1970, was selected to study the rise in reservoir water level from el 7020 to el 7160. The concrete temperatures for both dates were approximately the same. September 1 to November 23, 1970, was selected as the loading period for the seasonal temperature fluctuation. The reservoir water level remained nearly constant during the study period, changing from el 7157 to el 7160.

DATA FOR ANALYSIS

Data used in the analytical studies for Morrow Point Dam are listed below.

a. Top of dam, el 7165.

b. Base of maximum section, el 6700.

c. Reservoir water surface increased from el 6700 to el 7150 during the period between January 24, 1969, and February 2, 1969.

d. Reservoir water surface remained nearly constant at el 7150 from February 2 to July 25, 1969.

e. Reservoir water surface increased from el 7020 on January 5, 1970, to el 7157 before September 1, 1970.

f. Reservoir water surface increased from el 7157 to el 7180 between September 1 and November 23, 1970.

*Numbers designate references cited in the "Bibliography" at the end of this report.
g. Tailwater level increased from el 6700 to el 6750 between January 24, 1968, and February 2, 1969.

h. Tailwater level remained constant at el 6750 for all other study periods.

i. Unit weight of concrete, 148.5 pounds per cubic foot (pcf).

j. Unit weight of water, 62.5 pcf.

k. Coefficient of thermal expansion for concrete, $4.0 \times 10^{-6}$ per degree Fahrenheit.

l. Modulus of elasticity for concrete, 6.25 x $10^6$ pounds per square inch (psi) for January 24, 1968.

m. Sustained modulus of elasticity for concrete for all other dates assumed to be 4.3 x $10^6$ psi, Table 1.

n. Modulus of deformation for foundation rock varies by elevation as listed in Table 2.

o. Poisson's ratio for concrete and foundation rock, 0.20.

p. Concrete temperatures recorded at the time of contraction joint grouting were used to determine temperature loads.

q. Contraction joints which remained ungrouted above el 7100 through January 24, 1968, were grouted to el 7165 (top of the dam) before February 2, 1969.

Table 1

<table>
<thead>
<tr>
<th>Age of concrete * (days)</th>
<th>Time under load (days)</th>
<th>Modulus of elasticity x $10^6$ psi</th>
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<tbody>
<tr>
<td>365</td>
<td>0</td>
<td>6.25</td>
</tr>
<tr>
<td>370</td>
<td>5</td>
<td>5.26</td>
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<td>381</td>
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<td>181</td>
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<td>666</td>
<td>301</td>
<td>4.35</td>
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<tr>
<td>742</td>
<td>377</td>
<td>4.17</td>
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*Age of concrete at time of initial loading was 1 year.

Table 2

<table>
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<tr>
<th>Elevation</th>
<th>Left abutment</th>
<th>Right abutment</th>
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<tbody>
<tr>
<td>7165</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>7100</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>7040</td>
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<tr>
<td>6980</td>
<td>1.8</td>
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<td>6865</td>
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<tr>
<td>6800</td>
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</tr>
<tr>
<td>6750</td>
<td>1.8</td>
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<td>6730</td>
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<td>1.5</td>
</tr>
<tr>
<td>6710</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6700</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Values are based on data obtained from Morrow Point Dam and Powerplant foundation investigations.

r. Temperature change loads are differences between grouting temperatures and temperatures recorded for each of the dates selected.

**ANALYTICAL STUDIES**

The ADSAS is the computerized version of the trial-load method of analysis. The analytical method assumes that the dam is divided into a system of horizontal elements and a system of vertical elements. Each system occupies the entire volume of the dam and is independent of the other. The loads applied to the dam are divided between these systems in such a way as to attain geometrical continuity throughout. Three displacements and three rotations may be brought into agreement in steps called adjustments. Radial deflections of the elements are brought into agreement in radial adjustments. Tangential adjustments account for tangential deflections and may include vertical displacements and rotations about a radius. Rotations about the tangential and vertical axes are accounted for in a twist adjustment. The effects of vertical displacements and rotations about the extrados radius are usually found to be small and were not included in these studies.

Tangential and rotational agreements are obtained by introducing internal self-balancing tangential and twist loads at points common to the horizontal and vertical elements. The effects of foundation movements caused...
by the loaded dam are included. The distribution of loads is obtained from the solution of a set of simultaneous equations for each adjustment to maintain geometrical continuity at all node points (intersection of horizontal and vertical elements).

The analysis system is limited to a linear temperature variation from the upstream face to the downstream face. The measured temperatures, which rarely vary linearly, must, therefore, be represented by assumed equivalent linear temperature gradients. Stresses in analysis are then corrected for the variation of measured temperatures from the assumed gradients.

AODAS was used to perform analytical studies of Morrow Point Dam for loading conditions which existed on each of the selected dates. Stresses and deflections were determined for total water load as the difference between values for January 24, 1968, when the reservoir was empty and values for February 2, 1969, when the reservoir had increased to el 7180. The change of tailwater level was from the base of the dam to the normal tailwater level. The results represent the effect of the water load on the dam since the small variations in concrete temperatures are due primarily to the effects of the increased water levels.

Stresses and deflections caused by seasonal temperature fluctuations were determined by taking the differences from February 2 to July 25, 1969. Reservoir water level and tailwater level remained approximately constant throughout this period. Two additional loading conditions were analyzed in the same manner. During the first of these, for the loading change from January 5 to November 23, 1970, the reservoir water level increased from el 7200 to el 7180. Essentially the same stresses existed for both dates.

The second loading condition in this comparison was the temperature fluctuation for the period from September 1 to November 23, 1970. The loading change was approximately equal to the seasonal temperature fluctuation with a nearly constant water level (varying from el 7157 to el 7180). The tailwater level remained constant during this period.

**INSTRUMENTATION**

To study the effects of loads, instruments of various types have been installed in concrete dams. Results from some of these studies are available.

Morrow Point Dam has been instrumented to provide structural behavior information. Field measurements at Morrow Point Dam were made using 11 types of structural behavior installations: strain meters, stress meters, joint meters, resistance thermometers, pore pressure cells, deformation meters, tape gages, plumblines, foundation deformation observation wells, collimation and triangulation systems.

**Locations of Instruments**

The instruments embedded in Morrow Point Dam are: 972 strain meters, 14 stress meters, 73 joint meters, 24 pore pressure cells, 4 deformation meters, 22 thermometers, and 3 invar-type tape gages. Locations of the instrumentation are shown in Figures 2 and 3.

Strain meters in groups of 12 meters are embedded at several elevations in eight cantilever elements located in Blocks 2, 3, 4, 6, 10, 14, 16, and 17, respectively.

Figure 4 shows 11 strain meters attached to a "spider," or holding fixture, ready to be embedded as a cluster in concrete. The twelfth strain meter will be installed vertically, adjacent to the cluster to complete the group of 12 meters.

"No-stress" strain meters used to measure autogeneous change of the concrete are also located at six elevations in the crown cantilever element, Block 10. Thermometers are installed in a lattice pattern in Block 10. The spacing is 30 ft vertically by about 20 ft horizontally.

At el 6717.5 and el 6927.5 in Block 10, 3 strain-meter groups are embedded near the radial joints bounding the block, as shown in Figure 2. At el 7152.5, 21 stress meters are embedded in radial planes perpendicular to the axial direction, 3 meters each in Blocks 2, 6, 10, 14, and 17.

Joint meters are embedded across contraction joints at all elevations and on joints adjacent to blocks where strain meters or stress meters are located. At each of these locations, two joint meters are installed across each joint. Deformation meters are installed normal to the dam's abutments at el 6920.0. The meters, two on each abutment, extend to depths of 30 ft and 60 ft in the rock. The three-invar-type tape gages are installed in wells 30 ft, 60 ft, and 90 ft deep in the base of Block 9.

Four systems for measuring deflections are provided. The first consists of three plumblines located in 12-inch-diameter wells extending from the top of the dam to near the foundation in Blocks 6, 10, and 14, as shown in Figure 2. The plumblines are suspended by floats in liquid-filled tanks beneath the roadway of the dam. Plumbline deflections are obtained using a peep sight attached to a micrometer slide. The position of the plumbline is obtained with respect to a reference target. Readings are taken in the radial and axial directions at each reading station on each of the three plumblines. Readings are made to the nearest 0.001 inch (in.). The second system consists of a grid of 42 targets located on the downstream face of the dam. Triangulation measurements are made on the targets from four theodolite piers. The third system consists of three collimation stations on the parapet of the dam in the same blocks as the plumblines. Measurements between each station and a tangent line which extends from an instrument pier on the right of the dam to reference targets on the left of the dam are made periodically. The fourth system consists of observation wells which extend into the foundation at the base of each plumbline. Optical plummet observations on a target at the bottom of each well are made to determine the amount of horizontal movement at the observation elevation.

**Reading of Instruments**

Readings from strain meters, stress meters, joint meters, pore pressure meters, deformation meters, and thermometers were taken immediately following their embedding and were continued on an increasing time interval until readings were taken biweekly. Plumbline readings and collimation readings were begun in January 1968 and were taken weekly. Observation well and tape gage readings were taken monthly. Triangulation measurements which were begun in October 1967, were made at approximately 3-month intervals and include the high and low annual temperature periods. During the period of this study, records from all instrumentation were obtained on the indicated schedules.

At each scheduled reading of the embedded meters, a test set which is basically a Wheatstone bridge, was used to obtain values of resistance ratio, reverse ratio, and resistance sum for two coils of prestressed steel wire in each strain meter, stress meter, joint meter,
Figure 3. Structural behavior instruments, Block 10.

Figure 4. Orientation of meters in strain meter group. Photo 622-420-09870.

Table 3

<table>
<thead>
<tr>
<th>Concrete age at loading (days)</th>
<th>Modulus of elasticity x 10^6 psi at loading time</th>
<th>Creep strain x 10^-6 for 300 days</th>
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<tr>
<td>4</td>
<td>4.76</td>
<td>0.21</td>
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<tr>
<td>7</td>
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<td>(*)</td>
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<td>90</td>
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<td>0.07</td>
</tr>
<tr>
<td>730</td>
<td>6.85</td>
<td>(*)</td>
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*pCreep data erratic.

**No creep test for this age concrete.

A computer program was available for computing the "best fit" creep surface using the elastic and creep data from laboratory tests. The equation expresses the laboratory data in a form which can be used by the computer to calculate stress from strain meter data.

Bureau laboratory tests indicated a Poisson's ratio of approximately 0.20 and a temperature coefficient of approximately 4.0 x 10^-6 per degree Fahrenheit for Morrow Point Dam concrete.

**COMPARISON OF MEASURED AND ANALYTICAL RESULTS**

Comparisons of deflections at plumbline locations and stresses at meter locations were made for four different load changes during the first and second loading cycles for Morrow Point Dam. The measured data are shown on the figures as solid lines and the analytical results as dashed lines. Discussion of these comparison studies follows.

**Initial Reservoir Loading**

Radial deflection changes caused by the initial filling of the reservoir from the base at el 6700 on January 24, 1968, to about el 7145 on February 2, 1969, are shown in Figure 5. Measured radial deflections are much larger than the computed values at Blocks 6 and 10 even though the comparison at Block 14 is close. The maximum difference between measured and computed radial deflections for this loading change is 0.476 in. This lack of agreement indicates movement of the foundation rock in the left abutment and...
resulting deformations of the arch which are not accounted for in the computed values. A comparison of measured and computed radial deflections are listed for el 7152.5 and 7025 at each plumbine in Table 4.

<table>
<thead>
<tr>
<th>Block</th>
<th>Elevation</th>
<th>Radial deflections (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>7152.5</td>
<td>-0.170</td>
</tr>
<tr>
<td>10</td>
<td>7152.5</td>
<td>-0.400</td>
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<td>14</td>
<td>7152.5</td>
<td>-0.190</td>
</tr>
<tr>
<td>6</td>
<td>7025</td>
<td>-0.260</td>
</tr>
<tr>
<td>10</td>
<td>7025</td>
<td>-0.880</td>
</tr>
<tr>
<td>14</td>
<td>7025</td>
<td>-0.230</td>
</tr>
</tbody>
</table>

- indicates downstream deflection.

Tangential deflections for this loading change are also compared at the plumbine locations in Figure 5. The maximum difference between measured and computed tangential deflections is 0.30 in. The larger differences occur on the left side of the dam, again indicating the possibility of larger abutment deflections on that side.

Comparisons of horizontal and vertical stresses for this study are shown in Figures 6, 7, and 8. Linear stress distributions assumed for the analytical study were corrected for the deviation of measured temperatures from the assumed linear temperature gradient used in the analysis. A modulus of elasticity of 4.3 x 10^6 psi was used and 100 percent restraint was assumed in making these corrections. A representative linear stress distribution for the analytical study is shown at Block 10 on the arch at el 7040 in Figure 6. The corrected stress distribution described above is superimposed on the linear stress distribution for comparison.

Changes in assumed linear temperature distributions are shown, along with changes in recorded temperatures, adjacent to the meter locations.

Horizontal stresses are compared at meter locations on the arch elements in Figures 6 and 7. As shown in the figures, agreement is much closer at the right side of the dam and especially at the lower right side abutments. The areas of larger differences in stress comparisons are the same as those for the larger deflection differences.

Comparisons of changes in the vertical stresses are shown in Figure 8. The agreement in the vertical stress comparisons is generally closer than for horizontal stresses.

**Seasonal Temperature Change During Initial Loading Cycle**

Changes in radial deflections due to the seasonal temperature rise occurring from February 2 to July 25, 1969, during the initial loading cycle are shown in Figure 9 at the plumbine locations. Table 5 lists the computed and measured radial deflections for el 7152.5 and 7025 at the plumbines. The maximum difference between the analytical and measured radial deflection changes is about 0.390 in. Larger movements occurred on the right side of the dam as the temperature rise increased the forces transmitted to the abutments of the arches.

Comparisons of tangential deflections at the plumbines are also shown on Figure 9. The measured tangential deflections also show the increase in movement of the right side. The maximum difference in tangential deflection comparisons is 0.28 in.

<table>
<thead>
<tr>
<th>Block</th>
<th>Elevation</th>
<th>Radial deflections (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>7152.5</td>
<td>+0.570</td>
</tr>
<tr>
<td>10</td>
<td>7152.5</td>
<td>+0.600</td>
</tr>
<tr>
<td>14</td>
<td>7152.5</td>
<td>+0.510</td>
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<tr>
<td>6</td>
<td>7025</td>
<td>+0.080</td>
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<tr>
<td>10</td>
<td>7025</td>
<td>+0.120</td>
</tr>
<tr>
<td>14</td>
<td>7025</td>
<td>+0.060</td>
</tr>
</tbody>
</table>

+ indicates upstream deflection.
- indicates downstream deflection.

The changes in horizontal and vertical stresses are shown in Figures 10, 11, and 12. As stated for the previous study, the linear stress distributions assumed in the analytical study were corrected for the deviation of measured temperatures from the assumed temperature gradient. Temperature gradients and measured temperature changes are shown adjacent to the meter locations. A representative linear stress distribution is shown at Block 10, el 7040 in Figure 10.
with the distribution corrected for temperature assumptions superimposed.

Horizontal stress changes are shown at meter locations on the arch elements in Figures 10 and 11. The comparison is closer between measured data and analytical results for this loading change than for the previously discussed study.

Vertical stress changes are shown in Figure 12. The agreement between vertical stresses from measured data and those for the analytical study is much closer than for the horizontal stresses.

Reservoir Level Rise for Second Loading Cycle

Radial deflection changes due to the rise in reservoir water from el 7020 on January 5, 1970, to el 7160 on November 23, 1970, are shown in Figure 13. Comparisons for the water load change occurring in the second loading cycle are much closer than those for the initial reservoir filling. Although some foundation movements larger than those used in the analysis are still indicated by deflection differences in the upper part of the dam, agreement is very close in the lower two-thirds of the structure. The maximum difference between measured and computed radial deflection is 0.26 in. Table 6 lists the measured and computed radial deflection changes for el 7025 and 7152.5 at the plumbines.

Table 6

<table>
<thead>
<tr>
<th>Block</th>
<th>Elevation</th>
<th>Computed</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>7152.5</td>
<td>−0.240</td>
<td>−0.500</td>
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<tr>
<td>10</td>
<td>7152.5</td>
<td>−0.440</td>
<td>−0.640</td>
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<tr>
<td>14</td>
<td>7152.5</td>
<td>−0.220</td>
<td>−0.450</td>
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<tr>
<td>6</td>
<td>7025</td>
<td>−0.260</td>
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<td>7025</td>
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<tr>
<td>14</td>
<td>7025</td>
<td>−0.320</td>
<td>−0.370</td>
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</tbody>
</table>

- indicates downstream deflection.

Temperatures at the time of the reservoir level rise were generally within 1°F of assumed values. The maximum difference in measured and computed values for radial and tangential deflections for el 7025 is 0.04 in. Table 6 lists the measured and computed values at el 7025 and 7152.5.

The comparisons of tangential deflections at the plumbines are also shown in Figure 13. The maximum difference between measured and calculated tangential deflections is 0.14 in. These comparisons also indicate that the foundation is still moving more than indicated by the analysis, but the difference has decreased significantly after the first loading cycle.

Horizontal and vertical stress changes are compared in Figures 14, 15, and 16. Stresses from the analysis were corrected for the temperature assumption in the same manner as the two studies discussed earlier in this report.

Representative linear stress distributions from the analysis are shown with the corrected stress distributions superimposed at the meter locations in Block 10 on the arches at el 7050.0 and 6990.0 in Figures 14 and 15. Changes in assumed linear temperature gradients and recorded temperature changes are shown adjacent to meter locations.

The comparisons of horizontal stresses shown in Figures 14 and 15 are in close agreement, generally.

The vertical stress change comparisons also show good agreement between measured and computed data. Comparisons in the lower part of the dam for both horizontal and vertical stresses are closer than for the stress changes due to the initial filling of the reservoir.

Temperature Drop During Second Loading Cycle

Radial deflection changes due to the temperature drop between September 1 and November 23, 1970, are shown in Figure 17. As was noted for the comparison of radial deflections due to the water load change during the second loading cycle, the comparison of radial deflection changes for this loading condition show much closer agreement than those for the first cycle. Table 7 lists measured and computed radial deflections for the plumbines at el 7152.5 and 7025.5.

![Figure 6. Horizontal stress changes—Elevations 7040 and 7152.5—January 24, 1968 to February 2, 1969.](image)

![Figure 7. Horizontal stress changes—Elevations 6710, 6800, and 6920—January 24, 1968 to February 2, 1969.](image)
The maximum difference between measured radial deflections and those from the analysis is 0.17 in.

Table 7

<table>
<thead>
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<th>Block</th>
<th>Elevation</th>
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<th>Measured</th>
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<td>14</td>
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<tr>
<td>14</td>
<td>7025</td>
<td>-0.070</td>
<td>-0.050</td>
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</tbody>
</table>

Indicates downstream deflection.

Comparisons of the tangential deflections at the plumbline locations are shown in Figure 17. These also show much closer agreement than the temperature change for the first loading cycle with a maximum difference of only 0.05 in.

Horizontal and vertical stress changes for this loading change are shown in Figures 18, 19, and 20. Changes in assumed linear temperature gradients and in recorded temperatures are shown adjacent to the meter locations. Corrections for the differences between assumed and recorded temperatures were included in stress distributions for this loading change in the same manner described earlier in this report.

A representative linear stress distribution is shown at Block 10 on the arch at El 7040 in Figure 18 with the corrected stress distribution superimposed. In general, the horizontal stress distributions compare satisfactorily with the measured stress changes.

Comparisons of vertical stress changes plotted in Figure 20 also show close agreement between measured and calculated data.

CONCLUSIONS

The following conclusions were made as a result of the comparisons of analytical and structural behavior data:

a. Deflection comparison studies were made for two loading changes during the initial loading cycle of the dam. These comparisons indicate that the actual foundation deformations during the initial filling of the reservoir are significantly larger than those computed for the analytical studies. The moduli of elasticity for foundation rock used in the analyses are based on laboratory test and geologic evaluations. Inelastic behavior which may be caused by closing of open joints has not been included. However, drill hole logs for the left abutment show many joints and fractured zones which may have been a direct cause of the larger, nonsymmetrical deflections measured during the filling of the reservoir.

b. Although drill hole logs for the right abutment do not show as many open joints as noted on the left abutment, some are open sufficiently to contribute to the larger deflections measured on the right side. These deflections occurred as the arch thrusts continued to increase with a temperature rise while the reservoir water level remained high.

c. Comparisons of stresses indicate that the 100-percent restraint assumption used for temperature corrections is reasonable for modification of the linear stress distributions assumed in the analytical studies.

d. Stress comparisons for the two later studies agree sufficiently to show that the adaptations necessary for the more complicated geometry of double-curvature dams give satisfactory results.
Figure 14. Horizontal stress changes—Elevations 7040 and 7152.5—January 5 to November 23, 1970.

Figure 15. Horizontal stress changes—Elevations 6710, 6800, and 6820—January 5 to November 23, 1970.
Figure 18. Horizontal stress changes—Elevations 7040 and 7152.5—September 1 to November 23, 1970.

Figure 19. Horizontal stress changes—Elevations 6710, 6800, and 6920—September 1 to November 23, 1970.
BIBLIOGRAPHY

1. Roehm, L. H., "Investigation of Temperature Stresses and Deflections in Flaming Gorge Dam," a thesis submitted to the faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the Degree of Master of Science, Department of Civil Engineering, 1967 (see also Bureau of Reclamation Technical Memorandum 667, March 1967).


CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, F 300-61) except that additional factors ("h"") commonly used in the Bureau have been added. Further clarification of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for System International d'Unites, used by the International Committee for Weights and Measures); this system is also known as the "Gingrich MKSA" (meter-kilogram-second-ampere) system. This system has been adopted by the International Organization for Standardization (ISO Recommendation 91-3).

The metric unit of force is the kilogram-force: this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth’s center for sea level at 45-deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (constant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pounds" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass units) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as exact significant values.

### Table I

**QUANTITIES AND UNITS OF SPACE**

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<thead>
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<th>To Obtain</th>
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<td>Acres</td>
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<td>Cubic feet</td>
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### CAPACITY

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<tr>
<td>Gallons (U.S.)</td>
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<tr>
<td>Cubic feet</td>
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**Note:** The exact values for conversions are essential in SI units.
Table II

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<th>Unit</th>
<th>Value</th>
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</thead>
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</tr>
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<td>Iron ore (50% Fe)</td>
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<td>MMBtu/acre</td>
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<td>ft³/acre</td>
</tr>
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<td>Short tons (1000 lb)</td>
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<td>tons/acre</td>
</tr>
<tr>
<td>Long tons (2240 lb)</td>
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<td>tons/acre</td>
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Table II - Continued

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<tr>
<td>Long tons (2240 lb)</td>
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<td>tons/acre</td>
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</tbody>
</table>

ABSTRACT

Effectiveness of the Arch Dam Stress Analysis System (ADSS) in the analysis of double-curtain arch dams and the reliability of assumptions used in the design can best be demonstrated by comparison of analytical results with deflections and stresses from structural behavior measurements. Instruments that indicate length change, temperature and deflection, were installed in Morrow Point Dam. Stress and deflection changes were determined for the following loadings: (1) initial reservoir filling with constant temperature, (2) seasonal temperature change during the first loading cycle with constant water level, (3) change in water level during the second loading cycle with small temperature changes, and (4) large temperature drop during the second loading cycle. The computerized Arch Dam Stress Analysis System was used to make analyses for the same incremental loadings. Comparisons of deflection changes and stress changes are presented for each loading increment. For the 2 incremental changes during the initial loading cycle gave larger effects of inelastic foundation movements than predicted by the analyses. Comparisons for the 2 loading increments during the second loading cycle indicate that foundation deformations are nearer those predicted by the analytical studies. Generally, agreement between measured and analytical results is satisfactory. Has 16 references.

ABSTRACT

Effectiveness of the Arch Dam Stress Analysis System (ADSS) in the analysis of double-curtain arch dams and the reliability of assumptions used in the design can best be demonstrated by comparison of analytical results with deflections and stresses from structural behavior measurements. Instruments that indicate length change, temperature and deflection, were installed in Morrow Point Dam. Stress and deflection changes were determined for the following loadings: (1) initial reservoir filling with constant temperature, (2) seasonal temperature change during the first loading cycle with constant water level, (3) change in water level during the second loading cycle with small temperature changes, and (4) large temperature drop during the second loading cycle. The computerized Arch Dam Stress Analysis System was used to make analyses for the same incremental loadings. Comparisons of deflection changes and stress changes are presented for each loading increment. For the 2 incremental changes during the initial loading cycle gave larger effects of inelastic foundation movements than predicted by the analyses. Comparisons for the 2 loading increments during the second loading cycle indicate that foundation deformations are nearer those predicted by the analytical studies. Generally, agreement between measured and analytical results is satisfactory. Has 16 references.
DESSERT YUCCA IN FULL BLOOM
The Yucca, or "Spanish Bayonet" presents one of the largest blooms of any desert flora, and usually is found in a large group rather than singularly.

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Color by Stan Davis P32533
Cushion Hedgehog

DEsert BotaNical Gardens
Papago Park
Phoenix, Arizona

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A rare dome-shaped hedgehog cactus found in a remote area of Mexico.

Color Photo by Bob Van Luchene
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Sand dunes in the desert.
DESSERT SAND DUNES
Throughout the Southwestern area, sand dunes create a scene of unusual beauty. The California-Arizona State boundary line, in South Central New Mexico and Arizona, furnishes outstanding examples.
COLORADO RIVER STORAGE PROJECT

ROBERT E. GLOVER
1936 So. Lincoln
DENVER, COLORADO 80210

"YEAR OF THE FIRST HARVEST" A PROGRESS REPORT 1963
The year 1963 is a significant one for the Colorado River Storage Project. The first crops grown on new project lands go to market. The first project power goes on the line. And the first recreational benefits on project lakes and reservoirs await an outdoor-minded America. Because of these great advancements, 1963 is called "the year of the first harvest" in the Colorado River Storage Project.
The Colorado River Storage Project ... one of the most complex and extensive river developments in the world ... has been under construction in western America for the past seven years. During that time, great strides have been made toward completion of the initial phases of this gigantic reclamation undertaking which is fast reshaping the destiny of a vast basin in the arid West ... a basin covering one-twelfth of the continental area of the United States.

Work on CRSP has moved ahead swiftly since it was first authorized in 1956. Appropriations by the Congress have enabled construction to proceed according to plans ... and at costs within engineers' estimates. Already, undeveloped water resources in the four-state Upper Colorado River Basin are being captured, stored and diverted onto the thirsty soil. Already, transmission lines are reaching out in a network of electrical arteries to supply much needed hydroelectric power to America's Rocky Mountain stronghold. Already, the frontiers of a new land of opportunity are beginning to open to people looking for new jobs, new homes, and new fortunes.

The Colorado River Storage Project is a phenomenal undertaking. It culminates more than a half-century of engineering research, planning and interstate negotiations. The gigantic dams being built in the Upper Basin will stand as dynamic, functioning monuments to the ingenuity and hard work of surveyors, designers, engineers and laborers of our age.

The first seven years of the project have indeed seen remarkable progress. Navajo Dam on the San Juan River in northwestern New Mexico (see map adjoining page) was completed in 1962, the first of four great water Storage Units in the project to impound water. As the seventh construction season unfolded, Flaming Gorge Dam on the Green River had been “topped out” and neared completion. Glen Canyon Dam on the Colorado River also moved into the final stages of completion. Work was going ahead rapidly on Blue Mesa Dam on the Gunnison River, a principal feature of the Curecanti Unit, the latest Storage Unit to go under construction.

Four multi-purpose participating projects were completed in Utah, Colorado, and New Mexico, making much needed agricultural, industrial and municipal water available to the people in these States. Construction or preliminary work was also proceeding on other participating projects in the four Upper Colorado River Basin States.

Under authorizing legislation, the Storage Units will regulate stream flows and assure downstream users the delivery of their share of water. They will produce hydroelectric power and make development of water resources possible in the Upper Basin States. In addition, flood control, recreation and fish and wildlife development have been integrated into project plans.

In 1963, water will back up behind the huge storage reservoirs at Glen Canyon, Navajo and Flaming Gorge Storage Units, creating man-made lakes on lands once deemed trackless wasteland. And even as water collects, crews will be in the field erecting power lines to carry the power that will be generated by the massive turbines in the dam’s power plants. The Storage Project transmission system will be operated interconnected with other transmission systems under joint agreements between the federal government and public and private utilities operating in the area.

CRSP means a great deal to America and the free world. It means the subduing of one of America's wildest and most savage rivers and putting its energies to work for the benefit of mankind. Water and power from its dams and storage reservoirs mean opportunity for industrial expansion, agricultural development, growth of cities and towns and creation of new jobs for thousands of Americans. The project will give birth to new markets, will stimulate trade, broaden the tax base, bolster national economy and aid national defense. It will provide power and water necessary to develop minerals and other natural resources that are essential to the defense program of the United States. It will strengthen the Mountain West and contribute to a secure nation.
The Upper Colorado River Commission is an interstate administrative agency created under the terms of the Upper Colorado River Basin Compact executed at Santa Fe, New Mexico on October 11, 1948, and subsequently ratified by each of the legislatures of the States and by the Congress of the United States. The Commission represents the States of Colorado, New Mexico, Utah and Wyoming and the Federal Government.

The major purposes of the Upper Colorado River Basin Compact are: (1) to provide for the equitable division of the use of waters of the Colorado River System among the Upper Basin States, namely, Arizona, Colorado, New Mexico, Utah and Wyoming; (2) to establish obligations of each State with respect to the delivery of water to the Lower Basin; (3) to promote interstate harmony; (4) to remove causes of controversies; (5) to secure the expeditious agricultural and industrial development of the Upper Basin States, the storage of water, and the protection of life and property from floods.

- Robert J. Newell
  Chairman and Commissioner for United States

- Edwin C. Johnson
  Commissioner for Colorado

- John H. Bliss
  Commissioner for New Mexico

- George D. Clyde
  Commissioner for Utah

- Earl Lloyd
  Commissioner for Wyoming

- Ival V. Goslin
  Executive Director

Right: Workmen swarm over huge penstock on top of newly-placed block at Glen Canyon Dam.
The turbulent waters of the Colorado River began rising early in 1963 behind Glen Canyon Dam which will form Lake Powell, destined to be one of the largest man-made reservoirs in the world. The colossal dam will be finished in 1964, winding up one of the greatest construction projects in the history of western America. Meanwhile, as workmen place concrete in the uppermost blocks of the dam, water began backing up 186 miles into the rugged canyons and beautiful plateaus of Utah, filling the gigantic lake and creating a recreational paradise for millions of Americans.

It is planned to store sufficient water in Lake Powell to attain power generating capacity . . . 6,500,000 acre feet . . . by 1964, when power is scheduled to go “on the line.”

In the seven years that Glen Canyon Dam has been under construction, thousands of workmen . . . surveyors, draftsmen, truck drivers, contractors, laborers from all phases of construction work and others from almost every conceivable occupation or trade . . . have been involved in the massive project. In addition, products from all over America have gone into building this great dam. These include everything from equipment and building materials to a myriad of goods and services that went into the construction of Page, Arizona, the government town that sprang upon the nearby desert.

The entire unit is expected to cost $300,000,000. * However, power revenues alone will return far more than this to the Federal Treasury. At the start of 1963, workmen had placed more than four million cubic yards of concrete in the dam, with only one million more to go. Men were also at work on the completion contract for the dam and were installing turbines and other equipment in the huge power plant.

*Note: All costs shown in this report are from fiscal 1964 Congressional Justification Documents.
Right:
An aerial view of Glen Canyon dam shows Colorado River Canyon looking downstream.

Far right:
Bucket after bucket of concrete goes into Glen Canyon Dam.
Far left:
Workmen on scaffold are dwarfed on the upstream face of Flaming Gorge Dam.

Left:
This aerial view shows uppermost blocks being completed on Flaming Gorge Dam.
On November 15, 1962, the last bucket of concrete was placed in Flaming Gorge Dam, "topping out" this massive engineering giant on the Green River in northern Utah. As 1963 got under way, the U.S. Bureau of Reclamation had closed the diversion tunnel and began storing the spring run-off in a new Reclamation lake which will extend 90 miles behind the dam into Wyoming.

The picturesque concrete arch rises 502 feet above bedrock in the canyon of the Green River on the flanks of the Uinta Mountains, mid-way between the towns of Vernal, Utah, and Green River, Wyoming.

Since construction of Flaming Gorge Dam began four years ago, an army of workmen have toiled to raise this gleaming white concrete dam in the mountains. The government town of Dutch John mushroomed almost like magic on the nearby meadow, and a steady flow of machinery and materials have rolled by truck to the damsite, over new highways slashed through the wilderness.

The first power of the Colorado River Storage Project will be generated at Flaming Gorge Dam in 1963. Early in the year workmen installed the initial electrical equipment for three 36,000 kilowatt generating units.

The first generator is scheduled to "go on the line" in September 1963. The other two will go into operation at three-month intervals.

When its reservoir is filled, the Flaming Gorge Unit will store some 3,800,000 acre feet of water, making it the second largest of the four Storage Units in CRSP.

Total cost is estimated at $66,672,000. Flaming Gorge Reservoir, like Glen Canyon's Lake Powell, has tremendous recreation potential. Beautiful pine forests border much of the reservoir area within easy access of two transcontinental highways.
Navajo Dam, one of the largest earth-fill dams in the world, was completed in 1962 on the San Juan River, about 40 miles east of Farmington, New Mexico. On June 27 of that year, the “stop-logs” were dropped into position and water began forming Navajo Lake. This was the first impoundment of water among the four big Storage Units in CRSP.

The dam was dedicated September 15, 1962. Federal, State, and local dignitaries, citizens and hundreds of Indians from the Navajo Indian Reservation were on hand as the huge dam was officially dedicated to the task of storing water for the Colorado River Storage Project.

Completion of Navajo Dam now makes possible diversion of water from the San Juan River to the much needed Navajo Indian Irrigation Project which will open up thousands of acres of dry, now unproductive land on the Indian Reservation. It will also make possible diversion of water to the San Juan-Chama participating project, whereby supplemental water will be delivered to thousands of acres of inadequately irrigated land, and where water will be made available for municipal and industrial uses in the cities and towns of the Rio Grande Basin in New Mexico.

When the dam was completed in the summer of 1962, some 26,300,000 cubic yards of earth and rock had been placed by man and machines in the dam embankment.

The dam and reservoir are estimated to cost $36,474,000.

Navajo Lake will store 1,709,000 acre feet of water and will create a blue body of water, set like a sapphire on the dry desert, in the middle of an area rich in Indian lore and legend.
Ground-breaking ceremonies held July 7, 1962, at Blue Mesa damsite on the Gunnison River in central Colorado signaled start of construction of the Curecanti Unit. When completed, Curecanti will consist of a series of three dams on a 40-mile stretch of the river, downstream from the town of Gunnison.

After the ground-breaking, work moved ahead swiftly on Blue Mesa Dam and powerplant near Sapinero on U.S. Highway 50. At the same time, pre-construction surveys and exploratory drilling continued on Morrow Point damsite, 12 miles downstream near Cimarron.

The Bureau of Reclamation has also completed a special study of the proposed Crystal Dam, recommending that it be included in the Curecanti Unit. The Crystal Dam and powerplant, the third feature of the Curecanti Unit, is located downstream from Morrow Point before the Gunnison River flows through Gunnison National Monument.

At the beginning of 1963, workmen at Blue Mesa had completed drilling a tunnel and were planning to divert the river around the damsite in the spring. When completed, Blue Mesa Dam will contain some 3,000,000 cubic yards of rolled earth and rock. It will rise 342 feet above streambed and extend 880 feet across the gaping canyon. Blue Mesa Reservoir will store 941,000 acre feet of water, reaching 20 miles upstream.

Morrow Point Dam will be a 465-foot high thin arch concrete dam, which when completed will back up a narrow reservoir containing 117,000 acre feet of water. The powerplant at Morrow Point will be the first underground powerplant built by the Bureau of Reclamation.

Blue Mesa, Morrow Point, and Crystal powerplants will have a combined installed generating capacity of 200,000 kilowatts. Total cost is estimated at $100,300,000.
INTERCONNECTED TRANSMISSION SYSTEM

EXPLANATION

- C.R.S.P. TRANSMISSION LINES (EXISTING OR UNDER CONSTRUCTION)
- C.R.S.P. TRANSMISSION LINES (PLANNED)
- OTHER BUREAU TRANSMISSION LINES (EXISTING OR UNDER CONSTRUCTION)
- OTHER TRANSMISSION LINES (PLANNED)
- C.R.S.P. HYDRO PLANT
- C.R.S.P. SUBSTATION OR DELIVERY POINT
- OTHER BUREAU HYDRO PLANTS (EXISTING)
- OTHER BUREAU SUBSTATIONS (EXISTING)
- RELATED PRIVATE UTILITIES STEAM PLANT
- RELATED PRIVATE UTILITIES LINES (EXISTING, OR UNDER CONSTRUCTION)
- RELATED PRIVATE UTILITIES LINES (PLANNED)
- RELATED PREFERENCE CUSTOMERS HYDRO PLANT
- RELATED PREFERENCE CUSTOMERS STEAM PLANT
- RELATED PREFERENCE CUSTOMERS LINES (EXISTING OR UNDER CONSTRUCTION)
- RELATED PREFERENCE CUSTOMERS LINES (PLANNED)
When the authorized Units of the Colorado River Storage Project are completed, their powerplants will have an installed capacity of one and one fourth million kilowatts of electricity. This much needed power will be marketed in the four Upper Basin states, Arizona and parts of Nevada and California which are contiguous to the Colorado River . . . enhancing industrial, municipal and economic development in the West.

Revenues from the sale of CRSP's hydroelectric energy will repay all of the construction costs of the Storage Units and about 80 per cent of the costs of the participating projects.

At the beginning of 1963, transmission facilities were under construction and were scheduled to be completed as generators from the various projects begin humming.

The Colorado River Storage Project transmission system will be inter-connected with utility and other Bureau of Reclamation systems. (See map on previous page.) First CRSP power is scheduled from Flaming Gorge Dam in September 1963, with full 108,000 kilowatt output from this powerplant by the following summer. First power from Glen Canyon Dam is scheduled for June 1964, with 900,000 kilowatts on the line by July 1966. That same summer, 60,000 kilowatts are scheduled from Currecani's Blue Mesa Dam, with an additional 140,000 kilowatts from Morrow Point and Crystal Dam between 1967 and 1970.

Two of the authorized participating projects are also scheduled to produce power. A small unit of 10,000 kilowatts at Fontenelle Dam, a feature of the Seedskadee Project, is scheduled to go into operation in 1965. Tentative plans call for powerplants of the Central Utah Project to have an installed capacity of about 130,000 kilowatts.

Right:
Men at work on transmission lines from Vernal, Utah, to Craig, Colo.
The participating projects develop the water resources on the smaller tributary streams in the Upper Basin. While the Storage Units assure delivery to downstream users and generate revenue-producing power, the participating projects put water to beneficial use by diverting it higher upstream. These projects, through dams, diversion works and canals, open up new land for diversified irrigation farming, make supplemental water available to presently irrigated farms and provide new sources of water for municipal and industrial users.

By putting more water onto the soil, the participating projects actually diversify farming and help alleviate many farm problems in America. The non-surplus crops grown on reclamation project lands put dollars into the farmers' pockets, keep lands productive and discourage one-crop, surplus farming.

Four of the CRSP participating projects are already completed. Eight others are either under construction or ready to be built. Authorization of four others is pending. A number of others are in various stages of planning.

PAONIA

Paonia was the first participating project to be completed. Work on the earth-fill Paonia Dam was finished in the winter of 1961, and the project was dedicated September 29, 1962. The reservoir filled to capacity the first year and in the spring of 1962 gushed over the dam's spillway. During the 1962 irrigation season, project water was delivered to eligible users, enabling farmers at the dedicatory rites to display agricultural products grown with Paonia water.

Left, top:
The reservoir fills at Paonia in 1962.

Left, bottom:
Water gushes over spillway at Paonia Dam the first year.

Paonia Project is nestled in a beautiful valley on the North Fork of the Gunnison River. It is flanked on one side by the majestic Elk Mountains and on the other by towering Grand Mesa. Paonia Dam is located on Muddy Creek, a tributary of the North Fork. Its reservoir is capable of storing 21,000 acre feet of water, opening up 2,230 new acres of land for irrigation and supplying supplemental water to 13,070 acres. Most of this land is made up of irrigated fruit and livestock farms which in the past were hampered by lack of water.
The initial phase of the Central Utah Project authorized in 1956, has been divided into four separate units, the Vernal Unit, which has already been completed, the Bonneville Unit, Upalco Unit and Jensen Unit. Definite Plan Reports outlining major features of the various units are scheduled for completion in June 1963 on the Bonneville Unit and June 1964 on the Upalco and Jensen Units.

The Bonneville Unit, by far the most complex and comprehensive development of Central Utah Project, involves the local development of water for lands along the Duchesne River and the intercepting of Duchesne River tributary streams that drain the southern slope of the Uinta Mountains and conveying the water by gravity flow through the Wasatch Mountains to the populated Bonneville Basin of Utah. The water would be stored and moved through an intricate system of reservoirs, aqueducts, and canals. It would generate power, provide water for irrigation, municipal and industrial use, and allow Utah healthy economic growth. Cost of the entire initial phase of the project is estimated at more than $250,000,000. Supplemental water would be furnished for nearly 185,000 acres and a full supply for about 45,000 acres, with additional municipal and industrial water furnished to rapidly growing cities and towns in the Bonneville Basin.

Work on the Vernal Unit near the town of Vernal, Utah, was virtually completed in 1962 and surplus flows of Ashley Creek were being stored in off-stream Steinaker Reservoir for delivery during the 1963 irrigation season. The project is part of the initial phase of the vast Central Utah participating project. Principal features of the Vernal Unit Steinaker Dam, Fort Thornburg Diversion Dam, Steinaker Service Canal and Steinaker Service Canal, have all been completed. Steinaker Reservoir is capable of storing 37,200 acre feet of water to supply supplemental water to about 15,000 acres of inadequately irrigated land and municipal water to the towns of Vernal, Maeser and Naples.

In lieu of a water savings system which was to be built as part of the Vernal Unit, a domestic water system was installed by the local people with Bureau of Reclamation assistance to accomplish the same purpose and supply the three small towns with municipal water.

Total project cost, including non-reimbursable recreation and fish and wildlife development, is estimated at $8,035,000.

Construction of earth-fill Crawford Dam, a principal feature of the Smith Fork Project, was completed in the fall of 1962. Flows of Smith Fork and Iron Creek are being stored in Crawford Reservoir for delivery in the 1963 irrigation season to 8,056 acres in Delta County, Colorado. Crawford Dam is located on Iron Creek. Flows from Smith Fork are conveyed to the reservoir by way of the Smith Fork Feeder Canal. Construction of other features of the project, including Aspen Canal, Smith Fork Diversion Dam and Clipper Canal is also completed.

Crawford Reservoir, capable of storing 13,650 acre feet of water, will supply irrigation water to 1,423 acres of new land and supplemental supplies to 8,056 acres of inadequately irrigated land. Total cost is estimated at $4,502,000, including non-reimbursable costs.

All of the features of the Hammond Project in northwestern New Mexico have been completed, and limited water deliveries were made in 1962. The project is located on the south bank of the San Juan River below Navajo Dam and opposite the towns of Blanco and Bloomfield. Hammond will provide water to a narrow belt of land of 3,900 acres on the south side of the San Juan River.

The project works consist of Hammond Diversion Dam on the San Juan River, a main gravity canal, hydraulic-turbine driven pumping plant, three main laterals, distribution and drainage systems.

Right:
Men and machinery compact earth on Crawford Dam, Smith Fork Project.

Right, middle:
Diversion dam goes into operation on Hammond Project.

Far right:
Aerial view shows Steinaker Dam, Vernal Unit, shortly before storing water.
The Seedskadee participating project is located along the Green River in Southwest Wyoming.

Principal feature of this project, massive earthfill Fontenelle Dam, is being built on the Green River northwest of Green River, Wyoming.

As 1963 got under way, workmen had placed some 1,500,000 cubic yards of earth and rock in the dam's embankment which was more than one-third complete. When finished, Fontenelle Dam will contain 5,300,000 cubic yards of material. Fontenelle Reservoir will store 345,000 acre feet of water. The capacity of the lake was increased by 60,000 acre feet to the total of 345,000 acre feet when the Wyoming Legislature authorized the Wyoming Natural Resource Board to contract for additional capacity costing $900,000. The additional supply will be utilized for future industrial expansion. The project includes a 10,000 kilowatt powerplant at Fontenelle Dam.

Under the initial stage development, storage of project water will make diversion of water possible from the Green River for about 43,000 acres of new land. Additional acreage will be opened for settlement after the effects of trona mining in the southern part of the project are determined.

Total cost is estimated at $43,994,000.
Pre-construction surveys were under way in 1962 on Joe's Valley Dam, principal feature of Emery County participating project near the towns of Huntington, Castle Dale and Orangeville, Utah. Construction of the project is scheduled to start in 1963. The State of Utah has already started to re-locate State Highway 29 which lies in the reservoir area. Joe's Valley Reservoir will store 62,500 acre feet of water, supplying supplemental water to 18,000 acres of land and a full supply to 770 acres. The dam will rise 192 feet high, containing 1,400,000 cubic yards of earth and rock. Huntington North Reservoir will hold 4,850 acre feet of water. Total cost is estimated at $12,785,700.

Lemon Dam, principal feature of Florida participating project, was 66 per cent complete early in 1963. The 215-foot high earth-fill dam is located northeast of Durango, Colorado, on the Florida River. It is scheduled for completion in January 1964 with delivery of first project water the following irrigation season. Work has also begun on the Florida Farmers Ditch Diversion Dam and enlargement and extension of the Florida Farmers Ditch and Canal. When completed, the project will supply supplemental water to 13,720 acres and a full amount of irrigation water to 5,730 new acres, all located in the Florida River Valley and on Florida Mesa. Lemon Reservoir will store about 40,000 acre feet of water.

A definite Plan Report for Silt participating project in west-central Colorado was completed in 1961, and pre-construction surveys on Rifle Gap Dam are under way. Congress appropriated $350,000 in fiscal 1963 to complete these preliminary engineering investigations. Rifle Gap Reservoir will hold 12,650 acre-feet of water, improving the supply for 4,479 acres of irrigated land and opening up 2,118 acres of new land for irrigation. Besides Rifle Gap Dam, the project includes a pumping plant on the Colorado River to serve part of the lands. Estimated cost of the project is $6,600,000.

A definite Plan Report outlining features of the Lyman participating project in Southwestern Wyoming will be completed early in 1963. The engineering studies call for construction of Meeks Cabin Dam on Blacks Fork of the Green River near Mountain View, Wyoming, and China Meadows Dam on Smith Fork. Estimated project cost is about $12,000,000. The two reservoirs would supply 36,000 acres of land with supplemental irrigation water.
Congress appropriated $550,000 for fiscal year 1963 for the San Juan-Chama Project, located in the San Juan and Rio Grande Basins in south-central Colorado and north-central New Mexico. When completed, the project will divert from the head waters of the San Juan River into the Rio Grande Basin, providing supplemental water for 104,000 acres of land in existing irrigation projects and a full supply to 17,000 acres of new land. In addition, municipal and industrial water will be provided to the Albuquerque, New Mexico, metropolitan area. Estimated cost of the project is $86,000,000.

$300,000 was made available for fiscal 1963 to complete pre-construction surveys on the Navajo Indian Irrigation Project which will irrigate 110,630 acres of new land on the Navajo Indian Reservation near Farmington, New Mexico. The project will convey water from Navajo Reservoir through a two-mile tunnel and a series of canals, siphons and tunnels to the parched desert domain of the Navajo Indians, converting a large section from once dry grazing lands to productive soil. The Bureau of Indian Affairs is cooperating with the Bureau of Reclamation in the vast project, estimated to cost some $135,000,000.

SAVERY-POT HOOK

Legislation has been introduced into Congress seeking authorization of the Savery-Pot Hook Project on the Colorado-Wyoming border near Baggs and Dixon, Wyoming. Preliminary investigations call for construction of Pot Hook Dam on Slater Creek in Colorado and Savery Dam on Savery Creek in Wyoming, both tributaries to the Little Snake River. Cost of the project is estimated at $15,000,000. Feasibility investigations have indicated Pot Hook Reservoir will store 65,000 acre-feet of water and Savery Reservoir 18,600 acre feet. The project will supply supplemental water to 3,370 acres of land in Colorado and 9,975 acres in Wyoming and a full supply to 15,740 acres of new land in Colorado and 6,180 acres in Wyoming.

BOSTWICK PARK

Legislation has been introduced in Congress seeking authorization of the Bostwick Park Project near Montrose in western Colorado. Feasibility investigations show the best plan for the project will be construction of Silver Jack Dam on Cimarron Creek, storing 10,600 acre-feet of water and supplying supplemental water to 4,293 acres of land and a full supply to 1,315 acres of new land. Cost is estimated at $4,000,000.

FRUITLAND MESA

A feasibility report has been completed on the $102,000,000 Animas-La Plata Project on the Colorado-New Mexico border and has been submitted to the various States for review and comment. Under the proposed plan the principal storage facilities would consist of Howardsville Dam and reservoir on the Animas River and the offstream Hay Gulch Dam and reservoir on Hay Gulch. Additional offstream regulatory storage would be provided at the Meadows and Animas Mountain reservoirs. Supplemental water would be supplied to 20,100 acres in Colorado and 5,500 acres in New Mexico, and full supplies to 44,200 acres of new land in Colorado and 14,700 acres in New Mexico. The municipal and industrial water supply for Durango, Colo. would be increased by 9,200 acre-feet per year, and the source of the city's supply would be changed to eliminate diversions from the Florida River.
The year 1963 is also the "year of the first harvest" for Americans interested in outdoor recreation. Water backing up behind Storage Unit and participating project dams will create many lakes in the four-state area which are ideally suited for recreational and fish and wildlife development.

One of the largest man-made lakes in the world is being formed by Glen Canyon Dam, creating a veritable boater's paradise in a wild but spectacular wilderness area. Similar lakes are being created at Navajo and Flaming Gorge Storage Units.

In addition to the large lakes, CRSP is also creating many smaller reservoirs on the participating projects, each well-suited for recreational use.

It is hard to imagine the millions of hours of enjoyment the reservoirs of CRSP hold for Americans. In recognition of this growing demand, boating, fishing, water-skiing, camping and picnicking have been made as much a part of project development as dams, diversion works, canals and laterals. The National Park Service, U.S. Forest Service, Fish and Wildlife Service, and numerous State and local agencies are cooperating to develop these recreational features on project reservoirs, with facilities available as soon as water accumulates behind the dams.

Right:
Water skiing will be one of the popular recreational pastimes on CRSP reservoirs.
LAKE POWELL

Lake Powell is the name given the reservoir behind Glen Canyon Dam. The lake, because of its vast visitor potential, has been designated a National Recreation Area, to be administered and developed somewhat like downstream Lake Mead behind Hoover Dam. Lake Powell was named in honor of John Wesley Powell, pioneer explorer who was the first to navigate the Colorado River. When filled to capacity, the lake will stretch 186 miles up the Colorado from the dam to nearly 40 miles above the old river ferry at Hite, Utah. One 70-mile-long arm of the lake will extend up the San Juan River.

Other substantial arms will also go up the Escalante River and other smaller tributary streams. The National Park Service will provide boating facilities from the very beginning of water impoundment. Cruising through the spectacular red-rock canyon country will soon be a popular American pastime. With the filling of Lake Powell, boaters will also be able to cruise up Aztec Creek to the famous Rainbow Bridge. They will be able to dock at facilities provided by the government and then walk to the beautiful arch. Picnic, camping and lodge facilities are also under development in several other areas along the shoreline. Fish of several varieties are also being planted.

FLAMING GORGE RESERVOIR

Boating will also be excellent on Flaming Gorge Reservoir in northeastern Utah and southwestern Wyoming. Even in the first summer of water storage (1963), boaters will be able to launch their boats near Linwood, Utah, and cruise through the spectacular, gaping jaws of the Flaming Gorge and down the Green River 25 miles to the damsite, passing through the pine-studded, purple rock walls of Red Canyon. When the reservoir is full, it will extend 90 miles up the river, almost to the town of Green River, Wyoming. As on Lake Powell, shoreline developments are being built on Flaming Gorge Reservoir, including boat launching facilities, picnic and campgrounds, as well as commercial recreation sites. The National Park Service and U.S. Forest Service are cooperating with local agencies in the planting of fish, protection of wildlife, and development of recreation.

NAVAJO RESERVOIR

Three principal recreation sites are under construction at Navajo Reservoir. The National Park Service is developing a major facility at Pine River, including launching ramp and picnic and camping areas. The government is also cooperating with the State Park Commission in New Mexico and agencies in Colorado for development and administration of other sites on the Navajo Reservoir shoreline. Navajo Reservoir like Lake Powell and Flaming Gorge Reservoir will be a boater’s paradise. Fish have already been planted for the fishermen.

OTHER RESERVOIRS

Funds are also being allocated for recreational development along the shorelines of participating project reservoirs as they are completed. These facilities consist primarily of boat docks, campgrounds, picnic areas and equipment, and sanitary facilities. The government is also cooperating with State fish and game departments in the development of fishing.

Right:
Placid waters of Lake Powell will back up into spectacular red rock country of Glen Canyon, creating a boater’s paradise.
Fishermen will line banks of CRSP reservoirs.

CRSP reservoirs will produce millions of hours of fishing enjoyment for Americans.
Upper Colorado River Commission
355 South 4th East Street
Salt Lake City, Utah

Right:
Aerial view of Glen Canyon damsite.

Back cover:
Aerial view of Navajo Dam.
POWER OPERATIONS CENTER

The CRSP Power Operations Center controls one of the most far-flung hydroelectric generation and transmission systems in the United States. The center includes administrative offices for operation and maintenance of the Colorado River Storage project's entire power system, warehouses, centralized maintenance shops, and a highly automated power dispatching center. It went into operation in 1965.

Montrose was selected as the center's site because it is near the geographical center of the power generation and transmission system and for its proximity to the unattended powerplants of the Curecanti Unit, which are now remotely controlled from the center. The center also performs the necessary maintenance for these plants. Montrose is near the Curecanti Substation, hub of the high voltage power lines. Its centralized microwave radio system provides reliable communications to generating plants and points of interconnection with other power systems.

The center contains facilities and equipment to control the operation of the project's widely separated powerplants, ranging in size from Glen Canyon in Arizona to Fontenelle in Wyoming. Control of power flows between the CRSP system and between interconnected systems is also provided.

INTERCONNECTED TRANSMISSION SYSTEM

The Bureau of Reclamation has built a backbone system of high voltage transmission lines totaling 1,800 miles to carry CRSP power to key load points in the marketing area.

The CRSP system serves as a vital link in tying together public and private power systems to the north, south, east, and west.

In October 1964, the CRSP lines were used to interconnect systems of the Pacific Northwest and the Pacific Southwest. On February 7, 1967, all major power systems, including the CRSP, were tied into a nationwide grid.

These interconnections now enable the marketing and exchange of CRSP power beyond the area of the project. Likewise, other power systems can exchange power with each other through the CRSP transmission system.
HYDROPOWER FOR THE GROWING INTERMOUNTAIN WEST

Electric power needs are increasing rapidly as the economy of the Intermountain West expands and diversifies. Part of this demand is met by the hydroelectric power produced at the CRSP dams and powerplants. CRSP power output goes to more than 200 qualified preference user organizations, as required by Federal Reclamation law, throughout the marketing area covering the Intermountain West.

Power generated by the CRSP powerplants, with about 1,300,000 kilowatts of installed capacity, is marketed in Arizona, New Mexico, Utah, Colorado, Wyoming, and portions of California and Nevada. When in full operation, an average of six billion kilowatt hours annually will be sold from the CRSP. Power marketed by the CRSP will be sufficient to supply a city of almost two million people.
MORROW POINT DAM

SERVING A VITAL NEED
RECREATION AT CRSP RESERVOIRS

The dams from which CRSP power is derived and resulting man-made lakes provide extensive recreational opportunities for public use and enjoyment. Lake Powell, formed by Glen Canyon Dam, will be 186 miles long when full and have a shoreline of 1,960 miles. The National Park Service is cooperating by developing many recreation centers along its beautiful shores. Opportunities for water sports, fishing, and sightseeing are unlimited.

At Flaming Gorge, the U.S. Forest Service is similarly developing recreational sites in cooperation with the Bureau of Reclamation, U.S. Fish and Wildlife Service, and State and local agencies. At the Curecanti Unit and Navajo Reservoir, the National Park Service has this responsibility. Fish have been planted, boat ramps built, and picnic and campgrounds provided. Where smaller reservoirs are built, recreational facilities are planned by the National Park Service and the basic recreation needs provided. These smaller reservoirs are visited and enjoyed by thousands of people each year.

LAKE POWELL

THE COLORADO RIVER STORAGE PROJECT

The CRSP is a basinwide program for development and use of the water resources of the upper Colorado River, and is one of the most complex and extensive river water resources developments in the world. It takes in the drainage area of the Upper Colorado River Basin, encompassing parts of Wyoming, Utah, Colorado, Arizona, and New Mexico—about one-twelfth of the continental area of the United States. CRSP storage units (Glen Canyon Dam, Flaming Gorge Dam, Navajo Dam, and the Curecanti Unit dams) even out the erratic flows of the Colorado River and its main tributaries so that commitments to the Lower Basin States—California, Arizona, and Nevada—can be met even in years of low flow. The remaining water in the Upper Basin can then serve the needs of farmers, municipalities, and industries. Delivery of water to consumers is the job of the participating projects.
Seven participating projects have been completed and six more are under construction. Additional units may be built in coming years.

The cost of the CRSP and participating projects now authorized for construction totals approximately $1.9 billion dollars. Costs allocated to power and to municipal and industrial water must be repaid to the Federal Government, with interest, as required by law. Some of the money will come from the sale of water. Much more will come from the sale of hydroelectric power produced at Glen Canyon, Flaming Gorge, Curecanti Unit, and powerplants of the participating projects. Power revenues will pay a major share of the reimbursable costs, while irrigation, municipal, and industrial water users will repay the balance.

The CRSP Power Operations Center is responsible for the operation and maintenance of the storage units, powerplants, and approximately 1,800 miles of high voltage backbone transmission lines.

FOR INFORMATION

If you have questions about the CRSP or its Power Operations Center, please contact: CRSP Power Operations Office, Bureau of Reclamation, Box 1069, Montrose, Colo. 81401, or Region 4, Bureau of Reclamation, Box 11568, Salt Lake City, Utah 84111.

MOTION PICTURES

A number of excellent motion pictures can be obtained from the Bureau of Reclamation. All are 16-mm sound films and nearly all are in color. For a list of films available and to borrow prints for showings, write to: Film Management Center, Bureau of Reclamation, Bldg. 67, Denver Federal Center, Denver, Colo. 80225.
This folder describes Bureau of Reclamation projects on the lower Colorado River. These have been largely responsible for the tremendous development of the Pacific Southwest during the past several decades and they figure prominently in plans for the even greater future development which must be realized if this potentially rich area is to fulfill its manifest destiny.

Reclamation-constructed works irrigate more than a million acres in the lower Colorado today. Water stored and regulated by Hoover and other Reclamation dams on the lower Colorado River supplements the municipal and industrial needs of 10 million people and generates an average of 4.5 billion kilowatt-hours of hydroelectric energy annually. The clear reservoirs and river stretches created by these dams provide recreation and fish and wildlife habitats.

However, with millions of people flocking to the area, the need for water and electric power is increasing at an alarming rate. The impressive record already achieved by the Reclamation program in the lower Colorado Basin must be surpassed to meet these requirements, and plans are being formulated to accomplish this objective.

**HOOVER DAM**

Hoover Dam—selected by the American Society of Civil Engineers as one of this Nation’s Seven Modern Civil Engineering Wonders—is the key feature of the Boulder Canyon Project, authorized in 1928.

Hoover Dam provides all of Reclamation’s multipurpose benefits—flood protection, river control, water storage and conservation of water for irrigation, municipal and industrial uses, generation of low-cost hydroelectric energy, improvement of navigation, recreation, and preservation of fish and wildlife.

Located on the Colorado River between Nevada and Arizona, Hoover Dam was without precedent—the greatest such structure of its day. This arch gravity dam rises 726.4 feet above bedrock. Its reservoir, Lake Mead—backing up 115 miles behind the dam and capable of storing nearly 30 million acre-feet of water—is still this hemisphere’s largest manmade reservoir. Under supervision of the National Park Service, the Lake Mead National Recreation Area—including Lakes Mead and Mohave—attracts more than 3 million visitors each year.

Construction of Hoover Dam started in 1931 and was completed in 1935. The Hoover Powerplant generated its first commercial power on October 26, 1936. The 17th and last generator was placed in commercial operation on December 1, 1961, raising the plant’s nameplate capacity to 1,344,600 kilowatts.

**SOUTHERN NEVADA WATER PROJECT**

The Southern Nevada Water Project will deliver municipal and industrial water from Lake Mead to one of the fastest-growing areas of the country. The area to be served includes the cities of Las Vegas, North Las Vegas, Henderson, and Boulder City, and Nellis Air Force Base. The initial stage of the Project will divert up to 132,000 acre-feet annually from Lake Mead, which is part of Nevada’s allocated share of Colorado River water.

Project works will consist of intake facilities at Lake Mead, eight pumping plants, a 3.8-mile-long, 10-foot-diameter tunnel through River Mountains, and approximately 35 miles of pipeline. Construction of the Project began in the spring of 1968, with the first delivery of water scheduled for the summer of 1971.

*Showing feature locations of the Southern Nevada Water Project. This aerial view looking west shows Lake Mead, Lake Mead Marina, and Saddle Island in foreground. River Mountains are shown in center. Henderson and Las Vegas are barely visible in upper portion.*

**MEAD SUBSTATION**

Mead Substation, near Boulder City, Nev., is the southern terminal of one of the two 750-kilovolt, direct-current transmission lines of the Pacific Northwest-Pacific Southwest Intertie, interconnecting the power resources of the Pacific Northwest with Hoover Dam Powerplant and the power systems of the Pacific Southwest. The Bureau of Reclamation will construct the
southern portion of the direct-current line from Mead Substation to the Oregon border, a distance of 551 miles. The Bonneville Power Administration will construct the remainder of the line to Celilo Substation near The Dalles, Oreg.

At Mead Substation, 42 converter valves will change alternating current to direct current for transmittal to the Northwest, or change direct current from the Northwest to alternating current for use in the Southwest. Mead Substation will also contain the alternating-current facilities such as transformers, lightning arresters, circuit breakers, reactors, and switches to implement the interconnection of 13 major alternating-current lines with the direct-current terminal.

The Bureau of Reclamation has completed a 345,000-volt, alternating-current transmission line from Mead Substation to Liberty Substation near Phoenix, Ariz., where it interconnects with power systems which serve loads in that area.

![Artist concept of Mead Terminal](image)

**PARKER-DAVIS PROJECT**

Davis Dam and Powerplant, Parker Dam and Powerplant, and a 1,600-mile transmission system, serving Nevada, California and Arizona, comprise the Parker-Davis Project.

**Davis Dam**

Davis Dam was built primarily for regulation, at the International Boundary, of Colorado River water delivered to Mexico as required by the Mexican Water Treaty. The Davis reservoir—Lake Mohave—is used for that purpose through integrated operations of the Hoover and Davis Powerplants. Recreation and fish and wildlife preservation are also among Davis Dam's benefits. The Davis Powerplant—with an installed capacity of 225,000 kilowatts—teams with the Hoover and Parker Powerplants to serve markets in the Pacific Southwest.

Davis Dam is a 1,600-foot-long, earth- and rock-fill embankment, 140 feet high above riverbed, with a concrete-gated spillway, intake structure, and semi-outdoor powerplant. Construction of Davis Dam began in 1946 and was completed in 1953. The Davis Powerplant generated its first power in 1951.

Capable of storing 1,818,000 acre-feet of water, Lake Mohave when full extends to the Hoover Dam tailrace 67 miles upstream. The lake is part of the Lake Mead National Recreation Area, administered by the National Park Service.

![Davis Dam](image)

**Parker Dam**

Parker Dam, 88 miles downstream from Davis Dam, was designed and constructed by the Bureau of Reclamation with funds advanced by the Metropolitan Water District of Southern California. Parker Dam primarily provides a forebay and desilting basin for the District's Colorado River Aqueduct, which delivers water to the Los Angeles and San Diego metropolitan areas. The Parker Powerplant, interconnected with the Hoover and Davis Powerplants, supplies hydroelectric energy over the Parker-Davis Project transmission system.

![Parker Dam](image)
Construction of Parker Dam began in 1934 and was completed in 1938. Construction of the powerplant began in 1939. The plant, with an installed capacity of 120,000 kilowatts, generated its first energy December 13, 1942.

Parker Dam is a concrete variable radius arch structure with about two-thirds of its structural height of 320 feet below the riverbed. The dam's 45-mile-long reservoir, Lake Havasu, is capable of storing 648,000 acre-feet of water. Lands bordering the reservoir are in the Lake Havasu National Wildlife Refuge, administered by the Fish and Wildlife Service.

CENTRAL ARIZONA PROJECT

Authorized, but yet to be constructed, the Central Arizona Project will deliver water from the Colorado River to the Phoenix and Tucson areas for agricultural, municipal, and industrial uses. Pumping plants will lift water over 900 feet from the Bill Williams River arm of Lake Havasu upstream from Parker Dam to the Granite Reef Aqueduct, by which it will flow to Orme Dam and Reservoir on the Salt River near Phoenix. Utilizing additional pump lifts, the Salt-Gila Aqueduct will transport water on to Tucson. Charleston Dam and Reservoir on the San Pedro River will store water which will flow to Tucson via the Tucson Aqueduct. Other major Project features include Buttes Dam and Reservoir on the Gila River in Arizona; Hooker Dam, or suitable alternative, on the Gila River in New Mexico; and water salvage projects along the main stem of the lower Colorado River in Arizona. The Colorado River water imported by this multipurpose Reclamation development will aid greatly in reducing the annual ground-water depletion in the Project area.

This multipurpose Reclamation development will make it possible for the Central Arizona Project area to utilize an annual average of 1.2 million acre-feet of the State's legal allocation of 2.8 million acre-feet of water from the Colorado River.

COLORADO RIVER FRONT WORK AND LEVEE SYSTEM

Since 1949, Reclamation has engaged in an extensive river management program involving dredging and bankline revetment work along the Colorado River below Davis Dam. The primary goals of this multipurpose program are water salvage, additional flood protection, river stabilization, sediment control, and preservation of recreation and fish and wildlife resources in the area.

Thirty-two miles of the river in the Mohave Valley downstream from Davis Dam were dredged and changed from a shallow, braided, actively meandering river to a deep, free-flowing channel. An additional 16 miles of similar channel restoration and construction will soon be completed in the Cibola Valley south of Blythe, Calif. Water formerly lost will be saved for much needed use by farms and cities in the arid Southwest.

Portions of the river in the Parker and Palo Verde Valleys have been stabilized by land-based equipment. The completed work consists primarily of river-training and bank-protective structures. Two sediment settling basins—one above Topock, Ariz., and the other below Imperial Dam—have been created to trap large quantities of sediment eroded from upstream sources. Dredges pump the sediment from each basin onto adjoining land as required.

PALO VERDE DIVERSION PROJECT

Palo Verde Diversion Dam was completed in 1957. It diverts water into the Palo Verde Irrigation District's canal system, serving 87,500 acres in California's Palo Verde Valley.

The 1,300-foot-long, 50-foot-high, earth- and rock-fill dam spans the Colorado 214 miles downstream from Hoover Dam.
A drain 21 miles long and a levee 30 miles long on the Arizona side upstream from the dam are features of the Project. These works protect lands on the Colorado River Indian Reservation against floods, and intercept drainage water.

The dam provides farmers in the Palo Verde Valley with their first assured means of gravity diversion.

**SENATOR WASH DAM AND REGULATING RESERVOIR**

Senator Wash Dam and Regulating Reservoir is an off-stream pumped-storage development on the California side of the Colorado River 2 miles upstream from Imperial Dam. This 94-foot-high earthfill embankment structure and its reservoir are designed to save water and improve deliveries to water users in the United States and Mexico. Water in excess of scheduled deliveries is lifted from the river behind Imperial Dam by six dual-purpose pump-generators into the regulating reservoir. With a usable capacity of 12,250 acre-feet, the reservoir saves up to 170,000 acre-feet of water a year, enough to irrigate 27,000 acres of land or supply the municipal and industrial needs of one-half million people. As water releases are made back to the river, hydroelectric energy is generated and fed into the Parker-Davis Project transmission system. These pump-generators have a rated generating capacity of 1,200 kilowatts each for a total generating capacity of 7,200 kilowatts. The sale of this power helps offset the costs for pumping. The facility also provides recreation and fish and wildlife opportunities.
2,200 cubic feet per second. Imperial Dam, 3,475 feet long, raises the river level 23 feet at the dam. Construction of the dam and desilting works began in 1936 and was completed in 1938. The desilting works prevent vast quantities of riverbed sediment from entering the canals and creating operation and maintenance difficulties.

ALL-AMERICAN CANAL SYSTEM

The All-American Canal System—including Imperial Dam and Desilting Works on the Colorado River, the All-American Canal and its major branch, the Coachella Main Canal—was authorized under the Boulder Canyon Project Act of 1928, which also approved Hoover Dam.

Imperial Dam, 300 miles below Hoover, diverts water from the Colorado River on the California side into the All-American Canal, and on the Arizona side into the Gila Gravity Main Canal. The All-American Canal delivers water to the Imperial and Coachella Valleys of southern California and to the Yuma Project in southwestern Arizona and southeastern California. The Gila Gravity Main Canal carries water to the Gila and Yuma Auxiliary Projects.

The All-American Canal has a capacity of 15,155 cubic feet per second, and the Gila Gravity Main Canal

Grapefruit waiting to be shipped to processing plant near Indio, Calif.

The All-American Canal proper serves about 530,000 irrigable acres of land on the Imperial Division, while the Coachella Main Canal delivers water to some 78,000 acres on the Coachella Division, both in southern California. The canal also furnishes water to 67,000 acres on the Yuma Project in California and Arizona.

Hydroelectric energy is generated at plants constructed by the Imperial Irrigation District on the All-American Canal at Drops Nos. 2, 3, and 4, and at Pilot Knob Check and Wasteway.

Started in 1934, the All-American Canal delivered its first water to Imperial Valley in 1941. One of the world’s largest canals, it extends westward 80 miles, north of the Mexican border to Imperial Valley. The 123-mile Coachella Main Canal branches from the All-American Canal 20 miles west of Yuma and runs northwesterly to the Coachella Valley. The branch canal was completed in 1948, and its underground lateral system in 1952.

Imperial Valley crops include alfalfa hay and seed, cotton, sugar beets, winter vegetables, barley, flax, cantaloupes, and sorghum. The Coachella Valley produces winter vegetables, dates, table grapes, citrus fruit, and cotton.
YUMA PROJECT

This project is the oldest Reclamation development on the Colorado River and one of the first to be authorized (1904) and constructed. About 52,000 of the Project's 67,000 cultivated acres lie in Arizona and the remainder in California.

Laguna Dam, 13 miles north of Yuma on the Colorado River, was the Project's original diversion structure. Construction, started in 1905, was completed in 1909. First water deliveries began in 1910.

Water for the Project is diverted into the All-American Canal at Imperial Dam, 5 miles upstream from Laguna. The Project's 1,600-kilowatt Siphon Drop Powerplant generated the first hydroelectric energy on the Colorado River in 1926.

Yuma Valley produces alfalfa hay and seed, winter vegetables, cantaloupes and watermelons, cotton, sorghums and small grains, pasture crops, and some citrus. Feed crops provide for seasonal feeding and pasturing of livestock.

GILA PROJECT

The Project's 112,000 acres of irrigable valley and mesa lands lie along the Colorado and Gila Rivers in southwestern Arizona.

Project water is diverted at Imperial Dam to two divisions—the Yuma Mesa and the Wellton-Mohawk. The Gila Gravity Main Canal takes this water from the dam 21 miles southeast to the Yuma Mesa Pumping Plant, where it is lifted 52 feet to the head of the Mesa distribution system. The Wellton-Mohawk Canal, diverting from the Gila Gravity Main Canal 15 miles below Imperial Dam, extends along the Gila River eastward for 18 1/2 miles, then branches into the smaller Wellton and Mohawk Canals.

The Gila Project system delivered its first water to the Yuma Mesa Division in 1943, and to the Wellton-Mohawk Division in 1952.

YUMA AUXILIARY PROJECT

Containing 3,406 acres devoted to growing grapefruit, oranges, and lemons, this Project lies on the Yuma Mesa in Arizona about halfway between Yuma and Mexico. As authorized in 1917, the Project comprised 45,000 acres, of which only a limited area could be served through constructed works. Legislation passed in 1949 reduced the Project's boundaries to include the present area because the remaining arable land could be served better through the Yuma Mesa Division of the Gila Project. Colorado River water for the Project is diverted at Imperial Dam through the Gila Project canal system.

The Wellton-Mohawk Division's 75,000 acres of irrigable lands are along the Gila River and on bordering Mesa areas. Three large pumping plants along the Wellton-Mohawk Canal lift water a total of 170 feet. Two smaller plants lift water an additional 39 and 30 feet, respectively, to higher lands adjacent to the Mohawk Canal. Smaller relift pumps are scattered throughout the division.

The Yuma Mesa Division contains 37,000 acres of irrigable land, 20,000 of which are on the Yuma Mesa. The North and South Gila Valley units contain 17,000 acres.
The Yuma Mesa grows citrus, alfalfa hay and seed, grapes, and grains. Alfalfa, cotton, flax, cantaloupes, winter vegetables, small grains, and Bermuda grass seed are grown on the Wellton-Mohawk Division. Cattle and sheep brought from summer ranges are wintered on irrigated pastures of the Project before being shipped to feed lots and markets.

SALT RIVER PROJECT and adjacent areas

The Salt River Project in central Arizona, authorized in 1903, was the Bureau of Reclamation's first large multipurpose water resources project. The original Project, including Theodore Roosevelt Dam and Powerplant on the Salt River, Granite Reef Diversion Dam downstream, and a repaired and revamped canal network, was placed in service in 1910 and completed in 1911. The Project, with subsequently constructed diversion works, canals, laterals, and several smaller powerplants along the canals, was turned over to the Salt River Valley Water Users' Association for operation in 1917. The Association, between 1922 and 1930, constructed Horse Mesa, Mormon Flat, and Stewart Mountain Dams on the Salt River below Theodore Roosevelt Dam. Cave Creek Dam was built in 1923 by local public and private organizations for flood control. Private interests constructed Carl Pleasant Dam in 1928 on the Agua Fria for irrigation. That same year, the Bureau of Indian Affairs completed Coolidge Dam on the Gila River to store water for the San Carlos Irrigation Project and to generate power. Then between 1936 and 1939, the Bureau of Reclamation built Bartlett Dam on the Verde River, major tributary to the Salt River. Horseshoe Dam, upstream from Bartlett, was completed in 1945 as a World War II emergency measure and is now used by the Salt River Valley Water Users' Association.

The Salt River Project proper includes 238,000 irrigable acres of land. Another 96,000 acres adjacent to the Project receive supplemental water from the Project. Private developments, largely irrigated from wells, include about 300,000 acres. Winter fruits and vegetables, alfalfa, cotton, grain, citrus, and livestock are the Salt River Project's main agricultural products.

COLORADO RIVER FILMS

The Bureau of Reclamation has produced two 16-millimeter sound motion pictures on the development of the lower Colorado River. They are THE STORY OF HOOVER DAM and CORRALLING THE COLORADO. Free loan prints are available. Borrowers are required to pay return postage only. Address requests to the Chief Engineer, Bureau of Reclamation, U.S. Department of the Interior, Building 67, Denver Federal Center, Denver, Colo. 80225.

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PARKER DAM and POWERPLANT

ARIZONA • CALIFORNIA • NEVADA
PARKER-DAVIS PROJECT

Parker Dam is one of a series of structures built on the lower Colorado River by the Bureau of Reclamation which has transformed the unruly river into a useful servant. A primary function is to provide a forebay from which the world-famous Colorado River Aqueduct takes off to supply municipal and industrial water to the metropolitan area of southern California.

The dam and powerplant are major features of the Parker-Davis Project, which was established by the consolidation of the Parker Dam Power Project and the Davis Dam Project, authorized by an act of Congress dated May 28, 1954 (68 Stat. 143).

The Parker-Davis Project also includes Davis Dam and Powerplant and a transmission system serving power market areas in southern Nevada, southern California, and Arizona. The project is headquartered at Phoenix, Ariz. The Central System Dispatching Office in Phoenix is the "nerve center" of the Parker-Davis Project transmission system, capable of directing the flow of several billion kilowatt-hours of Colorado River hydroelectric energy annually.

PARKER DAM and POWERPLANT

Parker Dam, named for the nearby town of Parker, Ariz., is a concrete, variable radius arch structure. Two-thirds of its structural height is below river bed. Men and machines excavated 235 feet before placing the dam's concrete foundation. This makes it the deepest dam in the world. Only 85 feet of its bulk protrude above the bed of the Colorado River. Parker's superstructure rises another 63 feet above the roadway that crosses the dam's top. Almost 380,000 cubic yards of concrete were placed in the structure.

Under an agreement between the Bureau of Reclamation and the Metropolitan Water District of Southern California, the latter paid essentially the entire cost of Parker Dam and the reservoir created thereby, Lake Havasu. The aqueduct intake is on this lake 2 miles upstream from the dam. Approximately half of the Parker power output is reserved by the district for pumping water along the aqueduct to the coast. The Bureau retains the other half of the power output and has responsibility for the operation and maintenance of the entire powerplant and control of all water passing the dam. The portion of costs chargeable to the Federal Government is being repaid from power revenues.

The Parker Powerplant includes a penstock gate structure, four penstock tunnels, and a powerplant building which houses four hydroelectric generating units.

MULTIPLE PURPOSES

Besides the main benefit of providing a forebay and desilting basin for the Colorado River Aqueduct, Parker Dam serves other purposes as well. It captures and delays the discharge of flash floods from tributaries below Davis Dam. It assists downstream irrigators by partially reregulating river discharges from the Hoover and Davis Powerplants.

That part of the Parker Powerplant's energy not used for pumping water through the aqueduct is used to turn the wheels of industry, pump water from wells to irrigate farmlands and water livestock, light homes and operate their many electrical appliances in the Pacific Southwest.
TRANSMISSION SYSTEM

The Parker-Davis Project transmission system interconnects Parker, Davis, and Hoover Power-plants and extends to Henderson, Nev., down the river to Blythe, Calif., and Yuma, Ariz., and into Arizona to Prescott, Phoenix, and on to Tucson and Cochise.

Additional transmission facilities of the Colorado River Storage Project interconnect with the Glen Canyon Powerplant, and transmission facilities of the Pacific Northwest-Pacific Southwest Intertie. The total system consists of 1,910 miles of high-voltage transmission lines serving 38 power substations, which contain a total of 4,533,083-kva. transformer capacity, located in Arizona, Nevada, and California.

COLORADO RIVER AQUEDUCT

Metropolitan Los Angeles recognized many years ago that supplying domestic and industrial water to its fast-growing population was one of its most pressing problems. The Metropolitan Water District of Southern California was organized in 1928 as a public corporation and was vested with the authority to plan, finance, build, and operate an aqueduct system to deliver water from the Colorado River to cities and areas within the district. In September 1931 the voters of the district authorized a bond issue of $220 million to finance construction of the aqueduct in its first development. In 1957 the Metropolitan Aqueduct was completed to its ultimate capacity of 1,212,000 acre-feet annually.

With the Bureau of Reclamation's Hoover Dam in control of the river, Parker Dam was constructed 155 miles downstream to form a forebay from which an aqueduct could draw off the needed water. The Bureau of Reclamation, which for many years had envisioned such a structure at that point on the river, constructed Parker Dam with funds advanced by the district from its $220 million bond issue.

Construction of the aqueduct and dam proceeded simultaneously. Bids for the construction of Parker Dam were opened June 26, 1934, and excavation began that same year. The first bucket of concrete was placed July 29, 1937, and the dam was completed September 1, 1938. Construction of the powerplant began in July 1939, and the first power was generated December 13, 1942.

The first delivery of Colorado River water to the Coast was made June 17, 1941. The San Diego Aqueduct, placed in service in December 1947, extended the benefits of the system as far south as San Diego.
THE PROJECT and THE DAM

STATISTICS

Parker Dam is .......................... 320 feet high
Its crest is .............................. 856 feet long
At top it is .............................. 39.5 feet thick
At bottom it is ......................... 100 feet thick
Concrete content ....................... 380,000 cubic yards
Earth excavation totaled .............. 2,502,900 cubic yards
Steel and metal used ................... 2,935,000 pounds
Valves, gates, hoists .................... 4,138,300 pounds
Its crest altitude is ..................... 455 feet
Lake Havasu when full ............... 45 miles long
Its available capacity is ............... 619,400 acre-feet
Its maximum depth is .................. 75 feet
When full it covers ..................... 25,000 acres or 39 square miles
Maximum elevation ..................... 450 feet above sea level

Parker Powerplant has ................ 4 generating units
Each generator is ....................... 30,000 kilowatts or kilovolt-amperes
Each turbine is rated .................. 40,000 horsepower
Powerplant's capacity is .............. 120,000 kilowatts or kilovolt-amperes, 160,000 horsepower
Maximum head is ...................... 78 feet
Penstocks, number of .................. 4
Capacity of each ....................... 5,500 cubic feet per second
Diameter of each ....................... 22 feet
Lake Havasu is a major recreational area. Havasu sports include fishing, boating, swimming, waterskiing, auto touring and "just plain relaxing." Facilities for public use, including campgrounds, trailer parks, cabins, and boat docks, are located at several points on the lake. Fishing tackle and licenses may be obtained from concessioners. A fishing license from either Arizona or California, to which a special-use stamp from the opposite State is attached, is required for those fishing in Lake Havasu or in the Colorado River. Large-mouth black bass, crappie, bluegill, and catfish are caught in both the lake and river below the dam.

**DAVIS DAM and POWERPLANT**

Davis Dam and Powerplant span the Colorado River in Pyramid Canyon 67 miles downstream from Hoover Dam and 88 miles upstream from Parker Dam. The Mexican Water Treaty required the United States to construct Davis Dam and reservoir. The treaty states that a part of the reservoir's capacity shall be used to make possible the regulation at the boundary of the waters to be delivered to Mexico. The Davis Dam reservoir, named Lake Mohave, is being used for that purpose through integrated operations of the Hoover and Davis Powerplants. Davis Dam also contributes to recreation, fish and wildlife protection, and related purposes. The Davis Powerplant adds substantially to the Colorado River hydroelectric energy pool, serving market areas in southern California, Arizona, and southern Nevada.
ENVIRONMENTAL CONSIDERATIONS

Realizing the importance of multiple use of our national resources, the Bureau works with Federal, State, and local agencies and citizens to ensure proper utilization of the natural resources associated with Reclamation's projects. The Bureau will continue to implement public laws, such as the National Environmental Policy Act, the Wildlife Coordination Act, and the Federal Water Projects Recreation Act, to protect and provide for better utilization of our resources.

COLORADO RIVER STORAGE PROJECT

In addition to Hoover, Davis, and Parker Dams in the Lower Basin of the Colorado River, the Bureau of Reclamation has built three large storage dams in the Upper Basin: Glen Canyon on the Colorado River in northeastern Arizona, Flaming Gorge on the Green River in northeastern Utah, and Navajo on the San Juan River in northwestern New Mexico. The Curecanti Unit now includes Blue Mesa and Morrow Point Dams on the Gunnison River in western Colorado. All these dams join with those in the Lower Basin in controlling the Colorado River and its tributaries, adding to Reclamation's multipurpose benefits along the stream's full length. The Storage Project also includes participating irrigation projects scattered throughout the Upper Basin States.

The Parker-Davis Project supervised the construction of the Pinnacle Peak Substation and the Flagstaff-Pinnacle Peak portions of two 345-kilovolt transmission lines between Glen Canyon Powerplant and Pinnacle Peak Substation. The Parker-Davis Project operates and maintains these Storage Project facilities, which were constructed to permit delivery of Storage Project power to Arizona.

SELF-GUIDED TOURS

The powerplants at both Parker Dam and Davis Dam are open to the public at no charge 7 days a week from 8 a.m. to 5 p.m. Short recorded lectures, illustrated maps, and closeup views of major features of a powerplant make the tours educational, as well as entertaining. Special arrangements for guided-group tours can be made by writing to the Project Manager, Parker-Davis Project Office, P.O. Box 6457, Phoenix, Arizona 85005.

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

[Revised 1972]

U.S. DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary
Bureau of Reclamation
Ellis L. Armstrong, Commissioner
PHYSICAL DATA

THE DAM
It is ........ 726.4 feet high  At top it is .... 45 feet thick
Its crest is . 1,244 feet long  At bottom it is . 660 feet thick
It contains 3 1/4 million cubic yards of concrete.

THE RESERVOIR
Lake Mead when full is ............... 110 miles long
Its available capacity is .............. 26.2 million acre-feet
Its maximum depth is .................. 500 feet
It covers ................................ 157,900 acres
All figures are for the reservoir filled to the top of the spillway gates in the raised position—elevation 1221.4 feet.

THE POWERPLANT
Its capacity is 1,344,800 kilowatts
Its 17 large generators are rated at:
   One ........ 95,000 kilowatts
   Fourteen, 82,500 kilowatts each
   One ........ 50,000 kilowatts
   One ........ 40,000 kilowatts
Each of its 2 station service generators is rated at 2,400 kilowatts.
Its 17 large turbines are rated at:
   Fifteen, 115,000 horsepower each
   One .... 70,000 horsepower
   One .... 55,000 horsepower
Each of its 2 station service turbines is rated at 3,500 horsepower.

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U.S. DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary
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Revised 1972
BIRTH OF A PROJECT

HOOVER DAM WAS BORN OF NECESSITY

The Colorado River, for centuries, in its wild 1,400-mile descent from the lofty Rocky Mountains to the Pacific Ocean, had gouged great chasms such as Grand Canyon. Fed by melted snows in the spring and summer, the river yearly flooded low-lying farmlands along its route. Then in later summer and fall, the river dried to a trickle. Early settlers diverted water from the river with little success. There was either too much or too little. Floods destroyed crops, lives, and property, and often crops and livestock withered and died when the river ran too low to be diverted.

The disastrous flood in 1905–07 which swept through Imperial Valley in southern California provided added incentive for action. The Colorado River had to be controlled and regulated, but it was a long, drawn-out job.

Representatives of the 7 Colorado River Basin States met in Sante Fe, N. Mex., in 1922 and draft-
ed the Colorado River Compact. This agreement divided use of the river's water between the upper and lower basins and paved the way for construction of works to control, regulate, and utilize the stream's natural resources. The Congress in 1928 passed the Boulder Canyon Project Act, authorizing construction of Hoover Dam and the All-American Canal System.

Hoover Dam is the key to all downstream control and regulation. The All-American Canal System takes water, controlled and regulated by Hoover Dam, from Imperial Dam westward to the Yuma, Imperial, and Coachella Valleys—southward and eastward to the valley and mesa lands of the Gila and Yuma Auxiliary Projects. There has never been a flood or drought on lands served by the lower Colorado River since Hoover Dam began storing water in 1935.
RECLAMATION'S PIONEER PROJECT

Hoover Dam pioneered Reclamation's present-day giant multiple-purpose developments. Its benefits encompass the whole concept of river control.

The dam controls floods and stores water for irrigation, municipal and industrial uses, hydroelectric power generation, recreation, and fish and wildlife.

Hoover Dam's reservoir—Lake Mead—stores more than 2 years of average Colorado River flow. This water is released in a regulated, year-round flow to farms, homes, and factories downstream. Passing through Hoover's turbines, it generates low-cost hydroelectric energy for markets in Nevada, Arizona, and California.

Water stored in Lake Mead irrigates ¾ million acres of land in this country and nearly ½ million acres in Mexico. This water supplements the municipal and industrial needs of 10 million residents, and generates about 4.5 billion kilowatt-hours of hydroelectric energy annually. Sparkling clear reservoirs and river stretches, created by Hoover and other dams on the river, provide recreation for more than 10 million people each year. Fish and other wildlife abound in and around these bodies of water, once muddy and almost barren.

Hoover Dam changed the Colorado River from a natural menace to a national resource—strengthening the economy of the Pacific Southwest and the Nation.

WATER FOR FARMS

Colorado River water stored behind Hoover Dam irrigates some of America's richest farmlands. Valley and mesa lands in the warm desert climate along the river grow winter fruits and vegetables and other nonsurplus crops throughout the year for the Nation's dinner tables. Yearly gross income from these crops is high—averaging hundreds of dollars per acre.

Major irrigation developments which benefit from Hoover Dam's control and regulation of the Colorado River include the Palo Verde Valley, the Colorado River Indian Reservation, the Yuma and Gila Projects in Arizona, and the Imperial and Coachella Valleys in California. When water reaches its farthest point on the All-American Canal System—which diverts from the Colorado River at Imperial Dam, 300 miles downstream from Hoover Dam—it has traveled some 500 miles since leaving Lake Mead and has required 10 days to make the trip.

Wasted desert transformed into rich farmland.
WATER FOR CITIES

Hoover Dam’s regulation of the Colorado River assures municipal and industrial water for Los Angeles, San Diego, and other Pacific Southwest cities.

Since 1941, the Colorado River Aqueduct has delivered water from Lake Havasu behind Parker Dam to the Los Angeles metropolitan area. The San Diego Aqueduct, which began operations in 1947, taps the Colorado River Aqueduct to take water to the San Diego water system.

Parker Dam—155 miles downstream from Hoover Dam—provides a forebay and desilting basin for the Colorado River Aqueduct. Parker Dam was constructed with funds advanced by the Metropolitan Water District of Southern California. Part of the hydroelectric energy generated at Hoover and Parker Dams pumps water along the aqueduct. The 242-mile-long aqueduct has an annual capacity of 1,212,000 acre-feet, or a billion gallons of water a day. Five pumping stations lift this water 1,617 feet over mountain barriers between the Colorado River and the coastal plain.

Like Hoover Dam, the Colorado River Aqueduct was selected by the American Society of Civil Engineers as one of this Nation’s Seven Modern Civil Engineering Wonders.

Completed November 1, 1971, by the Bureau of Reclamation, the Southern Nevada Water Project is delivering water from Lake Mead to cities and industries in the Las Vegas metropolitan area.

WATER POWER FOR INDUSTRY

Hoover Dam is still one of the world’s largest hydroelectric installations, with a nameplate capacity of 1,344,800 kilowatts, provided by 17 large generating units and two station service units. The Hoover Powerplant became the world’s largest plant in 1939, but lost this distinction in 1949 to another Reclamation development, Grand Coulee Dam in Washington.

Hoover Dam’s first generator, N-2, began commercial operation October 26, 1936, and the 17th and last generator went on the line December 1, 1961—25 years later.

Hoover Dam’s approximate cost of $175 million is being repaid over a 50-year period with the exception of a $25 million flood control allocation which has been deferred, without interest, until 1987. The project has grossed approximately $311 million, with a net return to the Federal Treasury above operating costs of over $174 million, divided between principal and interest payments.

Hoover Dam energy is sold to both public and private agencies under contracts which expire in 1987. This energy is allocated as follows (by percent): States of Arizona and Nevada 17.6259 each, Metropolitan Water District of Southern California 35.2517, City of Burbank 0.5773, City of Glendale 1.8475, City of Pasadena 1.5847, City of Los Angeles 17.5554, and Southern California Edison Co. 7.9316.

The City of Los Angeles Department of Water and Power and the Southern California Edison Co. operate Hoover Dam’s generating equipment under contract as agents of the Federal Government.
WATER FOR RECREATION, FISH AND WILDLIFE

Hoover Dam and its Lake Mead have created one of America's most popular recreation areas. A 12-month season attracts more than 5 million visitors each year for swimming, boating, skiing, and fishing. Large-mouth bass, bluegill, black crappie, trout, channel catfish, and other species abound in the lake. There is no closed season on fishing, and anglers take large numbers of game fish each year.

Lake Mead—extending 110 miles upstream into the lower end of Grand Canyon and with a shoreline of 550 miles—was named in honor of Dr. Elwood Mead, Commissioner of Reclamation from 1924 to 1936.

The lake and surrounding area are administered by the National Park Service as part of the Lake Mead National Recreation Area. The area also includes Lake Mohave, which extends from the tailrace of Hoover Dam 67 miles downstream to Davis Dam.

The cold waters flowing through Lake Mohave—drawn from the depths of Lake Mead and stocked by the modern Willow Beach National Fish Hatchery—provide excellent trout fishing.

GUIDED TOURS

Bureau of Reclamation guides conduct visitors through Hoover Dam daily between 7:30 a.m. and 7:15 p.m. from Memorial Day through Labor Day, and from 8:30 a.m. to 4:15 p.m. daily the remainder of the year. In addition, an exhibit building, housing a model of a generating unit and a topographical model of the Colorado River Basin, is open to the public. More than 14 million visitors have gone through the dam and powerplant since the guided tours began in 1937. More than 600,000 people take the conducted tours each year.
HOOVER DAM
ONE OF THE SEVEN WONDERS

The American Society of Civil Engineers selected this pioneer Reclamation multipurpose project on the Colorado River in Black Canyon between Nevada and Arizona as one of this country’s Seven Modern Civil Engineering Wonders. A bronze plaque—mounted in a concrete pedestal on the upstream roadway parapet at the center of the dam with Arizona on one side and Nevada on the other—records this honor for visitors to see.

Hoover Dam was without precedent—the greatest dam construction of its day. This arch gravity dam—rising 726.4 feet above bedrock—still holds the distinction of being the western hemisphere’s highest concrete dam. And its reservoir, Lake Mead—backing up 110 miles behind the dam and capable of storing 28.5 million acre-feet of water, including dead storage—is still this country’s largest man-made reservoir.

Hoover Dam is 660 feet thick at its base, 45 feet thick at its crest, and stretches 1,244 feet across the canyon. Some 4,400,000 cubic yards of concrete were placed in the dam, powerplant, and related structures.

Bureau of Reclamation engineers designed Hoover Dam. The contract for construction was let to Six Companies, Inc. in 1931. The dam began impounding water in its reservoir February 1, 1935, and the last concrete was placed in the dam proper the following May 29. President Franklin Delano Roosevelt dedicated Hoover Dam on September 30, 1935. The dam was completed 2 years ahead of schedule. The powerplant structures were completed in 1936, and the powerplant’s first generator—N-2—went into commercial operation October 26 of that year. The 17th and final generating unit—N-8—went into commercial operation December 1, 1961, to complete the Hoover Powerplant, raising its nameplate capacity to 1,344,800 kilowatts—keeping it as one of the world’s largest hydroelectric installations.

In 1930, the Secretary of the Interior named Hoover Dam for Herbert Clark Hoover, 31st President of the United States. Later, the names Boulder Canyon Dam and Boulder Dam were used. Then, in April 1947, by Congressional action, the name Hoover Dam was restored.

HOOVER DAM
FILM AVAILABLE

A 28-minute, 16 mm. color film, “THE STORY OF HOOVER DAM,” is available upon request for showing to school and civic groups, clubs, and other public gatherings, and on television stations. Prints of this film may be ordered from the U.S. Department of the Interior, Bureau of Reclamation (code 922), Building 67, Denver Federal Center, Denver, Colorado 80225. There is no cost to the borrower except return postage.

The film tells the dramatic story of Hoover Dam’s construction and its impact on life in the Pacific Southwest. Pictures of construction of the dam, an internationally-known engineering achievement, are supplemented with more recent pictures of the big powerplant, recreation on Lake Mead, and developments downstream.
Parker-Davis Project

Davis Dam is one of a series of structures built on the lower Colorado River by the Bureau of Reclamation which has transformed the unruly river into a useful servant. A primary function is to regulate the flow of water to service the Mexican Water Treaty.

The dam and powerplant are major features of the Parker-Davis Project, which was established by consolidation of the Parker Dam Power Project and the Davis Dam Project, authorized by an act of Congress dated May 28, 1954.

The Parker-Davis Project also includes Parker Dam and Powerplant and a transmission system serving power market areas in southern Nevada, southern California, and Arizona. The Project is headquartered at Phoenix, Ariz. The Central System Dispatching Office in Phoenix is the "nerve center" of the Parker-Davis Project transmission system, and is capable of directing the flow of several billion kilowatt-hours of Colorado River hydroelectric energy annually.
Davis Dam and Powerplant

Davis Dam and Powerplant were constructed by the Bureau of Reclamation in Pyramid Canyon, 67 miles downstream from Hoover Dam and 88 miles upstream from Parker Dam. The site is about 10 miles north of the point where Arizona, Nevada, and California meet and about 32 miles by highway west of Kingman, Ariz.

The Davis Dam site originally was called "Bullshead" after a rock formation in the Canyon imagined by some to resemble the head of a bull. The site was renamed in 1941 in honor of the late Arthur Powell Davis, Director of Reclamation from 1914 to 1923, one of that small group of men whose early courage, foresight, and vision sparked the beginning of Colorado River development.

The Mexican Water Treaty of 1944 required the U.S. Government to construct Davis Dam and reservoir. The treaty states that a part of the capacity shall be used to make possible the regulation at the boundary of the waters to be delivered to Mexico. The Davis Dam reservoir (Lake Mohave) is being used for that purpose through integrated operations of the Hoover and Davis Powerplants. Davis Dam also contributes to recreation, fish and wildlife protection, and related purposes. The Davis Powerplant contributes substantially to the Colorado River hydroelectric energy pool.

Davis Dam, completed in 1953, is an earth and rockfill embankment with a concrete spillway, intake structure, and powerplant. Confined for most of its length between the steep walls of Pyramid, Painted, Eldorado, and Black Canyons, the lake is comparatively narrow—not more than 4 miles across at its widest point.

The dam, its powerplant, and appurtenant features were constructed at a cost of approximately $67 million. Except for contributions, primarily from the U.S. Bureau of Public Roads and the State of Arizona for bridge and highway construction, this cost is being repaid from power revenues.

The semi-outdoor-type Davis Powerplant is located on the Arizona side of the river, immediately downstream from the dam embankment. Water is delivered from the forebay to the powerplant through five 22-foot-diameter penstocks.

**Multiple Purposes**

Besides the main benefit of regulating the flow of Colorado River water to service the Mexican Water Treaty, Davis Dam and Lake Mohave serve other purposes as well. The lake captures and delays the discharge of flash floods from side washes below Hoover Dam and assists downstream irrigators by partially re-regulating river discharges from the Hoover Powerplant.

Energy from the Davis Powerplant is used to turn the wheels of industry, pump water from wells to irrigate farm-

A huge field of late lettuce, grown for the Nation's tables.
lands and water livestock, light homes and operate their many electrical appliances in the Pacific Southwest.

Transmission System

The Parker-Davis Project transmission system interconnects the Parker, Davis, and Hoover Powerplants and extends to Henderson, Nev., down the river to Blythe, Calif., and Yuma, Ariz., and into Arizona to Prescott, Phoenix, and on to Tucson and Cochise.

The Parker-Davis transmission facilities are interconnected with those of the Colorado River Storage Project at Pinnacle Peak Substation near Phoenix, and transmission facilities of the Pacific Northwest-Pacific Southwest Inter-tie, now under construction (1969).

Colorado River Storage Project

In addition to Hoover, Davis, and Parker Dams in the lower basin of the Colorado River, the Bureau of Reclamation has built three large storage dams in the upper basin: Glen Canyon on the Colorado River in northern Arizona, Flaming Gorge on the Green River in northeastern Utah, and Navajo on the San Juan River in northwestern New Mexico. Three smaller dams of the Colorado River Storage Project’s Curecanti Unit are being built on the Gunnison River in western Colorado. These dams will join with those in the lower basin in controlling the Colorado River and its tributaries, adding to Reclamation’s multipurpose benefits along the stream’s full length. The Storage Project includes participating multiple-purpose projects scattered throughout the upper basin States of Colorado, New Mexico, Utah, and Wyoming.

Nerve center of the Parker-Davis Project transmission system.
The Parker-Davis Project also includes the Pinnacle Peak Substation and the Flagstaff-Pinnacle Peak portions of two 345-kilovolt transmission lines between Glen Canyon Powerplant and Pinnacle Peak Substation. Parker-Davis Project personnel operate and maintain these Storage Project facilities, which were constructed to permit delivery of Storage Project power to Arizona.

**Recreation**

Lake Mohave, behind Davis Dam, is a part of the Lake Mead National Recreation Area administered by the National Park Service, a sister Department of the Interior agency to the Bureau of Reclamation. The area includes the reservoir and all public lands surrounding it, except for the area around the dam and the adjacent Government operating camp. Any inquiries relative to recreation should be addressed to the Superintendent, Lake Mead National Recreation Area, National Park Service, U.S. Department of the Interior, Boulder City, Nev., 89005.

The Lake Mohave region and the area along the Colorado River below Davis Dam provide a multitude of recreational possibilities, including fishing, boating, swimming, water-skiing, camping, picnicking and exploring, auto touring, photography, and “just plain relaxing.”

Facilities for public use are located at Katherine in Arizona near Davis Dam; at Cottonwood Cove, east of Searchlight, Nev.; at Eldorado Canyon, near Nelson, Nev.; and at Willow Beach, Ariz., 15 miles below Hoover Dam. Free public campgrounds are available at each of these locations where concessioners also have trailer parks, cabins, docking facilities, boat and fishing tackle equipment, and fishing licenses. A fishing license from either Arizona or Nevada, to which a special-use stamp from the opposite State is attached, is required for those wishing to fish on Lake Mead or Lake Mohave. Rainbow trout are found in the cool, clear waters at the upper end of Lake Mohave, while largemouth black bass are taken from the lower stretches of the lake.

**Parker Dam and Powerplant**

Parker Dam and Powerplant are 88 miles down the Colorado River from Davis Dam and Powerplant. Parker Dam provides a forebay and desilting basin for the 242-
mile Colorado River Aqueduct, constructed by the Metropolitan Water District of Southern California to deliver water to the Los Angeles and San Diego coastal areas. The dam assists Hoover and Davis Dams in controlling floods along the river and regulates the stream's flow for the benefit of downstream irrigation. Also, through interconnections with Hoover and Davis Powerplants, the Parker Powerplant furnishes hydroelectric energy over the Parker-Davis Project transmission system to load centers in Arizona, southern Nevada, and southern California and to the Metropolitan Water District for pumping into and along its Colorado River Aqueduct.

Parker Dam, a concrete, variable radius arch structure, was designed and constructed by the Bureau of Reclamation with funds advanced by the Metropolitan Water District of Southern California and was completed in September 1938. With Federal funds, construction of the powerplant began in July 1939, and the first power was generated December 13, 1942. The powerplant's four 30,000-kilowatt generators give it an installed capacity of 120,000 kilowatts.

Lake Havasu, with a total capacity of 648,000 acre-feet, backs up behind the dam 45 miles, covering 25,000 acres.

Motion Pictures

A number of excellent motion pictures can be obtained from the Bureau of Reclamation. All are 16-mm. sound films and nearly all are in color. For a list of films available and to borrow prints for showings, write to: Film Management Center, Bureau of Reclamation, Bldg. 67, Denver Federal Center, Denver, Colo. 80225.

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.
FOR A CAREFREE VISIT . . .

Camping. Camp in designated campgrounds or campsites. Keep your campsite clean and sanitary; place refuse in the receptacles provided. When camping from a vessel, return refuse to a landing and put it in a refuse container.

At Antelope Flat Campground and Lucerne Valley Campground there is a user’s fee during the season. The Federal Recreation Area Permit will admit the driver and passengers of a private automobile, or the purchaser regardless of mode of travel. Individual daily and seasonal permits can also be purchased.

Fishing. You can fish throughout the year at the National Recreation Area. A fishing license from either Utah or Wyoming is required. To the license must be affixed a special-use stamp from the other State if fishing within its boundary. Before fishing, read the current regulations. They can be obtained at ranger stations. Clean fish at designated sites—deposit refuse in cans provided for this purpose. Do not dump refuse into the lake.

Hunting and trapping are permitted at Flaming Gorge in accordance with Federal, State, and local laws, except in developed and concentrated public-use areas designated by the superintendent. Ask at the superintendent’s office to inspect the map on which those areas are marked.

Swimming is permitted only in designated places. Do not swim from unanchored boats, boat docks, or launching ramps!

Firearms and explosives. Carrying loaded firearms or explosives in developed or concentrated public-use areas is prohibited. In all other areas do not use firearms or explosives in a manner which would endanger persons or property.

Pets must be under physical control when in developed or concentrated public-use areas.

Keep clear of restricted areas. Construction is in progress at many points. If you are traveling through these areas, exercise caution. 

Obey warning signs.

Aircraft. Do not attempt to land aircraft in the National Recreation Area.

Fire is the area’s greatest enemy. Build fires only at designated places. Be sure your campfire is out before you leave it. Be careful with cigarettes and matches.

Accidents. Report all accidents or injuries to the appropriate agency.

Be sure that you comply with boating and fishing regulations of Federal and State agencies applicable to Flaming Gorge National Recreation Area.

ADMINISTRATION

Flaming Gorge National Recreation Area is jointly administered by the National Park Service, U.S. Department of the Interior, and the Forest Service, U.S. Department of Agriculture, under agreement with the Bureau of Reclamation, also an agency of the Department of the Interior.

A superintendent, whose address is Box 108, Dutch John, Utah 84023, is in immediate charge of the area administered by the National Park Service. The forest supervisor in charge of Ashley National Forest is in Vernal, Utah.

THE DEPARTMENT OF THE INTERIOR—the Nation’s principal natural resource agency—bears a special obligation to assure that our expendable resources are conserved, that renewable resources are managed to produce optimum benefits, and that all resources contribute to the progress and prosperity of the United States, now and in the future.

U. S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
Through spectacular canyons and arid, sagebrush valleys, Flaming Gorge Lake follows the ancient course of the Green River—opening a new world for boating, fishing, sailing, water-skiing and camping.

More than 90 miles long, Flaming Gorge Lake is flanked by the walls of Red and Horseshoe Canyons in the south, and by the rolling hills and occasional abrupt cliffs and promontories to the north. The shoreline ranges from low flat to cliffs more than 1,500 feet high. A few buttes rise above the general level of the uplands and stand out as landmarks in the otherwise rolling country.

The highly scenic canyon country in the south is within Ashley National Forest. With 7,000 acres of open water, it has several campgrounds, boat camps, and two boat-launching ramps. The remaining 187 square miles also offer many recreational opportunities. In the wide, shallow valleys north of the canyon area you will find excellent camp sites and boat-launching ramps.

Flaming Gorge Dam, constructed by the Bureau of Reclamation, rises 565 feet above bedrock in the Red Canyon of the Green River on the flanks of the Uinta Mountains. Storage capacity of the lake is 3.8 million acre-feet of water. Enough energy can be produced to supply the needs of an average city of 130,000 persons. The last bucket of concrete was placed in Flaming Gorge Dam on November 15, 1962; the first hydroelectric power was produced on November 11, 1963; the structure was dedicated on August 17, 1964.

ANCIENT AND MODERN MAN

On many cliff walls you will see ancient Indian petroglyphs, giving evidence that these native Americans at least passed through this area. To the aborigines, the Green River was known as the Sheeet-skadake—a Crow Indian word meaning prairie hen.

The part of the Flaming Gorge area in Wyoming once belonged to Mexico, but was annexed to the United States after the Mexican War. Parts of the area have been claimed by France, Spain, Britain, Mexico, the early state of California, and the Mormon state of Deseret, before becoming a part of the United States in the Territory of Dakota.

From 1824 to 1840, the fur trade flourished in the central Rocky Mountains. The sheltered valleys in the general region of Flaming Gorge were popular with traders and trappers because less snow was found there. This relieved mountain men of one of their most pressing problems—winter pasturage for their animals.

Only a few of the traders actually settled here. In 1834, John Robertson built a permanent home on Black's Fork to become the first white settler of the region. In 1842, Jim Bridger established a fort and trading post (today the town of Fort Bridger) to become the second. Flaming Gorge National Recreation Area lies south and southeast of the famous emigrant trails of the 1840's.

With Fort Bridger as a start, the cattleman's frontier moved to the reservoir area in the 1870's. This industry prospered early and has consistently remained the major enterprise.

The era of scientific exploration of the West also had its effect on the Flaming Gorge story. Princeton and Yale Universities and four Government agencies explored the area between 1868 and 1878. But it was John Wesley Powell, the one-armed major and professor, who initiated mapping and geological studies of the Green-Colorado River system and other western rivers. His first expedition left Green River, Wyo., in 1869, and passed through the area canyons. He named Flaming Gorge, Firehole Chimmneys, Red Canyon, Ashley Falls (now on lake bottom), Beehive Point, Kingfisher Canyon, and Harshness Canyon.

NATURE'S HANDWORK

Geology. The entire region is fascinating to the geologist—amateur or professional. Take time to study the twisted and distorted strata, produced by the thrust and exposed by erosion. Outstanding examples are located in Firehole Canyon and at the very portals of Flaming Gorge itself.

The National Recreation Area includes two very dissimilar geological situations. In the area within Wyoming, the rocks generally lie flat, one stratum upon the other, resembling the layers of a cake. They accumulated as silt and mud on the bottom of great fresh-water lakes which occupied much of what is now Wyoming during the early Tertiary period, some 40 million years ago. Fossils of ancient mammals occasionally have been found in these beds. The famous fish fossils of the Green River shale are found in similar formations farther to the north. These rocks are mostly light colored, soft and easily eroded by occasional flash floods and by wave action along the reservoir shore.

In the Utah section, colorful rocks, once lying flat, have been bent upward and forced into grotesque positions by tremendous earth movements which accompanied uplift of the Uinta Mountain Range some 60 million years ago. Most of these rocks were deposited as sediments in shallow areas. Erosion-resistant sandstones (such as the Blair and Frontier formations) stick out above and east-west ridges (such as the Hilliard and Momyer shales) have been washed away to produce narrow east-west valleys. These rocks are all of the Cretaceous period some 70 million years ago.

Possibly the most dramatic geological feature is the entrance to Flaming Gorge proper. Here the Green River has cut into steeply tilted layers of brightly colored rock of the Jurassic period (including the Morrison, Curtis, and Entrada formations and the cream-colored Navajo sandstone). The portals of Flaming Gorge have been of geologic interest since Powell's early explorations.

Plants and Animals. Most of the area's plant life is of the hillside and upland plain type. Dominant shrubs are sandalwood, big and little sagebrush, hopsage, grey mallee, winterfat, and little rabbitbrush. Principal trees include the narrowleaf cottonwood, river birch, juniper, pinyon, and yellow pine. More than 80 other plants grow here as well, many with blossoms of rare beauty and color, especially in spring and summer.

Mule deer, pronghorn, and American elk (wapiti) are common, particularly during spring and autumn. Skunks, cottontails, and predators like the coyote and bobcat are frequent. The badger, porcupine, and beaver are native, though not so common.

Summer residents of the reservoir area are the waterfowl—root, great blue and black-crowned night heron, American bittern, Canada goose, redhead, common merganser, pintail, and ruddy duck. Hawks, ospreys, and golden eagles are relatively common and you can see old eagle nests on cliffs in the canyon section. The sage grouse is a permanent resident, and the mourning dove is quite common.

The lake has been stocked with rainbow trout and kokanee salmon. While fishing in the reservoir, which lies in both Utah and Wyoming, a valid State fishing license must be in the possession of the angler at all times. (See section on Fishing.)
FLAMING GORGE
NATIONAL RECREATION AREA

- Campground
- Boat Camping
- Picnic Area or Overlook
- Launching Ramp
- Paved Road
- Gravel or Dirt Road

When to Visit

Flaming Gorge National Recreation Area is open all year. The normal visitation season is from mid-April to mid-November. Daytime temperatures in summer may reach 100°F, but nights are cool. Chilly weather is common in spring and autumn.

Winters are severe, with the thermometer occasionally dropping to -40°F, so come prepared with warm clothing. Due to fluctuating water levels, the ice on the reservoir is quite hazardous. You are therefore cautioned not to venture onto the ice; check with a ranger first!

How to Reach Flaming Gorge

From the north at Green River, Wyo., drive south on Wyo. 530.

From the south at Vernal, Utah, follow Utah 44 and 260 which lead to Dutch John and nearby camping and boating developments.

Unimproved dirt roads provide access to the eastern side of the reservoir in Wyoming. These are often impassable during rainstorms. Be sure to check with a ranger before traveling in this area.

Additional roads are under construction, including Utah 84 from Green River to Manila and from U.S. 30 leading southward along the east side of the reservoir. Inquire at the nearest ranger station regarding travel on these routes.

Major transportation facilities serve the nearby communities of Green River and Rock Springs, Wyo., and Vernal, Utah.

Development of Flaming Gorge

The National Park Service has constructed access roads and boat launching ramps at Lucerne Valley and Antelope Flat. Additional construction is planned which, when completed, will provide campgrounds, picnic areas, marinas, motels, restaurants, service stations, stores, and similar services.

Nearby Accommodations and Services

- Wyoming:
  - Green River
  - Rock Springs

- Utah:
  - Vernal
  - Manila
  - Dutch John
  - Flaming Gorge
  - Red Canyon Lodge

For Happy Boating...

Keep your boat in top shape. Be sure the hull is tight, bilges and engine clean, and all machinery and equipment in the best working condition.

Check equipment required by law and other equipment needed for safety and comfort.

Learn the “Rules of the Road”—who has the right of way, and the meaning of buoys.

Practice fire prevention. Be sure there is proper ventilation and no gasoline spillage or leakage.

Watch your speed. Waves from a speeding craft are annoying and dangerous to others.

Keep an eye on weather, wind, and currents. Don’t take chances; sudden, strong winds are common and can arise without warning. Be alert and prepared to head for shore and shelter.

Don’t overcrowd. An overcrowded boat is uncomfortable and unsafe. Conform with the manufacturer’s recommended capacity rating.

Know your boat—and its capabilities and limitations.

Always be alert when towing water skis, surfboards, and similar devices. Towing is permitted only from sunrise to sunset, and there must be two persons in the vessel, one as observer.
Colorado River - Salinity at the Mexican Border

Drainage pumps (p.p.m.)

\[ 3000000 \times 60000000 = 180000000000 \text{ T} \]

River release (ppm in river)

\[ 6000000 \times 8100000 = 48600000000 \text{ T} \]

Total flow to Mexico

\[ 48600000000 + 228600000000 = 228600000000 \text{ T} \]

Salinity at border (p.p.m.)

\[ \frac{228600000000}{9000000} = 25400000 \text{ T} \]
Memorandum

TO: Chief, Hydrology Branch

FROM: R. E. Glover

DATE: August 16, 1965

SUBJECT: Propagation of flow changes down the Colorado River

Purposes

Demands for irrigation water come into the Imperial Office on Wednesday of each week. Since it requires about 3 days for water released at Parker Dam to reach Imperial Dam, it is necessary to program the mean daily releases at Parker so that the water will be available at Imperial Dam when it is needed. This is done now by using factors derived from experience. It is suspected that these factors may be somewhat inaccurate because the constant demands on the river leave no opportunity for definitive experiments. There is good reason to suspect also that these factors may change somewhat with change of stage. A means of computing these factors from the stream properties would provide some new information on the characteristics of the response of the river to flow changes. It is the purpose of this memorandum to describe a formula for estimating these changes.

Propagation of Changes of Flow

This development will be based upon the following assumptions:

1. The flow is controlled by friction.

2. For changes varying by small amounts from the mean flow condition, flow changes can be assumed to be proportional to the slope changes.

3. The factor of proportionality $K$ can be evaluated from the stage-flow curves.

4. An increase of flow produces a step increase in stage which moves downstream at the mean velocity of flow $v$.

Conditions near the step are shown on Figure 1.

If $f$ represents the change of flow associated with the step then

$$f = -K \frac{\partial h}{\partial x}$$  \hspace{1cm} (1)\)
where \( \eta \) represents the increase of depth and \( x \) the distance measured from the step in the downstream direction.

The continuity condition is

\[
\frac{\partial f}{\partial x} \frac{dx}{dt} + \frac{\partial \eta}{\partial t} = 0
\]

where \( T \) represents the top width. This relation can be put into the form.

\[
\frac{\partial f}{\partial x} = - T \frac{\partial \eta}{\partial t}
\]  ... (2)

Elimination of \( f \) between (1) and (2) yields the differential equation.

\[
K \frac{\partial^2 \eta}{\partial x^2} = T \frac{\partial \eta}{\partial t}
\]  ... (3)

or if

\[
\alpha = K \frac{T}{L}
\]  ... (4)

The relation takes the form

\[
\alpha \frac{\partial^2 \eta}{\partial x^2} = \frac{\partial \eta}{\partial t}
\]  ... (5)

A solution satisfying the conditions that

\[
\eta + \eta_0 \quad \text{as} \quad x \to 0
\]  ... (6)

is, for \( x > 0 \):
\[ \eta = \eta_0 \left[ 1 - \frac{2}{\sqrt{\pi}} \int_0^{\sqrt{4\alpha t}} e^{-u^2} \, du \right] \quad \cdots (7) \]

**Example**

As an example of the use of this formula we can treat the stream as being represented by the Taylor Ferry Section at a flow of 10,000 ft³ per sec. Hydraulic considerations give the flow as

\[ F = Av = AC \sqrt{rS} \quad \cdots (8) \]

where
- \( A \) represents the area of the cross section (ft)²
- \( v \) the mean velocity of flow
- \( r \) the hydraulic radius
- \( S \) the slope maintaining the flow \( F \)
- \( C \) the Chezy coefficient

The change of flow as a function of the slope only is given by

\[ \frac{\partial F}{\partial S} = \frac{AC \sqrt{rS}}{2\sqrt{S}} = \frac{AC \sqrt{rS}}{2S} = \frac{F}{2S} \]

then

\[ K = \frac{F}{2S} \quad \cdots (9) \]

and

\[ \alpha = \frac{K}{T} = \frac{F}{2ST} \quad \cdots (10) \]

The wave front gradient is obtained from Equation (7) by differentiation with respect to \( x \). Then,

\[ \frac{\partial \eta}{\partial x} = -\frac{\eta_0 e^{-\frac{x^2}{4\alpha t}}}{\sqrt{x\alpha t}} \quad \cdots (11) \]
Application will be made to the reach of the Colorado River between Parker and Imperial Dams. The distance between these points is 147.0 miles or 776,160 feet. The section at Taylors Ferry will be taken as representative of the river hydraulics. From stage-flow tables for this section

\[
F = 10,000 \text{ ft}^3/\text{sec} \\
A = 3,284 \text{ ft}^2 \\
v = 3.045 \text{ ft/sec} \\
S = 0.00020268 \text{ (dimensionless)}
\]

The top width here is 354 feet but maps and photographs indicate that the top width is generally wider than this. A width of 800 feet will be used to obtain a realistic representation of the surface storage. This latter width is used in the evaluation of \( \alpha \). Then

\[
\alpha = \frac{10,000}{(2)(0.00020268)(800)} = \frac{10,000}{0.32428} = 30,840 \text{ ft}^2/\text{sec}
\]

With a velocity of 3.045 ft/sec the travel time between Parker and Imperial is

\[
\frac{776,160}{3.045} = 254,896 \text{ seconds or 2.950 days.}
\]

The computation is made in the manner shown in Table 1.

The first three columns are self-explanatory. Since the point of flow change is assumed to be carried along at the mean stream velocity the \( x \) distance is obtained by subtracting the distance moved by the point of flow change from the distance from Parker to Imperial. The next two columns are self-explanatory. The next column of figures is obtained from the relation

\[
\frac{\eta_{1}}{\eta_{0}} = \left[ 1 - \frac{2}{\sqrt{\pi}} \int_{0}^{\frac{x}{\sqrt{4\alpha t}}} e^{-u^2} \, du \right] \ldots (12)
\]
Value of \( \overline{\eta} \), for \( x \) positive, are obtained by multiplying the ratio \( \eta_1/\eta_0 \) by \( \eta_0 \). When \( x \) becomes negative \( \overline{\eta} \) should be interpreted as \( \overline{\eta} = 2\eta_0 - \eta_1 \). The value to be used for \( \eta_0 \) is one half the increase in depth due to the increased flow. This depth is 0.4105 feet. It is computed on the supposition that, for small changes, the velocity of flow remains unchanged and the top width is 300 feet. The flow due to the increased depth is obtained by multiplying the increased area of the cross section by the mean stream velocity. The next three columns are used for figures needed for estimating the increased gradient due to the slope of the wave front as given by Formula (11). The flow due to the slope of the wave front is obtained by use of (9) and (11) from the relation

\[
f_1 = \frac{F \eta_0}{2S} \cdot \frac{x^2}{4\alpha t} \cdot \frac{e}{\sqrt{\pi \alpha t}} \ldots (13)
\]

This implies that the flow is proportional to the gradient for small changes. The total flow increase is the sum of the flow due to increased depth and the flow due to increased slope. The factor of increase applies to flows at the end of the day. A similar factor for the mean daily flow is given in the next to the last column. Increments are shown in the last column. They are estimated by using Simpson's rule methods and the total flow increase values.

Comments

The wave propagation pattern obtained from the formulas given herein agrees well with the performance of the actual stream. Because both the stream cross sections and top widths vary widely along the course of the stream it will be difficult to fix accurately the proper values of the constants to be used on the basis of the hydraulics of the stream. It may be better to adjust them by trial to represent the actual performance of the stream.
### Table 1

**Base flow** 10,000 (ft³/sec)  
**Top width** 800 feet  

**Flow at Imperial due to 1,000 ft³/sec increase at Parker**

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Time (seconds)</th>
<th>( v_t )</th>
<th>( x )</th>
<th>( \sqrt{4ac_t} )</th>
<th>( \frac{x}{\sqrt{4ac_t}} )</th>
<th>( \frac{x^2}{e^{\frac{4ac_t}} \sqrt{4ac_t}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>776,160</td>
<td>0</td>
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<td>0.5</td>
<td>43,200</td>
<td>131,544</td>
<td>644,616</td>
<td>73,000</td>
<td>8.830</td>
<td>0.01547</td>
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<td>1.0</td>
<td>86,400</td>
<td>263,088</td>
<td>513,072</td>
<td>103,200</td>
<td>4.972</td>
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<td>1.5</td>
<td>129,600</td>
<td>394,632</td>
<td>381,528</td>
<td>126,400</td>
<td>3.018</td>
<td>0</td>
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<tr>
<td>2.0</td>
<td>172,800</td>
<td>526,176</td>
<td>249,984</td>
<td>146,000</td>
<td>1.712</td>
<td>0.01547</td>
</tr>
<tr>
<td>2.5</td>
<td>216,000</td>
<td>657,720</td>
<td>118,440</td>
<td>163,200</td>
<td>0.727</td>
<td>0.3038</td>
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<tr>
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<td>259,200</td>
<td>789,264</td>
<td>-13,104</td>
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<td>-0.073</td>
<td>0.9177</td>
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<td>302,400</td>
<td>920,808</td>
<td>-144,648</td>
<td>193,100</td>
<td>-0.749</td>
<td>2.8949</td>
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<td>345,600</td>
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<td>-1.337</td>
<td>0.0586</td>
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<tr>
<td>4.5</td>
<td>388,800</td>
<td>1,185,896</td>
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<td>219,000</td>
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<tr>
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<td>-539,280</td>
<td>230,800</td>
<td>-2.334</td>
<td>0.0096</td>
</tr>
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</table>

\[
\bar{\eta} = \eta > 0 \quad \text{Flow due to increase in depth (ft}^3/\text{sec})
\]

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>( 2\eta_0 - \eta ) for ( x &lt; 0 )</th>
<th>Flow due to slope of wave front (ft³/sec)</th>
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</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0.00318</td>
<td>0</td>
</tr>
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<tr>
<td>5.0</td>
<td>0.41050</td>
<td>5.448</td>
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</table>

\[
v_T = (800)(3.045) = 2,436
\]

\[
2\eta_0 = \frac{1,000}{(800)(3.045)} = 0.4105
\]

\[
\eta_0 = 0.20525 \text{ (ft)}
\]

\[
\frac{F_{\eta_0}}{28} = \frac{(10,000)(0.20525)}{2(0.00020268)} = 5,063,400
\]

\[
\frac{\sqrt{400}}{864-00} = 103240
\]

\[
\frac{\eta}{F_{\eta_0}} = 1.128380
\]

6
Table 1—Continued

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Total flow increase (ft³/sec)</th>
<th>Factor of increase (dimensionless)</th>
<th>Mean increase for the day (ft³/sec)</th>
<th>Increment of mean increase for the day (ft³/sec)</th>
<th>Factor of incremental mean increase (dimensionless)</th>
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<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<td>.627</td>
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<td>996.55</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>5.0</td>
<td>999.60</td>
<td>1.000</td>
<td>0</td>
<td>0</td>
<td>0.994</td>
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</table>
Fig. 1. Wave profile
WATER FLOWS AT MORROW POINT DAM

View from the crest access road

by V. Jetley
CURECANTI STORAGE UNIT

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

MORROW POINT DAM
Three dams on the Gunnison River...

MORROW POINT DAM

Construction of Morrow Point Dam and Powerplant was completed and power generation initiated in December 1970. The dam embodies three "firsts" in the Bureau of Reclamation's long history of outstanding engineering achievements:

1. The first large double-curvature, thin-arch, concrete dam to be built in the United States. Double-curvature design means that the dam curves not only from left to right but also from bottom to top. The dam is 469 feet high, 740 feet long, 52 feet thick at the base, 12 feet thick at the crest, and contains 365,000 cubic yards of concrete.
2. A unique free-fall spillway with four 15-foot-square openings in the crest of the dam and a stilling basin at the toe of the dam. If water should split from the reservoir, a spectacular free-fall of water would plunge from a height of more than 350 feet into the 60-foot-deep stilling basin.
3. An underground powerhouse in a room excavated in hard rock about 275 feet in from the canyon wall. The generator room is 50 feet wide by 202 feet long and the arched roof is 65 to 134 feet high. The powerhouse has a capacity of 117,000 acre-feet and covers an area of 817 acres, with a shoreline of 24 miles.

Morrow Point Powerplant contains two generating units with a total capacity of 120,000 kilowatts of electricity.

BLUE MESA DAM

Blue Mesa Dam, completed in December 1965, is a wedge of 3,080,000 cubic yards of earth and rock, 1,600 feet wide at its base and gently sloping to a narrow crest width of 30 feet. The dam rises 362 feet above streambed. It is 800 feet long at the crest.

The lake formed by the dam has a capacity of 940,800 acre-feet, covering 14.3 square miles with a shoreline of 96 miles. When filled to capacity, the lake is the largest in Colorado.

The lake provides water for irrigation, generation of electrical power, and recreation.

The powerplant consists of two generating units with a total capacity of 60,000 kilowatts of electricity.

CRYSTAL DAM

Construction of Crystal Dam and Powerplant began in 1972. Like Morrow Point, Crystal Dam will be a double-curvature, thin-arch concrete structure. The dam will be 507 feet high, 720 feet long, 29 feet thick at the base, 10 feet thick at the crest, and contain 143,000 cubic yards of concrete. The reservoir will have a capacity of 24,000 acre-feet, cover 308 acres, 6 miles long, with a shoreline of 19.6 miles. It will extend to the powerplant outlet discharge at Morrow Point Dam. The powerplant will have one generating unit of 28,000-kilowatt capacity.
THE CURENCTI UNIT

Since white settlers arrived in western Colorado in the 1880's, the Gunnison River has been a curse and a frustration. Spring floods often ravaged the low-lying valleys, yet the river always dwindled to a sickly stream in late summer, when irrigation water was desperately needed. One of the Bureau of Reclamation's first projects, the Uncompahgre Project (constructed from 1905 to 1912), successfully tapped the Gunnison River. Yet there was still no major dam to check the river's wide fluctuations.

Blue Mesa Lake, the major storage feature of the Curenti Unit, now serves to trap the raging spring floods. As the water is gradually released to meet downstream commitments, it generates hydropower at Blue Mesa and at Morrow Point Powerplants. When constructed, Crystal Powerplant will also add kilowatts to the CRSP system. Revenues from the sale of hydropower help to pay for the cost of the dams and the smaller units of the Colorado River Storage Project.

Construction of the three Curenti dams will cost about $120 million, much of which is spent locally. But more important are the long-range, stabilizing economic benefits to be derived in the coming years through the water and power resources developed by the Curenti Unit and other features of the Project.

THE CRSP

The long-range, basinwide development of water resources of the Upper Colorado River

The Curenti Unit is part of the comprehensive water resource plan known as the Colorado River Storage Project. Glen Canyon Dam, Flaming Gorge Dam, and Navajo Dam are also major units in the plan.

The CRSP Storage Units, including Curenti, supply long-term, carryover water storage and vital needed hydroelectric power. CRSP Participating Projects are delivering irrigation water to farmlands, as well as municipal and industrial water to many communities.

Additional Participating Projects are in various stages of planning or construction. Thus the CRSP and the Curenti are helping to make the economic future brighter in the four Upper Colorado River Basin States.

RECREATION

Blue Mesa Lake has brought boating to a semiarid country. From the inflowing Gunnison River down to the dam, the lake is 150 miles long, but its shoreline curves around 92 miles. Characterized by long arms and three large main-lake basins, the lake is suitable for boating, fishing, and water-skiing. Fishing from boat and shore in the heavily stocked lake is the most popular use.

POWER

From the three powerplants of the Curenti Unit will flow up to 208,000 kilowatts of hydroelectricity. This is enough power to supply the entire Western Slope of Colorado, or a city of over 300,000 population. From Montrose, the Power Operations Office of the CRSP dispatches power received from Curenti, from Glen Canyon Dam, from Flaming Gorge Dam, and from smaller plants. Interconnecting lines, both private and public, carry CRSP power to major metropolitan areas and to rural areas of the Intermountain West.

INFORMATION

If you have questions about the Curenti Unit, please write or contact: Construction Engineer, Montrose Construction Field Division, Bureau of Reclamation, 10th and Cascade, Box 1390, Montrose, Colorado 81401, or Upper Colorado Region, Bureau of Reclamation, Box 11568, Salt Lake City, Utah 84111.

MOTION PICTURES

A number of excellent motion pictures can be obtained from the Bureau of Reclamation. All are 16-mm. sound films and nearly all are in color. For a list of films available and to borrow prints for showings, write to: Film Management Center, Bureau of Reclamation, Bldg. 67, Denver Federal Center, Denver, Colo. 80225.

U.S. DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary
BUREAU OF RECLAMATION
Ellis L. Armstrong, Commissioner

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, minerals, land, park and recreational resources. Indian and Territories affairs are other major concerns of America's "Depart-
ment of Natural Resources."

The Department works to assure the widest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

[1972]
CURECANTI UNIT

COLORADO

RIVER

STORAGE

PROJECT

U. S. DEPARTMENT OF THE INTERIOR, STEWART L. UDALL, Secretary

Bureau of Reclamation, Floyd E. Dominy, Commissioner
The Curecanti Storage Unit is an important part of a vast program to store, regulate, and put to widespread beneficial use the waters of the Upper Colorado River and its tributaries—large and small. The purpose of the Curecanti Unit is to control the flows of the Gunnison River, a major tributary of the Upper Colorado River. Three other such storage units are now under construction—

the Flaming Gorge Unit on the Green River in the northeast corner of Utah

the Navajo Unit on the San Juan River in northwest New Mexico; and the Glen Canyon Unit on the Colorado River in northern Arizona.

The Curecanti Unit will involve the construction of two, and possibly three dams. They are the Blue Mesa Dam near Sapinero on U. S. Highway 50; the Morrow Point Dam near Cimarron also on U. S. 50; and probably the Crystal Dam, which is still under investigation. All three of these Curecanti Unit dams will be built in the deep canyon cut by the Gunnison River into some of the oldest rocks in the North American continent.

BLUE MESA DAM

Blue Mesa Dam will store 914,000 acre-feet of water in a large reservoir extending 19 miles upstream. The upper end of the Blue Mesa Reservoir will reach to within 5 1/2 miles of Gunnison, Colorado. The dam will be built of about 3 million cubic yards of rolled earth and rock. The 770-foot-long crest will stand 340 feet above the original streambed elevation. A 60,000-kilowatt powerplant will be located at Blue Mesa Dam.

Construction on the Curecanti Unit began in 1961 with the relocation of about 6 1/2 miles of U. S. Highway 50 through the lower part of the Blue Mesa Reservoir area. Portions of the highway will be flooded during high water periods when the Gunnison River is diverted through tunnels around the Blue Mesa damsite. During 1961, surveys and other preconstruction work will be completed for Blue Mesa Dam. Early in 1962, the contract for construction of Blue Mesa Dam is scheduled for award.

MORROW POINT DAM

Morrow Point Dam, a 465-foot-high, concrete-arch dam, will be located 12 miles downstream from the Blue Mesa Dam and immediately upstream from the point where Cimarron Creek enters the Gunnison River. The narrow Morrow Point Reservoir will have a total capacity of 122,000 acre-feet. Studies, now being made to determine the size of the Morrow Point powerplant, indicate that the installed generating capacity may exceed 40,000 kilowatts.

CRYSTAL DAM

Crystal Dam, which is now subject to detailed studies, may be recommended for inclusion in the Curecanti Unit.