RECOMMENDED MODIFICATIONS TO THE CHEESMAN OUTLET WORKS

Prepared for

Denver Board of Water Commissioners

By

J. Paul Tullis
Maurice L. Albertson
Sellards and Grigg, Inc.

September 1969

SUMMARY

The present condition of the gate valves at Cheesman Dam has created an urgent problem requiring immediate attention. There are four levels from which water may be withdrawn. Of these four, only the upper level, controlled by a 62-inch Larner-Johnson needle valve is in good operating condition. However, this valve can only be used when the lake elevation is above 152 feet. At lower lake elevations, release must be made through the gate valves. All of these valves and their operators are in very poor condition due to their advanced age (40 to 70 years old) and because of physical damage caused by corrosion, cavitation, and vibrations. None of the gate valves used for control, or their guard valves, operate smoothly. Only one outlet is presently being used for release of water. If this valve, located at the 14-foot level, ceases to function, the lake could be completely drained if the valve became inoperable in the open position, or no water could be released at all if the valve became inoperable in the closed position. It is, therefore, necessary to make immediate modifications at Cheesman to provide a safe reliable means of drawing water from the reservoir.

This report was prepared to aid the Denver Water Board personnel in selecting the most appropriate solution to the existing problems at Cheesman. The report includes: a discussion of the present condition of the outlet works and a brief history of past difficulties; a determination of the past flow requirements and of the present maximum "safe" possible discharge, to serve as a guide in sizing the modifications; and finally, the proposed modifications and alternate solutions, including cost estimates.

The proposed modification suggests installing new isolation-guard valves downstream of the existing gate valves, and connecting these valves with pipelines to free discharge valves installed at the present outlet portal.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Background

Cheesman Dam was constructed in 1905 to impound a water supply for the City of Denver. It is located on the South Platte River and is the last reservoir before the water arrives at the Marston Filter Plant. The dam is of arch construction and was built of granite block quarried from nearby sites.

The outlet works at Cheesman Dam consist of a series of tunnels through the rock abutment. There are four levels from which the water may be drawn. As shown on Figure 1, these four levels are at approximate elevations of 15, 64, 86 and 152 feet. The first three tunnels are interconnected to a single outlet portal. The upper level is independent of the three lower tunnels. The apparent reason for the multi-level outlets is that it makes it possible to withdraw water of varying quality from the reservoir. Another side benefit is that the higher valves operate with less head and therefore reduce the possibility of cavitation damage.

When the dam was first constructed, only the three lower levels were included. Forty-two-inch Rensselaer gate valves were installed in each tunnel to regulate releases from the reservoir. Single gate valves were installed at the 64 and 86-foot levels and the side-by-side (twin) valves placed at the 15-foot level. Figure 2 is a photograph of the twin valves during transportation. The arrangement of the valves on the wagons is the same as the valves were installed in the lower tunnel. Figure 3 shows the geometry of the twin valves installed in the lower tunnel as viewed from the inlet side. At the bottom of the photograph are the inlets for two 12-inch bypass lines.

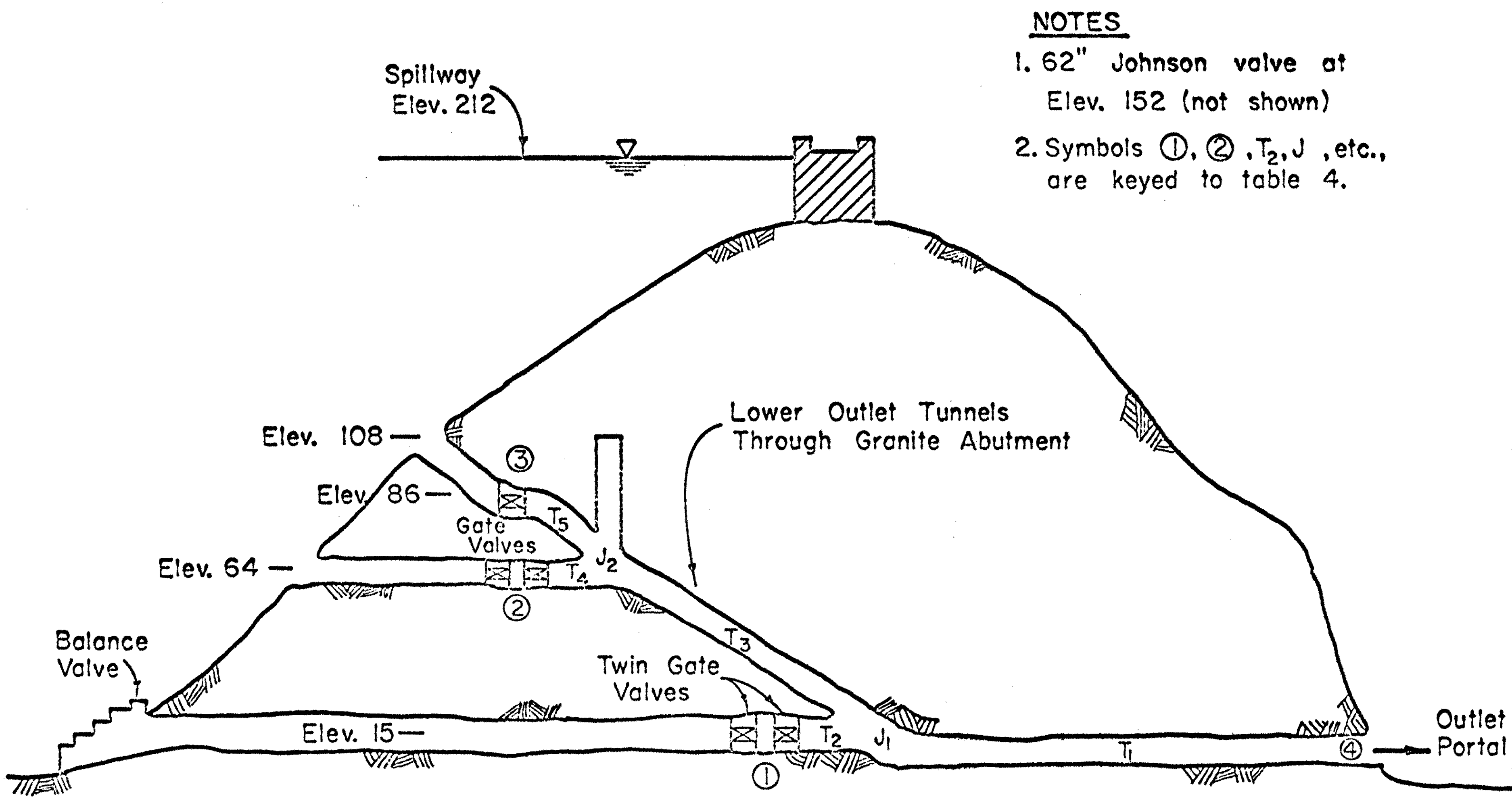


Figure 1. Schematic of Cheesman lower outlet works.

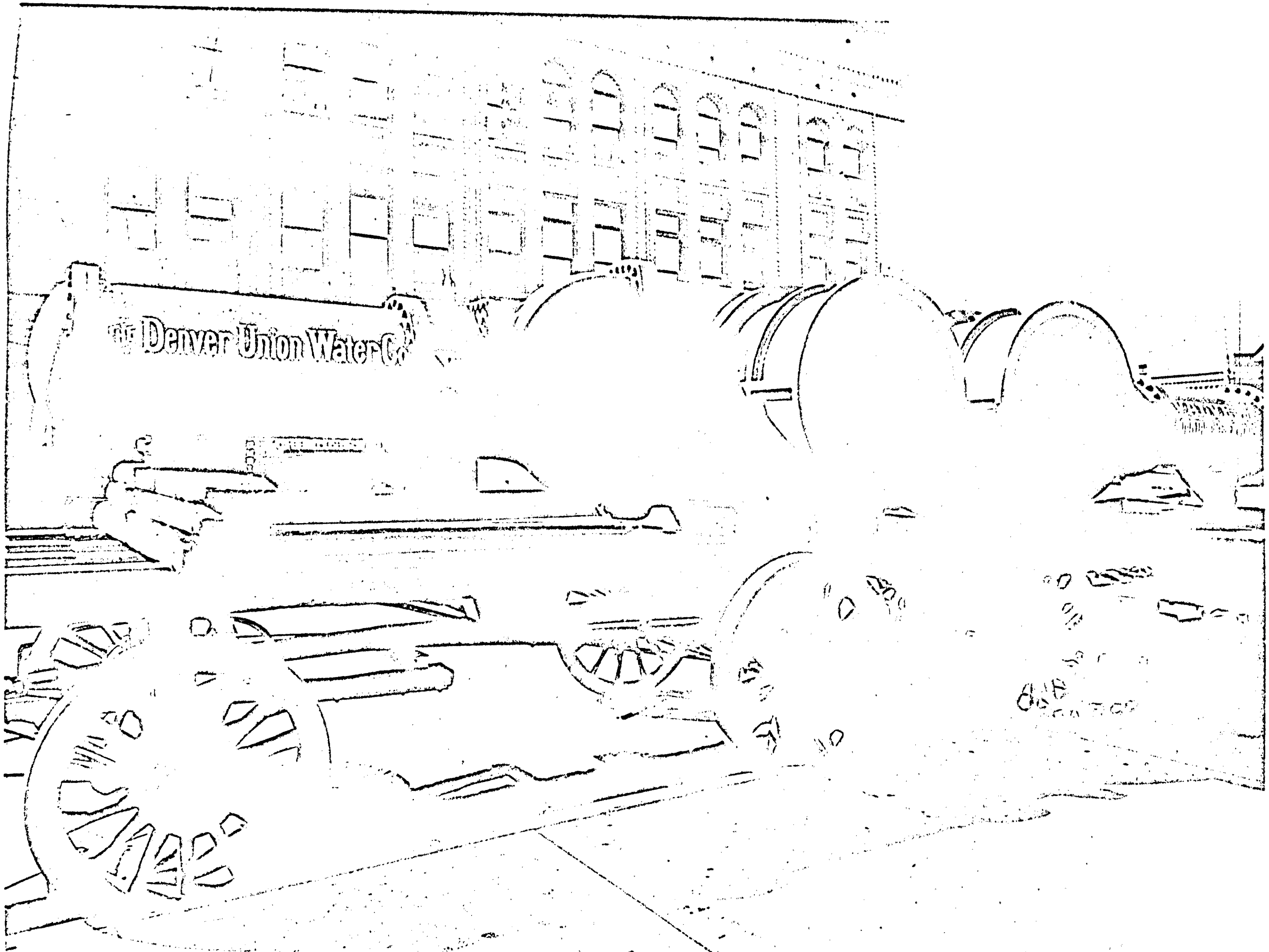


Figure 2. Photograph of the 42-inch Rensselaer twin gate valves before installation.

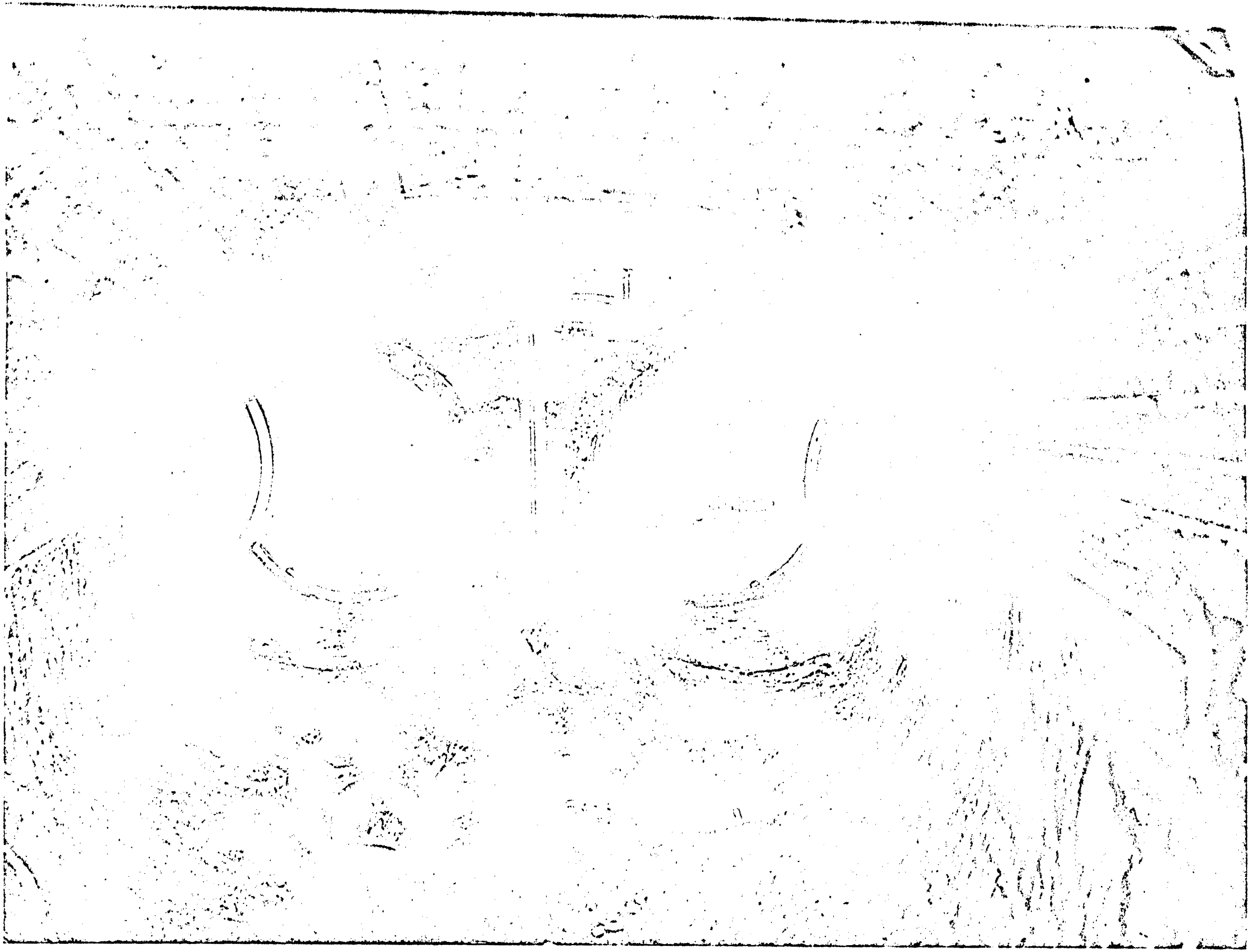


Figure 3. View of the twin gate valves installed in the tunnel - looking in the direction of flow.

A balance valve was placed at the entrance to the 15-foot tunnel to serve as a guard valve. A Tainter gate was located at the intersection of the 64 and 86-foot level tunnels. Details regarding the time of installation, the date of removal, and the intended function of the Tainter gate are not known. It is assumed that the gate valves in the 64 and 86-foot levels were to be used as guard valves with flow being regulated by operating the Tainter gate. When the Tainter gate was removed from service, the two gate valves were then used for control and were the only valves in those two tunnels.

After several years of operation, it was decided that an upper level outlet was desirable and the tunnel at the 152-foot level was constructed. Flow in this tunnel is regulated by a 62-inch Larner-Johnson needle valve which discharges to the atmosphere. A 5 x 7 foot gate was installed upstream of the needle valve so the needle valve can be isolated when repairs to it are necessary.

In about 1930, new 42-inch gate valves were installed at the 15 and 64-foot levels. The new valves were placed immediately downstream of the original valves, whereupon the original valves became guard valves only. These additional valves were no doubt installed due to the balance valve and the Tainter gate becoming inoperable.

Over the years numerous repairs and minor modifications to the gate valves have been necessary. Included in this report, as Appendix A, are two inter-office communications from Mr. R. G. Akin regarding the valve operation and maintenance at Cheesman Dam. At the present time all gate valves are in uniformly poor condition due to the advanced age of the valves and to cavitation, corrosion, and vibration damage. Currently only one of the gate valves is in operable condition. This is the left valve (looking upstream) in the 15-foot tunnel. However, recent difficulties at the dam have resulted in additional damage to this valve. The need to take corrective measures at Cheesman is therefore urgent because of the following possible consequences:

1. When the lake elevation drops below 150 feet, release from the reservoir can be obtained only from the one semi-operable gate valve in the 15-foot tunnel.
2. If this gate valve becomes inoperable in an open position, it is questionable whether the upstream gate valve, which now serves as the guard valve, could be closed and it is possible that the reservoir may be drained.
3. If the gate valve becomes inoperable in the closed position, there is no other line which can be safely used to obtain release from the reservoir.

Scope of Report

To aid in correcting the existing difficulties at Lake Cheesman, the authors of this report were contacted and requested to study the existing problems and to make recommendations for modifications. The study included determining the present physical condition of the control valves and the outlet tunnels, the operating procedures at the reservoir, and the demand requirements.

A field inspection was conducted as part of the investigation. The specific objectives and procedures of the study are listed in the proposal entitled, "Recommended Study of the Outlet Works at Cheesman Dam," dated May 14, 1969, which is included as Appendix B of the report.

EXISTING OUTLET WORKS

To document the need for immediate modifications at Cheesman Dam, a description of the present condition of the valves is included. Also included is a discussion of the historical flow requirements from Lake Cheesman and an analysis of the maximum present capabilities of the outlet works. The past requirement and the present capabilities will serve as the guideline for designing any proposed modifications such that the present capability is not reduced.

Condition of Valves

In the 15-foot tunnel there are presently four gate valves. The original size of the valves was 42 inches but they were later reduced in size to 38 inches by installation of new rings. During the field trip to Lake Cheesman, it was not possible to completely inspect all of these valves since many of them could not be safely operated. The present condition of the valves is therefore documented partly by the field inspection and partly by discussion with the personnel who operate and maintain the valves.

The right hand operating valve in the 15-foot tunnel (looking upstream) is in need of repairs and cannot be operated. However, repairs on this valve are presently not possible since its upstream guard valve cannot be completely closed. Consequently, the right hand side of the twin valve installation in this tunnel is essentially out of operation.

The downstream valve on the left hand side of the 15-foot tunnel is presently in only fair operating condition. This valve was completely overhauled during 1968 to improve its operating condition. However, recent difficulties at the dam has caused additional damage to the operating mechanism and reduced the reliability of this valve. The left hand guard valve can be operated when the downstream valve is closed but cannot be completely closed so that the flow is sealed off.

The two valves in the 64-foot level tunnel are damaged and considered to be unreliable. The operating personnel indicated that they do not operate these valves because their jerky operation makes then unsafe to operate.

The single valve in the 86-foot level tunnel is considered by the operating personnel to possibly be in the best condition of all of the valves. The field inspection of this valve indicated little sign of cavitation damage on the gate or on the rings. However, extensive cavitation damage has been done at the downstream spool section such that the metal was completely eaten away and cavitation had eroded several inches into the concrete lining. Although this valve appears to be in satisfactory condition, it cannot be inspected in an open position and it has not been operated for a number of years; hence, its actual condition has not been verified. The reason why it has not been used is that it has no guard valve and its possible failure under use could result in draining the reservoir to an elevation of 104 feet.

The 5 x 7-foot gate and the 62-inch Larner-Johnson needle valve at the 152-foot level are presently in satisfactory operating condition. This outlet was not studied as part of this report since it has operated satisfactory since its installation.

Past Discharge Requirements

In order to establish a basis by which modifications to the existing outlet works could be designed, it was necessary to evaluate the outlet requirements from the reservoir. There is a minimum discharge requirement of 15 cfs required for the maintenance of fish life in the downstream channel. This must be supplied year around. The only information which could be furnished by the Denver Water Board regarding the maximum flow requirements to aid in establishing design criteria, is the information relayed by Mr. William Schuler of the Water Resources Division. His instructions were that the present capabilities of the system should not be reduced by any new construction. Since there was no specified maximum discharge requirement established for Cheesman Reservoir, two aspects were considered in establishing a maximum flow requirement from the reservoir. First, what has been the maximum flow supplied by the outlet valves since the dam was built? Second, what is the present safe maximum capability of the outlet works?

Table 1 shows the listing of the yearly momentary maximum flows experienced at the flume downstream of the outlet works. Those discharges marked with an asterisk include both spillway and conduit discharges. Prior to about 1945, it is uncertain whether the spillway discharge is included. It can be stated that in the last 25 years the outlet works have not passed discharges in excess of 900 cfs. It is also not certain as to what percentage of this flow has been furnished by the Larner-Johnson needle valve. Since the needle valve is normally used to its fullest extent when the reservoir is at a high enough elevation, one may assume from the data in Table 1 that the maximum flow ever required from the three lower tunnels has never exceeded 900 cfs and is probably considerably less than that figure.

Present Safe Maximum Discharge

—To further establish guidelines for design modifications, the present gate valve outlets were analyzed to determine what their present maximum safe discharge capabilities are. The system was analyzed to establish

TABLE 1
YEARLY MAXIMUM RELEASES FROM CHEESMAN RESERVOIR
(From Denver Water Board Records)

Water Year	Momentary Maximum Discharge (cfs)	Date
1968	772	July 30, 1968
1967	462	September 4, 1967
1966	588	May 15, 1966
1965	867	April 25-27, 1965
1964	656	July 15, 1964
1963	515	July 22, 1963
1962	702	April 29, 1962
1961	628	August 17, 1961
1960	710*	June 23, 1960
1959	906	June 23, 1959
1958	1,110*	May 26, 1958
1957	1,120*	August 18, 1957
1956	692	June 8, 1956
1955	628	August 9, 1955
1954	646	July 13, 1954
1953	865	August 1, 1953
1952	835	August 3, 1952
1951	674	August 3, 1951
1950	741	November 6, 1950
1949	2,070*	June 15, 1949
1948	2,180*	April 22, 1948
1947	1,640*	June 24, 1947
1946	782	July 16, 1946
1945	1,110*	August 11, 1945
1944	636*	May 30, 1944
1943	921*	April 21, 1943
1942	3,020*	April 23, 1942
1941	1,020	April 30, 1941
1940	556	June 24, 1940
1939	728*	June 2, 1939
1938	932	August 29, 1938
1937	932	June 28, 1937
1936	1,630	June 25, 1936
1935	1,430	July 23, 1935
1934	521	May 29, 1934
1933	880	June 15, 1933
1932	600	July 14-16, 1932
1931	814	October 1, 1931
1930	1,310	July 31, 1930
1929	1,580	August 9, 1929
1928	860	June 5, 1928
1927	805	July 1, 1927
1926	1,220	May 28, 1926
1925	530	June 11-12, 1925

two facts: (1) What is the absolute maximum flow possible with a full reservoir and all gate valves open? (2) What is the maximum safe discharge for the same condition?

The maximum discharge, with the reservoir full, will be limited by two factors: (1) the resistance of the system (head loss caused by valves, tunnel, bends, boundary shear, etc.); and (2) choking of the flow because of very heavy cavitation. The results of calculations for various combinations of valves in use are listed in Table 2. These results are also summarized in Table 3.

TABLE 2
MAXIMUM DISCHARGE CAPABILITIES OF PRESENT OUTLET WORKS

Valves in Use	Maximum Discharge Based on Full Reservoir (cfs)	Notes
2 valves @ 14.9 ft elevation	1140	Flow limited by choking caused by heavy cavitation in the tunnel where the two valves discharge.
1 valve @ 63.9 ft elevation	640	Flow limited by choking caused by heavy cavitation in the tunnel where the valve discharges.
1 valve at 86.5 ft elevation	600	Flow limited by choking caused by heavy cavitation in the tunnel where the valve discharges.
1 valve each at 63.9 and 86.5 ft elevation	1180	Flow limited by resistance losses in the tunnels and valves. The cavitation would be heavy at the gate valves but choking would not occur.
All valves open	1800	Flow limited by resistance losses. The cavitation would be heavy at all gate valves and in the lower outlet tunnel.

Although the outlet works has the capabilities listed in Table 2, it is strongly advised that the system should never be subjected to those conditions. Rapid cavitation damage both to the valves and tunnels would result if such flows were attempted.

Since the outlet works has more potential than is safe, it is necessary to estimate the present safe operating limits based on cavitation. The maximum safe discharge, along with the past discharge requirements, will then serve as guidelines for sizing any proposed modification.

In reality, there is virtually no discharge for which the gate valves will operate cavitation free. The flow characteristics of this type of valve are such that cavitation will occur under all flow conditions, except for very low heads and velocities. Consequently, there is no safe discharge limit for the present gate valves below which they will be free of cavitation. Because of this fact, cavitation conditions in the gate valves were not utilized in establishing the maximum safe discharge.

The criteria used in establishing the the maximum safe discharge was the maximum tolerable velocity in the lower outlet tunnel. The following is the recommendation of the Corps of Engineers:

> Generally, velocities in unlined tunnels should not exceed 10 fps except during diversion flow when velocities to about 15 fps may be acceptable. For a tunnel with downstream turbines, penstocks, or valves, it has been recommended that velocities be limited to 5 fps or less[1] to prevent damage from migration of tunnel muck fines and rock falls.[2]

Using this recommendation, the maximum flow to keep the velocity in the tunnels upstream of the valves below 5 fps would be 630 cfs. For a

[1]Spencer, R. W., Taverty, B. R. and Barber, D. A., "Unlined Tunnels of the Southern California Edison Company," ASCE Power Division Journal, Vol. 90, PO3, Paper 4081, October 1964, pp. 105-132.

[2]Corps of Engineers, "Hydraulic Design Criteria."

limiting velocity in the tunnels downstream of the valves of 15 fps, the maximum flow would also be 630 cfs.

The granite through which the outlet tunnels for Cheesman Dam were cut is in very good condition. There is no evidence of erosion of the unlined tunnels. It is, therefore, possible that the above velocities could be exceeded for a limited duration. The maximum amount by which the Corps of Engineers' recommended velocities might be exceeded would be the velocity at which cavitation would be initiated at the wall of the downstream tunnel.

Four sources were utilized to obtain independent estimates of the velocity at which cavitation would begin in the tunnel. The first estimate was based on cavitation information obtained on ball valves.[3] The method used was to approximate a valve opening which would have a similar relative roughness as the tunnel. This resulted in a limiting velocity of 30 fps. The second estimate utilized data for three-dimensional roughness elements on a flat plate.[4] This reference also resulted in a velocity of 30 fps. The third[5] and fourth[6] estimates utilized information on offsets in linings and resulted in limiting velocities of 35 and 30 fps, respectively.

---

[3]Hogan, R. A., "Cavitation and Torque Characteristics of Butterfly and Ball Valves," M. S. Thesis, Colorado State University, Department of Civil Engineering, August 1968.

[4]Benson, B. S., "Cavitation Inception on Three Dimensional Roughness Elements," Hydromechanics Laboratory Research and Development Report, David Taylor Model Basin, Report No. 2104, S-F013 02 04, Task 1712, May 1966.

[5]Ball, J. W., "Importance of Smooth Surfaces on Flow Boundaries Downstream from Outlet Works Control Gates," Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-448.

[6]Ball, J. W., "Why Close Tolerances are Necessary Under High Velocity Flow," Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-473.

Each of the estimates, of necessity, incorporated several assumptions, since no information is presently available on cavitation inception in tunnels. However, the agreement between the independent estimates seems to justify selecting 27 fps (ten percent less than 30 for a safety factor to allow for scale effects) as a limiting velocity at the lower tunnel. This condition represents the onset of cavitation in the tunnel wall. It is the opinion of the authors that this value represents an absolute maximum safe discharge for the present outlet works, since exceeding it causes cavitation damage to the tunnel, and since it exceeds the maximum recommended by the Corps of Engineers by 100 percent. It also exceeds the past flow requirements by more than 25 percent.

Using a tunnel area of 42 sq ft, the maximum safe discharge is 1133 cfs. It must be re-emphasized that the gate valves would cavitate heavily at this flow rate; consequently, this limiting discharge is actually not a "safe" discharge, but one to be called such for the sake of designing the proposed modifications.

For information purposes, maximum safe discharges for each separate outlet, based on wide-open valves, were calculated. These values, summarized in Table 3, are based on moderate to heavy cavitation occurring at the valve outlet.

The design flow of 1133 cfs is well in excess of the maximum flow required in the past 25 years from all the valves, including the 62-inch needle valve. It is, therefore, felt that modifications using this valve as a criteria will actually be increasing the present capabilities of the outlet works rather than just maintaining them.

TABLE 3
MAXIMUM FLOW CAPABILITIES OF PRESENT OUTLET WORKS

Valves in Use Wide Open	Maximum Discharge from Table 1 Based on Full Reservoir (cfs)	"Safe" Discharge in cfs with Full Reservoir Based on Moderate to Heavy Cavitation at Valve Outlets
2 valves @ 14.9 ft elevation	1140	860
1 valve @ 63.9 ft elevation	640	420
1 valve @ 86.5 ft elevation	600	400
1 valve each at 63.9 and 86.5 ft elevation	1180	820
All valves open	1800	1133*

*Use for design based on incipient cavitation at tunnel walls.

PROPOSED MODIFICATIONS

This chapter discusses the design criteria used in selecting possible solutions to the problems at Cheesman, and presents a proposed scheme for modifying the existing outlet works. Alternative solutions are presented in the next chapter.

Design Criteria

The material presented in the preceding portion of this report was included mainly to document the existing difficulties at the outlet works and to aid in establishing criteria to be utilized in designing modifications. The general design criteria utilized in arriving at the proposed modifications and alternate solutions are summarized below.

1. Any modifications must maintain the present flow capabilities of the outlet works, which are a minimum discharge of 15 cfs and a maximum safe discharge of 1130 cfs.
2. The flexibility of withdrawing water independently from the three lower tunnels at 14.9, 63.9 and 88.9 foot elevations must be maintained.
3. None of the existing gate valves should be used in the new system because of their poor condition. They may be left in place in the open position, subject to design constraints.
4. Pressurizing of the tunnels downstream of the gate valves is not recommended unless a reinforced concrete lining is installed to control leakage. (See memo in Appendix A, dated May 13, 1966.)
5. Regulating valves should not be located in the outlet tunnels because of the large air demand, the possibility of cavitation damage to the tunnel walls at large discharges, and surging and vibration problems when the valves submerge at large flows.

6. More than one regulating valve is desirable, with guard valves installed such that continuous release is possible when repairs or maintenance is necessary to the regulating valves.
7. The new system should operate cavitation free at all normal operating conditions.
8. A small bypass line would be useful to pass flow in the winter months when the normal discharge is between 15 and 30 cfs.
9. In designing the piping system, a limiting velocity of 55 feet per second was used as the maximum allowable anywhere in the system, except at the free discharge valves. This limit was selected to avoid the possibility of cavitation due to roughnesses, misaligned conduits, bends, etc.

Recommended Modifications

After considering a number of possible solutions to the existing problems at the Cheesman Outlet Works, a single scheme was selected as the one recommended. It incorporates all of the design criteria and is considered to be the most reliable and flexible. The recommended scheme consists of the following:

A. Four 38-inch ball valves, one placed downstream of each existing gate valve outlet. These valves would serve as isolation and guard valves.

B. Two 42-inch hollow jet, free-discharge valves, placed at the outlet portal.

C. One 12-inch hollow cone, free-discharge valve placed at the portal and connected to one of the pipes in the 14-ft level tunnel, upstream of the 38-inch ball valves.

D. One 12-inch ball valve upstream of the 12-inch hollow cone for a guard valve.

E. All valves are connected with steel conduits of sizes as shown in Figure 4.

A discussion of the major features of the system are presented below.

Hollow-Jet Valves

The hollow-jet valve is considered to be the most reliable valve presently available for free-discharge release of water at the downstream end of a closed conduit. Its construction is similar to the Larner-Johnson type needle valve with the needle pointing upstream and the downstream portion of the valve removed. The discharge is tubular in shape, having a hollow core so that the energy is less concentrated than for a needle valve, thus spreading and reducing the effect of the destructive impact and erosive forces. A stilling basin is usually required for dissipating the energy of the jet. The size of the stilling basin may be reduced by installing the valves at an angle of about 20 to 30 degrees downward, and at a horizontal angle such that the two jets converge at the center of the basin.

Proportioning of the water passage is very important to prevent subatmospheric pressures which might result in cavitation. These valves have operated successfully at heads in excess of those at Cheesman. The only operating limitation that they will have for this installation is that they should not be operated at small discharges because of possible internal cavitation. Care must also be used in selecting the operator, so that the closure speed is properly controlled.

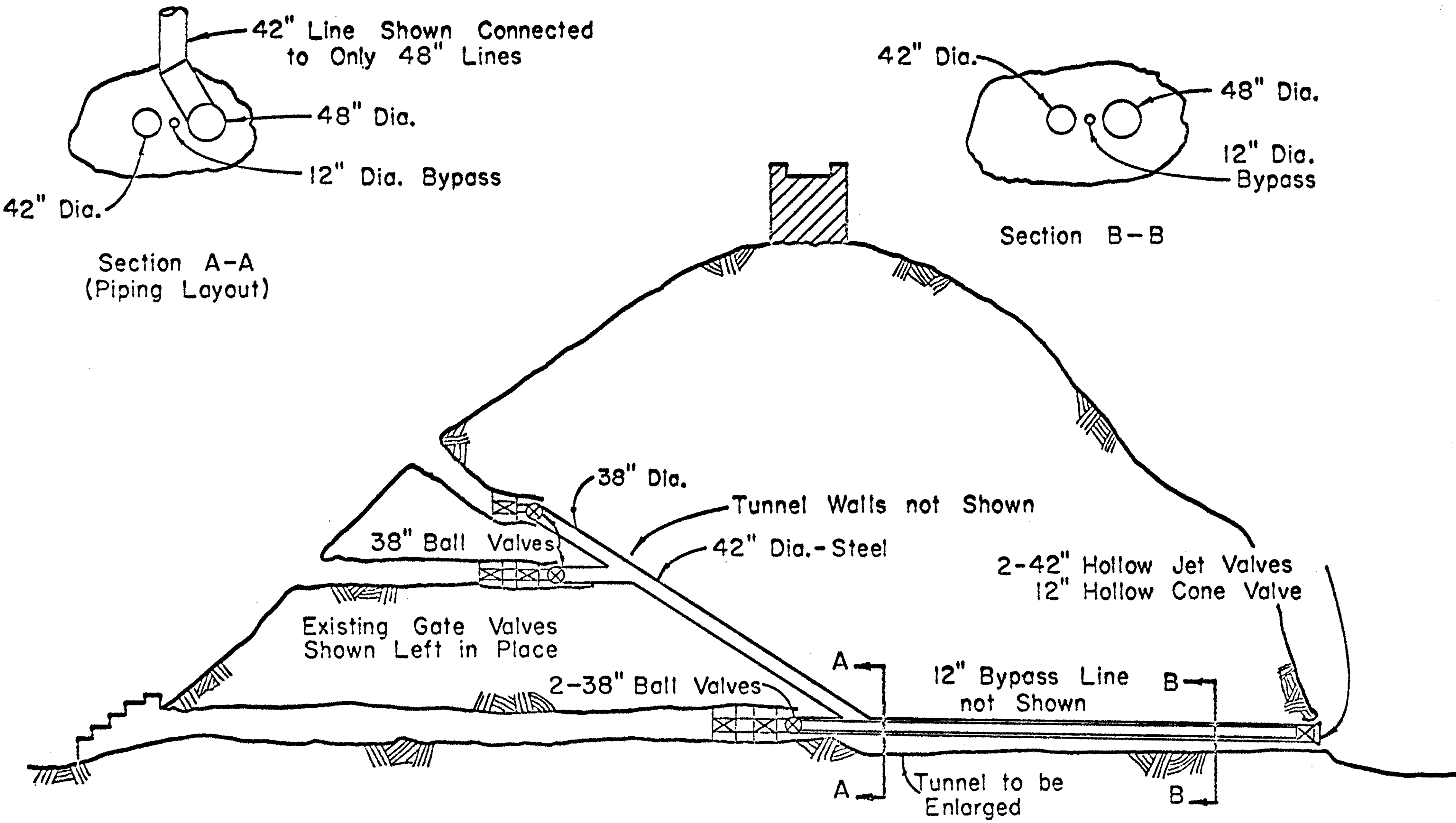


Figure 4. General features of recommended modification.

Ball Valves

A number of different types of isolation or guard valves were considered for this installation. Butterfly valves, which are frequently used for this purpose, are not suitable for this installation. The maximum discharge required at Cheesman, to maintain the present capability, results in mean pipe velocities in excess of 50 fps. In order to use a butterfly valve, the local pressure at the valve would need to be above 200 psi to suppress cavitation. The actual pressure in the pipe at the valve locations is closer to 40 psi. Consequently, the butterfly valves would be operating in a state of extremely heavy cavitation and would severely restrict the maximum flow as well as damage the valve and the downstream conduit.

The only type of valve which can operate cavitation free at such high velocity-low pressure requirements is a full opening type valve; i.e., a valve which has essentially no obstruction in the full open position. Willamette List 26 Ball valves are recommended for this installation for the following reasons: (1) Three of these valves - 6, 12, and 16 inches in size - have been tested at Colorado State University. Their general performance is very satisfactory. Operating torques appear to be at a tolerable level with no difficulties experienced when closing against pressures in excess of 100 psi. (2) These valves are compact so that installing them in the tunnels should be facilitated. (3) They are economical compared to other full opening type valves.

Since the isolation valves will normally be positioned either fully open or closed, and they will usually be operated with zero flow in the system, these valves will seldom be subjected to cavitation or large torques. However, they must have the ability to close against full reservoir head in an emergency. With the heads at Cheesman, the Willamette ball valves should experience no difficulties closing or opening. They should, however, not be operated for any length of time in an intermediate position, because of possible damage by cavitation erosion and vibrations. The pipes and ball valves must be securely tied down so that vibrations can be controlled during emergency operation.

Pipelines

The size of the pipelines connecting the isolation and regulating valves was determined by two criteria: (1) selecting the minimum size which would pass the required maximum flow, and (2) limiting velocities in the pipes to 55 fps to avoid cavitation. The sizes shown in Figure 4 were selected based on calculations for all valves wide open. Velocities in excess of those recommended are possible, so the instructions listed in a following section entitled "General Operating Guidelines" should be observed.

Calculations for the pipes were based on outside diameters with a one-inch wall thickness to allow for possible linings. Values of the friction factor used in the Darcy-Weisbach Equation to calculate resistance losses were f = .0120, .0110, and .0105 for the 38-, 42-, and 48-inch pipes respectively.

Bypass Line

A twelve-inch bypass line is recommended for use, primarily in the winter when flows less than 40 cfs are required. This will make it possible to simultaneously service both hollow-jet valves and yet maintain flow. It will also eliminate the need for operating the large valves at small openings where cavitation is most likely. A hollow-cone valve with a hood to control the dispersion of the discharge is suggested for this service. The maximum flow possible through this line with a full reservoir is slightly less than 40 cfs, which results in inlet velocities of about 50 fps. If short, thick vanes are used to support the cone, no difficulties due to vane failure should occur.

Discharge Capabilities

The maximum flow capacity of the proposed system varies with reservoir elevation. When the reservoir is full, the maximum safe discharge for the present system, 1130 cfs, can be supplied. At a reservoir elevation of 150 feet, 800 cfs can be supplied.

The capacity of the 12-inch bypass line ranges from 32 cfs at 150 feet elevation to about 37 cfs at 212 feet elevation.

When the reservoir is above 150 feet, the Larner-Johnson valve can also be used to increase the outflow if needed.

General Operating Guidelines

When the final design of the system is completed, a detailed check of the system should be conducted, and an operating procedure established if necessary, to ensure that velocities sufficient to cause cavitation do not occur anywhere in the system. The guidelines listed here are very general and intend to aid in developing the details of design and operation. Integration of the operation of the needle valve is not included in these guidelines, and should be incorporated into the detailed operating schedule.

Regulating valves

1. The 48-inch line at the 14-foot level is suggested as the primary control line, since the outlets from the three elevations

are connected to it. Discharges up to 600 cfs can be safely supplied by this line.

2. When discharges in excess of 600 cfs are required, both hollow-jet valves should be used, with the discharge approximately the same for each.
3. Normally the discharge in the 42-inch line at the 14-foot elevation should be limited to 400 cfs. Above this flow rate, cavitation is likely to occur in the 38-inch ball valve.
4. The 42-inch hollow-jet valves should not be operated at discharges below about 40 cfs. Use the bypass line for this purpose.

Isolation-guard valves

1. These valves should normally be either fully open or fully closed.
2. The valves should be exercised several times each year by cycling them open and closed under no-flow conditions.
3. Each pipeline should be flushed at least twice a year.
4. Guides for the number of isolation valves required versus flow rate are as follows: $Q = 40 - 300$ cfs, one valve open; $Q = 300 - 600$ cfs, two valves open; $Q = 600 - 900$ cfs, three valves open; and $Q > 900$ cfs, all four valves open. For $Q < 40$ cfs, use the 12-inch guard valve and 12-inch hollow-cone valve.

Cost Estimate

Two 42-Inch Hollow-Jet Valves	$144,000
Four 38-Inch Willamette List 26 Ball Valves	120,000
Pipe	62,000
Rock Excavation	12,000
Valve Control Systems	10,000
Engineering and Contingencies (15%)	52,000
	$400,000

Design Details

The scope of this study did not include recommending details for the final design of the system. Some of the items which should be carefully considered in the final design are:

1. Design of the passageway in the hollow-jet valves to ensure cavitation-free operation.
2. Location and orientation of the hollow-jet valves relative to the tunnel and the stilling basin.
3. Winterizing the regulating valves.
4. Placement and selection of air-release valves.
5. Type and location of tiedowns
6. New manways for access to valves.
7. Selection of type of pipe and lining.
8. Selection of type of valve operators and material for valves.
9. Design of stilling basin.

ALTERNATIVE DESIGNS

A number of possible variations of the proposed modifications exist. In general the possible alternate solutions consist of:

1. Reducing the flexibility or discharge by eliminating one or more of the present outlet tunnels.
2. Using different regulating valves.
3. Using a concrete lined tunnel in place of the closed conduits.

Eight alternatives are presented which represent variations from the recommended plan. The basic features of the alternatives are listed below and details regarding the components for installation as well as the maximum discharge for each alternate solution are tabulated in Table 4.

Alternate Number	Variation from Recommended Scheme
1	Eliminate 86-foot level outlet
2	Eliminate 86 and 64-foot level outlets and reduce the size of the hollow-jet valves to 38 inches
3	Eliminate 86 and 64-foot outlet levels but retain the 42-inch hollow-jet valves
4	Replace the two 42-inch hollow-jet valves with two 48-inch hollow-cone valves and make both pipelines in the lower tunnel 48 inches
5	Same as scheme 4 but eliminate the 86-foot level tunnel
6	Same as scheme 4 but eliminate both the 64 and 86-foot level tunnels
7	Install a single 66-inch pipeline in the 15-foot level tunnel and use a single 66-inch hollow-jet valve for discharge
8	Replace the closed conduit system with reinforced concrete lining throughout the tunnel system

TABLE 4. SUMMARY OF ELEMENTS TO DIFFERENT SCHEMES

	Valve Choices* 1	2	3	4	Tunnels* T_1	T_2	T_3	T_4	T_5	Junctions* J_1	J_2	Safe Capacity, cfs (Full Reservoir)
Proposed Scheme	2-38"BV	38"BV	38"BV	2-42"HJV 1-12"HCV 1-12"BV	48"S 42"S 12"S	48"S 42"S 12"S	42"S	38"S	38"S	Wye	Wye	1130
Alternate No.												
1	2-38"BV	38"BV	Plug	2-42"HJV 1-12"HCV 1-12"BV	48"S 42"S 12"S	48"S 42"S 12"S	42"S	38"S	--	Wye	Elbow	1030
2	2-38"BV	Plug	Plug	2-38"HJV 1-12"HCV 1-12"BV	2-42"S 12"S	2-42"S 12"S	--	--	--	--	--	900
3	2-38"BV	Plug	Plug	2-42"HJV 1-12"HCV 1-12"BV	2-42"S 12"S	2-42"S 12"S	--	--	--	--	--	1000
4	2-38"BV	38"BV	38"BV	2-48"HCV 1-12"HCV 1-12"BV	2-48"S 12"S	2-48"S 12"S	42"S	38"S	38"S	Wye	Wye	1130
5	2-38"BV	38"BV	Plug	2-48"HCV 1-12"HCV 1-12"BV	2-48"S 12"S	2-48"S 12"S	42"S	38"S	--	Wye	Elbow	∿1100
6	2-38"BV	Plug	Plug	2-48"HCV 1-12"HCV 1-12"BV	2-48"S 12"S	2-48"S 12"S	--	--	--	--	--	∿1000
7	2-38"BV	38"BV	38"BV	66"HJV 12"HCV 12"BV	66"S 12"S	42"S	42"S	42"S	42"S	Wye	Wye	1130
8	2-38"BV	38"BV	38"BV	2-42"HJV 2-42"BV 12"HCV 12"BV Vault	RCL 12"S	RCL	RCL	RCL	RCL	T	T	1130

*See Figure 1 for valve, tunnel, and junction locations

Explanation

BV - Ball Valve
HJV - Hollow-Jet Valve
HCV - Hollow-Cone Valve
S - Steel Pipe
RCL - Reinforced Concrete Lining
T - Transition

Comparative cost estimates for the proposed scheme and eight alternate solutions are presented in Table 5. Unit prices used to arrive at the estimates are listed in Table 6. Although an attempt was made to make the cost estimates accurate, it should be realized that, as usual, many unknowns prevent exact determination of the cost of the project. Some of these unknowns are: difficulties encountered installing the pipes and valves in the tunnels, the inability to obtain the exact price on the cost of the valves since they have not been designed and are a special order item, and the uncertainty as to the exact type of pipe and lining to be used.

Following are a few comments relative to the eight proposed alternate solutions which might aid in selecting the scheme most appropriate to the needs and objectives of the Denver Water Board.

Alternate 1

By eliminating the 86-foot tunnel, the possibility of drawing out water from the 105-foot elevation is eliminated, but the maximum discharge capability is not materially affected. By eliminating this one line, the maximum discharges only reduce by approximately 70 cfs. If desired, this deficit could be picked up by slight changes in the design of the system.

The only advantage of this alternate is that it reduces the initial installation cost by eliminating one 38-inch ball valve, some 38-inch pipe, one transition, and the labor for installation. The disadvantage is, of course, that some flexibility of selective withdrawal from various levels in the reservoir is lost. The main criteria in evaluating this alternate solution would, of course, be the need for maintaining all four levels for selection of water from the reservoir.

TABLE 5. COMPARATIVE COST ESTIMATES
(All Prices are In-Place Estimates)

Item	Proposed Scheme	Alternate Number 1	2	3	4	5	6	7	8
42" Ball Valves									64,000
38" Ball Valves	120,000	90,000	60,000	60,000	120,000	90,000	60,000	120,000	120,000
38" Hollow-Jet Valves			128,000						
42" Hollow Jet Valves	144,000	144,000		144,000					144,000
66" Hollow Jet Valve								120,000	
48" Hollow-Cone Valves					92,000	92,000	92,000		
Steel Pipe	41,000	39,000	30,000	30,000	43,000	41,000	30,000	35,000	
Bypass Line	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000
Transitions	10,000	10,000			10,000	10,000	10,000	10,000	
Plugs		2,000	4,000	4,000		2,000	4,000		
Reinforced Concrete Lining									41,000
Vault House									15,000
Regulating Valve Control System	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Rock Excavation	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	
Sub Totals	348,000	318,000	255,000	271,000	298,000	268,000	229,000	318,000	405,000
15% Engineering and Contingencies	52,000	48,000	38,000	41,000	45,000	40,000	34,000	48,000	61,000
Totals	400,000	366,000	293,000	312,000	343,000	308,000	263,000	366,000	466,000

Table 6
UNIT PRICES USED

Item	Unit	Material	Installation	Total
38" Ball Valves	each			30,000
42" Ball Valves	each			32,000
38" Hollow-Jet Valves	each	52,000	12,000	64,000
42" Hollow-Jet Valves	each	60,000	12,000	72,000
66" Hollow-Jet Valve	each	102,000	18,000	120,000
48" Hollow-Cone Valves	each	34,000	12,000	46,000
Steel Pipe, Per Foot, Installed Lin. Ft				
38"				66
42"				72
48"				82
66"				106
Bypass Line	LS			11,000
Transitions	LS			10,000
Plugs	each			2,000
Reinforced Concrete Lining	Lin. ft			113
Vault House	LS			15,000
Regulating Valve Controls	LS			10,000
Rock Excavation	Cu. yd			40

All prices include installation

Alternate 2

This alternate considers only using the 14-foot level tunnel and abandoning the upper two levels. With this scheme two pipes in the lower tunnel would be identical: each having one 38-inch ball valve, 42-inch pipe and one 38-inch hollow-jet valve. The maximum discharge for this arrangement is estimated to be 900 cfs.

This alternate contains an additional cost savings over that of alternate 1, but also causes further reduction in the flexibility of selective withdrawal from the reservoir.

The main disadvantages to this system are twofold: first, the maximum discharge is reduced from 1130 cfs to 900 cfs, and the levels of selective withdrawal are reduced from 4 to 2. The advantage again is a cost savings.

Alternate 3

This alternate is similar to alternate 2 with the exception that the hollow-jet valves are increased to 42 inches in size. This increases the maximum discharge to approximately 1000 cfs. The same general comments are applicable to this solution as were noted for alternate 2, except that the maximum possible discharge and total cost are both slightly increased.

Alternate 4

The variations of this alternate from the proposed modifications are: the two pipelines in the 14-foot tunnel are both 48 inches in diameter, and the two free discharge valves are 48-inch hollow-cone valves. This solution contains all of the flexibility and can supply the maximum discharge of 1130 cfs.

The reason that this solution was not suggested as the proposed modification is that hollow-cone valves in general are less reliable than hollow-jet valves when operating under high heads. A number of large hollow-cone valves installed and operated under high heads have resulted in vane failures. Such failures are apparently being caused by operating the valves at large valve openings with high inlet velocities which result in elastic waves being setup in the support vanes. When conditions are right, these vanes can fail and usually double over sealing off one of the entrance passages. To minimize the possibility of a vane failure, if this type of valve is selected for installation at Cheesman, the size of the valves has been increased such that they do not have to operate over 70 percent open to supply the maximum flow. This limits the inlet velocity to a tolerable level. If sufficiently thick vanes are installed, no difficulties with these hollow-cone valves should be encountered. If this solution is adopted, it is strongly recommended that a thorough analysis of the sizing of the vanes for the valves be conducted.

Alternate 5

This solution is similar to alternate 4 except the 86-foot level is abandoned. The results are that there is less flexibility of selective withdrawal but some cost savings is realized by eliminating one line. The maximum flow is only slightly reduced by this modification.

Alternate 6

This solution considers plugging the two upper level tunnels and using only the 14-foot tunnel with two 48-inch pipelines and two 48-inch hollow-cone valves. Again, the amount of selective withdrawal, the maximum discharge, and the total cost are reduced with this scheme.

Alternate 7

This solution is not highly recommended but is included primarily for a cost comparison. This scheme considers using only a single pipeline in the 14-foot tunnel and a single 66-inch hollow-jet valve for release. Referring to Table 5, it is seen that the cost for this installation is very similar to the total cost of the proposed modification. It therefore appears that no additional cost is involved in obtaining the additional flexibility of having two separate lines for release.

This alternate has the obvious disadvantage of only one regulating valve, in addition to the small bypass line. If this valve becomes inoperable for some reason, the outlet works are essentially shut down.

Alternate 8

This alternate considers use of a reinforced concrete lining rather than closed conduits between the valves. Bulkheads upstream and downstream of all isolation and control valves would be required and all connecting tunnels would need to be concrete lined with steel reinforcing. This scheme is considerably more expensive than the others suggested because it is necessary to install two additional 42-inch ball valves upstream of the two 42-inch hollow-jet valves so that the two discharge valves might be serviced separately.

Only general comments regarding each alternate solution have been included. Many of the comments regarding the proposed modifications discussed in the previous chapter would also apply to these alternate solutions. It is suggested that if one of the alternate solutions is selected in preference to the proposed modification, the general comments listed in the preceding chapter be studied carefully to see how they apply to the selected scheme.

Other Technical Considerations

In selecting the best alternative several special points should be considered. Because of the remote location of Cheesman Dam, the difficulty of construction and maintenance inside the tunnels and the importance of the reservoir to the Denver Water supply, it is important that the chosen modifications be able to serve reliably and adequately well into the future. The design should facilitate any proposed changes in use of the reservoir in the future as well as the present operation.

In selecting a final scheme, it is well to examine what percent of the total cost is represented by each component. The following is an approximate breakdown of the construction costs for the typical alternative.

Tunnel Piping	9 - 13%
Guard Valves	20 - 40%
Control Valves	35 - 50%
Transitions	15 - 20%
Bypass	2 - 4%

It is immediately apparent that the major costs are incurred in the valves. The choice of valves also determines, to a large extent, the reliability and longevity of the system.

APPENDIX A

BOARD OF WATER COMMISSIONERS

INTRA-OFFICE COMMUNICATION

DATE: May 13, 1966

TO: C. E. C. Carlson, Superintendent of Operations

FROM: R. G. Akin, Superintendent of Source of Supply

SUBJECT: Cheesman Dam - Valve Operation and Maintenance

Since the last report to you (see attached copy on the subject matter) all downstream valves in the Dam were restored to an operable state during the winter months of 1958-59, including the single gate valve at the 80 foot level. Further, the mechanical condition and operation of these valves has improved considerably. This is a result of a program set up by the Maintenance Division to thoroughly check the valves on a semi-annual basis, including the routine operation by this Division.

At the present, the Maintenance Division is in the process of completely overhauling the two downstream gates at the 15 foot level. The delivery on the two gates from the vendor was estimated by them to be June 20, 1966. However, the releases of water at this level may permit the installation of only one gate this spring.

As originally suggested, the addition of two operating valves would substantially increase the functional use of the present gate type valves, that is, utilize these for a standby or emergency use only. I am referring to the 15 foot level for the new operating valves. One of the two new valves could be 12 inches in diameter to accommodate flows up to 50 s.f. The second valve should have a capacity up to 1200 s.f.

It is advisable to retain the two valves at the 152 foot level, due to more frequent opportunity for inspection and maintenance. The gate valves at the 80 and 60 foot levels should be eliminated once new operating valves are installed at the lower elevation.

Grouting of the manways is recommended to reduce the seepage and, in turn, cut down on the safety hazard of the hydrogen sulfide coming in with the seepage. Grouting may be required if additional sections of the tunnel are pressurized.

See attached sketch for valve elevations.

RGA:bcm

Attach.

BOARD OF WATER COMMISSIONERS

INTRA-OFFICE COMMUNICATION

DATE: May 13, 1966

TO: C. E. C. Carlson, Superintendent of Operations

FROM: R. G. Akin, Superintendent of Source of Supply [redacted]

SUBJECT: Cheesman Dam - Valve Operation and Maintenance

Since the last report to you (see attached copy on the subject matter) all downstream valves in the Dam were restored to an operable state during the winter months of 1958-59, including the single gate valve at the 80 foot level. Further, the mechanical condition and operation of these valves has improved considerably. This is a result of a program set up by the Maintenance Division to thoroughly check the valves on a semi-annual basis, including the routine operation by this Division.

At the present, the Maintenance Division is in the process of completely overhauling the two downstream gates at the 15 foot level. The delivery on the two gates from the vendor was estimated by them to be June 20, 1966. However, the releases of water at this level may permit the installation of only one gate this spring.

As originally suggested, the addition of two operating valves would substantially increase the functional use of the present gate type valves, that is, utilize these for a standby or emergency use only. I am referring to the 15 foot level for the new operating valves. One of the two new valves could be 12 inches in diameter to accommodate flows up to 50 s.f. The second valve should have a capacity up to 1200 s.f.

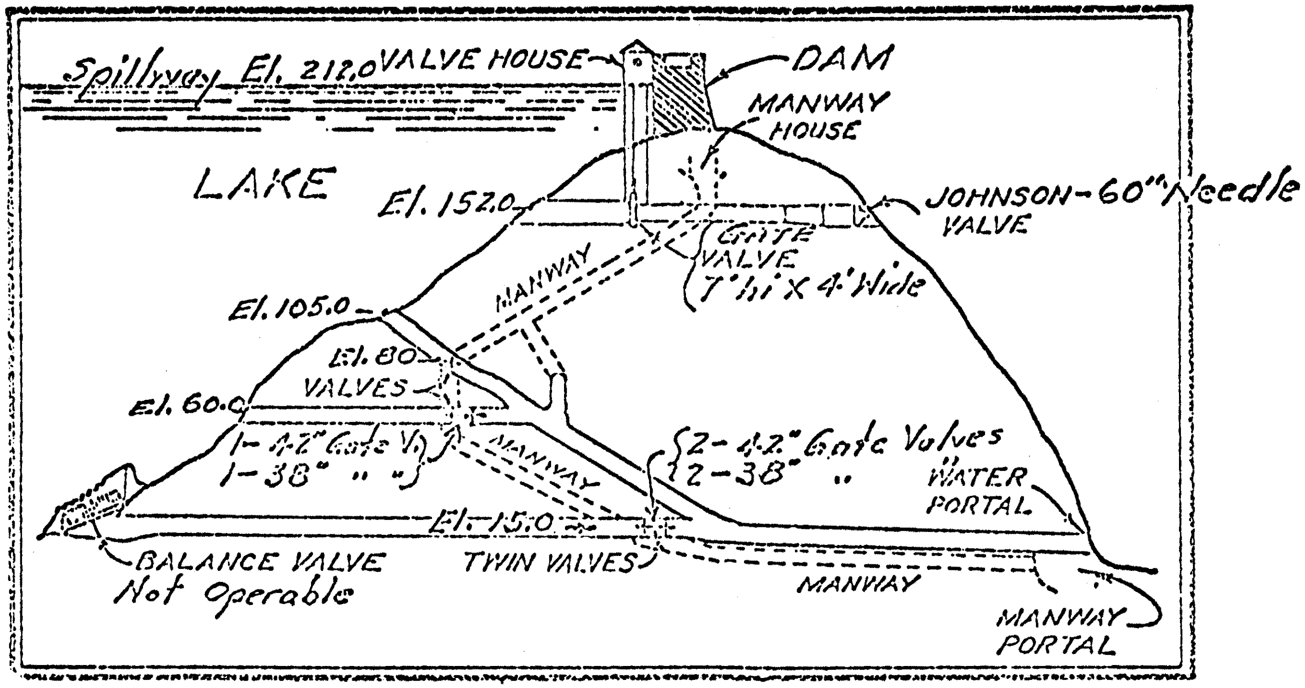
It is advisable to retain the two valves at the 152 foot level, due to more frequent opportunity for inspection and maintenance. The gate valves at the 80 and 60 foot levels should be eliminated once new operating valves are installed at the lower elevation.

Grouting of the manways is recommended to reduce the seepage and, in turn, cut down on the safety hazard of the hydrogen sulfide coming in with the seepage. Grouting may be required if additional sections of the tunnel are pressurized.

See attached sketch for valve elevations.

RGA:bcm

Attach.



Spillway El. 212.0
VALVE HOUSE
DAM
MANWAY HOUSE
LAKE
El. 152.0
JOHNSON-60" Needle VALVE
GATE VALVE 7' hi X 4' Wide
MANWAY
El. 105.0
El. 80 VALVES
El. 60.0
1-42" Gate V.
1-38" " "
MANWAY
2-42" Gate Valves
2-38" "
WATER PORTAL
El. 15.0
BALANCE VALVE Not Operable
TWIN VALVES
MANWAY
MANWAY PORTAL

BOARD OF WATER COMMISSIONERS

INTRA-OFFICE COMMUNICATION

DATE: October 13, 1958

TO: Mr. C. E. C. Carlson, Superintendent of Operations

FROM: Mr. R. G. Akin, Superintendent, Source of Supply Division R.G. Akin

SUBJECT: Lake Cheesman Valve Operation and Maintenance

The down stream channel flow or demands from Cheesman Dam can be regulated, except when the Reservoir is full and spilling, by four levels or elevations of valves, located within the northeast abutment and foundation rock. These valves are accessible by stairways to the 152' elevation, by man-ways and tunnels to the 80', 60', and 15' elevations. The operation of the valves at any elevation depends on the lake level; that is, the lake level this date is 186 ft. so the valve at the 152' level is in operation. In general, this method of operation is the same for the lower elevations as the lake level drops, with one exception. The gate at the 80' level is only operated during emergencies to by-pass heavy stream flows.

Eight of the nine valves in the structure are hydraulically operated by water pressure from a pump at the 15' elevation. The ninth valve is a 60" needle type, referred to as the Johnson Valve, and is semi-hydraulically operated. This valve is the operating valve for the 152' elevation. The upstream or emergency valve at this elevation is a Hardy-Tynen 7' high and 4' wide gate with a vertical cylinder. A hand booster pump is generally required to build up sufficient pressure to operate the valve. These valves were installed in 1926. One single 42" Rensselaer Gate Valve with a horizontal cylinder is at the 80' elevation. The inlet elevation to this valve is 105'. Two of the same type and make are at the 60' elevation. Two sets, referred to as twin valves of the same type and make as at the 60' and 80' levels, are connected in a Wye fashion at the 15' elevation. The two down stream valves at the 15' level were rebuilt with heavier gates and reduced seat rings of 38" diameter in 1931. Similar valves built at the factory were installed, one to replace the down stream valve at the 60' elevation and the single gate at the 80' elevation in 1933. The upstream gates at the 15' and 60' elevations are the original and perhaps the last time that they were operated was during the re-building of the down stream gates.

All down stream valves plus the Hardy-Tynen Gate are operable. The two up-stream valves of the 15' elevation and one upstream valve of the 60' will, no doubt, need cylinder inspection and maintenance before attempting to operate these valves.

BOARD OF WATER COMMISSIONERS

INTRA-OFFICE COMMUNICATION

DATE: October 13, 1958

TO: Mr. C. E. C. Carlson, Superintendent of Operations

FROM: Mr. R. G. Akin, Superintendent, Source of Supply Division [redacted]

SUBJECT: Lake Cheesman Valve Operation and Maintenance

The down stream channel flow or demands from Cheesman Dam can be regulated, except when the Reservoir is full and spilling, by four levels or elevations of valves, located within the northeast abutment and foundation rock. These valves are accessible by stairways to the 152' elevation, by man-ways and tunnels to the 80', 60', and 15' elevations. The operation of the valves at any elevation depends on the lake level; that is, the lake level this date is 186 ft. so the valve at the 152' level is in operation. In general, this method of operation is the same for the lower elevations as the lake level drops, with one exception. The gate at the 80' level is only operated during emergencies to by-pass heavy stream flows.

Eight of the nine valves in the structure are hydraulically operated by water pressure from a pump at the 15' elevation. The ninth valve is a 60" needle type, referred to as the Johnson Valve, and is semi-hydraulically operated. This valve is the operating valve for the 152' elevation. The upstream or emergency valve at this elevation is a Hardy-Tynen 7' high and 4' wide gate with a vertical cylinder. A hand booster pump is generally required to build up sufficient pressure to operate the valve. These valves were installed in 1926. One single 42" Rensselaer Gate Valve with a horizontal cylinder is at the 80' elevation. The inlet elevation to this valve is 105'. Two of the same type and make are at the 60' elevation. Two sets, referred to as twin valves of the same type and make as at the 60' and 80' levels, are connected in a Wye fashion at the 15' elevation. The two down stream valves at the 15' level were rebuilt with heavier gates and reduced seat rings of 38" diameter in 1931. Similar valves built at the factory were installed, one to replace the down stream valve at the 60' elevation and the single gate at the 80' elevation in 1933. The upstream gates at the 15' and 60' elevations are the original and perhaps the last time that they were operated was during the rebuilding of the down stream gates.

All down stream valves plus the Hardy-Tynen Gate are operable. The two upstream valves of the 15' elevation and one upstream valve of the 60' will, no doubt, need cylinder inspection and maintenance before attempting to operate these valves.

Our program of maintenance is as follows:

The 60" Johnson Valve is due for a complete inside cleaning and greasing. This requires a complete dismantling of the cone in order to remove the scale and barnacles and to thoroughly grease the bearings. The time element on this particular valve requires 10 to 12 days to clean. This valve requires this type of maintenance every 6 years. At this same elevation, the hand operated pump for boosting the pressure for operating the Hardy-Tynen Gate will be replaced with an electrical pump. The Maintenance Division, with the help of our operating force, is scheduled to start soon.

The three Rensselaer Valves, one at 60' elevation and two at the 15', upstream and generally considered as emergency valves, haven't been operated since the down stream gates were rebuilt in 1931 for the lower level and 1933 for the upper or 60' level. An attempt will be made to operate these valves under balanced pressure; however, the first approach will be to dismantle the cylinder heads for inspection, restore the packing and miscellaneous piping.

I concur with the Maintenance Division that these valves can be restored to an operable state. The question arises how effective they would be in case they had to be closed under pressure. It has been known by our Division that the seat rings are sheared some and that a complete shut-out is not possible as long ago as 1931 and 1933. The working over of these three Gates will follow the overhaul of the 60" Needle Valve and will probably take three weeks.

One alternate, which has merit, would be to abandon the three upstream valves and install one large or two medium size valves to carry approximately 1200 second feet and a 12 inch valve for low flow operation at the 10' elevation, which would control all three elevations. The outlet tunnel at this station would need enlarging into a Chamber for access and operating equipment. The Valve could be connected with flange piping to the existing flanged valves and concreted. The outlet chute or stopes from the 80' and 60' elevations can be connected with similar piping into a wye branch in back of the operating valve. Piping from the lower level should extend into the lower quarter of the stope and concreted for anchorage. The upper portion of the stope and outlet tunnel would require guniting and perhaps grout the surrounding area to reduce seepage. This installation would place the present operable valves in a position as emergency valves. This scheme is very much recommended over the present layout. Engineering details are lacking at this time to determine the cost.

RGA:tn

cc; M. M. Marshall
K. A. Day
Harry Probert

TO: J. E. Layne, Acting Chief Engineer

(4) My comments on the valves at Cheesman:

As stated in Mr. Akin's report, the 152' level or 60" Johnson Needle Valve is now in excellent condition, and should give the Board many more years of service.

At elevation 105' or 80' level, we have one gate valve installed in 1933. The body and bonnet of this valve is embedded in concrete, so all we have been able to do is maintain the hydraulic operating cylinder. In case of a failure on this valve, we could lose the reservoir to elevation 105'. Leakage is slight, but being unable to inspect this valve, we do not have any idea as to its condition.

The same holds true for the valves at the 60' elevation; except, at this location, there are two valves (installed in 1931 and 1933) and the danger of losing the reservoir due to the valve failure is lessened.

At the 15' elevation, we have two sets of operating valves. On the downstream 38" valves, the concrete has been chipped away from the valve bonnet, so we have been able to close the upstream 42" valves and service the 38" valves. The bodies of the downstream 38" valves are in poor condition, but we can do nothing about this at the present time. New gates have been ordered and should be installed soon; however, the 42" upstream valves are in poor condition, and the leakage excessive.

It is difficult to estimate how much service is left in all of the above valves. Cheesman Reservoir was completed in 1905, and new valves were contemplated in 1922. Valve installations were made between 1926 and 1933. The 152' valve would be lower in elevation, had it been feasible to lower the reservoir more at that time.

A new valve or valves should be considered in the next 5 to 7 years, with a type of valve that would give longer service than the present gate valves. I would recommend that design and cost estimates be prepared, so a valve replacement could be scheduled in the next few years.

CECC:bcm

APPENDIX B

RECOMMENDED STUDY OF THE OUTLET WORKS AT CHEESMAN DAM

SUMMARY

The following is a proposal to analyze and furnish a report on the outlet works at Cheesman Dam. The study will include a report on the present physical condition of the control valves and outlet tunnels, and a discussion of the present operating procedures. Field inspections and tests will be conducted to provide additional information. Alternate solutions for correcting the present difficulties will be provided in sufficient detail to allow the most appropriate solution to be selected. The specific tasks to be included in this study are as follows:

SCOPE OF WORK

1. Examination of information furnished by the Denver Water Board relative to the construction and operation of the outlet works including:

   a. Photographs and construction drawings of the valve installations and the outlet tunnels.

   b. Operating demands such as: maximum, minimum, and average discharges, variation of discharge with time and reservoir elevation, and any projected changes in these demands.

   c. Operating procedures such as: which valves are used versus reservoir elevation, quantities of flow required through each valve, length of time each valve is used during the year, percent use of each valve and the number of valves used at the same time.

   d. Present condition and records of past repair to the valves.

   e. Water quality information on Lake Cheesman.

   f. Maximum flow - minimum head requirements.

The above information will be examined to acquaint the consultants with the facility and procedures of operation. The information will serve as the basis for preliminary analysis of system capabilities and for calculations of cavitation potential, as well as for planning details of field trips to the site and evaluating the need for field testing.

2. Conduct a field inspection of the outlet works to determine the following:

a. The present condition of the valves, valve operators and outlet tunnels.

b. Possibility of continued use of the present gate valves for either throttling or as guard valves and the repairs to them that would be necessary for their continued operation.

c. The possibility of:

   (1) Pressurizing downstream conduits in their present condition, or

   (2) Lining one or more conduits to allow for pressurization, or

   (3) Installing a pipeline system inside the outlet tunnels.

d. The number and location of throttling valves required to satisfy all demand requirements and eliminate the present problems.

e. Geometry of the terrain at the outlet in the event it is recommended to place a free discharge valve at that location.

3. Provide a recommendation with regard to the feasibility of maintaining the capability of withdrawing water from the lake at different elevations.

4. Recommend an operating procedure for the present system which will minimize the present difficulties until permanent modifications are completed.

5. Present alternate solutions, including operating procedures and cost estimates, for solving the existing problems while maintaining adequate flexibility for present and future demands. Alternatives will be presented for each of the following:

   a. The types of feasible systems, such as merely changing the existing valves, eliminating certain valves, or replacing the present system with a closed conduit having a single valve at the exit of the tunnel.

   b. The type of valve suggested for each scheme.

   c. The tunnels which should be utilized.

6. Discuss proposed solutions with Water Board personnel to verify that each alternative is practical and in line with the objectives and requirements of the Denver Water Board.