USE OF SNOW SURVEYS BY DENVER WATER BOARD

By Robert W. Fischer [1/]

In order to describe the present and anticipated use of snow surveys by the Denver Water Board, a map of the present and proposed water system for Denver, Figure 1, is provided, and a brief history and description of this water system follows.

Water for the frontier town of Denver was first obtained from the South Platte River and Cherry Creek. Later, in 1872, a well near the South Platte River was used to serve 5,000 people. During the years immediately following this beginning, additional means of diverting water from the South Platte River were devised by various private water companies. In 1894, the Denver Union Water Company was organized and it absorbed many of the old private companies. During the 24 years existence of the Denver Union Water Company, the South Platte River was further developed as the main source of water for Denver. The major development was the construction of Cheesman Dam in 1905.

On November 1, 1918, the Denver Union Water Company was purchased by the City of Denver and was placed under control of the Board of Water Commissioners. The Board continued development of the South Platte source by acquisition of additional water rights and the completion of Eleven Mile Canon Dam in 1932.

The present South Platte Supply System includes Antero, Eleven Mile and Cheesman Storage Reservoirs having a total capacity of 193,000 Acre Feet; Marston and Platte Canon Operating Reservoirs having a total capacity of 19,000 Acre Feet; and the Intake Dam located approximately 21 miles southwest from the center of the City of Denver, from which raw water conduits transport the supply to the operating reservoirs, which in turn supply the filter plants.

As early as 1914, surveys and studies of possible transmountain diversions were made by the City of Denver, and in 1936, the first West Slope water was diverted through the Moffat Tunnel from the Fraser River. Since that first diversion, collection facilities have been extended, enlarged and improved to provide an important source of water from the Fraser River and its tributaries. In order to provide regulatory storage of this western slope water, Ralston Reservoir was completed in 1937 and Gross Reservoir in 1955.

The present Fraser River Supply System consists of 26 miles of tunnels, canals, siphons and buried conduits, the 6-mile Moffat Tunnel, Gross and Ralston Reservoirs having a total capacity of 54,000 Acre Feet, the ten mile long South Boulder Diversion conduit between Gross and Ralston Reservoirs, and two raw water conduits from Ralston Reservoir to Moffat Filter Plant.

In 1955 the Water Board acquired the Williams Fork Dam, Williams Fork Collection System, and the Jones Pass Tunnel which were constructed by the City of Denver. The collection system and tunnel were used for exchange purposes until 1959 when the Vasquez Tunnel was completed. This present system, consisting of 3.6 miles of buried conduits and two 3-mile tunnels, makes possible the direct use of water diverted from the headwaters of the Williams Fork River. The Vasquez Tunnel serves as the connecting link between this system and the Fraser-Moffat Tunnel system.

The Williams Fork Reservoir provides storage which is used as exchange water for transmountain diversions. In 1959, the Williams Fork Dam was enlarged to provide a reservoir having a capacity of 97,000 Acre Feet and a 3,000 K W power plant was installed.

To provide an additional source of water, the Board initiated construction of the 23-mile Harold D. Roberts Tunnel in 1946. Construction of this tunnel was accelerated in 1956. In 1959, construction of Dillon Dam was begun. Dillon Reservoir will have a capacity of 252,000 Acre Feet. The reservoir and tunnel are scheduled for completion in 1963.

An attempt has been made to briefly describe the system and facilities which provide the water supply for the City of Denver. This system derives its supply from three watersheds - The Fraser, Williams Fork, and South Platte; and, water from the fourth watershed, the Blue, will be available in a year or two. Operation in each of these watersheds presents various problems peculiar to each, and as time progresses, these problems will become more numerous and acute. Solution of these operating problems often can be found through the use of water supply and stream flow forecasts. These are utilized to develop an operating plan for the individual system of each watershed, in order to provide optimum operation of the integrated system. In most instances, snow surveys provide a portion of the basic data from which these forecasts and operating plans may be formulated.

in 1957, equations were developed to forecast the flow divertible by our Fraser Collection System. Using these equations, forecasts of the divertible flow during the period beginning with the forecast date and ending September 30, are made on March 1, April 1 and May 1. The equations were developed on an electronic computer using multiple correlation techniques. The historical divertible flow for a 20 year period was correlated with snow course data and precipitation data using various combinations of snow courses and precipitation stations, and the best equation developed for each forecast date has been used during the years 1958 through 1961. The equations chosen for use are based upon data of seven snow courses, three within the Fraser watershed and four located in adjacent watersheds; and, data of three precipitation stations, two located in the

1/ R. W. Fischer, Board of Water Commissioners, City and County of Denver, Colorado.

Fraser watershed and one in an adjacent watershed. Accuracy of the forecast improves as the date of forecast approaches the runoff season. The following table presents a comparison of forecasted supply with actual runoff during the forecast period for the years 1958 through 1961.

FRASER COLLECTION SYSTEM

MAY THROUGH SEPTEMBER DIVERTIBLE FLOW

1,000 Acre Feet

Year	Actual Flow	May 1 Forecast	Percent Error
1958	71.5	73	+ 2.1
1959	69.8	79	+13.2
1960	74.0	63	-14.9
1961	61.0	63	+ 3.3

The forecasts of Fraser divertible flow and estimates of monthly requirements are used in making operation studies from which operating plans for the coming season are formulated. The operation studies can be made on an electronic computer using the program which has been written for this purpose.

During recent years, growth within the portion of the Denver Metropolitan Area which is normally served from the Fraser System supply has been tremendous, and this past rate of growth is continuing. Storage capacity of the reservoirs on this system is limited. This combination produces a situation requiring careful operation. If an accurate early forecast indicates a coming season of low Fraser System supply, operation studies may indicate the need for pumping filtered water from the filter plants supplied from the South Platte supply into the normal Fraser service area. Pumping water into an area which can be served by gravity flow greatly increases operating costs and is avoided if possible. This method of conserving the Fraser supply must be employed previous to and after the runoff season; therefore, the necessity for conservation must be determined basically from the snow survey. The results of errors in forecasting and utilizing the forecasts in this instance could be of major significance. If conservation measures are taken, and later developments prove them unnecessary, additional operating costs will have been incurred to no avail. If, however, conservation measures are not initiated and later developments prove they were necessary, lack of sufficient water supply could develop.

Since the enlargement of the Williams Fork Reservoir, the installation of a power plant and the completion of the Vasquez Tunnel, which is the connecting link between the Williams Fork Collection System and the Moffat Tunnel System, the need for accurate forecasts and detailed operating plans has increased greatly. In 1959, forecast equations were developed to forecast the flow of the Williams Fork River at the Reservoir. Snow survey data and precipitation data were used to develop these equations utilizing methods identical to those used in formulating the Fraser forecast equations. By means of these equations, forecasts are made on March 1st, April 1st, and May 1st. The 1959 and 1960 forecasts of the flow of the Williams Fork River were not as accurate as desired. The lack of sufficient data on precipitation, snow pack, stream flow and water utilization in this watershed is probably the cause of the inaccurate forecasts. Additional effort will be made to develop adequate forecasts. The forecasts of Williams Fork River flow are used in operation studies to formulate plans for operating the Reservoir and the Collection System.

The primary purpose of the Williams Fork Reservoir is to store water during periods when the senior downstream rights on the Colorado River are fully supplied without Williams Fork River water, and to release this water during periods of low flow as replacement for the water diverted through the Moffat Tunnel from the Colorado River System. Subordinate to this primary use is the generation of electrical energy at the Williams Fork Power Plant. Dual use of the Reservoir water necessitates carefully formulated operating plans utilizing forecasts of the Fraser River Supply, the flow of the Williams Fork River, and the flow of the Colorado River. Operating plans for the power plant, developed from early season forecasts, must be consistent with the primary purpose of the Reservoir and also facilitate earning the optimum power revenue from the water available. Early season forecasts must produce an operating plan which will prevent spill during a year of high stream flow or a plan must be developed which will provide the necessary carry-over storage during a year of low stream flow.

Water originating above the Williams Fork Collection System may either be diverted through the system to the Moffat Tunnel and used directly or bypassed at the Collection System intakes and permitted to flow down the Williams Fork River for storage in the Williams Fork Reservoir. Forecasts of the supply available from the Fraser River and the flow of the Williams Fork River and operation studies of the Fraser-Williams Fork System provide the information necessary to plan for using the Williams Fork Collection System supply in the most beneficial manner.

With the completion of Dillon Dam and the Roberts Tunnel, water from the Blue River will be available for use by the City of Denver. Addition of the Blue River System will increase the complexity of operation of the Board's raw water facilities. In addition to its present uses, Williams Fork Reservoir water will be released as replacement for water diverted from the Blue River during periods of low flow of the Colorado River.

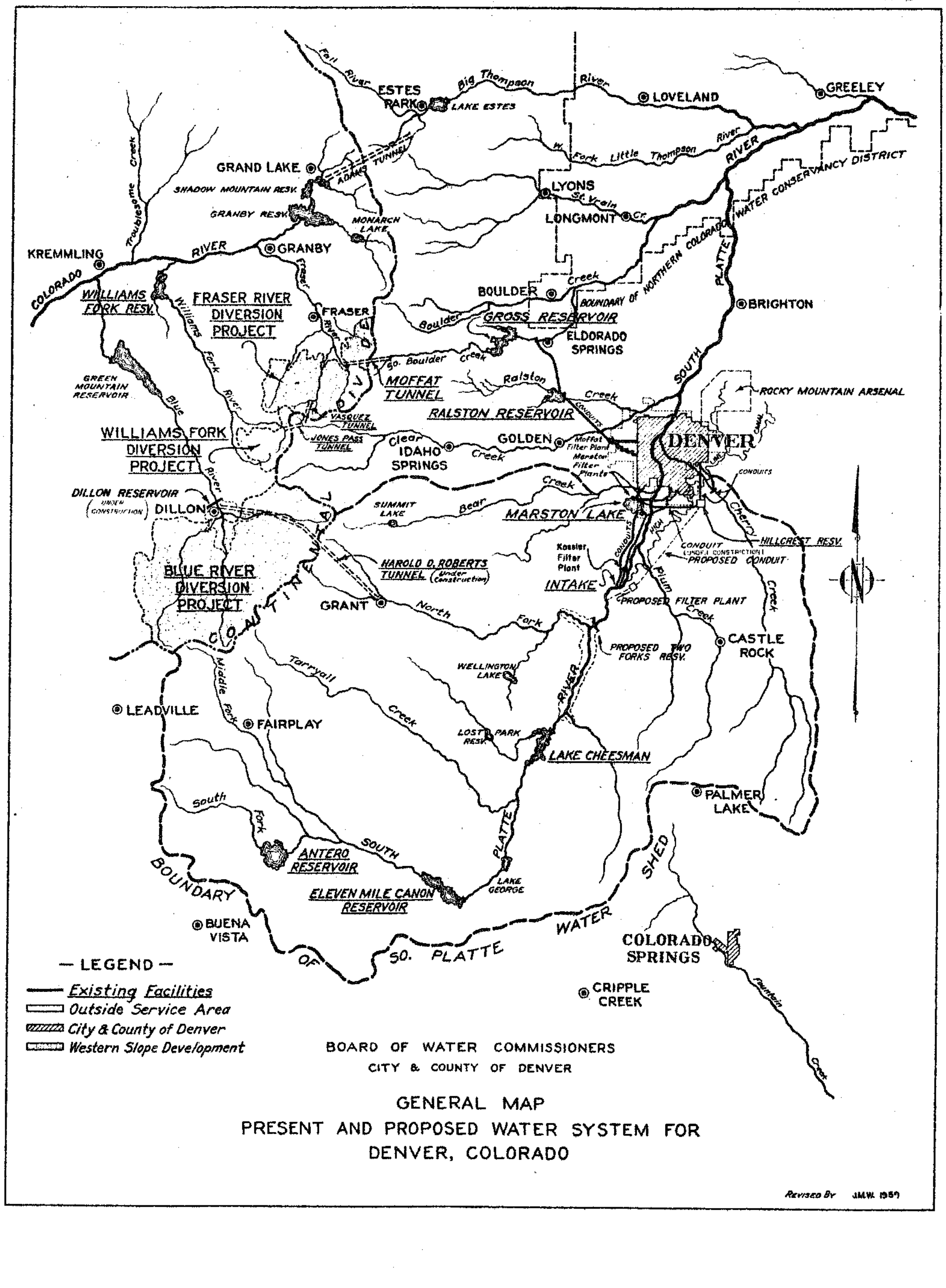
Denver's Blue River Diversion will reduce the amount of energy possible for the U. S. Bureau of Reclamation to generate at their Green Mountain Reservoir and Power Plant, located on the Blue downstream from Dillon Reservoir. This loss of energy by the Bureau will be replaced with energy generated at the Williams Fork Power Plant. In order to operate both systems, the Blue and Williams Fork, in the most economical manner and with maximum benefits accruing to the City of Denver, integrated operating plans will be required. The need for such operating plans emphasizes the importance of accurate snow surveys and water supply forecasts. As was stated earlier in this paper, efforts to improve the accuracy of forecasting the flow of the Williams Fork River will be made. A procedure for forecasting the flow of the Blue River at Dillon will need to be developed by the Board in the near future.

Inflow to the Bureau's Green Mountain Reservoir will be reduced by Denver's Blue River Diversion. Court decree requires the filling of Green Mountain Reservoir once each year, subject, of course, to insufficient total flow of the Blue River. The Bureau of Reclamation and the Board of Water Commissioners of Denver have an enviable record of working well together. Snow surveys and water supply forecasts will provide data which will leave little chance for differences of opinion when the two agencies will be operating on the Blue River.

The storage reservoirs on the South Platte River provide the capacity for carry-over storage of water needed during years of low water supply. The annual average supply available for storage in these reservoirs is less than 15% of the capacity of these reservoirs. Through the method of exchange, water diverted from the Blue River will provide additional opportunities to store water in the South Platte Reservoirs. Since it is impossible to accurately predict a coming drouth period, a prime objective of system operation is to maintain reserve storage at the highest level possible. Blue River water will be used in this manner in order to attain this objective. In order to utilize Blue River water most efficiently and economically in this manner, accurate snow surveys producing South Platte water supply forecasts will be required.

Throughout this paper, an attempt has been made to show how each individual part of the water supply system affects or is affected by another part of the system, and that the system can only be operated as an integrated system. For such an integrated operation to be successful and economical, careful planning based upon the best information available is required. Snow surveys and water supply forecasts comprise the major portion of the basic information available. A number of specific examples of present applications of snow surveys and of applications planned for the future have been described in an effort to indicate their importance to the Denver Water Board. Providing a water supply capable of meeting the needs of the growing Denver Metropolitan Area is a task of great magnitude and importance. Snow surveys play an important role in the overall performance of this task.

FIGURE 1



BOARD OF WATER COMMISSIONERS
CITY & COUNTY OF DENVER

GENERAL MAP
PRESENT AND PROPOSED WATER SYSTEM FOR
DENVER, COLORADO