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COLORADO'S
WATER RESOURCES

Prepared by Colorado Water Conservation Board

Denver, Colorado

for

Colorado State Department of Natural Resources

September, 1957

CONTENTS

WATER RESOURCES OF COLORADO

I. STATE WATER SUPPLY

The origin of the State's water supply is the moisture that falls in the mountains in the form of snow and flows down the creeks and rivers with the advent of spring, together with the rain which falls over the entire area of the State. The amount of water produced in other States which flows into Colorado is insignificant as compared with the water production of Colorado.

An estimate of the amount of water falling on the State of Colorado has been made by measuring the area between isohyetal precipitation lines on a map of the State. In this manner the precipitation over the State was weighted. The same procedure was followed to obtain estimates of the precipitation falling on the east and west slopes of the Continental Divide. The following table shows the result of this study:

Weighted average annual precipitation on Colorado	17.8 in.
Total area in Colorado	66,718,080 acres
Average annual precipitation on Colorado	99,000,000 acre-feet
<u>WESTERN SLOPE</u>	
Weighted average annual precipitation	20.34 in.
Total area	24,916,480 acres
Average annual precipitation on area	42,233,400 acre-feet
" " " rate	1,085 A.F./Sq.Mile
<u>EASTERN SLOPE</u>	
Weighted average annual precipitation	16.32 in.
Total area	41,801,600 acres
Average annual precipitation on area	56,766,600 acre-feet
" " "	869 A.F./Sq.Mile

For the period 1914-55 stream flows resulting from this precipitation which reached the boundaries of the State, have averaged 11,653,000 acre-feet. The 1950 U. S. Census credits Colorado with 2,943,895 acres of irrigated lands. Stream depletion resulting from the growing of crops varies with the types of crops and the location of the irrigated lands. On an average basis, if each acre of land consumed 1.3 acre-feet of water, the total consumptive use would be 3,827,000 acre-feet approximately. The water put to use plus the quantity leaving the State would amount to 15,480,000 acre-feet. The remainder, about 84 percent of the precipitation, is lost principally through evaporation and transpiration from trees and non-productive plant life. A portion is lost by deep percolation to ground-water aquifers not tributary to surface streams.

A. SURFACE FLOWS

Eastern Slope.

The North Platte River and tributaries, including the Laramie River are governed by decisions of the United States Supreme Court and modifications thereof. There appears to be no opportunity for a major increase in the use of the water supplies of these areas except by the discovery of ground-water not tributary to the stream. As shown in Table II, flow across the State Line averaged 572,300 acre-feet for the period 1914-55, and 453,000 acre-feet for the drier period of 1934-55.

The waters of the South Platte River basin are diverted for irrigation, municipal and industrial purposes. There is extensive re-use of return flows resulting from these diversions.

The South Platte River Compact states, in effect, that (1) Colorado shall have the full flow of the river within the boundaries of the State between October 15th and April 1st of the succeeding year, (2) that between April 1st and October 15th of each year, Colorado will not permit diversions in the lower section of the river whose priority dates are subsequent to the 14th of June, 1897, if the use of such rights would diminish the flow of the river below 120 second feet. Return flow from future additional transmountain diversions will result in some increases in the total quantity available, the amount of which is not certain at this time. A flood control dam at the Narrows near Sterling, would, in some years, capture water which would otherwise flow unused out of the State. Local people of the basin to be flooded have vigorously opposed the construction of this project. Average flow across the State Line was 327,800 acre-feet for the longer period and 267,200 acre-feet for the shorter.

Water impounded in John Martin Reservoir on the Arkansas River is divided between Colorado and Kansas by the Arkansas River Compact. When the reservoir is empty, administration of water rights reverts to the priority basis in Colorado without consideration of uses in Kansas. With regard to future development, Article IV-D of the Compact reads as follows:

> "This Compact is not intended to impede or prevent future beneficial development of the Arkansas River Basin in Colorado and Kansas by Federal or State agencies, by private enterprise, or by combinations thereof, which may involve construction of dams, reservoirs and other works for water utilization and control, as well as the improvement or prolonged functioning of existing

works: Provided that the waters of the Arkansas River, as defined in Article III, shall not be materially depleted in usable quantity or availability for use to the water users of Colorado and Kansas under this Compact by such future development or construction."

Future development in this basin will depend to a large degree on the interpreations of the word "materially". The proposed Fryingpan-Arkansas project, whose water supply would be derived from transmountain diversion plus storage of water now used for winter irrigation, would not "materially" deplete the inflow into John Martin Reservoir. In fact, it would probably increase such inflow somewhat. State Line flow averaged 298,500 acre-feet for the 1914-55 period and 272,000 acre-feet for 1934-55.

The Rio Grande flows across the State Line into New Mexico and is subject to the Rio Grande Compact between Colorado, New Mexico and Texas. There has been difficulty in meeting the scheduled deliveries at the State Line during the last few years of unprecedented drought. The Compact was entered into to facilitate the provision of storage in the San Luis Valley. The Platoro Reservoir on the Conejos has been constructed. On the Rio Grande, the proposed Wagon Wheel Gap Reservoir would regulate the present erratic stream flow which is used for irrigation. No new water would become available or new lands irrigated. State Line deliveries for the periods indicated above were 443,800 and 335,400 acre-feet on an average.

The Republican River Compact allocates to Colorado, Kansas, and Nebraska specific quantities of water from the several sub-basins covered. The Kansas River basin, including the Republican River, furnished 188,300 acre-feet at the State Line during 1914-55 and 153,500 acre-feet as an average during 1934-55.

Western Slope.

The Colorado River and its tributaries, including the Gunnison, Dolores, Yampa, White and San Juan Rivers drain the Western Slope of the State.

Table I of Section IV, "Preliminary Tabulation of Land Classification Coverage by Bureau of Reclamation, Colorado", shows the arable land, irrigated and non-irrigated, in the various basins in the State. In the several Eastern Slope basins there are hundred of thousands of arable acres for which there is no water. In the Colorado River basin, Table II of Section IV indicates a total of 713,910 arable acres not irrigated at the present time. Also, for thousands of these acres there can be no water supply.

a. Water supply. The beneficial consumptive use basically apportioned to Colorado under the Colorado River Compact amounts to 3,855,375 acre-feet per year. Taking into account anticipated salvaged water and loss due to evaporation, "this would leave 3,727,000 acre-feet as the limit (under Section (a) Article III of the Colorado River Compact) of all depletions in Colorado arising from consumptive uses by agriculture, consumptive uses by industry, and diversions out of the drainage basin of the Colorado River". This estimate, from the report of Leeds, Hill and Jewett, is based on the assumption that the flow of the river will produce 7,500,000 acre-feet for the Upper Basin after providing a similar amount for the Lower Basin. During the period 1930 to 1952, an extremely dry period, the flow was reduced so much that Colorado's share of depletions would have amounted to but 3,100,000 acre-feet, according to this same report. These quantities would be available only if cyclic storage were built to carry water over from a wet period to be used during a dry period, some twenty years in the case of the 3,100,000 acre-feet estimate. This means large storage reservoirs on the Main Stem and major tributaries of the Colorado, and small ones at higher altitudes to serve the irrigation projects. State Line average flow for the river and its tributaries for the period 1914-55 was 9,822,000 acre-feet and 8,429,600 acre-feet for the period 1934-55 (Table III).

Data furnished by the Engineering Research Committee of the Colorado Water Conservation Board indicates that there is now a depletion of 1,035,000 acre-feet on account of irrigation agriculture on the Western Slope; the total present and authorized depletion, according to the Hill Report, is approximately 1,650,000 acre-feet per yea r. Some feel that this quantity is not large enough because it is claimed there are more presently irrigated acres than have been included. Using the quantities given, an uncommitted balance of 2,077,000 acre-feet is the result in case the large supply figure is used, or 1,450,000 acre-feet for the smaller estimate.

b. Surplus Water. From this point on an estimate of the amount of water remaining for allocation, after proposed projects and other claims are satisfied, varies greatly with the assumptions used in making the estimate.

(1) A number of potential irrigation projects were authorized or given priority in planning in the act authorizing the Colorado River Storage Project. Assuming (a) 456,000 acre-feet aggregate depletion for these projects in this category for which the presently indicated benefit cost ratios are at least unity, and with repayment capacity by irrigators of at least nine percent of construction costs, (b) 300,000 acre-feet depletion for industry on the Western Slope, (c) 163,000 acre-feet depletion for unclassified land presently irrigated or capable of being irrigated in the future by private initiative, (d) 194,000 acre-feet for Colorado's portion of the Mexican Treaty obligation (this may vary from 100,000 acre-feet or less to 375,000 acre-feet, according to the authority cited), (e) 196,000 acre-feet for Denver and Colorado Springs-Blue River diversion, and (f) 75,000 acre-feet for the proposed Fryingpan-Arkansas project, a total additional use of 1,384,000 acre-feet may be calculated. Subtracting this amount from 2,077,000 leaves a surplus of 693,000 acre-feet in case the full 3,855,375 acre-feet of

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beneficial consumptive use, plus salvage, is available to Colorado. Should the consumptive use available to Colorado be 3,100,000 acre-feet, the surplus would be 1,450,000 minus 1,384,000 or 66,000 acre-feet, under the further assumption that stream depletions of all projects would remain the same under all water supply conditions.

(2) On the basis that all of the projects covered in the Upper Colorado River Storage Project Act with a benefit-cost ratio of unity or better might be built regardless of amounts repayable on construction costs by irrigators, it would be necessary to replace the amount of 456,000 above under (1)(a) with 703,000 acre-feet. In this case there would remain a surplus of 446,000 acre-feet under the condition of availability of the State's full share under the Compact. There would be a deficit if Colorado's share of depletions should be 3,100,000 acre-feet.

(3) According to Bureau of Reclamation reconnaissance surveys, there are 713,910 unirrigated arable acres in the Colorado River Drainage Basin, (Table II, Section IV). Allowing 1.3 acre-feet per acre as the consumptive use, these acres would cause a depletion of 928,000 acre-feet. The irrigation of these lands, along with the other uses which have been considered above, would not be possible if Colorado's depletions are held to the lower limit by lack of water supply.

It should be noted that the total water is well known.

However, the local supplies for the proposed participating projects require the collection of much additional data and more study. The cost of applying water to much of the arable land is unknown and hence the economic feasibility for at least half of the land classified as arable by reconnaissance surveys is undetermined.

Transmountain Diversions. There are records of the diversions which have been made from the Colorado River basin to other basins of the State. The historic diversions do not represent in all cases the total potential diversions which may be made with completed facilities. Estimates of possible future diversions may vary because of water supply periods considered, drainage areas assumed and other assumptions as to the extent of future development of diversion facilities.

Table I contains data on transmountain diversions based on the periods 1914-45 and 1934-55. The estimates of total future diversions have been compiled from various sources.

TABLE I.

Transmountain Diversions from Colorado River Watershed in Colorado [1]

(1,000 AF)

Name of Diversion	32-Year Average 1914 - 1945			22-Year Average 1934 - 1955		
	Historic	Increase	Total Future	Historic	Increase	Total Future
To South Platte Basin						
Grand River Ditch	14.4	5.8	20.2	18.1	1.1	19.2
Moffat Tunnel	8.5	71.5	80.0	25.5	55.5	# 81.0
Jones Pass Tunnel	1.2	19.8	21.0	4.8	31.2	# 36.0
Colorado-Big Thompson	---	278.1	* 278.1	41.3	197.2	*238.5
Denver-Blue River Project	---	177.0	177.0	---	148.0	#148.0
Englewood	---	15.0	15.0	---	14.4	# 14.4
Minor Ditches	0.8	0.2	1.0	0.9	0.1	1.0
Subtotal	24.9	567.4	592.3	90.6	447.5	538.1
To Arkansas Basin						
Busk-Ivanhoe Tunnel	2.9	3.1	6.0	4.2	1.1	5.3
Twin Lakes Tunnel	11.4	43.6	55.0	33.5	14.2	47.7
Colorado Springs (Hoosier)	---	17.0	17.0	0.8	10.6	# 11.4
Fryingpan-Arkansas	---	72.2	* 72.2	---	63.8	* 63.8
Minor Ditches	3.2	2.3	5.5	4.4	1.6	6.0
Subtotal	17.5	138.2	155.7	42.9	91.3	134.2
To Rio Grande Basin						
Weminuche Pass Div.	---	15.0	15.0	---	9.7	9.7
Minor Ditches	1.3	3.0	4.3	2.0	3.0	5.0
Subtotal	1.3	18.0	19.3	2.0	12.7	14.7
Grand Total	43.7	723.6	767.3	135.5	551.5	687.0

Note: The estimated diversions are for existing, authorized or approved projects only. Do not include recent filings for diversion from Eagle River, Piney River, and Homestake Creek.

* Future totals include losses from Western Slope Reservoirs.

\# Future total taken from studies by W. W. Wheeler, Tipton, and Kalmbach.

1. **Prepared by J. R. Riter, Chief, Planning and Development, U. S. Bureau of Reclamation.**

TABLE II

AVERAGE HISTORICAL RUNOFF[1]

EAST SLOPE RIVERS IN COLORADO
(In thousands of acre-feet)

State Line Flows	Average 1914-1955	Average 1934-1955
North Platte River Basin	572.3	453.0
South Platte River Basin	327.8	267.2
Kansas River Basin	188.3	153.5
Arkansas River Basin	298.5	272.0
Rio Grande Basin	443.8	335.4
Total	1,830.7	1,481.1

1. Based on records of U. S. Geological Survey and Colorado State Engineer.

TABLE III

AVERAGE HISTORICAL RUNOFF[1]

WEST SLOPE RIVERS IN COLORADO
(In thousands of acre-feet)

State Line Flows	Average 1914-1955	Average 1934-1955
Colorado River less Gunnison River	3,253.5	2,763.6
Gunnison River near Grand Junction	1,943.1	1,681.9
Dolores River	695.3	610.9
San Juan River	2,001.9	1,730.8
Yampa River	1,374.5	1,170.4
White River	553.7	472.0
Total	9,822.0	8,429.6
Flows at Key Gaging Stations		
Colorado River at Glenwood Springs	1,990.2	1,708.0
Roaring Fork River at Glenwood Springs	993.9	873.5
Colorado River below Roaring Fork	2,984.1	2,581.5
Colorado River near Cameo	3,353.5	2,885.1

1. Based on records of U. S. Geological Survey and Colorado State Engineer.

B. GROUND WATER[1]

Cooperative investigations of the ground-water resources of Colorado have been made since 1945 by the Colorado Water Conservation Board and the United States Geological Survey. The results of these investigations have been published as time and finances permitted. Two detailed reports have been published as Bulletins of the Colorado Water Conservation Board, one of which was also released as a Geological Survey Water-Supply Paper, and other detailed reports are in preparation or in press. Shorter reports have been published as Circulars of the Colorado Water Conservation Board.

Detailed ground-water reports contain not only the basic hydrologic data gathered during a ground-water investigation, but also a text, maps, and charts that interpret these data for the use of the public. Thus, they contain the basic ground-water information that will be useful for many years in the planning of any ground-water development. The data are used by municipalities, State and Federal agencies, industries, well drillers, consulting engineers and geologists, and individuals. In varying degrees which are dependent on the detail of the investigation the reports outline the origin, movement, quality, and availability of ground water in the area of study. The reports generally contain maps showing the location of the wells that were measured, the depths of water, and the shape and slope

1. By Thad McLaughlin, District Geologist, U. S. Geological Survey.

of the water table, as well as cross sections showing the character and thickness of the water-bearing materials.

The reports discuss the occurrence of ground-water in the area, the quality of the water, and if sufficient data are available, the quantity of water available.

Although only a part of the State of Colorado has thus far been covered by detailed ground-water studies, our present knowledge of the geology of the State is adequate to permit outlining the general features of our ground-water resources.

Occurrence of Ground-Water in Colorado. It is common knowledge to those familiar with water in Colorado that the part of the State lying west of the Continental Divide has an abundance of surface water but a deficiency of irrigable land, whereas the part lying east of the Divide has an abundance of irrigable land but a deficiency of surface water. It is not common knowledge, however, that the major supplies of ground-water in the State are east of the Continental Divide and, in general, underlie those areas having the best irrigable land.

Ground-water is unique in that it lies beneath the earth's surface where it is stored in tremendous quantities in what are largely "evaporation-free" reservoirs. It is unique among "mineral" deposits lying beneath the earth's surface in that it is replenishable by recharge from precipitation, from streams, and from other sources. It is unique in mode of exploitation in that it is developed almost entirely by individuals with little or no expenditure of public funds.

Ground-water has long been used in Colorado for domestic, industrial, and municipal supplies but until recently it was used only on a minor scale for irrigation. With the development of efficient pumps, engines, and motors and the availability of cheaper electricity and petroleum products for fuel, the pumping of ground-water for irrigation has grown by leaps and bounds since the early 1930's and is continuing to grow at an ever-accelerated pace. Data accumulated to date indicate that the number of irrigation wells in Colorado doubled between 1940 and 1950 and has doubled again since 1950. The data indicate also that there are now at least 8,500 pumped wells and 7,000 flowing wells in Colorado which discharged more than 2,000,000 acre-feet of ground-water in 1956 for the irrigation (largely supplemental) of more than 1,000,000 acres of land. In view of the fact that hundreds of millions of dollars of funds will be required to develop the remaining unappropriated surface water resources of Colorado, the value of ground-water now being used for irrigation is a sizable factor in the State's economy.

Principal Aquifers. Colorado is blessed with ground-water supplies larger than those of most of the States in the Rocky Mountain Area. The water is contained largely in four major aquifers - namely, (1) the alluvium and terrace deposits of the South Platte Valley and its major tributaries, (2) the alluvium and terrace deposits of the Arkansas Valley and its major tributaries, (3) the valley fill in the San Luis Valley, and (4) the Ogallala formation in the High Plains. As irrigation is the principal use of ground-water in Colorado, the following discussion is concerned largely with irrigation supplies.

a. South Platte Basin. The alluvium and terrace deposits in the South Platte Valley and its major tributaries constitute the most highly developed aquifer in Colorado. It is estimated that there are now more than 5,000 pumped wells that discharged about 1,000,000 acre-feet of water in 1956 for the irrigation of about 550,000 acres of land. Some indication of the rate of growth and of the magnitude of pumping for irrigation in the South Platte Valley is given by the records of electric power consumption that were obtained from power supplies by Colorado State University. Ground-water studies made in the South Platte Valley and tributaries between Hardin, Colorado, and the Nebraska State line indicate that the average irrigation-well pump in the main stem of the valley consumes considerably less than 100 kilowatt-hours of electricity in pumping one acre-foot of water and that the average pump in the tributary valleys, where the water table generally is deeper, consumes a little more than 100 kilowatt-hours in lifting one acre-foot of water. As most of the wells are in the main stem of the valley where pumping lifts are less, the assumption that each pump used 100 kilowatt-hours per acre-foot pumped in 1956 will give a conservative estimate of the total amount of water pumped for irrigation in 1956--particularly in view of the fact that those pumps not electrically operated are not included in the tabulation.

Listed below are the records of electric power consumption and estimates of the quantity of water pumped (assuming that 100 kilowatt-hours of electricity was required to pump one acre-foot).

Year	Number of pumps served	Kilowatt-hours used	Average Kilowatt-hours used, per pump	Estimated quantity of water pumped, in acre-feet
1935	428	3,610,000	8,435	36,000
1940	1,077	15,340,000	14,243	153,000
1945	1,630	14,230,000	8,730	142,000
1950	2,800	39,700,000	14,179	397,000
1955	4,780	76,840,000	16,075	768,000
1956	4,850	93,410,000	19,260	934,000

Most of the wells in the alluvium in the South Platte Basin are along the main stem of the South Platte Valley where they are used largely for supplemental irrigation. Owing to the rapid infiltration of surface water that is spread for irrigation, the water levels have not declined during the past 20 years, except for seasonal fluctuations and local overdevelopment. In tributary valleys, such as Beaver, Bijou, Badger, and Kiowa, no surface water is used for irrigation and the only sources of recharge are local precipitation and infiltration through the stream beds during periods of flood runoff--plus the fraction of the ground-water that returns to the water table from irrigated fields. As a consequence, the amount of water being pumped annually probably exceeds the annual replenishment, the water levels are declining at a serious rate (as much as 4 or 5 feet a year), and the aquifer is locally approaching exhaustion.

Studies of the occurrence of ground-water have shown that there is about 11,000,000 acre-feet of ground-water in storage in the alluvium in the South Platte Valley and tributaries between Hardin, Colorado, and the Colorado-Nebraska State line. On this basis it can be estimated conservatively that there is at least 25,000,000 acre-feet of ground-water in storage in the alluvium in all the South Platte Valley in Colorado and in all its tributaries. This large body of ground-water is a valuable adjunct to the irrigation economy of the South Platte Basin in that the ground-water may be used at any time to supplement the surface-water supply or it may be drawn upon heavily during periods of low streamflow.

Although ground-water in several of the tributary valleys now appears to be seriously overdeveloped, there is no hydrologic reason why ground-water in the main stem of the South Platte cannot be developed to an even greater extent. When irrigation wells were first drilled in the South Platte Valley there was some concern about the possible ill effects of pumping, but after more than 20 years of rapid development there has been no persistent decline of water levels and there still remain areas of land that have been waterlogged by the application of surface water, where the pumping of ground water not only would do no harm, but would be of great benefit in reclaiming the land.

The diversion of new water from the West Slope will have an important effect on the ground-water situation in the South Platte Basin. New water applied to areas where no wells have been drilled will cause water levels to rise and may waterlog some of the land, making it unsuitable for use. In other areas where water levels have been prevented from rising because of pumping for supplemental irrigation, the availability of the new water may eliminate the need for pumping with the result that there also water levels may rise to the point of endangering the land. If new water is applied to lands not heretofore irrigated, an aquifer may be developed in previously dry sand and gravel so that at a later date the pumping of ground-water for supplemental use may become feasible. If new water is applied to areas where irrigation was previously by ground-water alone, water levels may be restored before the aquifer in those areas is exhausted.

b. Arkansas Basin. The alluvium and terrace deposits of the Arkansas Valley and its principal tributaries constitute an important aquifer in Colorado, but few data concerning the extent of development are available. On the basis of detailed studies in some parts of the Arkansas Basin and of data on electric power consumption, it is estimated that there are now nearly 1,500 irrigation wells that obtain water from alluvial deposits in the Arkansas Basin. It is also estimated that they discharged more than 200,000 acre-feet of water in 1956 for the irrigation (largely supplemental) of more than 100,000 acres of land.

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In the table below are listed the number of plants served by electricity in the Arkansas Valley, the consumption of electricity, and the estimated quantities of water pumped. As the pumping lifts in the Arkansas Basin generally are less than in the South Platte, it is assumed that 90 kilowatt-hours of electricity is required to lift one acre-foot of water in that area. (Data obtained by Colorado State University.)

Year	Number of pumps served	Kilowatt-hours used	Average Kilowatt-hours used, per pump	Estimated quantity of water pumped, in acre-feet
1950	550	4,050,000	7,364	45,000
1955	1,110	9,730,000	8,766	108,000
1956	1,165	12,370,000	10,618	137,000

In the main stem of the valley, ground-water is used largely as a supplementary supply and, because of the rapid recharge from the spreading of surface water for irrigation, there has been no apparent permanent decline of water level. On the contrary, there has been considerable waterlogging of land in the flood plain, due to a rising water table.

The aquifer in the tributary valleys has been developed only to a small extent. Inasmuch as recharge is dependent largely upon precipitation and infiltration through stream channels in many of the tributary valleys, future large-scale development may deplete the supplies. There is already some local overdevelopment in a few of the valleys, owing largely to inadequate spacing of wells.

The application of new water from the West Slope to lands in the Arkansas Basin will create new problems similiar to those expected in the South Platte Basin. Lands to be irrigated with water from the Fryingpan-Arkansas Project include some underlain by fine-grained materials in which large wells cannot be developed and in which water levels may rise sufficiently to cause drainage problems, but also some underlain by terrace deposits consisting of sand and gravel in which wells can be developed in the future for supplemental or stand-by use.

c. San Luis Valley. The water-bearing materials beneath the floor of the San Luis Valley constitute one of the most unique aquifers in the country. The aquifer consists of a series of beds of sand and gravel interbedded with clay and extending to a depth of many thousand feet. A recent oil test penetrated more than 5,200 feet of sand, gravel, and clay before encountering a thick section of volcanic rocks, beneath which were more sand, gravel, and clay. The well was bottomed in gravel at a depth of 8,023 feet. The layers of clay serve as confining beds and create artesian pressures in the underlying beds of sand and gravel. One well drilled to a depth of 1,000 feet encountered more than 50 separate flows of water.

There are now more than 1,500 pumped wells in the valley which probably discharged nearly 700,000 acre-feet of water in 1956 for the irrigation (largely supplemental) of nearly 150,000 acres of land. In addition, there are believed to be about 7,000 flowing wells in the valley. The flowing wells have a potential yield of about 500,000 acre-feet a year, but as many are shut in during part of the year, their actual yield is not known--perhaps 250,000 acre-feet a year. Most of the flowing wells are used for irrigation and it is believed that they supply water for the complete or supplemental irrigation of about 150,000 acres.

Detailed studies in the San Luis Valley indicate that, because of the very shallow water table in that area, it requires only about 70 kilowatt-hours of electricity to lift one acre-foot of water. On this basis it is possible to calculate with reasonable accuracy the amount of water discharged by wells equipped with electricity operated pumps. As there are a large number of pumps in the valley that are not electrically operated, the data in the table below do not show the full magnitude of pumpage in the San Luis Valley.

Year	Number of pumps served	Kilowatt-hours used	Average Kilowatt-hours used, per pump	Estimated quantity of water pumped, in acre-feet
1935	7	16,000	2,286	200
1940	84	2,320,000	27,619	33,000
1945	242	1,360,000	5,620	19,000
1950	473	8,880,000	18,774	127,000
1955	1,183	32,250,000	27,261	461,000
1956	1,341	42,360,000	31,588	605,000

Recharge to the upper zones of the aquifer in the San Luis Valley is supplied largely by the use of surface water for irrigation. For many years the crops have been subirrigated by a shallow water table maintained by the infiltration of surface water through ditches. During the drought of the 1930's, when the supply of surface water was not adequate, wells were drilled to supply supplemental water. The two methods of irrigation are at cross-purposes--one trying to hold the water table at the root zone and the other pulling the water table down.

Because of the large amount of water available for recharge, there has been very little permanent decline of water level or pressure head of wells tapping the shallower zones. In fact, data collected in 1936 and between 1946 and 1953 indicate that the pressure head and flow of some artesian wells have increased even though withdrawals have been large. There have been temporary declines of water levels in pumped wells, particularly during periods of drought when supplies of surface water were inadequate and pumping heavy. During the drought of 1951 water levels declined in the area north of Monte Vista by as much as 10 feet, but with the above-normal supply of surface water in 1952 the water levels returned to a normal or near-normal position. In an area of 283 square miles north of Monte Vista this rise represented a gain in ground-water storage amounting to 135,000 acre-feet. Water levels again declined during the period 1954-56 but are rising rapidly again in 1957 with the above-normal runoff.

Many of the deeper zones of the aquifer crop out beyond the area of application of surface water and, hence, have a comparatively small rate of recharge. These zones are being tapped by deep wells at a rapidly increasing rate, and there is danger that large-scale development will cause serious declines in head. In addition, little regard has been given to the proper construction of these wells with the result that there is constant movement of water from zones of high head to zones of low head. There is also likely to be mixing of water of poor quality with water of good quality.

Ground-water in the San Luis Valley is only partially developed but problems of quality will impede maximum development. There are, however, areas of no present ground-water development where new ground-water supplies can be obtained and areas of present development where the deeper zones can be tapped for additional supplies.

It is estimated that approximately two billion acre-feet of ground-water is in storage in the San Luis Valley. It would not be economically feasible to withdraw all this water, owing to the great depths involved. However, the hydraulic conditions are such that artesian pressures will force water from almost any of the deeper zones to the surface at no cost for pumping, so long as the development is not so great as to lower the head enough to require pumping. The extent to which it may be feasible to pump from zones that will no longer yield an adequate flow is largely a matter of economics and remains to be determined.

d. High Plains. The High Plains of eastern Colorado are underlain by the Ogallala formation, which is one of the most remarkable aquifers in the United States. It underlies an area extending from the Black Hills of South Dakota to the southern part of the Texas Panhandle and includes parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico and Texas. In the southern High Plains of Texas it yields water to more than 36,000 irrigation wells which in 1956 were used to pump 7,000,000 acre-feet of water. In eastern New Mexico the aquifer yielded about 115,000 acre-feet of water in 1950 for irrigation and other uses. In the other States the aquifer is only slightly developed but the development is increasing at a rapid rate.

In Colorado the Ogallala formation underlies an area of more than 12,000 square miles in all or part of the following counties: Lincoln, Elbert, El Paso, Pueblo, Crowley, Baca, Prowers, Cheyenne, Kiowa, Kit Carson, Washington, Yuma, Phillips, Logan and Sedgwick. In many areas the formation is largely drained and large supplies of water cannot be developed, but in other areas wells of large capacity can be developed.

The Ogallala formation beneath the High Plains of Colorado has a large storage capacity but a low rate of recharge. It is essentially undeveloped. Owing to its great thickness, large quantities of water have accumulated gradually in the aquifer over a period of many thousand years. It is estimated that in Colorado alone the water in storage in the aquifer exceeds 150 million acre-feet.

The recharge to the aquifer is derived entirely from local precipitation, and it can be easily seen that if every drop of the 15 to 18 inches of annual precipitation reached the water table the entire area could be irrigated with the use of 15 to 18 inches of water each year. Inasmuch as only a small percentage of the precipitation reaches the water table, only a small percentage of the land can be irrigated adequately with ground water without permanently withdrawing water from storage. The rate of recharge to the Ogallala formation ranges from a small fraction of an inch per year in the southern High Plains to more than two inches in the sandhills of northeastern Colorado and western Nebraska. Although this is a small amount, over the 12,000 square miles of the High Plains in eastern Colorado, it may amount to several hundred thousand acre-feet a year.

At the present time, there are about 500 irrigation wells in the Ogallala formation in the entire area in Colorado, and they are estimated to discharge about 75,000 acre-feet of water a year for the irrigation of about 50,000 acres of land.

The ground-water situation in the Ogallala formation in the High Plains poses a serious problem. The aquifer can be developed in one of two ways: (1) it can be developed under regulation only to the extent of the salvageable recharge so that the supply, although comparatively small, will last forever, or (2) its water can be considered an expendable resource similar to oil, gas, lead or zinc and can be "mined" over a period of several generations, after which it will be depleted to the point where it can no longer be used for large scale irrigation.

There are sound arguments for both types of development. By developing only the salvageable recharge, a well-balanced irrigation and dry-land economy can be developed in the High Plains and the ground-water supply will last forever. On the other hand, there is a vast amount of water in storage that will never be made available if only the salvageable recharge is developed. If it is decided to "mine" the water, thousands of irrigation wells could be developed and the area would enjoy a prosperity for several generations that would not otherwise be possible.

Other Aquifers. There are many aquifers in Colorado in addition to the four principal ones described above, but they are too numerous and diverse to describe in a report of this scope. A few of the sandstone aquifers in Colorado, however, are of Great economic importance; not because they yield abundant supplies of water, but because they generally are located in areas of water scarcity or dense population.

a. Sandstones in Denver Basin. Some of the principal sandstone aquifers in Colorado are those of the Arapahoe, Laramie, and Fox Hills formations underlying the Denver Basin. The aquifers are tapped by thousands of wells in the Denver Metropolitan area where the water, which generally is soft, is used for many purposes. No data are yet available on the amount of water being pumped from these aquifers, but studies to determine the extent of development are now under way. The first flowing well in Denver was drilled in March 1883 and within a few years there were more than 200 flowing wells in downtown Denver. The aquifer (Arapahoe formation) was developed so extensively that by December, 1890, only six wells were still flowing in the downtown area. Water levels in some downtown areas are now about 450 feet below ground surface. In other areas, the aquifer has been developed only slightly and the wells still flow.

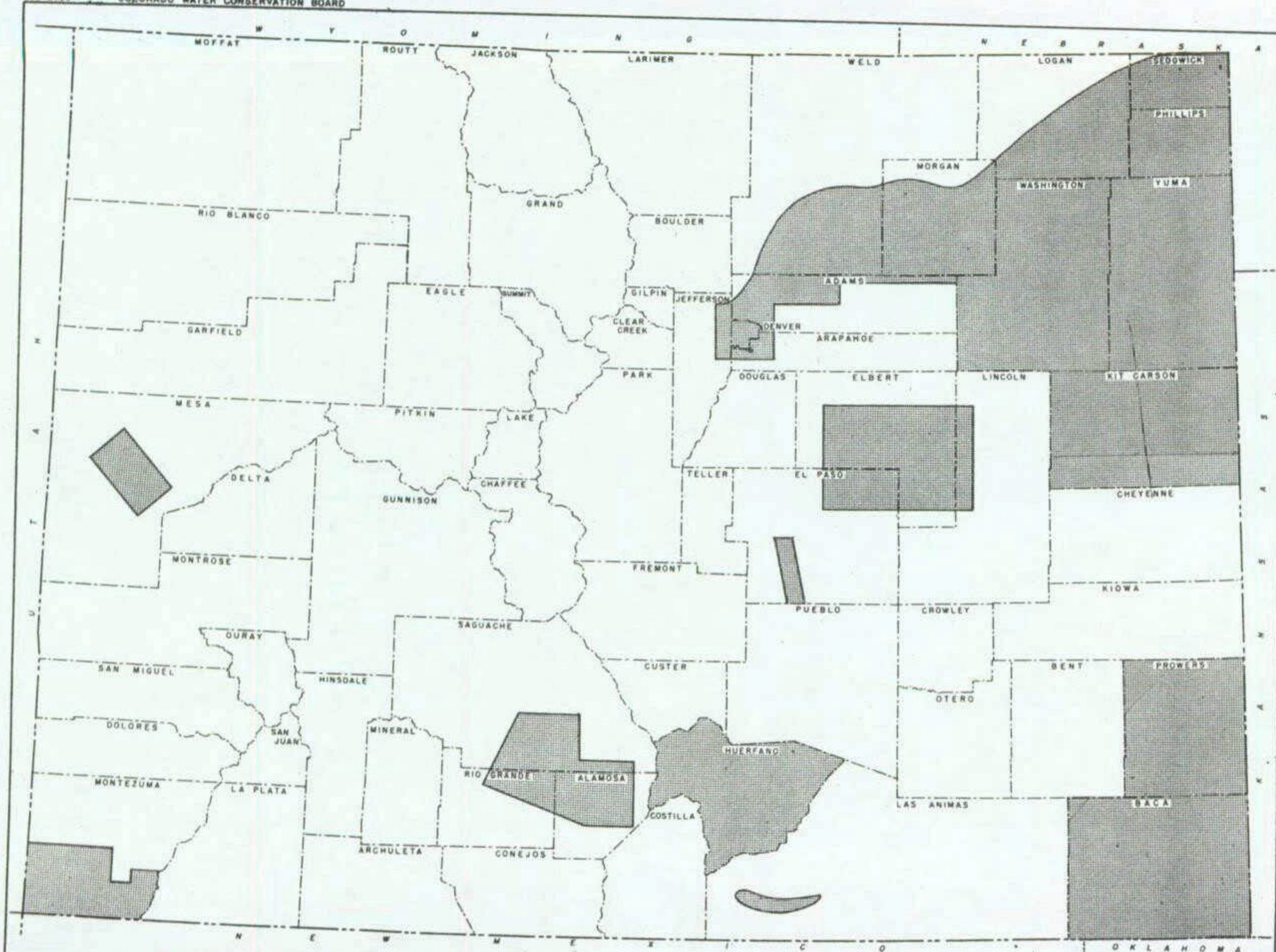
b. Dakota and Purgatoire Formations. Some of the most valuable aquifers in Colorado and, indeed, in the entire Great Plains are the sandstones of the Dakota and Purgatoire formations. The sandstones generally underlie (sometimes at considerable depth) the areas of outcropping shale where water supplies are very scarce. As a result, they commonly are the most dependable source of potable water for domestic and stock use in large areas from Canada to Mexico - principally east of the Rocky Mountains. The water is commonly under artesian pressure and in many areas the pressure is sufficient to cause the water to flow at the surface.

The aquifers have been developed extensively in southeastern Colorado and flowing wells have been obtained in many parts of the Arkansas Valley, near Penrose, and in the Walsh area in Baca County. Wells tapping the aquifers generally have relatively small yields but large yields have been obtained in the Penrose and Walsh areas where the sandstones apparently are more permeable. Because of the severe drought which began in southeastern Colorado in 1950, nearly 100 large-capacity pumped wells have been developed in these aquifers. As the water is under artesian pressure, the water levels have declined rapidly, and most of the artesian wells have stopped flowing. Further development of these aquifers in this area should proceed with extreme caution.

c. Sandstones in the Colorado Plateau. There are many areas in the Colorado Plateau of western Colorado where ground-water supplies are difficult to obtain and where supplies large enough for municipal, irrigation, or other large-scale use are almost impossible to obtain. In these areas, the deep-lying sandstones of the Navajo, Wingate, Entrada, Bluff, and other formations yield small but valuable supplies of ground-water - principally for domestic and stock use. Near Grand Junction and on the Ute Mountain Ute Indian Reservation wells have been drilled to depths of nearly 2,000 feet in order to obtain a few gallons a minute of potable water. Although these supplies are very valuable, they have not been developed extensively because of the great costs involved.

Status of Investigations. Studies of ground-water development and use and the recording of water-level fluctuations was begun by Colorado State University in 1929 and has continued on a small scale. Their early inventory of irrigation wells and their establishment of a network of observation wells have been of great value in determining the effects of large-scale pumping and in pointing up those areas where overdevelopment is imminent. More detailed studies of the origin, movement, quality, and availability of ground-water were begun in 1945 by the U. S. Geological Survey in cooperation with the Colorado Water Conservation Board. Additional studies using only Federal funds were begun in 1947 as a part of the Missouri River Basin Development Program. From time to time when the State-Federal cooperative funds were inadequate or where special studies were needed, some work has been done in cooperation with local governmental agencies.

State-Federal Cooperative Program. The cooperative program between the U. S. Geological Survey and the Colorado Water Conservation Board has been on a very small scale until recently. Areal studies have included (a) Big Sandy Creek area in parts of Lincoln, Elbert, and El Paso Counties; (b) Baca County; (c) San Luis Valley (financed in large part by the U. S. Bureau of Reclamation); (d) Huerfano County; (e) Grand Junction Artesian Area; (f) Purgatoire Valley above Trinidad; (g) Kit Carson County; (h) Prowers County (in progress); (i) Yuma County (in progress);



DETAILED INVESTIGATIONS OF GROUND-WATER RESOURCES OF COLORADO
COMPLETED AND IN PROGRESS

U.S. Geological Survey in cooperation with Colorado Water Conservation Board and other cooperating agencies.

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(j) Washington County (in progress); and (k) the Denver Metropolitan Area (in progress, financed in part by the Denver Board of Water Commissioners). Additional small-scale studies have been made near Brush and Julesburg.

Other Cooperative Programs. Other studies have been made in Colorado by the U. S. Geological Survey in cooperation with local governmental agencies. These have included (a) a study of Fountain Creek Valley between Colorado Springs and the Pueblo County Line in cooperation with the City of Colorado Springs and the Fountain Valley Water Users Association; (b) a study of the Ute Mountain Ute Indian Reservation in cooperation with the Ute Mountain Ute Tribe of Indians; and (c) a study of the Denver Metropolitan area in cooperation with the Denver Board of Water Commissioners. This study is being financed also by the Colorado Water Conservation Board (see item (k) above).

Missouri Basin Program. The Missouri Basin Program was begun in Colorado in 1947 by the Geological Survey using only Federal funds. The funds made available for this work have averaged about $25,000 annually but they probably will be discontinued after Fiscal Year 1958. Studies made under this program include (a) South Platte Valley from Hardin, Colorado, to the Nebraska State line; (b) South Platte Valley between Denver and Hardin, including right-bank tributaries (in progress); (c) the Frenchman Creek Area (including parts of Sedgwick, Phillips, Logan, Washington, and Yuma Counties); (d) a reconnaissance of the High Plains in the Republican River basin; and (e) a reconnaissance of an area north of the South Platte Valley in Larimer, Weld, Morgan, and Logan Counties.

Additional Information Needed. Although information on the occurrence and availability of ground-water throughout Colorado is sorely needed, particularly in view of the administration of the new ground-water code, a large-scale long-range program of investigation will be required to approach such a goal. Some of the more pressing needs for study are outlined below.

Information is needed on the High Plains so that we can learn how much water is in storage, how much water is available from recharge, how much irrigation from wells can be developed, and how long the supply would last under various types and rates of "mining" development. Such data are essential to the proper administration of the ground-water code.

Information is needed for all the counties along the Arkansas Valley and its major tributaries to determine the quantity and quality of water available for development, to determine the areas of shallow water that will be in danger of waterlogging with the application of new water from the West Slope, and to determine the area and distribution of unsaturated sand and gravel that will be saturated with water upon the application of new water from the West Slope and will then be capable of yielding enough ground-water for supplemental irrigation. The information is needed also to point out possible new sources of potable water for municipalities in the valley that are now forced to use water of such poor quality that Public Health standards cannot be met and that the establishment of new industries is discouraged. On the basis of new information on the South Platte Valley, for example, one city was able to replace its old supply of very hard water with a new supply of soft water having a hardness of only 72 parts per million. Information is needed on the counties along the Arkansas Valley also to outline the distribution of and depths to sandstone aquifers in the areas of shale adjacent to the valley where domestic and stock supplies are difficult to obtain. This type of study will reveal the areas in which flowing wells can be obtained by drilling to the sandstones of the Dakota and Purgatoire formations.

Information is needed on the Wet Mountain Valley in regard to the areas of artesian flow and to the availability of ground-water for supplemental irrigation and municipal supplies.

Information is needed on the availability of ground-water for irrigation in North Park. The supply of surface water is frequently inadequate for proper late-season irrigation.

In the Trinidad coal-mining area information is needed as to the availability and suitability of mine waters for irrigation or other uses. If the waters are suitable for some use, Colorado not only would obtain a new supply of water but flooded coal seams might then become workable.

Studies similar to those completed or in progress in the South Platte Valley below Denver are needed in the valley and its tributaries above Denver and in its left-bank tributaries. Irrigation from wells in this area has grown at a tremendous rate and a great many problems have risen or will arise because of the pumping of ground-water and because of the application of new water from the West Slope.

Information on the availability of stock-water supplies in the area south of the Arkansas River is needed in order to improve the livestock industry in that area.

Much information is needed in western Colorado in order to facilitate the development of domestic, stock, industrial, and municipal supplies and, locally, irrigation supplies. Supplemental supplies of ground-water are needed for irrigation in the Paradox Valley. Data on the thickness and permeability of the alluvium in the major valleys are needed for the development of moderate to large supplies of ground-water for municipal and industrial use, particularly in areas having a deficiency of surface water. Data on the thickness, distribution, and water-bearing properties of many of the bedrock formations on the West Slope are needed for the development of domestic, stock, and municipal supplies of ground-water in the many large areas where even small supplies of water are difficult to obtain.

Very few data are available on the occurrence of ground-water in igneous and metamorphic rocks in the mountainous areas of Colorado. With the rapid growth of the tourist trade in Colorado since World War II there has been a greatly increased demand for data on the availability of ground-water in the most heavily traveled areas. Inasmuch as the cost of drilling wells in these hard-rock areas is many times as great as in other parts of the State, information on the occurrence of ground-water in the hard-rock areas will materially reduce the hazard and cost involved in developing ground-water supplies in the summer resort areas.

Summary

The preceding data and discussion indicates that so far as the Eastern Slope is concerned, the surface water supplies have been fully appropriated, and that further development is dependent upon (1) more efficient water use and (2) the location and evaluation of ground-water supplies. The northeastern section of the State has benefitted by the importation of water from the headwaters of the Colorado River. A bill now before Congress would authorize a project dependent upon a transmountain diversion, bringing water from the Fryingpan River to the headwaters of the Arkansas River.

Of the utmost importance to the State of Colorado is an early determination of the location and extent of undeveloped ground-water supplies, especially on the Eastern Slope. Such information would be of great value not only to farming interests, but also for the development of industrial and municipal supplies.

The surface water supplies of both the Eastern and Western Slopes are well known. On the Western Slope, the location of future irrigation projects, the supplies for the individual projects have not been thoroughly determined. State financial cooperation with the United States Geological Survey must be continued until this information is available, that is, if the project studies are to be completed so that authorization for construction and an appropriation will be in order.

An estimate by the United States Geological Survey, Ground Water Branch, indicates that to complete the ground-water survey of Colorado will cost in the neighborhood of $2,000,000, one-half to come from State appropriations and the other half from matching funds by the Federal Government. The 41st State Assembly voted an appropriation of $50,000 for cooperation with the U. S. Geological Survey during fiscal year 1957-1958.

II. MUNICIPAL WATER SUPPLIES

Sources of Supply. Reports relative to water supplies were tabulated for 245 Colorado communities. 102 of these secure water supplies from surface sources, while 143 depend upon ground-water pumped from wells. In these communities, which are situated on the Eastern Slope, some 692,000 people use surface water and approximately 118,000 are served by wells. In the Western Slope towns reporting, over 65,500 people have surface water to use while 11,400 take their supplies from ground-water sources.

The following table shows the number of communities reporting and their sources of supply by basin:

Basin	Source of Water Supply	
	Surface	Wells
Platte	32	71
Arkansas	19	48
Rio Grande	2	4
Colorado	28	16
San Juan	7	1
White & Yampa	6	2
Dolores	8	1

Quite generally the ground-water sources become more heavily mineralized and less suited for municipal use as the Eastern border of the State is approached.

Per Capita Consumption. Colorado municipalities, considered as a group, report an average daily consumption of approximately 220 gallons per capita. Since this figure includes industrial uses, resort and rural communities, and cities with little industry, it does not indicate the wide variance from the average which may occur. Within the State the daily per capita consumption may vary from 40 to as high as 500 gallons. Statistics from Denver show that average daily consumption per capita was 206 gallons in 1953 and that this figure is increasing. The maximum daily consumption came in 1953 and was 255.8 gallons.

Many cities and towns of the State do not measure the municipal water used.

There is a tendency for the daily rate of consumption to increase.

Value of Water for Municipal and Industrial Use.

a. Surface Water Supplies for municipalities in many cases have been obtained by purchase of agricultural water rights. However, inasmuch as municipal supplies must be absolutely dependable nothing but a very early right is acceptable, unless the city has storage or other dependable rights to carry it over a dry period.

The difference between irrigated land worth $500 an acre with a full supply of water and the same quality of land worth $50 unirrigated, or $450 an acre, affords a rough indication at the upper limit of the worth of a second foot of water for agricultural purposes. This approach would be logical where there is an adequate water supply in an agricultural community with lands of high productive capability. In this case if crops can be raised with three acre-feet of water, delivered over a growing season of 150 days the theoretical value of the water would be $45,000 per second foot if no consideration is given to application losses. At six percent interest this cost would be $9.00 per acre-foot annually.

If land capability is such that it is worth only $250 after irrigation, under similar assumptions the value of the required water would be $20,000 per second foot. The annual interest cost would be $4.00 per acre-foot.

For small quantities to insure crops, farmers under the proposed Fryingpan-Arkansas Project have agreed to pay $5.40 an acre-foot.

Enough has probably been said to indicate that the value of water for agriculture is anything but a fixed quantity. However, the values indicated are low compared with those of municipal water. Denver water is expected to cost $25.00 per acre-foot before treatment; Pueblo, Colorado Springs, and other Arkansas Valley towns have indicated a willingness to pay over $55.00 an acre-foot for bringing the water to the borders of the municipalities.

b. Ground Water Supplies. When obtainable, the expense of these supplies is that of drilling and pumping. Under present regulations the prior appropriation doctrine applies when such supplies are tributary to surface water systems.

The extremely dry year of 1956, and the preceding drought years, emphasized in several areas of the State the precarious position of a number of municipal water supplies. A primary function of municipal authorities, it would seem, is to have on hand plans for future water development. With increasing population in all sections of the State, added emphasis on this subject should be in order.

Summary

Nearly fifteen per cent of the people in Colorado secure domestic water from ground-water sources while the remaining eighty-five percent use surface water supplies resulting from precipitation.

Average per capita consumption is rather high, although there is a wide variance between limits. A distinct tendency for the daily rate of consumption to increase is indicated.

Additions to the water supplies of municipalities can frequently be secured by the purchase of agricultural water rights. In general the value of water for municipal and industrial use is much higher than the value for agricultural purposes.

Ground-water supplies for municipalities on the Eastern Slope show promise for the future. A thorough inventory of the ground-water supplies is of the utmost importance in planning industrial development as well as increased supplemental water for agriculture.

Planning for additions to the water supplies as population increases is required if a municipality is to remain abreast of the times.

III. WATER LOSSES

In Section I it is noted that over 80 percent of the precipitation disappears in evaporation and transpiration from trees and non-productive plant life, and in ground-water aquifers not tributary to streams. Approximately seventeen percent of the precipitation is accounted for by consumption due to the growing of crops and by the residual stream flow that passes over the State boundaries.

Water losses of diverted and stored water in Colorado can be classified as (a) conveyance losses including seepage, evaporation, and waste; (b) reservoir losses including seepage, evaporation, spills and loss of storage capacity due to sedimentation; and (c) municipal losses.

a. Conveyance losses, mostly seepage, occur on the main canals and laterals serving an irrigation project. Such losses depend on the length of the canal, the size and geometry of the canal, the quantity of water carried, the type of soil through which the canal passes, and the type of lining, if any. On diversions made in high mountain valleys such losses can be quite high because the canals are built in porous soils. On lower farmlands the losses may be large because the canals are long, may pass through porous soils, and may have leaky structures. Evaluation of the magnitude of such losses has been made for selected projects in Colorado and the results are summarized in the following paragraphs:

(1) The Fruitgrowers Dam Project has about 2000 acres under irrigation. The farm headgate deliveries have averaged 3.87 ac.ft./acre, or 87.7% of the diversion rate of 4.41 ac.ft./acre for the period 1948 to 1953.[1]

(2) On the Grand Valley Project, Garfield Gravity Division, which has about 20,000 irrigated acres, the 1927 to 1948 diversion rate averaged 9.19 ac.ft./acre. This high rate

1. Data from Annual Crop Reports and Related Data, U. S. Dept. of Interior, Bureau of Reclamation.

can be partially explained by necessity for high farm applications to maintain salt balance, and also for winter diversions to meet stock water requirements. Losses, for the period 1927 to 1948, averaged 52.9% of the diversion rate of 4.86 ac.ft./acre. The farm delivery for this same period was 47.1% of the diversion rate or 4.33 ac.ft./acre.[1]

Losses have decreased since 1936 because of the installations of canal linings. For the recent period 1947 to 1953 the diversion rate averages 7.95 ac.ft./acre and losses were 50.7% of this rate or 4.03 ac.ft./acre. Farm delivery averaged 49.3% of the diversion rate. Return flow from the Grand Valley Project is by deep open drains and is unmeasured.[2]

(3) The Uncompahgre Project has about 65,000 acres under irrigation, and diversions, including reuse, for the period 1927 to 1948, averaged 7.84 ac.ft./acre. Excess water is applied to much of the project lands to maintain salt balance, and some mesa soils have low moisture holding capacity requiring frequent irrigation. Losses for this same period averaged 2.62 ac.ft./acre or 33.4% of the diverted water. Farm deliveries averaged 5.22 ac.ft./acre or 66.6% of the diversion rate.[1]

Figures for the later period, 1947 to 1952, for this project, indicate a diversion rate of 8.00 ac.ft./acre and

1. Data from "Use of Water on Federal Irrigation Projects", U. S. Dept. of Interior, Bureau of Reclamation.

2. Data from Annual Crop Reports and Related Data, U. S. Dept. of Interior, Bureau of Reclamation.

losses to be 38.3% or 2.06 ac.ft./acre. Farm deliveries averaged 61.7% of the diversion rate or 4.94 ac.ft./acre.[1]

The mean average consumptive use on this project has been estimated by the Colorado Water Conservation Board, for the years 1938 to 1941, to be 2.24 ac.ft./acre, and the return flow to be 5.40 ac.ft./acre or 66.3% of the diversion rate for this same period, indicating that most of the seepage is recovered and reused.

(4) Water losses in the main conveyance system of the Colorado-Big Thompson Project, from the Adams Tunnel to Carter and Horsetooth Reservoirs, totaled 18,500 acre-feet or 8.7% of the amount diverted in 1956. For 1955 these losses were 16,400 acre-feet or 6.3% of the amount diverted.[2]

While some of these losses will inevitably occur, they can be reduced. Canal linings reduce seepage losses as shown on the Garfield Gravity Division. These linings may be made of concrete, soil-cement, asphalt, or other materials. The use of swelling-type clay to seal the canal and reduce water plant growth shows promise. In some locations, water losses have been cut from as high as 50% before treatment with a bentonite sealer to as low as 7% after treatment. Cost of the

1. Data from Annual Crop Reports and Related Data, U. S. Dept. of Interior, Bureau of Reclamation.

2. Annual Operating Plan, Upper Platte System, U. S. Dept. of Interior, Bureau of Reclamation.

material is considerably less than that of any other sealing method now in use. More research is needed, however, if the method is to be applied to a wider range of canal conditions.

Losses on the farms themselves are of a similar nature to those described above. It is generally estimated that 50% of the farm headgate delivery is lost due to the following factors:

1. Distribution losses.
2. Runoff or waste water.
3. Evaporation.
4. Deep percolation.

Distribution losses can be reduced by use of sprinkler systems, gated pipe, lining farm laterals, and by use of underground pipe. Weed and erosion problems can be reduced by a good distribution system.

It must be considered, however, that extensive programs of canal and lateral lining which might be carried out by owners of the more senior water rights could conceivably have a detrimental effect on water users dependent on return flows.

b. Reservoir Losses. Losses on reservoirs can be reduced by thoughtful selection of reservoir sites. Tight foundations or foundation treatment by use of an impervious blanket to increase the length of the path of percolation will reduce seepage losses around or under the dam. Reservoir evaporation losses can be reduced by selection of the reservoir site with

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the smallest surface area, other things being equal. Evaporation varies to a great extent with temperature and since temperature drops with increase in altitude, it is generally true that the higher the reservoir the less the evaporation. This is illustrated by the following table which gives evaporation in inches per year at selected sites in Colorado along with elevation of the site above sea level, as determined by the Upper Colorado River Commission

Evaporation at Selected Sites in Colorado

Location	Evaporation in year	Elevation foot
Grand Junction	50.3	4730
Grand Valley	41.0	5090
Montrose	40.0	5810
Glenwood Springs	38.0	5820
Lower Wagon Wheel Gap	29.2	8500
Sugar Loaf Reservoir	21.8	10000
Upper Wagon Wheel Gap	21.5	9610

Other things, of course, influence evaporation, such as relative humidity, wind, area of the water surface, etc. The use of monomolecular films to reduce evaporation losses from those factors is currently undergoing study. Reductions of as much as 64% have been reported under special conditions.

Gradual encroachment of sediment can reduce the storage capacity of an irrigation system to the extent of causing losses to the water supply through excessive spills. For example, the conservation storage pool in John Martin Reservoir has been reduced from approximately 400,000 acre-feet to about 366,600 acre-feet between 1943 and 1956.

c. Municipal Losses. Losses in municipal systems reflect the actual consumption of water by the municipality. Records for the city of Denver indicate that return flow to the streams has averaged 69% of the water delivered, or a loss of 31%. Irrigation restrictions, etc., actually increase this loss since the city consumes a greater proportion of its diversion. Leaks in the distribution systems are usually minor.

Water Improvement Programs. Water losses may be salvaged by the drainage of seeped lands with a consequent reduction in free water surfaces and areas infested with phreatophytes. Storage of flood runoff also can result in reduction of losses from the inundation of flood plains.

Reservoir sedimentation can be reduced by forestation and watershed improvement programs. In this connection there may be a minor reduction in water yield due to increased retention and plantings in the watershed.

Consolidation of ditches in some instances has been advocated as a means of reducing distribution losses and waste. In an address before the Association of Western State Engineers, in 1942, R. J. Tipton said:

"In practically every stream basin in Colorado, however, where the water supplies have been overappropriated and there is need for supplemental supplies, much more efficient use can be made of the water if certain consolidations of ditches can be made. In many cases much more efficient and better use of water would result, as well as material decrease in cost of operation and maintenance by one operating system rather than several."

He further says,

"The desirability of changes in the present practice has been recognized for many years but little has been done about it, due probably to the inherent resistance to any change in the order of things which has been long established. Since water rights are in the nature of a property right, it would not be possible or desirable to change the fundamental doctrine which would deprive a water user of the benefits he has enjoyed from his water right, without due compensation."

Undoubtedly the pathway toward consolidation of ditches would be a long and difficult one to follow. The final objective which might be obtained appears to be worth the effort. The first step would be surveys and studies to determine where consolidations could be made and the savings that might be effected.

A more restrictive definition of the term "beneficial use" would enable better control by state administrative authorities and thus conserve water.

IV. ARABLE LANDS, IRRIGATED AND NON-IRRIGATED

Acreages and Costs. The amount of land irrigated in Colorado varies from year to year according to water supply, farm prices and other factors. Much of it also receives a short supply even in good water years. The following tables furnish a general indication of the extent of irrigation development in the various drainages.

Table I, entitled "Preliminary Tabulation of Land

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Classification Coverage by Bureau of Reclamation - Colorado" is of particular interest inasmuch as it shows the non-irrigated arable land available in the State of Colorado which might be brought under cultivation if the necessary water were available. In considering this table, it should be noted that it is not complete so far as the Western Slope lands of Colorado are concerned.

Table II shows a reconnaissance land classification covering the entire Colorado River Drainage in Colorado. Entitled "Land Classification Summary of Areas - Arable and Irrigated Lands Colorado River Drainage Basin, Colorado", it shows that there are 713,910 arable acres on which water has not been placed and segregates these acres among the several drainage subbasins.

Table III entitled "Irrigated Land in Colorado" has been compiled from the United States census reports and divides the land into basins.

Cost Of Irrigating Land. The cost of irrigating land will, of course, vary with each project. In many cases the land to be benefited needs only a supplemental supply because it already receives some water. Reconnaissance estimates of such costs are contained in reports of the Bureau of Reclamation relative to potential development in Western Colorado.

a. Cliffs-Divide Project. The cost per acre as estimated in the status report of February, 1954, varied from approximately $300 per acre to $500 an acre, leaving out the extremes on the low cost and the high cost sides.

b. Gunnison River Project. According to this report, proposed projects have costs per acre varying between $100 and $1,000 with the general average in the neighborhood of $700 per acre.

c. Yampa-White Project. The costs of the units are reported to range between $400 and $740.00.

As has been noted elsewhere, there is much more arable land available than there is water to bring that land under irrigation. However, in addition to the land and the water, there is a third factor which must be considered and that is the cost of placing water on the land and the ability of the irrigator to repay something on the cost of construction.

A study of the cost per acre on some of the proposed projects on the main stem of the Colorado River, on the Gunnison and in the Yampa-White basins indicates that they do not have the ability to pay anything on the cost of construction, and in some cases they would be unable to pay even the operation, maintenance and replacement costs.

The projects which have been designated for early feasibility studies are the most promising ones. It is probable that a large proportion of the arable acres cannot be converted into economically feasible projects under present economic standards.

V. OPERATION OF PRIOR APPROPRIATION DOCTRINE IN COLORADO.

The Water Law of Colorado is solidly based on the doctrine of prior appropriation.

Section 5, Article XVI of the Constitution reads as follows:

"The water of every natural stream, not heretofore appropriated, within the State of Colorado, is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the State, subject to appropriations as hereinafter provided."

Section 6, Article XVI says:

"The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better right as those using the water for the same purposes; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes."

From the foregoing it is quite clear that the ownership of water remains with the public until some one appropriates it. Also, it should be noted that "the right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied". The right acquired by appropriation is the right to the use of the water. The Constitution provides a preference in uses, placing domestic use first. Then comes agricultural followed by industrial use. When a lower preferred use such as agricultural has the prior appropriation, its water can be taken for the higher domestic use only by condemnation, that is, payment must be made as for any other property right.

Part Played in Development of State. It is generally agreed that the Colorado Water Law, based as it is on the doctrine of prior appropriation, was largely responsible for the early development of agriculture in the State. Under this system, and with no Federally financed Reclamation projects, came all of the development in the Arkansas River basin. The same situation prevailed in the South Platte River drainage until the recent completion of the Colorado-Big Thompson project which furnishes supplemental water. The North Platte River area, including the Laramie River basin, developed early under prior appropriation as did the Rio Grande, White and Yampa River basins. On the Colorado River and the Gunnison River, two Bureau of Reclamation projects have been constructed; the Uncompahgre Project in 1904 and the Grand Valley Project in 1912. But this was long after private initiative on the part of early ranchers had started irrigated farming. On the San Juan and its tributaries in Colorado no Federal projects were commenced until 1938. Only two small ones have been completed in that area to date.

Irrigated farming was developed quickly and on a sound basis by the individual and groups of individuals acting together until the summer flow and the easily stored flow of the river system had been entirely appropriated. Extensive and costly tunnels and canal systems brought the Reclamation Service into the State to construct the two projects in the Gunnison and Colorado River areas. The water supply in each case was procured and is administered in conformity with Colorado law.

Even with the benefit of hind sight, no other system, let alone a better system, than prior appropriation has been proposed for the development of the State's water resources up to the present point.

Present Situation. The situation faced by the State in planning its future development has changed materially within the past few years, and especially with regard to (1) the economics surrounding the remaining arable lands, (2) the approaching industrialization of the State and (3) the diminishing available water supply.

Proper planning for industrial development involves the procurement of, or at least an indication of, a dependable source of necessary water supplies. The oil-shale resources on the Western Slope appear to be on the very edge of bringing industrialization to that area. On the Eastern Slope each year sees the erection of new manufacturing plants.

Additional water must be available for municipal use as the population increases. Denver's acquisition of Western Slope supplies brings into being a public water supply system which will provide for an expected growth. Colorado Springs participates in this development and looks about for other supplementary supplies. All data available point to a heavy increase in urban population. Communities that expect to participate in this growth should be studying plans to augment their water supplies.

Much more arable land is available in the State than there is water with which to bring it under irrigation. The available surface water supply is quite well known. With the construction of each additional irrigation project and city supply the unappropriated remainder becomes less. Each new irrigation project constructed depletes the supply to some extent. Under the Colorado River Storage Act the farmer on a project is required to pay only that portion of the construction cost within his ability to pay. Profits from the sale of electrical current generated under the Act will pay the remaining costs.

Today the State faces increased demands for water for municipal and manufacturing uses. The agricultural demand is also present, but in general, arable lands can no longer be brought under cultivation without assistance in meeting the construction costs.

Defects.

a. Inflexibility. The provisions of the Constitution quoted above are intended to be the base on which the water law of the State is erected and consequently are not meant to have one meaning today and another meaning tomorrow. Application of these principles to the obtaining of water rights in the State has built up an economy on the rights and use of water. These laws are necessarily inflexible.

During the early period of development, state water planning was not affected. However, at the present time water supplies for future industrial development within the State cannot be assured even though a water supply may be presently available. The available supply may be appropriated by some other interest any time that its economic value makes such a procedure worth while prior to the commencement of the industrial development. This situation, of course, militates against proper planning of water resources for the future.

In making this criticism it is recognized that the appropriation doctrine has served Colorado well and that it is not possible or even desirable to change the basic principles of this system.

b. Effect on Soil Conservation Programs. Some people have thought that the small flood reduction structures employed by the Soil Conservation Service would operate to the injury of junior water right holders. In a letter on this subject Mr. Kenneth Chalmers, State Conservationist, of the Soil Conservation Service says:

"Well designed and practically operated flood prevention and watershed improvement projects as provided for by P. L. 566 as amended by P. L. 1018 can have a far reaching effect upon the State's water resources.

These projects can materially reduce the monetary damage annually sustained in flash floods and at the time improve the lands within the boundaries of the watershed projects.

There is no question in my mind but that these projects will, under certain circumstances, possibly damage junior appropriators lower on the streams, conversely however they will benefit the senior appropriators.

I believe that a definite milestone was achieved when the landowners in the Big Sandy Flood Prevention Project in southern Elbert County arrived at a basis of understanding with the water users in the Arkansas River Valley where it was mutually agreed that the benefits accruing from the proposed Big Sandy Flood Prevention Project would, in their opinion, more than offset the damages which might possibly accrue to junior appropriators below the confluence of the Big Sandy with the Arkansas.

I cannot too strongly emphasize that it is imperative in my opinion that such agreements and understandings be achieved between the various interests in the watershed before such a project is put into operation. If possible, long and expensive litigation in all instances should be avoided.

Multiple purpose flood prevention projects now made possible by the amendments to P. L. 566 by P. L. 1018 further increase the area of benefits which these projects can achieve. Irrigation drainage and even municipal water supplies can be an integral part of the project providing of course that the proposed project meets all of the basic requirements of the statute.

In addition to stabilizing the flow of our streams, flood prevention projects can materially reduce annual flood damages previously sustained.

Another extremely important phase of the flood prevention and watershed improvement program is the improvement of the watershed. Through the media of this cooperative type of program, it should be possible in many instances to increase the delivery of water from a given watershed and achieve a more sustained and regular flow therefrom.

* * * * * * * * * *

As the demand for the State's available water supplies increases, more attention will of necessity have to be given by landowners and operators to comply with existing water laws. This is particularly true in the field of water spreading on ranges and pastures.

In my opinion this problem can best be solved by one or more of the following methods:

1. The owner or operator of land who desires to spread water should acquire a water right.

2. Adequate outlet tubes should be provided in the water spreading dike or dam so that the State Engineer can adequately administer the water.

3. Dry land operators and livestock interests should be made thoroughly informed as to the State's water laws and how they apply to the usage of water."

c. <u>Appropriation Doctrine and Ground Water</u>. The following summaries of Colorado Supreme Court decisions touching on ground water and its relation to surface water show the legal situation with regard to this subject as of the present time.

"In Colorado it is the presumption that all ground water situated in the basin or watershed of a stream is tributary to the stream and subject to the appropriation of the waters of the stream; and the burden of proof to the contrary is on one asserting that such ground water is not tributary." Safranek v. Town of Limon (1951) 123 C. 330, 228 P. 2d 975.

"'Natural streams' include all tributaries and streams draining into other streams, and 'tributaries' include all water supply which goes into it whether rainfall, natural springs, or percolating water finding its way to a natural stream." In re German Ditch & Reservoir Co. (1914) 56 C 252 139 P. 2.

<u>Effect of Ground Water Pumping on Surface Water Rights</u>. Where the pumping of ground water lessens the quantity of water reaching a particular surface water stream there will be an adverse effect on surface water rights in that stream. In the case of pumpage from depths well below and not connected with the stream bed there will be no ill effect with respect to that stream.

Complaints have been made, and in considerable number, that wells drawing water from the alluvium create a partially empty space and that surface water flowing down the stream is absorbed in the more or less dry bed and thus lost to those possessing surface water rights. Irrigators on the upper reaches of the South Platte and Arkansas Rivers charge that such a situation existed on both those streams during the dry year of 1956, and during previous water-short seasons, and that on account of this situation their headgates were closed early in the season so as to pass more water down stream. In other cases irrigators down stream below a pumping area say that water, the use of which they are entitled to, vanishes into the dry river beds to take the place of that pumped.

When asked for his experiences with this problem, Mr. J. E. Whitten, State Engineer, wrote:

"Since the early days when irrigation in the area began, to the present time, a great change has taken place in the river flow. We are told that prior to development of irrigation systems along the South Platte, the river flow diminished as the season advanced and usually became entirely dry in its lower reaches during late summer.

The intensive development of irrigation works changed the former condition by spreading the winter and spring runoff in areas adjacent to the river. This retarded the rapid escape of water from the area and created an underground supply of water which found its way back to the river as 'return-flow' or seepage. Return flow became an ever increasing factor in the water distribution program of the South Platte and by the middle 1930's reached about its maximum, there being a return flow of substantially 1,400 c.f.s. between Denver and the Nebraska State line. The impact of drought years, such as 1934-1937-1940, were not very damaging to the apparent return flows. Water could be and was moved along the river from reservoirs and on account of rains, with reasonable loss in transit. In recent years, during which time a rather severe drought has been experienced, a heavy pumping program has developed which apparently, together with the drought, has had a marked effect on the return flow to the river; at times it became almost impossible to transit water down the river without prohibitive loss. Part of this condition can be attributed to the shortage of precipitation, and part to the heavy pumping program, the exact proportions being indeterminate up to this time."

<u>Appropriation Doctrine in Neighboring States.</u>

a. <u>Surface Water</u>. Colorado has the basis for the prior appropriation water doctrine imbedded in its Constitution. Idaho, New Mexico and Wyoming followed the example of Colorado in this respect. Nebraska's Constitution dedicates "the use of water of every natural stream to the people of the State", and provides that the right to divert unappropriated water thereof for beneficial use shall never be denied except when such denial is demanded by the public interest. Arizona, Utah, Kansas and Montana adopted the prior appropriation doctrine by statute.

California, for surface water, has adopted by Constitutional amendment the principle that "All stream waters above the quantities required for existing riparian and appropriative rights - are public waters of the State, subject to appropriation and use under State control".[1]

b. Ground Water. Colorado is surrounded by States that have abandoned the common law and adopted by statute the doctrine of prior appropriation as the law governing the use of ground water. Idaho, Utah, Wyoming, New Mexico and Kansas administer their ground water supplies under this principle; also, Montana and Nevada. Nebraska is an exception. In that State, as recently as 1936, the Supreme Court has "reaffirmed the principle that the American rule of reasonable use, in conflict with the common law, had been adopted in Nebraska, and was the law in that State".[2] Washington and Oklahoma also are prior appropriation

1. Select Problems in the Law of Water Rights in the West by Wells A. Hutchins, Government Printing Office, 1942, p. 31.

2. Water Resources Law, Report of the President's Water Resources Policy Commission, Vol. 3, p. 741.

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States while Oregon and Texas, in varying degrees, stay with the common law doctrine that percolating waters belong to the owner of the ground.

State Control of Unappropriated Water.

None of the Western States operating on the doctrine of prior appropriation has been able to devise a positive legal method of reserving a block of water for development at a future time. However, in California, "The Department of Water Resources is authorized by the provisions of Part 2, Division 6, of the Water Code, to file applications to appropriate water which 'in its judgment is or may be required in the development and completion of the whole or any part of a general or coordinated plan looking toward the development, utilization or conservation of the water resources of the State. . .' (Water Code Par. 10500). Such applications are, in general, subject to the requirements and rules which govern applications by others, except that the Legislature has provided from time to time that they are not subject to the statutory requirements relating to diligence."

* * * * * * * * * * *

"The foregoing procedure, whereby the Department of Water Resources may file applications to appropriate unappropriated water for general or coordinated plans of development, is the only presently authorized method whereby rights to the use of unappropriated water may be preserved in furtherance of planning by the State."[1]

1. Bulletin No. 3, The California Water Plans, p. 216. Department of Water Resources, Sacramento, California.

"This ability to file applications for future use is further limited by the 'county of origin'.

To the extent, therefore, that a unit of the California Water Plan must depend upon a State application for necessary water rights, under present law, only water in excess of that necessary for development of the counties of origin would be available for use elsewhere."[1]

VI. STATE WATER PLAN

Some History. The use of water within the State developed in accordance with the prior appropriation doctrine "first in time, first in right". (See Section V.) Individuals or groups envisioned opportunities to create productive farm lands by applying water to the semi-desert. Construction of irrigation facilities resulted in new farming communities in all the basins of the State. Soon the dependable flows of Eastern Slope streams were entirely appropriated and some of the Western Slope streams were in a similar situation.

The average flow of Colorado streams was appropriated and irrigated farm lands developed in accordance with Colorado water law. State wide planning, outside of the Constitution and the water code, was not in existence. However, these laws were effective in enforcing a policy approved by the people of the State. In general, lands and water were brought together in the most economic way available to the settlers.

1. Ibid, p. 217.

Under the Reclamation Act of 1902, two large projects were developed in Colorado. One, the Uncompahgre, required a long tunnel and an extensive canal system; the other, the Grand Valley, consisted of a diversion dam and an extensive canal system. A quick survey revealed these projects as the most promising in the State for construction under the Reclamation Act, and with the support of the affected localities they were brought into being.

A report from the State Engineer's office in 1934 entitled "Summary of Water Resources of Colorado" inventoried the possible projects in the various basins. A State Planning Commission consultant and staff submitted preliminary reports on the Arkansas, Colorado, South Platte, Republican and Smokey River basins in 1936.

Growing out of the Water Resources Committee of the State Planning Commission, the Colorado Water Conservation Board was established by legislative act in 1937, and since that time has been the official agency of the State charged with the duty of conserving, developing and protecting the water resources of the State of Colorado.

<u>The State Water Development Plan</u>. At a meeting of the Colorado Water Conservation Board held on September 14, 1945, it was resolved that "the following projects and activities constitute the immediate post-war water development program for the State of Colorado, namely:

a. The Colorado-Big Thompson Project, a continuation of the construction of that project.

b. The Mancos Project, a continuation of the construction of the project.

c. Animas-La Plata Project.

d. The Pine River Extension Project.

e. The Paonia Project.

f. The Silt Project.

g. Cherry Creek Flood Control Project. Authorized; support appropriation for construction.

h. Colorado Springs Flood Control and Improvement Project. Support request for appropriation.

i. San Luis Valley Project. Two parts: (1) Conejos Unit and (2) Wagon Wheel Gap and Weminuche Diversion."

In the resolution there is the following statement: "An immediate program is understood to mean the inclusion of such activities and proposed developments as may reasonably be expected in the near future and does not exclude the broader and more extensive program which will proceed as fast as project investigations may be completed and projects made ready for development in the future".

In accordance with this announced policy, the Board has added the following to the water development program:

j. Smith Fork Project.

k. Fryingpan-Arkansas Project.

l. Curecanti (940,000 acre-foot) Project.

m. Denver-Blue Diversion Project

n. Florida Project.

o. Trinidad Reservoir Project (Purgatoire River).

Present Situation With Respect to Development Program.

a. Colorado-Big Thompson - practically completed.

b. Mancos - completed.

c. Cherry Creek - completed.

d. Colorado Springs Flood Control - completed.

e. San Luis Valley, Conejos Unit - completed.

The Colorado River Storage Project Act (P. L. 485, 84th Congress, 2nd Session) includes the following Colorado participating projects:

f. Pine River Extension Project.

g. Smith Fork Project.

h. Florida Project.

i. Paonia Project (partially completed).

j. Silt Project.

These are authorized for construction subject to an agricultural economics report. Such a report has been completed on the Paonia and the project is now awaiting an appropriation.

Under this Act, Colorado is to be credited with 46 percent of the revenues from the sale of energy from the generating plants in excess of operating needs. However, this credit can only be expended for the "repayment of construction costs of participating projects or parts of such projects in the State to which such revenues are apportioned . . . . . .". A participating project is an irrigation project including such power generating facilities as are directly related thereto.

k. The Curecanti (940,000 acre-feet) project is authorized in the Act subject to a feasibility survey which is now practically complete and favorable.

l. The Denver-Blue Diversion project is now under construction by the City of Denver at a cost of approximately $75,000,000.

m. Twenty-one Colorado projects were included in the Colorado River Storage Act with priority for completion of planning reports. Those meeting requirements will be added to the State water plan.

Federal Funds Expended. To date the Bureau of Reclamation has constructed projects in Colorado which have cost $195,684,735; studies have been completed on projects which will, when authorized, cost an additional $209,881,450. The Corps of Engineers, U. S. Army has spent $31,088,489 on flood control projects; authorized projects in the amount of $38,968,000 await appropriations.

Defects in Plan. There is an inherent defect in the plan with respect to reserving water for future use. As the State arrives at a position where its unclaimed water resources shrink to a comparatively small amount and are located almost entirely in the Colorado River basin, we become conscious of an urgent need of additional water for municipal use as a result of population increases. An excellent example of this situation is presented by the cities of Denver and Colorado Springs. A number of water rights on the Eastern Slope were purchased by Denver, but the amount secured was insufficient for the growing population. By means of a costly transmountain diversion from the Blue River, and full development of other sources of supply on the Western Slope, Denver can look ahead assured of an adequate water supply for a long period in the future. Colorado Springs has improved her position. These supplies were appropriated under State law and will be administered in accord with the priority system. For future development, municipalities may make filings on extensions to their supply systems and apply to the Courts for decrees conditioned on periodic showings of due diligence toward an eventual diversion of the water for beneficial use.

Industrial use of water also becomes relatively more important as the State becomes industrialized to a greater degree. The amount of water required for full industrialization is difficult to estimate. However, the needs for the near future are fairly well known, but there is no way of definitely laying aside a supply for those needs. Water is now available for such needs on the Western Slope, with the provision of regulatory storage. By withholding approval of the use of this water on irrigation projects, the Water Conservation Board could conceivably further the possibility of reserving the supply. However, if private parties or municipalities find it worth while to construct necessary works and divert to other beneficial uses, they have the right to do so.

Possible Remedies. Even in areas where dependable surface water supplies have been fully appropriated, water for urban expansion may still be obtained by purchase of old agricultural rights. If a change in the point of diversion is required, legal action is necessary to obtain in effect the consent of all surface water users on the same stream. The purchase of the land on which the water has been used may be involved in some cases. Ground-water supplies, as yet, are not governed by prior appropriation and thus the municipality is free to develop such supplies if it can find them.

Water for industrial uses may also be obtained by the purchase of existing rights if it is not available through appropriation. Ground-water sources may also be developed in favorable areas. Inasmuch as industrial use in many instances is not large, it seems that industrial development in the State should not be badly handicapped for the present and some distance into the future. For the projected development on the Western Slope, water by appropriation is available at the present and will undoubtedly be protected in every way possible.

What changes should be made in the plan to better fit conditions of today? It is admitted that prior appropriation is the basis on which Colorado's economy is built and that in general it has served the State well. Particularly well fitted for private initiative in our early development period, under today's conditions it fails to provide a method of guaranteeing a water supply, holding a firm reserve for future expansion.

As previously mentioned, California by constitutional amendment makes it possible for the Department of Water Resources to file on unappropriated water, under certain conditions excuses the Department from the requirement of diligence and hence holds water for future development. Would such an amendment be an aid in the industrialization of Colorado and in providing water supplies for a greatly increased population?

Summary

Units of water development have been adopted after full consideration by the people of the area concerned, by the Bureau of Reclamation which has made the studies and by the State Water Conservation Board. The Curecanti, Pine River Extension, Florida, Smith Fork, Paonia and Silt projects have been authorized by Congress subject to certain qualifications. Generally speaking these projects promise the greatest advantages from an economic point of view of any so far proposed in the State.

Twenty-one projects have been selected for priority of study by Public Law 485. Of these, those that possess engineering feasibility and economic soundness, to the degree required, will be eligible for construction from the funds credited to the State of Colorado under the law.

The projects now authorized should all go into the construction phase within the next year or two. The units under investigation and those to come under investigation, the twenty-one, will be ready for construction when reports are completed that indicate compliance with all requirements. This procedure will take considerable time, perhaps twenty to twenty-five years.

If projects should evolve meanwhile, on which water could apparently be used to greater advantage to the State, changes can be made. There is common agreement that so far as possible, a block of water should be protected for industrial development in the Colorado River watershed. Just how this can best be done has not been determined.

SYNOPSIS

It has long been known that the dependable surface water supply on the Eastern Slope of Colorado is over-appropriated, with practically none available for future development. The tables in Section I and the appendix show the river discharge at several selected points in each basin. On the Western Slope there is some water for future irrigation and industrial developments if reservoirs are built to store water over the required periods of time. Inasmuch as the land to be irrigated cannot pay the entire cost of constructing these reservoirs, the principal source of financing appears to be Colorado's share of the income from the Upper Colorado River Storage Act.

The total amount of water produced in the basins in past years is quite well known. From this data projections may be made into the future. However, accurate determinations of the local water supplies available for individual proposed irrigation projects have not yet been completed. Procurement of the required data requires several years of stream flow measurements and must be accomplished before final reports recommending construction of the projects can be made. The State of Colorado cooperates financially with the United States Geological Survey, Surface Water Branch, in making such studies and must continue to do so if the required reports are to be available for Congressional action at the proper time.

Colorado has a large undeveloped source of water supply in its ground-water basins. The extent of this supply will be determined when a complete ground-water inventory of the State is finished. Twenty years will be required to complete the survey in case present appropriations and cooperation with the United States Geological Survey are continued. Coincidentally with this work, the State should be locating possible underground storage reservoirs for storing surface water in advantageous situations.

A majority of the population of municipalities receives water from surface water sources. The long drought of recent years has emphasized, especially on the Eastern Slope, the possibility of securing water from underground sources. This situation has also impressed municipal authorities with the necessity of making studies for additional supplies in order to keep abreast of expected increases in population.

The Report notes the very considerable losses experienced between the point of origin of the supply and its application to the crops. Research on low cost canal linings is recommended. Studies on the subject of consolidation of ditches, it is thought, would point the way in many cases to the conservation of the water supply. A more strict interpretation of the term "beneficial use" would also assist in conserving the supply and reducing waste.

Tables are presented which show that there is much more arable land than there is water available to bring such land under cultivation. In the past there has been an economic selection of lands brought under irrigation and no doubt this selection will continue in the future. Several of the proposed projects now in the reconnaissance study stage will not, it appears, be able to pay any part of the construction cost. It will become progressively more difficult in the future to present projects which will measure up to the prescribed economic yardsticks.

The doctrine of prior appropriation has served the State well in the past with the result that the economy of the entire State is based upon it. The doctrine was well suited to the conditions which obtained during the early economic development of the area. At the present time, with the limited available supply, it does not seem to be possible, under the law, to unequivocally reserve water for future planned development. The State of California amended its Constitution by granting to the Department of Water Resources the power to file on unappropriated waters and escusing that Department from the diligence requirement after the filing. In this way it is possible in that State to reserve blocks of water for future industrial or agricultural use. Such a procedure seems to be one possible solution to Colorado's problem of how to reserve water for use in future developments.

The State water plan of the past has been based largely upon a selection of the best available irrigation projects - both large and small. Since the advent of the Bureau of Reclamation, these projects have been thoroughly studied and subjected to State scrutiny before final approval for construction. Future developments on the Western Slope call for the planning of irrigation projects whose construction costs will be paid for largely by income from the sale of electrical energy.

APPENDIX

STREAM FLOW AT SELECTED GAGING STATIONS IN COLORADO
(In Thousands of Acre Feet)

	Average Runoff 1914-1955 *	Average Runoff 1934-1955 *
Colorado River Basin		
White River		
White River near Meeker	459.0	419.4
White River near Watson, Utah	558.7	474.8
Yampa River		
Yampa River at Steamboat Springs	338.1	298.4
Elk River at Clark	260.1	227.4
Little Snake River near Dixon	397.1	316.7
Slater Fork near Slater		51.4
Yampa River near Maybell	1149.4	987.7
Little Snake River near Lily	449.4	365.0
Main Stem		
Colorado River at Hot Sulphur Springs	426.7	334.8
Williams River near Parshall	106.4	88.8
Troublesome Creek near Troublesome		34.5
Blue River at Dillon	83.3	75.4
Snake River at Dillon	48.8	41.6
Tenmile Creek at Dillon	89.9	81.3
Blue River below Green Mountain Res.	(1938-1955)	362.1
Roaring Fork at Aspen	92.3	65.5
Crystal River near Redstone		254.7
Plateau Creek near Cameo	171.5	138.7
Roaring Fork at Glenwood Springs	993.9	873.5
Colorado River at Glenwood Springs	1990.2	1708.0
Colorado River near Cameo	3353.5	2885.2
Colorado River near Cisco, Utah	5866.1	5073.7
Gunnison River		
Taylor River at Almont	246.6	216.5
East River at Almont	250.9	225.5
Tomichi Creek at Gunnison		121.0
Lake Fork at Gateview	(1938-1955)	181.8
Cebolla Creek at Powderhorn	(1938-1955)	73.8
Gunnison River below Gunnison Tunnel	1004.9	820.1
No. Fork Gunnison River near Somerset		314.6
Surface Creek at Cedaredge	20.2	17.5
Uncompahgre River at Colona	201.5	181.9
Kahnah Creek near Whitewater	31.2	26.4
Gunnison River near Grand Junction	1943.2	1681.9

*Except for periods as noted.

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		Average Runoff 1914-1955 *	Average Runoff 1934-1955 *
Dolores River			
Dolores River at Dolores	(1922-1955)	332.5	308.5
Dolores River at Gateway		718.8	631.6
San Juan River			
East Mancos River near Mancos			7.1
West Mancos River near Mancos			26.6
Middle Mancos River near Mancos			4.8
La Plata River at Hesperus		34.6	31.5
Animas River at Howardsville			75.4
Animas River at Durango		624.0	559.8
Florida River near Durango		84.1	69.8
Los Pinos River near Bayfield			255.0
San Juan River at Pagosa Springs			86.3
Piedra River near Piedra			227.7
Rio Blanco near Pagosa Springs			61.4
Rito Blanco near Pagosa Springs			12.1
Navajo River at Banded Peak Ranch, near Chromo			76.6
Navajo River at Edith		119.5	106.7
La Plata River at Colorado-New Mexico State Line		27.6	24.3
Animas River near Cedar Hill, New Mexico			661.4
San Juan River at Rosa, New Mexico		878.7	777.9
Mancos River near Towaoc		45.3	35.9
Missouri River Basin			
North Platte River			
North Platte River near Northgate		326.8	253.1
Laramie River near Jelm, Wyoming		114.1	97.4
South Platte River			
South Platte River at South Platte		280.7	247.8
Bear Creek at Morrison		41.0	36.5
South Platte River at Denver		264.6	229.7
Clear Creek near Golden		169.8	159.9
St. Vrain Creek at Lyons		92.8	86.1
Boulder Creek near Orodell		67.2	61.7
South Boulder Creek near Eldorado Springs		54.0	50.9
Big Thompson River below Powerhouse, near Drake	(1918-1955)	134.6	130.2
Cache la Poudre River at mouth of canyon, near Fort Collins		289.5	245.0
South Platte River near Kersey		534.7	444.6
South Platte River at Julesburg		341.9	278.7

*Except for periods as noted.

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		Average Runoff 1914-1955 *	Average Runoff 1934-1955 *
Kansas River			
Arikaree River at Haigler, Nebraska			20.4
Frenchman Creek below Champion, Nebraska	(1936-1955)		30.2
No. Fork Republican River at Colorado - Nebraska State Line	(1925-1955)	35.6	34.8
Arkansas River Basin			
Arkansas River at Granite		250.1	254.4
Arkansas River at Salida		448.3	433.1
Arkansas River at Canon City		507.0	480.5
Arkansas River near Pueblo		498.6	452.4
Arkansas River at La Junta		198.7	189.7
Huerfano River at Manzanares Crossing near Redwing	(1924-1955)	24.4	24.0
Apishipa River near Fowler	(1940-1955)		27.2
Purgatoire River at Trinidad	(1916-1955)	64.5	63.0
Purgatoire River near Las Animas		98.7	87.9
Arkansas River at Colorado-Kansas State Line		265.6	241.0
Rio Grande Basin			
Rio Grande near Del Norte		680.5	598.0
Rio Grande at Alamosa		211.0	140.9
Conejos River near Mogote		253.5	228.3
Alamosa Creek below Terrace Reservoir			78.8
Rio Grande near Lobatos		440.3	332.7
Conejos River near La Sauses		161.2	131.4

*Except for periods as noted.

Based on records of U. S. Geological Survey and Colorado State Engineer. In some instances extensions by correlation have been made for years of no record.