WATER RESOURCES OF COLORADO

State of Colorado

Department of Natural Resources

November 1957

AN INTEGRATED POLICY FOR THE CONSERVATION AND DEVELOPMENT OF THE NATURAL RESOURCES OF COLORADO

PRELIMINARY REPORT

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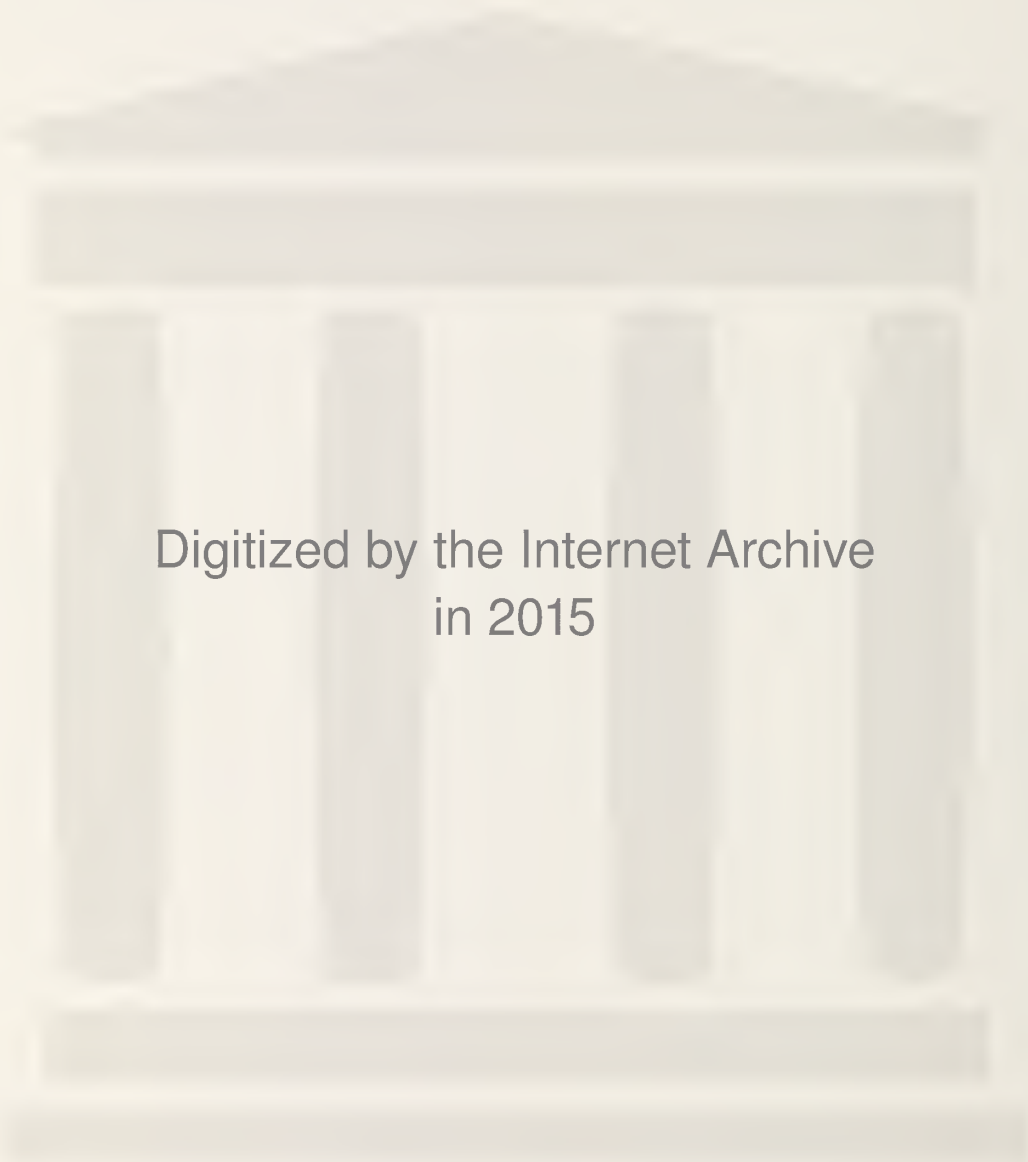
Technical Paper No. 1. "A Critical Survey of Several Forecasts of the Population of Colorado," by William Petersen, Associate Professor of Sociology, University of Colorado.

Technical Paper No. 2. "Location Patterns of Shale Processing—Shale Oil Refining Industrial Complexes," by Walter Isard, Professor of Economics, and Eugene Schooler, Lecturer in Industries, University of Pennsylvania.

WATER RESOURCES OF COLORADO



UNIVERSITY OF COLORADO

BOULDER, COLORADO

November 1 1957

Hon. Stephen L. R. McNichols
Governor of Colorado
State Capitol
Denver, Colorado

Dear Governor McNichols:

In accordance with your desire to provide for the integrated development and conservation of the natural resources of Colorado, and to supply the newly created Department of Natural Resources with a basis for policy formation, I have the honor to submit the attached report.

"Water Resources of Colorado" is the third of nine studies which are designed to give an overview of the interdependence of the state's resources and the interrelationships of its resource problems. These studies are listed on the inside cover.

Since water supply and water use constitute Colorado's most pressing resource problems, the present report was planned as the joint effort of many resource agencies and experts. Dr. Stefan H. Robock, of the Midwest Research Institute, is responsible for the general direction of the work and the final form of the report. The report is based upon statements prepared by the Colorado Water Conservation Board, Colorado State Department of Public Health, Office of the State Engineer, Soil Conservation Service of the U. S. Department of the Interior, U. S. Geological Survey, and the Bureau of Reclamation of the U. S. Department of the Interior.

To these agencies and to many individuals who furnished valuable information and suggestions, Dr. Robock expresses his indebtedness and his gratitude.

Sincerely yours,

Morris E. Garnsey

Morris E. Garnsey,
Consultant in Natural Resources

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PART I

BACKGROUND AND SUMMARY

Prepared by Midwest Research Institute
Kansas City, Missouri

I. A GENERAL FRAMEWORK FOR WATER POLICY

In Colorado, as in most of the Western States, water is the No. 1 problem. The conservation and use of water resources may be the single most important factor determining Colorado's future progress and the economic and social welfare of its citizens. Colorado must maintain a clear, broadly accepted and reasonably stable body of principles for the guidance of water resource development in the public interest. But resources policies should be re-examined periodically in light of changing conditions.

This preliminary report, summarizing the present status of water policy and programs in the state, is presented as a basis for modernizing and integrating policy for the conservation and development of Colorado's natural resources. The report does not represent a comprehensive or final study on which Colorado can revise its water policy. Instead, it summarizes the information currently available and makes recommendations for research and action which can guide the work of the new Department of Natural Resources.

Many complex and difficult problems are involved in a valid and successful water policy for Colorado. Above all, water policy must be part of over-all, state-wide programming for resource and economic development. The water problem is inter-related with the problem of utilizing all other natural resources and cannot be treated in isolation. Water must be used in the public interest and as a means of achieving the state's economic and social development goals.

Water resources development must be planned with regard to the changing economic and social conditions. Throughout the nation, water resources development is entering a transition pericd. Non-agricultural activities have become the principal sources of new jobs and new income, and domestic and industrial water supply demands have become more controlling than ever before. Colorado must thoroughly understand its future economic growth potential and develop its water policy in close harmony with its economic planning for future expansion.

Colorado's water policy also must be part of a regional water resource and economic development plan because the state is competing with its neighboring states for scarce water resources. However, as the principal trade, finance and transportation center for the Mountain region, Colorado must also recognize that it is dependent upon the economic welfare and growth of the rest of that region.

Colorado's water policy must be consistent with national interests and national policies because funds in the water resource field are predominantly Federal. Only in this way can Colorado guarantee maximum Federal support for its State water resource program. The increasing difficulties in securing Federal funds for expanding irrigated agriculture in Colorado, in the face of a Federal effort to reduce agricultural surpluses, illustrate the need for recognizing and resolving conflicts between State and Federal economic objectives.

Colorado's water policy must recognize all the growing forces which may dominate the future, rather than give excessive emphasis to the underlying forces of the past. For example, the doctrine of "prior appropriation" adopted in the 1876 Constitution, which was largely responsible for the early development of agriculture in the State, may need to be adjusted to meet the changed situation which faces the State in planning its future development.

Changing technology -- in irrigation equipment design, in applied meterology and climatology, in waste disposal methods, in ground water exploration, in supplying energy from new sources such as nuclear energy, in selective gathering of hydrologic and other data through the use of refined statistical techniques and electronic computing aids -- must be taken into account in development of future water policy.

The State of Colorado has taken a pioneering step in establishing an agency with over-all responsibility for an integrated resource policy. The success of this agency demands that Colorado's horizons be raised to recognize the profound and far reaching changes in the nation, the region and the state which are involved in the water resources challenge.

II. A BRIEF DESCRIPTION OF COLORADO'S ECONOMY

The present and future demand for water and other natural resources arises out of the nature and location of economic activity in

Colorado and the region. Furthermore, the future economic growth of the state will in large part be determined by policies and programs followed in the management of these resources. It is essential, therefore, to be familiar with the structure of Colorado's economy and the implications of growth trends to resource use. This is particularly true of water -- the major resource problem in this region.

Population

Colorado's population is increasing at a rapid rate. Total population in 1956, has been estimated by the Bureau of the Census at 1,612,000. This represents an average annual rate of increase since 1950, of 2.9 per cent, or almost twice the 1.6 per cent rate for the nation as a whole.

A projection of recent trends indicates a total population by 1980, of from 2.4 to 2.8 million for the State.[1/] For the period as a whole, this means an annual net increase of roughly between 30,000 and 50,000 persons per year.

The geographic pattern of population growth is extremely important for resource policy, particularly water policy. The rapid growth of the Denver metropolitan area, the lesser gains in the remaining area of the Eastern Colorado and the Western area are shown in Table I. The

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1/ Wm. Petersen, A Critical Survey of Several Forecasts of the Population of Colorado, University of Colorado, 1957, Table 13, p. 34.

projections for 1980, however, do not include estimates of the effect of an extensive oil shale industry in Western Colorado, which would reverse past trends.

TABLE I

GEOGRAPHICAL DISTRIBUTION OF POPULATION IN COLORADO

Region	Per Cent Distribution			
	1940	1950	1956	1980 Projected
Western	21	17	16	14
Eastern Agricultural	43	40	40	36
Denver Metropolitan Area	36	43	44	50
	100	100	100	100

Source: Wm. Petersen, A Critical Survey of Several Forecasts of the Population of Colorado, University of Colorado, 1957, p. 32.

Income

Although personal income in Colorado has fluctuated somewhat with the changing fortunes of farming, average per capita income has reached a relatively high level. In 1956, the average income for each person in Colorado was $1,863, or 96 per cent of the national average. This was higher than for any other state in the Rocky Mountain area, except for Wyoming, and above the income level for all states in the Plains area, the Southwest and the Southeast. Only 19 of the 48 states had a higher average per capita income than Colorado.

Colorado income has continued at a high level despite the large and consistent declines in farm income during recent drought years. Net farm income in Colorado declined from $310 million in 1947, to $114 million in 1956. This sharp drop, however, has been more than offset by rapid gains in non-agricultural activities.

Farm income in the peak year of 1947, accounted for almost one-quarter (23.7%) of Colorado's personal income from production activities, but has since steadily declined in relative importance. By 1956, farm income constituted only 5 per cent of personal income in the state.

Colorado's position as a regional trade center for trade, services and transportation is shown by the comparison of industrial sources of income for the State and in the nation as a whole (see Table II). Another major feature is the importance of Colorado as a center for government operations. Of the basic production activities, manufacturing contributed most to State income in 1956, followed by farming and mining. Manufacturing income has been growing in importance and agriculture has been declining.

TABLE II

INDUSTRIAL SOURCES OF CIVILIAN INCOME RECEIVED BY PERSONS FOR PARTICIPATION IN CURRENT PRODUCTION: 1956
(Per Cent)

Source	Colorado	United States
Farms	5.0	5.5
Mining	3.8	1.7
Manufacturing	14.7	31.5
Government	14.8	10.6
Wholesale and Retail Trade	25.5	20.0
Services	12.4	11.4
Finance, Insurance and Real Estate	4.6	4.4
Transportation	7.0	5.5
Communication and Public Utilities	3.5	2.8
Contract Construction	8.7	6.3
Other	--	0.3
	100.0	100.0

Source: U. S. Department of Commerce, Survey of Current Business, August, 1957, Table 70.

Employment

Employment as well as income patterns describe the character of the Colorado economy. In 1950, out of a total population of 1,325,000, about 477,000 were employed. The active working population, therefore, was 36 per cent of the total. Farming employed 15 per cent of the total, as shown in Table III, and was more important than in the nation generally. Mining, although a relatively small source of jobs, was also more important than in the national pattern.

TABLE III

INDUSTRY GROUP OF EMPLOYED PERSONS FOR COLORADO: 1950

Industry Group	Total		Per Cent Distribution	
	1950	1940	1950	1940
Agriculture	71,808	73,281	15.1	21.1
Forestry and Fisheries	659	630	0.1	0.2
Mining	10,254	15,897	2.2	4.6
Manufacturing	58,279	35,482	12.2	10.2
Construction	38,085	18,034	8.0	5.2
Wholesale and Retail Trade	100,431	67,451	21.1	19.5
Transportation, Commerce and Other Public Utilities	45,002	29,337	9.4	8.5
Finance, Insurance and Real Estate	16,947	11,555	3.6	3.3
Business and Repair Services	15,146	9,313	3.2	2.7
Personal Services	29,675	28,969	6.2	8.4
Entertainment and Recreation Services	5,715	3,359	1.2	1.0
Professional and Related Services	50,975	32,860	10.7	9.5
Public Administration	26,582	14,166	5.6	4.1
Industry Not Reported	7,086	6,201	1.5	1.8
Employed	476,644	346,535	100.0	100.0

Source: Census of Population: 1950

The trend of farm employment in Colorado deserves additional study. Farm employment has been steadily declining for the Mountain region, but specific data on the Colorado situation need to be developed. The total work force on Colorado farms, including family and hired workers, was 96,043 in October, 1954. However, the Census of Agriculture reports

that almost 10,000 farm operators worked off the farm 100 days or more. Another 8,000 worked off the farm from one to 99 days.

Non-agricultural employment has been increasing rapidly in the state, from a total of 340,000 jobs in 1948, to 456,700 in 1956. This represents an increase over the eight-year period of almost 15,000 non-farm jobs per year. Furthermore, the increase has been at twice the rate for the nation as a whole.

The fields in which the new jobs have been developing are of special interest. Of the 116,700 expansion in non-farm employment from 1948, to 1956, almost one-fourth was in Government and 28 per cent in wholesale and retail trade. The complete distribution was as follows:

TABLE IV

SOURCES OF NEW JOBS IN COLORADO FROM 1948, to 1956

Wholesale and retail trade	27.8%
Government	24.5%
Manufacturing	11.8%
Contract construction	11.5%
Service and miscellaneous	11.5%
Finance, insurance and real estate	6.9%
Mining	3.2%
Transportation and public utilities	2.8%
	100.0%

Source: U. S. Department of Labor, Employment and Earnings, June, 1957, and May, 1954.

The Denver metropolitan area has accounted for the major share of recent employment expansion. The available employment data, although incomplete, suggest that more than 70 per cent of the increase in Colorado's non-farm employment over the period from 1949, to 1956, occurred in the Denver labor market area (see Table V). Data on Denver are not available for 1948.

TABLE V

DENVER'S SHARE IN INCREASE IN EMPLOYMENT IN COLORADO BY INDUSTRY CATEGORY, 1949 - 1956

Industry Category	Employment in Colorado (Thousands) 1956	1949	Incr.	Employment in Denver (Thousands) 1956	1949	Incr.	Denver as (%) of Colo. Incr.
Mining	16.0	10.6	5.4	3.0	1.0	2.0	44.5
Contract Construction	32.5	19.1	13.4	20.9	12.2	8.7	65.0
Manufacturing	71.3	53.9	17.4	48.0	34.6	13.4	76.8
Transportation & Public Utilities	44.9	41.2	3.7	29.0	23.8	5.2	136.0
Wholesale and Retail Trade	122.9	89.7	33.2	75.9	53.6	22.3	67.2
Finance, Insurance, Real Estate	20.8	12.6	8.2	15.2	9.0	6.2	75.7
Service and Miscellaneous	59.7	45.0	14.7	34.6	--	--	--
Government	88.6	61.7	26.9	41.9	--	--	--
Total	456.7	333.8	122.9				

Source: Employment and Earnings, U. S. Department of Labor, June, 1957, and May, 1954.

Future Trends

Several excellent economic studies have been made in Colorado, including Working Denver by the Denver Planning Office, and the University of Colorado Bureau of Business Research Study on The Economic Potential of Western Colorado. These studies, however, are now about five years old. Furthermore, they were not undertaken to study the state-wide situation nor the specific relationship of economic expansion potential to water needs.

Some very rough calculations can illustrate the need for state-wide economic studies to indicate the amount and location of future water and other resource needs in Colorado. In 1950, 36 per cent of the Colorado population was actively employed. Assuming that this proportion continues to prevail in the future, Colorado will need from 262,000 to 417,000 new jobs over the period from 1956, to 1980, on the basis of the population projections described above. On the average, this will mean from 10,000 to 18,000 new jobs per year, in addition to the number of jobs required by workers leaving agriculture.

An Economic Background for Resource Use Policy

As economic background for resource policy, projections are needed of future employment possibilities in each major field of activity. In the area of water policy, for example, such questions must be considered

as the comparative advantages to the state of additional water being used for agricultural activities, where employment is not expanding, rather than for new industrial and recreation projects which can increase job opportunities. The expansion possibilities in each category of industry must be surveyed so that all the future competing demands for water are well known. The studies of the oil shale deposits on the Western Slope are an excellent start, but such investigations should be extended to include the other major competing demands for water.

The geographical pattern of future development as well as the industrial pattern must be studied for the state as a whole. To what extent will the expansion of population and employment be concentrated in the Denver metropolitan area as has been true in recent years, and what are the State's interests in facilitating the water base for the Denver urban development as compared to other geographical areas.

A better understanding of the implications of water programs and policies for future economic expansion in Colorado would help to resolve some intra-state conflicts and provide a more objective basis for water resources policy. Furthermore, sound economic studies of future economic expansion possibilities by type of economic activity and by geographical area will identify some of the important public policy issues which are generally not made clear.

III. AN OVERVIEW OF THE WATER SITUATION IN COLORADO

In order for Colorado to achieve an optimum use of its water resources, the governmental agencies and the citizens must have and understand certain types of basic information. As a contribution toward this objective, detailed studies are presented in Parts II and III on the State's water supplies, water losses, irrigated and non-irrigated arable lands, operation of the prior appropriation doctrine, the State water plan and water pollution and its control in Colorado. Related aspects of the water problem are discussed in the separate reports on agriculture and forestry, climate, recreational resources and fish and wildlife.

This section presents a brief overview of the water situation with special emphasis on what is and is not known concerning certain key questions. The general conclusion is that much of the basic data on water supplies and water requirements, which are absolutely essential for an integrated resource and development policy, is not available. The lack of much of this information may be a major reason for the intense and continuing controversy within the state concerning water resources.

How Much Water Does Colorado Have?

Colorado is unique in that the State's water supply has its origin almost completely in precipitation over the state. The amount of water produced in other states which flows into Colorado is insignificant.

Surface water supplies, on both the Eastern and Western Slopes, are well known. Western Colorado has 69 per cent of the surface water yield, but only 37 per cent of the total State land area. The part of the State east of the Continental Divide has 31 per cent of the surface water and 63 per cent of the total area of Colorado.1/

The average annual precipitation on Colorado has been estimated at 99 million acre-feet. Over the last 40 years, the amount of water leaving the State in stream flows has averaged 11.7 million acre-feet. The difference between precipitation and the stream flows leaving the State is not, however, a measure of the water supply available for use. The Water Conservation Board has estimated that over 80 per cent of the precipitation is lost principally through evaporation and transpiration from trees and non-productive plant life and through deep percolation to ground water aquifers not tributary to surface streams.

Ground water is a separate source, but practically all ground water, like soil moisture, is derived ultimately from precipitation.2/ Colorado's ground water supplies are only partially known. The major supplies are east of the Continental Divide, but only a part of the State has been covered by detailed ground water studies. An estimated 20 years will be required to complete the ground water survey of Colorado now under way as a Federal-State cooperative program.

1/ Colorado Year Book, 1951 to 1955, The Colorado Planning Commission, p. 253.

2/ Harold E. Thomas, "Underground Sources of Our Water", Yearbook of Agriculture: 1955, p. 73.

Estimates of ground water storage are available for the following areas:

South Platte Valley	25 million acre-feet
San Luis Valley	2,000 million acre-feet
High-Plains-Eastern Colorado	15 million acre-feet

The ground water potential may be indicated by the extimated 2 million acre-feet discharged from Colorado wells in 1956. This flow, however, is not based on a full development of this water source. Also, in many areas the pumping has been in excess of ground water recharging, with a resulting fall in the water table.

The answer to the question of how much water Colorado has must be as follows:

1. The <u>total</u> supply of water on a state-wide basis is not known because of incomplete information on ground water.

2. Information on the total water supply of sub-areas in the state is incomplete.

3. Even though the level of precipitation is fixed by nature (except for weather modification possibilities), the <u>effective</u>, <u>usable supply</u> of water in Colorado can be increased significantly through stream sanitation programs which permit greater domestic and industrial re-use of water, through steps

to reduce evaporation and other losses, and through completion of water storage and water control projects.

4. Increasing the usable supply of water is largely an economic question of how much the government or private interests are willing to spend for stream sanitation, reducing losses, and for storage and river control projects.

How is Colorado Using Its Water Supply?

Colorado does not have complete and current information on how it is using its water supply. The U. S. Geological Survey, however, has made estimates of water use in Colorado (see Table VI). These estimates indicate a total water use of about 10 million acre-feet in 1950, and about 8 million acre-feet in the drought year of 1955. They are extremely helpful, but have many recognized shortcomings.

According to the USGS studies, irrigation use accounted in 1950, for almost 97 per cent of the total combined withdrawal of surface and ground water in Colorado. Although ground water supplied only a small share of the total irrigation water, almost 89 per cent of total ground water use was irrigation.

In 1955, the withdrawal of water for irrigation was substantially below the 1950 level of use, but still accounted for 89 per cent of total State water use. As a consequence of the drought period, ground water was

exploited very heavily for irrigation. As a result, the total ground water use in the state almost doubled.

TABLE VI

ESTIMATED WITHDRAWALS OF WATER IN COLORADO FOR YEARS 1950 and 1955
(Millions of Gallons Per Day)

1950

	Ground Water (mgd)	(%)	Surface Water (mgd)	(%)	Total (mgd)	(%)
Rural[1]	30	4.5	20	0.2	50	0.6
Municipal	20	3.0	150	1.8	170	1.9
Industrial[2]	25	3.8	45	0.5	70	0.8
Irrigation	588	88.7	8,010	97.5	8,598	96.7
Total	663	100.0	8,225	100.0	8,888	100.0

1955

Rural[1]	39	3.5	7	0.1	46	0.7
Municipal	28	2.5	200	3.3	228	3.2
Industrial[2]	35	3.2	470	7.9	505	7.1
Irrigation	1,000	90.8	5,300	88.7	6,300	89.0
Total	1,102	100.0	5,977	100.0	7,079	100.0

Source: U. S. Geological Survey Circular 115. Estimated Use of Water in the United States, 1950, by Kenneth A. MacKichan; U. S. Geological Survey Circular 398. Estimated Use of Water in the United States, 1955, by Kenneth A. MacKichan.

1/ Not including irrigation.
2/ From private sources.

Municipal water use, which includes industrial uses served by municipal water systems, was the second most important use in 1950, but accounted for less than 2 per cent of total withdrawals of water. By 1955, municipal use had increased to more than 3 per cent of total withdrawals, but had fallen behind the industrial use from "private sources".

The growth of industrial water use over the five-year period has been phenomenal. The 1955 withdrawals were sevenfold greater than in 1950 and accounted for 7 per cent of total withdrawals in the State. Significantly, the bulk of the increase in industrial water use came from surface water supplies.

The "withdrawal" concept for measuring water use indicates the amount of water that is taken from either ground or surface sources but does not measure the amount that is "used up" and not returned to the stream. The concept of "consumptive use", on the other hand, reflects the loss in stream flow through a particular use.

The total consumptive use of water for irrigation has been estimated at about 3.8 million acre-feet. This means that more than a third of the withdrawal for irrigation is lost through evaporation and transpiration, except for a part which may go to recharging ground water supplies.

The use of water for domestic and industrial purposes is not highly consumptive and can be used and re-used if water quality is maintained through appropriate stream sanitation practices.

Colorado's pattern of total ground and surface water use by sub-areas or river basins is not available. Such information on surface water can be developed, however, through an analysis of the records in the office of the State Engineer.

The use of surface water in Colorado is determined through the operation of the prior appropriation doctrine. Under constitutional provision, surface water supply becomes the property of the person who first puts it to "beneficial use" for the highest priority purpose.

The surface water supplies on the Eastern Slope have been fully appropriated, except for occasional years of high run-off. The major surplus surface water supply not yet appropriated is on the Western Slope. However, estimates of the amount of water remaining for allocation will vary greatly with the assumptions used. The uncommitted balance varies from about 1.5 million to 2 million acre-feet, depending upon the time period used for estimating the water supply. The actual surplus, however, might range from 693,000 acre-feet to actual shortages, depending upon the ultimate action taken on irrigation projects authorized or given priority in the Colorado River Storage Project Act and other contingencies.

How Will the Uses of Water Change in the Future?

A serious shortage exists in Colorado of studies and projections on the changing uses for water over the next 15 or 25 years. The general

problem has been summarized by the Colorado Water Conservation Board as follows:

"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".

"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".

These statements broadly define the problem of the changing water uses necessary for Colorado's continued economic and population growth. However, detailed studies and projections of future requirements are not available which cover all competing uses and all competing areas.

One special subject has received considerable attention, namely, the prospective water requirement for development of the oil shale deposits on the Western Slope. Other studies have been made of the future water requirement for bringing additional arable land into cultivation. But the urgent need is for a thorough investigation of all the future water needs so that water policy decisions can recognize alternative losses or gains by making available water for one use as against another. With water as a

limiting factor on economic growth, it is essential to know that a diversion of 100 acre-feet for agriculture is the equivalent of supplying the human needs for 400 persons, or whatever the competing needs may be.

Some rough calculations concerning changing future needs can be presented as illustrative of the problem that should be studied. The resources and time arrangements for this report have not permitted a thorough study of possible future requirements for water in Colorado. The rough calculations, however, may serve the purpose of giving a more concrete impression of the problem and stimulate the new Department of Resources to undertake a systematic and comprehensive study of future water needs by type of use and by area.

Municipal and rural use, not including irrigation, may require an additional withdrawal of 560,000 to 675,000 acre-feet over the 20 years from 1955 to 1975. The low estimate assumes a population of 2.2 million in Colorado for 1975, and a consumption per capita of 350 gal. per day. This estimate may be conservative both as to population increases and per capita consumption. The Water Conservation Board estimated per capita consumption in Colorado at about 225 gal. per day in 1956. The estimates of the Presidential Advisory Committee on Water Resources Policy (House Document No. 315, 1956) imply a doubling of the average per capita consumption over the 20-year period from 1955 to 1975.

Future direct industrial water requirements are estimated for illustrative purposes to require an additional withdrawal of 790,000 to 1,600,000 acre-feet by 1975. Any rough estimate for industrial use is extremely precarious, however, because of the extreme variations in water requirements among different types of industries.

For the United States as a whole, "direct industrial" water requirements have been estimated to increase by 170 per cent from 1950, to 1975, on the assumption that industrial production will almost double over this period. The estimate for Colorado is for a 20-year period and for separate assumptions of a 100 per cent and 200 per cent increase in industrial production over the 20-year period from 1955, to 1975. Even the 200 per cent production increase over the next two decades may be conservative because the industrial base in Colorado is still relatively small and the per cent increase will be large figured on a small base. Furthermore, Colorado has been industrializing at a rate much above that for the nation as a whole for a number of years.

For irrigation, the Water Conservation Board has made several estimates. For the potential irrigation projects authorized or given priority in planning in the Colorado River Storage Project Act, and for which the benefit-cost ratios are at least unity, 456,000 acre-feet depletion will be required. 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, the requirement will be 703,000 acre-feet.

To irrigate all of the unirrigated arable acres shown by the Bureau of Reclamation reconnaissance surveys in the Colorado River Drainage Basin, a depletion of 928,000 acre-feet would be required.

The additional water requirements for 1975, as compared to 1955, can be summarized as follows assuming that the withdrawal requirement for irrigation is roughly three times depletion:

	Thousand acre-feet		
Municipal and rural use	560	to	675
Direct industrial	790		1,600
Irrigation	1,400		2,800
Total	2,750		5,075

These could conceivably be the competing demands -- a water requirement of from 2.8 to 5 million acre-feet and a small uncommitted surface water supply on the Western Slope plus additional pumpings from ground water, principally on the Eastern Slope.

The problem of the future is not only to have the increased total quantities of water available, but to have water available for the type of use which will be most in the public interest, and in the geographic area in which the economic activity can most efficiently develop.

What is the Optimum Use of the Water of the State by its Citizens and What Policies are Required to Achieve Optimum Use?

In considering the future water situation in Colorado, one conclusion seems certain. The struggle among competing users for limited water supplies will become even more intense as Colorado continues to expand.

The optimum use of water in the public interest is not necessarily the same as the optimum use for an individual. If a major objective of Colorado is to encourage population growth and increased income, the optimum use for uncommitted water may be industrial and urban. On the other hand, an individual farmer trying to increase agricultural production would have a different optimum use.

Colorado needs to articulate and secure widespread agreement on clearly stated development objectives. The absence of information on such matters as the projected future demands for water has made it difficult both to crystallize the issues and to secure popular understanding of the implications of water questions to Colorado's future.

If there is understanding and agreement on what is optimum use, there are several principal ways in which the future demands will have to be met, without any basic change in the prior appropriation doctrine.

1. Increased exploitation of ground water supplies.

2. Increased availability of surface water through construction of scheduled storage projects, through

conservation and storage of flood flows and through small dam and small watershed projects.

3. More efficient use of present supply reducing conveyance losses, reservoir losses, and municipal losses.

4. Purchase of water rights from present users.

5. Modification of prior appropriation doctrine to permit the State to reserve uncommitted water for future use.

It is important to make the best projections of future use as are technically possible. But the best of such projections are not predictions for the future. The actual demands will only be known as the future unfolds. Consequently, water policy must have the necessary flexibility to reserve uncommitted water for future use.

IV. SUMMARY OF RECOMMENDATIONS

In its simplest form, the water problem in Colorado is to increase the usable supply of water, to make optimum allocation of scarce water among sharply competing demands -- giving adequate recognition to changing conditions and future needs, and to secure the maximum popular understanding and support for programs based on the over-all public interest. As Judge Breitenstein has said, Colorado needs "to create a constructive attitude as to water".

The allocation of uncommitted surface water on the Western Slope has received almost the exclusive attention of Colorado's citizens, although this question is only a part of the total water problem. The intense controversy concerning this issue should not obscure the fact that the water problem is substantially broader and involves possibilities for increasing the effective supply of water and for improving the administration of water policy. The best hope for a broader perspective and for a recognition of what may need to be done to ensure the future economic welfare of Colorado may be through more adequate information on future needs, future supply possibilities, and an appreciation of the precise consequences of alternative paths of action, and better popular understanding of these issues based on the increased knowledge and a clarification of State development objectives.

The Need for Comprehensive State-Wide Economic Development Programming

The most urgent need in Colorado for improving resource development, as well as for other public and private activities, is more comprehensive and state-wide economic development programming. The lack of comprehensive programming is not uniquely a problem for the water resource agencies. The task probably should be undertaken by the new Department of Natural Resources or some other state agency that can make such information generally available. Detailed recommendations as to programming activities can be presented subsequently, providing the need for such action is accepted.

If long range economic and social development objectives are to guide resource use, Colorado needs detailed projections of its development possibilities. To decide among competing demands for water, and to secure popular understanding and support, Colorado must have the best available information on both (1) the future employment and income expansion prospects in agriculture, manufacturing, mining, recreation and the other fields of economic activity, and (2) the prospective water requirements for supporting the expected future growth. Such information must be developed within a consistent framework for all fields of activity and for all sub-areas within the State, or else the alternatives are not completely known. The programming work must also give consideration to the regional and national setting.

It has been observed concerning the East Slope-West Slope controversy that the claims of both parties are based upon imponderables, and that "no categorical (emphasis supplied) answers can be given to questions such as these: To what extent shall irrigated agriculture be subsidized, if at all? What industrial development may be reasonably anticipated? What will be the growth of cities? What recreational values must be protected and preserved?" But categorical answers are not essential. The State of Colorado can do long range programming, following the example of the outstanding private enterprises in the country, and secure extremely valuable assistance for guiding policies and resolving controversies on

resource policy. Modern techniques in the programming field do not involve predicting the future, but are directed toward identifying alternative paths of development.

Hydrologic Data Research

The new Department of Natural Resources should initiate a thorough review of the factual basis required for adequate planning and regulation of water use and for all phases of planning, design construction and operation of water resource projects.

The Water Conservation Board has emphasized (1) the urgent need for an early determination of the location and extent of underdeveloped ground water supplies, especially on the Eastern Slope, (2) studies by municipal authorities of potential additional supplies to keep abreast of expected increases in population, and (3) the need for data on the cost of applying water to at least half of the arable land in the Colorado basin so that the economic feasibility of irrigation for this area will be known. The State Department of Public Health has emphasized the need to maintain current inventories of all water supply sources, sewerage disposal facilities and other types of information.

The question should be raised, however, as to the possibilities of using refined statistical techniques, new electronic aids to computing and the new analytical possibilities recently developed by scientists for

a selective, highly imaginative and significantly less expensive attack on the gigantic problem of data collection.

Regulation of Right to Use Water

It is recognized that almost all of Colorado's surface water supply is already committed under the prior appropriation doctrine to existing users, that water rights are now private water rights and that water policies must be reasonably stable. However, the comments of Judge Breitenstein deserve consideration in setting long range water policies. He said, "It is a fair comment that Colorado's existing constitutional and statutory provisions were designed to meet the requirements of the era of private development that has long since passed. To apply our existing laws to the vast public developments which must occur if Colorado is to utilize to the fullest extent its water resources is completely unrealistic".

More specifically and without intending to upset the basic structure, several recommendations have been made by Colorado State agencies.

1. "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 excusing 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".

2. To reduce losses in current water use, a more strict interpretation of the term "beneficial use" should be developed. The problem is that the law does not have much to say about what is not "beneficial use". As elaborated upon in the report on Colorado's Agriculture and Forestry, "Some individuals may be poorly informed concerning the consequences of practices they employ in using resources. As a result they may fail to provide the resource protection deemed necessary by the state". (p. I-2)

3. Legislation for control of ground water use should be adopted. The prior appropriation doctrine does not extend to ground water; furthermore, no provision has been made in the 1957 Ground Water Law for establishing or defining in any way the right to use ground water, or for the administration of such rights in relation to each other or to the natural streams of the State.

Legal Research

Colorado water law should be given thorough study with the end view of bringing it in step with current conditions. Revision of the so-called Administration Code was under consideration by the State Bar Association, but according to the State Engineer, no report was ever made or presented to the State Legislature.

Some revision was made under the 1951 Statutory Revision Act. One or two minor amendments were passed at the last legislative session relating to the fees collected by the Division of Water Resources. It is recommended that a revision of this code be enacted in the near future.

The following is only one example from the State Engineer of a needed revision:

> "The State Engineer by Statute, as a protection to life and property, is required to supervise the construction of reservoir dams in the State. Chapter 147, Article 5, Section 6, 1953, Revised Statutes limits the State Engineer to $10.00 per day for the services of an Engineer Inspector, thus making the State Engineer responsible for the performance of a duty which he is unable to carry out".

Water Pollution Control

Better stream sanitation must be recognized as a significant opportunity for making more water available for more uses. Removal of

pollutants has a double effect in increasing the usable supply water. First, less dilution water is required and the dilution water becomes available for other uses. Secondly, the water from which the pollutants are removed is available for a wider range of uses than before treatment. To emphasize the increasing importance of stream sanitation as part of Colorado's water problem, a special study by the State Department of Public Health which presents many detailed recommendations, has been included as Part III of this report.

The water pollution control program in Colorado is comparatively new and needs to be attacked on many fronts. There is a serious need for stream surveys to secure and maintain adequate data on the volume and quality of waters flowing at different points along the streams. Information is needed on the dollars and cents cost of pollution to give sensible directions to programs for better stream sanitation.

Other recommendations have been spelled out as to the need for more staff to control the problem, for better legislation on stream pollution control, for legal relaxation of bond debt limits for communities to permit local financing of sewage disposal plants, for legislation more favorable to the unification of treatment facilities in areas where such a unification is desirable, for additional state and federal financial assistance and for a substantial research program on water pollution

problems. Research into better sewage treatment methods, and recycling of industrial water are just a few items needing investigation.

Federal Relations

Colorado faces several levels of problems in its relations with the Federal Government, the most basic of which is the limited orientation by law and by tradition of the principal Federal agencies now active in developing Colorado's water resources.

The primary legal responsibility of the Bureau of Reclamation has always been irrigation and agricultural development. In planning specific projects with a land reclamation objective, the Bureau does include municipal, industrial, power, recreational and other related interests. But the Bureau is not required to base its water development program on studies and projections of the full range of economic expansion possibilities for the region in which it operates.

In light of the changing economy of Colorado and the Western States, the question should be raised as to whether the legal authority and orientation for the most active Federal water program in the State should be broadened. In this way, the emphasis on water development would be extended to include other fields of employment and income which have greater expansion potential than agriculture.

Another series of issues involves influencing the Federal agencies as they now exist and operate. More specifically, is Colorado satisfied with the priorities for Federal projects?

The key step in determining the priorities for Reclamation projects is the priority given to economic feasibility investigations. The rest of the process of engineering and construction generally follows from the order of feasibility studies. The question then becomes one of whether Colorado is getting its fair share of investigational funds.

The Colorado Water Conservation Board recently requested from the Bureau of Reclamation an accounting of the allocation of investigation funds among the states. On the basis of the information received, the Board has concluded that there has not been favoritism. The intra-state priority schedules, in general, have corresponded quite closely to those recommended by the Water Conservation Board, although there have been some minor differences.

In recent years, the State of Colorado has discovered that it can influence the priorities for Federal projects by sharing the cost of making project investigations. During the past two years, Colorado has contributed financially to the cost of feasibility studies when assured by the Bureau of Reclamation that the State's contribution would advance the date of completion of the studies. This procedure has resulted in expediting two large projects of interest to Colorado.

It should be emphasized, however, that for the next five years or so, it may be extremely difficult to secure construction appropriations for new projects in the Upper Colorado Basin. The three major projects now under construction -- Flaming Gorge, Glen Canyon and Navajo -- will shortly require a total annual appropriation of about $100 million, or more than one-half of the Bureau's total appropriation for all areas in recent years.

The lack of intra-state unity on specific Federal projects has been a serious problem from time to time. The range of recommendations presented above may help to reduce this type of obstacle to Federal water resource development and develop better ways for securing united State action on Federal projects.

Another matter that should be explored as a means for improving Federal relations is the initiation of a regional working group under the Western Governors to plan cooperatively, discuss and possibly resolve interstate conflicts in the water field.

Relations with Local Governments

Planning for the State as a whole requires counterpart activities at the local and sub-area levels. Therefore, an expanded program for stimulating local participation in water resource planning on a regular basis is recommended.

Greater local participation can increase the supply of technical data on local water situations available to State and Federal agencies. Conversely, stronger and more unified support for State policies should result from a better understanding by local groups of the broad aspects of the water problem and through participation by local leaders in the formulation of State policy.

Technological Research

Technological advance has affected the course of water development and is likely to affect it even more in the future. Yet we seem to take it more or less as it comes, not trying to assess its impact on our water development planning.

Colorado should undertake its own research and stimulate research by others on technology as related to future water policy. Such information as changes in irrigation equipment design, applied meteorology, and climatology, together with improved ground water exploitation adds another dimension to water development. Another technology problem such as waste disposal methods, the question of alternative energy sources such as nuclear energy and its effect on hydro-electric development must also be considered. Colorado's water policy must not be based on the technology of the past, even if it is the immediate past.

PART II

WATER RESOURCES OF COLORADO

Prepared by Colorado Water Conservation Board
Denver, Colorado

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 discharges 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 these 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 excusing 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.

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	
WESTERN SLOPE		
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 ac-ft/sq mile	
EASTERN SLOPE		
Weighted average annual precipitation		16.32 in.
Total area	41,801,600 acres	
Average annual precipitation on area	56,766,600 acre-feet	
" " " rate	869 ac-ft/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 per cent 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, p. 55, 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 increase 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 interpretations 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 Tabulations 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 hundreds 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 20 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, p. 56).

Data furnished by the Engineering Research Committee of the Colorado Water Conservation Board indicate 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 year. 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 9 per cent 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 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 acre-feet)

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

TABLE I (Concluded)

(1,000 acre-feet)

Name of Diversion	32-Year Average 1914 - 1945			22-Year Average 1934 - 1955		
	Historic	Increase	Total Future	Historic	Increase	Total Future
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, 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

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

slope 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 are 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 are 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.

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 water-logging 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 similar 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 ft. 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 ft. 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 ft. 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 150,000,000 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 15-18 inches of annual precipitation reached the water table the entire area could be irrigated with the use of 15-18 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 2 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 way: (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 Planes 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. Area 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); (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

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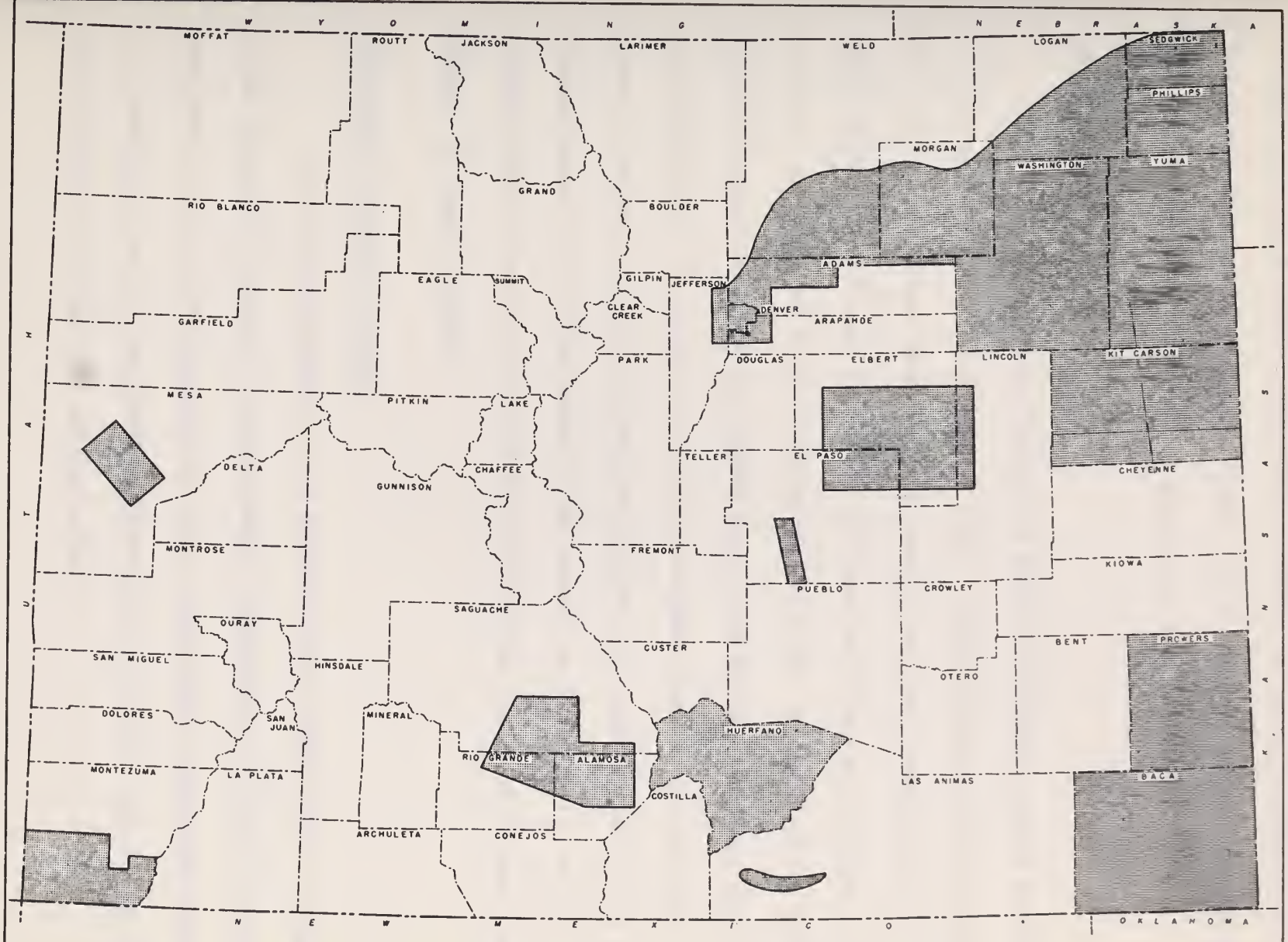

DETAILED INVESTIGATIONS OF GROUND-WATER RESOURCES OF COLORADO COMPLETED AND IN PROGRESS

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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 indicate 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 benefited 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.

Estimates were made for the City of Denver of the additional water that will be required by the year 1975 based on an estimated population increase of 320,000 persons by that time. The additional diversion requirement was estimated to be 92,000 acre-feet per year.

In a report on Depletion of Surface Water Supplies of Colorado West of Continental Divide published in 1953, the engineering firm of Leeds, Hill and Jewett estimated that the population of the Western Slope of Colorado might be increased eventually by about one million persons by reason of development of the oil shale and other industries. If it is assumed that such development would take place by 1975, and if the rate of increased water requirement is the same as estimated for Denver, the additional

diversion requirement for raw water for municipal purposes due to such a population increase on the Western Slope would be 290,000 acre-feet per year.

These estimates of the additional amounts of water required to be diverted for municipal purposes do not represent the consumptive use resulting from such diversions. The corresponding stream depletions would be considerably less than the amount diverted.

There are no estimates available of population increases in the Rio Grande Basin, the Arkansas River Basin or the balance of the Platte River Basins in Colorado upon which to base estimates of additional water requirements.

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 3 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 6 per cent 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 15 per cent of the people in Colorado secure domestic water from ground-water sources, while the remaining 85 per cent 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 per cent 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 17 per cent 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 2,000 acres under irrigation. The farm headgate deliveries have averaged 3.87 acre-feet/acre, or 87.7 per cent of the diversion rate of 4.41 acre-feet/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 acre-feet/acre. This high rate 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 per cent of the diversion rate of 4.86 acre-feet/acre. The farm delivery for this same period was 47.1 per cent of the diversion rate or 4.33 acre-feet/acre[2].

Losses have decreased since 1936 because of the installation of canal linings. For the recent period 1947 to 1953, the diversion rate averages 7.95 acre-feet/acre and losses were 50.7 per cent of this rate or 4.03 acre-feet/acre. Farm delivery averaged 49.3 per cent of the diversion rate. Return flow from the Grand Valley Project is by deep open drains and is unmeasured[3].

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

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

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

(3) The Uncompahgre Project has about 65,000 acres under irrigation, and diversions, including re-use, for the period 1927 to 1948, averaged 7.84 acre-feet/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 acre-feet/acre or 33.4 per cent of the diverted water. Farm deliveries averaged 5.22 acre-feet/acre or 66.6 per cent of the diversion rate[1/].

Figures for the later period, 1947 to 1952, for this project, indicate a diversion rate of 8.00 acre-feet/acre and losses to be 38.3 per cent or 2.06 acre-feet/acre. Farm deliveries averaged 61.7 per cent of the diversion rate or 4.94 acre-feet/acre[2/].

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 acre-feet/acre, and the return flow to be 5.40 acre-feet/acre or 66.3 per cent of the diversion rate for this same period, indicating that most of the seepage is recovered and re-used.

(4) Water losses in the main conveyance system of the Colorado-Big Thompson Project, from the Adams Tunnel to Carter and Horsetooth

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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.

Reservoirs, totaled 18,500 acre-feet or 8.7 per cent of the amount diverted in 1956. For 1955 these losses were 16,400 acre-feet or 6.3 per cent of the amount diverted[1/].

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 per cent before treatment with a bentonite sealer to as low as 7 per cent after treatment. Cost of the 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 per cent 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.

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

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 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 (ft.)
Grand Junction	50.3	4,730
Grand Valley	41.0	5,090
Montrose	40.0	5,810
Glenwood Springs	38.0	5,820
Lower Wagon Wheel Gap	29.2	8,500
Sugar Loaf Reservoir	21.8	10,000
Upper Wagon Wheel Gap	21.5	9,610

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 per cent 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 per cent of

the water delivered, or a loss of 31 per cent. 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 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 sub-basins.

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.

TABLE I

PRELIMINARY TABULATION OF LAND CLASSIFICATION COVERAGE
BY BUREAU OF RECLAMATION - COLORADO[a,b]

Region	Project	Irrigated Arable[c]	Non-irrigated Arable	Total Arable	Total Land Classified
4	Animas-La Plata	26,600	61,000	87,600	-
4	Cliffs Divide	174,700	368,400	543,100	-
4	Collbran	19,500	2,500	22,000	60,000
4	Dolores	30,600	35,500	66,100	129,000
4	Fruitgrowers Extension	9,500	15,800	25,300	-
4	Grand Valley	24,600	0	24,600	43,200
4	San Miguel	10,000	33,000	43,100	85,100
4	Uncompahgre	63,000	0	63,000	127,600
4	Paonia	13,100	2,200	15,300	33,000
4	Silt	5,400	1,900	7,300	-
4	Pine River Extension	-	-	15,000	-
4	Florida	-	-	18,900	-
5	San Luis Valley-Conejos Division	72,900	12,300	85,200	116,200
5	San Luis Valley-Rio Grande Division	224,300	18,200	242,500	509,200
7	Colorado-Big Thompson[d]	707,710			
7	CBT (Boulder Creek Supply Canal)	30,900	4,000	34,900	55,000
7	CBT (South Platte Supply Canal)	42,800	2,600	45,400	63,700
7	Narrows	217,700	108,100	325,800	611,600
7	Upper Arkansas Basin	461,000[e]	1,622,000	2,083,000	2,736,200
7	St. Francis	750	6,000	6,750	-
7	North Republican	3,300	2,100	5,400	-
7	North Park	134,467[f]	10,318[g]	10,318[g]	95,300[g]
7	South Park[h]	-	-	-	-
7	Blue-South Platte	271,120	268,564	539,684	1,046,435

Footnotes

a/ Tabulation of Region 4 projects in this table is not complete, but provides data for projects where semi-detail or detail land classification results are or currently are being made available. A separate complete reconnaissance land classification tabulation is attached.

b/ A dash line in table indicates that data are not immediately available.

c/ Unless indicated otherwise, the acreages are arable land by Reclamation standards -- non-arable irrigated lands occur on most projects receiving supplemental water, but such lands are not tabulated separately herein.

d/ An entire land classification survey was not made on this project -- irrigated acreage shown is based on preliminary tabulation of land use survey by Region -- entire acreage would not be arable by Reclamation standards.

e/ Acreage from AWR report -- includes non-arable irrigated land.

f/ Area not classified by Reclamation -- data from Colorado Water Conservation Board.

g/ Non-irrigated area of North Park classified by Reclamation.

h/ Area was classified by Reclamation, but tabulations not currently available.

TABLE II

LAND CLASSIFICATION[1/]

SUMMARY OF AREAS - ARABLE AND IRRIGATED LANDS

COLORADO RIVER DRAINAGE BASIN

COLORADO

Description of Area	Arable Acres	Irrigated Acres	Total Acres
Green River Drainage	8,090	1,840	9,930
Yampa River Drainage	182,070	73,370	255,440
White River Drainage	51,030	30,660	81,690
Colorado River Drainage	126,860	256,900	383,760
Gunnison River Drainage	109,680	243,640	353,320
Little Dolores-Coates Creek	720	1,880	2,600
Dolores River Drainage	146,940	73,790	220,730
San Juan River Drainage	88,520	84,980	173,500
Total	713,910	767,060	1,480,970

1/ Furnished by U. S. Bureau of Reclamation.

TABLE III

IRRIGATED LAND IN COLORADO
(Acres)
Compiled from U. S. Census Reports

	Crop Seasons					
	1899	1909	1919	1929	1939	1949
NORTH SLOPE						
North Platte River Basin	49,243	158,050	143,102	124,915	158,377	147,713
EAST SLOPE						
South Platte River Basin	660,285	1,098,547	1,179,880	1,223,423	1,113,042	929,706
Kansas River Tributaries	1,734	4,528	8,471	3,405	3,190	6,517
Arkansas River Basin	281,592	464,236	641,476	558,072	469,535	461,146
East Slope Totals	943,611	1,567,311	1,829,827	1,784,900	1,585,767	1,397,369
SOUTH SLOPE						
Rio Grande Basin	294,089	449,429	608,924	627,391	632,047	592,645
WEST SLOPE						
San Juan - Dolores	38,835	110,918	162,144	210,247	185,304	184,647
Gunnison River	113,152	197,162	250,913	258,872	296,112	269,397
Colorado River	108,733	216,095	259,472	283,406	263,261	263,522
Green-Yampa-White	63,408	93,067	94,005	103,888	99,817	88,602
West Slope Totals	324,128	617,242	766,532	856,413	844,494	806,168
STATE TOTALS	1,611,071	2,792,032	3,348,385	3,393,619	3,220,685	2,943,895

The decrease shown in 1949 is partly due to the definition of "Irrigated Land" used in the 1950 Census and to elimination of duplicated acreages. It excludes irrigated lands not used for purposes of farming such as rural residential areas; cemeteries; parks; golf courses; and lands not actually irrigated at the farm such as roads and farmsteads.

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.

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 between 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 someone 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 systems 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 hindsight, 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 worthwhile 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 stablizing 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 interest should be more thoroughly informed as to the State's water laws and how they apply to the usage of water."

c. Appropriation doctrine and ground water: 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.

Effect of Ground Water Pumping on Surface Water Rights

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 downstream. In other cases, irrigators downstream 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."

Appropriation Doctrine in Neighboring States

a. Surface water: 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,

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

had been adopted in Nebraska, and was the law in that State[1]." Washington and and Oklahoma also are prior appropriation 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

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

whereby rights to the use of unappropriated water may be preserved in furtherance of planning by the State[1]."

"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[2]."

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.

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

2/ Ibid, p. 217.

The average flow of Colorado streams was appropriated and irrigated farm lands developed in accordance with Colorado water law. Statewide 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.

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.

The State Water Development Plan

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 postwar 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-feet) 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 per cent 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 worthwhile 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 20 to 25 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.

APPENDIX

STREAM FLOW AT SELECTED GAGING STATIONS IN COLORADO

(In Thousands of Acre Feet)

	Average Runoff	
	1914-1955*	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

		Average Runoff 1914-1955*	Average Runoff 1934-1955*
Gunnison River (concluded)			
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
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 Pargosa Springs			86.3
Piedra River near Piedra			227.7
Rio Blanco near Pagosa Springs			61.4
Rio 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

	Average Runoff 1914-1955*	Average Runoff 1934-1955*
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
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.

PART III

WATER POLLUTION AND ITS CONTROL IN COLORADO

Prepared by Colorado State Department of Public Health
Division of Sanitation
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I. INTRODUCTION

Water is Colorado's most vital natural resource as it is in every other state. The problem in Colorado is made more complex by a low normal rainfall, terrain which accentuates the run-off factor, an elevation which places this State as the water source for surrounding states and a mountain range which requires lifting the water over natural barriers. The water supply is limited and is difficult of alteration but the water use and the water pollution control deserve attention.

The ultimate solution to the critical water quantity problem lies in our ability to preserve water in a condition suitable for use and re-use.

This suitability must be such as is in keeping with the needs for:

1. Public Health
   Water Supplies
   Waste Disposal

2. Industrial
   Manufacturing
   Agriculture
   Mining

3. Recreation
   Fishing and Hunting
   Swimming
   Water Sports

Some of these needs would seem to weigh more heavily than others. It therefore would seem feasible to delineate streams in such a manner that one stream or reach of a stream would be protected for one type of use,

another stream for another type of use, etc. But this type of thinking seems to be inadequate since we do not often have several streams in the same locality.

It is easy to say that an industry requires water of only a certain quality and can locate on a given stream. But the people working in the industrial establishment must live in the same locality and they must have water. Granted that surface waters must be treated in order to be satisfactory for human consumption, the reliability of such treatment is enhanced by keeping the water source free from unreasonable pollution. As a practical matter, the basic water sources available in a locality will probably be the same for industry and agriculture as for human use.

On the other hand, communities as well as industries and even agriculture, need water channels into which to discharge their liquid wastes. Dilution water is needed in order to prevent the creation of nuisances.

How then can these seemingly paradoxical needs be met? There are two parts to this solution. The first is that the wastes should be treated prior to discharge to keep the amount of pollution going to the stream to the practicable minimum. The other part of the solution is that the streams have certain natural recovery powers which enable them to overcome the effects of small amounts of certain kinds of pollution. However, some pollutants cannot be counteracted in the stream. These pollutants

generally are chemical in nature and they must be kept out of the streams except where dilution water is available.

A good pollution control program should consider all of the uses of the water in determining what degree of pollution control is needed.

In Colorado there are two agencies having official functions in stream pollution control. The State Department of Public Health has power to control pollution as needed to protect the public health. The State Game and Fish Department can effect controls to protect fish life.

This material hereafter deals with the direct interests of the State Health Department.

Prior to 1947, the State Department of Public Health did not have any specific authority to control pollution of streams. However, there are and were prior to that time several other statutes pertaining to pollution control.

One statute in the criminal code prohibits the discharge to streams of any vegetable or fleshy matter subject to decomposition. It also prohibits the discharge of oils.

Municipalities also have and have had the authority to prohibit the contamination of streams within five miles of their water supply intakes.

The City and County of Denver has special authority to control pollution of the South Platte and tributaries above the mouth of Clear Creek.

The 1947 revision of the laws concerning the State Department of Public Health established the power and duty to "establish and enforce minimum general sanitary standards as to the quality of effluent of sewerage systems and trade wastes and to advise with municipalities, industries as to methods or processes believed best suited to provide such treatment of sewage and trade wastes to meet such minimum general sanitary standards." A definition section defined minimum general sanitary standards as being the minimum reasonably consistent with the protection of the public health.

Pursuant to adoption of this law, the Department recognized the basic inadequacy of limiting pollution control to the public health aspects and tried for several years to promote legislation aimed at the whole water pollution complex.

After two failures, the Department adopted standards in 1953, for the quality of effluent of sewerage systems and trade wastes. In 1955, the State Legislature set up a standard in the statute for coliform density in sewage discharges having human excreta as a component. The amendment also set up a hearing procedure, requiring a hearing before the State Board of Health before the Department could take legal action. In 1957, the

Department amended its standards for effluent quality so as to bring them more in line with the statutes.

Geographically Colorado has four major drainage basins. They are the Missouri, Arkansas, Rio Grande, and Colorado.

II. STREAM POLLUTION BY BASINS

Missouri Drainage Basin

The Missouri drainage basin covers the Northeast quarter of the State as well as the North Park and South Park areas.

There are 78 communities in this basin having collection systems. These serve an estimated 847,728 population. Sewage from 7 communities is discharged into the streams without treatment. Sewage from 24 communities is treated by sedimentation or primary treatment. Sewage from 47 communities receives some form of secondary treatment.

Waters of the South Platte are diverted for municipal use as far downstream as Englewood. Clear Creek water is diverted for municipal use as far downstream as Tennyson Street in Denver (not used in Denver, but diverted in Denver).

Water from the Big Thompson River is diverted for municipal use just above Loveland. Water on the St. Vrain is diverted for public use as far downstream as Lyons. On other tributaries there are no towns with sewer systems located above points of diversion for public water supplies.

The pollution problem in this basin is made more acute by the high density of population, particularly in the Denver region, and in the areas where beet sugar refineries are located.

As the Denver region grew, outlying neighborhoods developed community sewerage systems. Even though some degree of treatment was usually provided, the projects were not contemplated on a large enough scale to provide adequate treatment facilities or efficient operation. Furthermore, the people involved did not constitute a large enough population to be able to provide facilities for growing adjacent territories. Consequently these new areas repeated the same process over again. The result has been that numerous small communities in the Denver Metropolitan area have built sewage treatment plants incapable of doing a satisfactory job.

In some areas the total sewage flow frequently is greater than the stream flow. These same communities discharging wastes to the stream are in some cases taking their drinking water out of the stream -- above their own discharge to be sure, but below the sewage discharge point of numerous other communities.

This illustrates the point previously mentioned -- that ultimately the people must get their water from the stream and put it back in when they are through. (Note: There are, of course, ground water resources which enable some communities to draw water from sources not normally affected by surface pollution and which partly lessens the effect of heavy

stream pollution in some areas.) The largest year round contributor of pollution to streams in this basin is the City of Denver. Its discharge frequently creates a critical problem during the summer months when stream flows are normally low as the volume of sewage effluent frequently is greater than the volume of stream flow. This is also a potentially explosive public health hazard, because the mixture of sewage effluent with little dilution water is used for irrigation of truck crops north of Denver. The hazard is lessened by heavy chlorination of the Denver sewage effluent.

Another large contributor of pollution in this basin is the beet sugar industry. This is a seasonal operation, but the pollution does come primarily at a time when stream flows are lowest. Through some realignment of plant operations and by a concerted effort at by-product recovery, the amount of pollution has been decreased. Due to the seasonal character of these operations there are limits on the number of processes applicable for treatment of these wastes after all of the reduction, re-use, and by-product recovery practicable have been effected.

However, the substantial progress made in the last several years in reduction of the amount of this type of pollution is a credit to the industry.

Several oil refineries near Denver have wastes problems but have met with moderate success in keeping them directly out of the stream.

One problem not confined to this basin, but perhaps more acutely felt is the variability of stream flow caused by the many diversions and return flows. This practice creates a problem for a municipality or industry with wastes to discharge. Adequate diluent water may be available one minute but not the next. This creates wide fluctuations in the quality of water downstream when adequate waste treatment is not provided.

MISSOURI DRAINAGE BASIN

Disposal of Wastes - September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
Deer Trail	390	Akron	1,520	Altura	2,000
Georgetown	338	Baker MW&SD	3,000	Arvada SD	7,000
Johnstown	900	Brush	2,431	Ault	600
Merino	300	Burlington	2,200	Aurora SD	25,000
Milliken	500	Cheyenne Wells	1,000	Baker MW&SD	8,000
Ovid	850	Clear Creek SD	2,000	Berthoud	1,000
Platteville	700	Crook	250	Brighton*	6,000
		Denver (2 plts)	578,000	Boulder*	21,400
TOTAL	3,978	Eaton	1,300	Broomfield Hgts.	2,000
		Flagler	793	Brush*	2,500
		Ft. Lupton	1,907	Camp George West	200
		Ft. Morgan	7,250	Castle Rock	784
		Fruitdale SD	1,000	Buckley Field	1,900
		Golden	5,238	Erie	1,000
		Lafayette	2,000	Englewood	16,000
		LaSalle	800	Estes Park	6,000
		Loretto Hts. Coll.	400	Fed.Cor.Inst.	500
		Lyons	600	Fitzsimons Hosp.	5,000
		N.W. Lakewood	2,000		
		Schreiner Sub.	150		

MISSOURI DRAINAGE BASIN

Disposal of Wastes (Concluded) — September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
				Ft. Logan	800
		Sterling	7,500	Fleming	713
		Walden	696	Ft. Collins	15,000
		Wellington	594	Frederick)	
		Wray	2,100	Firestone)	1,500
				Evanston)	
		TOTAL	624,729	Greeley	21,000
				Haxtun	1,200
				Holyoke	1,230
				Idaho Springs*	1,800
				Julesburg*	1,800
				Keenesburg	250
				Kersey	244
				Littleton	8,000
				Longmont	8,000
				Louisville	2,000
				Louviers	380
				Ind. Sch. for Girls	200
				N. Wash. St. W&SD	10,000
				Otis	250
				Rocky Mtn. Arsenal	375
				Sky Ranch	75
				S. Adams Co. W&SD*	5,000
				Strasburg SD	300
				Stratton	720
				Thornton	8,000
				Westminster	8,000
				Wheatridge	11,900
				Windsor	2,000
				Yuma	1,400
				TOTAL	219,021

* Under Construction

MISSOURI DRAINAGE BASIN

Source of Water Supplies

September, 1957

GROUND		SURFACE					
		FILTERED & CHLORINATED		DISINFECTED ONLY		NO TREATMENT	
Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served
Akron	1,605	Baker MW&SD	6,000	Boulder	20,000	Alma	149
Arapahoe	120	Berthoud	867	Central City	371	Blackhawk	285
Arriba	367	Brcomfield		Estes Park	1,590	Empire	135
Arvada*	10,000	Hts.	2,000	Fairplay	700	Jamestown	75
Arvada Hts.	-	Denver2/	640,000	Georgetown	375	Silver Plume	150
Ault	866	Englewood	16,700	Golden1/	5,500	Shawnee	75
Bancroft W&SD	500	Evergreen	500	Grand Lake	1,000		
Bennett	272	Erie	1,050	Ideldale	250	TOTAL	869
Bethune	71	Ft. Collins2/	20,000				
Beulah	250	Frederick3/	700	TOTAL	29,786		
Branson	-	Greeley2/	20,400				
Brighton	6,000	Ida. Spgs.*	2,000				
Broomfield	125	Johnstown	900				
Brush	2,431	Kittredge	300				
Buckley Field	-	Lafayette	2,073				
Buffalo Creek	60	Longmont	10,000				
Burlington	2,247	Louisville	2,000				
Byers	400	Loveland	10,000				
Charlou Park	-	Lyons	1,000				
Castle Rock	800	Mead	200				
Cheraw	450	Morrison	275				
Cheyenne Wells	695	Nederland*	400				

MISSOURI DRAINAGE BASIN

Source of Water Supplies
(Continued)

September, 1957

GROUND		SURFACE					
		FILTERED & CHLORINATED		DISINFECTED ONLY		NO TREATMENT	
Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served
Cons.M.W.Co.	8,000	Thornton	8,000				
Crook	200	Wahkeney Pk.*	100				
Dacona	280						
Deer Trail	400	TOTAL	745,465				
East Lake	350						
Eaton	1,300						
Eckley	500						
Elizabeth	250						
Federal Hts.	200						
Firestone	316						
Flagler	900						
Fleming	370						
Florence Gdns.	100						
Ft.Lupton	2,000						
Ft.Morgan	5,300						
Genoa	300						
Grover	137						
Haxtun	1,000						
Holyoke	1,540						
Hudson	325						
Illif	120						
Indian Hills	-						

MISSOURI DRAINAGE BASIN

Source of Water Supplies
(Continued)

September, 1957

GROUND		SURFACE					
		FILTERED & CHLORINATED		DISINFECTED ONLY		NO TREATMENT	
Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served
Julesburg	1,940						
Keenesburg	500						
Keota	10						
Kelton Hts.	-						
Kersey	310						
Larkspur	200						
LaSalle	750						
Leydon	-						
Littleton	8,000						
Louviers	380						
Merino	285						
Milliken	750						
Mills Subd.	150						
Nunn	200						
Oberon Hts.	-						
Otis	540						
Ovid	800						
Pierce	380						
Platteville	700						

MISSOURI DRAINAGE BASIN

Source of Water Supplies
(Concluded)

September, 1957

GROUND		SURFACE					
		FILTERED & CHLORINATED		DISINFECTED ONLY		NO TREATMENT	
Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served	Name of Community	Pop. Served
Seibert	355						
Sedgwick	-						
Silver Plume	150						
Sky Ranch	75						
S. Adams Co. W&SD	5,000						
Sterling	7,500						
Stratton	900						
Tinytown	550						
Vona	226						
Walden	649						
Ward	135						
Wellington	600						
Westminster**	8,000						
Wiley	413						
Wray	1,860						
Yuma	1,780						
TOTAL	95,235						

1/ Some water filtered.
2/ Serves other communities.
3/ Construction planned.

* Infiltration gallaries.
** Also has surface water supply.

Colorado River Basin

All of Colorado west of the Continental Divide is in the Colorado River drainage basin. However, the waters leave the State at several points in streams having individual names. The principal ones are the Yampa, White, Colorado, Dolores, and San Juan, which re-enters the State after collecting other tributaries which left the State separately. The relatively high volume of water and the less dense population gives these streams a distinct advantage over those in other parts of the State as far as pollution is concerned. However, there are several factors which make it necessary to control pollution as a conservation measure. It is easier to prevent pollution than it is to correct it. This also makes it easier for new industries to locate in this basin because they do not have to avoid some waters. The uranium producing and milling operations are mostly located in this part of Colorado. This poses a unique problem about which scientific information is to a degree lacking. The problems of radioactivity are such that we must advance into this new "age" with caution. Conventional treatment processes are only partly effective in preventing radioactive pollution. We lack sound baseline information on radioactivity in streams prior to the birth of this new industry. An adequate research program into this whole problem of radioactivity is needed. Information that is needed includes:

1. How much radioactivity is permissible in streams.

2. How rapidly are we approaching these limits.

3. How can we treat wastes to keep the level below that point.

In other parts of the basin the oil shale industry is promising to spur rapid development. Just what the requirements of this industry may be are not known. Large population growths in this area will also impose additional requirements for public water supplies as well as for waste discharge. At the present time there are 46 sewered communities in this basin. Fourteen discharge their wastes without treatment, seventeen treat their sewage by only sedimentation, and fifteen provide some degree of secondary treatment.

COLORADO RIVER DRAINAGE BASIN

Disposal of Wastes September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
Breckenridge	280	Bond	100	Aspen*	916
Delta	3,085	Collbran	165	Clifton	500
Eagle	445	Craig	2,770	Climax	1,200
Fruita	1,450	Durango	5,500	Cortez	2,680
Gunnison	1,850	Ft. Lewis	100	Dolores	725
Gypsum	245	Glenwood Spgs.	2,160	Dove Creek*	750
Hotchkiss	655	Hayden	690	Gilman	100
Meeker	990	Mesa	125	Grand Junction*	18,000
Olathe	800	Montrose	4,360	Granby	500
Ouray	1,080	New Castle	483	Grand Lake	309
Paonia	1,250	Oak Creek	1,275	Ignacio	488
Redcliff	60	Palisade	855	Mancos	620
Silverton	1,200	Rangely	1,000		

COLORADO RIVER DRAINAGE BASIN

Disposal of Wastes
(Concluded)

September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
Telluride	1,060	Rifle	1,500	Norwood	294
		Silt	350	Nucla	500
TOTAL	14,450	Steamboat Spgs.	1,750	Rifle Mines	300
		Van Coram	600	Ute Agency	350
		TOTAL	23,783	TOTAL	28,232

* Under construction.

COLORADO RIVER DRAINAGE BASIN

Source of Water Supplies

September, 1957

GROUND		SURFACE					
		Filtered & Chlorinated		Disinfected Only		No Treatment	
Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served
Artesia	200			Aspen	204	Brecken-ridge	296
Basalt	173	Climax	1,200	Bayfield	338	Cedaredge	572
Bond	100	Craig	3,000	Cortez	4,500	Collbran	236
Carbondale	440	Debeque*	253	Crested Butte	780	Fraser	400
Crawford	162	Dove Creek*	700			Minturn	1,000
Delta	4,077					Newcastle	483
Grand Valley	291	Durango	7,437	Dillon	189	Ouray	1,077
		Frisco*	150	Dolores	616	Red Cliff	555
		Granby*	445				
Mesa	90	Grand Jct.	15,000	Eagle	436	Rico	211
Orchard City	700	Gunnison	2,730	Ft. Lewis	250	Ridgway	354

COLORADO RIVER DRAINAGE BASIN

Source of Water Supplies (Concluded) — September, 1957

GROUND		SURFACE					
		Filtered & Chlorinated		Disinfected Only		No. Treatment	
Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served
Palisade	850	Hyden	718	Fruita	1,450		
Paonia	1,248	Hotchkiss	711	Gilman	250	Silt	472
TOTAL	8,331	Hot Sul. Spgs.*	251	Glenwood Spgs.	2,400	Silverton	1,366
				Grand Lake	309		
				Kokomo	150		
		Ignacio	553	Mancos	778	Gypsum	350
		Kremmling	586	Mt. Harris	891	Telluride	1,097
		Meeker	1,649	Naturita	600	Yampa	411
		Montrose	5,000				
		Oak Creek	1,408	Norwood	550	TOTAL	8,880
		Olathe	806				
		Rangely	1,200	Nucla	500		
		Rifle	1,518				
		Rifle Shale Plant	245	Pagosa Spgs	1,378		
		Rogers Mesa	100	Steamboat Springs	1,900		
		Uravan	500	Van Coram	600		
		Ute Agency*	500				
		TOTAL	46,660	TOTAL	19,069		

* Infiltration galleries.

Arkansas River Basin

The Upper Arkansas River Basin extends from the Continental Divide in central Colorado to the Colorado-Kansas boundary. It includes all or

parts of 18 counties in southeastern Colorado and encompasses an area of approximately 26,000 square miles with an estimated 1950 population of 305,000.

The headwater region of the Arkansas Valley is mountainous. Eastward from the foothills above Pueblo, the topography develops into the Great Plains Region. The climatic conditions are characterized as sub-humid in the mountains where the precipitation averages slightly more than 20 inches and arid in the plains region were the average rainfall is less than 15 inches. Most of the stream discharge at the headwaters originates from light rainfall and melting snow. Intense rainfall of short duration in the plains region gives rise to flash floods and generally intermittent stream flows. Much of the river flow is diminished before it reaches the Kansas line by evaporation, channel absorption, and diversion for irrigation.

The discovery of gold in 1859 brought the original settlers to the basin. Mining then became the principal economic activity until the turn of the century when, as a result of the decreased mining activities, there began a gradual shift to agriculture and livestock raising. Agriculture now is the principal occupation in the basin. Mining, manufacturing and recreation also contribute a fair share of the basin's income.

The water resources are an important asset to the basin and are used mainly for public and industrial water supplies, irrigation and livestock watering, fishing and other recreational activities.

The use of waters for irrigation is considered the principal water use in the basin. Approximately 322,000 acres of land are irrigated from the main stem of the Arkansas River. The use of streams and irrigation canals for livestock watering is also regarded as an important use associated with agriculture.

Recreational opportunities contribute a significant part of the State's income. The mountainous western portion of the basin offers excellent fishing and other inducements to tourists and campers. Conservation interests are active in conserving and developing the fish and wildlife resources and are strong advocates of stream pollution abatement.

Pollution reaching the waters of the basin originates mainly from municipal and industrial sources and also from natural sources such as sediment and dissolved salts and minerals.

There are 38 sewered communities in the area. Ten discharge their sewage without any form of treatment, 13 treat their sewage by only sedimentation, and 14 provide some form of secondary treatment.

Added to the domestic sewage are the wastes from any industries which use the municipal sewerage systems to dispose of their wastes. The lack of data regarding the volume and strength of the industrial wastes discharged to municipal sewers precludes an estimate of the total pollution load discharged from municipal sewerage systems.

In addition to the industries connected to public sewers, there are known industries which have outlets discharging directly to the water courses. These industries include mining and ore processing, iron and steel mills, food processing plants, beet sugar refineries and a rendering plant. Several industries provide some waste control facilities; however, the majority discharge their wastes with no treatment. The lack of data regarding these sources of pollution also precludes an estimate of the total industrial pollution load discharged directly to the water courses. Results of a water pollution investigation made by the Colorado State Department of Public Health show, however, there has resulted a progressive deterioration of the river waters from the headwater to the Kansas line from the discharge of wastes from municipal and industrial sources.

Silt eroded from old mine tailings deposits cause damage to the fish resources of the Upper Arkansas River. The public health hazards associated with the use of polluted waters for sources of municipal supplies and irrigation purposes are of continual concern to the water plant operators and health authorities.

Toxic and other deleterious substances originating from industrial wastes reaching waters used for livestock watering can result in serious economic loss to the extensive livestock raising enterprises.

The damages to the fish resources, irrigation facilities, and public and industrial water supplies, from silt pollution and dissolved minerals also present serious problems throughout the basin.

Numerous direct benefits to all principal water uses are associated with pollution abatement. The indirect and intangible benefits, however, are of equal or greater importance when evaluating a program of pollution control. Some of the indirect benefits, to which monetary value cannot be assigned readily, include benefits to public health, aquatic life, recreation, and purely aesthetic considerations.

Available information regarding existing industrial waste treatment facilities shows deficiencies exist in this field. Of 30 industrial sources of pollution known, 13, including mostly small-scale dairies, food processing plants and two beet sugar refineries, have some type of waste control facilities. The remaining 17 industries, which discharge the bulk of inorganic type wastes produced in the basin, do not have waste control facilities.

An estimate of the pollution prevention measures required is based on admittedly incomplete data and, at best, should be considered as the basis of an initial water pollution control program.

Information regarding the industrial waste pollution abatement needs is incomplete for an adequate evaluation of the problem. One iron and steel industry requires a new plant, two beet sugar refineries require enlargement of their waste control facilities; it is recommended that smaller industries, including dairies and food processing plants, connect to city sewers when possible, and the needs for the remaining industries

producing both inorganic wastes from mining and ore processing operations and organic wastes from food processing are undetermined.

Current status of action regarding the pollution abatement projects required for both municipalities and industries indicates some have taken cognizance of their responsibility and are taking action to provide for adequate treatment of their wastes.

ARKANSAS RIVER DRAINAGE BASIN

Disposal of Wastes — September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
Blende	200	Colorado Springs[1]	53,000	Buena Vista	783
Cripple Creek	800	Eads	1,011	Canon City[2]	10,000
Florence	2,765	Ft. Lyons	1,500	Fountain	2,000
Holly	1,236	Hugo	845	Fowler	1,016
La Junta	7,268	La Veta	696	Granada	440
Lamar	7,715	Leadville	5,000	Las Animas*	2,422
Manzanola	490	Limon	1,294	Portland	205
Rocky Ford	4,000	Ordway	1,162	Pueblo Air Base	-
Victor	677	Pueblo	54,027	Rye	160
Walsenburg	3,621	Ramah	130	Salida*	4,200
		Simla	260	Security	3,062
TOTAL	28,772	Springfield	2,030	Trinidad	7,200
		Sugar City	420	Walsh	897
				Wiley	417
		TOTAL	126,675	TOTAL	32,802

1/ Serves outside communities
2/ Serves Canon City, S. Canon City, and State Penitentiary
* Under construction.

ARKANSAS RIVER DRAINAGE BASIN

Source of Water Supplies — September, 1957

GROUND		SURFACE					
		Filtered & Chlorinated		Disinfected Only		No Treatment	
Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served
Aguilar	1,400	Buena Vista*	776	Colorado Spgs. 1/	70,000	Cripple Creek	800
Beulah	300	Broadmoor	1,500	Fountain	711	Palmer Lake	264
Blende	75	Canon City	10,000	Gr. Mtn. Falls	104	Penrose	75
Boone	475	Florence	2,765	LaVeta	696		
Bristol	200	Portland	205	Leadville	4,000		
Calhan	378	Rocky Ford	5,000	Manitou Spgs.	3,000	TOTAL	1,139
Campo	238	Trinidad	16,000	Pueblo	75,000		
Coal Creek	195	Walsenburg	5,570	Rye	160		
Crowley	380	Woodland Park*	300	Victor	677		
Delaqua	422						
Eads	1,011	TOTAL	42,116	TOTAL	154,348		
Fort Lyons	1,500						
Fowler	1,016						
Granada	547						
Hartman	168						
Hasty	70						
Haswell	150						
Holly	1,244						
Hugo	885						
Kim	150						
Kistell Sub.	140						
Kit Carson	400						
La Junta	7,900						
La Junta Village	600						
Lamar	5,468						
Las Animas	2,422						
Lime	250						
Limon	1,438						
Manzanola	544						
Monument	128						
Olney Springs	275						

ARKANSAS RIVER DRAINAGE BASIN

Source of Water Supplies (Concluded) September, 1957

GROUND		SURFACE					
		Filtered & Chlorinated		Disinfected Only		No Treatment	
Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served
Ordway	1,291						
Pritchett	282						
Pueblo Ordnance	5,000						
Pure Spgs. W. Co.	750						
Ramah	143						
Rockvale	381						
Salida	4,516						
Eastern Salt Cr.	150						
Western Salt Cr.	100						
Security	5,000						
Silver Cliff	239						
Simla	504						
Springfield	2,000						
Starkville	150						
Sugar City	521						
Swink	330						
Two Buttes	42						
Walsh	718						
Westcliffe	426						
Wiley	413						
TOTAL	53,325						

* Infiltration galleries.

1/ Filters some water and obtains some from wells.

Rio Grande Basin

This basin is the smallest major river basin in Colorado not only from size but from the standpoint of population. There are only five communities in the basin with public sewers and only six communities with public water supplies. Three of the communities obtain their water from surface sources while three use ground sources. One of the communities having principally a surface source also uses a ground source, primarily in the summer time to supplement the supply.

Two of the sewered communities do not have any treatment facilities, one has primary treatment, and two dispose of their sewage by sewage ponds, which provide very satisfactory treatment.

RIO GRANDE RIVER DRAINAGE BASIN

Sources of Water Supplies September, 1957

GROUND		SURFACE					
		Filtered & Chlorinated		Disinfected Only		No Treatment	
Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served	Name of Comm.	Pop. Served
Alamosa	4,100	Antonito*	1,225	Creede	550		
Masonic Park	100	Del Norte	2,000				
Monte Vista	3,221			TOTAL	550		
		TOTAL	3,225				
TOTAL	7,421						

* Infiltration galleries.

RIO GRANDE RIVER DRAINAGE BASIN

Disposal of Wastes

September, 1957

NO TREATMENT		PRIMARY TREATMENT		SECONDARY TREATMENT	
Name of Community	Population Served	Name of Community	Population Served	Name of Community	Population Served
La Jara	1,100	Center	1,500	Alamosa	5,330
Monte Vista	3,865			Del Norte	1,800
		TOTAL	1,500		
TOTAL	4,965			TOTAL	7,130

III. PRESENT WATER POLLUTION CONTROL PROGRAM

The present program for Water Pollution Control in Colorado stems from tri-level authority - local, state, and federal.

Municipalities have authority to prohibit pollution within 5 miles of their water supply intakes. Some exert practically no control, while others maintain somewhat strict control. The City of Denver further has authority to control pollution on the South Platte and all tributaries above the mouth of Clear Creek.

The State Department of Public Health has the power and duty to establish and enforce standards for the quality of effluent of sewerage systems and trade wastes discharged onto the land or into surface or ground waters and to advise with municipalities concerning the methods or processes believed best suited to provide such treatment of sewage or trade wastes to meet such standards. Thus the state has a regulatory function and an advisory function.

In addition the State Department of Public Health administers the federal grants program for sewage treatment plant construction (P.L. 660) in Colorado.

In the regulatory part of the program, the Department has established standards for effluent quality. (Copy attached.) These standards prohibit the discharge of toxic materials in quantities toxic to man (2) prohibit the discharge of excess quantities of settleable or floating

matter (3) prohibit the discharge of effluents containing excessive suspended matter (4) prohibit the discharge of excess dissolved organic matter as measured by the Biochemical Oxygen Demand, and (5) (by statute) prohibit the discharge of excessive coliform bacteria. Item (4) above is worded so that a higher degree of purity is required when the discharge is to a watercourse used downstream in Colorado as a source of domestic public water supply.

Under this regulatory program, extensive testing is required to establish whether a violation exists. The advisory program (to be discussed more fully below) goes on before, during, and after the tests. In cases where satisfactory progress cannot be obtained by negotiation, the Director makes tentative findings and a hearing is held before the State Board of Health. (The State Board of Health, a division of the State Department of Public Health, is an "advisory board" which establishes policy, rules and regulations and serves in a quasi-judicial capacity.) If the Board finds that a violation does exist, it is empowered to issue orders to correct the violation in such time as it may determine reasonable. Penalties are provided for violation of such orders upon conviction.

The advisory part of the program consists of the promotion of construction of sewage and waste treatment facilities designed to meet regulations. Design standards are in use by the department as general guides in the design and arrangement of facilities.

The advisory program is also aimed at education of the communities into the needs for water pollution control, and as to the development of a willingness on the part of the people to pay for needed facilities.

The Department also inspects sewage treatment facilities to determine the status of operation and maintenance and consults with the operators on problems of an operational nature. Operator training is also a Department function under this advisory program. An annual one-week school for water and sewage plant operators is held. The school is conducted by a school council which has representatives from the various interested agencies and organizations. The Department has always been a "prime mover" for the school.

In administering the construction grants program, the Department must clear the application for eligibility and must determine whether the proposed project is to have priority over other eligible projects not previously certified for priority. The matter of eligibility is determined on the basis of whether the project will solve the pollution abatement needs, and whether the design is satisfactory to the Department. Priorities are established by the Board of Health, but all applicants must have a need for the money as well as the proposed facilities in order to qualify.

The Federal program is administered by the Public Health Service, Department of Health, Education, and Welfare. Its authority stems from P.L. 660, which not only sets up a program of federal grants, but gives that agency the authority to regulate interstate pollution.

In administering P.L. 660, the Public Health Service allocates the money appropriated by Congress. The law authorized the annual appropriation of $50,000,000 for each of the next 10 years beginning in fiscal

year 1957. The $50,000,000 is divided up based directly on population and inversely on per capita income. Colorado received a grant of $624,300 the first year and $636,675 for fiscal year 1958. The amount of the grant to a municipality cannot exceed 30 per cent of the project, land excluded, or $250,000, whichever is the smaller amount. The appropriation for 1958 was somewhat less than the $50,000,000; however, the reduction was made at the expense of some territories, states or districts not in position to use all of their allotment.

The Public Health Service also exercises a more technical control over the applications and supporting documents, as well as approval of plans for the facilities. Federal propriety must be established by one or more of several criteria.

The Public Health Service is also given authority to control interstate pollution. This is usually accomplished by giving strong support to the states rather than by direct action.

The Public Health Service was also given an appropriation for administering the program, part of which appropriation is allotted to the states on a matching basis. These monies must be matched equally by the state in their program. Colorado received $20,751 for fiscal year 1957 and has been allotted $28,400 for fiscal year 1958.

The Public Health Service also provides technical advisory service to the states on pollution matters. That agency sponsors technical task committees which are comprised of representatives of industry and other

technical experts, which committees develop recommendations for handling wastes from the specific industry concerned. Limited research is also carried on by the Public Health Service at the Robert A. Taft Sanitary Engineering Center, Cincinnati.

Future Problems

The problems with respect to pollution control are expected to increase much more rapidly than would be indicated by growth alone. The experience in recent years has been that pollution has increased several-fold while population growths are still measured quite adequately by fractions. The rapid rise of the chemical industry has been largely responsible for the increase in areas where that industry has developed. If parts of it locate in Colorado we may expect some problems in pollution. New industries create new waste problems and research is needed to determine effective control measures. However, there has always been a lag in provision of sewage and waste treatment facilities. This lag results from a failure to employ waste treatment practices even when it is known how the wastes may be treated. An example of this is sewage treatment. Satisfactory methods of treating sewage have been known for some time. There may be some refinements to be made, but the basic processes are the same as have been in use for many years. However, for some reason, not all of the communities have seen fit to build and operate the necessary facilities. Even if the people treated their wastes the best they knew how, there would

still be a tremendous challenge in devising and developing satisfactory waste treatment facilities for the new industries. Continuous research is needed on new waste problems to prevent the fouling of our watercourses with toxic wastes and to develop methods of treatment.

Financing of pollution abatement projects has always been a problem and there is no indication that it won't be in the future. In Colorado, municipalities have a debt limit on general obligation bonds of 3 per cent, excluding debt for waterworks. With other capital expenditures needed, many communities just haven't been able to build treatment works. In many cases the cost of needed facilities exceeds 3 per cent of the assessed valuation. It is possible to establish service charges and to float revenue bonds to pay for needed improvements, although interest rates are generally higher for this type of bond. Even in some incorporated towns, separate quasi-municipal districts have been organized in order to float the bonds needed to establish a satisfactory sewerage facility. This then creates another separate governmental unit, supported by taxes and charges from the same community, whose municipal government could not accomplish the objective due to limitations.

IV. OVERALL PROBLEMS IN POLLUTION CONTROL

A summary of the State problem as far as domestic sewage is concerned indicates that there are 166 sewered communities in the State. There are 33 communities discharging their wastes without treatment. There are 55 communities that provide only primary treatment or treatment by sedimentation. These communities may be expected at best to be removing only a third of their wastes prior to discharge. There are 78 communities with some form of secondary treatment although many of these are not adequate to provide the efficiency necessary to comply with minimum standards.

All of the 33 communities discharging wastes without treatment and the 55 providing only primary treatment are in need of major additions or new plants in order to comply with the minimum standards for protection of public health. Many of the 77 communities providing some form of secondary treatment are in need of improved treatment facilities.

The limited size of the staff has not permitted the Department to keep abreast of the industrial waste problem. This is a serious deficiency because of the complexity of industrial waste treatment problems. The last information, admittedly out-of-date and scanty, indicates that there are 120 industries discharging wastes to streams having a population equivalent of 2,670,000 persons. Twenty-four industries were regarded as having adequate industrial waste treatment, 46 as having inadequate waste treatment, and the needs of 50 were undetermined.

Recent progress has been encouraging. The Federal Grants Program gave the pollution abatement program a "shot in the arm". However, the grants available to the State are not sufficient to keep pace with the needs in Colorado. It appears that at least twice that much money will be needed in the next few years in order to satisfy the needs. Department estimates indicate that $27,000,000 worth of treatment facilities are needed to correct the present problem. The present Federal program at approximately $630,000 annual allotment if continued for 10 years as the law authorizes would assist in $21,000,000 worth of construction at 30 per cent of the total project costs. The $27,000,000 estimate includes provision of treatment for many communities not now sewered. However, it does not include estimates to cover all of the expansion needed in the Denver metropolitan area according to a recent engineering report on that problem.

One difficulty that may be expected from the Federal Grants Program is that communities may have to await their turn to get Federal aid. Then there is the uncertainty of the annual appropriation which makes it difficult to plan adequately.

The Federal program is fine; there just isn't enough money available to Colorado to keep the program going at a satisfactory pace.

One difficulty experienced in the present program has been lack of an adequate staff to cope with the problem. There are on our staff the following personnel which devote some time to this problem:

1 Division Director for the entire field of Sanitation.

1 Section Chief who manages all of the public health engineering programs.

5 District public health engineers, one of whom is currently on educational leave, devote part of their time to water pollution control.

However, we have a generalized program and the same people must also work on public water supplies, public swimming pools, community refuse collection and disposal problems, insect and vector control, as well as many other problems which are in the general field of public health engineering. However, most of their time is spent on water pollution control and public water supplies.

Experience has shown that communities cannot be persuaded to do something about their problem unless they are contacted frequently. As a result the department has been forced to concentrate on a few of the major problems in order to secure correction. This results necessarily in some neglect to the other towns. The rapid growth of Colorado has imposed additional problems in prevention of pollution. The present staff is well qualified, but just too few in number.

A staff should be adequate to:

1. Work with each community to secure adequate waste treatment facilities.

2. Review plans and specifications for new facilities to secure adequate design and freedom from sanitary defects.

3. Make inspections during construction to detect failure to comply with design specifications.

4. Make periodic inspections of all sewage treatment plants.

5. Counsel with operators of all plants to assist them with operational problems in order to secure the most efficient treatment within the capability of the plant.

6. Maintain current inventories of all sources of pollution and the treatment facilities provided.

7. Investigate all sources of industrial pollution and determine the needs for improvement.

8. Maintain an adequate testing program on the amount and nature of all pollution.

9. Maintain adequate studies on the effect of the various sources of pollution on the stream itself so as to be able to plan for protection of our water resources.

10. Research on new pollutants and potential pollutants so that our waters can be protected.

11. Increased laboratory services.

The protection of public water supplies goes hand in hand with the water pollution control program. One hundred twenty-two Colorado communities serving 837,520 persons obtain their water from surface

sources. Sixty-three of these serving 214,641 persons do not receive treatment by filtration. All of these surface water sources should receive complete treatment consisting of coagulation, sedimentation, filtration, and disinfection, or treatment by equally effective methods.

The program in this field is carried on by the same personnel that carry on the water pollution control program. There are two major differences in financing. Municipalities have no statutory debt limit on general obligation bonds that may be issued for waterworks. On the adverse side there is no Federal Grants Program to assist the communities with construction of needed treatment facilities. The needs for this program include a larger staff to make it possible to accomplish the following:

1. Work with each community to secure adequate water treatment facilities.

2. Review plans and specifications for new facilities to assure adequate design and freedom from sanitary defects.

3. Make periodic inspections of all public water supply facilities.

4. Counsel with operators of all plants to assist them with operational problems in order to secure the most efficient treatment possible from the plant.

5. Maintain current inventories of all water supply sources and facilities.

6. Maintain an adequate testing program for the water produced as well as for the nature of water to be treated. This should include numerous chemical, physical, and bacteriological tests to assure safe water supplies.

Future Trends Affecting Water Usage And Pollution In State

1. Oil Shale

Largest foreseeable is probably for oil shale and gilsonite processing and conversion. The character of the oil shale is such that extraction of the crude oil and perhaps some refining can be expected near the mining site to reduce freight and hauling costs. The Green River shales contain about 60 gallons of oil per ton of shale. Shale also contains (NH_4) SO_4. Retorting and refining operations would require about 150-250 gallons of water per ton of shale, mostly for cooling.

Anticipated capacities:

10,000 Tons shale/day = 600,000 gal/day (oil)

200 (10,000) = 2,000,000 gal/day (water)

100,000 T/day = 20,000,000 gal/day (water)

Anticipated pollution:

Wastes may be similar to petroleum refinery wastes - may contain sulfides and mercaptans - also may get some ammonium sulfate in wastes.

Water supplies of downstream shale oil processors may be degraded to point of non-usability.

Refinery wastes - acids, caustics, etc., and hot cooling water may be detrimental to fish life and aquatic organisms.

Effects on irrigation water: Domestic water supplies - if any - can anticipate treatment and taste and odor problems. Ground-water supplies also may be affected. Amount of operating personnel unknown - but can expect appreciable population increase in area - increased or new water supplies will be needed and problems will be created in sewage disposal. Suggest that Denver Research Institute - Denver University - can provide more details.

2. Wood Products (Including Pulp and Paper)

There is a large amount of infested and aged timber on U. S. forest lands in Colorado. Utilization is the best solution to disposal of the infested and dying timber and it seems likely that a lumber and other wood products conversion industry will be established for this purpose. Although several previous efforts and plans have not materialized, a future installation (or more) seems highly likely. It appears that pulp and/or paper mill or another type can be expected with or without a lumber mill.

Water supply needs for a 150 T/day pulp mill - Kraft process - would be from 3-10 mgd, depending on operations used, water saving procedures

in the plant, and the character of the final product - (bleached or unbleached paper, paper, hardboard, etc.).

Waste from a pulp plant with nominal capacity of 150 T/day will again depend on the final product and waste prevention devices and facilities built into the plant. It is estimated that a P.E.of 30,000 to 100,000 would result, with low P.E. for a Kraft mill which puts out unbleached pulp and has closed circuit pulp washing system. The wastes may have some color and may contain sulfides and mercaptans which may give the waste an odor. In addition, these constituents and others may be toxic to aquatic life.

A comprehensive report on this subject was prepared for the Colorado Department of Public Health by the USPHS in 1950.

A 150-ton Kraft mill will require about 50 persons for its operation. If paper and other products are made, personnel required will be about 100-150.

3. Mineral Industry - General

Without specific knowledge of the minerals and estimated reserves, it is difficult to predict the future of this industry. It is conceivable, however, that additional commercial uranium deposits will be found, and that expansion in this industry will continue.

Continued growth of the country should bring about expansion of existing mineral processors such as The Climax Molybdenum Company and Colorado Fuel & Iron.

The availability of new cheap power from the Colorado River projects should encourage the development and expansion of mineral industry and perhaps result in new discoveries, new industries and a more intensified exploration.

Water will be required for almost any and all mineral operations and liquid wastes can be expected from most of these operations.

4. Agriculture - General

The Colorado River projects will increase the output of agricultural products and thus the number and capacity of vegetable processing industries. This will create a water supply need and industrial waste disposal problem.

5. Coal - General

The future of coal and coal-like materials looks good. Its full and maximum utilization, as a raw fuel source and as an intermediate for production of other products, including other fuels, has not been realized.

When cheaper sources of hydrocarbons, such as gas and oil, become exhausted, coal should become the major source of hydrocarbons for the production of plastics, insecticides, gasoline, oil and numerous other organic products. At least, the minimum expected expansion due to such increased usage of solid hydrocarbons would be the increase in mining. Undoubtedly, however, some plants for conversion of these materials to the final marketed products will be constructed. The water needs of these plants,

their waste products and personnel needs obviously are not predictable at this time.

V. RECOMMENDATIONS TO BE CONSIDERED IN FUTURE PROGRAM

1. Maintain a staff adequate to control the problem.

2. Modify law, as weaknesses are brought to light, so that the enforcing agency has a better legal tool.

3. Relax laws limiting bond debt so that municipalities are on a basis equal with sanitation districts.

4. Increase federal assistance to municipalities for water pollution abatement facilities, or provide some assistance from the state.

5. Provide a comparable grants-in-aid for improvement of public water supply.

6. Provide adequate research facilities to make for sound use of streams without impairing their usability.

7. Provide laws more favorable to unification of treatment facilities for adjacent areas.

APPENDIX

COLORADO STATE DEPARTMENT OF PUBLIC HEALTH

DIVISION OF SANITATION

1955 Water and Sewage Laws (Health Department)

The following items are taken from the laws governing the Colorado State Department of Public Health. These items consist of pertinent extracts contained in Chapter 66 of the Colorado Revised Statutes, 1953, together with the amendments to the law made by House Bills No. 34 and No. 35, as enacted by the General Assembly in 1955. These particular items deal with the minimum standards allowable for water supplies used for human consumption and domestic sewage and trade wastes. They also deal with the standards and hearing procedures for the control of domestic sewage.

66-1-7. POWERS AND DUTIES OF THE STATE DEPARTMENT OF PUBLIC HEALTH. The State Department of Public Health shall have and exercise, in addition to all other powers and duties imposed upon it by law, the following powers and duties:

(5) To establish and enforce minimum general sanitary standards as to the quality of water supplied to the public and as to the quality of the effluent of sewerage systems and trade wastes discharged upon the land or into the surface or ground-waters, and as to the quality of fertilizer derived from excreta of human beings or from the sludge of sewage disposal plants; and to advise with municipalities, utilities, institutions, organizations and individuals, concerning the methods or processes believed best

suited to provide the protection or purification of water and the treatment of sewage and trade wastes to meet such minimum general sanitary standards:

(8) To establish, maintain and approved chemical, bacteriological and biological laboratories, and to conduct such laboratory investigations and examinations as it may deem necessary or proper for the protection of the public health:

(9) To make, approve and establish standards for diagnostic tests by chemical, bacteriological and biological laboratories, and to require such laboratories to conform thereto; and to prepare, distribute and require the completion of forms or certificates with respect thereto:

(18) (Subsection revised by Amendment enacted by the General Assembly, 1955) The phrase "minimum general sanitary standards" as used in this section shall mean the minimum standards reasonably consistent with protection of the public health, and in the case of minimum general sanitary standards as to the quality of water supplied to the public, the same shall in no event be less than the drinking water standards of the United States Public Health Service. The word "standards" as used in this section shall mean standards reasonably designed to promote and protect the public health.

(19) (Subsection added by the General Assembly, 1955) To enforce the public policy of the state of Colorado with reference to the pollution of waters of the state by human excreta as herein expressed:

It is hereby declared that the health, safety and welfare of the inhabitants of the State of Colorado require that the streams, lakes and other waters of the State be kept free of pollution by human wastes, and it is therefore declared to be the public policy of this State that no discharge which contains human excreta shall be permitted to flow in the streams, lakes or other waters of this State, unless such discharge shall comply with all standards of the State Board of Health adopted pursuant to law; and in addition thereto, the number of coliform count in such discharge shall not average more than one thousand per milliliter, such average being based upon a total of not less than four samples taken at the rate of at least one sample per day over a period of four consecutive days, and the methods of examination used to determine such count shall be those set forth in Standard Methods for the Examination of Water and Sewage, Ninth Edition, prepared and published jointly by the American Public Health Association and the American Water Works Association, New York, 1946.

In addition to all other powers, duties and means of enforcement of the above stated standards, it shall be the duty of the Department of Public Health to investigate and determine the facts with reference to the discharge or disposition of sewage or any other matter containing, or having had as a component part thereof, human excreta in any stream, lake or body of water within the State, upon its own initiative or upon the filing with such department of a verified petition as herein provided. Said petition

may be filed with the department by the governing body of any municipality, or any county, or any county or district health department, or any state agency or any twenty-five residents of any county complaining of pollution resulting from any one source which pollution exists in the county of residence of the petitioners, alleging that such discharge or other disposition in such stream, lake or other body of water is in violation of any law or of any rules or regulation of the State Board of Health, and identifying the person, or persons, instrumentalities or agencies responsible for such discharge or other disposition. Such study, investigation or survey may include engineering studies and bacteriological, biological and chemical analyses of the effluent or other matter so discharged or disposed of in said waters to the extent that they may be necessary to determine the facts and to establish ways and means of eliminating such violations of law, rules or regulations as may be found to exist. The director shall, within a reasonable time, make tentative findings in writing which shall set forth the matters investigated and shall specify the violations, if any, found to have occurred, and the extent and degree thereof, together with a tentative determination of the person or persons, instrumentalities or agencies responsible therefor, and also the methods of eliminating the source or cause of the violation. If no violation is found the director shall forthwith order the proceedings dismissed, in which case the petitioners, if any, may have the director's findings and order of dismissal reviewed as provided in

section 66-1-13. If one or more violations are found, said tentative findings shall fix a time and place for a hearing before the State Board of Health which shall be not less than thirty days after issuance and service as herein provided of said tentative findings. A copy of such tentative findings shall be served by registered mail upon each person, agency or instrumentality alleged by said petition or determined by said findings to be responsible therefore and upon at least one of the initiators of the petition, if any; or service may be made in the same manner as is provided by the Rules of Civil Procedure for personal service of process. The hearing by the board shall be held as is provided by section 66-1-8 (8).

66-1-8. POWERS AND DUTIES OF THE STATE BOARD OF HEALTH. In addition to all other powers and duties conferred and imposed upon the State Board of Health by the provisions of this article, the board shall have and exercise the following specific powers and duties:

(5) To hold hearings, administer oaths, subpoena witnesses and take testimony in all matters relating to the exercise and performance of the powers and duties vested in or imposed upon the State Board of Health.

(8) (Subsection added by the General Assembly, 1955). Upon the issuance of a tentative finding as provided by section 66-1-7 (19), the State Board of Health shall, on the day set for hearing by said finding or any day to which the same may be continued, proceed to hear the matter. The Board shall afford a fair and full opportunity to all parties in .

interest to be heard in person or by counsel as to the correctness of the tentative findings of the director, and said board shall then make its findings. If the board finds that the tentative findings of the director with respect to any violation of law or of the rules and regulations of the board is substantially correct, and if the person, persons, agencies or instrumentalities responsible for such violations have been before the board, then the board shall direct such person, persons, agencies or instrumentalities to abate the violations. If, however, it appears that the person, persons, agencies or instrumentalities responsible for the violations have not been before the board, then the hearing shall be continued until such time as jurisdiction over such parties is acquired by service upon them in the manner provided in section 66-1-7 (19) of a copy of the director's tentative findings and of the board's determination that the presence of such person, persons, agencies or instrumentalities is necessary to a complete determination of the procedure. Every such person, persons, agencies or instrumentalities shall be given full and fair opportunity to be heard, and the hearing to which the proceeding shall be continued shall be de novo, unless the new party or parties, having been properly served shall fail to appear.

A copy of the decision of the board shall be promptly served upon each party in interest by registered mail and shall set forth a reasonable

time as determined by the board for the abatement of any violations found to exist, which reasonable time may at the discretion of the board be extended from time to time for good cause shown by the party responsible for such abatement.

All findings of violations, and orders for abatement thereof, must be made by a vote of a majority of the members of the State Board of Health. All such decisions of the board shall be subject to judicial review as provided in section 66-1-13, and all orders of the board issued hereunder may be enforced as any other standard rule, regulations or order of the board.

66-1-13. JUDICIAL REVIEW OF DECISIONS. Any person aggrieved by a decision of the board or the director and affected thereby shall be entitled to judicial review by filing in the district court of the county of his residence, or of the city and county of Denver, within ninety days after the public announcement of the decision, and appropriate action requesting such review. The court may make any interested person a party to the action. The review shall be conducted by the court without a jury and shall be confined to the record, if a complete record is presented, except that in cases of alleged irregularities in the record or in the procedure before the board or the division of administration, testimony may be taken in the court. The court may affirm the decision or may reverse or modify it if the substantial rights of the appellant have been prejudiced

as a result of the findings and decisions of the board being:

(1) Contrary to constitutional rights or privileges; or

(2) In excess of the statutory authority or jurisdiction of the board or the director, or affected by any error of law; or

(3) Made or promulgated upon unlawful procedure; or

(4) Unsupported by substantial evidence in view of the entire record as submitted; or

(5) Arbitrary or capricious.

Any party may have a review of the final judgement or decision of the district court by writ of error to the supreme court.

Compiled 1955

January 14, 1957

COLORADO STATE DEPARTMENT OF PUBLIC HEALTH

DIVISION OF SANITATION

Sewage and Trade Wastes Effluent Regulations

Under authority contained in Chapter 66-1-7 (5), Colorado Revised Statutes 1953, the following regulations are established governing the minimum quality of the effluents of sewerage systems and trade wastes discharged upon the land or into the surface or ground-waters.

1. The following definitions shall apply to terms used in these regulations:

A. Effluent of Sewerage Systems means any liquid containing toxic substances or suspended, floating, or dissolved matter discharged upon the land or into the surface or ground-waters.

B. Trade Wastes means any liquid containing toxic substances or suspended, floating, or dissolved matter originating from industrial processes as distinct from domestic or sanitary sewage and discharged upon the land or into the surface or ground-waters.

C. Matter means chemical substances of animal or vegetable origin.

D. Discharged upon the land is not to be considered as applying to land used as part of a special disposal process for the purpose of eliminating trade wastes and effluent from sewerage systems.

2. The effluent of sewerage systems or trade wastes shall not contain substances in quantities toxic to man.

3. No floating matter shall be discharged in the effluent of sewerage systems or trade wastes.

4. The effluent of sewerage systems and trade wastes shall not contain settleable matter exceeding five-tenths (0.5) milliliter per liter.

5. The effluent of sewerage systems and trade wastes shall not contain suspended matter exceeding seventy-five (75) parts per million.

6. That portion of domestic sewage or industrial waste that is dissolved or suspended in the effluent of sewerage systems or trade wastes shall not exceed fifty (50) parts per million when measured in terms of five-day, twenty-degree Centigrade, Biochemical Oxygen Demand (5-day, 20°C BOD) in any case. However, if the effluent of sewerage systems or trade wastes are discharged into a water course used downstream in Colorado as a surface source of public domestic water supply, the dissolved or suspended matter shall not exceed thirty (30) parts per million when measured in terms of five-day twenty-degree Centigrade, Biochemical Oxygen Demand.

7. Methods used in determining compliance with these standards shall be in accordance with Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, 10th Edition. Such determinations shall be based on the average of results during the period under study and in all cases shall consist of at least four (4) samples taken at intervals of at least one hour.

8. Regulations 1 through 7 shall apply immediately to all new construction, including that financed under Public Law 660, and to effluents of sewerage systems and trade wastes discharged upstream of sources of domestic public water supply; for other municipalities, sanitation districts and industries time for compliance with these standards is extended until January 1, 1958.

Adopted by the State Board of Health, January 14, 1957.

Reference: Chap. 66-1-7 (5) CRS 53 - Effluent Regulations and Enforcement.
Chap. 66-1-7 (19) CRS 53 Amended - 1,000 Coliform Organisms per Milliliter Maximum Allowable in Effluent.
Chap. 40-12-22 CRS 53 - Polluting Streams - Penalty.
Chap. 40-12-23 CRS 53 - Unlawful to Flow Oil into Streams - Penalty.