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BUREAU OF RECLAMATION

Project Effect on South Platte River Pollution

by C. T. CARNAHAN

Denver, Colorado
September, 1949 25 cents

United States Department of the Interior

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Bureau of Reclamation

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Engineering Monographs

No. 4

Project Effect on

South Platte River Pollution

This monograph is an adaptation of a report prepared by C. T. Carnahan, Public Health Engineer, U. S. Public Health Service, District 8, Denver, Colorado. The original report, which summarized a study made by the U. S. Public Health Service for the Regional Director of the Bureau of Reclamation, Denver, Colorado, was submitted to the Project Engineer, Blue-South Platte Project, in July 1947.

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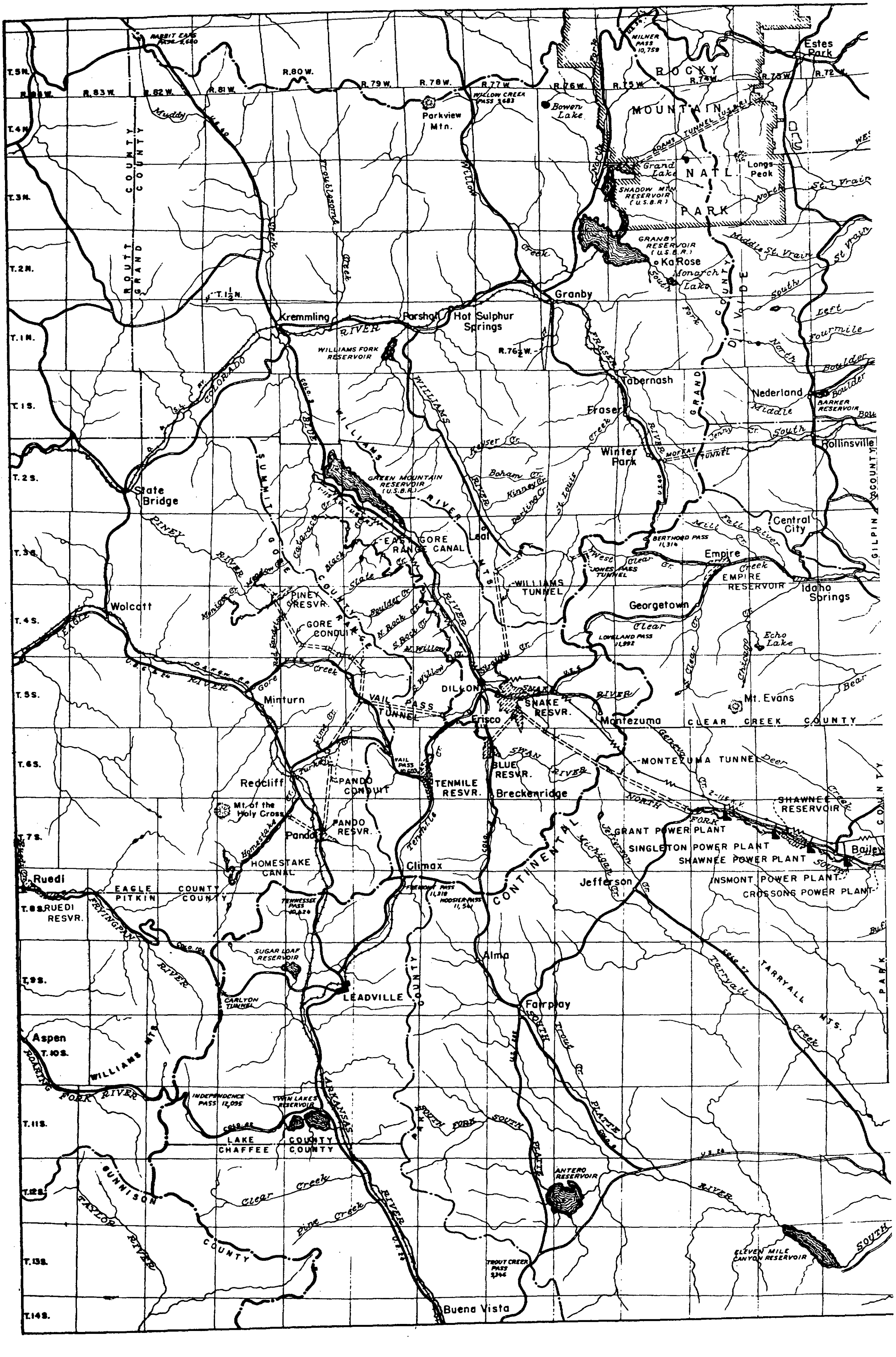
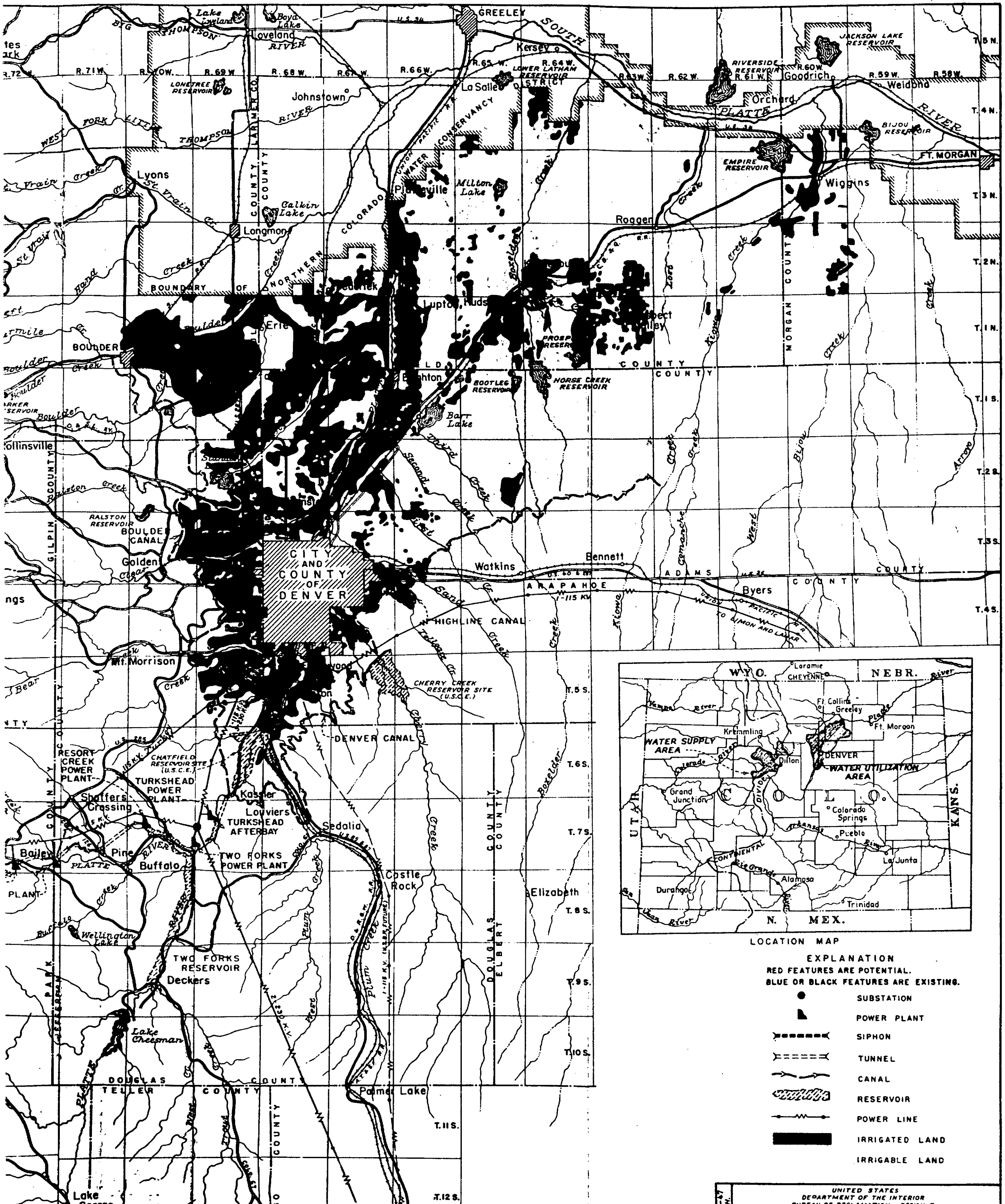
CONTENTS

LIST OF FIGURES



ROCKY MOUNTAIN NATL. PARK
Estes Park
MILNER PASS 10,759
RABBIT EARS PASS 9,680
WILLOW CREEK PASS 9,683
Parkview Mtn.
Bowen Lake
ADAMS TUNNEL (U.S.B.R.)
Grand Lake
Longs Peak
SHADOW MTN. RESERVOIR (U.S.B.R.)
GRANBY RESERVOIR (U.S.B.R.)
Ka Rose
Monarch Lake
Granby
Kremmling
Parshall
Hot Sulphur Springs
WILLIAMS FORK RESERVOIR
ROUTT COUNTY
GRAND COUNTY
Muddy
Troublesome Creek
Willow Creek
COLORADO RIVER
Tabernash
Fraser
Winter Park
Nederland
BARKER RESERVOIR
Rollinsville
MOFFAT TUNNEL
GRAND COUNTY
GILPIN COUNTY
Central City
BERTHOUD PASS 11,314
Empire
EMPIRE RESERVOIR
Idaho Springs
JONES PASS TUNNEL
WILLIAMS TUNNEL
Georgetown
LOVELAND PASS 11,992
Echo Lake
Mt. Evans
CLEAR CREEK COUNTY
State Bridge
PINEY RIVER
GREEN MOUNTAIN RESERVOIR (U.S.B.R.)
SUMMIT COUNTY
GORE RANGE
EAST GORE RANGE CANAL
WILLIAMS RIVER
BLUE RIVER
PINEY RESVR.
GORE CONDUIT
Wolcott
EAGLE RIVER
Minturn
VAIL PASS TUNNEL
DILLON
SNAKE RESVR.
SNAKE RIVER
Frisco
Montezuma
MONTEZUMA TUNNEL
Redcliff
PANDO CONDUIT
TENMILE RESVR.
BLUE RESVR.
Breckenridge
SWAN RIVER
SHAWNEE RESERVOIR
Mt. of the Holy Cross
Pando
PANDO RESVR.
HOMESTAKE CANAL
GRANT POWER PLANT
SINGLETON POWER PLANT
SHAWNEE POWER PLANT
INSMONT POWER PLANT
CROSSONS POWER PLANT
Bailey
NORTH FORK
Climax
FREMONT PASS 11,318
HOOSIER PASS 11,541
CONTINENTAL DIVIDE
Jefferson
Ruedi
RUEDI RESVR.
EAGLE COUNTY
PITKIN COUNTY
TENNESSEE PASS 10,424
FRYINGPAN RIVER
SUGAR LOAF RESERVOIR
Alma
LEADVILLE
CARLTON TUNNEL
Fairplay
TARRYALL MTS.
Tarryall Creek
PARK COUNTY
Aspen
WILLIAMS MTS.
ROARING FORK RIVER
INDEPENDENCE PASS 12,095
TWIN LAKES RESERVOIR
ARKANSAS RIVER
SOUTH FORK SOUTH PLATTE
LAKE COUNTY
CHAFFEE COUNTY
GUNNISON COUNTY
TAYLOR RIVER
Clear Creek
Pine Creek
ANTERO RESERVOIR
ELEVEN MILE CANYON RESERVOIR
TROUT CREEK PASS 9,346
Buena Vista



GREELEY
SOUTH PLATTE RIVER
Loveland
BIG THOMPSON RIVER
Kersey
JACKSON LAKE RESERVOIR
RIVERSIDE RESERVOIR
LONETREE RESERVOIR
LOWER LATHAM RESERVOIR
Johnstown
La Salle
Goodrich
Weldona
Orchard
BIJOU RESERVOIR
EMPIRE RESERVOIR
FT. MORGAN
Wiggins
Lyons
St. Vrain Cr.
Longmont
Calkin Lake
Platteville
Milton Lake
Roggen
BOUNDARY OF NORTHERN COLORADO WATER CONSERVANCY DISTRICT
BOULDER
Erie
Collinsville
RALSTON RESERVOIR
BOULDER CANAL
Golden
Brighton
BOOTLEG RESERVOIR
HORSE CREEK RESERVOIR
Barr Lake
CITY AND COUNTY OF DENVER
Watkins
Bennett
Byers
ADAMS COUNTY
ARAPAHOE COUNTY
HIGHLINE CANAL
TO LIMON AND LAMAR
Mt. Morrison
CHERRY CREEK RESERVOIR SITE (U.S.C.E.)
DENVER CANAL
CHATFIELD RESERVOIR SITE (U.S.C.E.)
RESORT CREEK POWER PLANT
TURKSHEAD POWER PLANT
Shaffers Crossing
Kassler
Louviers
TURKSHEAD AFTERBAY
Sedalia
Bailey
Pine
Buffalo
TWO FORKS POWER PLANT
Castle Rock
Elizabeth
Wellington Lake
TWO FORKS RESERVOIR
Deckers
Lake Cheesman
DOUGLAS COUNTY
TELLER COUNTY
ELBERT COUNTY
Palmer Lake
Lake George
EL PASO COUNTY
COLORADO SPRINGS
Manitou
0 4 8 12 16
SCALE OF MILES
WYO.
NEBR.
UTAH
KANS.
N. MEX.
WATER SUPPLY AREA
WATER UTILIZATION AREA
DENVER
Kremmling
Dillon
Grand Junction
Colorado Springs
Pueblo
La Junta
Durango
Alamosa
Trinidad
LOCATION MAP
EXPLANATION
RED FEATURES ARE POTENTIAL.
BLUE OR BLACK FEATURES ARE EXISTING.
SUBSTATION
POWER PLANT
SIPHON
TUNNEL
CANAL
RESERVOIR
POWER LINE
IRRIGATED LAND
IRRIGABLE LAND
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION - REGION 7
GENERAL MAP
BLUE-SOUTH PLATTE PROJECT-COLO
DRAWN: G.W.H.
TRACED: G.W.H.
SUBMITTED:
RECOMMENDED:
APPROVED:
8A.1-1
DENVER, COLORADO. OCT. 1, 1946

INTRODUCTION

The Blue-South Platte Project is now being studied by the Bureau of Reclamation as an important addition to the irrigation facilities of the upper South Platte Valley. Among the many benefits which are anticipated from this project will be regulation of flow in the upper South Platte River, which should result in simplification of the pollution problems existing along that river. In the area under consideration, metropolitan Denver contributes the largest volume of wastes to the South Platte River. This analysis is an attempt to evaluate possible benefits in regard to the pollution problem in the South Platte River below Denver which may be ascribed to operation of the Blue-South Platte Project in the year 2000.

In the absence of factual data concerning actual conditions which will exist in the river below Denver in the year 2000, the problem is approached from an entirely theoretical standpoint. Assumptions made are based upon the best available current data concerning population estimates, pollutional loadings, sewage disposal practices, stream flows, and behavior of polluted waters during their natural recovery period as determined by the oxidation-reaeration relationships. The results obtained from such treatment of this problem are, of course, only the roughest of approximations and can by no means be taken as an accurate statement of the actual stream conditions to be expected some fifty years hence. There are far too many variable factors entering the problem to permit an accurate solution by any rigid mathematical treatment. However, with limitation, the results obtained herein may be considered as an indication of what might be expected under the assumptions made. By assuming standard conditions with and without operation of the proposed Blue-South Platte Project, a comparison may be made which will evaluate probable future effects of the project's operation upon the South Platte River below Denver.

This monograph includes a brief discussion of the status and application of sanitary quality requirements and standards for irrigation water, which at the present, are the subject of considerable controversy. As yet there are insufficient data upon which to base adequate standards for measuring the sanitary quality of irrigation water.

DESCRIPTION OF THE BLUE-SOUTH PLATTE PROJECT

As is shown in the frontispiece, the western slope portion of the Blue-South Platte Project, with its system of dams, reservoirs, canals, conduits, and tunnels for collecting, storing, and conveying waters, covers an area of nearly 800 square miles and covers parts of the drainage areas of the Frying Pan, Eagle, Piney, Tenmile, Blue, Snake, and Williams Rivers. A replacement reservoir located on the Frying Pan River near Ruedi, outside the water supply area proper, is part of the project.

The agricultural region to be served by the project extends over the upper South Platte River drainage area, a region 60 miles long and 30 miles wide on the eastern slope of the Divide. Eastern slope features include reservoirs, conduits, canals, power plants, and appurtenant works to supply water for irrigation, municipal, power, and other purposes. Water will be supplied for the irrigation of 97,000 acres of additional land and to supplement the irrigation of 279,000 acres of land presently irrigated but subject to seasonal water shortages. In addition, the project will provide:

(1) Additional water for municipal needs.
(2) Additional electrical power for domestic, commercial, and industrial use from the power plants contemplated for the project.
(3) Additional recreational facilities and fish and wildlife conservation.

The scope of the project precludes the concurrent construction of all features. Plans call for construction by progressive stages, which will provide for the maximum utilization of the water resources and the attainment of maximum benefits at minimum costs.

POLLUTION IN THE UPPER SOUTH PLATTE RIVER

Since there is now no other source of water of sufficient quantity for irrigation below Denver except that which contains reclaimed sewage from the city of Denver, any abatement of pollution, which will result from regulated stream flows made possible by the proposed Blue-South Platte Project, will contribute to the general welfare of the entire community. Both raw and treated sewage from other communities on the upper South Platte and its tributary streams contribute to the problem of sewage pollution of waters used for irrigation on the project. However, the amounts of such pollution are small in comparison with that contributed by Denver. Appendix C shows the type of sewage treatment, or method of disposal used by communities in the vicinity of Denver.

An interesting relationship between the volume of flow of the South Platte River at Denver and the volume of sewage contributed thereto by the city of Denver may be noted from a study of the several tables of Appendix B. Table I, Appendix B, is a record of discharge of the South Platte River at Denver, while Table II is a record of the annual discharge of sanitary sewage from Denver during the period 1927-1946. The 20-year average of sewage discharge is 0.1442 acre-feet per capita per year or 129 gallons per capita per day. Table III, Appendix B, shows the actual Denver sewage flow by months for 1945, and the estimated flow for the year 2000 based upon estimated populations of 700,000 without the Blue-South Platte Project and 1,000,000 with the Blue-South Platte Project. Table IV of Appendix B which shows as percentages the proportion of Denver sewage in relation to the total flow of the South Platte River below Denver in 1945 and A. D. 2000 (estimated), was compiled on the basis of the figures from Tables I and II. Particular attention is invited to the headings at the top of Table IV which indicate the various assumed conditions to which data shown pertain.

A study of Table IV, Appendix B, discloses that, during times of low flow in 1945, the sewage content of the South Platte below Denver varied from approximately 30 to 70 percent. Nearly half the runoff for July and August consisted of reclaimed sewage. With the Blue-South Platte Project in operation, minimum estimated flow will have a more uniform sewage content on a year-round basis, varying from 50 to 60 percent. Under maximum actual flow conditions in 1945, Denver sewage comprised 2 to 20 percent of the total flow below Denver. By the year 2000, without construction of the Blue-South Platte Project, these percentages should increase to about 3 to 25 percent. With the project in operation in the year 2000, and with estimated maximum regulated flows, Denver sewage should comprise 5 to 30 percent of the flow of the South Platte below the city. Under average runoff conditions, it is estimated that Denver sewage presently comprises from 9 to 40 percent of the stream flow below the city. Estimated contribution of sewage for the year 2000, under average stream flow conditions, should result in percentages of sewage ranging from approximately 15 to 53 percent without the project, and from 17 to 52 percent with the project in operation.

With Denver contributing such a large volume of sewage to the water used for irrigation below the city, Denver should have an efficient sewage treatment process if the public health is to be safeguarded. It does not appear that operation of the Blue-South Platte Project will provide increased dilution under average or maximum stream flow conditions, but it should be of considerable benefit at times of extreme low flow, since at such times it should result in approximately 20 percent additional dilution. Under such conditions, esthetic considerations alone would require that effluent discharged into the stream be of good sanitary quality.

Where a stream is utilized as a source of domestic water supply or for irrigation, a high degree of treatment of any sewage discharged into the stream may be necessary for the protection of the public health. Raw sewage contains disease-laden human excreta and organic waste materials. The organisms causing typhoid, paratyphoid, dysentery, cholera, and infantile paralysis, as well as intestinal parasites of various kinds, are often present in raw sewage. Since some organisms, such as those causing amoebic dysentery and poliomyelitis, are quite resistant to usual treatment processes, possibility of the spread of these diseases is present wherever raw or only partially treated sewage is discharged into streams utilized for domestic water supplies or for irrigation of vegetables.

It is suspected that the relatively high rate of recurrent "summer complaints," or diarrhea, in some western states may be due to the eating of vegetables which have been irrigated with sewage-polluted water. However, such incidents are difficult to trace because much of the illness of this type is unreported unless it reaches epidemic proportions. Many cases are never seen by a physician, since they are self-limiting, and recovery often occurs after one to three days. Outbreaks of gastroenteritis resulting from water-borne organisms are not uncommon.

A typhoid, diarrhea, and enteritis rate above average was recently reported for Denver in a survey of sanitation for that city (McGavran Survey, 1947). It would be interesting if a study could be made of the frequency and location of those cases of illness in their relation to the consumption of vegetables from farms using sewage-polluted waters from the South Platte River for irrigation.

STANDARDS OF WATER QUALITY

The question of standards of quality for water used for various purposes has been the subject of much controversy. The rights of riparian owners are governing factors in many cases. These rights have been defined by common law and by numerous and varied state laws and court decisions. Since there are laws in some states concerning stream pollution, much litigation has resulted from the pollution of streams by sewage and by industrial and other wastes.

Domestic Water Supplies

In 1914, the United States Public Health Service, under authority of the Interstate Quarantine Laws, established standards of quality applicable to drinking water used in interstate traffic. Since that time the various editions of the U. S. Public Health Service Drinking Water Standards gradually have become the accepted standards for public water supplies throughout the United States. The 1946 standards[1] were adopted by the American Water Works Association for all public water supplies.

Several years ago the Public Health Service made an exhaustive study of the limiting coliform[2] densities of waters to which various methods of treatment should be applied so as to produce a treated water satisfying the U. S. Public Health Service Drinking Water Standards, 1925 edition. The results of this study[3] are summarized as follows:

Relative fitness	Limiting average monthly coliform density in most probable numbers per 100 milliliters
For purification by simple chlorination only	0 to 50
For purification by filtration and post-chlorination	51 to 5,000
For purification by auxiliary treatment in addition to complete filtration and post-chlorination (unsuitable if coliform numbers are greater than 20,000 in more than 5 percent of samples)	5,001 to 20,000
Unfit for treatment	over 20,000

1 "Public Health Service Drinking Water Standards," 1946, Public Health Reports, Vol. 61, No. 11, March 15, 1946, pp. 371-384.

Waters from the western slope should fall within the first of the above groups. In any event, waters of the Blue-South Platte Project should be amenable to treatment by filtration and post-chlorination.

In the Ohio River Pollution Control Report[4] there is a discussion on water quality standards covering various water uses. These standards were conceived as applying to the Ohio River Basin and should not be arbitrarily applied to other streams. Each stream should be reviewed in the light of its own biological characteristics. However, these standards can well serve as a guide for establishing requirements for different stream uses since they are based upon the best available evidence covering each category. The requirements established in the Ohio River Pollution Control Report are summarized in Appendix D.

Irrigation Water

There is little information available concerning the degree of pollution which should be allowed in irrigation water. No definite standards are available except those established by various state health departments. In this regard, California laws are the most explicit. Colorado restrictions are covered under Rule 20 of "Regulations Relating to Sanitary Engineering, Public Water Supplies, Water Purification Plants, Sewer Systems, and Sewage Treatment Plants."[5] This regulation states in part as follows:

> "Rule 20. Irrigation with sewage or sewage-laden water. No domestic sewage nor water containing domestic sewage in amount and condition such

2 Coliforms are defined "to include all aerobic and facultative anaerobic Gram-negative non-spore-forming bacilli which ferment lactose with gas formation." (These organisms are considered to be of intestinal origin.) Standard Methods for the Examination of Water and Sewage, 9th ed., American Public Health Assn. and American Water Works Assn., 1946, p. 193.

3 Public Health Bulletins Nos. 172, 1927, and 193, 1930, U. S. Public Health Service, Washington, D. C.

4 Ohio River Pollution Control Report, House Document No. 266, 78th Congress, First Session, Table 4, p. 177.

5 Colorado State Division of Public Health Laws, Rules and Regulations (Revised 1942), Colorado State Board of Health, Denver, Colo., p. 164.

that bacteria of the coli-aerogenes group[6] are present in quantities of ten or more per cubic centimeter, shall be used to irrigate or be permitted to overflow any fruits or vegetables for human consumption, the edible portions of which grow in the ground or above it within one foot of the surface, except with the written permission of the State Board of Health obtained as hereinafter provided.

. . . .

"Upon receipt of a request, in writing, for permission to use sewage or sewage-laden water contrary to the above stipulations, claiming that the conditions of the particular case are such as to prevent any reasonable possibility of impairing the public health and stating full details upon which this claim is based, the State Board of Health will make an investigation and determine whether or not such use should be permitted, following which, its approval will be given or denied."

Under the above regulation, the limiting value for the coliform content of sewage or sewage-laden water used for irrigation is 1,000 per 100 milliliters, which is comparable to the upper limits recommended for water used for natural bathing purposes.[7]

The Final Report of the Joint Committee of the Sanitary Engineering Division and the Irrigation Division of the American Society of Civil Engineers on the Salvage of Sewage[8] states:

"At a given time sewage may or may not contain pathogenic organisms. 'In case of illness, particularly in epidemic form, among the inhabitants contributing to the (sewage) flow, (there may be contained)...large quantities of such organisms not otherwise disposed of by direction of the public health authorities.'* The ever-present possibility of such occurrence is considered by health authorities to render untreated sewage a potential source of infection. It is appreciated that raw sewage has been used for irrigation for many years, in many places, both in the United States and abroad, and that evidence of ill results is generally absent or not conclusive. Nevertheless, the hazard exists, and its perpetuation is not in the public interest.*

. . . .

"There seems little doubt that the presence of pathogenic bacteria will persist in raw sewage, or ground contaminated therewith, for many days,** and that under the circumstances there is danger of the spread of contamination through the use of vegetables grown under such conditions, particularly if eaten raw. It has been reasonably well determined, however, that water of such purity and freedom from bacterial contamination may be reclaimed from sewage as to be fairly safe for use in irrigation; and it is also demonstrable that sewage sludge undergoing digestion for a period of ten days or more is quite free of pathogenic bacteria causing intestinal diseases, although the cyst of the amoeba has been discovered in well-digested sludge.***

. . . .

"Thus it would appear that, except for use upon vegetables or fruits to be eaten raw, an effluent from about the treatment afforded by subsidence, trickling filters, and secondary subsidence effecting about 85% reduction in bio-chemical oxygen demand (B.O.D.) and suspended solids, followed by chlorination, should satisfy health requirements, and that the use of reclaimed water for irrigation of growing crops--as well as of processed sewage solids as fertilizer--may not be ruled out on strictly public health grounds."

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* Hutchins, Wells, A., "Sewage Irrigation as Practiced in the Western States," Technical Bulletin No. 675, U.S.D.A. 1939, p. 30.

** Tanner, Fred W., "Public Health Significance of Sewage Sludge When Used as a Fertilizer," Sewage Works Journal, Vol. 7, 1935, p. 611.

*** Wolman, Abel, "Hygienic Aspects of Use of Sewage Sludge as Fertilizer," Engineering News-Record, Vol. 92, 1924, p. 198.

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6 Organisms of presumably intestinal origin. Same as coliform group as defined in footnote 2.

7 "Recommended Practice for Design, Equipment, and Operation of Swimming Pools and other Public Bathing Places," American Public Health Association, 1942.

8 Transactions, A.S.C.E., Vol. 107, 1942, pp. 1658-1659.

The question of bacteriological standards for irrigation water remains unsettled and is the source of much controversy as to practical limiting values. No such exhaustive studies as were made on drinking water standards have been undertaken for irrigation water although many studies have been reported on the chemical quality of good irrigation water. Investigation concerning the bacterial quality of irrigation water is a basic need, especially in those areas with limited water resources where streams are used for sewage disposal and the sewage-laden water then used for irrigation.

The above-mentioned report on salvage of sewage[9] states on this point as follows:

> "From the standpoint of existing facts, it would appear that bacteriological standards for irrigation waters to be used without restriction might be drawn without reference to those (Standards--Ed.) of drinking water, and that sewage effluents from about the quality of treatment imposed to reduce the biochemical oxygen demand and suspended solids from 85%, followed by chlorination to a residual, should be adequate although esthetic considerations might reject this view. It should also be clear, that sewage effluent need not be ruled out of the irr'gation scheme because of its bacterial content when the latter has been substantially reduced from that of raw sewage."

In the summation of the section of the same report[10] on the use of reclaimed sewage water for irrigation, it is stated as follows:

> " ... Incentives for irrigation with sewage are almost totally lacking in western United States because of the high relative cost of reclamation of sewage water and the relatively insignificant acreage which may be reclaimed. Furthermore, the attitude of the public toward sewage irrigation, particularly with respect to the esthetic considerations involved, tends to exclude sewage irrigated crops from competition with those raised with fresh water ... "

[9] Ibid., p. 1661.

[10] Ibid., pp. 1664-1665.

As a related item of interest, it recently has been noted[11] that the new Riverside, California, sewage disposal plant is to treat sewage sufficiently to permit use of its effluent as irrigation water and its digested solids as fertilizer. The Riverside plant consists of the following treatment process: coarse screening, grit removal, chemical precipitation, flocculation, primary sedimentation, trickling filtration, secondary sedimentation, post-chlorination, two-stage sludge digestion, air drying of sludge, and gas recovery for heating. Plant capacity is 5 mgd average and 8 mgd maximum. The effluent from this plant is to be sold to farmers for irrigation purposes, while the dried sludge is to be sold for fertilizing citrus groves.

CONDITIONS OF STREAM RECOVERY

The tendency of a stream to purify itself is dependent upon certain biological activity which results in the decay or reduction of the organic materials contained in the water. This process of reduction involves the utilization as food of the organic material present by several separate groups of bacteria living in the water. As the organic material is used for food by successive groups of these bacteria, it is reduced in form and character to simple basic inorganic compounds which are inoffensive and relatively harmless. This bacterial activity may occur under either of two extreme conditions involving the amount of oxygen present, or under any of the many possible intermediate conditions which may exist between these two extremes. Under one extreme condition, there is adequate dissolved oxygen present. Changes occurring under such a condition are said to be aerobic, that is, the result of action by aerobic bacteria. Under the other extreme condition, there is an absence of dissolved oxygen. Changes occurring under this condition are said to be anaerobic, that is, the result of action by anaerobic bacteria. Changes which occur under the intermediate conditions mentioned are usually the result of action by facultative bacteria which can work with or without oxygen.

Aerobic decomposition normally occurs in streams where the discharge of sewage or other organic wastes is not sufficient in quantity or strength to result in the depletion of the oxygen in the stream, and in those sewage or waste treatment processes in which, either by natural or mechanical

[11] Jackson, L. W., "Sewage Plant Sells Sludge and Effluent," Engineering News-Record, Vol. 139, July 10, 1947, p. 122.

means, there is maintained sufficient atmospheric oxygen. The aerobic processes consist essentially of oxidation and reduction, the end products of which are such simple compounds as carbon dioxide, water, nitrites, and nitrates. No nuisance or obnoxious products are formed during active aerobic decomposition.

Anaerobic decomposition normally occurs in streams where sewage or other organic waste is present in quantity or strength sufficient to result in the depletion of the dissolved oxygen in the stream. Anaerobic decomposition occurs in sewage or waste treatment processes in which, by design or otherwise, oxygen is excluded from the substance being treated. Anaerobic decomposition occurs in the bottoms of septic tanks and in sludge digesters. The anaerobic processes consist essentially of fermentation and putrefaction, the end products of which are organic acids, methane, carbon dioxide, hydrogen sulphide, ammonia, mercaptans, and allied substances which usually have extremely offensive odors.

Naturally, streams subjected to heavy organic pollution become quite offensive when their dissolved oxygen is depleted and anaerobic decomposition occurs. However, such streams will recover from the effects of anaerobic decomposition when the rate of absorption of oxygen from the atmosphere exceeds the demands of the decomposition processes and aerobic conditions are reestablished. The rate at which this recovery occurs, or the rate at which oxygen is absorbed, varies greatly in accordance with many factors, such as the type of flow, the degree and type of pollution, flow time, temperature, additional dilution or pollution from tributary streams, and the presence of dams or other obstructions.

Since the presence of dissolved oxygen in sufficient quantity to support aerobic decomposition determines whether nuisance conditions will prevail in a polluted stream, it is important to maintain adequate dissolved oxygen by every possible means. Where dilution is not sufficient to furnish enough dissolved oxygen to maintain aerobic activities, the organic content of the wastes discharged into the stream should be reduced by treatment processes to a point where its presence will not result in the depletion of what oxygen is present and the establishment of anaerobic decomposition.

EFFECT OF REAERATION ON OXYGEN DEFICIENCY

To determine the probable effect that full operation of the Blue-South Platte Project may be expected to have upon the stream pollution conditions below Denver, we shall consider the theoretical oxygen depletion occurring in the South Platte River below the city. Such a consideration will be based upon the mathematical approach to the problems of the biochemical oxygen demand (B. O. D.) of polluted waters and of atmospheric reaeration of streams which has been developed by Streeter, Phelps, Theriault, and others of the United States Public Health Service.[12]

When decomposable waste matters are discharged into a stream, dissolved oxygen in the stream is used in satisfying the B. O. D. of those wastes. The result is a deficiency of dissolved oxygen in the stream. This dissolved oxygen deficit is then replaced by the process of atmospheric reaeration at a rate proportional to the deficit created.

The Oxygen Sag Curve

A graphical representation of the effect which reaeration has upon oxygen deficiency is shown by the "dissolved oxygen sag curve," which is obtained by plotting oxygen deficiency in ppm on rectangular coordinates against time of stream flow in days. Figure 1 shows a typical oxygen sag curve. Attention is invited to the typical spoon-shaped profile which results when coordinate scales are arranged as shown. There are two points on this curve which are of particular interest to the investigator, the critical point of maximum deficit and the point of maximum rate of recovery. Both of these points are important, since they show the degree and the extent of the pollution and the point beyond which, barring additional pollution, recovery may be expected to continue to normal stream conditions. For the derivation of the equation for the sag curve developed by Streeter and Phelps, see Appendix A.

To develop approximate theoretical sag curves for the South Platte River below Denver, assuming conditions with and without operation of the Blue-South Platte Project, it is necessary to estimate the pollution load to be carried by the stream.

A number of studies have shown that, for United States sewage, the average contribution of B. O. D. is approximately 0.25

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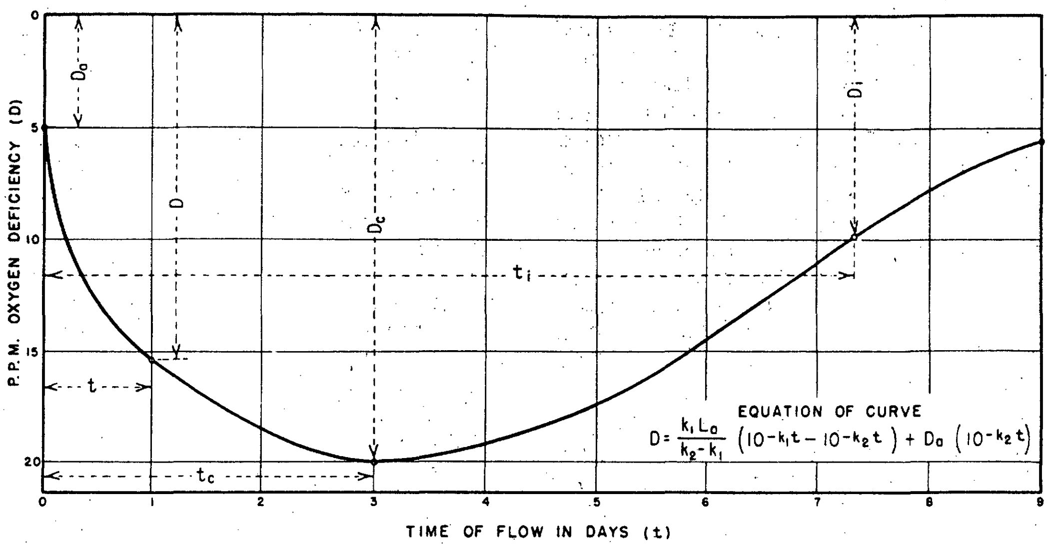
12 Public Health Bulletins 146, 1925, and 173, 1927, U. S. Public Health Service, Washington, D. C.



D_a = Initial dissolved oxygen deficit at zero flow time.
D = Dissolved oxygen deficit at any time, t.
D_c = Maximum or critical oxygen deficit at lowest point at time, t_c.
D_i = Oxygen deficit at point of inflection. (Max. recovery rate)
L_a = B.O.D. at initial or reference point.
k_1 = Deoxygenation constant.
k_2 = Reaeration constant.

For derivation of equation of curve and further explanation of oxygen sag curves refer to Appendix A.

TYPICAL OXYGEN SAG CURVE

FIGURE 1

pounds per capita per day.[13] For convenience in the calculations, the following relations[14] may be noted:

"1 c.f.s. = 86,400 cu. ft. per day
= 5,400,000 lb. per day
1 p.p.m. in that flow = 5.4 lb. per day
Hence, p.p.m. x c.f.s. x 5.4 = lb. per day
Conversely, lb. per day ÷ 5.4 ÷ c.f.s. = p.p.m."

The temperature relationships in the stream are important factors. The saturation point for dissolved oxygen decreases with increase in temperature while the rate at which the B.O.D. of the wastes is satisfied increases with increased temperatures. Critical conditions may be expected, therefore, when stream flows are lowest and temperatures are highest.

A review of the reports of the Board of Water Commissioners, Denver, Colorado, from 1940 to 1946 shows that minimum raw water temperatures usually occur in February and maximum temperatures in August. Temperature ranges are from maximums of approximately 20° C to minimums of approximately 5.0° C. At these temperatures, the saturation level of dissolved oxygen[15] is 9.17 ppm and 12.80 ppm, respectively (neglecting effect of altitude which reduces the amount of oxygen available at saturation level), and the value of the deoxygenation constant k_1 (see Figure 1) is 0.1 and 0.0502, respectively.[16]

Actual stream flow records are available for the South Platte at Denver for the period 1910 to 1944 as shown in Table I(a), Appendix B. These flow records have been modified to show the 1910 to 1944 discharges as they would have been had the Blue-South Platte Project been in operation during that time. These modified discharges are also shown in Table I(b), Appendix B. The actual flow records show that the minimum flows in the South Platte occur during the winter months while the maximum flows occur during the spring runoff in April, May, and June. The minimum recorded runoff for

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13 Phelps, E. B., Stream Sanitation; John Wiley and Sons, 1944, p. 137.

14 Ibid., p. 138.

15 Op. cit., A.P.H.A. and A.W.W.A., Table 14, p. 137.

16 Public Health Bulletin 173, 1927, U. S. Public Health Service, Washington, D. C. [$k_t = K_{20} \times 1.047^{(T-20)}$]

August is nearly six times that recorded for February. This is advantageous because the critical low flows occur when the oxygen content of the water is normally high, and the biochemical oxidation rate is lowest. This neglects any consideration of ice conditions which may have a serious effect on reaëration by preventing contact between the water surface and the atmosphere. Conversely, when the biochemical oxidation rate has doubled, the stream flow is much increased and its oxygen resources are accordingly two and one-half to four times greater than during minimum flow.

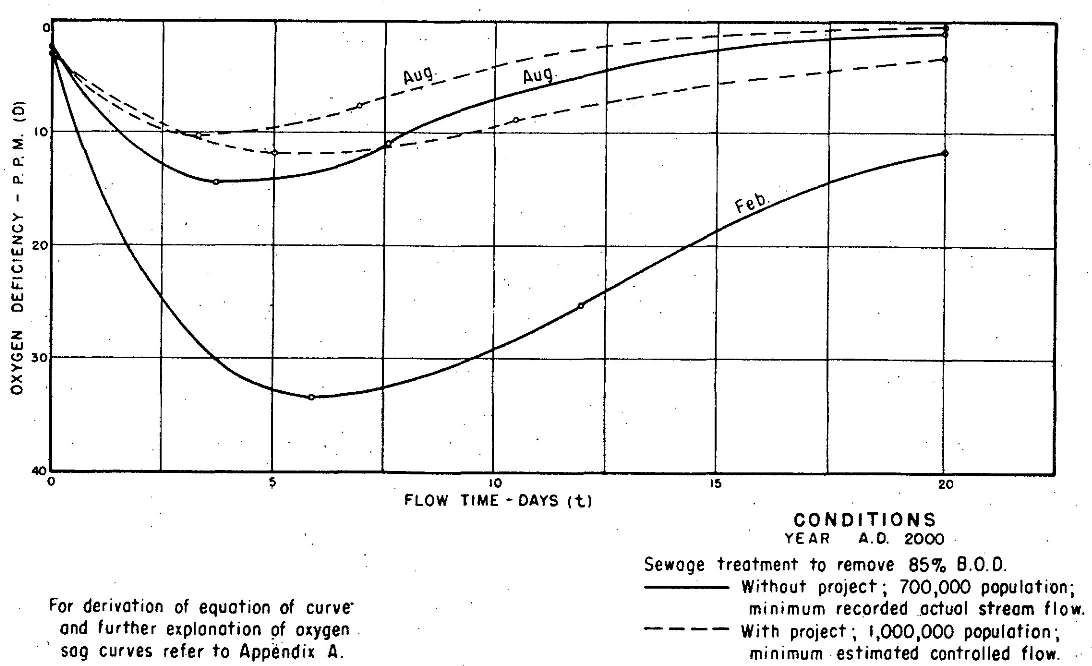
With the Blue-South Platte Project in operation, the minimum February flow should be approximately four times the recorded minimum, while the August minimum should be approximately twice the recorded minimum for that month. The oxygen resources of the stream during low runoff periods would be increased accordingly. There should be less difference between the minimum flows occurring in February and August. By flow regulation from storage, the February maximum controlled flow should exceed the past recorded February maximum by about 40 percent, while August maximum controlled flow should be reduced below the past recorded August maximum by about 20 percent.

Theoretical oxygen sag curves for the Blue-South Platte Project flow below Denver, which have been computed by means of Fair's formulas (Appendix A) for several hypothetical conditions, are shown in Figures 2 and 3.

It should be kept in mind that the theoretical sag curves shown in Figures 2 and 3 are approximations only and are for purposes of comparison on such basis. They do not show actual conditions below Denver. Actual conditions can be shown only after a comprehensive stream pollution survey has been made. A rigid mathematical treatment is not possible without much more comprehensive data on all the factors involved in this problem than are now available. It is assumed that all the sewage reaching the stream remains in suspension and decomposes aerobically in accordance with the normal laws of biochemical oxidation. The formation of sludge beds in the stream or establishment of anaerobic decomposition would modify the conditions greatly. Also, no account is taken of the effect of additional pollution or dilution by tributaries or return irrigation flows below the major source of pollution. The effects of ice coverage during winter are not considered. All such factors have a great bearing on the problem. Their effects can be ascertained only after a comprehensive stream survey and collection of adequate engineering and laboratory data.

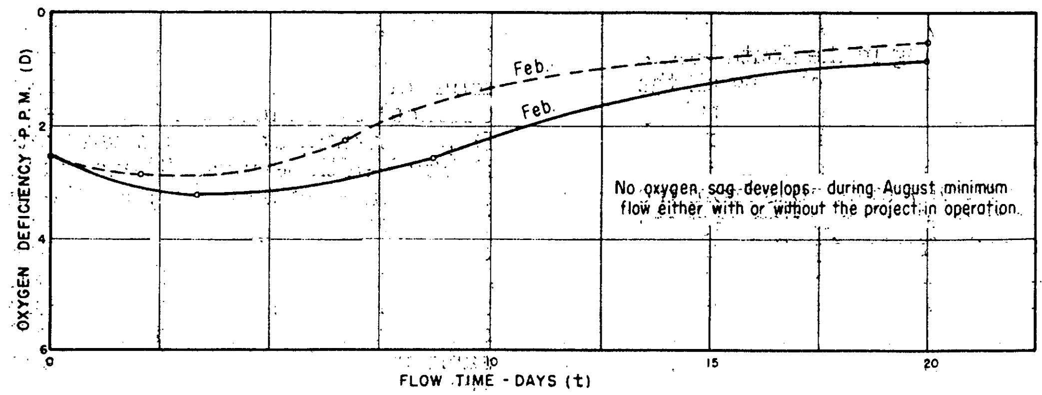
<u>Minimum Flow Conditions--A. D. 2000</u>

Figure 2 is an oxygen sag curve for



OXYGEN SAG CURVES FOR MINIMUM FLOW IN YEAR A.D. 2000

FIGURE 2



CONDITIONS
YEAR A.D. 2000
Sewage treatment to remove 85% B.O.D.
——— Without project; 700,000 population; maximum recorded actual stream flow.
– – – With project; 1,000,000 population; maximum estimated controlled flow.

For derivation of equation of curve and further explanation of oxygen sag curves refer to Appendix A.

OXYGEN SAG CURVES FOR MAXIMUM FLOW IN YEAR A.D. 2000

FIGURE 3

the South Platte River below Denver which might be expected under the indicated conditions assumed to exist in the year 2000 for minimum flow both with and without operation of the Blue-South Platte Project.

Without the project in operation, critical conditions should occur in February when stream flows are a minimum. Oxygen requirements will far exceed the stream's resources, and anaerobic decomposition should prevail for a considerable distance below the city, even with sewage treatment to remove 85 percent of the initial B. O. D. August minimum flow should also produce anaerobic conditions in the stream, but recovery should be faster because of the more rapid rate of biological activity and more active reaeration during turbulent stream flow.

With the Blue-South Platte Project in operation and stream flow regulated, critical conditions should prevail in August when an oxygen deficiency would bring about anaerobic conditions for a short time. However, recovery should be fairly rapid even though the organic load placed upon the river might be greater because of the estimated increase in population growth brought about by the project. It would seem, therefore, that the project should result in direct benefits upon the sewage disposal problem at Denver during extreme low flow conditions some fifty years from now.

Maximum Flow Conditions--A. D. 2000

Figure 3 is a comparison of the oxygen sag curves to be expected under indicated assumed conditions in the year 2000 for maximum flow conditions both with and without operation of the Blue-South Platte Project. No nuisance conditions should prevail under these conditions, provided sewage treatment removes 85 percent of the B. O. D. A slight oxygen sag should develop during February under low temperature conditions. Under maximum flow conditions during August, no oxygen sag should occur.

CONCLUSIONS

It would seem from consideration of the analysis presented herein that:

(1) Denver will be required to install a highly efficient sewage treatment process if nuisance conditions are to be prevented in the South Platte River under the extreme low runoff conditions, which occur from December to March.

(2) The operation of the Blue-South Platte Project will probably improve conditions of pollution below Denver during critical low flow periods but not to such an extent as to modify requirements for a high degree of sewage treatment by the city of Denver.

(3) A survey of the actual sanitary conditions existing in the South Platte River and tributaries, including all the necessary engineering and laboratory studies, should be carried out over a period of at least one year. The need for such a survey is obvious from the paucity of factual information regarding the actual effects of pollution upon the sanitary quality of the water of the South Platte River below Denver.

(4) Cooperative studies concerning the sanitary quality of irrigation water should be carried out by the Bureau of Reclamation, the United States Department of Agriculture, the State agricultural agencies, the State Health Departments, and the United States Public Health Service. These studies should have as their purpose the establishment of practical standards of sanitary quality for irrigation water. Such standards should involve relatively simple diagnostic procedures such as are now used to determine the sanitary quality of potable waters and should be equitable and easy to apply under a wide variety of conditions.

APPENDIX A

DERIVATION OF THE EQUATION OF THE OXYGEN SAG CURVE DEVELOPED BY STREETER AND PHELPS[17]

The basic differential equation for the sag curve developed by Streeter and Phelps states, in effect, that the rate of change in the oxygen deficit is equal to the difference between the rate of biochemical oxygen demand and the rate of reaeration, or

$$\frac{dD}{dt} = K_1L - K_2D, \text{ where}$$

- D = oxygen deficit at any point at time of flow "t" following introduction of pollution
- t = time of flow in days below initial point of pollution
- L = biochemical oxygen demand remaining at time "t"
- K_1 = reaction-velocity constant of biochemical oxygen demand
- K_2 = reaction-velocity constant of reaeration

Integration of this equation yields the following expressions for the oxygen sag curve:

$$D = \frac{K_1L_a}{K_2-K_1}\left(e^{-K_1t} - e^{-K_2t}\right) + D_a\left(e^{-K_2t}\right)$$

where

- L_a = biochemical oxygen demand at the reference point or point of pollution
- D_a = dissolved oxygen deficit at point of pollution

Substituting $k_1 = 0.4343\ K_1$ and $k_2 = 0.4343\ K_2$ yields

$$D = \frac{k_1L_a}{k_2-k_1}\left(10^{-k_1t} - 10^{-k_2t}\right)$$

$$+ D_a\left(10^{-k_2t}\right),$$

which merely changes the logarithm base from e to 10, i.e., from napierian to common. Fair[18] has simplified the equations of Streeter and Phelps by introducing a term "f" which he calls a "self-purification constant" and which equals k_2/k_1. He then develops the following useful equations for purposes of analysis of the sag curve:

$$(1)\quad k_1t_c = \left(\frac{1}{f-1}\right)\log_{10}\left(f\left[1 - (f-1)\frac{D_a}{L_a}\right]\right)$$

from which the critical time "t_c" may be computed (Figure 1)

When $f = 1$, $k_1t_c = 0.4343\left(1 - \frac{D_a}{L_a}\right)$

$$(2)\quad D_c = \frac{L_a}{f}\left(10^{-k_1t_c}\right)$$ from which the critical deficit, D_c, may be computed

$$(3)\quad k_1t_i = \left(\frac{1}{f-1}\right)\log_{10}\left(f^2\left[1 - (f-1)\frac{D_a}{L_a}\right]\right)$$

from which the time "t_i" at the point of inflection or maximum rate of recovery may be computed

When $f = 1$, $k_1t_i = 0.4343\left(2 - \frac{D_a}{L_a}\right)$

$$(4)\quad D_i = \left(\frac{f+1}{f^2}\right)L_a10^{-k_1t_i}$$ which will give the value of D_i, the deficit at the point of inflection.

Fair has suggested the following approximate values of "f" based upon the best available information:

Nature of receiving water	Value of "f" at 20° C
a. Small ponds and backwaters	0.5 to 1.0
b. Sluggish streams and large lakes or impounded waters	1.0 to 1.5
c. Large streams of low velocity	1.5 to 2.0
d. Large streams of normal velocity	2.0 to 3.0
e. Swift streams	3.0 to 5.0
f. Rapids and waterfalls	over 5.0

The above values of "f" are for water temperatures of 20° C (68° F).

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17 Public Health Bulletin 146, 1925, U. S. Public Health Service, Washington, D. C.

18 Fair, G. M., "Dissolved Oxygen Sag - An Analysis," Sewage Works Journal, Vol. XI, May 1939, pp. 445-461.

The magnitude of "f" decreases with higher temperatures and increases with lower temperatures at a rate of about 3 percent compounded per degree centigrade.

Temperature						
°F -	41	50	59	68	77	82
°C -	5	10	15	20	25	30

for which the respective values of "f" are: 1.58, 1.35, 1.16, 1.0, 0.859, 0.737.

For other temperatures, the value of "f_t" will have the following relationship:

(5) $f_t = f_{20} \times 0.970^{(T-20)}$

For the purpose of this report, the following values of Fair's self-purification constant (f) were used:

Runoff in cfs	f_{20} August	f_5 February
30 to 120	1.25	1.98
121 to 500	1.50	2.37
501 to 1,000	2.00	3.16
1,000 and over	3.00	4.74

These values were chosen due to the change in character of the stream flow from sluggish to swift with increased runoff.

APPENDIX B

TABLE I(a)

RUNOFF OF SOUTH PLATTE RIVER AT DENVER - Actual Record
1000 A. F. Units

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1910-11	6.8	5.4	5.5	7.6	5.3	5.0	7.3	12.7	20.4	36.6	16.6	7.8	137.0
12	6.4	5.3	6.0	4.3	3.5	5.5	4.7	23.3	52.0	59.7	46.5	16.3	233.5
13	13.7	15.2	11.1	7.4	5.0	5.8	23.8	28.1	41.1	25.0	16.8	14.0	207.0
14	15.4	13.4	15.0	21.0	19.9	31.4	114.2	177.1	116.6	92.2	141.7	25.8	783.7
1914-15	22.8	19.6	15.5	11.6	10.5	15.2	88.1	71.9	72.0	21.7	26.3	22.8	398.0
16	24.6	15.2	14.1	11.3	9.8	11.2	8.6	26.4	30.3	24.4	27.4	13.6	216.9
17	12.6	9.6	9.1	8.5	6.6	8.1	10.5	65.8	105.9	37.1	28.9	14.8	316.5
18	10.0	7.3	8.5	6.5	6.7	6.9	19.0	32.5	59.5	50.3	21.9	19.0	248.1
19	15.4	13.7	11.6	10.1	7.4	9.9	35.5	73.8	52.1	42.0	51.7	23.4	346.6
1919-20	9.2	8.6	9.6	9.0	6.7	6.0	13.9	82.4	31.1	45.5	37.3	18.7	278.0
21	10.0	8.9	9.0	6.2	6.4	8.3	42.7	78.1	229.0	68.9	69.5	24.2	561.2
22	12.1	13.1	12.1	10.4	9.2	9.8	21.5	31.6	33.1	23.1	27.7	12.6	216.3
23	10.1	8.8	11.6	8.9	8.4	8.8	8.6	19.7	47.6	65.2	98.4	37.8	333.9
24	51.4	40.0	23.3	19.9	23.8	18.0	50.5	81.2	91.0	32.7	15.1	11.1	458.0
1924-25	11.9	8.9	10.5	11.4	8.3	4.9	3.9	10.3	12.3	13.6	19.8	15.6	131.4
26	9.3	9.8	7.5	5.8	6.6	11.2	58.8	90.4	72.6	48.1	23.3	12.4	355.8
27	6.2	9.8	6.9	7.1	6.6	9.2	10.9	21.7	23.5	29.0	24.0	14.7	169.6
28	7.6	7.3	7.4	6.3	5.6	7.4	7.7	48.4	43.6	23.3	17.5	8.9	191.0
29	10.1	9.2	6.8	5.2	4.1	12.8	6.7	14.4	19.2	26.0	55.2	28.7	198.4
1929-30	10.3	13.9	9.7	5.6	10.7	6.5	13.3	17.1	28.0	34.0	66.4	21.1	236.6
31	13.9	9.6	6.8	5.5	5.8	8.1	12.6	41.9	33.3	22.8	20.2	5.8	186.3
32	7.1	6.7	5.5	4.2	4.6	4.4	6.8	18.0	25.8	23.2	15.6	5.9	127.8
33	7.4	4.9	3.4	2.6	2.2	3.3	17.2	100.0	53.4	33.0	35.6	45.2	308.2
34	7.0	8.2	7.7	5.6	6.7	10.1	9.5	19.4	12.2	7.0	10.1	5.0	108.5
1934-35	3.8	4.8	3.7	2.1	2.1	3.6	4.7	43.8	28.8	23.2	27.2	10.7	158.5
36	7.5	7.8	3.8	2.9	2.8	4.1	8.8	35.6	37.2	30.7	58.2	20.0	219.4
37	21.7	9.8	6.0	2.9	3.9	4.3	11.7	19.6	29.2	17.3	10.9	8.0	145.3
38	8.1	5.9	5.4	3.7	2.9	4.4	26.2	91.0	40.2	25.1	33.2	57.3	303.4
39	22.0	19.0	13.2	10.6	7.8	56.3	46.6	39.7	19.2	12.5	8.9	4.4	260.2
1939-40	5.0	5.0	4.1	4.4	4.1	10.7	13.9	19.4	11.4	6.5	7.2	12.7	104.4
41	6.4	7.8	4.1	5.2	3.8	5.2	13.7	53.3	54.9	26.7	31.9	18.5	231.5
42	31.4	18.2	8.9	7.7	7.9	35.0	201.7	247.4	134.1	47.7	42.5	19.1	801.6
43	21.5	9.2	11.3	12.7	8.4	7.2	11.0	24.2	21.5	19.6	20.2	6.4	173.3
44	5.3	5.8	8.0	4.9	5.6	7.2	25.6	90.1	50.6	26.9	14.3	6.9	251.1
Min.	3.8	4.8	3.4	2.1	2.1	3.3	3.9	10.3	11.4	6.5	7.2	4.4	63.2
Max.	51.4	40.0	23.3	21.0	23.8	56.3	201.7	247.4	229.0	68.9	141.7	57.3	1161.8
Total	444.0	365.7	302.7	259.1	239.7	365.8	960.2	1850.3	1732.7	1120.6	1168.8	589.2	
Average	13.1	10.8	8.9	7.6	7.1	10.8	28.2	54.4	51.0	33.0	34.4	17.3	

APPENDIX B

TABLE I(b)

ESTIMATED RUNOFF OF SOUTH PLATTE RIVER AT DENVER HAD BLUE-SOUTH PLATTE PROJECT BEEN IN OPERATION 1000 A. F. Units

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1910-11	9.3	9.2	9.2	8.2	18.1	18.3	19.3	44.6	50.9	61.5	49.3	40.2	338.1
12	9.3	9.2	9.2	8.2	8.1	8.3	10.8	26.0	37.5	19.6	39.9	35.6	221.7
13	9.3	9.2	14.7	10.6	9.1	11.8	20.5	34.8	32.5	21.0	22.5	36.2	232.2
14	9.3	9.2	20.8	24.1	24.5	25.6	55.1	237.6	94.0	105.5	112.7	21.1	739.5
1914-15	9.3	13.8	19.8	14.9	14.8	19.0	49.4	112.5	80.8	35.0	27.1	15.7	412.1
16	9.9	11.8	21.8	19.6	19.5	18.0	15.3	33.1	38.7	31.4	35.3	22.3	276.7
17	9.3	9.2	9.8	11.9	8.8	8.3	13.6	58.8	115.6	62.5	37.3	25.7	370.8
18	9.3	9.2	11.8	12.9	12.8	11.3	15.1	27.1	85.4	66.0	29.1	22.4	312.4
19	9.3	10.8	17.8	16.9	16.3	10.2	34.6	92.1	69.2	62.3	69.9	42.4	451.8
1919-20	9.3	9.2	11.8	13.9	8.8	8.3	11.3	36.4	62.4	64.6	51.5	32.1	319.6
21	9.3	9.2	11.8	9.9	8.8	9.0	44.8	97.8	231.1	102.6	68.2	24.2	626.7
22	9.3	9.2	15.8	17.9	14.8	21.0	13.6	50.9	64.0	53.7	56.4	38.7	365.3
23	9.3	9.2	14.8	12.9	12.8	12.8	15.0	26.9	20.8	59.3	77.4	26.1	297.3
24	25.4	27.8	30.6	30.2	33.6	20.7	43.4	103.5	118.9	44.1	38.7	35.1	552.0
1924-25	9.3	9.2	14.8	14.9	12.8	8.3	9.8	38.8	45.3	45.4	47.3	35.7	291.6
26	9.3	9.2	15.5	12.3	12.9	17.4	42.6	40.6	41.6	63.9	41.6	34.0	340.9
27	9.3	9.2	9.2	9.9	9.8	11.0	14.4	41.6	51.1	48.6	46.6	35.7	296.4
28	9.3	9.2	11.8	9.9	8.1	8.3	12.3	31.9	30.7	36.1	31.5	27.0	226.1
29	9.3	9.2	9.2	8.2	8.1	15.0	9.4	40.2	50.4	49.8	60.1	36.1	305.0
1929-30	9.3	9.2	9.2	8.8	9.5	8.3	12.7	37.5	51.7	43.5	41.0	34.5	275.2
31	9.3	9.2	9.2	8.2	8.1	8.3	12.9	66.6	61.9	52.8	31.9	30.1	308.5
32	9.3	9.2	9.2	10.8	8.1	8.3	9.3	31.9	22.5	21.1	23.9	26.0	189.6
33	9.3	9.2	9.2	8.2	8.1	8.3	9.3	40.0	87.2	50.7	32.9	38.1	310.5
34	11.4	9.2	9.2	9.3	8.1	8.3	9.3	30.5	22.4	20.5	20.8	23.2	182.2
1934-35	9.3	9.2	9.2	8.2	8.1	8.3	9.3	46.1	27.8	32.2	30.8	28.3	226.8
36	9.3	9.2	9.2	8.2	8.1	8.3	14.6	80.9	85.7	61.0	90.1	46.0	430.6
37	9.5	9.2	9.2	8.2	8.1	8.3	9.5	30.3	50.5	30.7	32.2	26.2	231.9
38	9.3	9.2	9.2	8.2	8.1	8.3	20.8	62.5	66.9	33.4	34.1	27.2	299.6
39	12.2	23.4	20.2	17.0	9.1	26.3	51.5	65.5	60.2	48.9	46.9	35.6	416.8
1939-40	9.3	9.2	9.2	8.2	8.1	12.6	9.3	21.4	14.1	13.3	13.0	17.7	145.4
41	9.3	9.2	9.2	8.2	8.1	8.3	15.1	55.4	52.3	20.6	22.8	20.5	239.0
42	14.1	9.2	9.2	8.2	8.5	24.7	64.6	47.6	18.0	37.8	20.8	16.1	278.8
43	9.3	9.2	14.9	23.4	22.4	23.0	36.6	46.8	50.1	49.6	50.0	45.1	380.4
44	9.3	9.2	9.2	8.2	8.1	8.3	21.7	41.2	84.8	51.7	48.9	39.2	339.8
Min.	9.3	9.2	9.2	8.2	8.1	8.3	9.3	21.4	14.1	13.3	13.0	15.7	139.1
Max.	25.4	27.8	30.6	30.2	33.6	26.3	64.6	237.6	231.1	105.5	112.7	45.1	970.5
Total	342.9	354.4	434.9	418.6	401.1	440.5	756.8	1879.4	2077.0	1600.7	1482.5	1040.1	
Average	10.1	10.4	12.8	12.3	11.8	13.0	22.3	55.3	61.1	47.1	43.6	30.6	

APPENDIX B

TABLE II

ANNUAL DISCHARGE OF SANITARY SEWERS OF CITY OF DENVER*

1927-1946

	Sanitary sewage (acre-feet)	Population	Acre-feet per capita
1927	52,595	320,000	.164
1928	53,181	323,000	.164
1929	53,143	325,000	.163
1930	51,103	326,000	.157
1931	50,614	329,000	.154
1932	48,464	331,000	.146
1933	46,276	331,000	.139
1934	42,671	338,000	.123
1935	41,648	340,000	.122
1936	46,593	345,000	.135
1937	47,962	350,000	.137
1938	46,486	354,000	.131
1939	46,964	360,000	.130
1940	51,535	370,000	.139
1941	55,899	380,000	.147
1942	60,523	405,000	.149
1943	59,238	407,000	.145
1944	60,790	409,000	.147
1945	59,669	414,000	.144
1946	62,582	423,000	.148

Average = 0.1442 acre-ft/capita/yr or 129 gal/capita/day

* Report of the Board of Water Commissioners, Denver, Colorado. Year ending December 31, 1945.

APPENDIX B

TABLE III

DISCHARGE OF DENVER SANITARY SEWERS

Actual for Year 1945 and Estimated for Year 2000

	(1)	(2)		(3)	(4)
	Acre-feet	Acre-feet	C.F.S.	C.F.S.	C.F.S.
January	4,924	4,933	80	138	197
February	4,482	4,491	81	140	200
March	4,961	4,971	81	140	200
April	5,124	4,134	86	148	212
May	5,311	5,321	87	150	214
June	5,245	5,255	88	152	217
July	5,505	5,516	90	155	222
August	5,289	5,299	86	148	212
September	4,764	4,773	80	138	197
October	4,748	4,757	77	133	190
November	4,544	4,553	77	133	190
December	4,772	4,781	78	134	192
	59,669	59,784			

(1) Actual discharge of sanitary sewers for 1945 from City and County of Denver Water Board.

(2) Average of period 1941-1946, inclusive. (Average population was 406,000 persons.) Monthly distribution based on actual 1945 record.

(3) Estimated flow based on population of 700,000 persons, predicted for A. D. 2000 without Blue-South Platte Project.

(4) Estimated flow based on population of 1,000,000 persons, predicted for A. D. 2000 with Blue-South Platte Project.

APPENDIX B

TABLE IV

Contribution of Denver Sewage to Flow of South Platte River under Maximum, Minimum, and Average Flow Conditions

Month	Average sewage flow 1000 acre-feet			Minimum actual runoff South Platte River				Minimum project runoff		Maximum actual runoff South Platte River				Maximum project runoff		Actual average runoff				Average project runoff	
	1945	(1) 2000	(2) 2000	1945		(1) 2000		(2) 2000		1945		(1) 2000		(2) 2000		1945		(1) 2000		(2) 2000	
	Actual	Esti-mated	Esti-mated	1000 A.F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage	1000 A. F.	Percent Sewage
January	4.92	8.48	12.11	7.02	70.0	10.58	80.1	20.31	59.6	25.92	19.0	29.48	28.7	42.31	28.6	12.52	39.4	16.08	52.7	24.41	49.7
February	4.48	7.77	11.11	6.58	68.0	9.87	78.7	19.21	57.9	28.28	15.6	31.57	34.6	44.71	24.8	11.58	38.7	14.87	52.3	22.91	48.5
March	4.96	8.61	12.30	8.26	60.0	11.91	72.4	20.6	59.7	61.26	8.1	64.91	13.3	38.6	31.8	15.96	31.5	19.41	44.4	25.30	48.7
April	5.12	8.81	12.62	9.02	56.8	12.71	69.3	21.92	57.6	206.82	2.48	210.51	4.1	77.76	16.2	33.32	15.9	37.01	23.8	34.92	36.1
May	5.31	9.22	13.16	15.61	35.1	19.52	47.2	34.56	38.1	253.7	2.10	256.62	3.6	250.76	5.26	59.71	8.89	63.62	14.5	68.46	19.2
June	5.25	9.04	12.91	16.65	31.6	20.44	44.2	27.01	47.8	234.25	2.24	238.04	3.8	244.01	5.29	56.25	8.79	60.04	15.1	74.01	17.4
July	5.51	9.53	13.65	12.01	45.5	16.03	58.2	26.95	50.6	74.71	7.37	78.43	12.1	119.15	11.5	38.51	14.3	42.53	22.4	60.75	22.5
August	5.30	9.10	13.04	12.50	42.4	16.30	55.8	26.04	50.1	147.0	3.61	150.8	6.03	125.74	10.4	39.70	13.3	43.50	20.9	56.64	23.0
September	5.76	8.21	11.72	10.16	56.7	12.61	65.1	27.42	42.8	63.06	9.12	65.51	12.5	56.82	20.6	23.06	25.0	25.51	32.2	42.32	27.7
October	5.74	8.18	11.67	9.54	60.1	11.98	68.1	20.97	55.7	59.84	9.59	62.28	13.1	37.07	31.5	18.84	30.5	21.28	38.4	22.77	51.3
November	5.54	7.91	11.31	10.34	53.6	12.71	62.2	20.51	55.1	45.54	12.2	47.91	16.5	39.11	28.9	16.34	33.9	18.71	42.3	21.71	52.2
December	4.77	8.24	11.80	8.17	58.4	11.64	70.8	21.00	56.1	28.07	17.0	31.54	26.2	42.40	27.8	13.67	34.9	17.14	48.1	24.60	48.0

(1) Without project; population estimated at 700,000.

(2) Project in operation; population estimated at 1,000,000.

APPENDIX C

TYPE OF SEWAGE DISPOSAL FACILITIES - DENVER AND SURROUNDING TERRITORY - 1945[a]

Municipality or Area	Population 1940	Const. Date	M.G.D.[b] Capacity	Type of Treatment Primary - Secondary - Complete	Sewage or Effluent Disposal
Boulder	12,958	1934	R.5 to 6	Primary Treatment - separate sludge digestion, clarifier, chlorine	Effluent to Boulder Creek
Brighton	4,029	1937	R. 0.5 Opr. 0.3	Complete Treatment - trickling filter (rotary). Bar screens settling (Dorr Clarigester) sludge drying beds and septic tank for clarigester skimmings	Effluent to South Platte River. Effluent from Sugar Factory and Kuner-Empson Factory does not go through plant.
Ft. Lupton	1,692	1937	Not available	Primary Treatment - clarifier and separate sludge digestion	Effluent to South Platte River
Hudson	295			None	Septic tanks and cesspools
Lafayette	2,052			None	---
Louisville	2,023			None	---
Erie	1,019			None	---
Denver (two plants)	322,412	1937	R. 54 Opr. 53 Max. 70	Primary Treatment - automatic bar screens, detritor, clarification separate sludge digestion, chlorination	One outlet to Platte River B.O.D. of river below plant equals 20-45 p.p.m.[c] Sludge disposal - fertilizer
				Suburban areas and towns near Denver	
Berkeley Gardens (Census precinct 17)	1,043	---		Sewage for portion of the area treated in Denver Plant	Cesspools and septic tanks. Natural drainage to Clear Creek
Derby, Dupont, Adams City, and Welby	---	---	---	None	Cesspools, septic tanks, and privies
Garden Homes (Census precincts 15-18 inclusive)	3,734			None	Cesspools, septic tanks, and privies
Daniels Gardens (Census precinct 33)	1,251			None	Cesspools, septic tanks, and privies
Mountain View and Lakeside	750			None	Raw sewage to Clear Creek
Olinger Gardens - Columbia Heights (Census precinct 31)	1,080[c]			Sewage from 325 connections to Denver Plant. Balance private disposal	See Denver
Lakewood Sanitary District	6,700[d]			Lakewood Sanitary District sewage treated in Denver Plant	Area not under district served by cesspools and septic tanks
Arvada	1,482	1939	R. 0.25	Primary Treatment - mechanical clarifier - separate sludge digesters	To Ralston Creek
Aurora	3,437	1929	R. 0.5 Opr. 0.5	Primary Treatment - Dorr clarifier - Dorr digester and sludge dosing beds	To Sand Creek via dry gulch

Edgewater	1,648			Sewage treated in Denver Plant	See Denver
Englewood	9,680			75% sewage treated in Denver Plant. Septic tanks and cesspools	
Golden	3,175			None	Raw sewage to Clear Creek
Littleton	2,244	1920	Opr. 0.4	Primary Treatment - Imhoff tank and trickling filters, secondary sedimentation	Effluent to lagoon and thence to South Platte River
Westminster	534			None	Septic tanks and cesspools
Military Establishments:					
Buckley Field	12,000[f]	1942	R. 3.0	Complete Treatment - Clarifiers, separate sludge digestion, trickling filters (rotary) chlorination of effluent	Effluent to Sand Creek.
Fitzsimons General Hospital	4,000[f]	1941	R. 0.9	Complete Treatment - Clarifiers, separate sludge digestion, standard trickling filters	Effluent to Sand Creek. 60'' pipe through Stapleton Field. Effluent used for irrigation of golf course and grounds
Fort Logan	5,000[f]	1941	R. 0.9	Complete Treatment - Clarifier, separate sludge digester, standard trickling filter	Effluent to Bear Creek
Lowry Field	10,000[f]				Sewage treated in Denver Plant
Rocky Mountain Arsenal	6,000[f]	1942	R. 0.6	Complete Treatment - Imhoff tanks and standard trickling filters	First Creek (Dry gulch on reservation)
				Towns on streams which extend into benefit area	
Morrison	216			None	Cesspools and septic tanks
Silver Plume	139			None	Stream affected - Clear Creek
Georgetown	391			None	Stream affected - Clear Creek
Idaho Springs	2,112			None	Stream affected - Clear Creek
Central City	706			None	Stream affected - Clear Creek

a - Source: State Board of Health, Sanitary Engineering Division, National Resources Planning Board.
b - R. - Rated capacity, Opr. - Operating capacity.
c - B.O.D. - The Biochemical Oxygen Demand is the requirement of raw sewage for the necessary chemicals and oxygen for its stabilization.
d - Estimated 1080 serviced.
e - Estimated.
f - Estimated wartime population.

APPENDIX D

Water Quality Requirements--Summary of Limiting Quality Requirements for Stream Waters with Principal Stream Uses and Conditions Involved in each Category--From Ohio River Pollution Control Report

ITEM		Desirable	Doubtful	Unsuitable
WATER SUPPLY--GENERAL SANITARY CONDITIONS				
Coliform bacteria per milliliter	Avg	Not over 50 in any month (filtration treatment required if over 0.5)	50 - 200 in any month (unsuitable if greater than 200 in more than 5 percent of samples)	Over 200 in any month
BATHING--RECREATION				
Coliform bacteria per milliliter	Avg Max	Not over 1.0 Not over 10.0	1.0-10.0	Over 10.0
FISH LIFE--RECREATION--GENERAL SANITARY CONDITIONS				
Dissolved oxygen ppm	Avg Min	Not less than 6.5 in any month Not less than 5.0 on any day	5.0[1] - 6.5 in any month 3.0 - 5.0 on any day	Less than 5.0 in any month[1] Less than 3.0 on any day
GENERAL SANITARY CONDITIONS--RECREATION				
5-day BOD ppm	Avg	Not over 3.0 in any month	3.0 - 5.0 in any month	Over 5.0 in any month
WATER SUPPLY--FISH LIFE--RECREATION--NAVIGATION--INDUSTRY				
pH	---	6.5 - 8.6	4.0 - 6.5 or 8.6 to 9.5[2] Suitable for water supply prior to treatment	Less than 4.0 or over 9.5[2] Unfavorable for water supply prior to treatment
FISH LIFE--RECREATION--GENERAL SANITARY CONDITIONS				
Sludge deposits	---	No preventable deposits present	Slight to moderate - localized	Moderate to heavy - general
WATER SUPPLY				
Phenols, ppbillion	---	Not over 1	1 - 10	Over 10
WATER SUPPLY--RECREATION--FISH LIFE				
Other conditions	---	No toxic substances, oils, tars, or free acid at any time; no floating solids or debris, except from natural sources; no taste-producing substances	Free acidity at any time, chlorides over 250 ppm; occasional taste-producing substances.	Toxic substances, oils, or tars present at any time; free acidity present frequently; taste-producing substances present frequently.

1 In general, it may be said that a 5 parts per million minimum is desirable, except where local conditions may be favorable to allowing a 4 ppm minimum in limited zones immediately below fairly isolated sources of pollution.

2 U. S. Public Health Service drinking water standards permit pH 10.6 in "treated" water.