STATE OF CALIFORNIA
GOODWIN J. KNIGHT
Governor

WASTE TREATMENT
AND
DISPOSAL ASPECTS
to
Development of California's Pulp and Paper Resources

1957

A Cooperative Study by

State Department of Natural Resources, Division of Forestry
University of California, School of Forestry, Berkeley
United States Forest Service, California Forest and Range Experiment Station
National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc.
State Department of Water Resources
Central Valley Regional Water Pollution Control Board
North Coastal Regional Water Pollution Control Board
State Water Pollution Control Board

Publication No. 17
STATE WATER POLLUTION CONTROL BOARD
SACRAMENTO, CALIFORNIA

STATE OF CALIFORNIA

STATE WATER POLLUTION CONTROL BOARD

ROOM 610
721 CAPITOL AVENUE
SACRAMENTO 14, CALIFORNIA

BOARD MEMBERS

A M RAWN, *Chairman*
Los Angeles

DeWITT NELSON, *Vice Chairman*
Sacramento

HARVEY O. BANKS
Sacramento

PAUL BEERMANN
San Diego

SETH GORDON
Sacramento

WILLIAM U. HUDSON
Oakland

W. C. JACOBSEN
Sacramento

J. J. KROHN
Arcata

DON C. McMILLAN
Pasadena

MALCOLM H. MERRILL, M.D.
Berkeley

R. KEITH METS
Holtville

WALTER R. SCHMID
Garden Grove

HERBERT S. STARK
Portola Valley

RICHARD S. WHITEHEAD
Santa Barbara

PAUL R. BONDERSON
Executive Officer

Charles A. Sweet
Robert M. Cousins
Assistants to Executive Officer

STATE OF CALIFORNIA
GOODWIN J. KNIGHT
Governor

WASTE TREATMENT
AND
DISPOSAL ASPECTS

to

Development of California's Pulp and Paper Resources

1957

A Cooperative Study by

State Department of Natural Resources, Division of Forestry
University of California, School of Forestry, Berkeley
United States Forest Service, California Forest and Range Experiment Station
National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc.
State Department of Water Resources
Central Valley Regional Water Pollution Control Board
North Coastal Regional Water Pollution Control Board
State Water Pollution Control Board

Publication No. 17
STATE WATER POLLUTION CONTROL BOARD
SACRAMENTO, CALIFORNIA

TABLE OF CONTENTS

TABLE OF CONTENTS—Continued

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES—Continued

FOREWORD

The following report has been prepared for the California State Water Pollution Control Board, through the joint effort of many contributors and authors, as a reference document. It is intended to be a technical review and analysis of a complex subject which is of great importance to the future development of California.

Although this study was sponsored and is published by the State Water Pollution Control Board, it was not the function or obligation of the various contributors necessarily to reflect the policies and responsibilities of this Board.

Control of water pollution and the regulation of waste discharges in California is vested primarily in nine regional boards. The appropriate regional water pollution control board must determine initially the conditions under which the waste may be discharged at any particular location.

One of the primary responsibilities of the State and Regional Boards is so to regulate waste disposal into waters of the State that such disposal does not adversely and unreasonably affect or infringe upon other beneficial uses of these waters. The fulfillment of this responsibility will require both caution and vision.

Intensive urban, industrial, agricultural and recreational development of California is underway. However, the potential wealth and value of these developments will be realized only to the extent that the natural waters are maintained at their highest possible quality.

Consideration of the future multiple needs of water and full economic development of the area concerned points up the folly of assigning the full waste assimilative capacity of any stream to a single industry or function. Insofar as fish and wildlife are concerned, the objective must be the maintenance of a favorable habitat, not merely avoidance of toxic conditions. Furthermore, realistic margins of safety must continue to be a permanent characteristic of the pollution control program in California.

It is believed that this important compilation will be useful to these ends.

I. OBJECTIVES OF THE STUDY

The future growth of northern California is vitally dependent on the area's two most important resources, water and timber. In recent years much attention has been given to solution of California's water problems by development of her water resources but comparatively little note has been taken of the tremendous potential for utilization of her forest resources.

In particular, California is unique among states with large timber stands, in that it has experienced virtually negligible growth in production of wood pulp. While the State ranks second in the United States in volume of lumber production, it is only twenty-third in installed pulp capacity. In 1952 the State produced about one-eighth of the national volume of saw logs but only one percent of the nation's pulpwood.

There can be little doubt of the potential for development of a sizable pulp industry in California, but a number of important questions have arisen in anticipation of this event. Of particular importance are such questions as:

(1) What is the tonnage of wood pulp which potentially can be developed from the available fiber resources of northern California?

(2) What pulping processes are most suitable for northern California?

(3) What are the water quantity and quality requirements for the pulp industry?

(4) What are the characteristics of wastes which may result from the various processes?

(5) How are water quality requirements determined to protect beneficial uses of northern California waters and how are they administered?

(6) What factors affect the assimilative capacity of receiving waters of northern California for wastes from the pulp industry?

In anticipation of the need for answering such questions as these, it was proposed by the State Water Pollution Control Board that a cooperative study group be organized for the purpose of preparing a report in which could be assembled all available information pertinent to the pulp industry in northern California. This group was formed of individuals representing agencies concerned with all phases of the problem, the State Water Pollution Control Board acting as the coordinating agency. The various agencies and the persons representing them in the cooperative study group are listed as follows:

State Water Pollution Control Board
- Vinton W. Bacon, Executive Officer, April 1950 to December 1956
- Paul R. Bonderson, Executive Officer, December 1956 to date
- Gerald T. Orlob, Special Consultant

Central Valley Regional Water Pollution Control Board
- Col. J. S. Gorlinski, Executive Officer

North Coastal Regional Water Pollution Control Board
- William G. Shackleton, Executive Officer

State Division of Forestry
- T. F. Arvola, Deputy State Forester

California Forest and Range Experiment Station, U. S. Forest Service
- L. N. Ericksen, Chief, Div. of Forest Utilization
- E. V. Roberts, Chief, Div. of Forest Economics

National Council for Stream Improvement
- Anthony F. Gaudy, Jr., West Coast Resident Engineer

University of California, School of Forestry
- John A. Zivnuska, Associate Professor

State Department of Water Resources
- Carl B. Meyer, Principal Hydraulic Engineer
- Darrell J. Smith, Assistant Hydraulic Engineer

Industrial Representatives
- Howard S. Gardner, Director of Research and Development, Fiberboard Paper Products Corp.
- Walter F. Holzer, Manager, Technical Projects, Crown Zellerbach Corp.
- Ray E. Shreck, Industry Consultant

State Department of Public Health
- H. B. Foster, Jr., Supervising Sanitary Engineer

State Department of Fish and Game
- Jack Fraser, Water Projects Coordinator

Various persons from the cooperative study group were assigned tasks of preparing certain sections of the following report. The group as a whole reviewed each section and contributed to revision or modification of the report until it attained the form in which it is herein presented. While each section was independently authored by the individuals designated at the beginning of each chapter, all authors took cognizance of the content of other sections, revising their contributions. The report is truly a cooperative effort.

During the latter phase of preparation of the report, Professor Gerald T. Orlob of the University of California served as special consultant to the State Water Pollution Control Board in editing and assisting in preparation of the final manuscript.

Five of the maps appearing in the report were made available through the cooperation and courtesy of two of the cooperating agencies. Figures 1, 2, 4, and 5 were furnished by the State Department of Water Resources and Figure 3 was furnished by the California Forest and Range Experiment Station.

II. SUMMARY

The following report has been concerned with several of the primary problems which will confront an expanding pulp industry in California. Particular emphasis has been placed on the availability of wood fiber, adequacy of water for process uses and waste disposal, and the assimilative capacities of receiving waters. The report has been prepared with the expectation that it will serve as a useful guide to forest products industries in their plans for development of California's forest resources. It is hoped also that water pollution control, sanitary, chemical, and hydraulic engineers will find the content of the following pages valuable in their future considerations of the waste disposal problems of the pulp industry.

A summary of the content of this report is as follows:

Fiber Resources

At present California ranks second among the states in volume of lumber production, third in the volume of soft-plywood production, but twenty-third in installed wood-pulp capacity. In 1952 lumber took 91 percent of the State's timber cut, plywood 5 percent, and all other products 4 percent.

Further significant increases in volume of timber cut in California are not likely. Future expansion of forest industries to contribute to support of the State's population must come primarily from increased use of present timber cut rather than from additional increases in volume of timber cutting.

California has 17.3 million acres of commercial forest land, mostly in Northern California, and includes some 20 percent of the nation's total volume of saw timber. Annual cut in these forests can be expected to exceed growth for the next few decades because of the necessity for harvesting mature or overmature saw-timber volume to avoid losses from insects and disease and to make room for younger stands. Most of this cut will continue to be used for lumber and veneer with low-quality or low-market-value material available for pulpwood.

The principal sources of wood supply for initial expansion of the pulp industry in California will be mill residues from sawmills and plywood plants and residual material left in the woods after logging. In 1952 about 242 million cubic feet of coarse mill residues suitable for pulping were produced at primary forest products plants in California. Since 1952 both the demand for and the supply of coarse residues have increased. Two major pulp mills operating in the State have made increased use of wood chips from mill residues for pulp production. Several sawmills have installed barkers and chippers to supply this limited demand.

All of the commercial softwood and several hardwood species found in California are suitable for pulping by presently used commercial processes.

Pulp and Paper Mill Potentialities From the Standpoint of Fiber Resources

Groundwood or other mechanical processes are generally promising in application to northern California pulp woods. The pulp produced from such processes is cheap and yields are high.

Sulfite and soda processes, on the other hand, do not appear to have much potential for application in California. Both are in a comparatively static position in the pulp industry. They are most suitable for pulping of woods which do not predominate in California forests. California pulpwoods are more readily pulped by other processes.

Sulfate and semi-chemical processes are particularly applicable to California pulpwood. The sulfate, or "kraft," process is especially versatile, accomodating almost any wood. Yields, although lower than groundwood, are comparable to other chemical processes.

The average size of established pulp mills in the West is as follows: mechanical—125 tons (per day), semi-chemical—125 tons, and chemical—300 tons. Maximum sizes are: mechanical—400 tons, semi-chemical—160 tons, and chemical—700 tons. Considering northern California fiber resources and pulp process characteristics, the minimum plant size for a wood pulp mill would probably range from 50 tons for mechanical and semi-chemical processes to 250 tons for unbleached sulfate pulp.

From the viewpoint of fiber resources alone, there is a potential for an increase in pulp production from the present level of 521 tons to a level of approximately 6,000 tons. The sources of raw material and the potential production attributable to each source are estimated as follows:

Unused coarse mill residues	2,160 tons/day
Diversion of coarse mill residues now used for fuel	540 " "
Logging residue	1,440 " "
Cutting in timber stands	1,860 " "
Total	6,000 " "

The extent to which this potential is realized will depend on such factors as water supply, power costs, available sites, waste disposal potential, and detailed market analyses as well as wood supply.

The estimated increase in potential pulp capacity in the principal timbered areas of Northern California is distributed as follows:

Humboldt Area (Humboldt, Del Norte, and Western Trinity Counties)	1,900 tons/day
Mendocino Area (Mendocino, Lake, and northern Sonoma Counties)	950 tons/day
Upper Sacramento Valley (North of Colusa County)	1,600 tons/day
Lower Sacramento Valley	1,550 tons/day

Water Requirements for the Pulp and Paper Industry

Quality requirements for water used in pulping processes are usually high, often requiring treatment beyond the levels usually necessary for domestic use. Production of bleached pulp, for example, generally requires water meeting the following specifications:

Color	< 25	ppm
Turbidity	< 10	ppm
Iron	< 0.1	ppm
Manganese	< 0.05	ppm
Total Hardness	100-60	ppm

The quantity of water required for pulp production varies with the type of pulp produced and the process employed. The debarking operation for preparation of pulpwood may require up to 7,500 gallons per ton of pulp depending on process, equipment, and pulping technique. A typical kraft pulp mill will require additional water averaging 20,000 gallons per ton and a bleach plant may require up to 100,000 gallons per ton depending on the degree of bleach desired. Total water requirements for a representative 400-ton-per-day kraft mill may range between 8 and 50 million gallons per day. Sulfite mills have comparable requirements. Groundwood mills may be expected to average less than 10,000 gallons per ton of unbleached pulp.

Paper mill operations typically require from 5,000 to 25,000 gallons of water per ton of pulp processed. An average value is about 10,000 gallons per ton.

Availability of Water for Pulp Processes and Waste Assimilation

Local development of dams, reservoirs, and appurtenant works together with major hydraulic works contemplated by the California Water Plan in the Sacramento River Basin will provide sufficient water for all foreseeable beneficial uses. The estimated annual runoff in north coastal streams is adequate to support all local needs including potential requirements for process water by the pulp and paper industry.

Stream locations which most favor the development of potential pulp and paper mills were selected on the basis of the following considerations: (1) apparent sufficiency of water resources; (2) availability of fiber resources; (3) the problem of waste disposal; and (4) availability of data permitting an adequate hydrologic analysis.

In the north coastal region, waste disposal directly to ocean waters was considered desirable. Specific locations which met this requirement and for which adequate data was available were the Smith River near Crescent City, and Klamath River near Klamath, and the Eel River near Scotia. In the absence of flow regulation by storage only the Klamath River site appears feasible from the standpoint of adequacy of water supply. With upstream storage, each of the subject streams as well as Mad River, Redwood Creek, and Russian River offer some potential for pulp mill location.

In the Sacramento Valley adequate water supply is available at many locations along the main stream. The feasibility of mill location appears to be dependent primarily upon waste disposal considerations.

Wastes From Pulp and Paper Processes

Waste volumes from pulp and paper processes usually exceed 90 percent of the total water requirement; less than 10 percent of the water is used consumptively.

The quality of pulp mill wastes vary widely with process. Characteristics of greatest concern from the point of view of waste disposal are biochemical oxygen demand (B.O.D.), dissolved mineral solids, settleable solids, and toxicity.

Kraft mill wastes, which are likely to be of greatest concern in the development of the pulp industry in California, are generally low in B.O.D. as a consequence of chemical recovery procedures which result in burning of much of the organic residue produced in the pulping operation. B.O.D. (5 day 20°C) loadings average about 30 pounds per ton of pulp produced. Total solids in a kraft effluent may range from 200 to 300 pounds per ton, with about 35 percent mineral composition. Suspended solids average less than 20 pounds per ton. The effluent has a color ranging from 300 to 500 ppm. Hydrogen ion concentration expressed as pH varies from 7.5 to 9.

Sodium losses in the effluent from the kraft process may average about 16 pounds per ton while sulfate loss is about 34 pounds per ton.

Bleaching operations result in the addition of chlorides to mill effluents. In an average bleaching process, waste chlorides may run to 150 pounds per ton.

Toxicity of kraft effluents is not likely to be critical if waste dilutions of 20:1 with receiving waters can be obtained. Usually oxygen depletion becomes critical before toxicity produces a problem in disposal.

The sulfite process, with the possible exception of the magnesium base technique, appears to have little application in California. In the MgO process 85 to 90 percent B.O.D. reduction may be achieved by base chemical recovery similar to that used in the kraft process. In general oxygen demanding properties of waste from this process are of critical concern in disposal.

The groundwood process yields wastes of comparatively low volume but with higher B.O.D. Suspended solids may range from 20 to 80 pounds per ton depending on recovery procedures. In general, approximately 10 to 20 pounds of B.O.D. per ton may be expected.

Neutral sulfite semi-chemical plants are often integrated with kraft installations thereby reducing waste loadings to values comparable in most respects to those from the kraft process.

Pollution Control in Relation to Beneficial Use of Receiving Waters

Pollution control in California recognizes the singularity of each individual waste disposal problem. The solution of each problem usually requires a unique analysis of chemical, physical, and biological characteristics of the waste and receiving water, the beneficial uses of water which may be affected by the potential discharge, and the waste disposal practices of the discharger. Effluent and stream quality requirements are established only after careful consideration of all factors and complete discussion with all persons or agencies concerned.

Water uses in the survey area are extremely diverse, including virtually all recognized uses to which water may be put. Drinking and culinary uses are most important from the standpoint of quality but represent only a fraction of the total volume usage. Agriculture, support of aquatic life, recreation, and industrial uses are also extremely important to the area.

Most of the receiving waters in the survey area presently stand at a comparatively high level of quality. It is a primary objective of the Regional Water Pollution Control Boards in California to conserve the quality of these waters at the highest possible level consistent with the best interests of the people of the State.

Assimilative Capacity of Receiving Waters

The potential development of the pulp and paper industry in California is greatly dependent on the waste assimilative capacity of natural receiving waters such as streams, estuaries and bays, ground waters, and the ocean.

Stream Disposal—Stream disposal is largely a matter of providing adequate dilution of waste materials such that the resulting degradation resulting from interaction of waste and receiving water does not endanger other beneficial uses. For example, the discharge of organic wastes which undergo decomposition in the stream and require oxygen for stabilization should not result in a depression of oxygen concentrations below the level necessary to support fish life. Given a particular waste, a receiving water, and the requirements to protect beneficial uses, it is possible to estimate the assimilative capacity of the stream to receive the waste.

This report has presented the procedures for making this estimation with respect to wastes from various pulp and paper processes. Using the waste composition presented in another section of the report, estimates of the characteristics of "typical" mill effluents were obtained. A typical 400-ton unbleached kraft mill, for example, discharges an effluent which is defined as follows:

Flow—8.8 million gallons per day
B.O.D.—245 ppm
Total Solids—1,800 ppm
Suspended Solids—300 ppm
Sodium—90 ppm
Calcium—25 ppm
Sodium Ratio—0.75
Sulfates—200 ppm
Hydroxides—30 ppm
Carbonates—500 ppm
Methyl mercaptans—4 ppm
Sodium sulfide—2 ppm
Resin soap—6 ppm

Using an "oxygen sag" analysis which takes account of both stream and waste characteristics, the upper and lower limit critical waste loadings were determined. The requisite stream flow to provide adequate dilution of kraft effluents to maintain prescribed oxygen levels can be estimated with the aid of charts given in the report. A typical solution indicates a minimum stream flow of 155 cfs is necessary to maintain a level of 5 ppm dissolved oxygen if the mill discharging untreated waste to a saturated stream (9.2 ppm @ 20° C). Similar analyses using the sag equation can be performed for other mill effluents.

Consideration of toxicity thresholds indicates that dilutions of 20:1 will probably be adequate to sustain aquatic populations in receiving streams. However, there is considerable difference of opinion among biologists as to the required factor of safety for dilution of toxic components. The California State Department of Fish and Game recommends an application factor of 1:5 and the U. S. Public Health Service suggests that application factors as low as 1:10 may be necessary.

The mineral components of pulp mill effluents are not likely to adversely affect the quality of receiving waters to the point where they would be unsuitable for irrigation uses. In certain streams the high proportion of sodium in kraft effluents could potentially be damaging but in most instances dilutions less than 10:1 are adequate to maintain a satisfactory sodium ratio. Increases in sulfates, chlorides, and hardness would not be particularly critical in most northern California streams.

If receiving waters are potentially usable as sources of domestic drinking water, considerable attention needs to be given problems of taste, odor, and color. Dilution necessary to satisfy the maximum taste and odor threshhold for kraft mill waste may exceed 50:1 while dilution to reduce color to tolerable levels without supplementary treatment may exceed 25:1.

Floating debris, temperature increases, and pH are not likely to create serious problems in northern California streams.

The assimilative capacity of a given stream may be increased in several ways: (1) by reducing the concentration of deleterious substances in the wastes by in-plant practices, (2) by treatment of the wastes in biological processes, (3) by regulating waste discharges in proportion to stream flow, and (4) by increasing the effectiveness of dilution.

In most instances waste prevention has a definite economic return to the industry so it may be expected that progressive management will lead to minimizing waste.

Treatment of pulp mill wastes in biological treatment units such as high rate trickling filters or activated sludge has been moderately effective when waste volumes are small. For large waste volumes, particularly with the kraft process, use of oxidation ponds with supplementary addition of nutrient chemicals has been successful in reducing B.O.D. values by 75 to 90 percent.

Use of storage lagoons for regulating waste discharge through critical low stream flow periods can be an effective method for increasing the pulp potential of a given site. An analysis of stream flow data and preparation of drought frequency analyses are useful in design of such installations.

Multiple diffuser lines are useful in obtaining the maximum effectiveness of the receiving stream. A series of outlets across the stream channel insures the maintenance of minimum possible waste concentrations. Such installations have been effectively used for stream disposal of pulp mill wastes at several locations in the Pacific Northwest.

Land Disposal—Discharge of pulp mill wastes through the medium of infiltration, evaporation, or both may prove advisable in instances where waste volumes are not large. Wastes from the groundwood process, for example, are not voluminous and could probably be handled conveniently through infiltration basins. Kraft wastes, on the other hand, would require considerable pond area and perhaps would need to be treated to facilitate infiltration.

Bay and Estuary Disposal—Bays and estuaries are often the most critical locations for pulp mill waste discharge although they are often preferred because of their proximity to population centers, transportation and markets.

Tidal action is particularly important in the determination of the time of excursion of pulp mill wastes through a bay or estuary. Several analytical methods are available for analysis of the flushing characteristics of tidal basins but all are somewhat unreliable when applied to complex cases. Frequently hydraulic models of estuarial areas can be particularly helpful in investigation of potential pollution problems.

The peculiar nature of estuaries gives rise to several special beneficial use considerations. If the stream feeding the estuary is used for support of a salmon fishery, for example, the likelihood of creation of an oxygen deficient barrier across the channel should be investigated. Also, estuarial areas are often prime locations for shellfish propagation, a factor which may necessitate special attention to the toxic properties of waste discharges.

Ocean Disposal—Direct discharge of pulp mill wastes to the open ocean is probably the most attractive mode of disposal from the standpoint of waste assimilative capacity. If proper attention is given to the design of submarine diffuser lines, waste materials can often be discharged without discernable damage to receiving waters. An investigation of an ocean disposal site should include a thorough study of current and wind behavior in the vicinity and should take cognizance of the mechanisms of turbulent mixing which tend to disperse waste discharges throughout the receiving medium.

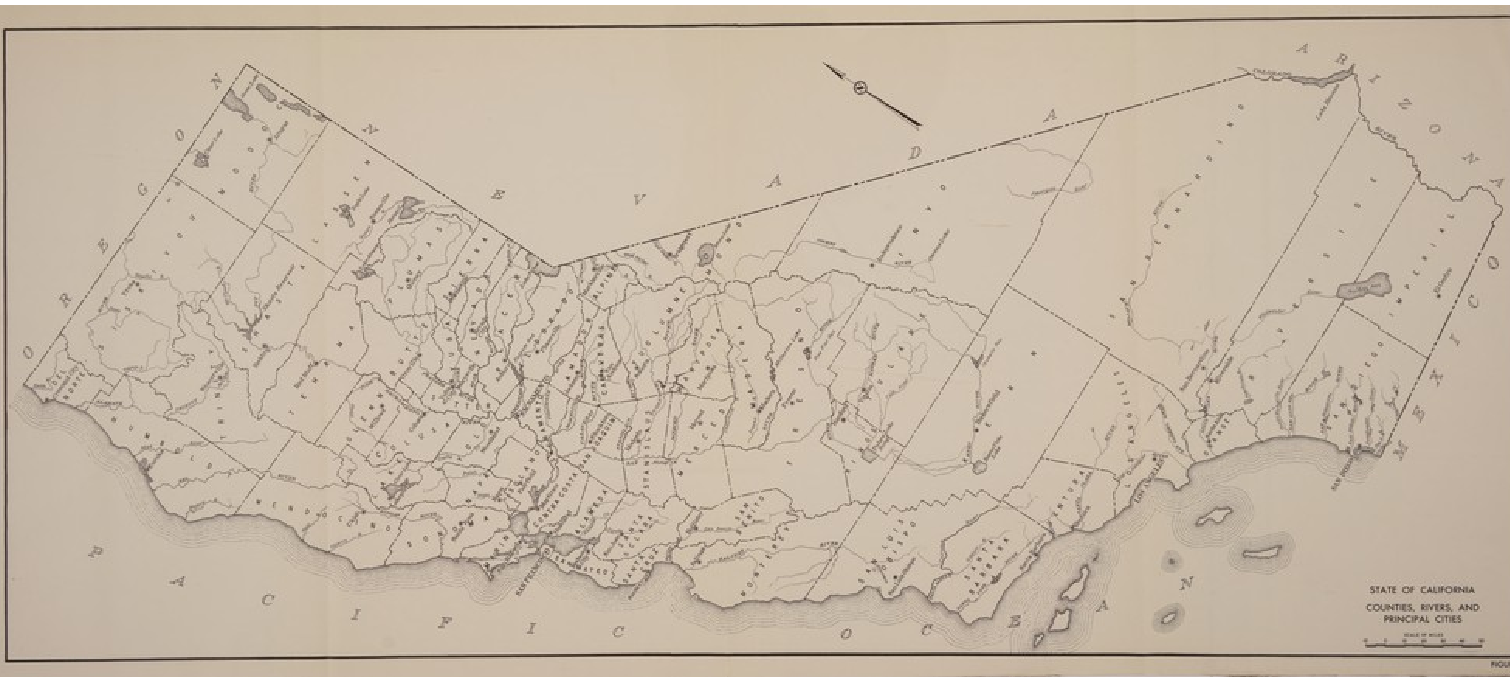
The conjunctive use of underground and stream assimilative capacity involves consideration of the effects of pulp mill wastes on the quality of waters potentially usable for domestic purposes. Decomposition of organic materials after release to ground water may result in the production of odoriferous and aesthetically undesirable end products such as hydrogen sulfide. Movement of ground waters away from the recharge area toward a natural water course or other source of ground water depletion and the fact that dilution of added wastes is likely to be minimal suggests the possibility of easy contamination of domestic supplies.

The presence of suspended solids, organic matter, and mineral constituents which may influence soil structure suggest potential difficulties in the operation of infiltration basins.

* * * * *

No attempts have been made in this report to define precisely the capacities for development of the pulp industry in any one location in California. It is clear that much additional study will be necessary for each unique situation and that no two problem solutions will be identical.

The primary objective of this report has been to summarize in one document some of the more significant data which in general concern the future of the pulp and paper industry in California. It is hoped that those persons who may wish to examine facets of this rather intricate problem will find the product of this cooperative study of some value in their deliberations.



STATE OF CALIFORNIA
COUNTIES, RIVERS, AND PRINCIPAL CITIES

FIGURE 1

RELIEF MAP OF
STATE OF CALIFORNIA

FIGURE 2

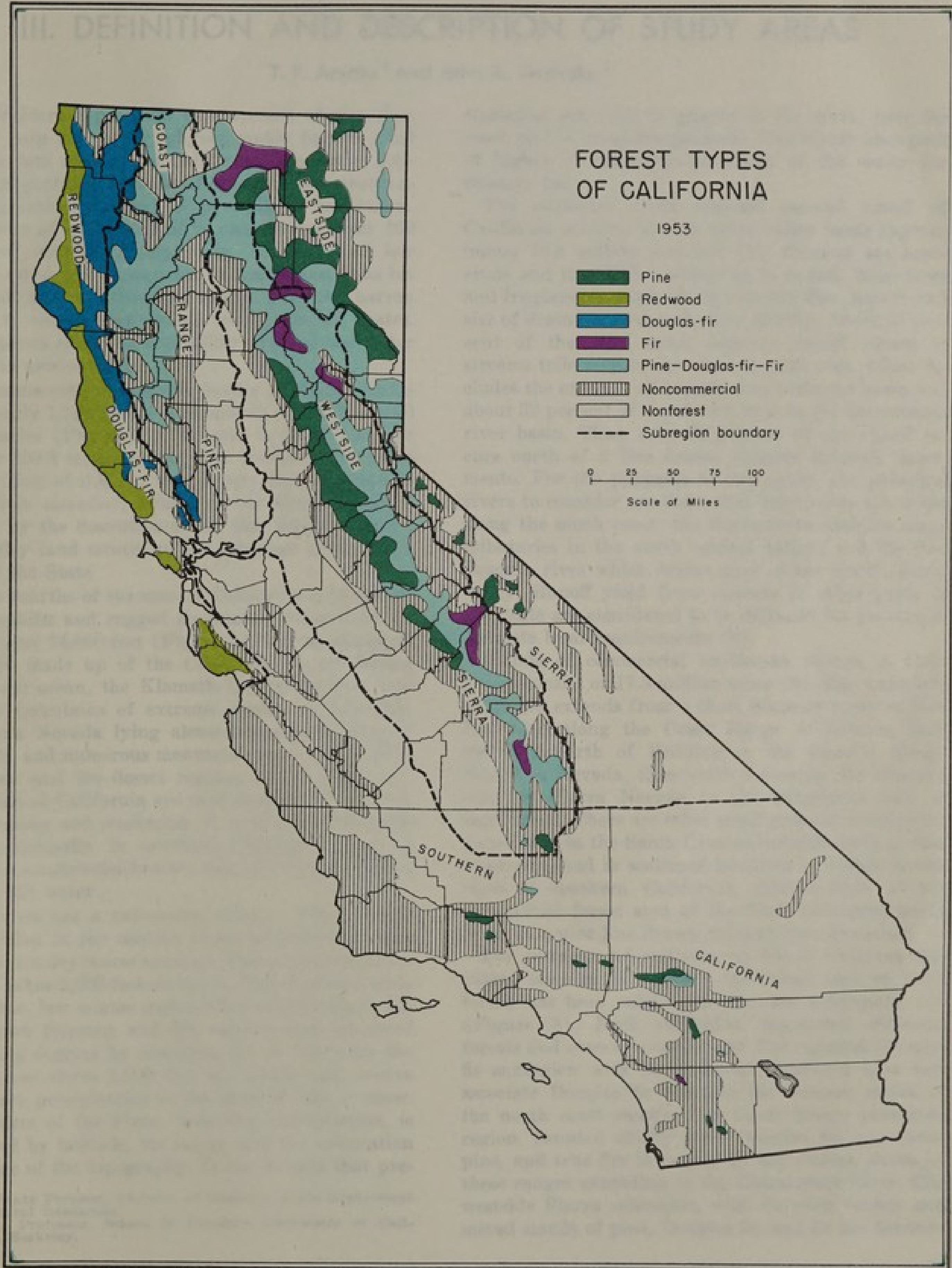

FOREST TYPES
OF CALIFORNIA
1953
Pine
Redwood
Douglas-fir
Fir
Pine-Douglas-fir-Fir
Noncommercial
Nonforest
Subregion boundary
0 25 50 75 100
Scale of Miles
REDWOOD
COAST
RANGE
DOUGLAS-FIR
PINE
EASTSIDE
WESTSIDE
SIERRA
SIERRA
SOUTHERN
CALIFORNIA

FIGURE 3

III. DEFINITION AND DESCRIPTION OF STUDY AREAS

T. F. Arvola[1] and John A. Zivnuska[2]

In considering potential development of manufacture of pulp and paper, physiographic factors must be taken into account. In California they are of particular importance because of the extremes encountered—extensive valleys to precipitous mountains, large areas of little rainfall to ones having over 100 inches of seasonal precipitation, drainages of low runoff to streams of maximum instantaneous flows between 500 and 700 thousand second feet, and barren deserts to the densest forests in the United States. These factors affect the availability of wood and water needed to produce pulp.

California extends from the border of Mexico northward nearly 1,000 miles; it ranges in width from 150 to 375 miles (Figure 1). The area is 156,803 square miles or 100.3 million acres. One fourth of the State is level. Most of this flat land is between sea level and 500 feet in elevation, located in the Central Valley, drained by the Sacramento and San Joaquin rivers. This valley land comprises the principal agricultural areas of the State.

Three fourths of the area of California is in rolling hills, foothills and rugged mountains rising to elevations of over 14,000 feet (Figure 2). The mountainous lands are made up of the Coast Ranges paralleling the Pacific ocean, the Klamath-Trinity-Siskiyou and Cascade mountains of extreme northern California, the Sierra Nevada lying along the eastern edge of the State, and numerous mountain ranges in southern California and the desert regions. The foothills and mountains of California are used extensively for livestock grazing and recreation. It is in these mountain areas, principally in northern California there is found the commercial forests, and here also originates most of the water.

California has a two-season climate, with rainfall concentrated in the months from November through April, and a dry warm summer. The warm temperate belt lies below 2,000 feet elevation. Here is found little or no snow, few winter nights when temperatures fall much below freezing, and dry summer heat tempered in varying degrees by maritime air or fogs near the coast. Areas above 2,000 feet are colder and receive much more precipitation in the form of rain or snow. The climate of the State, including precipitation, is influenced by latitude, the ocean, and the orientation and range of the topography. It can be said that precipitation generally is greater in the north, near the coast, and in mountainous areas. The winter snowpack of higher elevations yields much of the water for summer use.

The estimated mean seasonal natural runoff of California streams as they enter valley lands approximates 70.8 million acre-feet (1). Streams are numerous and they differ widely as to runoff, flood flows and frequencies, variation in monthly flow, nature and size of drainage area, and water quality. About 41 percent of the total mean seasonal runoff occurs in streams tributary to the north coastal area, which includes the extensive Klamath river drainage basin, and about 32 percent of the state's total in the Sacramento river basin. Thus, over 72 percent of the runoff occurs north of a line drawn roughly through Sacramento. For the purposes of this study, the principal rivers to consider are those that empty into the ocean along the north coast; the Sacramento with its many tributaries in the north central valley; and the San Joaquin river which drains most of the south central valley. Runoff yield from streams in other parts of the State are considered to be deficient for present or ultimate local requirements (2).

Stands of commercial coniferous timber in California consist of 17.3 million acres (3). The main belt of timber extends from a short distance north of San Francisco along the Coast Range to Oregon, then eastward north of Redding to the Cascade Range almost to Nevada, then south following the Cascade and the Sierra Nevada to the mountains east of Bakersfield. There are other small areas of commercial forest land in the Santa Cruz mountains south of San Francisco, and in scattered locations in higher mountains of southern California. Almost 91% of the commercial forest area of the State is located north of an east-west line drawn through San Francisco.

For purposes of statistics on forest resources discussed later in this report, the forest land of California has been subdivided into five subregions (3) (Figure 3). Each subregion represents different forests and economic conditions. The redwood-Douglas fir subregion with its distinctive redwood type and associate Douglas fir occupies the western slopes of the north coast ranges. The Coast Range pine subregion, forested chiefly with Douglas fir, ponderosa pine, and true firs is located on the eastern slopes of these ranges extending to the Sacramento River. The westside Sierra subregion, with its pine forests and mixed stands of pine, Douglas fir, and fir lies between

[1] Deputy State Forester, Division of Forestry, State Department of Natural Resources.
[2] Associate Professor, School of Forestry, University of California, Berkeley.

the central valley and the Cascade-Sierra Nevada divide. The eastside Sierra subregion, with its slow-growing, predominantly pine forests, is situated to the east of this divide. The southern California subregion includes the remainder of the State; its widely scattered pine and fir stands are devoted primarily for recreation and watershed protection and but little for timber production.

Forest Resources and Development

The 17.3 million acres of commercial forest land in California represent 3.6 percent of the nation's commercial forest area, but the State's present position as a source of supply for the forest industries is far more important than this relative area might suggest. About 11 million acres of the State's forests are still stocked with old growth timber. Although a considerable part of these old-growth stands have been partially cut, the volume of timber remains very high. Many of the areas of excellent young-growth timber also have high volumes. As a result California ranks second among the states in standing timber inventory, with 20 percent of the nation's volume of sawtimber and 13½ percent of the volume of timber of all sizes. These volumes are predominantly in valuable softwood species. In 1952 California cut 5.7 billion board feet of sawtimber (3), amounting to 12 percent of the national cut (4). In terms of cubic foot volume of timber of all sizes, the cut was 9 percent of the national total.

At present California ranks second among the states in volume of lumber production, third in the volume of softwood plywood production, but twenty-third in installed wood pulp capacity. In 1952 the State produced 12½ percent of the national volume of sawlogs used by the lumber industry, 11 percent of the veneer logs, but only 1 percent of the nation's pulpwood. As these figures indicate, California's forest industries are based primarily on a single product, lumber. In 1952 lumber took 92 percent of the State's cut, plywood 6 percent, and all other products 2 percent.

Although largely limited to lumber, the forest industries occupy an important position among the basic industries of the State, especially in the northern part. Lumber production is carried on in at least forty of the counties, but three-fourths of the production is in ten of the northern counties. In a number of these counties lumber is the dominant basic industry and the principal support of the widely varied service industries. Rapid expansion in the forest industries has been one of the major sources of the expanded economic base for the greatly increased population of this part of the State. California's lumber production has nearly doubled from the 1946 output of 2.7 billion board feet to the current level of over 5 billion board feet.

The current rate of cutting is roughly double the current rate of growth of sawtimber. Some excess of cut-over growth is logical and necessary in the present situation of the State's forests, in which the large remaining areas of uncut old-growth timber make little contribution to net growth. However, there is substantial evidence to indicate that the cut from California forests has reached a plateau level and that further significant increases in the volume of cut are not likely. Further expansion of the forest industries to contribute to the support of the expanding population and to add to the supply of needed forest products in the State must come primarily from increased use of the timber which is cut rather than from additional increases in the volume of cutting.

To meet this situation will require a major diversification of forest products output in California and an integration of the complementary forms of production. It is estimated that the output of dressed lumber from pine and fir logs represents only 47 percent of the cubic-foot volume of the logs brought to the mills, while for redwood the corresponding factor is 37 percent (5). In addition, it is estimated that 18 percent of the cubic-foot volume cut is left in the forest due to problems of size and quality. Thus the volume of wood appearing in saleable products is somewhat less than 40 per cent of the total cubic-foot volume cut, with the balance remaining in logging and milling residues. Generally these residues do not represent economic waste by the individual operators, because these are materials of a size and quality for which markets do not now exist in California. The economic waste, if any, in this situation lies in any factors which may be unnecessarily acting to prevent the development of integrated utilization practices which could obtain economic values from these materials.

Under existing technology the wood pulp industry is particularly promising as a market for such materials. Very rapid progress in the integration of lumber and pulp production has been made in the Pacific Northwest in recent years, while the limited pulp capacity in California at present is based almost entirely on residues and materials of quality too low for other uses. It is through diversified utilization of such types which enable the fuller and more economical use of the timber cut that any future expansion of California's important forest industries must lie.

It is also important to note that California represents a major and rapidly expanding market for products based on wood pulp. A recent study of long term trends in the consumption of forest products in the United States prepared by Stanford Research Institute (6) predicts that the national consumption of all grades of paper and paperboard will rise to 53.5 million tons by 1975. This consumption level is equivalent to 41.2 million tons of pulp, to which must be added a predicted 1.8 million tons of pulp consumption in non-paper products. Prorating the total of 43 millions tons simply on the basis of the anticipated ratio of California population to national population (10.7 percent) indicates a 1975 market in California for products requiring 4.6 million tons of wood pulp. This is 50 percent higher than the total volume of wood pulp produced in the entire western region of the United States in 1952.

Over the long run, of course, the magnitude and success of California's forest industries will be determined by the management given the forests on which they are based. Here, too, diversified markets and integrated utilization appear essential. The management of a forest property on a permanent basis necessarily results in the production of wood in trees and logs of a very wide range of sizes and qualities. Such management becomes economical only when diversified markets enable recovery of a high proportion of the values in both quantity and quality which are potentially present. The values involved in the establishment of diversified wood-using industries in California are not simply those of the additional concerns or the particular industry. The stake at issue is the development of a better balanced and expanded economic basis for the forested areas of the State. The long term future of the established lumber industry is also involved. Only a sound, well balanced, and widely diversified group of forest industries can provide the necessary economic setting for the intensive management of the forests of California and the attendant values of expanding employment, useful products, a pleasant environment for outdoor recreation, and healthy conditions on the timbered watersheds.

IV. FIBER RESOURCES

T. F. Arvola,[1] L. N. Ericksen,[2] and E. V. Roberts[3]

The fiber resources of California are well suited to expansion of the pulp industry. The State's 360 billion board feet of sawtimber is one of the nation's largest remaining blocks of old-growth timber. Though much of it is of the size and quality prized by the lumber and veneer industries, a large volume is available for pulping. A great deal is in trees that should be harvested—overmature trees that are easy prey to forest pests, young trees too crowded for good growth, cull and dead trees, and species of little value for lumber. Time will be needed to bring some of this material to market; time to build access roads and to create economic conditions favoring more intensive harvests. But right now unused wood residues are available from sawmilling and logging to supply several large pulp mills.

Forest Area

California has 42.5 million acres of forest land (Table 1). Of this, 17.3 million acres are growing or are capable of growing usable crops of wood. The other 25.2 million acres are classified as noncommercial. Most of this noncommercial forest land is incapable of producing timber of sawtimber quality because of poor growing conditions and is occupied by chaparral and a mixed cover of hardwoods, noncommercial conifers, and grass. The other 1.2 million acres of noncommercial forest land are productive forest lands withdrawn from timber utilization as parks and wilderness areas. The 17.3 million acres of commercial forest land are concentrated in an inverted U-shaped band around the northern end of the Central Valley (Figure 3). Fifty-three percent of this land is in Siskiyou, Humboldt, Trinity, Mendocino, Shasta and Plumas counties, listed in order of importance by forest area.

Forest Types

Forty-five percent of the commercial forest land is occupied by mixed stands of ponderosa, Jeffrey, and sugar pines, Douglas fir, white fir, and incense cedar in varying combinations and proportions (Table 1). This pine-Douglas fir-type is located at elevations

[1] Deputy State Forester, Division of Forestry, State Department of Natural Resources.
[2] Chief, Division of Forest Utilization, California Forest and Range Experiment Station, U. S. Forest Service.
[3] Chief, Division of Forest Economics, California Forest and Range Experiment Station, U. S. Forest Service.

TABLE 1

TOTAL LAND AREA IN THE FOREST SUBREGIONS OF CALIFORNIA BY COVER TYPE AND USE, 1953

Cover types and use	Thousand acres					
	California	Subregions				
		Eastside Sierra	Westside Sierra	Coast Range pine	Redwood-Douglas fir	Southern California
Commercial forest land						
Pine	3,928	1,833	1,715	213	10	157
Redwood	1,929	--	--	--	1,918	11
Douglas fir	2,481	--	--	476	2,005	--
Fir	990	348	505	90	39	8
Pine-Douglas fir-Fir	7,775	1,641	3,390	2,423	266	55
Lodgepole pine	214	97	117	--	--	--
Total commercial	17,317	3,919	5,727	3,202	4,238	231
Noncommercial forest land						
Productive-reserved	1,202	113	640	250	186	13
Unproductive	24,022	3,045	6,638	3,478	1,382	9,479
Total noncommercial	25,224	3,158	7,278	3,728	1,568	9,492
Total forest land	42,541	7,077	13,005	6,930	5,806	9,723
Nonforest land	57,773	10,970	9,126	2,934	1,772	32,971
All land	100,314	18,047	22,131	9,864	7,578	42,694

SOURCE: Forest Survey Release No. 25.

of 4,000 to 7,000 feet, primarily in the westside Sierra and Coast Range pine subregions.

The pine type covers 23 percent of the commercial forest land. Composed predominantly of ponderosa and Jeffrey pine stands, this type is concentrated in the Sierra subregions at elevations of 1,000 to 5,000 feet.

The Douglas fir type covers 14 percent of the commercial forest area of the State. Located at elevations of 50 to 6,000 feet, this type occurs primarily in the redwood-Douglas fir subregion but also in the adjacent Coast Range pine subregion.

The true fir and lodgepole pine types, located at elevations generally above 5,000 feet, occupy 1.2 million acres of commercial forest land. These types occur chiefly in the Sierra subregions.

The redwood type—composed of stands of redwood and associated Douglas fir—is located in a narrow belt bordering the Pacific Ocean at elevations varying from sea level to 3,000 feet.

Ownership

A little more than half of the commercial forest land—9.3 million acres—is in public ownership (Table 2). National forests compose 93 percent of the publicly-owned timber producing land. Public agencies own about three-fifths of the commercial forest land in each of the major forest regions of the State except the redwood-Douglas fir subregion. In this subregion only 31 percent of the commercial forest land is publicly owned.

Privately owned commercial forest land totals 8.1 million acres. Eighty percent of this is in industrial and other nonfarm holdings. The other 20 percent is located on ranches and farms. In California, 3.1 million acres of commercial forest land are in 16 industrial holdings (4). Large timberland holdings of this nature are an important consideration in the expansion of the pulp industry. To justify heavy plant investment a pulp producer must be assured of a large supply of timber over a long period of time. The stable nature of much of California's timberland ownership indicates that growth of the pulp industry will require integration with already established large-scale sawmill and plywood operations or outright purchase of timberlands adequate to support a pulp operation. Most of the large industrial holdings are in the northern part of the State.

Stand-size Classes

Logging operations have been active in California for more than a century, yet 11.2 million acres, or almost two-thirds of the timber producing land, are still occupied by old-growth sawtimber stands (Table 3). Some of these stands are partially cut but contain enough volume in mature and overmature trees to be classified as old-growth. Young-growth sawtimber stands occur on an additional 2.8 million acres. Thus, 81 percent of the commercial forest land supports sawtimber stands.

Pole timber and seedling and sapling stands occupy only 1.2 million acres, 7 percent of the commercial forest area. This low proportion reflects the methods of cutting normally applied. On national forests light cuttings removing overmature poor-risk trees are the general rule. On private lands selective cutting is generally applicable and the state forest practice rules establish minimum cutting diameters or require that seed trees be left. Consequently, most cutover areas retain sufficient standing timber to remain in the sawtimber classification.

The remaining 2.1 million acres are classified as nonstocked. This nonstocked area originally supported stands of merchantable timber which have since been burned-over and cut-over until only scattered trees or groups of commercial conifers remain. Today, much of this area is covered with dense stands of chaparral and poor-quality hardwoods. The nonstocked lands offer opportunity for increasing future timber sup-

TABLE 2

OWNERSHIP OF COMMERCIAL FOREST LAND BY SUBREGION, CALIFORNIA, 1953

Subregion	Thousand acres								
	Total all ownerships	Federally owned or managed					State	County and municipal	Private
		Total federal	National forest	Indian	Bureau of Land Mgt.	Other			
Eastside Sierra	3,919	2,426	2,376	8	42	[1]	10	[1]	1,483
Westside Sierra	5,727	3,270	3,148	6	78	38	20	--	2,437
Coast Range Pine	3,202	2,019	1,897	14	107	1	54	1	1,128
Redwood-Douglas fir	4,238	1,207	1,006	103	97	1	102	7	2,922
Southern California	231	148	146	2	[1]	--	--	--	83
California	17,317	9,070	8,573	133	324	40	186	8	8,053

[1] Less than 500 acres.
SOURCE: Forest Survey Release No. 25.

TABLE 3

OWNERSHIP OF COMMERCIAL FOREST LAND BY STAND-SIZE CLASS, CALIFORNIA, 1953

Stand-size class	Thousand acres		
	Total all ownerships	Public	Private
Old-growth sawtimber	11,240	6,919	4,321
Young-growth sawtimber	2,798	799	1,999
Pole timber and seedlings and saplings	1,166	524	642
Nonstocked	2,113	1,022	1,091
All classes	17,317	9,264	8,053

SOURCE: Forest Survey Release No. 25.

plies providing satisfactory methods of planting them can be developed.

Throughout the long history of logging in California, timber operations have occurred predominantly on the 8.1 million acres of privately-owned commercial forest land. Because most private holdings were acquired before national forests were established, these operations have been in the better and most accessible timber stands.

Old-growth sawtimber stands thus occupy only 54 percent of the private commercial forest land in contrast to 75 percent of the publicly owned. Young-growth sawtimber stands occur on 25 percent of the commercial forest land in private holdings and on only 9 percent in public ownership.

Stocking

In California, 35 percent of the commercial forest land is well-stocked with present or potential growing stock (Table 4). Another third is medium-stocked. The remainder of the commercial forest land (31 percent) is either poorly-stocked or nonstocked with commerical conifers.

TABLE 4

DEGREE OF STOCKING ON COMMERCIAL FOREST LAND BY STAND-SIZE CLASS, CALIFORNIA, 1953

Stand-size class	Thousand acres				
	All areas	Degree of stocking			
		Well-stocked	Medium-stocked	Poorly-stocked	Non-stocked
Old-growth sawtimber	11,240	4,808	4,609	1,823	
Young-growth sawtimber	2,798	1,029	872	897	
Pole timber and seedlings and saplings	1,166	196	451	519	
Nonstocked	2,113				2,113
All classes	17,317	6,033	5,932	3,239	2,113

SOURCE: Forest Survey Release No. 25.

Best stocking occurs on the sawtimber areas, poorest on the pole timber and seedling and sapling areas. About 40 percent of the old-growth sawtimber area is well-stocked. Almost equal segments of the young-growth sawtimber stands are well-, medium-, and poorly-stocked. The timber on these lands—combined with the young trees in the old-growth stands—comprise the sawtimber supply of the future. Only 17 percent of the pole-timber and seedling and sapling stands are well-stocked.

Site Quality

About one-third of the commercial forest land of the State is rated highly productive for timber growing (Table 5). An additional 47 percent is rated medium in productivity. Only 18 percent is poor timber-growing land.

TABLE 5

SITE QUALITY OF COMMERCIAL FOREST LAND BY TIMBER TYPE, CALIFORNIA, 1953

Timber type	Thousand acres			
	Total	Site quality		
		High	Medium	Low
Pine	3,928	673	2,094	1,161
Redwood	1,929	1,561	337	31
Douglas fir	2,481	1,323	930	228
Fir	990	205	565	220
Pine—Douglas fir—Fir	7,775	2,305	4,139	1,331
Lodgepole pine	214		70	144
All types	17,317	6,067	8,135	3,115
Percent	100	35	47	18

SOURCE: Forest Survey Release No. 25.

Productivity of the timberland in the different timber types shows wide variation. The proportion of high site class is greatest in the redwood type. Eighty-one percent of the area in this type is rated highly productive. Fifty-three percent of the Douglas fir type is rated high in site quality. The great timber-growing capacity of the redwood and Douglas fir types is further emphasized by the paucity of low site, namely: 2 and 9 percent respectively. The pine type has the lowest proportion of high site of all the types except lodgepole pine. This condition reflects the low timber-producing capacity of the pine type in the eastside Sierra subregion. The pine-Douglas fir-fir type, which comprises about half of the commercial forest land in California, is rated 30 percent highly productive and 53 percent of intermediate productivity for growing timber crops. The lodgepole pine type, unimportant in both timber producing area and current timber products output, is found preponderantly on low site timberland.

Sawtimber Volume

In 1953, the net live sawtimber volume on the commercial forest land in California was 360 billion board feet. This volume estimate includes all merchantable conifer and hardwood trees, 11.0 inches and larger in diameter, after allowance for cull and breakage and without consideration of current availability for utilization. Part of this volume is in inaccessible stands, in young or scattered stands at present not economically operable or on areas in which watershed management, recreation or other uses curtail timber operations.

Almost one-third (117 billion board feet) of the live sawtimber volume of California is Douglas fir, located primarily in the redwood-Douglas fir subregion (Table 6). The true firs—white, California red, and grand fir—contain about 89 billion board feet; ponderosa and Jeffrey pine, another 67 billion board feet. These species plus redwood (36 billion board feet) and sugar pine (27 billion board feet) account for more than 90 percent of the State's sawtimber volume. The total live sawtimber volume of hardwoods is 6 billion board feet, principally tanoak and California black oak.

Forty-one percent of the live sawtimber volume in California is in trees 41.0 inches and larger in diameter (Table 6). Two species, redwood and sugar pine, have more than half of their board-foot volume in this largest diameter class. Only 11 percent of the total volume of all species is in the smallest diameter class, 11.0 to 20.9 inches. Forty-two percent of the board-foot volume in hardwoods is in this smallest class.

Eighty-five percent (306 billion board feet) of the State's sawtimber volume is in old-growth sawtimber stands (Table 7). These stands contain a large volume of mature and overmature timber, which is ready for harvesting to make lumber, plywood, and other high-quality timber products. But much of this volume, particularly on the national forests, is still in inaccessible timber stands.

In California fifty-four percent (194 billion board feet) of the live sawtimber volume is on publicly-owned commercial forest land (Tables 7 and 8). National forests contain 92 percent of this volume, primarily in old-growth sawtimber stands. The other publicly-owned sawtimber volume, 15 billion board feet, is chiefly on Bureau of Indian Affairs, Bureau of Land Management, and state holdings. Minor volumes occur on other federal, county and municipal holdings. Public ownership of commercial forest is prevalent in all major timber regions of the State, except the redwood-Douglas fir subregion.

The privately-owned sawtimber volume (166 billion board feet) is mostly on industrial and other nonfarm ownerships. Three-fourths of this volume is in old-growth sawtimber stands. About half the privately-owned sawtimber volume is in the redwood-Douglas fir subregion.

TABLE 6

LIVE SAWTIMBER VOLUME ON COMMERCIAL FOREST LAND BY DIAMETER CLASS GROUPS AND SPECIES, CALIFORNIA, 1953

Species	Million board feet[1]				
	Total	Diameter class groups			
		11.0-20.9 inches	21.0-30.9 inches	31.0-40.9 inches	41.0 inches and larger
Douglas fir	116,912	9,171	23,033	28,750	55,958
True firs	88,724	11,474	25,455	24,933	26,862
Ponderosa pine[2]	66,741	7,533	17,136	21,184	20,888
Redwood	36,124	3,358	4,490	4,438	23,838
Sugar pine	27,384	1,621	4,072	5,788	15,903
Other softwoods	18,139	4,728	5,330	4,457	3,624
Hardwoods	5,977	2,499	2,328	977	173
Total	360,001	40,384	81,844	90,527	147,246

[1] Log scale, International ¼-inch rule.
[2] Includes Jeffrey pine.
SOURCE: Forest Survey Release No. 25.

TABLE 7

OWNERSHIP OF LIVE SAWTIMBER VOLUME ON COMMERCIAL FOREST LAND BY STAND-SIZE CLASS, CALIFORNIA, 1953

Stand-size class	Million bd. ft.								
	Total all ownerships	Federally owned or managed					State	County and municipal	Private
		Total federal	National forest	Indian	Bureau of Land Mgt.	Other			
Old-growth sawtimber	305,691	175,467	166,889	3,639	4,668	271	4,123	182	125,919
Young-growth sawtimber	45,786	10,232	8,973	268	918	73	337	11	35,206
Pole timber and seedling and saplings	4,308	1,569	1,439	24	101	5	40	1	2,698
Nonstocked	4,216	1,801	1,612	38	130	21	47	1	2,367
All classes	360,001	189,069	178,913	3,969	5,817	370	4,547	195	166,190

SOURCE: Forest Survey Release No. 25.

TABLE 8

OWNERSHIP OF LIVE SAWTIMBER ON COMMERCIAL FOREST LAND BY SUBREGION, CALIFORNIA

Subregion	Million board feet		
	Total all ownerships	Public	Private
Eastside Sierra	40,685	25,482	15,203
Westside Sierra	124,350	81,493	42,857
Coast Range Pine	62,579	42,792	19,787
Redwood—Douglas fir	130,443	42,845	87,598
Southern California	1,944	1,199	745
Total	360,001	193,811	166,190

SOURCE: Forest Survey Release No. 25.

All Timber Volume

The timber volume in the sawlog portion of sawtimber trees is of primary importance as a source of lumber and veneer although an active pulpwood market could draw a substantial volume of low grade or marginal logs to this use. There is, however, additional tree volume (on commercial forest areas) that is at present largely unused and that offers opportunity for fiber production. The volume in the upper stems of sawtimber trees is nearly 8 billion cubic feet (Table 9). This is equivalent to 14 percent of the volume in the sawlog portion of these trees. Of course, this material is only available for use after harvesting of the sawlogs. An additional 5 billion cubic feet is in pole timber trees (sound trees 5-11 inches in diameter). These trees are the sawtimber supply of the future, but thinnings from overstocked stands are a potential pulpwood source. The volume in cull trees, salvable dead trees and hardwood tops make up 3 billion cubic feet which could also be used for fiber production. Removal of the cull and dead trees would provide a source of wood without reduction in growing stock and would be beneficial to the development of the timber stands.

Growth

Average annual net growth on the commercial forest land in California is 2.9 billion board feet (Table 10). This is equivalent to an average annual net growth per acre of 170 board feet. Average annual per acre mortality is 107 board feet.

In 1952, young-growth sawtimber stands showed the highest net growth rate, 322 board feet per acre (Table 10). Old-growth sawtimber stands had a net annual growth per acre of 157 board feet. But, equally important, mortality losses in these old-growth stands amounted to 149 board feet per acre.

Mortality currently claims a heavy toll from California's timber supply. Annual timber loss from insects, diseases, fire and other causes is 1.9 billion board feet. This loss is equivalent to 36 percent of the volume of timber products harvested. Forest insects are the primary killers of forest trees. Some of this wood is converted to usable products through salvage operations, but much of this timber is a complete loss. A strong market for pulpwood would greatly increase the possibilities of salvaging dead and dying trees.

About 92 percent of the sawtimber growth in California in 1952 occurred on the seven leading species: Douglas fir, the true firs, ponderosa and Jeffrey pines, redwood, and sugar pine (Table 11). The leading species was Douglas fir, with an annual growth of 787 million board feet. The true firs, with an annual growth of 780 million board feet, were a close second.

Two subregions produce most of the net forest increment in the State, westside Sierra and redwood-

TABLE 9

ALL TIMBER VOLUME ON COMMERCIAL FOREST LAND BY SPECIES AND CLASS OF MATERIAL, CALIFORNIA, 1953

Class of material	Million cubic feet							
	Total	Ponderosa and Jeffrey pine	Sugar pine	Redwood	Douglas fir	True firs	Other softwoods	Hardwoods
Growing stock								
Sawtimber trees								
Sawlog portion	53,668	9,617	3,913	5,328	17,165	13,564	2,869	1,212
Upperstem	7,788	1,681	391	818	2,623	1,612	663	--
Total	61,456	11,298	4,304	6,146	19,788	15,176	3,532	1,212
Pole timber trees	4,955	637	128	214	970	923	548	1,535
Total growing stock	66,411	11,935	4,432	6,360	20,658	16,099	4,080	2,747
Other material[1]	3,220	119	50	226	556	180	75	2,014
Total	69,631	12,054	4,482	6,586	21,314	16,279	4,155	4,761

[1] Other material includes the net cubic foot volume in cull trees, salvable dead trees, and hardwood limbs.
SOURCE: Forest Survey Release No. 25.

Douglas fir subregions. These are also the areas of greatest timber use.

TABLE 10

AVERAGE ANNUAL GROWTH OF LIVE SAWTIMBER ON COMMERCIAL FOREST LAND BY STAND-SIZE CLASS, CALIFORNIA, 1953

Stand-size class	Million board feet		Board feet	
	Total		Average per acre	
	Gross	Net	Gross	Net
Old-growth sawtimber	3,435	1,769	306	157
Young-growth sawtimber	1,029	900	368	322
Pole timber and seedlings and saps	237	202	203	173
Nonstocked	103	68	49	32
All classes	4,804	2,939	277	170

SOURCE: Forest Survey Release No. 25.

TABLE 11

AVERAGE ANNUAL NET GROWTH OF LIVE SAWTIMBER ON COMMERCIAL FOREST LAND BY SPECIES AND BY SUBREGION, CALIFORNIA, 1952

Species	Million board feet					
	All sub-regions	East-side Sierra	West-side Sierra	Coast Range pine	Red-wood-Doug-las fir	South-ern Cali-fornia
Softwoods						
Ponderosa and Jeffrey pines	553	60	351	130	4	8
Sugar pine	196	3	158	25	10	--
Redwood	396	--	--	--	396	[1]
Douglas fir	787	19	122	164	482	--
True firs	780	106	550	85	38	1
Other	183	17	76	15	74	1
Total	2,895	205	1,257	419	1,004	10
Hardwoods	44	—1	10	11	24	--
All species	2,939	204	1,267	430	1,028	10

[1] Less than 0.5 billion feet.
SOURCE: Forest Survey Release No. 25.

Annual Cut

Annual cut of live sawtimber from the forest resource during 1952 was 5.7 billion board feet (Table 12). Of this, 5.3 billion board feet was removed from the sawtimber growing stock as sawlogs and other products, and 0.4 billion board feet was left in the woods as logging residue. The total cut from the national forests of California during the same year was 0.7 billion board feet.

The bulk (80 percent) of the annual cut in California comes from three species: Douglas fir, ponderosa pine (including Jeffrey), and redwood (Table 13). In 1952, the cut of Douglas fir comprised 40 percent of the total for the State or about twice that for the next most important species, ponderosa pine.

Net Growth vs. Annual Cut

In 1952, annual cut from the forests of California was almost twice the annual sawtimber growth (Tables 11 and 13). For Douglas fir the ratio was 3 to 1. And, for other valuable species—redwood and ponderosa pine—about two and a half times as much sawtimber volume was being removed as grown. Growth of the less valuable true firs was greater than the cut.

In California, annual cut can be expected to exceed growth for the next few decades because of a large proportion of the sawtimber volume in mature and overmature trees which must be harvested to avoid heavy insect and disease losses and to make room for younger stands. Because of the large size and high

TABLE 12

ANNUAL CUT OF LIVE SAWTIMBER ON COMMERCIAL FOREST LAND BY PRODUCT AND BY SUBREGION, CALIFORNIA, 1952

Subregion	Million board feet				
	All prod-ucts	Saw-logs	Veneer logs and bolts	Pulp-wood logs	Other prod-ucts[1]
Eastside Sierra	759	745	12	1	1
Westside Sierra	1,589	1,544	34	3	8
Coast Range pine	519	506	12	0	1
Redwood-Douglas fir	2,856	2,479	274	56	47
Southern California	8	8	0	0	0
California	[2]5,731	5,282	332	60	57

[1] Cooperage, fuelwood, poles, piling, round mine timbers, fence posts, hewn ties, shingles, and miscellaneous.
[2] Includes 462 million board feet of logging residue.
SOURCE: Forest Survey Release No. 25.

TABLE 13

ANNUAL CUT[1] OF LIVE SAWTIMBER ON COMMERCIAL FOREST LAND BY SUBREGION AND SPECIES, CALIFORNIA, 1952

Species	Million board feet					
	All sub-regions	East-side Sierra	West-side Sierra	Coast Range pine	Red-wood-Doug-las fir	South-ern Cali-fornia
Softwoods						
Douglas fir	2,338	56	255	240	1,786	1
Ponderosa and Jeffrey pines	1,274	450	604	191	24	5
Redwood	988	0	[2]2	0	985	1
True firs	663	209	403	29	21	1
Sugar pine	324	28	233	56	7	[3]
Others[4]	124	16	89	3	16	0
Hardwoods	20	0	3	[3]	17	0
All species	5,731	759	1,589	519	2,859	8

[1] Includes logging residue.
[2] Giant sequoia.
[3] Less than 0.5 million board feet.
[4] Incense cedar; Port Orford white and western red cedars; Sitka spruce; western hemlock; lodgepole and western white pines.
SOURCE: Forest Survey Release No. 25.

TABLE 14

ESTIMATED VOLUME OF RESIDUES FROM PRIMARY WOOD-USING PLANTS BY KIND OF PLANT, REGION, AND UTILIZATION, CALIFORNIA, 1952

Origin by kind of plant and region	Million cubic feet[1]									
	Used			Unused			All residue			
									Total	
	Coarse	Fine	Total	Coarse	Fine	Total	Coarse	Fine	Vol.	Pct.
Sawmills[2]										
Pine region	42.1	38.3	80.4	72.5	27.8	100.3	114.6	66.1	180.7	49
Redwood region	29.7	23.2	52.9	86.6	37.6	124.2	116.3	60.8	177.1	48
Total	71.8	61.5	133.3	159.1	65.4	224.5	230.9	126.9	357.8	97
Veneer plants[3]										
Pine region	2.6	0.3	2.9	0.3	[4]	0.3	2.9	0.3	3.2	1
Redwood region	5.2	0.9	6.1	2.8	0.2	3.0	8.0	1.1	9.1	2
Total	7.8	1.2	9.0	3.1	0.2	3.3	10.9	1.4	12.3	3
Other plants[5]										
Pine region	[4]	[4]	[4]	[4]	[4]	[4]	[4]	[4]	[4]	[4]
Redwood region	0.4	0.8	1.2	0.1	0.2	0.3	0.5	1.0	1.5	--
All plants										
Pine region	44.7	38.6	83.3	72.8	27.8	100.6	117.5	66.4	183.9	50
Redwood region	35.3	24.9	60.2	89.5	38.0	127.5	124.8	62.9	187.7	50
Total volume	80.0	63.5	143.5	162.3	65.8	228.1	242.3	129.3	371.6	--
Percent of total	21	17	38	44	18	62	65	35	--	100

[1] Solid wood equivalent.
[2] Sawmills and integrated planing mills.
[3] Veneer plants, including integrated plywood plants.
[4] Less than 50,000 cubic feet.
[5] Shingle (including sawn shake), pulp and cooperage plants.
SOURCE: Technical Paper No. 13, California Forest and Range Experiment Station.

quality of the timber, most of this cut will continue to be as logs for the production of lumber and veneer. Sawlog size material of too low quality for use in sawmills or of species with low market value will be available for pulpwood. With economic conditions becoming more favorable for the practice of forestry, additional pulpwood supplies will be available through thinning and cleaning operations. However, the principal source of wood supplies for the initial expansion of the pulp industry in California will be mill residues from sawmills and plywood plants and residual material left in the woods after logging.

Mill Residues

The manufacture of lumber and other primary wood products inevitably results in a large volume of residues—slabs, edgings, trimmings, sawdust, shavings, and other material. In 1952, about 370 million cubic feet of residue material was produced at primary forest product plants (Table 14). This material was distributed about equally between the pine and redwood regions.

Coarse residue (slabs, edgings, trimmings, veneer clippings, and veneer cores) suitable for pulping accounted for 242 million cubic feet or 65 percent of the total. Of this, 80 million cubic feet was utilized, primarily as fuel. The other 162 million cubic feet of coarse material was burned as waste. This is a loss in wood equivalent to the annual net growth on 4.8 million acres of California's timber-producing lands.

Not all of this coarse residue can be used economically. Some is produced in plants with too low volume, or too isolated to pay the cost of collecting and transporting the wood to fiber industries. Most of the unused wood is, however, concentrated in four sections of northern California and is strategically located to encourage development of new residue-using industries (Table 15).

In 1952, sawmills were the source of 97 percent of the residues developed in the state. Veneer plants furnished most of the remainder (Table 14). Large mills produced 40 percent of the sawmill residues, and medium and small mills produced about equal parts of the remainder (Table 16). Seventy percent of the residue produced by the large mills was used, as compared with 24 percent for medium and 7 percent for small mills.

Since 1952, both the demand for and the supply of coarse residues from primary wood-using industries have increased. In this same interval, the two major pulp mills in the state have made increased use of wood chips as a source of pulp. Consequently, several

TABLE 15

PRODUCTION AND USE OF COARSE RESIDUE BY AREAS OF CONCENTRATION, CALIFORNIA, 1952

Concentration area[1]	Million cubic feet		
	Volume of coarse residue		
	Produced	Used	Unused
Humboldt	68.8	20.8	48.0
Mendocino	40.0	9.7	30.3
Upper Sacramento	37.8	13.2	24.6
Lower Sacramento	35.7	15.9	19.8
Rest of state	60.0	20.4	39.6

[1] The principal concentration areas are: (a) the Humboldt area, consisting of Humboldt and western Trinity counties; (b) the Mendocino area, consisting of Mendocino, Lake and northern Sonoma counties; (c) the Upper Sacramento Valley, within a 75-mile radius of Redding; and (d) the Lower Sacramento Valley, within a 75-mile radius from Sacramento.
SOURCE: Technical Paper No. 13, California Forest and Range Experiment Station.

TABLE 16

PRODUCTION AND USE OF WOOD RESIDUE BY SIZE OF SAWMILL, CALIFORNIA, 1952

Mill size class[1]	Million cubic feet		
	Volume of all wood residues		
	Produced	Used	Unused
Large	144.0	100.6	43.4
Medium	103.4	24.5	78.9
Small	110.4	8.2	102.2
Total all sawmills	357.8	133.3	224.5

[1] Sawmill size classes are defined as follows: Large—mills producing 25.0 and more million board feet of lumber annually. Medium—mills producing 10.0 to 24.9 million board feet of lumber annually. Small—mills producing 9.9 and less million board feet of lumber annually.
SOURCE: Technical Paper No. 13, California Forest and Range Experiment Station.

sawmills have installed barkers and chippers to provide for this limited demand. A substantial volume of coarse mill residues are still available for expansion of the pulp industry in California. And, more coarse material may become available if it is shown that chips are more valuable for pulp than fuel.

An additional supply of mill residues is produced at secondary wood manufacturing plants, such as planing mills separate from sawmills, moulding plants, flooring mills, furniture factories, and box mills. The volume of material available from this source has not been determined. These secondary plants are centered in Los Angeles and are known to ship some residue to pulp mills and roofing plants.

Logging Residue

As a result of logging operations, some growing stock is destroyed or left in the woods as rough or short logs, upper stems, or damaged trees. In 1952, this logging residue amounted to about 167 million cubic feet (Table 17) or about 22 percent of timber

TABLE 17

ESTIMATED VOLUME OF LOGGING RESIDUE, BY REGION, SPECIES, AND CLASS OF TIMBER, CALIFORNIA, 1952

Region and species	Million cubic feet		
	All timber	Sawtimber trees	Poletimber trees
Pine region			
Pines	26.1	24.7	1.4
True firs	9.3	8.6	0.7
Douglas fir	8.4	7.5	0.9
Other softwoods[1]	7.6	6.7	0.9
Hardwoods	0.9	0.7	0.2
Total	52.3	48.2	4.1
Redwood region			
Douglas fir	74.7	74.2	0.5
Redwood	27.3	27.0	0.3
Other softwoods[2]	2.3	2.1	0.2
Hardwoods	10.2	7.8	2.4
Total	114.2	111.1	3.4
Total	166.8	159.3	7.5

[1] Primarily incense cedar.
[2] Grand fir, Sitka spruce, Port Orford white cedar, western hemlock, etc.

products output in California that year. Much of this material cannot be used by existing mills because of small size or poor quality. Also, this material is scattered, and costs of handling and transporting it are high. Even so, these logs do provide a potential source of raw material for fiber-using plants—particularly if removed in conjunction with a sawlog operation.

Sixty-eight percent of the logging residue occurred in the redwood region. Two-thirds of this material was Douglas fir (Table 17).

Other Pulpwood Sources

Another potential source of pulpwood is the timber on the noncommercial forest land in the State. Extensive stands of blue oak occur in the woodland-grass areas bordering the Central Valley and the valleys of the Coast Range. Small hardwoods and digger pine occupy large portions of the foothill areas. California laurel, cottonwood, and other hardwoods border streams in many parts of the State. Eucalyptus plantations are common in central and southern California. Much of this material is of small size, poor form, and scattered but it has the advantages of being accessible and abundant. It is estimated that these noncommercial forest areas throughout the State contain about 6.5 billion cubic feet of wood.

Species Suitability for Pulping

All of the commercial softwoods and several hardwood species found in California are suitable for pulping by presently used commercial processes.

Douglas Fir—Douglas fir is being pulped in large volume by the kraft (sulfate) process. It produces a good yield of pulp that is notably high in tearing strength but somewhat low in bursting strength. The pulp blends well with pulps that have better bursting strength but lower tearing strength. The unbleached pulp can thus be used for making strong wrapping paper and liner board. The bleached pulp can be used in writing, book, magazine and other white papers and also white paperboards such as milk-carton and other food-container boards.

By pre-treating with alkali or steam, Douglas fir can be ground in pulpwood grinders or fiberized in attrition mills into pulp suitable for shipping-container board. A small amount of Douglas fir is pulped with hardwoods by the neutral sulfite semi-chemical process for use in corrugating board. In California it is being made into hardboard by a process in which wood chips are subjected to high steam pressure for a short period and then "exploded" into loose fiber form by sudden release of the pressure. Separation of the wood fibers is aided by a partial hydrolysis that takes place rapidly under the temperature and pressure involved.

True (White) Firs—White fir, a collective term applied to the western true firs of the genus Abies, includes three important species in California. Grand fir is found in the coastal area of the northwestern part of the State. White fir occurs throughout the coast range, the Sierra Nevada, and south into the mountains of southern California. California red fir is found at higher elevations in the Coast Range and Sierra Nevada. It is mixed with the white fir in the lumber markets.

The white firs can be readily pulped by all of the processes, including sulfite. They yield high quality pulps which, except for red fir, are comparable to spruce pulp. Red fir pulp is somewhat more difficult to bleach but otherwise is of comparable high quality.

Pines—The three commercially important pines in California are ponderosa pine, Jeffrey pine, and sugar pine. Lodgepole pine grows at higher elevations and to date has had very little commercial use.

All of these pines are readily pulped by the alkaline processes. They are also suitable for groundwood and semi-chemical pulps.

The growth ranges of ponderosa pine and Jeffrey pine overlap, the wood of the two species is quite similar, and the lumber produced from them is mixed and distributed as ponderosa pine. No distinction would need to be made so far as pulping properties are concerned.

With the kraft process, all of the pines produce normal yields of high strength pulps with satisfactory bleaching qualities.

Redwood—Redwood can be readily pulped by either the sulfite or kraft processes. Because of operating factors, including relative pollution potentials, it is probable that the kraft process will be used; unless for some specific reason an operator wishes to make sulfite pulp.

With the kraft process, redwood produces pulp of higher bursting strength but with a tearing strength below that of Douglas fir. Pulp yields are lower than normal, due largely to the presence of extractives. Compared to old-growth Douglas fir a recent study showed the percentage yield on a weight basis of unbleached kraft pulp to be about 7 percent lower for redwood old-growth and about 1.5 percent lower for redwood young-growth.

Bleaching qualities are comparable to other softwoods.

Redwood is being used to produce hardboard by the Mason process. At this operation the sugars (produced in the partial steam hydrolysis involved in the process) and the extractives are not run into the river but are disposed of by evaporation and burning.

Hardwoods—A number of California hardwoods are suitable for pulping. They are readily pulped by chemical and semi-chemical processes. They produce typically short-fibered pulps in normal yields. Several are available in volumes that make them of potential importance as pulp species. Among these are eucalyptus, the oaks and tanoak.

For a number of years eucalyptus was used as a fiber for roofing felt. Recently it has come into use in California as a sulfate semi-chemical pulp for a part of the blend in corrugating board. Eucalyptus is used for pulping in Australia, southern Europe, Brazil, and South Africa.

While the other local hardwoods are not being used for pulp in California, experience in other parts of the country demonstrates the suitability of similar woods as pulpwoods.

A mixture of southern red and white oak and cottonwood has been experimentally pulped by the cold soda and neutral sulfite semi-chemical processes to produce satisfactory corrugating board. California oaks would be expected to have similar pulping qualities.

Recent work has shown that kraft pulp comparable in strength to pulp from other hardwoods can be made from tanoak. Because of the high density of the wood and the high yield, the ratio of pulp yield per unit volume of wood is very favorable.

Other local hardwoods have good pulping characteristics but are found in volumes which may be too small for economic pulp operations. Under certain conditions, several might be used in mixture, thereby making a raw material supply sufficient to permit economic operation.

Red alder has been shown to be suitable for the production of kraft, semi-chemical, cold-soda and chemigroundwood pulps.

Western (Rocky Mountain) aspen has much the same characteristics as that from the Lake States when pulped chemically and by the semi-chemical and groundwood processes. Cottonwood is similar to aspen in pulping characteristics. The volume of these two woods is rather small and scattered.

Waste Paper, Rags, and Other Fibrous Materials

The major secondary fiber used in the manufacture of paper products is waste paper. Rags and other fiber materials are used to a lesser extent. Nationally, the pulp and paper industry consumed over 8.4 million tons of waste paper and some 1.3 million tons of rags and other miscellaneous fibers (such as straw, cotton linters, etc.) in 1953. This tonnage represented 34.4 percent of the total fiber that went into paper and board that year (7).

Data of this nature are not available by states. It is not likely that much fiber of this sort from California goes at present into pulp production. Nonetheless, these resources exist here, have potential value, and should not be overlooked.

The magnitude of this potential source of raw material in California can be roughly estimated by assuming that this State can furnish that percentage of fiber (other than wood utilized for pulp each year in the United States) as represented by its proportionate share of the nation's population (8.1%—1956). If that premise can be accepted, it would appear that California can produce annually about 800 thousand tons of waste paper, rags, and similar fiber normally used in the pulp and paper industry.

What amount of these fibers might be consumed for pulp will depend upon a number of factors. The extent of expansion of the pulp and paper industry will have an important effect. Changing economic conditions in terms of costs of fiber raw materials will be a strong influence. Advancements in research and technology also will affect the amount used. Because these factors are somewhat unpredictable, fiber in the form of waste paper, rags, straw, and cotton linters cannot alone form a basis for increased pulp production in this State, but can only be considered as an auxiliary source of fiber that would complement wood pulp.

V. PULP AND PAPER MILL POTENTIALITIES FROM THE STANDPOINT OF FIBER RESOURCES

T. F. Arvola[1] and John A. Zivnuska[2]

The wood fiber resource indicates that there are good potentialities for further development of the wood-pulp industry in California. Extensive timber stands exist here; they include a variety of species suitable for pulping. In addition, logging and mill wood residues are sufficient in quantity, adequate as to quality, and favorable from the standpoint of location for use for pulp manufacture. Some of this wood fiber resource is being utilized. Of the wood-pulp mills in this State (7), one located near Antioch is a combination kraft (sulfate) and semi-chemical mill having a daily capacity of 285 tons, one at Ukiah is a 160-ton hardboard mill using an "exploded" pulp process, and the remaining four plants are of less than 50-ton capacity manufacturing roofing felt and such by miscellaneous means. Except for one plant in Ventura County, the latter mills are situated in the San Francisco Bay and Los Angeles areas.

Application of Pulping Processes

Most of the available pulping processes have potential application in this state. A number of general processes are used commercially in making pulp for paper, paperboard, and wallboard from wood. One is the groundwood process in which wood bolts are reduced to pulp mechanically by grindstones. Another mechanical process used mainly for production of a coarse fiber product involves the treatment of wood chips with steam or water at high temperatures to weaken fiber bonds, followed by a mechanical fiberization. The two important commercial coarse-fiber pulps produced are called "defibrated" pulp (Asplund process), and "exploded" pulp (Mason process). Three processes, the sulfite, soda, and sulfate or kraft, depend upon the dissolving action of chemical reagents to remove essentially all of the constituents of the wood except the cellulose fibers, which remain in a fairly pure state. This is accomplished by digesting wood chips with the proper chemical under steam pressure. A combination process, the semi-chemical, causes the removal of only part of the wood constituents by chemical means and so affects the fiber bonds that the pulping can be completed by mechanical fiberizing.

[1] Deputy State Forester, Division of Forestry, State Department of Natural Resources.

[2] Associate Professor, School of Forestry, University of California, Berkeley.

Groundwood—Pulping by the groundwood process has a number of possibilities in California. Groundwood pulp is cheap and yields of pulp high. It is characterized in general by lack of strength and rapid deterioration. Therefore, it is usually mixed in varying amounts with some stronger chemical pulp for conversion into newsprint, lower grade magazine, book, box, and wrapping papers. Certain building boards and absorbent for explosives also are made mostly from groundwood pulp. Only a few species in the United States are employed in this process; those found most desirable are the long fibered, light-colored spruces and balsam fir. Hemlocks, other true firs and young, fast-growth pine and Douglas fir are also suitable. However, the groundwood pulp obtained from old-growth pines and Douglas fir cause more or less trouble in paper-making because of their pitch content in their heartwood. Old-growth Douglas fir, pretreated with steam or hot dilute alkali, can be ground for pulp suitable for shipping-container board. From the California standpoint, species most suitable for groundwood pulp are limited to young-growth ponderosa pine, sugar pine, and Douglas fir and the true firs. Red fir, however, yields a rather dark pulp. Although native to California, western hemlock and Sitka spruce do not occur in sufficient amounts to be readily available; Sitka spruce also yields a rather coarse fibered pulp.

Other Mechanical Processes—Mechanical pulping of wood in California by means other than the groundwood process not only shows real promise but has been proven to some extent. The yields are high, similar to groundwood and relatively independent of the kind of wood used. The pulp produced is composed of a mixture of single fibers and fiber bundles used principally for the production of a coarse-fiber product. The Asplund process uses wood chips which first are subjected to high-pressure steam treatment. The chips having been softened are then reduced to fiber by the use of metal grinding disks. The fiber thus produced is discharged into a cyclone separator and given a water shower to form a fiber-water suspension.

In the "exploded" pulp (Mason) process, the separation of wood fiber depends on the explosive force of steam. Chips are loaded in an explosive cylinder, or "gun," and given a high-pressure steam treatment. Upon instantaneous discharge from the "gun" at atmospheric pressure, the chips explode into a fibrous mass which is diluted with water, screened, and processed by machines similar to those used in paper-making.

These mechanical processes and others like them are used in the manufacture of hardboard, insulating board, absorbent felts for roofing, and similar papers. In general, the same species are suitable for these mechanical processes as for groundwood pulp. Since the end product is usually a coarse-fiber product, there is, however, more latitude in use of species. For instance, as in the case of the one "exploded" pulp plant in California, such species as Douglas fir and coast redwood are used.

Sulfite—There is little likelihood that the sulfite process will be used in California. The sulfite process is virtually in a static position in the industry. The national trend in recent years has been to not increase sulfite pulp production appreciably. This process employs an acid chemical (calcium, magnesium, or ammonium bisulfites plus sulfurous acid). Yields are lower than groundwood, but the pulp is much stronger. The unbleached pulp is comparatively light colored and is readily bleachable. Long-fibered, low resin-content softwoods, such as spruce, balsam and hemlock are preferred. Small amounts of young-growth southern pine, aspen, birch, and other eastern hardwoods also are utilized. The pulp is used in better grades of book, wrapping, bond, and tissue papers. It also is combined with groundwood pulp for numerous products, notably newsprint. Refined sulfite pulp is used for manufacture of viscose rayon and other cellulose derivatives. Except possibly for the white firs and redwood, most California species are not particularly suitable for the sulfite process, and most native species are more readily pulped by other processes. There are no sulfite pulp mills in California.

Soda—Likewise, the soda process has little application in this State. More so than in the sulfite process the trend nationally has not been to install additional soda pulp capacity. It employs caustic soda as the pulping agent and is used principally for the reduction of hardwoods in the east, like aspen, cottonwood, basswood, beech, birch, maple, gum, and oak. Yields generally are lower than by other processes. Soda pulp is used for bulky papers, such as blotting, where strength is not important; it is often mixed with sulfite pulp to manufacture book, lithograph, and envelope papers.

Sulfate or Kraft—Of the chemical pulps, the most promising for use in California is that produced by the sulfate or kraft process. It is applicable to almost any wood; the chemical used is alkaline (a solution of sodium hydroxide and sodium sulfide) and resins, waxes, or fats in wood do not hinder the pulping action. Yields are comparable to the sulfite process. Kraft pulp is generally the strongest of the commercial pulps. Unbleached it is used principally for kraft wrapping paper, bag paper, and box-board. When properly treated, it can be used to produce strong pulp for high-grade papers, including book, magazine, writing, bond, and specialty papers. By using modern techniques, it can be bleached satisfactorily. A considerable amount of Douglas fir sawmill waste is pulped by this process. This process lends itself to the mixed timber stands, the great variety of species, and some of the hardwoods in California.

Semi-chemical—Another process of some promise in California is the semi-chemical process. In it wood chips are merely softened and only partly dissolved by chemicals and then are reduced to pulp by mechanical action. The chemical solutions vary; the agents may be neutral sodium sulfite, acid sulfite, or modified soda and sulfate liquors. The yield of pulp is relatively high, intermediate between mechanical and chemical processes. In the United States as a whole, the semi-chemical process is applied predominantly to hardwoods using neutral sodium sulfite as the chemical agent. However, by using different agents all woods can be reduced to semi-chemical pulp, but less favorable results are obtained with softwoods. The pulp is dark-colored and is used principally for corrugating board and specialty boards. Most California timber species lend themselves to this process. One plant in the state at Antioch uses an alkaline semi-chemical process; for raw material, chips made from sawmill and plywood wastes are utilized. The species are the true firs, Douglas fir, and pines.

Size of Mills

As is true elsewhere, the size of wood-pulp mills in California is governed by economics, raw materials available, process used, and type of product. The smallest economical size for mechanical and semi-chemical wood pulp mills is about 50 tons per day (8). For chemical pulp mills, the minimum economic size is 100 tons. High-tonnage products such as kraft-pulp wrapping or paperboard have a minimum capacity of around 250 tons. Sulfate or kraft mills for making bleached paper pulp or purified pulp for chemical conversion possibly could operate economically with smaller capacities, but not less than 150 tons per day. However, these minimum size classes apply only to old established mills and highly specialized cases. The average sizes of established mills in the West are as follows: mechanical—125 tons; semi-chemical—125 tons; and chemical—300 tons. Maximum sizes are: mechanical—400 tons; semi-chemical—160 tons; and chemical—700 tons. Considering the wood resources in this State and the most likely processes, minimum plant size for a wood pulp mill in California would range from 50 tons for mechanical and semi-chemical processes to 250 tons for unbleached kraft pulp.

Wood requirements for pulp mills likewise vary according to species and process used. Rule of thumb figures are commonly used. Groundwood pulping requires 0.9 to 1.3 cords of wood per ton of pulp (9). In the West, 500 board feet is equivalent to one cord or 80 cubic feet solid wood. Pulping by the semi-chemical process takes 1.0 to 1.5 cords per ton while chemical pulping requires 1.7 to 2.4 cords per ton of pulp. Considering capacity of the types of mills applicable in California, daily wood requirements would range from at least 100 cords for a 50-ton groundwood mill to 600 for a 250-ton unbleached kraft mill. On a yearly basis these wood demands of minimum sized mills would vary from 35,000 to about 200,000 cords; larger mills would require correspondingly greater amounts of wood.

Types of Products

The types of products that can be produced from wood pulp mills in California are dependent upon the species used, the process, and other factors. As indicated by the discussion heretofore, pulping of the true firs, Douglas fir, the pines, and redwood, which occur in considerable amounts, and even other species found in this State, is entirely within the realm of possibility. Processes most applicable are the mechanical, sulfate or kraft, and semi-chemical. Pulp and paper products that could be produced would be numerous. They would include roofing felt, corrugated boxboard, food carton board, and hardboard which are being manufactured to some extent at present in California as well as a host of other products. Pulp for export to paper conversion plants in bale (lapped) form, newsprint, bleached pulp high-grade papers, kraft wrapping, bag paper, boxboard, and construction paper and board all have possibilities.

Production Potential

From the standpoint of the wood resource alone, there is the potential for a major increase in the production of wood pulp in California. Analysis of the available wood supply indicates that the daily productive capacity of pulp mills in the State could be increased from the present level of 521 tons to a level of approximately 6,000 tons. This is equivalent to twelve 500-ton mills. It must be stressed that this is not a prediction that a pulp industry of this size will develop in California. Actual developments will depend on factors such as water supply, power costs, available sites, transportation facilities, waste disposal potential, and detailed market analyses as well as on wood supply. Neither is the figure an indication of the maximum size of pulp industry which might be developed. If a price structure were developed which would cause a major diversion of wood from other products to pulp, the forests could sustain a pulp industry very much higher than the level indicated. The estimate is intended as an indication of the size of the pulp industry which could readily be supported by existing wood supplies under foreseeable conditions and is developed solely for the purpose of water requirements analysis.

The most promising and readily available wood resource for pulp use lies in the large supply of unused wood residues at sawmills and plywood plants. In 1952 these plants sent 162.3 million cubic feet of slabs, edgings, and other coarse trimmings suitable for pulpwood to waste burners (5). Some of these residues are produced in too low a volume or too isolated a location to enable economical collection and transportation. However, most of the unused plant residues are concentrated and are strategically located to enhance development of new residue-based wood industries. A reasonable estimate would be that three quarters of these unused coarse mill residues can be used for pulp, or 121.7 million cubic feet.

Coarse wood residues being used at present for plant fuel purposes also deserve serious consideration. Of the 80 million cubic feet of coarse mill residues which are utilized for any purpose, some 77 percent are burned for fuel. In 1952 about 61.6 million cubic feet of coarse residues were used for fuel at plants. A reasonable possibility for the use of this material for fiber purposes in a state such as California (where low cost petroleum fuels are normally available) would be the diversion of at least half of the volume to pulp production. On this basis an additional 30.8 million cubic feet of coarse mill residues are potentially available to pulp mills.

In addition to mill residues, there are large quantities of wood left in the forest after logging due to lack of suitable markets. Estimates that 166.8 million cubic feet of materials equivalent to those included in the forest inventory of the State were left in the forest in 1952 as logging residues (3). Substantial additional quantities of cull sawlogs and standing cull and dead trees are also left. In view of current trends in the industry for the development of economical methods of handling such materials, it is reasonable to assume that at least one-half of these logging residues, or 83.4 million cubic feet, could be recovered for pulpwood.

Although residue wood can be expected to be the primary basis for any expansion of the pulp industry in California, some direct cutting of pulpwood in the forests is both probable and desirable. These materials would consist both of low grade logs unsuitable for other uses and, more important in the long run, thinnings from young stands under good management. Such thinnings can improve the quality of the stand and enable the use of materials otherwise lost to natural mortality. They are a substantial source of pulpwood in the southern and eastern United States.

The possibilities of future cuttings for pulpwood are difficult to evaluate. In countries such as Norway and Sweden, with economies heavily based on the forest industries and highly developed forest practices, more than half of the wood cut for industrial purposes goes to the pulp industry. In California, with major investments and property management decisions based on the established wood-using industries, such a development does not appear likely. A more realistic basis for estimating the magnitude of pulpwood cutting which might be possible in the near future is the current ratio of pulpwood in the timber harvest in the Pacific Northwest. In 1952 pulpwood represented 12 percent of the timber cut in Oregon and Washington (4). Applying this ratio to an assumed annual level of cutting in California of about 5½ billion board feet for the next two decades gives 660 million board feet (105.6 million cubic feet) as a potential pulpwood cut.

To recapitulate, wood resources potentially available each year in California for pulp purposes are estimated as follows:

	Millions of cubic feet	*Millions of cords*
Unused coarse mill residues	121.7	1.52
Diversion of coarse mill residues now used for fuel	30.8	0.38
Logging residues	83.4	1.04
Cutting in timber stands	105.6	1.32
Totals	341.5	4.26

This volume of wood could support 6,000 tons of daily pulp capacity assuming that the processes used averaged 2.0 cords of wood per ton of pulp and 350 days of operation per year.

Obviously the amounts of milling and logging residues on which this estimate is based are subject to change with any change in the total cut from the forests of California. This gives rise to an important question. Does this estimated level of potential pulpwood supply depend on a temporary situation and represent a quantity larger than can reasonably be expected to be maintained on a permanent basis?

As was discussed in an earlier section, in 1952 the cut of sawtimber (5.7 billion board feet) was roughly double the sawtimber growth (2.9 billion board feet). Such a ratio of cut to growth cannot be maintained indefinitely. However, in view of the remaining reserves of old-growth timber and the expanding cut on the national forests, it is not unlikely that a cut of above 5 billion board feet can be maintained for another 20 years. Eventually the cut must be brought into balance with the growth. It is estimated that, with a continuation of present trends in forestry, the annual growth can be brought up to 4 billion board feet or 800 million cubic feet—a volume still well below the potential under general application of intensive management. With the cut at this level an established pulp industry might well take 20 percent of the volume, or 160 million cubic feet (2 million cords). With the same intensification of the levels of residue recovery assumed earlier, the remaining 80 percent of the cut could supply an additional 165 million cubic feet (2 million cords). Thus, the estimate of potential pulpwood supply appears to be consistent with long term possibilities. Furthermore, the establishment of more diversified markets for timber in California would be a favorable factor in creating an economic setting which would raise the level of future growth above that assumed.

The estimate of potential production of pulp from available wood resources does not take into consideration other pulpwood resources discussed earlier in this report. They include about 6 billion board feet (4.7 billion cubic feet) of hardwoods on commercial forest land and another 6.5 billion cubic feet of so-called noncommercial timber (by present standards). Neither are waste paper and rag resources and other nonwood materials taken into account in estimating the above pulp production potential.

Although the estimate presented here is based entirely on an analysis of the wood situation, it is worth noting that the level of output indicated is less than one-half of the estimated market for pulp-based products in California by 1975 (6).

Potential Locations

The four areas in California that offer good possibilities for development of wood pulp mills, from the standpoint of the wood resource only, are:

1. The Humboldt area, consisting of Humboldt, Del Norte, and western Trinity counties.
2. The Mendocino area, consisting of Mendocino, Lake, and northern Sonoma counties.
3. The upper Sacramento valley, north of Colusa County.
4. The lower Sacramento valley, including the lower reaches of the Sacramento and San Joaquin rivers.

The Humboldt area has the largest concentrated timber stand and is the greatest producer of logging and mill residues. The amounts of the wood available indicate that this area has the potential to support at least 1,900 tons daily capacity. Processes that are particularly applicable are the sulfate or kraft, semichemical, and mechanical means.

In the Mendocino area, the wood resource there is capable of supporting 950 tons of daily capacity in addition to one plant located at present at Ukiah. The wood resource is similar to the Humboldt area and the same processes would apply.

Although somewhat less concentrated than in the north coastal area, extensive timber resources about the upper Sacramento Valley suggest that the possibilities are good for the development of 1,600 tons daily capacity. The nature of the available wood supply is such that it lends itself to all the processes mentioned above, including groundwood. This is true because in this area timber stands contain large quantities of true firs.

In the lower Sacramento Valley, wood resources, although more widespread, are sufficient to support at least 1,550 tons of daily pulp capacity. This would be in addition to the one plant already operating at Antioch. The processes that would be applicable would be the same as in the upper Sacramento Valley.

Although other areas of the State may have possibilities for further development of pulp mills using large quantities of wood, the location of the timber resource is not so favorable. Economic and other factors are controlling in such instances.

VI. WATER REQUIREMENTS FOR THE PULP AND PAPER INDUSTRY

Anthony F. Gaudy, Jr.[1]

Each major component process in pulp and paper manufacture requires the use of water of varying quantities and qualities. From the debarking operation through preparation of cooking chemicals, pulp making and washing, bleaching, sheet forming and final drying of the sheet or board, water has played an integral and necessary role. Over 90% of this water passes through the plant and is returned to the stream.

Water Quality Requirements

This chapter will be confined primarily to a discussion of water quantity requirements for the pulp and paper industry. Comments on water quality requirements will be limited to the following observations. It is true that water quality is of extreme importance; however, it would be impossible to find a water in nature that could totally satisfy the exacting requirements of all the various paper products. A detailed list of maximum allowable concentrations of elements and compounds for specific paper products is somewhat beyond the scope of this report and would probably be of little value without an equally detailed analysis of water resources. However, as an aid to rapid assessment of possible mill sites, a list of approximate allowable concentrations of certain critical elements may be of value. It is generally considered that the most important water quality characteristics for pulp and paper manufacture are color, turbidity, iron, manganese, hardness, and chloride concentration. Alkalinity, pH, carbon dioxide, and silica are also of considerable importance.

The true color of water is defined as that which is caused wholly by dissolved matter, as distinguished from turbidity which is that characteristic caused by suspended matter. The color of process water is extremely important in the production of bleached pulp and high grade papers. The importance of turbidity is apparent since the pulp mat or paper sheet acts as an effective filter to entrain the suspended particles.

Iron, even in dilute concentrations, causes a decrease in brightness and staining of the product. Manganese forms a readily precipitable black oxide which not only affects pulp and paper quality, but can cause serious damage to equipment.

[1] West Coast Resident Engineer, National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc.

Hardness is caused by the presence of the cations calcium (Ca^{++}) and magnesium (Mg^{++}). These elements combine with carbonates and bicarbonates in the water, forming slightly soluble compounds which are easily precipitated to form scale, with small increases in temperature or pH. Soluble calcium and magnesium react with many types of sizing to form sticky resin soaps which interfere with the sizing effect.

Chlorides are important because they enhance the possibility of corrosion. Tolerable chloride concentrations are difficult to set. However, for water employed for pulping or bleaching, chloride concentrations under 50 ppm are most desirable.

Only a few of the more important characteristics have been described. To make a complete list would require considerable space and a detailed discussion of the specific requirements of the numerous varieties of paper products. It is considered adequate for the purpose of this report to employ the following broad product categories:

1. Board mill requirements (lowest)
2. Unbleached fiber requirements (medium)
3. Bleached fiber requirements, fine paper to dissolving pulp (highest)

Dissolving pulp is that which is used primarily in the synthetic textile and plastics industries. It is characterized by a high alphacellulose content and represents the purest product of the pulp industry. Hence, water used for its production must meet rigid specifications.

TABLE 18

GENERAL WATER QUALITY REQUIREMENTS FOR PULP PRODUCTS

(Approximate maximum tolerable concentration, ppm.)

	Board products	Unbleached products	Bleached products
Color	200	100	25 to 0
Turbidity	150	40	10 to 5
Iron	1.0	0.3	<0.1
Manganese	0.5	0.1	<0.05
Total hardness	300	200	100 to 60

Often the required quality can be attained only by in-plant treatment of the raw water. This treatment, in general, is identical to processes used in producing a drinking water supply in that it may include chemical coagulation, aeration, sedimentation, filtration, and chlorination. In some specialized cases, softening, deionization, and iron and manganese removal are practiced.

Water Quantity Requirements

The cost of such treatment has undoubtedly been influential in bringing about the present trend toward diminishing the industrial water requirements. Of even greater importance has been the rapid expansion of industry and the decreasing availability of ideal mill sites, which has necessitated the choosing of locations where water quantity is critical. Added to these factors, the industry in the past 20 years has accelerated its efforts to control stream pollution. One of the means of accomplishing this has been recycling or water re-use at various stages in the manufacturing processes. Process changes and the trend toward using recoverable pulping chemicals have enhanced the feasibility of re-using and concentrating wash waters which are subsequently routed into recovery systems.

All of the factors given have been important in lessening overall industrial water requirements. This trend is an encouraging one in that it has enabled industrial expansion in critical areas and has fostered conservation of our natural water resources. However, it has not been accomplished without accompanying operational problems and difficulties in pulp and paper quality control. Some of these difficulties have been overcome and others are being solved through individual mill research and cooperative industry-sponsored research. It should be noted that although in-plant water economy measures have decreased industrial water requirements, the demand for bleached pulp with its relatively high water requirement is steadily increasing.

In order to arrive at figures which will be of use in rapidly assessing a potential mill site, it is first necessary to categorize the paper-making techniques and break them down into their major water-requiring elements.

Elemental process divisions comprising major water requirements common to pulp and paper-making techniques may be broadly listed as:

1. Debarking
2. Pulp mill
3. Bleaching
4. Paper mill

Consideration will be given to the following major pulping techniques:

1. Groundwood
2. Hardboard
3. Neutral sulfite (semi-chemical)
4. Sulfate (kraft) and soda
5. Sulfite

1. **Debarking**—The debarking operation employed is not entirely independent of the subsequent pulping techniques used. Water requirements may vary from essentially no water usage to 7,500 gallons per ton of pulp produced. In general, the higher grades of pulp require more thorough log debarking and cleaning; thus, the water requirement is higher than for lower grades of pulp. In summary, the water requirements for debarking will vary according to the pulping technique and the debarking process and equipment employed.

2. **Pulp Mill**—Water is essential here for preparing cooking chemicals, digesting of wood chips, pulp washing, and transporting the fibers. In mechanical pulping processes, water is necessary for cooling the grinding stone and providing the proper pulp slurry consistency and temperature. The pulp mill water requirements are fairly low for mechanical pulping and follow an ascending order according to the degree of digestion and washing required to produce the higher grade of chemical pulps.

3. **Bleaching**—Bleaching may, in a sense, be considered a continuation of the digestion process in that the bleaching agents attack the remaining non-cellulosic constituents of the wood, thus further purifying the pulp. The net result is to enhance pulp brightness and other desirable characteristics. Mechanical pulp is bleached primarily to deter discoloration of the pulp and microbial attack of organic matter since, unlike the chemical processes, there is very little leaching or cooking out of the wood sugars and lignin, the fiber bonding constituent of the wood. Maintaining optimum bleach concentrations and removing excess bleach require the use of good quality water in fairly large amounts. The water requirement depends on the degree of bleaching and the pulping technique employed.

4. **Paper Mill**—Paper mill operation represents the final step in conversion of the wood fibers to paper. After debarking, reduction to fibers in the pulp mill, and in many cases bleaching, the fibers are ready to be formed into sheets or boards. To accomplish this the fibers are held in aqueous suspension and run onto a vibrating screen which aids in weaving the fibers and binding them into a mat or sheet. The screen also provides drainage for excess water. The sheet thus formed is compressed between press rolls, forcing out still more water. The sheet now has attained sufficient strength and dryness to be transported by a series of drying rolls. After traversing the drying rolls, the finished product is cut and made ready for shipping. Water is used in the paper mill to provide steam for drying, in addition to its major role in sheet forming.

In order to clearly delineate the manufacturing techniques for which water requirements are to be given, the following brief definitions seem warranted:

1. **Groundwood**—This is a purely mechanical process in which the debarked log is held against a grinding stone. Water is played on the stone; the resulting pulp slurry is screened, refined, and fine screened. In most cases it receives some degree of bleaching and is ready for transportation to the "paper side" in an integrated operation, or is sent to the "wet machine" and formed into sheets (pulp laps) ready for shipment as groundwood pulp. Groundwood is a major constituent of newsprint.

In the United States the so-called "hot process" is used in which the temperature of the slurry immediately below the stone is maintained at approximately 185° F. Since cooling water comprises the major water requirement, water usage for this technique is significantly lower than for the "cold process" prevalent in European practice.

2. **Hardboard**—The manufacture of hardboard products cannot truly be placed in the groundwood classification. The defibration is accomplished by mechanical means. However, the wood is pretreated with steam under varying amounts of pressure. Under these conditions of heat and pressure the fiber binding materials are weakened and may be partially hydrolyzed. This enhances rapid defibration in the attrition mill and produces pulp fibers which are ideal for board formation. The water requirements for these processes are somewhat greater than for groundwood, but are less than for chemical techniques. Because of the many possible variations in hardboard techniques, it is felt that accurate average figures cannot be given that would embrace the general technique. Mill site possibilities for these processes should be considered using the range of figures between groundwood and neutral sulfite semi-chemical. In general, water usage for hardboard processes may vary between 5,000 and 20,000 gallons per ton of production, depending on the particular process employed.

3. **Neutral Sulfite (Semi-chemical)**—This process may be considered a combination of mechanical pulping and chemical digestion of the wood. After debarking, the wood is formed into chips and impregnated with the cooking liquor. This is followed by mild digestion in the presence of cooking liquor. The chips are softened but remain intact and are subsequently reduced to pulp by mechanical means. There are many variations of semi-chemical techniques but, except for some quick-cook kraft pulps, the major process employed is "neutral sulfite" in which the active pulping agent is sodium sulfite.

4. **Sulfate and Soda (Alkaline Cook)**—These processess will be considered together since their water requirements are essentially identical. They are true chemical techniques and differ only in the active pulping chemical used. In both techniques, the fiber bonding constituents and wood sugars are acted upon by the cooking chemicals under conditions of elevated temperature and pressure.

Sodium hydroxide is the active agent in the soda process whereas both sodium hydroxide and sodium sulfide are the active digesting agents in the sulfate process. The name "sulfate process" arises because sodium losses in the digestion and washing system are made up by the addition of sodium sulfate in the chemical recovery system. Although a slight misnomer, it is the sulfate process which is generally called *kraft*. The great expansion of the paper industry has been largely directed toward this technique, and it is unlikely that new soda mills will be constructed because of the greater strength of the pulp and high yield obtained by the sulfate, as well as increasing demand for sulfate pulp.

In the kraft process the wood is debarked, chipped, segregated as to chip size, and digested for 2 to 4 hours. The resultant slurry is drained, washed, and further processed before bleaching or entering the paper mill. Some of the digester liquor is retained for the next "cook," and the remainder enters the chemical and heat recovery plant inherent in the process. This recovery technique has had a great influence in reducing both the pollutional characteristics of the waste waters and the water requirements, since counter-current washing and recycling of wash water aids in concentrating base chemicals, thereby enhancing the feasibility of incorporating some wash water in the recovery system. For these reasons the sulfate or kraft water requirements are somewhat lower than other chemical techniques.

5. **Sulfite (Acid Cook)**—Like kraft, the sulfite technique is a true chemical process. The active digesting agents are the bisulfite of calcium, ammonia or magnesium, and an excess of sulfurous acid. Wood is prepared as in the sulfate process, but is digested for approximately 12 hours in the bisulfite solution. Subsequent pulp treatment is essentially the same as for sulfate. Recovery of spent sulfite liquor is possible, depending on the base chemical employed. Magnesium base liquor is recoverable, but capital cost for such units is higher than that of the other two bases. Theoretically, calcium base liquor and ammonia base liquor can be recovered, but there are attendant economic and technical problems. Water requirements for sulfite mills are somewhat higher than for kraft, since chemical recovery is not widely practiced. Sulfite pulp also is more generally used for products requiring a great degree of purity, thereby increasing washing and bleaching requirements.

The above process descriptions were necessarily brief. Excellent and detailed descriptions of pulp and paper technology can be found in the literature (10, 11, 12, 13, 14).

Numerous surveys have been conducted, aimed at obtaining average industrial water requirements. These surveys represent monumental tasks of careful analysis. One of the most complete and detailed reports available on this subject has recently been completed by the U. S. Department of the Interior (15).

Surveys of this type, however, although admirably serving the purpose for which they were conducted, are not ideally suited for use in rapid assessment of potential mill sites. The figures for water usage of individual mills vary according to the finished paper product manufactured, the type and age of equipment employed, and the availability of water. Therefore, average or weighted-average water usage figures for existing mills are not generally applicable to new mills. It is also difficult to apply the classifications of water usage generally included in such surveys in presenting accurate and useful figures for mill site evaluation. It is felt that the classifications used in Table 19 are optimum for this purpose. The figures presented represent water requirements for new mills operating at economic levels of water usage, but not at the absolute minimum which would entail serious operational and quality-control problems. These figures are representative of water usage in present mills operating with reasonable efficiency using modern equipment and operating methods.

TABLE 19

WATER QUANTITY REQUIREMENTS FOR ELEMENTAL PULP PROCESSES

(In gallons per ton of pulp produced)

Operation	Pulping technique				
	Ground wood	Hard-board	NSSC*	Kraft	Sulfite
Debarking	Can vary from 0 to 7,500 depending on pulping technique, process used, equipment employed				
Pulp mill	1,000		3,000 to 20,000	20,000	30,000
Bleaching	1,000				
Partial			20,000	20,000	
Full			40,000	40,000	40,000
Dissolving pulp				50,000 to 100,000	50,000 to 100,000
Paper mill	7,000 to 10,000	5,000 to 20,000	10,000 to 25,000	10,000	10,000

* Neutral sulfite semi-chemical.

NOTE: Ranges shown for NSSC (neutral sulfite semi-chemical) for pulping and paper mill arise because of variation in washing technique. Where 3,000 is used in the pulp mill, 25,000 is used in the paper mill. Where the pulp is washed before going to the paper mill, 20,000 is used in the pulp mill and 10,000 in the paper mill. The total pulp mill and paper mill requirements are essentially the same.

Water Conservation Practices

In considering conservation practices, it is well to realize that pulp and paper water requirements are generally less than ten percent consumptive in nature. It should be emphasized that the figures listed in the process water requirements table represent quantities of water coming into the mill. Ninety percent of the waters pass through the mill and are returned to the stream as waste waters of varying pollutional strengths. After treatment or reasonable downstream flowing time, these waters remain a part of the natural water resource. A large portion of the consumptive requirement is due to evaporative losses on the paper machine. Some water is also lost due to evaporation in chemical recovery systems.

The major conservation practices involve recycling of waste waters or using the waste water from one operation to satisfy wholly or partially the requirements of another.

In general, the industry has effected its decreased water usage by new techniques of manufacturing and water handling, and by the introduction of new equipment designed with an eye toward diminishing water usage.

One of the most fruitful sources of water re-use is machine water from the pulp side and water extracted from the final product of the pulp mill, used to convey the pulp through the system. These waters are commonly called "white waters." It was found that effluent white water from deckers or thickeners could, in many cases, be re-used for diluting or thinning fresh stock for screening operations. Installation of modern savealls has reduced fiber losses in the effluent, leaving a white water suitable for use in many operations where suspended matter formerly prohibited such use. Today, in many instances, white water is used for pulp washing in both kraft and sulfite industries.

Water re-use has not been restricted to white water reclamation. In many bleach plants effluent from the various washing operations are re-used for stock movement and consistency regulation.

In many sulfite pulp mills various phases of pulp washing are carried out using dilute liquor as wash water. This not only diminishes fresh water use, but aids in collection of strong spent liquor, and is especially beneficial where retention of strong liquor is necessary as an effluent disposal measure (14).

Only a few of the conservation measures employed in paper and board mills and in pulping operations have been mentioned. There are, of course, many more.

The figures given in Table 19 are representative of requirements for mills operating with optimum or economically feasible conservation practices. It is theoretically possible to operate at somewhat lower figures than those shown, and some mills have found it possible to accomplish this, depending on product requirements. However, until the technological problems accompanying further reductions can be overcome, further tightening or closing of systems cannot be highly recommended.

VII. AVAILABILITY OF WATER FOR PULP PROCESSES AND WASTE ASSIMILATION

Carl B. Meyer[1] and Darrell J. Smith[2]

This chapter describes present State plans for developing California's water resources, and relates the pulp mill water requirements (for both processing water and waste disposal) to other anticipated water needs. It is shown that, even if full development of fiber resources were to occur by means of the maximum water demanding process, there would still be adequate supplies of process water in all areas of potential pulp mills. However, the waste receiving potential at a particular mill site is demanding of special investigation with regard to the properties of the mill wastes and the assimilative capacity of the receiving waters. Some of the more important aspects of this latter problem are treated in Chapter X.

By combining the unit water requirements listed in Chapter VI with the potential wood fiber resources, it can be shown that the amount of water that might someday be required by the pulp and paper industry in California could vary between 33,600 and 521,000 acre-feet annually, depending on the process employed (Table 20). Prospective operators of course want to know if this volume of water will be available for development of their pulp mills. Local areas attempting to attract industries are also concerned with the availability of water resources to support anticipated growth.

[1] Principal Hydraulic Engineer, State Department of Water Resources.
[2] Assistant Hydraulic Engineer, State Department of Water Resources.

The California Water Plan

Bulletin No. 3, "The California Water Plan," is the final of a series of three bulletins (19, 20, 21) setting forth the results of the Statewide Water Resources Investigation, which has been in progress for the past 10 years under provisions of Chapter 1541, Statutes of 1947. This investigation entailed a three-fold program of study to evaluate the water resources of California, to determine present and probable ultimate water requirements, and to formulate plans for the orderly development of the State's water resources to meet its ultimate water requirements.

The California Water Plan is a master plan gigantic in scope. It contemplates the full control, conserva-

TABLE 20

ESTIMATED PROCESS WATER REQUIREMENT FOR PULP AND PAPER MILLS

NORTHERN CALIFORNIA

Wood resource available in tons of pulp per day	Hardboard process				Kraft process			
	Water requirement		Consumptive use		Water requirement		Consumptive use	
	Million gal/day	Acre-ft. per year	Million gal/day	Acre-ft. per year	Million gal/day	Acre-ft. per year	Million gal/day	Acre-ft. per year
Humboldt Area[a] 1,900	9.5	10,600	9.5	10,600	147.3	165,000	147.3	165,000
Mendocino Area[b] 950	4.8	5,000	0.5	500	73.6	82,000	7.4	8,200
Total North Coastal Area 2,850	14.3	15,600	10.0	11,100	220.9	247,000	154.7	173,200
Upper Sacramento Valley[b] 1,600	8.0	9,000	0.8	900	124	140,000	12.4	14,000
Lower Sacramento Valley[b] 1,550	7.8	9,000	0.8	900	120	134,000	12.0	13,400
Total Sacramento Valley 3,150	15.8	18,000	1.6	1,800	244	274,000	24.4	27,400
Total Northern California 6,000	30.1	33,600	11.6	12,900	464.9	521,000	179.1	200,600

[a] Waste water assumed to be discharged to ocean and, therefore, all water used consumptively.
[b] Waste water assumed to be returned to stream. Consumptive use computed as 10 percent of gross requirement.

tion, protection, distribution, and utilization of the water resources of California, both surface and underground, to meet present and future water needs for all beneficial purposes and uses in all areas of the State, insofar as practicable.

The formulation of The California Water Plan was predicated upon and guided by certain basic concepts. Summarized, these concepts define The California Water Plan as a comprehensive pattern, with broad flexibility and susceptible of orderly and progressive development as needed, under which the forecast ultimate requirements for water by individuals and agencies for all purposes in all parts of the State can be met. Water is not to be taken away from people who will need it; rather, it is proposed to supply the needs of areas of deficiency by transfer only of excess or surplus water from areas of abundance. Under The California Water Plan, water development by all agencies, federal, state, local, and private, can proceed in a coordinated manner toward common objectives and for maximum ultimate benefit. The Plan is not intended in any way to constitute an inflexible regulation or construction proposal.

The California Water Plan does not purport to include all possible water development projects in the State. Rather, it serves to demonstrate that the full satisfaction of ultimate water requirements in all parts of the State is physically possible of accomplishment. Therefore, the omission therein of any project does not preclude its future construction and integration into The Plan. Further investigation may indicate alternative projects which are more feasible than those discussed therein and which would accomplish the same results.

The works comprising The California Water Plan can be divided easily into those works designed to develop and transport water from areas of surplus to areas of deficiency, and those works designed to develop local supplies to meet local needs.

California Aqueduct System

The following paragraphs discuss general features of the California Aqueduct System, which is the name given to those parts of The California Water Plan designed to develop and transport water from areas of surplus to areas of deficiency.

The California Aqueduct System, comprising a complex combination of many large dams, canals, tunnels, streamways, hydroelectric power houses, pumping plants and other structures proposed to supplement existing water resources developments works, would extend from the Oregon line to the Mexican border. It would ultimately transport more than 21,000,000 acre-feet of regulated water each season, about half of which would be from the North Coastal Area and half from the Sacramento River Basin.

For purposes of presentation, this immense interarea water conservation and transportation system has been divided into six divisions, designated as follows: Klamath-Trinity and Eel River Divisions in the North Coastal Area; Sacramento Division; Delta Division; San Joaquin Division; and Southern California Division. Only the Klamath-Trinity, Eel River, and Sacramento Divisions are of interest to the pulp and paper study. The major features of the California Aqueduct System are shown in Figure 4, titled "California Aqueduct System."

Klamath-Trinity Division—This division comprises those features of the California Aqueduct System that would be constructed to conserve surplus waters of the Klamath, Trinity, Van Duzen, Mad and South Fork Smith Rivers; as well as the necessary pumping plants, conduits, and hydroelectric power plants utilized in the conveyance of those surplus waters to the Sacramento Valley. The aqueduct system would include a series of 15 major regulating reservoirs, which for the most part, would be located contiguously along the Klamath and Trinity Rivers from the vicinity of their junction upstream. The resultant effect of this series of reservoirs would be the conservation of the flows of these streams and their conveyance down the Klamath River and thence up the Trinity River by appurtenant pumping plants and conduits to Burnt Ranch Reservoir. This reservoir would be the common collecting reservoir for all the waters of this Division. A tunnel would extend from Burnt Ranch Reservoir eastwardly through the Trinity Mountains, and would conduct water exported from the Klamath-Trinity Division to the Sacramento Valley.

Eel River Division—The Eel River Division comprises those features of the California Aqueduct System that would be constructed on the Eel River to conserve surplus waters over and above local requirements together with those used to convey them to the Sacramento Valley and the North Bay area and Napa Valley.

A series of three major reservoirs would be constructed on the main stem of the Eel River and one on its middle fork. The conserved waters would be lifted from reservoir to reservoir, up the Eel River, and transported through the southerly divide by two tunnel systems. One tunnel would receive water for export to the Sacramento Valley and to Napa Valley by way of Clear Lake and Putah Creek, while the second tunnel would convey water to the Russian River Basin.

A summary of the major reservoirs proposed for construction in The California Water Plan in the North Coastal area and the Sacramento Valley is given in Table 21.

Sacramento Division—The Sacramento Division of the California Aqueduct System would comprise

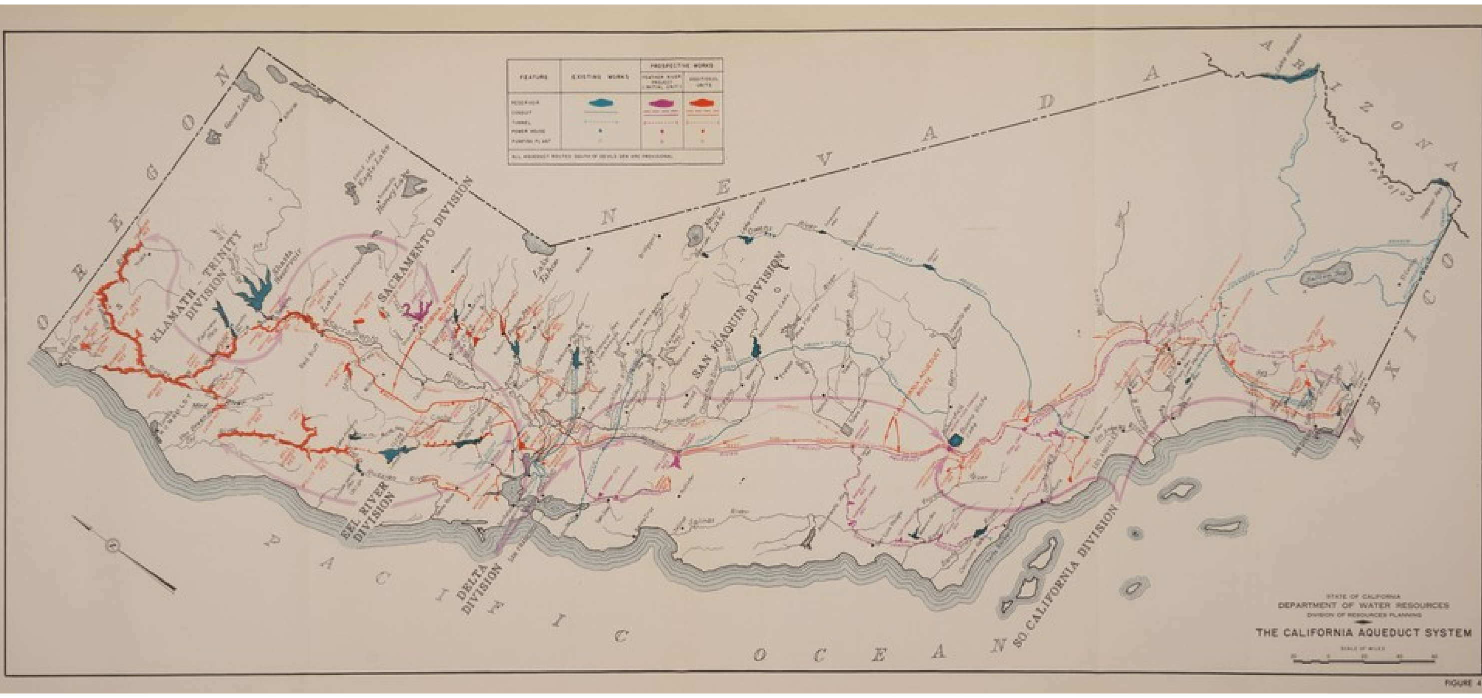

FEATURE
EXISTING WORKS
PROSPECTIVE WORKS
FEATHER RIVER PROJECT (INITIAL UNIT)
ADDITIONAL UNITS
RESERVOIR
CONDUIT
TUNNEL
POWER HOUSE
PUMPING PLANT
ALL AQUEDUCT ROUTES SOUTH OF DEVILS DEN ARE PROVISIONAL
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
KLAMATH - TRINITY DIVISION
SACRAMENTO DIVISION
EEL RIVER DIVISION
DELTA DIVISION
SAN JOAQUIN DIVISION
SO. CALIFORNIA DIVISION
Shasta Reservoir
Lake Tahoe
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
THE CALIFORNIA AQUEDUCT SYSTEM
SCALE OF MILES

FIGURE 4

TABLE 21

SUMMARY OF MAJOR RESERVOIRS PROPOSED FOR THE CALIFORNIA WATER PLAN IN NORTH COASTAL AREA AND SACRAMENTO VALLEY

	Number	Storage capacity (in acre-feet)
California Aqueduct System		
North Coastal Area		
Klamath Trinity Division	15	28,726,000
Eel River Division	10	12,615,000
Subtotal North Coastal Area	25	41,341,000
Sacramento Division	15	7,805,000
Total California Aqueduct System	40	49,146,000
Local Development Projects		
North Coastal Area		
Humboldt Forest Resource Area	12	1,350,000
Mendocino Forest Resource Area	28	1,385,000
Subtotal North Coastal Area	40	2,735,000
Sacramento River Basin		
Upper Sacramento Valley Forest Resource Area	19	2,944,000
Lower Sacramento Valley Forest Resource Area	54	4,583,000
Subtotal Sacramento River Basin	73	7,527,000
Total Local Development Projects	113	10,262,000
Grand Total Aqueduct System and Local Development North Coastal and Sacramento Valley	153	59,408,000

those features that would be required to develop and regulate the surplus flows of the Sacramento River Basin, together with those features necessary to convey surplus waters developed in both the North Coastal and Sacramento Valley areas on to the south. This Division would include 15 surface reservoirs, as well as the natural underground storage capacity available in the alluvium of the Sacramento Valley.

The Sacramento River would be utilized to convey regulated flows from Shasta Reservoir to the Sacramento-San Joaquin Delta. In addition, the river would receive water released from other foothill reservoirs, and, at times, would carry supplies pumped from ground water storage. The Folsom South Canal would carry water released from Folsom Reservoir southward along the eastern border of the Sacramento Valley floor. The Sacramento West Side Canal would divert from the Sacramento River in the vicinity of Red Bluff, and would be used to carry waters exported from the North Coastal area together with local surpluses along the west side of Sacramento Valley. A summary of the proposed reservoirs is given in Table 21.

Plans for Local Development

The preceding sections have described those portions of The California Water Plan whose purpose is primarily the developing and transporting of water from areas of surplus to areas of deficiency. Superimposed on this aqueduct system is a less dramatic, but no less important, system: those portions of The California Water Plan designed to serve local needs. In addition to providing for all water requirements in the area, these local projects provide opportunities for generation of hydroelectric power, and consider problems of flood control and maintenance of water quality. In formulating these local developments, the importance of fish and wildlife to the economy of the area was recognized, and special provisions were made wherever feasible to improve stream flow conditions and maintain desirable minimum pools in reservoirs.

In the chapters of this report dealing with forest resources, certain conclusions were drawn on the pulp mill potential for certain rather arbitrary areas, namely the Humboldt, Mendocino, Upper Sacramento Valley, and Lower Sacramento Valley areas. In order to make the following discussion of plans for local water development more applicable to the present study, particularly in the North Coastal Area, the description of these local projects has been divided into the same forest regions. For purpose of this report, hydrographic units 6, 8, 9, 10, 11, 12, and 13 in the North Coastal Area, as shown in Figure 5, are considered to be in the Humboldt area, and units 14 and 15 in the Mendocino area. Only those local projects affecting the listed hydrographic units will be described, although it must be remembered that The California Water Plan serves lands throughout the region.

In the Humboldt and Mendocino forest resource areas, there are 40 dams proposed to serve local needs. A summary of proposed dams in the Humboldt and Mendocino areas designated for local development projects is included in Table 21. Included are 18 such reservoirs proposed primarily to develop water supplies sufficient to meet the major portion of the estimated ultimate seasonal water requirements of the North Coastal Area, 11 reservoirs planned primarily for stream flow maintenance, and 11 that would provide water for both purposes. As can be seen, nearly every major stream in the Humboldt and Mendocino areas will be at least partially controlled by some dam, either on the main stream or on a major tributary.

Twelve reservoirs and appurtenant works constitute the works for local development under The California Water Plan for the Humboldt area. They would be operated in conjunction with existing facilities to make available additional water supplies for utilization under ultimate conditions of development. Flood control is an inherent part of The California Water Plan and the construction of local and fishery enhancement reservoirs, in addition to those for the California Aqueduct System, would provide a high degree of flood control, particularly on the Eel River.

The local development phase of The California Water Plan for the Mendocino area would comprise 28 reservoirs and appurtenant works. Operated coordinately, these developments would accomplish a threefold purpose; namely, (1) provision of sufficient water to meet all potential beneficial uses within the area, (2) enhancement of anadromous and resident fish life and recreational opportunities, and (3) provision of a substantial measure of flood control.

In summary, the proposed local developments in the North Coastal area would make water available in quantities sufficient to satisfy all forseeable ultimate requirements, and the many secondary benefits would provide for a greater expansion of some of the principal industries basic to the economy of the region.

As in the North Coastal Area, an attempt has been made to divide plans for local development in the Sacramento Valley into the forest regions previously described. Thus, hydrographic units 5 through 10, and 17 through 21, as shown in Figure 5, are considered to comprise the Upper Sacramento Valley forest region, while units 11 through 16, 22 through 30, 61, and 63 comprise the Lower Sacramento Valley. Again, only those projects affecting the listed units are described.

The plans for local development in the Upper Sacramento Valley area include 23 dams and appurtenant works. These reservoirs, operated in conjunction with those planned for the California Aqueduct System will provide sufficient water for all foreseeable beneficial uses and will also help regulate the flood flows of the area and provide water to be exported to areas of deficiency.

Sixty-two reservoirs and appurtenant works in the Lower Sacramento Valley area will provide considerable flood control, and, when operated in conjunction with the ground water basins, will provide water for all ultimate requirements for local development and all estimated export requirements.

In summary, local works planned for the Sacramento River Basin, together with the 14 foothill reservoirs included in plans for the California Aqueduct System and the extensive ground water basins, will provide water to meet local and export requirements under conditions of ultimate development. Other benefits which will result include flood control, enhancement and protection of the fisheries, wildlife and recreational resources, and generation of hydroelectric power.

Reservoirs proposed for construction to meet local needs in the Upper and Lower Sacramento Valley are summarized in Table 21.

Water Resources Available for Industrial and Other Development

The preceding sections have briefly outlined those portions of The California Water Plan applicable to the area covered in this present study. As was stated previously, this Plan was developed in order to satisfy all anticipated ultimate needs for water throughout the State. Among these ultimate water needs is that of increased industrial operations, including pulp and paper mills. It is emphasized that studies leading to forecasting of ultimate water needs throughout California were too broad in scope to allow provision for specific amounts of water for specific purposes at specific locations. Ultimate water needs were forecast by summing the estimated needs for irrigated agricul-

TABLE 22

ESTIMATED PROBABLE ULTIMATE MEAN SEASONAL WATER REQUIREMENTS
NORTH COASTAL AREA

(In acre-feet)

Hydrographic units No.	Hydrographic units Name	Irrigated lands	Farm lots	Urban and suburban	Other	Approximate totals
	Humboldt Forest Resource Area					
6	Klamath	27,900	100	8,100	1,500	37,600
8	Del Norte	44,400	200	3,900	700	49,200
9	Redwood Creek	4,600	0	500	200	5,300
10	Mad River	58,700	400	3,500	600	63,200
11	Upper Eel	102,000	800	4,100	2,700	109,600
12	Humboldt	166,000	800	20,000	1,400	188,000
13	Mattole	10,200	0	0	300	10,500
	Estimated supplemental requirements for pulp industry [a]			165,000		165,000
	Subtotal	413,800	2,300	205,100	7,400	629,000
	Mendocino Forest Resource Area					
14	Mendocino Coast	95,800	800	4,500	1,700	103,000
15	Russian River	318,000	2,800	24,000	1,000	346,000
	Estimated supplemental requirements for pulp industry [a]			8,200		8,200
	Subtotal	413,800	3,600	36,700	2,700	457,000
	Approximate totals, North Coastal Area	828,000	6,000	242,000	10,000	1,086,000

[a] Represents the possible increase in the estimated ultimate water requirement for the pulp industry as a result of studies for this report. To be developed by additional storage capacity of works for local utilization.

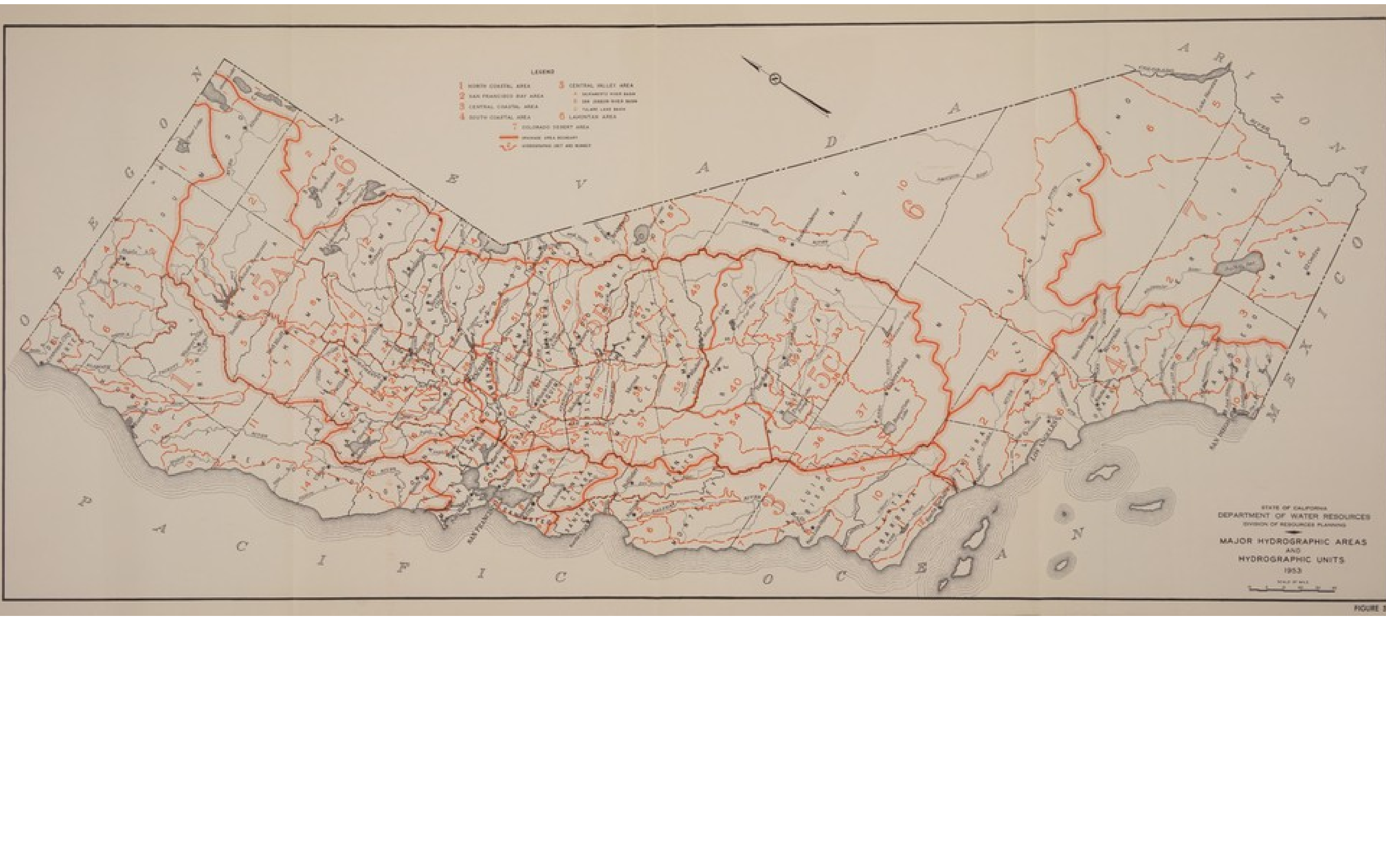
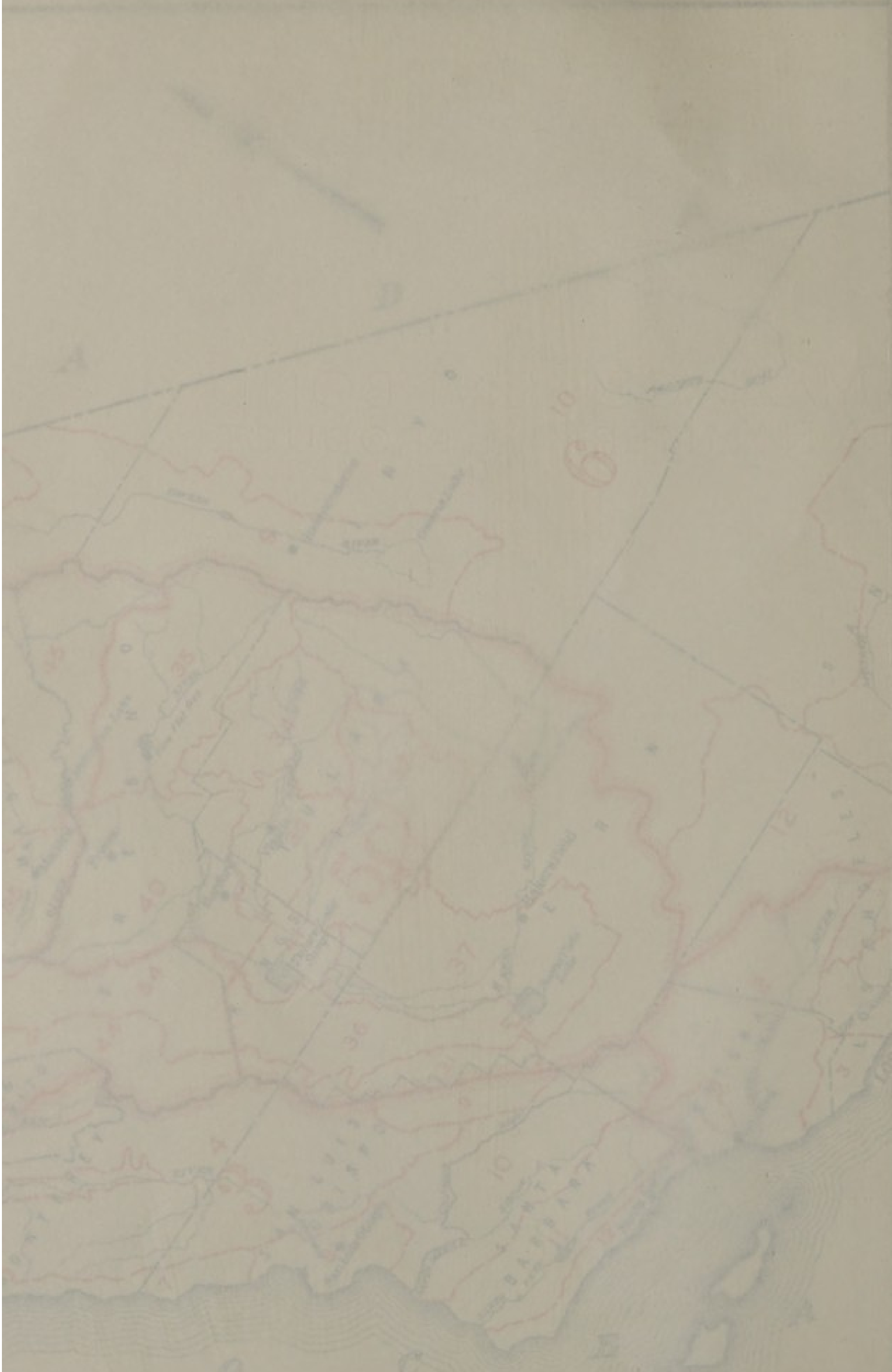

LEGEND
1 NORTH COASTAL AREA
2 SAN FRANCISCO BAY AREA
3 CENTRAL COASTAL AREA
4 SOUTH COASTAL AREA
5 CENTRAL VALLEY AREA
A SACRAMENTO RIVER BASIN
B SAN JOAQUIN RIVER BASIN
C TULARE LAKE BASIN
6 LAHONTAN AREA
7 COLORADO DESERT AREA
DRAINAGE AREA BOUNDARY
HYDROGRAPHIC UNIT AND NUMBER
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
LOS ANGELES
SAN DIEGO
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
MAJOR HYDROGRAPHIC AREAS
AND
HYDROGRAPHIC UNITS
1953
SCALE OF MILES

FIGURE 3



ture, farm lots, urban and suburban areas, and other water service areas within each hydrographic unit. Industrial development was assumed to occur in urban or suburban areas, and its anticipated water needs were included in the amount estimated for those areas. It is pointed out that all anticipated ultimate water needs are at best only informed guesses, and that constant revision of these estimates is necessary in order that water development planning can keep abreast of changing trends in land and water utilization.

In order to show the estimated future water needs in the area of this study, and, consequently, the amount of water to be made available by The California Water Plan, the following tables have been prepared. Table 22 lists the hydrographic units in the North Coastal Area for both the Humboldt and Mendocino forest areas, together with their estimated ultimate water requirements for irrigated lands, farm lots, urban and suburban areas, and other water service areas. The water available for pulp and paper production is included in that for urban and suburban areas. This table shows that there will be about 40,100 acre-feet provided in the Humboldt area and 28,500 acre-feet in the Mendocino area for urban needs. In Table 20 it was shown that maximum possible water requirements for pulp and paper production alone in these two areas might be as high as 165,000 and 82,000 acre-feet, respectively. It should be borne in mind, however, that in the Mendocino area, actual consumptive use by pulp industries would be on the order of only 8,000 acre-feet. The difference between the gross requirement and the consumptive use represents waste water which, if adequately treated, would be available for further use downstream.

In Table 25 there is shown the undeveloped surplus which would be available after satisfying uses for local development and export requirements. Any additional requirements not contemplated at the time these estimates were prepared could be supplied from the undeveloped surplus.

It should be borne in mind that the values shown in Table 22 are the estimates for Bulletin No. 2 "Water Utilization and Requirements of California" and represent the best available at that time. If subsequent studies indicate that these estimates are incorrect they will be revised to meet the current fore-

TABLE 23

ESTIMATED PROBABLE ULTIMATE MEAN SEASONAL WATER REQUIREMENTS SACRAMENTO RIVER BASIN

(In acre-feet)

Hydrographic units		Irrigated lands	Farm lots	Urban and suburban	Other	Approximate totals
No.	Name					
	Upper Sacramento Valley Forest Resource Area					
5	West Side, Shasta Dam to Cottonwood Creek	108,000	500	1,000	800	110,000
6	East Side, Cow Creek to Paynes Creek	*149,200	0	3,600	1,200	*154,000
7	Red Bluff to Thomes Creek	157,000	500	1,300	900	160,000
8	Antelope to Mud Creek	*13,900	0	200	600	*14,700
9	Stony Creek	126,000	600	1,300	1,000	129,000
10	Butte and Chico Creeks	*50,400	0	2,600	200	*53,200
17	Anderson-Cottonwood	83,400	400	9,800	0	93,600
18	Tehama	196,000	1,300	6,200	0	204,000
19	Vina	135,000	1,200	5,000	0	141,000
20	Orland	303,000	1,700	3,900	0	309,000
21	Chico	204,000	2,300	15,100	700	222,000
	Subtotal	1,525,900	8,500	50,000	5,400	1,590,500
	Lower Sacramento Valley Forest Resource Area					
11	Cortina Creek	134,000	500	1,300	200	136,000
12	Feather River	*518,600	0	16,000	12,400	*547,000
13	Yuba and Bear Rivers	432,000	1,800	14,400	15,100	463,000
14	Cache Creek	158,000	1,000	4,800	1,000	165,000
15	American River	223,000	1,400	15,400	4,600	244,000
16	Putah Creek	94,400	400	1,000	400	96,200
22	Arbuckle	225,000	1,400	1,500	0	228,000
23	Colusa Trough	1,574,000	5,800	5,200	116,000	1,701,000
24	Feather River to Butte Slough	676,000	3,000	5,000	38,500	722,000
25	Yuba	159,000	1,200	6,200	1,400	168,000
26	Marysville-Sheridan	413,000	2,400	8,600	0	424,000
27	Woodland	401,000	2,100	9,100	0	412,000
28	Carmichael	571,000	2,800	144,000	2,000	720,000
29	Dixon	303,000	2,400	5,300	0	311,000
30	Yolo	559,000	2,000	1,200	100	562,000
61	Stockton	929,000	6,900	57,800	0	994,000
63	Sacramento-San Joaquin Delta	742,000	6,400	7,000	100	756,000
	Subtotal	8,112,000	41,500	303,800	191,800	8,649,200
	Approximate totals, Sacramento Valley	9,638,000	50,000	354,000	197,000	10,239,700

* Includes estimates for farm lots.

casts. For example, in addition to the present study which indicates the possibility of increased water requirements for pulp production, the Department of Water Resources is currently studying the possibilities of increased agricultural, urban, recreational, and industrial water requirements in several other investigations. It is emphasized that as these revised requirements become available, revisions will have to be made in plans for development. As brought out later in this section, there is ample water to meet all anticipated local and export requirements in the areas considered as potential pulp mills. This is one of the basic concepts of The California Water Plan, that it is to be flexible and will be altered to meet changing conditions.

Another basic concept which is repeated and emphasized here, is that water requirements for local development will be met before those for export.

In the Upper Sacramento Valley, 57,000 acre-feet will be supplied seasonally by The California Water Plan for urban and suburban development including industrial needs, while about 304,000 acre-feet will be served in the Lower Sacramento Valley for the same purpose (Table 23). In Table 20 it was estimated that as much as 140,000 and 134,000 acre-feet annually might be required by pulp mills in these two areas. Actual consumptive use by pulp mills in the Sacramento Valley would be approximately 10 percent of the gross requirement.

Export Requirements From Potential Mill Areas

The general features of The California Aqueduct System have already been described. It is through these facilities that water ultimately will be exported from areas of surplus to areas of deficiency. Major diversions for export will be made on the Klamath, Trinity, and Eel rivers in the North Coastal Area, and from the Sacramento, Feather, and American rivers in the Sacramento Valley. In addition, smaller amounts of water will be exported from the Van Duzen, Mad, and South Fork Smith rivers in North Coastal Area, and from numerous streams and from the underlying ground water basin in the Sacramento Valley. These export requirements from streams and basins in the North Coastal Area total 11,600,000 acre-feet per year and from the Sacramento River Basin area total 10,300,000 acre-feet per year as summarized in Table 24.

Undeveloped Surplus Waters

The foregoing sections of this report have evaluated the possible maximum water requirements for pulp and paper mills in California, described certain features of The California Water Plan, and listed

TABLE 24

EXPORT WATER REQUIREMENTS FROM NORTH COASTAL AND SACRAMENTO RIVER BASIN HYDROGRAPHIC AREAS

(In acre-feet per year)

Stream or basin	Export requirement
NORTH COASTAL AREA	
Klamath-Trinity Division	
Klamath River	5,086,700
Trinity River	2,739,700
Van Duzen River	[a]398,400
Mad River	------
Smith River	830,400
Total, Klamath-Trinity Division	9,055,200
Eel River Division	
Eel River	2,565,000
Total, North Coastal Area	11,620,000
SACRAMENTO RIVER BASIN	
American River	700,000
Feather River	[b]4,800,000
Upper Sacramento River	800,000
Remainder of Sacramento River Basin	[c]4,000,000
Total, Sacramento River Basin	10,300,000
Total, Northern California	21,900,000

[a] Combined yield of Mad and Van Duzen Rivers.
[b] Yield of Feather River Project measured at Delta pumping plant, and includes surplus flows from other sources in addition to water developed on Feather River.
[c] Average amount of surplus flows occurring during wet years and transferred as available from the Delta to the San Joaquin Valley for further regulation in underground storage.

TABLE 25

ESTIMATED SEASONAL RUNOFF AND ULTIMATE REQUIREMENTS, NORTH COASTAL AREA

(In acre-feet)

No.	Hydrographic units	Seasonal natural runoff	Local development requirement	Export requirements	Undeveloped surplus
1	Tule Lake	2,008,000[a]	465,000		
2	Shasta Valley	201,000	327,000		
3	Scott Valley	417,000	170,000		
4	Upper Klamath	714,000	56,800		
6	Klamath	5,710,000	37,600		
	Subtotal	7,189,000[b]	1,056,400	5,086,700	1,045,900
5	Trinity	3,932,000	80,600	2,739,700	1,111,700
7	Rogue	370,000	1,400	0	368,600
8	Del Norte	2,981,000	49,200	830,400	2,101,400
9	Redwood Creek	837,500	5,300	0	32,200
10	Mad River	1,195,500	63,200		
12	Humboldt	1,681,000	188,000		
	Subtotal 10, 12	2,876,500	251,200	398,400	2,226,900
11	Upper Eel	5,267,000	110,000	2,565,000	2,592,000
13	Mattole	1,355,000	10,500	0	1,344,500
14	Mendocino Coast	2,335,000	103,000	0	2,232,000
15	Russian River	1,623,000	346,000	0	1,277,000
16	Bodega	120,000	87,800	0	32,200
	Supplemental requirements for pulp industry[c]		173,200		—173,200
	Totals	28,886,000[b]	2,275,000	11,620,000	14,991,000

[a] Includes 1,861,000 acre-feet of water originating in State of Oregon.
[b] Does not include 1,861,000 acre-feet of water originating in State of Oregon.
[c] Represents the increase in the estimated water requirement for pulp industry since studies for report on The California Water Plan.

the amounts of water to be made available for local needs and exported by the Plan. The question naturally arises: "Will there be sufficient water to meet all the local needs and export requirements, and still provide for any unforeseen increases in water needs in the areas of origin?" To answer this question, Table 25 has been prepared. This table shows the estimated natural runoff, local needs, export requirements, and undeveloped surplus waters in the North Coastal Area. Examination of this table, indicates that all hydrographic units of the North Coastal Area will have surplus water available to meet any unexpected increases in water needs.

As is true in the North Coastal Area, the estimated mean seasonal natural runoff in the Sacramento Valley exceeds the total of the estimated ultimate requirements for local development and for export. Due to inter-basin exchanges it was impracticable to compile a table showing the values for each hydrographic unit. However, of an estimated 22,390,000 acre-feet of mean seasonal runoff in this area, a surplus of approximately 3,913,000 acre-feet including the use of upstream return flows, is not at present included in plans for development. This surplus probably could be developed if subsequent study indicates future water requirements will be greater than presently estimated.

Stream Flow in Relation to Mill Location

This section presents pertinent data concerning the discharge of rivers in the areas of potential pulp and paper mills, both under present conditions and those anticipated in the future under The California Water Plan.

From a practical standpoint, all water resources stem from precipitation. Its regimen and other characteristics profoundly affect the nature and occurrence of water supplies. California receives most of its precipitation during the winter months, November through April, in the form of rain at lower elevations and snow in the higher mountain regions.

The regimen of runoff in California reflects in large measure these characteristics of precipitation. In general, runoff closely follows the monthly and seasonal patterns associated with precipitation occurrence. This results from the fact that steep slopes typifying most California watersheds are not conducive to development of any great time lag or peak-reducing storage capacity. Thus, stream flow in California is generally sporadic in nature, with short, fast runoff followed by long periods of little or no flow. A modifying influence, however, results from the fact that a large portion of California's precipitation occurs on forested land in the form of snow in the higher mountains. This water accumulates during the winter in extensive snowfields at high elevations and is released, as runoff, months later during the late spring and early summer snowmelt period. This flow is far more uniform than runoff resulting directly from rainfall, and its value is greatly enhanced by its more or less predictable nature and the fact that it is sustained well into the growing season when precipitation is negligible.

This seasonal regimen of flow is almost completely out of phase with the pattern of demand. During the summer growing seasons, water requirements are at a maximum while natural flows diminish to trickles or disappear entirely. A complete reversal exists throughout the winter period. Thus, all but the *most elementary utilization* of stream runoff generally requires provision of some carry-over storage.

Superimposed upon this seasonal variation in flow is the problem resulting from wide fluctuations in season-to-season runoff. Total seasonal runoff for the State, historically, has varied from about one-fourth to almost twice the long-time mean. Furthermore, the dry years have generally outnumbered the wet years during the period of record. Therefore, the conservation of surplus flows in wet periods, for utilization during the droughts which inevitably follow, requires provision of much more storage capacity than that needed for the previously-mentioned seasonal regulation.

In order to determine the regimen of flow in rivers in the areas of potential pulp and paper mills, it was first necessary to determine the potential sites of pulp mills. The selection of the streams to be studied was affected by four basic considerations: (1) apparent sufficiency of water resources; (2) availability of fiber resources; (3) the problem of waste disposal; and (4) availability of data. A brief discussion of these factors is given in the following paragraphs.

Inasmuch as the pulp industry requires water on a constant demand schedule, only those streams which have a year-round flow were considered. However, the construction of storage facilities to conserve surplus flows during times of heavy runoff could make an intermittent stream suitable as a source of water supply.

The availability of fiber resources was considered to be of less importance than the ready availability of water resources. However, the selection of locations to be studied was limited to those which were considered to be within a practicable radius of the source of suitable raw material.

Although it varies according to the product manufactured and the process employed, a relatively large amount of waste material is produced by the pulp and paper industry. In most instances, the location to be studied was selected on the assumption that the wastes would be discharged directly to ocean or bay waters, or occurred so far downstream as to preclude the re-use of the water. However, in the Sacramento Valley and along the Russian River, studies were made based on the assumption that the wastes would be sufficiently treated so as to be suitable for discharge into the stream and be available for beneficial use downstream.

Study locations had to be restricted to those for which considerable hydrographic data was already available. It was considered that ten recent consecutive years of streamflow records were desirable, but in some instances, studies were made for locations with less than ten years' record.

Specific locations which met all of the above requirements included the Smith River near Crescent City, the Klamath River near Klamath, and the Eel River at Scotia. Locations selected for study where wastes could not be disposed of directly to ocean or bay waters, included the Sacramento River at Red Bluff, the Sacramento River near Sacramento, and the Russian River near Hopland. The selection of Hopland as the site of study for the Russian River was influenced by the belief that the mouth of this river would be too far removed from the source of fiber resources. Locations for which ten recent consecutive years of streamflow records were not available, but for which studies were made, included Redwood Creek at Orick, the Mad River near Arcata, and the Noyo River near Fort Bragg. Inasmuch as data for these three locations were limited, the required studies were accomplished through correlation with data for the Eel River at Scotia. Therefore, it should be borne in mind that studies for these last three locations are approximation only, and are subject to the errors inherent in any correlation method.

Data compiled included location, drainage area, period of record, average discharge (for those stations with ten or more years continuous record), maximum and minimum discharges, and probable value of one-day and seven-day minimum flows recurring at five, ten, twenty, and one-hundred-year intervals (Table 27). In addition to this summary, flow-duration and drought-frequency analyses were made. Flow-duration curves for selected northern California rivers are shown in Figure 6. Drought frequencies for the Eel, Noyo, and Smith Rivers are shown in Table 26. A brief description of the streams and the findings of the investigation appear in the following paragraphs. Stream locations are shown in Figures 1 and 5.

The records for the discharge of the Smith River near Crescent City are good and, except for a short period during the water year of 1938, are continuous from 1931 to the present. There are no storage or diversion facilities above Crescent City. A study of the drought-frequency curve for this station indicates that the present minimum average discharge for a drought of seven days' duration recurring each five years is 200 cubic feet per second (cfs), or approximately 129 million gallons per day. No definite minimum flow has been established for this location under

TABLE 26

DROUGHT FREQUENCIES—MINIMUM AVERAGE DISCHARGE RECURRING AT STATED INTERVAL

(In cubic feet per second)

Number of consecutive days	Recurrence interval in years			
	5-year	10-year	20-year	100-year
Eel River				
1	46	38	29	11
7	48	40	31	12
15	51	41	32	13
30	55	44	35	15
60	61	47	37	19
Noyo River				
1	3.2	3.0	2.7	less than 1
7	3.5	3.2	2.9	less than 1
15	3.6	3.3	3.1	less than 1
30	3.8	3.5	3.2	less than 1
60	4.2	3.9	3.5	1
Smith River				
1	195	170	153	122
7	200	175	157	124
15	205	180	162	127
30	210	185	165	132
60	220	195	174	140

The California Water Plan, but the Department of Fish and Game has recommended that a minimum flow of 200 cfs be set to maintain the present fishery by keeping the channel open to the ocean. With sufficient storage upstream, the Smith River could be regulated to provide minimum flows of about 2,800 cfs.

Records of the discharge of the Klamath River near Klamath are available for periods from December 1910, to June 1926, and from October 1950, to October 1955. The present flow is considerably regulated by reservoirs and power plants above the stations, and large diversions are also made above this station for irrigation. As indicated by Table 27, the minimum average seven-day discharge which could be expected to recur every five years is 1,840 cfs or approximately 1,189 million gallons per day. The minimum average flow to maintain fish life in this stream recommended by the State Department of Fish and Game is 1,200 cfs. Since there are at present no known appropriators of water downstream from this point, it appears that from the standpoint of water supply, this stream could support several large pulp and paper mills utilizing any of the present processes.

Studies of flow in Redwood Creek at Orick indicate that a minimum seven-day average discharge of 2.4 cfs or about 1.5 million gallons per day may be expected at five-year intervals. Estimated average discharge at this station is 980 cfs, and the recorded maximum and minimum flows are 50,000 and 1.0 cfs, respectively. A minimum average flow of 40 cfs has been recommended by the State Department of Fish and Game to maintain present fish populations. Construction of Green Point Dam on Redwood Creek, a

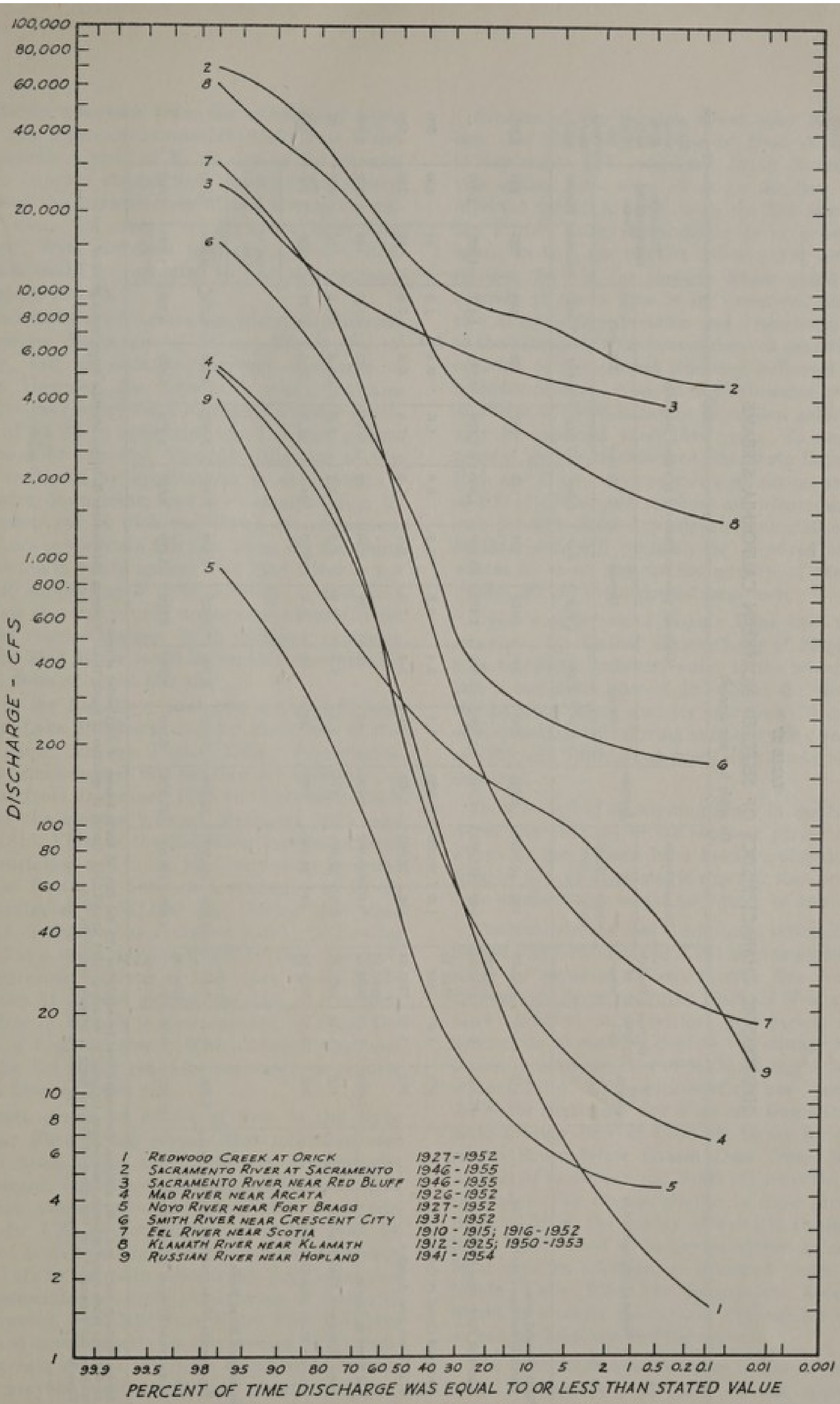


FIGURE 6

FLOW-DURATION CURVES FOR SELECTED NORTHERN CALIFORNIA RIVERS

TABLE 27

HYDROLOGIC CHARACTERISTICS OF SELECTED NORTHERN CALIFORNIA STREAMS

(In cubic feet per second)

Name of gaging station	Drainage area in sq. mi.	Hydrographic unit	Period of record	Instantaneous		Average	Minimum average recurring at stated intervals								Minimum recommended flow [c]		Minimum flow with added upstream storage [d]
				Minimum	Maximum		5-year		10-year		20 year		100-year				
							1 day	7 day	1 day	7 day	1 day	7 day	1 day	7 day	Summer	Winter	
North Coastal Area																	
Smith River near Crescent City	613	1-8	1931-52	168	165,000	3,543	195	200	170	175	153	157	122	124	200	800	2,800
Klamath River near Klamath	12,200	1-6	1912-25 1951-54	1,340	425,000	17,010	1,690	1,840	1,470	1,580	1,330	1,420	1,075	1,140	1,200	2,000	--
Redwood Creek at Orick [a]	278	1-9	1912, 13 1954	1.0	50,000	980	1.1	2.4	0.8	1.9	0.6	1.6	0.4	1.3	40	250	600
Mad River near Arcata [a]	485	1-10	1951-54	16	77,800	1,100	9.0	9.4	7.8	8.1	7.2	7.4	6.8	7.0	15	350	650
Eel River at Scotia	3,070	1-11	1910-15 1916-52	10	541,000	6,403	46	48	38	40	29	31	11	12	100	500	3,600
Noyo River near Fort Bragg [a]	105	1-14	1952-54	3.5	27,600	117	3.2	3.5	3.0	3.2	2.7	2.9	<1.0	<1.0	10	200	60
Russian River near Hopland	362	1-15	1941-54	24	34,100	688	29	38	25.5	30.5	24.5	27.5	23.5	27	100	250	150
															Sept. to Dec.	Jan. to Aug.	
Sacramento River Basin																	
Sacramento River near Red Bluff [b]	9,300	5-7	1895-1955	3,040	291,000	10,140	3,700	3,900	3,620	3,820	3,580	3,800	3,500	3,720	4,000	3,000	--
Sacramento River at Sacramento [b]	19,700	5-28	1904, 05, 21, 1924-55	4,400	104,000	22,364	5,900	6,200	5,700	5,970	5,650	5,870	5,570	5,730	4,000	4,000	--

[a] Average discharge and 1- and 7-day minimum discharges derived by correlation with Eel River at Scotia because of short period of record.
[b] All discharge values except maximum instantaneous are based on records of 1946 through 1955 (period of operation of Shasta Dam). Maximum instantaneous discharges are those during entire period of record.
[c] Minimum flow recommended by Department of Fish and Game to maintain present fish life.
[d] These flows indicate a physical possibility; however, the economic feasibility has not been determined.

short distance upstream from the crossing of State Highway 299, is proposed under The California Water Plan to provide a yield of 15 cfs during the summer months to improve stream flow, enhance the fishery, and increase the attractiveness of this stream for recreational uses. No export requirements have been anticipated. With sufficient upstream storage, Redwood Creek could be regulated to provide minimum flows of about 600 cfs.

The Mad River near Arcata has recorded minimum and maximum discharges of 16 and 77,800 cfs, respectively, and an estimated average discharge of 1,100 cfs. However, the correlative study indicates that, at five-year intervals, a minimum average seven-day flow of 9.4 cfs or approximately 6 million gallons per day may be expected. Present utilization of this water is indicated by applications to appropriate 9 cfs of water downstream and a recommendation by State Department of Fish and Game of a minimum flow of 15 cfs to maintain fish life. From the foregoing considerations it would appear that Mad River is not capable of supporting a pulp industry in this area on the basis of water supply under present conditions, and would require storage. With sufficient upstream storage the Mad River could be regulated to provide minimum flows of about 650 cfs.

Flows in the Eel River at Scotia are slightly regulated by Lake Pillsbury and by diversion to the Russian River through Potter Valley Powerhouse. Records of discharge at this location are available for the period from December 1910 to September 1955, except for the months between February 1915, and October 1916. Flow in the Eel River has an extreme seasonal variation and in the relatively short recorded history has fluctuated between a minimum of 10 cfs and a maximum of 541,000 cfs. During this same period the discharge has averaged 6,000 cfs. Studies indicate that a seven-day minimum average flow having a recurrence interval of five years would be 48 cfs or about 31 million gallons per day. A minimum average flow of 100 cfs is recommended by State Department of Fish and Game. With sufficient upstream storage the Eel River could be regulated to provide minimum flows of 3,600 cfs.

The short period of record of flow in the Noyo River near Fort Bragg reveals that minimum and maximum flows of 3.5 and 27,600 cfs, respectively, have occurred, but correlative studies indicate that a minimum average seven-day flow of 2 cfs or approximately 1.29 million gallons per day may be anticipated at five-year intervals. A minimum average flow of 10 cfs to maintain present fish population has been recommended by State Department of Fish and Game; however, The California Water Plan indicates no proposed developments on this stream. With sufficient upstream storage the Noyo River could be regulated to provide minimum flows of about 60 cfs.

Studies of the Russian River near Hopland indicate that the available records, from December 1939 to September 1955, are good. Small diversions above this station have some effect on the flow, but water diverted into this basin from the Eel River through the Potter Valley Powerhouse is of greater significance. In fact, our studies indicate that without these releases, flow in the Russian River would disappear entirely at times. Due to its variation, this importation affected flow-duration and drought-flow analyses to the extent that the curves derived therefrom do not conform to the general tendency indicated by the remainder studied. A seven-day minimum average flow of 28 cfs or approximately 18 million gallons per day may be expected every five years. To maintain the present fishery in this area, the State Department of Fish and Game recommends a minimum average flow of 100 cfs. Inasmuch as there are numerous beneficial uses for this water downstream, any mill constructed in this area will probably be required to treat its wastes so as to protect the quality of the receiving waters for all these downstream uses.

Upon completion of Coyote Dam, now under construction, the United States Corps of Engineers propose to release sufficient water to the stream to maintain a minimum flow of 150 cfs at the confluence of the Russian River and its east fork 20 miles north of Hopland, except during extremely dry years similar to 1924 and 1931, when small deficiencies would have occurred.

Data compiled concerning flows in the Sacramento River were limited to the ten-year period since 1945. Flows in this stream have been regulated since that time by Shasta Dam and it was felt that previous records of discharge would no longer be applicable.

Studies indicate that a minimum seven-day average flow of 3,900 cfs or about 2,520 million gallons per day could be expected to recur every five years in the Sacramento River near Red Bluff. If Shasta Reservoir were operated in a critical dry period in such a manner as to entirely deplete the storage in the reservoir, a minimum flow of 2,500 cfs might be expected at Red Bluff. A recommendation has been made by the State Department of Fish and Game that a minimum average flow of 4,000 cfs be set for the Sacramento River below Shasta Dam from January to August of each year and 3,000 cfs from September to December. For reasons similar to those given for the Russian River, the quality of water in the Sacramento River would need to be protected for its many beneficial uses. In addition, as proposed under The California Water Plan, the Sacramento River channel would be a major conveyance channel for water conserved for local use and for export.

The drought-frequency curve indicates that a minimum average flow of 6,200 cfs or approximately

4,000 million gallons per day may be expected to occur every five years in the Sacramento River at Sacramento. In addition to beneficial uses for the Sacramento River water mentioned previously, the municipal water supply for the City of Sacramento is appropriated just below the confluence of the Sacramento and American Rivers.

Similar studies were contemplated for the lower San Joaquin River near Stockton, but flow characteristics of this stream made this impracticable. Due to tidal effects and diversions of large amounts of water upstream, flow in the lower reaches of the San Joaquin River is upstream at times which makes a flow-duration and drought-frequency study infeasible.

In summary, studies of flows at the previously-mentioned locations indicate that, of those locations where it is assumed wastes would not be returned to the respective streams, only one, the Klamath River near Klamath, would be capable of supplying sufficient water for a pulp and paper industry under *present* conditions. It should be borne in mind that this conclusion is applicable only so long as present conditions remain unchanged. In other words, any subsequent storage or diversion above the site of study alters the regimen of flow and vitiates earlier hydrographic data in its application to ensuing conditions. If storage facilities are provided to augment low flows, water supplies for pulp industry development would probably be sufficient at any or all of the coastal locations studied. If this requirement is met, there are probably several sites in addition to those studied where a sufficient water supply would be available.

It appears that there would be sufficient water at the sites considered on the Sacramento River to make development of the pulp industry practicable, if the waste disposal problem is solved. However, in order to develop a pulp industry on the Russian River near Hopland, storage facilities would be required to regulate flows and furnish supplies during times of drought, and waste treatment practices would need to be of a high order.

During times of drought, flows in some of the streams studied are so low that, after meeting the recommendations set by the California Department of Fish and Game to maintain present fish populations, little if any water would be available for other beneficial uses.

The conclusions derived from the discharge studies made have necessarily been general because of the lack of specific information concerning the location and amount of water required. It is felt that a comprehensive study of a definite proposed mill site with specific information as to proposed product (pulp and/or paper), mill size and process to be used, would be more conclusive and probably necessary in order to determine the adequacy of the water supply and waste-receiving potentialities. However, it is believed that these additional detailed studies do not fall within the scope of this report, and more properly are in the province of private engineering.

A summary of data compiled from discharge studies is given in Table 27.

VIII. WASTES FROM PULP AND PAPER PROCESSES

Anthony F. Gaudy, Jr.[1]

It has been stated previously that water requirements for the industry are less than 10% consumptive in nature. Volumes of waste, therefore, are readily discerned from the previous section and need not be listed here.

To enhance the meaningfulness of the subsequent discussion of the specific nature of pulp and paper making waste waters, it may be desirable first to define the nature of the raw material and the finished product since the difference between their characteristics, when account is made of chemical changes wrought by cooking chemicals, depicts the nature of the waste.

In general, pulp and paper making techniques bring about a structural dearrangement, cleansing, and harvesting of the wood fibers in the pulp mill, and subsequent rearrangement and alignment of the harvested fibers in the paper mill. During the first process of dearrangement and purification, chemical changes take place which lead to the extraction and solubilization of some of the natural constituents of the wood. These extracted, and in many cases chemically altered, constituents, along with excess chemicals, comprise the waste, and it is the degree of solubilization and reaction with cooking chemicals that contributes largely to the basic differences in the characteristics of wastes from specific techniques.

Wood, in decreasing order of magnitude, consists of cellulose, lignin, hemicelluloses and many minor constituents such as resins, terpenes, tannins, fats, etc. The quantity of each varies with the particular species of tree, season of the year and, to some extent, the geographic location of the stand. Very generally, these constituents may be distributed as follows:

Cellulose	55%
Lignin	30%
Hemicelluloses	13%
Resins, fats, etc.	2%

Of these components, cellulose is the most desirable in paper manufacture. The distribution of components offers a partial explanation of the fact that low-yield, high-grade pulps generally produce wastes of the greatest strength. The higher yield processes leave a greater proportion of lignin and hemicellulose in the pulp and tend to produce wastes of lower strength. In general, waste characteristics of specific pulping techniques vary primarily according to (1) pulping technique and chemicals employed, (2) yield of the process, and to a lesser degree, (3) the species of wood pulped, and (4) season of the year. Waste liquors from autumn-cut wood will generally contain more sugars than liquors obtained from wood cut in the spring. Due to variations in storing periods and mixture of autumn and spring-cut wood, the slight seasonal variations are smoothed out and need not be given serious consideration in the overall picture.

[1] West Coast Resident Engineer, National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc.

Definition of Waste Characteristics

The terms most generally used in defining waste characteristics of any aqueous effluent are biochemical oxygen demand (BOD) and solids concentration, since these factors are the ones which manifest the greatest effects on receiving streams. Toxicity has also received much attention in recent years. A brief explanation of these terms may add to the clarity of the subsequent discussion.

Biochemical Oxygen Demand (BOD)—Perhaps the greatest single consideration in determining the welfare of a stream is its dissolved oxygen content because of the importance of oxygen to the stream biota. It is considerably beyond the scope of this report to define stream pollution or to give a detailed description of stream biology.

Briefly, however, all living organisms except anerobic bacteria require molecular oxygen for respiration. The amount of oxygen, and to some extent the concentration level of oxygen required may be quantitatively related to the size of the organism. Thus, fish require more oxygen than bacteria. The stream biota consists of bacteria, protozoa, crustacea, etc., and smaller and larger fish. The components of this biological system are interdependent in that the small organisms provide food for each succeedingly larger form. Any upset or unbalance of relative numbers of these organisms can cause serious effects to the overall ecological picture, and the causative agent may be classified as a stream pollutant whether it is from natural runoff or from domestic or industrial waste discharge.

The meaning of BOD and its relation to the health of the stream may be illustrated by a hypothetical case: Assume a normal healthy stream, one in which the biological population is in balance. The term balance merely means there is sufficient organic matter and oxygen present to support bacterial growth, which in turn supports the growth of protozoa, etc. Into this stream a large amount of dissolved or readily soluble organic matter may be introduced. The dissolved matter is assimilated by the bacteria which multiply more rapidly than other forms and deplete the oxygen supply. The oxygen concentration may be lowered sufficiently to cause serious stress to the higher forms which normally feed on the bacteria. This results in accelerating the unbalance between bacteria and predators and, as the ratio of bacteria to predators increases, the oxygen supply decreases. In some streams where reaeration is not sufficient to supply the increased need for oxygen and the bacterial food supply is overabundant, the dissolved oxygen may drop to zero. If such a condition exists for an extended period of time, the anaerobic bacteria previously mentioned will attack the remaining food. Unlike the aerobic metabolic process, which utilizes the waste to ultimate destruction as carbon dioxide and water, the anaerobes only partially utilize this food supply, yielding organic acids and gaseous end products. These compounds result in the universally known malodorous characteristics of a polluted stream.

While the process described above is being enacted in the stream, there is concurrent with it a recovery process whereby the oxygen supply is being replenished. Oxygen from the atmosphere immediately above the water surface diffuses through this interface and is dissolved in the stream. The capability of the stream to absorb and hold oxygen is dependent on its temperature, depth, velocity, and turbulence. Cold, fast-running, turbulent streams of high volume seldom are deficient in oxygen and exhibit high waste-assimilating capacities and quick recovery from effects of waste discharge.

It is essential to the health of the stream that the waste assimilation process (oxygen utilization) be balanced by the recovery process (reaeration) in such a way that the dissolved oxygen does not fall below levels which would cause stress to the higher forms, and that the oxygen deficit is replenished in a reasonable downstream flowing time.

The BOD test offers a means of predicting the amount of oxygen required by the stream organisms in utilizing the influent organic matter. Knowing the oxygen demand of the waste and the rheology of the stream (its depth, velocity, turbulence, surface area, and quantity of flow), it is possible to determine how much waste material may be put safely into the stream. The BOD test provides for the microbiological utilization of a known amount of organic waste in a specific time interval using standard nutritional factors simulating stream conditions. The initial dissolved oxygen is determined and compared to that remaining after the standard incubation time of five days. The amount of oxygen required for a specific amount of waste is then easily calculated. Through national standardization of analytical methods, the BOD test in the hands of a competent analyst offers an excellent means of grading organic wastes according to their pollutional potential. An excellent and more detailed discussion of oxygen assets of receiving bodies, together with a graphical representation of the dissolved oxygen profile and its quantitative estimation based on the BOD reaction, can be found in Phelps' *Stream Sanitation* (25).

Solids Concentration—The terms used in describing solids are as follows:

1. Total solids
2. Dissolved solids
3. Total suspended solids
4. Volatile solids
5. Mineral solids or ash
6. Settleable solids

Total Solids—These include all solid matters present in the waste. They are generally broadly classed as dissolved, total suspended, and settleable suspended.

Dissolved Solids—These include organic and inorganic compounds which are in true solution. They are important in consideration of the industrial waste since it is the organic portion of the dissolved solids which comprises the BOD. Other organic portions, particularly lignin, which is not readily metabolized by microorganisms, contribute to the color of the waste. Inorganic dissolved solids are not generally important except that certain concentrations of inorganic solids are necessary for bacterial growth. Extreme concentrations of some inorganic solids may be toxic or may otherwise render water undesirable for some specific uses, such as industrial process water, irrigation, and domestic supply.

Total Suspended Solids—These include those solids of colloidal or larger dimensions, suspended in water. They contribute to the turbidity of the waste. They may act as nuclei for adsorption of other particles, become coagulated and settle to the stream bottom. This phenomenon is dependent on the chemical composition and rheology of the receiving body as well as the stability of the colloidal particles.

Volatile Solids—These include the solid material, either dissolved or suspended, which will volatilize at a temperature of 600° C or less. These solids may be considered totally organic.

Mineral Solids or Ash—These include the inorganic content of the dissolved, suspended, or total solids fractions.

Settleable Solids—These include those fractions of the total suspended solids which settle under quiescent conditions in an arbitrarily fixed time.

Toxicity—Most chemicals are toxic to aquatic life if present in water at sufficient concentration. Since kraft mills discharge a very dilute effluent, the only constituents of concern are those which are toxic in very high dilutions. Research by the National Council for Stream Improvement, the Institute of Paper Chemistry, Oregon State College, and others has indicated that kraft effluent diluted 20:1 by stream water is a safe environment for the aquatic life tested (26, 27, 28, 29, 30). A number of mills are operating at dilutions considerably lower than this without difficulty.

Toxicity problems seldom arise from the current discharge of kraft mills, but rather from spillage of black liquor due to irregularities in operation and breakdowns. Adequate means now are available to prevent such occurrences, and have become part of good construction and operating practice. Hence where reasonable dilution is afforded, the toxicity of kraft effluents to aquatic life should not present a problem.

Sulfite and neutral sulfite semi-chemical effluents are not toxic to aquatic life in concentrations below those necessary to deplete the dissolved oxygen supply in receiving waters. Extensive experiments by the State of Washington Fish and Game Commission have indicated this to be the case (31). These studies have been verified by the National Council for Stream Improvement, Oregon State College, and the U. S. Public Health Service.

There are no constituents of known toxicity in paper machine effluents. Their effect upon aquatic life is limited to possible depletion of dissolved oxygen in insufficient dilution or the formation of benthal deposits which may affect fish food organisms. The latter problem has now been virtually eliminated by the development of adequate methods for removing suspended matter from such effluents.

Waste Characteristics of Elemental Processes

It is felt that the classifications of elemental process divisions and individual pulping techniques discussed in the previous section on water requirements may again be usefully employed in discussing the wastes. These items have been previously described and further description will be confined to those cases where more detailed discussion is required to delineate the source of the waste or to describe an inherent process feature that alters or eliminates the waste.

Debarking—The bark-bearing aqueous waste from this operation is screened; the screenings are pressed and used as fuel. In some cases, depending upon the species of tree, tannins are extracted before pressing and burning. These tannins may be used in the manufacture of roofing felts.

The discharged water contains small amounts of dissolved solids, as well as small pieces of bark and wood slivers. The suspended solids load entering the stream depends on the debarking technique employed and the opening size of the bark recovery screens. This load may vary from 30 to 50 pounds per ton of product. The BOD loading is also dependent on the above factors and, to some extent, on the species of tree and the storage period. It may vary between 5 and 20 pounds per ton of production.

Total solids amount to approximately 0.1% of the weight of effluent. Approximately 50% of these solids are dissolved. Approximately 50% of the dissolved solids and approximately 10% of the suspended solids are mineral in nature.

The color, pH, temperature, and toxicity of this waste are of little or no importance.

Pulp Mill Wastes—1. *Groundwood*—The waste characteristics for groundwood mills vary considerably, depending on mill operation. In an integrated operation there may be practically no waste except for a small amount of excess overflow water, since all the product is transported to the "paper side" as "slush pulp." If the pulp is considerably dewatered before further processing, suspended solids in the effluent may vary between 50 and 80 pounds per ton of pulp produced. Depending on stream conditions and the economy of recovering this material, in-plant measures may be taken leading to effluent loadings as low as 20 pounds per ton of pulp.

Yields from the groundwood process are high, often greater than 95%. Thus, the BOD loading from groundwood pulping is comparatively low. In general, approximately 10 to 20 pounds of BOD per ton of production may be expected.

Color is not an important consideration. The effluent has a whitish turbid appearance due to the presence of extremely fine wood particles in suspension. The pH is slightly lower than neutral since small amounts of wood acids are released during the grinding process, partly as a result of the temperatures maintained. The acetates and small amounts of wood sugars released during grinding comprise the major portion of the BOD of the effluent. Although grinding temperatures often approach 190° F, the temperature of the effluent leaving the mill seldom exceeds 75° F.

2. *Hardboard*—Hardboard manufacture generally involves chipping and steam treatment prior to defibration. Under conditions of moist heat and pressure, it is to be expected that more of the natural wood constituents are released by this process than by the groundwood process. This fact is reflected in the slightly lower yields obtained.

The waste exhibits a slightly depressed pH ranging from pH 6 to pH 7, due to release of acetates. Some wood sugars are extracted from the wood. These acetates and sugars are readily utilized by the stream biota, thereby imparting an oxygen demand to the waste. The amount of BOD produced is dependent to a large degree on the duration and severity of the stream treatment and may vary between 20 and 80 pounds per ton of pulp produced.

Fiber losses, expressed as suspended solids, from this operation may be in the neighborhood of 100 pounds per ton of pulp produced, depending upon operational procedures. In-plant fiber recovery may reduce pulp mill fiber losses to 20 pounds per ton of pulp. Temperature of the pulp mill effluent may range from 70° F to 80° F.

3. *Neutral sulfite semi-chemical*—Yields from this process are comparatively high and may range between 65% to 85%. Yields vary primarily according to the cooking conditions. In general, cooking times are shorter than for other chemical processes. The wide variation in yields is a reflection of (a) versatility of this technique and its applicability to almost any type of wood, and (b) the many different products made from semi-chemical pulp, all of which require variations in cooking conditions.

Acetates comprise approximately 70% of the BOD; the remaining 30% is contributed mainly by wood sugars. Load factors may vary between 200 and 400 pounds per ton of pulp produced. As previously suggested, this rather wide variation arises because of differences in cooking times and temperatures.

There is very little suspended solids loss from the cooking process since the chips remain intact. Total solids of the black liquor have been found to vary between 8% and 22% (by weight), and average approximately 12%. Volatile solids account for 50% of this total. pH ranges from 6.5 to 8.5. The color of the black liquor ranges from 15,000 to 30,000 ppm. The volume of digester black liquor is small compared to total mill effluent volume, and final color in the discharged waste is considerably reduced from the above figure.

It is important to note that many neutral sulfite semi-chemical plants are integrated with kraft plants. When the semi-chemical production is held to one-third the kraft production, it is possible to send all semi-chemical black liquor to the kraft recovery system, thereby eliminating 90% of the pollution load. Separate recovery systems for neutral sulfite semi-chemical mills have recently been successfully employed. This aspect will be discussed in the section on waste elimination.

4. *Kraft*—The kraft process is a truly chemical technique in that the wood chips are pulped or reduced to fibers solely by the action of the cooking liquors under conditions of elevated temperature and pressure. Yields from this process may vary considerably, according to the length of the cooking period and the temperature and pressure employed. In general, yields may vary between 40% and 55%, although yields as high as 75% to 80% have been obtained with certain coniferous woods, using short digesting periods.

Since kraft yields are, in general, lower than for neutral sulfite semi-chemical, it would be expected that more noncellulosic material is extracted from the wood, thereby increasing the BOD of the black liquor. In solubilizing the lignin much of the hemicellulose associated with it is released as sugars, which constitute the major proportion of the BOD of the waste.

The gradual replacement of the soda process by the kraft process has come about because of the desire of the industry to find a technique which will allow acceleration of lignin release without correspondingly increasing the rate of carbohydrate attack. It was discovered that the addition of sodium sulfide to the sodium hydroxide of the soda process resulted in higher pulp yields for the same final lignin concentration in the finished pulp. It is believed that the sodium mercaptides formed accelerate delignification without a corresponding acceleration of carbohydrate attack, thereby increasing the yield and decreasing the sugar concentration in the waste liquor.

The BOD of the digester black liquor may be in excess of 600 pounds per ton of pulp produced. It should be noted, however, that this does not represent the BOD discharged to the stream. The digester liquor is evaporated and burned and the chemicals are recovered by the kraft recovery system. This reduces the pollution load by over 90% and loadings of 30 pounds BOD per ton or less are not uncommon.

Since recovery of cooking liquors is practiced in all kraft installations, the following waste characteristics apply to kraft effluents after recovery.

The total solids of the effluent may vary between 200 and 300 pounds per ton. Approximately 65% of these solids are volatile. Less than 20 pounds per ton are suspended. The effluent has a color ranging from 300 to 500 ppm. The total alkalinity of the waste may range from 100 to 300 ppm, with pH values ranging from 7.5 to 9.

There have been a few instances where tastes and odors in the receiving body may be attributed to kraft mill effluents. Where the stream is used for bathing or for a potable water supply receiving only cursory treatment, tastes and odors are of considerable concern. Most mills, however, are not situated at such locations, and taste and odor problems seldom arise.

Where the downstream uses of the receiving body involve irrigation, sodium concentration may be a concern depending on the type of soil and crops irrigated (32). Sodium is present in a kraft effluent because it is impossible to recover 100% of sodium sulfate used in the manufacturing process. Total ''saltcake'' make-up requirements may vary from considerably under 100 to 140 lb per ton of pulp produced. This total loss is made up of:

1. That which remains in the pulp
2. That which is lost in the burning process
3. That which is lost in the mill effluent

Approximately 35% of the total loss may be found in the effluent (33). Since saltcake losses may be subject to variation, depending on mill operation, 50 lb of sodium sulfate may be used as a conservative basis for calculation of sodium concentration in the effluent. The sodium loss in the effluent is, therefore, 16 lb per ton of pulp produced, and the sulfate loss is 34 lb per ton of pulp produced. Taking an effluent volume of 20,000 gallons per ton of pulp (see water requirements table), the sodium concentration is calculated to be slightly under 100 ppm. It should be emphasized that this is a concentration figure and will remain constant regardless of the tonnage produced. In like manner, the concentration of sulfate is calculated to be slightly under 200 ppm.

In terms of milliequivalents, the concentration of both sodium and sulfate are approximately 4 M.E./liter. It should be remembered that this concentration is reduced by dilution with process water from other components of the mill and by dilution in the receiving body.

As a sample calculation, assume a total diluting flow of 1,000 cubic feet per second and a 500-ton kraft pulp mill with an effluent flow of 20,000 gallons per ton of pulp. This is equivalent to an effluent flow of approximately 16 cubic feet per second, which yields a dilution factor of 62 to 1. This reduces sodium concentration in the receiving body contributed by the effluent to approximately 1.6 ppm, or 0.07 M.E./liter, and sulfate concentrations to approximately 3.2 ppm, or 0.07 M.E./liter.

5. *Sulfite*—The sulfite process produces pulps approaching pure cellulose fiber. Since most of the noncellulosic constituents are separated from the wood, it is to be expected that the aqueous waste bearing these constituents would contain more organic material than that from other pulping techniques. Yields from this process may vary from 42% to 48%, depending on the severity of the cook, which is a function of the ultimate use for which the pulp is manufactured. It is noted that the yields are generally less than the original cellulosic content of the wood, a fact which attests to the completeness of reaction in the digester.

A portion of the cellulose is converted into hexose and pentose sugars. Total sugars account for about 65% of the BOD of the waste. Fatty acids and alcohols released or formed in the digester contribute the major portion of the remaining BOD. The total BOD load from sulfite pulping may vary from 550 to 750 pounds per ton of pulp produced, depending upon such cooking conditions as time, temperature, composition of the cooking acid, and the species of wood pulped. Where a magnesium-base liquor is used, this BOD loading may be reduced by 85% to 90% due to base chemical recovery inherent in the technique.

Total solids from sulfite pulping practicing no recovery may approximate 2,500 pounds per ton of pulp. Approximately 10% of these solids are mineral. Lignin composes the major portion of the combustible solids. The remainder is made up of carbohydrates, resins, fats, and proteins, which are the prime constituents of the BOD. The pH of the pulp mill waste is approximately 3 to 4, and its color may exceed 500 ppm.

Bleach Plant Wastes—It has been previously stated that bleaching of the pulp may, in a sense, be considered a continuation of the digesting process. Its aim is to eliminate from the pulp the lignin not previously removed in the digester. This removal is accomplished through three major chemical reactions. The first reaction solubilizes or prepares the lignin for solution, the second is one of oxidation, and the third one of extraction of the oxidized lignin components.

The first two reactions take place in an acid medium and are brought about by chlorine and hypochlorite. After washing the pulp, the extraction stage is accomplished in an alkaline medium. This leads to two major wastes. The first, or acid waste, has a BOD of minor consequence and is relatively larger in volume. The caustic extraction stage produces a waste of considerably lower volume, but with a higher oxygen demand and color concentration. Combination of the wastes from both stages produces a waste substantially neutral in reaction. Volumes of waste are readily determined from the water requirements table.

The pH of the combined bleach plant effluent may range between pH 4.5 and 8.0; total solids from 0.1 to 0.2% by weight. Approximately 50% of these solids are mineral in nature. Turbidity may range from 60 to 300 ppm. The suspended solids load of this effluent may range from 15 to 25 pounds per ton of pulp bleached. Approximately 50% of the suspended solids are volatile. The BOD of the combined effluent ranges from 10 to 25 pounds per ton of pulp bleached. This effluent may be given chemical treatment employing lime coagulation and sedimentation, with BOD reductions of approximately 50%.

Paper and Board Machine Wastes—The chief interest of this report lies in wastes from the processing of new pulp into paper or board products; therefore, the manufacture of paper or board from materials other than new wood pulp will not be considered.

There is a distinct difference in the characteristics of the wastes from paper and board manufacture. As shown in the previous section, board mill water requirements are fairly low. This is true because complete washing is not generally required. As a result, some of the solubilized organic matter is carried over to the board machine and appears in the machine overflow water, yielding waste waters somewhat higher in pollutional potential than paper machine waters, which represent merely transport water for thoroughly washed pulp. The most important characteristics of all types of machine wastes, from a pollutional standpoint, are suspended solids and BOD.

1. *Paper machine waters*—Suspended fiber is the major potential pollution problem with these wastes. The fiber loss depends to a large degree on the type of product manufactured. The suspended solids in the

effluent may vary from approximately 5 pounds per ton of product for kraft papers to 60 pounds per ton for tissues made from combined sulfite and groundwood pulps. The BOD of these waters is relatively low and may range from 5 pounds per ton for kraft to 15 pounds per ton for certain sulfite-groundwood tissues.

Fibers appearing in the machine waters are extremely small in size. Waste treatment measures taken to reduce the suspended solids load, therefore, include high-efficiency flotation save-alls and diatomaceous filters. These devices may be capable of reducing the effluent fiber concentration to below 5 pounds per ton of product. Since these solids are so finely divided, they seldom cause sludge deposits and are rapidly dissipated in the stream.

2. *Board machine wastes*—These wastes generally contain significantly more BOD than do paper machine wastes. In discussing the wastes from the board-producing operation, the same difficulties are encountered as were evidenced in discussing water requirements, since both these items are entirely dependent on which of the many varied techniques of board manufacture is employed. In general, BOD loadings may vary from 15 to 25 pounds per ton of product, and suspended solids from 20 to 40 pounds per ton.

The ranges quoted above for board machine waters are representative of mills using modern equipment and optimum recirculation practices. The major treatment method employed to reduce suspended matter is the use of sedimentation lagoons. Lime precipitation in thickener type clarifiers has not proved successful because of the hydrous nature of the material which resists dewatering.

Pulp Mill Waste Elimination Through Base Chemical Recovery

In discussing the characteristics of pulping wastes, it was shown that the oxygen demand was caused wholly by organic matter in the waste. The remaining portion is that which is subject to recovery and re-use in subsequent cooks. It can readily be seen that if the organic and inorganic fractions can be separated and the organic fraction destroyed, two aims can be accomplished: (a) the waste is largely eliminated, and (b) operational economy is increased. Both these results are beneficial to the industry and to the general public.

All practical recovery systems in use today involve the following three basic steps:

1. Evaporation
2. Burning off of organic material
3. Regeneration of the reclaimed mineral solids or cooking chemicals

The second step destroys by chemical oxidation (combustion) the BOD causative constituents which would otherwise be subject to biochemical oxidation in the stream. The degree of waste elmination is related to water re-use in the pulp mill since the major portion of BOD entering the stream originates from the weak wash waters which are not economically rerouted to the evaporators. Wash water recycling aids in concentrating the liquors and makes feasible the sending of more of the waste solids to the evaporators.

Recovery systems are in operation for neutral sulfite semi-chemical, kraft, and magnesium-base sulfite pulping techniques.

1. *Neutral sulfite semi-chemical*—As noted previously, neutral sulfite semi-chemical is often integrated with kraft and the wastes combined in the recovery system. Recent recovery systems, however, have been successfully employed for neutral sulfite semi-chemical black liquor alone. Both the Mead process and the Institute of Paper Chemistry process involve evaporation, burning, and regeneration. The Zimmerman process involves oxidation of weaker spent liquor under conditions of high pressure and temperature. Reductions of 80% to 90% of the oxygen demand of the mill effluent may be obtained with these recovery systems.

2. *Kraft*—The recovery plant is an integral part of all kraft mills. Since the kraft technique is of prime importance, it is felt that a full description of the recovery system would be of value and provide a clearer insight into all pulping liquor recovery techniques.

This recovery system, like those for neutral sulfite semi-chemical, consists of the same three major phases: evaporation, burning, and regeneration of the reclaimed chemicals. Generally, a portion of the black liquor is routed back to the digester where it forms a part of the next cook. The remaining portion is concentrated in a multiple-stage evaporator system. When sufficient water has been removed, this concentrated liquor may be spray-injected into an incinerating furnace where it immediately dries and falls as black ash to a smelting furnace below. Here it is ignited, burning off all organic matter. The mineral residue is then drawn off in a molten mass. The small amount of sodium lost in the pulping and washing processes is replaced by the addition of sodium sulfate to the concentrated black liquor before it is sprayed into the incinerating furnace.

The molten mass or "smelt" may contain from 15% to 20% by weight of sodium sulfide, 60% to 80% of sodium carbonate, and small amounts of sodium sulfate, sulfite, and thiosulfate. This mass is channeled to a dissolving tank where it is readily dissolved in weak wash waters recycled for this purpose. The resulting liquid is known as "green liquor." Regeneration of the liquor is accomplished by the addition of lime. This phase of the recovery system, called causticizing, converts the sodium carbonate to sodium hydroxide, which is one of the active cooking chemicals. In this simple replacement reaction the carbonates are precipitated as calcium carbonate. The supernatant liquor, which is called "white liquor," is sent to a reservoir where it is mixed with a portion of untreated black liquor. This mixture comprises the final cooking liquor sent to the wood digester.

The precipitated calcium carbonate is washed with weak liquor from previous washes and finally with fresh water. The washed calcium carbonate is sent to the kiln, where it is converted into calcium oxide and, after addition of makeup lime, is sent back to the causticizing plant.

This brief description was presented here to emphasize the sound economy of a practice which not only results in a savings in costs, but has the dual purpose of eliminating or treating a waste to a degree not easily attained by accepted waste treatment methods.

3. *Sulfite*—In the sulfite process, recovery is possible depending on the base chemical employed. The most commonly used base is calcium. Unfortunately, it is possible to recover only a small portion of calcium base cooking chemicals since burning of the organic portion results in the formation of calcium sulphate from which recovery of the original cooking chemicals is practically impossible.

Recovery of heat from burning the organic portion is of dubious value. A serious scaling or caking problem presents itself during the evaporation phase, which makes evaporation extremely difficult. This may be somewhat overcome by the "Rosenblad" system of multiple-effect evaporators with heat exchangers. By periodically reversing circulation, steam from the evaporator curtails scale formation to some degree. However, because of the attendant operational problems and damage to equipment during evaporation, the disposal of calcium base liquor by burning is not practical.

The principles of ammonia base liquor recovery are somewhat different than for the true metal bases merely because ammonia is a gas and there is no utilization of a smelt. Recovery of ammonia and sulfur dioxide has been subjected to much research. However, the process has not yet been developed sufficiently to warrant full-scale operation. The process involves solidification of the waste liquors by heat and pressure aided by additions of dry solids from a previous evaporation stage. During partial pyrolysis of the mass, the ammonia and sulfur dioxide pass off and are routed to a scrubbing tower for the production of fresh cooking acid. The coke resulting from the pyrolysis phase may be burned for its heat value.

Recovery is an inherent feature of a magnesium base sulfite operation, just as it is in kraft pulping. The operations are essentially the same and include evaporation and burning. However, the magnesium oxide ash which is formed during burning must be suspended in the combustion gases and passed rapidly through the combustion chamber to prevent crystallization, which chemically changes the oxide to a nonreactive form. The suspended oxide must be quickly cooled and separated from the gases. It is then formed into an aqueous slurry for the absorption of sulfur dioxide from the combustion gases, with the ultimate production of magnesium bisulfite, the active cooking chemical. Recovery of approximately 90% of the base is accompanied by a parallel reduction of BOD in the pulp mill effluent.

Pulp Mill Waste Abatement Through Treatment

1. **Groundwood and Hardboard**—Wastes from groundwood and hardboard pulp mills are not normally treated since they do not cause adverse stream conditions unless the mill is located on a stream of extremely low flow during portions of the year. During critical periods of flow, the most practical means of abating pollution would appear to be holding lagoons, since the waste volume is fairly low. The waste would then be released only when there was sufficient flow to render it harmless to the receiving body.

The major concern with these wastes is suspended solids, since if proper in-plant measures are not taken to prevent fiber losses, sludge deposits may be formed in the stream. Such sludge deposits would consist mainly of cellulose and lignin, which are not readily assimilated by the stream microflora. They would, therefore, undergo slow decomposition and would contribute to the benthal or stream bottom oxygen demand.

Save-alls are commonly used to reclaim fibers which formerly were admitted to the stream. Even so in many cases, depending on the receiving body, fiber or suspended solids in the effluent must be further reduced. Flotation and vacuum filtration units have been developed in recent years which have made it possible to treat these effluents, reducing final pulp mill suspended fiber loads to approximately 5 pounds per ton of pulp produced. It is doubtful that reductions lower than this can ever be realized because of the extremely fine size of the remaining fibers.

2. **Chemical Pulping**—The chemical pulping techniques solubilize and extract a greater amount of the wood constituents and are much more important from a waste standpoint than either of the mechanical processes. Treatment methods have been sought and applied where stream conditions warrant their use. The treatment methods applicable to the three major chemical pulping techniques are not entirely unique for any specific process. Due primarily to slight differences in the wastes, however, certain treatment practices have been generally adopted specifically for each.

(a) *Neutral Sulfite Semi-chemical* — The major treatment or abatement method employed for neutral sulfite semi-chemical effluents is the use of holding lagoons for the spent black liquors. The waste is merely stored during periods of low flow and discharged when the rate of flow is high enough to render discharge harmless to the stream.

Since the pH of this waste is essentially neutral, odor problems sometimes develop due to anaerobic decomposition during the storage period. This problem may be overcome by concentrating the waste to 15% solids by evaporation prior to lagooning. The waste at this concentration manifests a bacteriostatic action, thus eliminating the odors.

Land disposal by spray irrigation has been successfully employed at a number of mills. The black liquor has been successfully used as a road binder for traffic-bound macadam surfaces. In some instances, the black liquor is concentrated and burned without accompanying recovery of chemicals. Biological treatment employing a somewhat modified version of the basic high-rate activated sludge principle is also employed. BOD removals of 80% to 90% are obtained by this method.

The most recent development in neutral sulfite semichemical waste abatement is the successful application of the recovery system, which has already been described. It is interesting to note that the recovery system provides pollution reductions comparable to those obtained by any of the above-mentioned treatments or effluent disposal schemes. In addition, it eliminates most of the color, which is not affected by biological treatment. It is realized that in some cases reductions of greater than 90% may be required. In such cases, treatment of the weak plant effluent after recovery of chemicals may be accomplished using the above-mentioned disposal plans or treatments.

(b) *Kraft*—Kraft effluents are weak in comparison to those of other chemical pulping techniques since the recovery system which is always included in the process reduces the BOD, solids, and color to small fractions of the original concentrations. Where kraft mills are located on critical streams, oxidation ponds have often been successfully employed. These are large, shallow ponds (approximately 3 feet deep) which are seeded with bacteria, protozoa, and algae. The shallowness and large surface area accelerate the transfer of oxygen to the waste, which is necessary for aerobic metabolism. It is often found necessary to add nitrogen and phosphorus in proportions necessary to satisfy the inorganic nutritional requirements of the microflora in the pond. BOD removals of 75% to 98% have been obtained by this highly successful treatment. It can be truly stated that where land area is available and soil conditions do not endanger ground water supplies, this treatment method is by far the most economical and successful of all methods used to date. At sites where sufficient land area is not available, accelerated biological treatment has proven successful. Modifications of the activated sludge process have been installed yielding BOD reductions of 75% to 90%.

In a few instances, crop irrigation has been employed as a disposal method. After a short storage period, the effluent is used to water such crops as corn, beans, alfalfa, etc. The results in increased crop yields have been extremely encouraging. The use of this method of disposal depends on the proximity of produce farms. It has not yet been tested with a sufficient number of different types of crops, but its development shows promise.

It has been noted previously that tastes and odors imparted to the receiving stream may be of concern, depending upon the mill location and the beneficial uses of the stream. Experimentation has shown that sulfides and mercaptans are the most probable source of tastes and odors, and that chlorination can effect satisfactory removal.

(c) *Sulfite*—Sulfite waste liquor disposal has for many years been subject to intensive investigation directed toward the development of methods of treatment and by-products recovery. Much progress has been made, but to date there has been found no one solution applicable throughout the industry.

Base chemical recovery, which has been discussed previously, would seem to be the ultimate solution, and the major effort of future research should be directed toward the solution of the remaining problems in this process. Biological treatment of spent sulfite liquor has proved somewhat successful in small-scale semipilot plant research. BOD reductions of 70% to 85% have been obtained after 24 hours aeration. However, it has yet to be shown that these removals can be reproduced and sustained in a large-scale operation. The techniques of biological treatment used for domestic sewage are not directly applicable to industrial wastes—this is particularly true of spent sulfite liquor. Satisfaction of the air requirements and foaming problems encountered offer formidable hurdles yet to be overcome. The tremendous size of the treatment plant required to treat this waste and the large amounts of biological solids produced, make it mandatory that a means be devised to market the by-products of treatment, which are essentially the bacterial cells and the desugared lignin of the effluent.

TABLE 28

DEBARKING EFFLUENT CHARACTERISTICS *

Characteristic	Quantity
BOD (5-day)	5-20 lb/ton
Total solids	0.1% of effluent (by weight)
a. Total suspended solids	30-50 lb/ton
1. Mineral	10% of suspended solids
b. Dissolved solids	50% of total solids
1. Mineral	50% of dissolved solids

* Debarking effluent characteristics given represent effluents from aqueous debarking processes. As the water requirement decreases, the characteristics above will decrease in magnitude. The figures above, therefore, are representative of the upper limits of debarking effluent characteristics.

Efforts are now being made in this direction. It may be possible to process and harvest the bacterial cells grown on the waste and use them as a cattle feed supplement. These efforts are necessary lest the high cost involved in treatment be reflected in product costs to the consumer. The difficulties of biological treatment make its application at present somewhat doubtful. It should be noted that approximately 1,000 patents and disposal schemes for sulfite waste treatment have been developed. Some of these have brought about local solutions, but none are universally adaptable.

Since future expansion of the sulfite technique is improbable, particularly in California, it is felt that a detailed description of these methods is not warranted here. In general, the most successful disposal methods have been the use of storage lagoons during periods of low flow.

In conclusion, almost all treatment methods are aimed at reducing BOD. In such treatments, BOD reductions average approximately 80% to 90%. Solids concentrations are equivalently reduced. Approximately 90% to 98% of the color may be removed by chemical treatment. Color removal is not generally practiced since it is rapidly dissipated in the receiving body.

TABLE 29

PULP MILL EFFLUENT CHARACTERISTICS *

Characteristic	Load factors—modern mills using optimum in-plant measures	Additional treatment customarily provided where necessary
Groundwood:		
BOD	10-20 lb/ton	Holding lagoons
Total suspended solids	20-80 lb/ton	Flotation and vacuum save-alls may reduce suspended solids loading to 5 lb/ton
pH	Slightly <7	
Temperature	±75° F.	
Hardboard:		
BOD	20-80 lb/ton	Holding lagoons
Total suspended solids	20-100 lb/ton	Flotation and vacuum save-alls may reduce suspended solids loading to 5 lb/ ton
pH	6-7	
Temperature	70-80° F.	
Neutral Sulfite Semi-Chemical:		
BOD	200-400 lb/ton	Holding lagoons
BOD after chemical recovery	30-60 lb/ton	Biological treatment = 80-90% removal Burning = 90% removal
Total suspended solids	Negligible	
Total solids (black liquor)	8-22% (by weight)	
a. Mineral	50% of total	
Color (black liquor)	15,000-30,000 ppm	Considerably reduced by dilution with wash waters in total effluent
pH (black liquor)	6.5-8.5	
Kraft		
BOD	30 lb/ton	Biological treatment = 75-90% removal a. Oxidation ponds = 75-98% removal Crop irrigation = approaches 100% removal (method now under study)
Total suspended solids	<20 lb/ton	
Total solids	200-300 lb/ton	
a. Mineral	35% of total	
Color	300-500 ppm	
pH	7.5-9.0	
Sulfite:		
BOD	550-750 lb/ton	Biological treatment = 70-85% removal after 24 hr. aeration at high solids concentration (experimentally). Burning with no recovery. Storage lagoons most widely used abatement method.
a. After recovery	50-100 lb/ton	
Total solids	Up to 2,500 lb/ton	
a. Mineral	10% of total	
Color	Up to 500 ppm	
pH	3-4	

* Does not include debarking effluent.

Summary and Future Outlook

It is felt that the usefulness of the data given in the text may be enhanced by compilation of summary tables. Concentrations of certain components of the effluent are dependent on the industrial water usage. Where possible, units of pounds per ton of production are used. Because some loading quantities are more

TABLE 30

BLEACH PLANT EFFLUENT CHARACTERISTICS *

Characteristic	Load factors—modern mills using optimum in-plant measures	Additional treatment customarily provided where necessary
BOD	10-25 lb/ton	Lime coagulation and sedimentation = 50% removal
Total suspended solids	15-25 lb/ton	
a. Mineral	50% of suspended solids	
Total solids	0.1%-0.2% (by wt.)	
a. Mineral	50% of total	
pH	4.5-8.0	

* In general, factors vary in ascending order from partial bleaching through dissolving pulp.

TABLE 31

PAPER AND BOARD MILL EFFLUENT CHARACTERISTICS *

Characteristic	Load factors—modern mills using optimum in-plant measures	Additional treatment customarily provided where necessary
Paper mill:		
BOD	5-15 lb/ton	
Total suspended solids	5-60 lb/ton	Flotation save-alls and diatomaceous filters may reduce this load to 5 lb/ton
Board mill:		
BOD	15-25 lb/ton	
Total suspended solids	20-40 lb/ton	Sedimentation lagoons where necessary

* In general, factors vary in ascending order according to completeness of pulp washing and treatment before reaching the machine room.

critically dependent upon the amount of water used, they are given as percent (by weight) of effluent. Certain other characteristics such as color are given in units accepted as standard expression.

It should be remembered that figures given are approximations based on the best available data, and that the tables are not intended to replace the text but are presented as a useful adjunct to the more detailed treatment given in the foregoing report.

Since the kraft process is the one most likely to receive serious consideration in California, it is considered desirable to summarize the elemental process effluents. Combinations of possible loadings may then be calculated easily.

In Table 32 only BOD and suspended solids are listed since these are the characteristics of the effluent which are most critical in considering the assimilatory capacity of the stream.

TABLE 32

KRAFT PROCESS LOADINGS

Process division	BOD (lb/ton)	SS (lb/ton)
Debarking	5-20	30-50
Pulp mill	30	20
Bleach plant	10-25	15-25
Paper side		
Paper mill	5	5
Board mill	15	20-30

To illustrate the use of Table 32, it can be seen that if an unbleached kraft mill operating on waste wood was considered, the estimated BOD loading could be approximated as 35 lb/ton of production. Depending on the particular process division to be installed, estimate of total loadings can be computed in like manner.

Brief notations of effluent treatment and disposal methods have been included in Tables 28 through 31. Discussion of the applicability and results of these techniques is included in the text.

The trend in the past 20 years has been one of accelerated progress toward abatement of stream pollution. The most promising avenue of future progress seems to lie in further development and broader application of recovery systems tending to eliminate a large proportion of the pollutional potential of the waste. Further research also must be directed toward finding and improving methods of treatment or disposal of the weak wastes in critical areas.

The greatest progress in the area of waste abatement has been made in the neutral sulfite semi-chemical and kraft techniques, which are the chemical processes most likely to be used in California. This does not indicate that less effort has been expended in searching for methods of eliminating or reducing the sulfite loadings, but rather attests to the complexity of the problems encountered in dealing with spent sulfite liquor.

IX. POLLUTION CONTROL IN RELATION TO BENEFICIAL USES OF RECEIVING WATERS

LEGAL BASIS FOR WATER POLLUTION CONTROL IN CALIFORNIA

Joseph S. Gorlinski[1]

In order to carry out the dual task of preserving the State's waters for maximum use, and, at the same time, of permitting the use of the waters for the disposal of wastes without detriment to the general welfare, the California State Legislature in 1949 adopted the present water pollution control laws (34).

Under California statutes, when the waters of the State, including both surface and underground supplies, are impaired by a discharge of sewage or industrial wastes to a degree which creates an actual hazard to the public health, a ''contamination'' is said to exist. When such impairment is of a degree which does not create an actual public health hazard, but which does adversely and unreasonably affect the waters of the State for domestic, agricultural, navigational, recreational or other beneficial uses, a ''pollution'' is said to exist. A third objectionable condition, ''nuisance'' is said to exist when damage results to any community by reason of odors or unsightliness caused by what the law terms ''unreasonable practices'' in the disposal of sewage or industrial wastes.

The California water pollution control statutes provide means for the control of water pollution to meet changes in water requirements as brought about by changing conditions, such as expanding needs. The law gives both local and state health officers authority to deal with those phases of waste disposal which affect the public health. Contamination, by the very urgency of its nature, is subject to immediate correction upon order of local or state health departments. The solution of pollution and nuisance problems on the other hand, is delegated to nine regional boards and the State Water Pollution Control Board created for this purpose. These latter problems call for balancing economic and benefit considerations, often with a resultant compromise of the interests involved. To assure an intimate understanding of local conditions, these boards are decentralized with one regional board assigned and established in each of the nine major drainage basins of the State (Figure 7). Where such action is necessary, the law establishes enforcement provisions for injunctive relief after appropriate notice, public hearings, and other reasonable efforts by the regional boards or the state board have failed to bring about necessary corrections to offending waste discharges. There is nothing in the statutes which prevents communities or political subdivisions within a region from adopting and enforcing additional regulations on waste disposal. In other words, the state law does not rescind local provisions which have been or may be set up to handle special local problems.

The water pollution control statutes creating the boards are incorporated in the California State Water Code as Division 7. Sections 13052 to 13055 of the Water Code outlines the specific duties of the regional water pollution control boards as follows:

13052. Each regional board, with respect to its region, shall:

(a) Obtain coordinated action in the abatement, prevention and control of water pollution and nuisance by means of formal meetings of the persons involved;

(b) Encourage and assist in self-policing waste disposal programs for industry, and upon application of any person shall advise the applicant of the condition to be maintained in any disposal area or receiving waters into which the waste is being discharged;

(c) Require any state or local agency to inspect and report on any technical factors involved in water pollution or nuisance;

(d) Request enforcement of laws concerning water pollution or nuisance by appropriate federal, state and local agencies;

(e) Formulate and adopt long-range plans and policies with respect to water pollution control within the region;

(f) Recommend to the state board projects for the reduction of water pollution which the regional board considers eligible for any financial assistance which may be available through the state board;

(g) Report to the state board and appropriate local health officer any case of contamination in its region which is not being corrected;

(h) File with the state board, at its request, copies of any official action with respect to any particular case of actual or threatened pollution;

[1] Executive officer, Central Valley Regional Water Pollution Control Board.

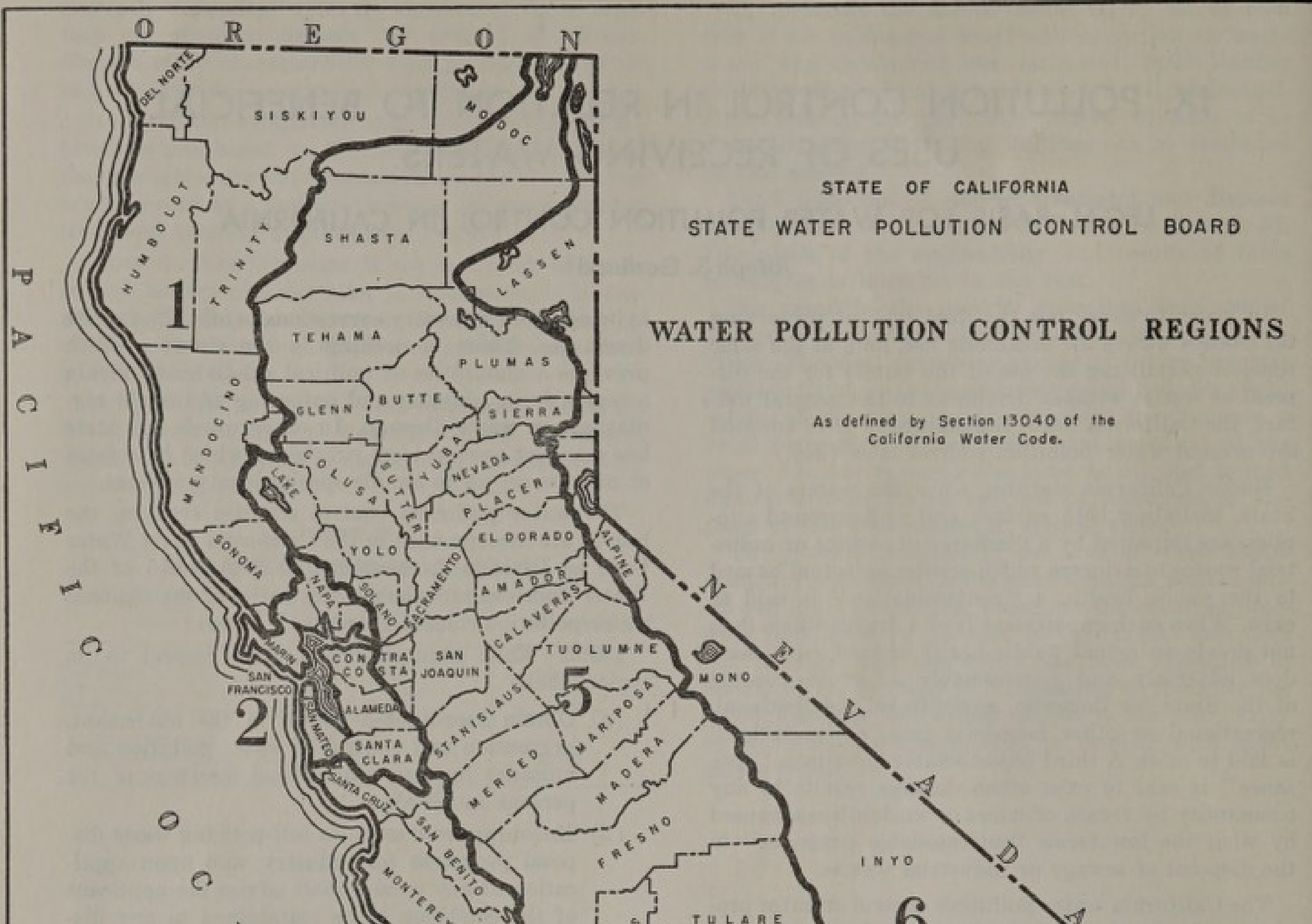

STATE OF CALIFORNIA
STATE WATER POLLUTION CONTROL BOARD
WATER POLLUTION CONTROL REGIONS
As defined by Section 13040 of the California Water Code.
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
LAKE
COLUSA
SUTTER
YUBA
NEVADA
PLACER
SONOMA
YOLO
EL DORADO
ALPINE
NAPA
SOLANO
SACRAMENTO
AMADOR
CALAVERAS
MARIN
SAN FRANCISCO
CONTRA COSTA
SAN JOAQUIN
TUOLUMNE
MONO
ALAMEDA
SAN MATEO
STANISLAUS
MARIPOSA
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
1
2
3
4
5
6
7
8
9
N
S

FIGURE 7

(i) Have the power to require any state or local agency to obtain and submit analyses of well water.

13053. Each regional board shall prescribe requirements relative to any particular condition of pollution or nuisance, existing or threatened, in the region.

13054. Any person proposing to discharge sewage or industrial waste within any region, other than into a community sewer system, shall file with the regional board of that region a report of such proposed discharge. The reporting of a discharge of sewage from family dwellings in any area may be waived by the regional board. The regional board, after any necessary hearing, shall prescribe requirements as to the nature of such discharge with relation to the conditions existing from time to time in the disposal area or receiving waters upon or into which the discharge is proposed and notify the person proposing the discharge of its action. Such requirements may be revised from time to time. After receipt of such notice, the person so notified shall provide adequate facilities to meet any such requirements with respect to the discharge of sewage and industrial waste.

13055. A regional board may investigate any source of water pollution or nuisance within its region and may require that any person responsible for meeting prescribed requirements furnish such technical reports as the board may specify.

Board Policies, Programs, and Operations

Policy. In setting up their policies for control of water pollution, the regional boards have been guided in their actions by these principles:

1. Any water pollution control or abatement program shall be governed by the need to balance control of water quality with beneficial water uses;
2. Requirements established for water pollution control or abatement are not fixed but are subject to change as the balance between water quality and water use changes; and,
3. Once established, requirements will be enforced.

The policies and programs of the regional boards will be carried out with due regard for the policy enunciated by the State Water Pollution Control Board as stated in its Objectives and Policy, adopted 12 January 1950. These objectives stated in part, "It will be the policy of this board that its actions and those of the regional water pollution control boards shall be so directed as to secure that degree of care in the planning and operation of works for the treatment and disposal of sewage and industrial wastes as will adequately protect the public health and all of the beneficial uses of the waters in this State and, at the same time, permit the legitimate planned usage of those waters for receiving suitably prepared wastes so that an orderly growth and expansion of cities and industries may be possible."

Program. In carrying out their policies, the regional boards have usually followed a program which includes the following operational procedures:

1. Determine the beneficial water uses to be protected;
2. Determine water quality conditions necessary to support the most critical water use;
3. Establish individual waste discharge requirements in accordance with the determined water quality conditions and economic factors;
4. Police and enforce the established waste discharge requirements;
5. Review receiving water conditions and waste discharge requirements periodically to maintain a realistic control program in the light of an expanding economy.

Operations. The details of operating procedures for any particular board may vary depending upon the local factors but, generally speaking, the fundamental modus operandi of all of the regional boards is essentially the same.

Policing and Enforcement of Waste Discharge Requirements

After waste discharge requirements have been established, it is the responsibility of the regional boards to determine if stream conditions and water quality needs are being maintained at acceptable levels. The regional boards have established programs for the checking of waste discharges for compliance with established requirements and the checking of critical stream reaches for impairment to water uses. Prompt action is taken by the boards in those cases where waste discharge requirements are not being met and where water uses are being impaired. In the former case steps are taken to insure compliance by cooperative action with the discharger or by proceeding against the discharger as provided in the law. In the latter case, discharge requirements which are being met may be reviewed in the light of changing conditions and adjustments made. Conservation and maximum utilization of the State's water resources is essential to the general welfare of California. Available usable waters must be maintained at quality levels acceptable for multi-purpose use. The water pollution control boards will establish, police and enforce their waste discharge requirements to this end.

THE SACRAMENTO RIVER BASIN

Joseph S. Gorlinski [1]

General Description of the Basin

The Sacramento River is an excellent stream to consider as an example of regional board operations for purposes of this report. All problems likely to be encountered in any region in California, excepting disposal to the open ocean, can be found in this stream basin. In addition, the balancing of water quality against beneficial uses in the Sacramento River Basin is complicated by the use of the basin streams as conduits for the transport of surplus waters to other areas of the State. It may be necessary to maintain the quality of these export waters at high levels over long distances for delivery to diversion points in the lower Sacramento River. This is a serious problem in the face of an expanding industrial, agricultural and urban economy in the Sacramento Valley if all local and state-wide interests are to be protected.

Before discussing the matter of waste disposal in the Sacramento watershed, it is first necessary to describe a little of the peculiarities of the region. The Sacramento River rises in the Cascade and Trinity Mountains in Siskiyou County and flows southward for a distance of 385 miles to its outlet in Suisun Bay. The east side tributaries (the Pit, McCloud, Feather, Yuba, Bear, and American rivers) rise in the Modoc Plateau and the Sierra Nevada Mountains, and the west side tributaries (Stony, Cache, and Putah creeks) descend from the Coast Ranges. The drainage area covers about 26,960 square miles, including the Goose Lake Basin. The watershed is rugged, with 64 percent of the area classified as mountain and foothill lands. Elevations range from below sea level in the Delta to 14,161 feet at the summit of Mount Shasta. The valley floor is comparatively level, covering an area of nearly 5,000 square miles and extending for about 150 airline miles from Suisun Bay to Red Bluff, with an average width of about 30 miles.

Above the valley floor, the streams have immense fall in relation to their reach. Storm effects are reflected on the main stem in a matter of a day or two and in some cases it is only a matter of hours. This means abrupt and transitory high flows, sudden peaks. Add to this, definite wet and dry seasons, and we have indeed streams of extreme seasonal variation as well. Most of the lesser tributaries dry up entirely during the summer. The mean annual runoff of the Sacramento River system is about 22,390,000 acre-feet which represents slightly less than 32 percent of the total annual runoff of all California streams.

Under natural conditions, the availability of water for beneficial use, and of water to provide a carrying capacity for waste disposal, is subject to extreme variation. The natural stream flows have been modified decidedly by dams, storage, diverting canals, and by-passes and channel works in the interest of flood control and navigation.

The valley population in 1956 was estimated at 618,600. The Sacramento metropolitan area has the third largest percentage increase in population of any metropolitan area in the State since 1950. Its rate of increase is exceeded only by those of the San Jose and San Diego areas. The reported rates are about 44, 60, and 47 percent, respectively. Outside of the Sacramento metropolitan area the growth of the valley population has been a moderate 11 percent as compared to 27 percent for the State as a whole. Each of the features enumerated above has a decided effect on the overall problem of water pollution control for the Sacramento River.

Water Uses in the Sacramento River Basin

Major beneficial surface water uses in the Sacramento River Basin at this time are: municipal, industrial, and domestic water supply; irrigation; power production; fish propagation; salinity control; navigation; and recreation (including hunting, fishing, swimming, boating, and related water sports). The streams are also used for the disposal of drainage and of the liquid wastes from communities and industries along their courses. The main consumptive water uses are: municipal, industrial and domestic water supply, and irrigation. Releases of water for salinity control in the Delta may also be classed as a consumptive use as this water is not available for other consumptive uses. Other uses are nonconsumptive, although power production may remove water from the streams or shift it from one watershed to another and may, at times, release water (in excess of other demands downstream) to waste.

The export of surplus waters from the Sacramento River Basin, such as now occurs under the Central Valley Project and which will greatly increase under the California Water Plan (35), will not change the purposes for which the water will eventually be used to any appreciable extent. What it has done and will do is to add another water user with rights to divert large quantities of water from the basin streams for multi-purpose use. Ground waters in the basin are used for municipal, industrial and domestic water supply and for agricultural purposes. Ground water use in this basin has not developed as extensively as in other areas of the State where surface supplies are less plentiful.

[1] Executive officer, Central Valley Regional Water Pollution Control Board.

Water Quality in the Sacramento Basin

The quality of the water necessary to support the many beneficial water uses is as varied as the uses themselves. Much of the water use outlined above demands high quality water. About half of the basin population rely on surface supplies for their drinking water and other domestic needs. The average annual diversion from basin streams for irrigation amounts to upwards of 4,400,000 acre-feet in recent years.

Present water quality is satisfactory for all uses at the present time as is shown by the continuing state-wide water quality survey of the State Department of Water Resources. In general, waters from the east side tributaries and the upper Sacramento River are of the calcic carbonate type, low in dissolved solids, relatively soft, low in color, low in turbidity (except during heavy run-off) and free of toxic or other deleterious substances.

There are exceptions to the above statements. West side tributaries are usually more highly mineralized than the east side tributaries. Cache Creek waters often contain boron in excess of the toxic limits for some agricultural crops. Copper and heavy metals are found in some waters which receive drainage from mines as in the Spring Creek area on the upper Sacramento.

Ground waters in the basin are, for the most part, of good quality and suitable for the uses made of them. They are mostly of the calcic carbonate type. Waters of the magnesium carbonate type are found on the west side in the Clear Lake area and extending southward along the eastern slope of the Coast Ranges. These waters are generally higher in sodium than calcium and often contain boron in significant amounts. Highly mineralized springs are frequently found in this general area.

General Waste Discharge Considerations in the Sacramento River Basin

The ultimate development of the State is dependent upon the conservation, use and re-use of the State's available water supply. In order to do this it is incumbent on each water user to return any water not actually consumed in such condition as to be acceptable to the next user. It is the responsibility of the water pollution control boards to see that this is done. For example, the use of headwater streams for recreation, industry or agriculture must not imperil irreplaceable domestic water supplies or result in excessive water treatment costs. Likewise, water discarded after domestic or industrial use must be returned to the water pool in such a condition as to make it adaptable for agricultural, recreational or other use. There is no argument as to the relative merits of one water use as opposed to another, nor need there be under circumstances which make it possible, within limits, to balance the quality of the water against the various beneficial uses.

The Sacramento River receives all of the organic and mineral constituents of all of the waste discharges to the basin streams. The organic constituents may become stabilized by biologic action in the streams but the mineral constituents such as chlorides, sulphates, etc., will remain essentially unchanged. At any given point, the river will contain all of the unstabilized and stabilized organic constituents and the mineral matter which has entered the river above that point.

Waste Discharge Requirement Procedures for the Sacramento Basin

The Central Valley Regional Water Pollution Control Board, which has jurisdiction over the Sacramento River Basin, has determined that the basin streams divide themselves into specific reaches based upon the patterns of beneficial water uses which have become established for the particular stream reaches. Requirements for any particular waste discharge to a stream are governed by the nature of the water quality conditions which the regional board has established, or will establish, for the stream reach or portion thereof affected by the waste discharge. This procedure will insure that all waste discharges within the same zone of influence will have requirements established on the same basis.

Requirements are specific for each particular waste discharge and are tailor-made to fit both local and over-all stream quality needs. In every waste discharge requirement two aspects must be considered. First is the local effect of the waste discharge upon water quality. Second is the cumulative effect that the discharge may have on more remote downstream water users beyond the range of the local effect. For example, let us consider an industrial waste discharge located several miles above the City of Sacramento. In this instance, the effect of the discharge on the local water uses in the Sacramento metropolitan area, especially as it might affect the city water supply, fish life, aesthetic considerations, recreation, irrigation and navigation, would largely determine the requirements. The protection of the public water supply of the City of Sacramento would receive careful consideration to insure that the supply would continue to meet the U. S. Public Health Service drinking water standards after treatment. Fish life would require that consideration be given to dissolved oxygen, oil, pH, suspended matter, and substances toxic to fish and aquatic life. Aesthetic considerations would include the effects of color, odor nuisance, general appearance, and floating materials. Recreational use would limit color, oil, floating materials, toxic materials, aesthetic considerations, and fish protection. Irrigation would require that total dissolved solids, chlorides, and toxic materials be kept at acceptable levels. Navigation would not be affected if water quality is maintained for other uses. All of the above

3—70277

considerations would then be superimposed upon the effects of other waste discharges in the Sacramento area so as to produce a river water of acceptable quality for diversion into the cross channel of the Central Valley Project or the proposed aqueduct system of the California Water Plan located in the delta area below the City of Sacramento.

Before adoption by the regional board, the requirements would be reviewed by state and local health authorities, the Department of Fish and Game, and the Department of Water Resources, to insure that all important water uses were amply protected and to avoid the need for the discharger to deal with these agencies separately. The waste discharger would be given every opportunity to review the requirements and to protest any items he feels are economically or otherwise unreasonable. All differences of opinion are resolved, if possible, before final action of the board.

Proposed Water Quality Criteria for the California Water Plan

The California Water Plan as now proposed by the Department of Water Resources will utilize the Sacramento River as a channel for conveying surplus waters to a delta diversion point for transfer south to the San Joaquin Valley and to Southern California. The State Department of Water Resources is proposing water quality criteria which the Department considers necessary to make the plan feasible. These criteria were formulated by a Board of Consultants for the State Water Resources Board. The consultants' report stated that:

"In the opinion of this Board, it is neither practicable nor desirable at this time to define quality of water objectives for the various water resources of the State. It was the conclusion of this Board that all immediate and most future requirements for effectuating The California Water Plan could be met by establishing certain limits of deterioration of quality of the water to be transferred from areas of surplus to areas of shortage, measured at points of diversion along the southern boundary of the delta of Sacramento and San Joaquin Rivers."

The consultants considered the increased development of the Sacramento Valley and probable principal use of the exported water for municipal, industrial and domestic water supplies, and irrigation in arriving at the proposed criteria. The recommended criteria for water quality at the point of diversion were stated as follows:

"Total dissolved solids	400 ppm
Electric conductance (Mhos $\times 10^6$)	600
Hardness as $CaCO_3$	160 ppm
Sodium percentage (Milligram—equivalents of sodium relative to the total milligram—equivalents of calcium, magnesium, and sodium)	50%
Sulphate	100 ppm
Chloride	100 ppm
Fluoride	1.0 ppm
Boron	0.5 ppm
pH Value	7.0-8.5
Color	10 ppm
Other constituents as to which the U.S. Public Health Service has or may establish mandatory or recommended standards for drinking water	U.S.P.H.S. Stds.

"It is the opinion of this Board that the limits set forth above will permit full agricultural development in Northern California, provide for greatly increased population in that area, and allow the establishment of all industries required for the support of that population. It is the further opinion of this Board that these limits will permit the use of this water for agricultural purposes without detrimental effects, and enable this water to be used for domestic and industrial purposes without placing any undue burden upon the distributors or users."

These criteria are only a proposal at this time. If adopted by the Legislature they would become the official quality criteria for water at the diversion point and would have the force of law. From the standpoint of mineral quality, the California Water Plan presents the most critical water use to be considered in the Sacramento River. Even so, there are other aspects such as taste and odor, suspended solids, dissolved oxygen, color, oil, etc., which may be more critical locally than any criteria which may be applied at the intake to the California Aqueduct. The maintenance of adequate oxygen levels for protection of the state fisheries may be the governing factor in many instances.

Waste Receiving Capacity of the Sacramento River System Based Upon Present Water Quality and Proposed California Water Plan Water Quality Criteria

The following determination of the waste assimilation capacity of the Sacramento River (using the criteria recommended by the Board of Water Quality Consultants as limits of maximum permissible degradation) is for illustrative purposes only and should not be construed in any manner as the policy of the Central Valley Regional Water Pollution Control Board nor as indicating approval of or concurrence in the limiting values as outlined in the consultants' report.

Present water quality in the Sacramento River is shown in Table 33 which was compiled from data obtained from the results of the permanent stream sampling program carried out since April 1951 by the Department of Water Resources as a cooperative project with the State Water Pollution Control Board, the State Department of Public Health, and the State Department of Fish and Game. Table 34 was compiled from data obtained by the U. S. Geological Survey for the Central Valley Regional Water Pollution Control Board from daily samples at three points on the Sacramento River during 1955 and 1956. Figure 8 shows

TABLE 33

SACRAMENTO RIVER WATER QUALITY, 1951-1956

D.W.R. CONTINUING WATER QUALITY SURVEY

Station	Item	Concentrations parts per million*			Remarks
		Maximum	Minimum	Median	
Delta—Mile 349	Dissolved solids	118	51	64	40 % over 100
	Conductance	239	60	115	75% 75 to 150 1 over 170
	Hardness	131	26	46	85% 35 to 55 1 over 56
	Sulphates	5	1	3	80% 2 to 4
	Chlorides	12	0	3	83% 1 to 8
	Percent sodium	37	10	21	69% 15 to 30
McCloud River—Mile 330	Dissolved solids	88	69	84	
	Conductance	120	79	94	78% under 100
	Hardness	44	33	37	
	Sulphates	3	2	2	
	Chlorides	8	0	1	81% 0 to 2
	Percent sodium	26	15	21	
Pit River—Mile 325	Dissolved solids	128	98	113	
	Conductance	183	114	153	59% 140-160
	Hardness	74	45	54	87% 50 to 60
	Sulphates	17	3	4	78% 3 to 5
	Chlorides	8	1	3	80% 2 to 4
	Percent sodium	33	20	28	
Keswick—Mile 309	Dissolved solids	95	68	80	70% 76 to 85
	Conductance	138	95	116	83% 100 to 125
	Hardness	50	37	43	92.5% 40 to 48
	Sulphates	11	3	5	73% 3 to 5
	Chlorides	9	0	2	83% 1 to 4
	Percent sodium	30	17	23	84% 20 to 25
Hamilton City—Mile 209	Dissolved solids	113	79	88	83% 79 to 99
	Conductance	161	97	127	82% 110 to 145
	Hardness	65	25	49	85% 44 to 60
	Sulphates	9	4	6	
	Chlorides	9	0	3	82% 1 to 4
	Percent sodium	35	18	22	82% 20 to 25
Stony Creek—Mile 198.8	Dissolved solids	219	144	174	
	Conductance	404	157	316	90% 200 to 400
	Hardness	170	65	136	93% over 100
	Sulphates	21	13	15	
	Chlorides	31	4	15	80% 9 to 25
	Percent sodium	28	14	23	
Knights Landing—Mile 96.5	Dissolved solids	309	91	237	
	Conductance	676	106	205	72% 100-300
	Hardness	169	43	70	74% under 90
	Sulphates	52	3	13	30% over 20
	Chlorides	57	2	9	79% 1 to 20
	Percent sodium	52	18	35	86% 20 to 50

* Electric conductance in micromhos ($K \times 10^6$).

TABLE 33—Continued

SACRAMENTO RIVER WATER QUALITY, 1951-1956

D.W.R. CONTINUING WATER QUALITY SURVEY

Station	Item	Concentrations parts per million*			Remarks
		Maximum	Minimum	Median	
Sacramento Slough—Mile 93.7	Dissolved solids	346	119	254	
	Conductance	621	106	405	70% over 300
	Hardness	214	44	150	75% over 100
	Sulphates	86	5	12	Wide variation
	Chlorides	85	2	25	70% 10 to 40
	Percent sodium	48	20	27	81% 20 to 30
Feather River—Mile 93.4	Dissolved solids	97	45	58	
	Conductance	183	55	99	79% 70 to 140
	Hardness	72	23	41	84% 30 to 60
	Sulphates	11	0	3	
	Chlorides	8	0	2	82% 1 to 3
	Percent sodium	23	11	17	67% 15 to 18
American River—Mile 63.6	Dissolved solids	73	27	44	
	Conductance	129	35	71	89% under 100
	Hardness	50	12	28	75% 20 to 40
	Sulphates	5	2	3	
	Chlorides	10	0	2	92% 0 to 4
	Percent sodium	25	10	17	71% 15 to 18
Sacramento—Mile 62.5	Dissolved solids	179	56	110	45% under 100
	Conductance	296	63	176	80% 100 to 250
	Hardness	97	25	62	80% 40 to 80
	Sulphates	18	2	13	64% over 10
	Chlorides	20	1	8	78% 4 to 16
	Percent sodium	37	14	28	83% 20 to 35
Rio Vista—Mile 14.3	Dissolved solids	188	73	94	
	Conductance	336	109	190	
	Hardness	122	40	64	79% 50 to 99
	Sulphates	20	3	9	
	Chlorides	26	3	10	84% 5 to 15
	Percent sodium	37	19	28	69% 20 to 30

* Electric conductance in micromhos ($K \times 10^6$).

graphically the relationship between the maximum reported concentrations of total dissolved solids, electric conductance, total hardness, sulphates, chlorides, and percent sodium and the proposed maximum concentrations of these items allowable under the proposed water quality criteria for the California Water Plan at the delta diversion points.

In general, it is seen that present water quality at the delta cross channel diversion is well within the limitations proposed for the California Water Plan. Water quality above Hamilton City is excellent. There are rather wide fluctuations in the reported data in the unregulated tributary streams and in the Sacramento above Shasta Dam. These variations are leveled out by storage so that water quality in the Sacramento from Keswick to Knights Landing is more uniform and it is expected that more uniform water quality will be found in the American River below Folsom in

TABLE 34

SACRAMENTO RIVER WATER QUALITY—DAILY SAMPLES, 1955-1956

Station	Item	Concentrations parts per million*			Remarks
		Maximum	Minimum	Median	
Bend—Mile 207	Dissolved solids	124	82	94	83% 80 to 100
	Conductance	153	71	129	71% 120 to 140
	Hardness	56	28	49	73% 45 to 55
	Sulphates	14	3	6	82% 4 to 8
	Chlorides	6	0	3	89% 0 to 4
	Percent sodium	26	16	22	93% 20 to 25
Butte City—Mile 115.8	Dissolved solids	120	65	100	77% 90 to 110
	Conductance	168	91	136	75% over 130
	Hardness	70	35	53	80% 40 to 60
	Sulphates	10	2	5	88% 3 to 8
	Chlorides	8	0	3	82% 2 to 4
	Percent sodium	25	18	21	
Sacramento—Mile 62.5	Dissolved solids	175	45	105	52% 100 to 150
	Conductance	270	57	151	68% 100 to 200
	Hardness	82	22	56	86% 40 to 80
	Sulphates	14	1	8	59% under 10
	Chlorides	17	1	8	79% 4 to 13
	Percent sodium	36	15	28	91% 20 to 35

* Electric conductance in micromhos ($K \times 10^6$).

the future. Water quality remains good until the effects of agricultural and other drainage from the valley becomes manifest in the reach below Hamilton City. There is an increase of 170 percent in dissolved solids in the reach extending to Knights Landing, a distance of slightly more than 100 miles. Knights Landing is the key point in any consideration of water quality in the Sacramento River. Below this point the water quality is largely determined by the dilution afforded by the flows of excellent quality waters from the now unregulated Feather River and the now regulated American River. The maximum permissible chemical degradation at Knights Landing under present conditions is shown below:

Item	*Maximum Concentrations* *Present*	*Ultimate*	*Difference*
Dissolved Solids, ppm	309	525	216
Conductance ($K \times 10^6$)	676	900	224
Hardness, ppm	169	200	31
Sulphate, ppm	52	130	78
Chloride, ppm	57	130	73
Percent Sodium	52	60	8

The difference between the present and ultimate concentrations represents the maximum available waste receiving capacity of the Sacramento River at Knights Landing which would produce a water at the cross channel diversion meeting the maximum criteria values recommended in the Board of Water Quality Consultants' Report for the California Water Plan.

Under present stream conditions an increase of 200 parts per million in total dissolved solids, of 200 micromhos in electrical conductance, of 30 parts per million in total hardness, of 75 parts per million in sulphates, of 75 parts per million in chlorides, and of an 8 percent increase in sodium would be the maximum allowable. No attempt has been made to evaluate other possible waste constituents such as toxic materials, heavy metals, color, odor, etc., or to evaluate the oxygen assets of the streams.

Any allocation of waste receiving capacity to other control points or to specific stream reaches would be unrealistic at this time. The statement in the Board of Water Quality Consultants' Report that—"It is neither practical nor desirable at this time to define quality of water objectives for the various water resources of the State" applies equally as well to the waste receiving capacity of its waters. The location of control points, other than at Knights Landing, and the exact pattern to be followed in any allocation of the Sacramento River Basin waste receiving assets will depend entirely upon the manner in which the

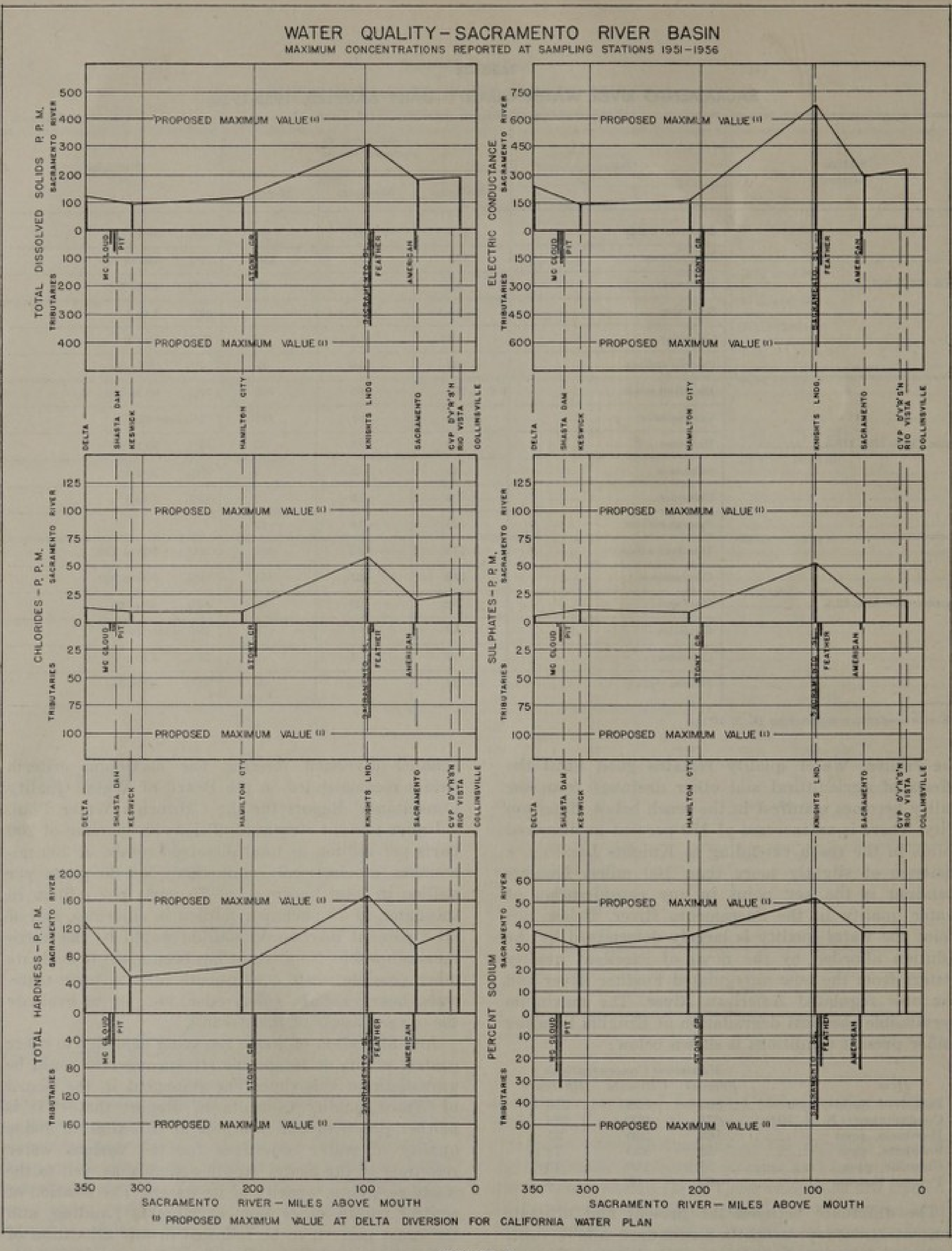


FIGURE 8

WATER QUALITY—SACRAMENTO RIVER BASIN

economic and water resources development proceeds. There can be no specific allocation of any portion of the waste receiving capacity to be held in reserve for any particular industry or segment of the economy. Allocations will be made strictly as needed in accordance with the actual development and requirements of the area as a whole. In effect, a sort of bank account has been created, the total assets of which consists of the difference between the present water quality and the ultimate maximum allowable degradation. Each waste discharge becomes a check withdrawing a portion of the assets. It is the responsibility of the regional water pollution control board to prevent overdrafts on the assets.

THE NORTH COASTAL BASINS

William G. Shackleton[1]

General Description of the Area

The North Coastal Water Pollution Control Region (Figure 7), is comprised of Mendocino, Humboldt, Trinity and Del Norte counties, most of Sonoma and Siskiyou counties and parts of Lake, Marin, Modoc and Glenn counties. It includes the natural drainage basins of the Trinity, Eel, Mad, and Russian Rivers as well as many small coastal streams and that portion of the Klamath River drainage which lies within the boundaries of California. About 40 percent of the natural runoff of the state occurs along the coast line of the North Coastal Region.

The area is generally mountainous ranging in elevation from sea level to over 8,000 feet at the head waters of some of its streams in the Trinity Alps. Some gently sloping or comparatively flat lands are found along the lower reaches of the rivers and along the coast in Humboldt and Del Norte counties.

The 1950 population of the North Coastal Region was approximately 232,000 persons. It is estimated that the 1956 population was about 300,000. The rate of increase in population for the region as a whole was well above the average of 27 percent recorded for the state between 1940 and 1950. In the coastal counties of Del Norte, Humboldt, and Mendocino alone the total population increased more than 50 percent during this period.

Future growth of the North Coastal Region is closely related to the development of its prime resources; water, timber, and recreation. Conservation of its water resource, abundant in quantity and high in quality, is the key to all development. Expansion of forest products industries, with which this report is concerned, is vitally dependent on water. The recreational potential of the area rests, in turn, almost entirely on the attractions afforded by forests and streams. It is, therefore, logical that water pollution control in the North Coastal Basins be directed toward conservation of the area's water resource at levels of quality which will permit the maximum beneficial use to accrue to the public.

[1] Executive officer, North Coastal Regional Water Pollution Control Board.

Water Uses in the North Coastal Basins

Water use in the North Coastal basins is extremely diverse including virtually all recognized beneficial uses to which water may be put.

Drinking and culinary uses are, of course, highest on the list in most aspects of quality although from the standpoint of quantity these uses represent only a trivial fraction of the total waters available. The area has been generously endowed with abundant supplies of easily developed high quality waters which rarely require more treatment than simple chlorination. This endowment has been recognized by the California Water Plan and is a primary basis of feasibility for the plan. Without the advantage of export waters with the highest possible initial quality, subsequent degradation during transport would render the waters unsuitable for many beneficial uses.

Industrial use of water often requires a higher level of quality than can be tolerated for domestic uses. This is true to a certain extent for certain process waters of the pulp industry, whose potential in the North Coastal basins is discussed in this report. Consumptive use of water by industry in the area is not ordinarily very great although use of water for waste assimilative purposes is of considerable concern. Many of the small coastal streams experience very low flows during the summer months; hence, problems of waste disposal are liable to become critical.

Irrigation water service areas comprised approximately 223,000 acres in the North Coastal area in 1950. The ultimate potential for this region is estimated at 1,023,000 acres requiring approximately 1,880,000 acre feet of water (21). Water of excellent quality is available or can be comparatively easily developed for most potentially irrigable lands.

Recreational use of water in northern California is exceedingly important to the area. These uses include support of both fresh and salt water fisheries, bathing, swimming and boating. Most of the streams of the area are abundant in trout and all of the major coastal streams support an annual salmon run. Coastal beaches are important for bathing, boating, and propagation of shell fish. Forested areas support large populations of deer and small game. It is estimated that the State's 1,900,000 hunting and fishing license holders spend about three-quarters of a billion dollars annually on their favorite sports. It is safe to estimate that the proportion of this money spent in northern California is many times the fraction of the state's population which is resident in this area.

Commercial fisheries are also very important water users in the area and will depend heavily on maintenance of high quality waters, both fresh and salt. Rivers such as the Klamath and Trinity and their tributaries support substantial commercial salmon migrations, and Humboldt Bay is rapidly being developed into an important oyster producing area. Water quality problems associated with such industries will, no doubt, become increasingly important in the years to come.

Water Quality in the North Coastal Basins

Water quality requirements for beneficial uses of North Coastal Region waters range from those associated with domestic and certain industrial uses downward through the requirements for use of water as a waste disposal medium. At the present time the area is fortunate to have waters whose quality is adequate for all beneficial uses.

As the area continues to grow, it is anticipated that considerable care must be exercised to preserve the present high quality of North Coastal waters. The possibility of water export under the California Water Plan may also place some additional burdens on residual waters. For these reasons the North Coastal Regional Water Pollution Control Board has oriented its control program, not only toward elimination of existing pollution, but toward the preservation of water quality at the highest levels consistent with present and future beneficial uses.

Waste Discharge Requirements

In a fundamental sense waste disposal problems in California are all approached in the same manner—they are all regarded as unique problems in themselves. It is evident that no two control problems are ever identical in character of waste, quality and use of receiving water, assimilative capacity, and all the other special characteristics which must be considered. It is equally clear that the solutions of the problems are rarely, if ever, identical. This philosophy was recognized by the California Legislature in establishing regional water pollution control boards in accordance with the Water Pollution Control Act, 1949 Statutes, Chapter 1549.

It is not appropriate at this time to attempt delineation of specific requirements for wastes of different characteristics which could potentially be discharged to any of the waters of the North Coastal basins. However, it may be helpful to outline the general procedure which is followed in determining the ultimate waste discharge requirement for a potential industrial waste discharger.

First, a meeting between pollution control board representatives and industry representatives is called to define the problem. The industry is advised of any incipient difficulties which are anticipated from previous experience with the receiving water in question and information regarding the chemical, physical, and biological characteristics of the waste are gathered. A complete review of waste characteristics relative to receiving water quality and beneficial uses is carried out. Suggested requirements for waste discharge or receiving water quality, or both, are then prepared for consideration by the board. All other interested agencies or individuals are invited to comment to insure that all considerations which may bear on the case have been accounted for. Finally, at a public meeting the requirements are presented, discussed by parties concerned, and approved by the board or returned to the staff for additional study or revision.

In the spirit of cooperation and rational deliberation fostered by this procedure, pollution control programs in California have been effective and well received by the public and industry alike. It is expected that future problems can also be met and solved with dispatch in the best interests of all the people.

X. ASSIMILATIVE CAPACITY OF RECEIVING WATER IN RELATION TO THE PULP AND PAPER INDUSTRY

Gerald T. Orlob[1]

INTRODUCTION

The potential development of the pulp and paper industry in California is dependent to a considerable degree on the capacity of receiving waters to assimilate process wastes. Even though adequate fiber resources and process water of adequate quantity and quality are available, a specific mill site may prove infeasible from the standpoint of waste disposal.

The problem of waste assimilation by a receiving water is an intricate one. Assimilative ''capacity'' is fundamentally defined in terms of water quality as dictated by a particular beneficial use of the receiving water. If a certain beneficial use requires the total exclusion of a specific waste component the receiving water may be said to possess no capacity for that component. At the other extreme, if the only beneficial use of water is for waste conveyance the assimilative capacity may be limited only by conditions which tend to create a public nuisance. In general, however, some definite quality criteria are prescribed for the water and the permissible strength and quantity of waste to be discharged is determined.

Occasionally, the problem is one of simply diluting one liquid into another to meet the requisite quality criteria. But, more often a solution is obtained only after consideration of the multivariant characteristics of the particular waste, the peculiar physical, chemical, and biological behavior of the receiving water, and the interaction of both waste and receiving water. This section of the cooperative study purports to examine the particular wastes of typical pulping processes together with the characteristics of potential receiving waters with a view toward determining the general requirements for disposal of pulp mill wastes.

The analysis presented herein is based on data given in previous sections of this report and is necessarily general in application. It is the intent of this section to treat the general rather than the specific case. Although hypothetical examples are given, no attempt has been made to indicate the exact requirements for a particular mill at a given location. It is recognized that water quality criteria, as well as the quality of mill effluents, are subject to change; hence, it is apparent that each situation is unique and should be treated as such.

[1] Assistant Professor of Civil Engineering, University of California, Berkeley.

TYPICAL MILL DISCHARGE

A previous section of this report has outlined in a general way the characteristics of liquid effluents from various pulping processes and the significance of the standard analytical techniques for the evaluation of waste quality. It is true that no two mills are identical; and it is illogical to expect two effluents to be closely comparable in composition. Raw materials, process water quality, pulping process, market conditions, and a host of other factors determine both the character of the product and the waste. For these reasons Tables 30, 31, 32, and 33 are designed to show the range of waste quality and quantity experienced in modern, well operated pulp mills.

However, in the interest of simplicity in the discussion of assimilative capacity it is considered desirable to deal with the waste from ''typical'' mills which are both representative in types of process, size, and waste characteristics of mills which potentially could be constructed in California. The processes considered as most probable of application in California include the kraft process, both with and without a bleaching operation, the magnesium base sulfite process, the neutral sulfite semi-chemical process, and the ground wood process. Particular attention will be given the kraft process since it is acknowledged to possess the greatest potential in future development of Northern California's fiber resources.

The most likely sizes to be constructed were taken as 400 tons per day for chemical processes and 125 tons per day for semi-chemical and ground wood. Table 35 outlines the most important characteristics of waste discharges resulting from each typical mill and Table 36 summarizes the mineral composition of typical bleached and unbleached kraft effluents.

STREAM DISPOSAL

California streams generally possess a runoff pattern which runs to extremes. Peak runoffs are closely associated with the occurrence of precipitation and usually occur in the late fall and winter months. Most of the streams may be characterized as ''flashy'', that is, they exhibit rapid rates of runoff with peaks of comparatively short duration. In the spring and early summer months runoff from snow melt in the headwaters sustains flows at moderate levels. But in the late summer and fall flows are minimal; many streams

4—70277

TABLE 35

CHARACTERISTICS OF TYPICAL PULP MILL EFFLUENTS

Process or operation	Debarking	Groundwood*	Neutral Sulfite* semi-chemical	Kraft*	Sulfite* (MgO)	Bleach plant	Paper** mill
Capacity tons/day	1	125	125	400	400	400	400
Discharge							
million gal. daily	0.002	0.375	2.75	8.8	12.8	16.0	4.0
cubic feet per second	0.003	0.58	4.26	13.7	19.7	24.8	6.2
B. O. D. (5 day, 20°C)							
pounds per day	15	3,750	7,500	18,000	36,000	8,000	2,000
ppm	900	1,200	327	245	337	60	60
Total solids							
pounds per day				†132,000	132,000	65,000	
ppm				1,800	1,235	490	
Suspended solids							
pounds per day	40	11,300		22,000	32,000	8,000	2,000
ppm	2,400	3,600		300	300	60	60

* Includes debarking operation with the following characteristics:

Discharge	2,000 gal. per ton.
B. O. D.	15 lbs. per ton.
S. S.	40 lbs. per ton.
Total solids	80 lbs. per ton.

** Chemical pulping only.
† Includes 35,000 lbs. per day mineral solids (— 480 ppm.).

TABLE 36

MINERAL CONSTITUENTS OF TYPICAL KRAFT MILL EFFLUENTS—PPM.

Constituent \ Process	Unbleached Kraft 400T/day	Bleached Kraft 400T/day
Sodium, Na^+	90	85
Calcium, Ca^{++}	*25	110
Sodium Ratio	0.75	0.40
Chlorides, Cl^-	--	300
Sulfates, SO_4^{--}	200	80
Hydroxides, OH^-	30	8
Carbonates, CO_3^{--}	500	200

* Highly variable depending on recovery practice.

drying up completely only to be restored by sporadic rain storms. In many areas of the state storage is necessary to produce dependable flows for beneficial use through the low water period.

The success of a scheme for disposal of pulp mill waste to a receiving stream is dependent to a considerable degree upon the availability of adequate diluting water during the period of lowest stream flow. Those waste components which cannot be destroyed by chemical or biological treatment may often be reduced in concentration to less than the maximum permissible limits by the simple mechanism of dilution. In particular, disposal of the mineral constituents of pulp mill wastes such as sodium, calcium, and magnesium as well as certain stable organic compounds is usually dependent entirely on dilution. Certain unstable compounds such as mercaptans, sulfides, and sulfur dioxide may require only minimal dilution before oxidation reduces them to less harmful products. In order to conserve its oxygen resources the stream's capacity to assimilate organic wastes may be limited, a consideration which dictates still another dilution requirement.

The discussion which follows presents the basic considerations for determining the stream dilution requirements for each of the several types of waste components, organic, mineral, and toxic and concludes with an analysis of methods for increasing the assimilative capacity of the receiving stream.

Organic Components

The successful operation of any pulping process which results in the production of large quantities of organic residue requires the ultimate reduction of this material to compounds which are fundamentally stable in nature. Stabilization may be achieved in several ways; by chemical reaction, by combustion, by biological action, or by combinations of these processes. Certain organic compounds produced in the pulping operation for example, are inherently unstable and readily oxidized to stable compounds by simple chemical reactions. Such is the case with the sulfides produced in the kraft process. Combustion of digestor liquor for the recovery of chemicals and heat is practiced in both the kraft and magnesium base sulfite processes. However, complete recovery and stabilization of organic matter is never achieved inside the plant. Some organic matter leaves the plant as a fraction of the water-borne wastes of the operation. Stabilization of this material is conveniently accomplished biologically either in controlled treatment units or in the natural receiving water.

Biological stabilization of organic matter requires the presence of bacteria operating in an environment which permits their growth and reproduction while they biochemically reduce complex organics to simple stable forms of matter. Usually the most efficient decomposition is achieved in the presence of oxygen which may be used to satisfy bacterial respiratory requirements or to oxidize certain organic compounds. Dissolved oxygen in natural receiving waters provides the most convenient source of oxygen for stabilization and permits this process to be carried out naturally as the waste materials are conveyed from the mill site by the stream discharge.

The Oxygen Sag

The oxygen resources of the stream are subject to depletion by the action of bacteria but are continually replenished by atmospheric oxygen. If the waste concentration is high enough and other conditions are favorable the rate of oxygen utilization (deoxygenation) may exceed the rate of replenishment (reaeration) and the dissolved oxygen level in the stream below the waste outfall may be observed to drop. The oxygen requirements for stabilization are usually greatest immediately below the outfall and may be expected to diminish with time and distance of stream flow. Conversely, since the rate of reaeration is proportional to the oxygen deficit, the rate at which oxygen is restored to the stream gradually increases. Ultimately, at some point below the outfall the rates of deoxygenation and reaeration may be exactly equal. The oxygen deficit at this point is termed the "critical deficit" and is a measure of both the effect of the waste on the stream and the stream's ability to assimilate the waste. Beyond the location of critical deficit the effect of deoxygenation continues to diminish and the stream is observed to "recover". The characteristic curve of dissolved oxygen (or deficit) versus time of flow is the so-called "oxygen sag". An example of a typical sag curve is shown in Figure 9.

As noted in a previous section of this report the characteristic deoxygenation effect of a waste is defined in terms of its biochemical oxygen demand (B.O.D.). It is customary to designate the strength of an organic waste for purpose of comparison and to evaluate its potential effect on receiving waters by its "5-day, 20-degree centigrade B.O.D.". This value is conveniently related to the oxygen demand over other time intervals by the relation

$$y_t = L_a\,(1 - 10^{-k_1 t}) \qquad (1)$$

where y_t is the B.O.D. at any time, t, in days, L_a is the ultimate first state (carbonaceous) demand and k_1 is a constant characteristic of the reaction. The value of k_1, the deoxygenation coefficient, is often taken as 0.1 for dilute wastes in large streams of moderate velocity but has been observed to range from 0.07 to 0.15 depending on physical and environmental factors.

The effect of reaeration on the oxygen resources of a stream can be described in terms of the oxygen deficit and a reaeration coefficient, k_2, which is characteristic of the particular stream. Since both k_1 and k_2 can be regarded as virtually constant for a given waste and stream, their ratio which is defined as

$$f = \frac{k_2}{k_1} \qquad (2)$$

may be taken as constant. The value of k_2 is greatly influenced by the physical characteristics of the stream, whether it is slow moving and sluggish or rapid and turbulent. The value of k_1 reflects both the influence of the stream and the characteristics of the waste. For pulp mill waste in large streams of moderate velocity, typified by the lower reaches of rivers like the Sacramento and the Klamath, k_1 would probably range between 0.1 and 0.15. Fair and Geyer (36) recommended values of the self-purification constant, f, in accordance with those given in Table 37

TABLE 37

VALUES OF THE SELF-PURIFICATION CONSTANT, "f"

Nature of Receiving Water	f* at 20°C	Typical Northern California Streams
Small ponds and backwaters	0.5-1.0	
Sluggish streams or large lakes or impoundments	1.0-1.5	
Large streams of low velocity	1.5-2.0	Sacramento and San Joaquin in Delta region
Large streams of moderate velocity	2.0-3.0	Sacramento and Klamath in lower reaches
Swift streams	3.0-5.0	Salmon, Trinity, Smith
Rapids and water falls	above 5.0	

* After Fair, G. M., and Geyer, J. C., "Water Supply and Waste Water Disposal," 1st Ed., John Wiley and Sons, 1954, p. 846.

Combining the effects of both deoxygenation and reaeration results in the expression for oxygen sag

$$D_t = \frac{L_a 10^{-k_1 t}}{f-1}\left\{1 - 10^{-k_1(f-1)t}\left[1 - (f-1)\frac{D_a}{L_a}\right]\right\} \qquad (3)$$

where D_t is the deficit at any time t in days flow below the outfall, L_a is the first stage B.O.D. of the waste and stream mixture, D_a is the deficit of the mixture at the outfall and f and k_1 are as defined above.

Using equation (3) it is possible to compute the permissible B.O.D. loading which can be placed on a given stream such that the deficit will not exceed a certain prescribed value, say some percentage of normal saturation. There are two critical limits for such a loading. The *lower critical loading* is the maximum allowable loading which could be tolerated with the waste outfall located at the point of critical deficit.

This situation is representative of the problem of locating a new source of pollution on an already polluted stream. *The upper critical loading* is the maximum allowable loading which could be tolerated with the outfall located at an upstream point well above any other sources of pollution.

The requisite streamflow and dissolved oxygen conditions for typical kraft and bleach kraft mills on streams of varying physical characteristics are illustrated graphically in Figures 10 and 11. As an example of the use of these figures let it be assumed that a 400-ton bleached kraft mill is to be located on the lower Klamath River ($f = 2.5$) and that the minimum permissible oxygen level is fixed at 70 percent of saturation (temperature $= 20°$ C). According to Figure 11 if the mill outfall is situated on the river where the dissolved oxygen is normally at saturation the required stream flow is approximately 355 cfs. This flow would provide the equivalent of a 26 to 1 dilution of the bleached kraft waste. A similar analysis for a magnesium base sulfite mill using equation (3) indicates as required flow of 440 cfs and a necessary dilution of 22 to 1.

If it is assumed that unbleached kraft will be produced at this site, that the minimum permissible oxygen level is 5 ppm (54 percent at 20° C), and that the outfall will be located at a point of critical deficit the required flow is estimated at 160 cfs for the typical 400-ton mill. This flow would provide a 11.7 to 1 dilution of the waste.

Toxic Components

It has been frequently observed with respect to the more toxic components of pulp wastes that critical depletion of dissolved oxygen in the receiving water occurs at waste concentrations much less than the threshhold levels required to protect aquatic life. This is particularly true in the case of the sulfite process and has also been observed for kraft operations.

Sulfur dioxide, which may be toxic in concentrations exceeding about 10 parts per million (ppm), comprises about 1.5 percent of fresh waste sulfite liquor by weight. In general, oxygen conditions have been noted to become critical for aquatic life, as evidenced by actual fish kills, at about 100 ppm of waste liquor. (37) Corresponding sulfur dioxide levels, assuming no reduction, would be roughly 1.5 ppm.

Experiments conducted by biologists of the Washington State Fisheries Department indicated that fingerling salmon can survive exposure to 500 ppm of sulfite waste liquor (S.W.L.) for periods of several weeks duration providing adequate oxygen is available to meet respiratory requirements (31). However, there were indications in these studies that, at concentrations as low as 50 ppm, certain of the lower forms of aquatic life comprising fish food were adversely affected.

A number of experiments have been conducted on wastes from the kraft process. One comprehensive study undertaken by the National Council for Stream Improvement (of the pulp, paper, and paperboard industries) (28, 29, 38) resulted in evaluations of a "minimum lethal limit" for certain waste components to aquatic life. In this study bioassays were conducted over a period of 120 hours. If all of the test animals survived this period, it was concluded that the concentration of toxicant was less than the minimum lethal limit. Table 38 summarizes the pertinent results of these investigations together with the probable concentrations of toxic constituents in kraft mill effluents and the probable minimum dilutions necessary to meet the "minimum lethal limit." Also shown are the dilutions which would be required with an application factor of 1:5.

Techniques of performing reliable bioassays and interpretations which can be given to bioassay results are still under intensive investigation. Biologists are not in agreement as to how much of a "factor of safety," or application factor, is necessary in adjusting a minimum lethal limit or a median tolerance limit * to a level which will guarantee that aquatic life will be unaffected by the particular waste component. The California Department of Fish and Game has proposed an application factor of 1:5 for continuous-type bioassays and the Public Health Service has suggested that application factors as low as 1:10 may be necessary for bioassays in which the median tolerance limit is determined. Much additional study is needed to clarify many aspects of this important waste disposal problem.

The components methyl mercaptan and sodium sulfide are both unstable and easily oxidized to compounds apparently less toxic. Van Horn, et al (38) observed a decrease in toxicity if the waste was stored for even a short period and noted that the apparent concentration of these compounds in fresh mill wastes decreased by as much as a factor of three during a period as short as ten minutes. This characteristic can be expected to facilitate successful disposal of kraft mill wastes.

Also, it should be noted that when a bleaching operation is included with the kraft pulping process, a combination of bleach plant effluent and evaporator and blow condensates is usually effective in reducing the concentration of mercaptans and sulfides. The resulting mixture may possess a very low pH but can be neutralized before disposal by the addition of caustic stage effluent.

Studies by the National Council for Stream Improvement † have indicated that well-operated, modern kraft mills should be capable of producing effluents

* The median tolerance limit or "TLm" is defined as the concentration of toxin which will kill 50 per cent of the test animals within a specified time period (24, 48, or 96 hours).

† See Chapter VIII, this report.

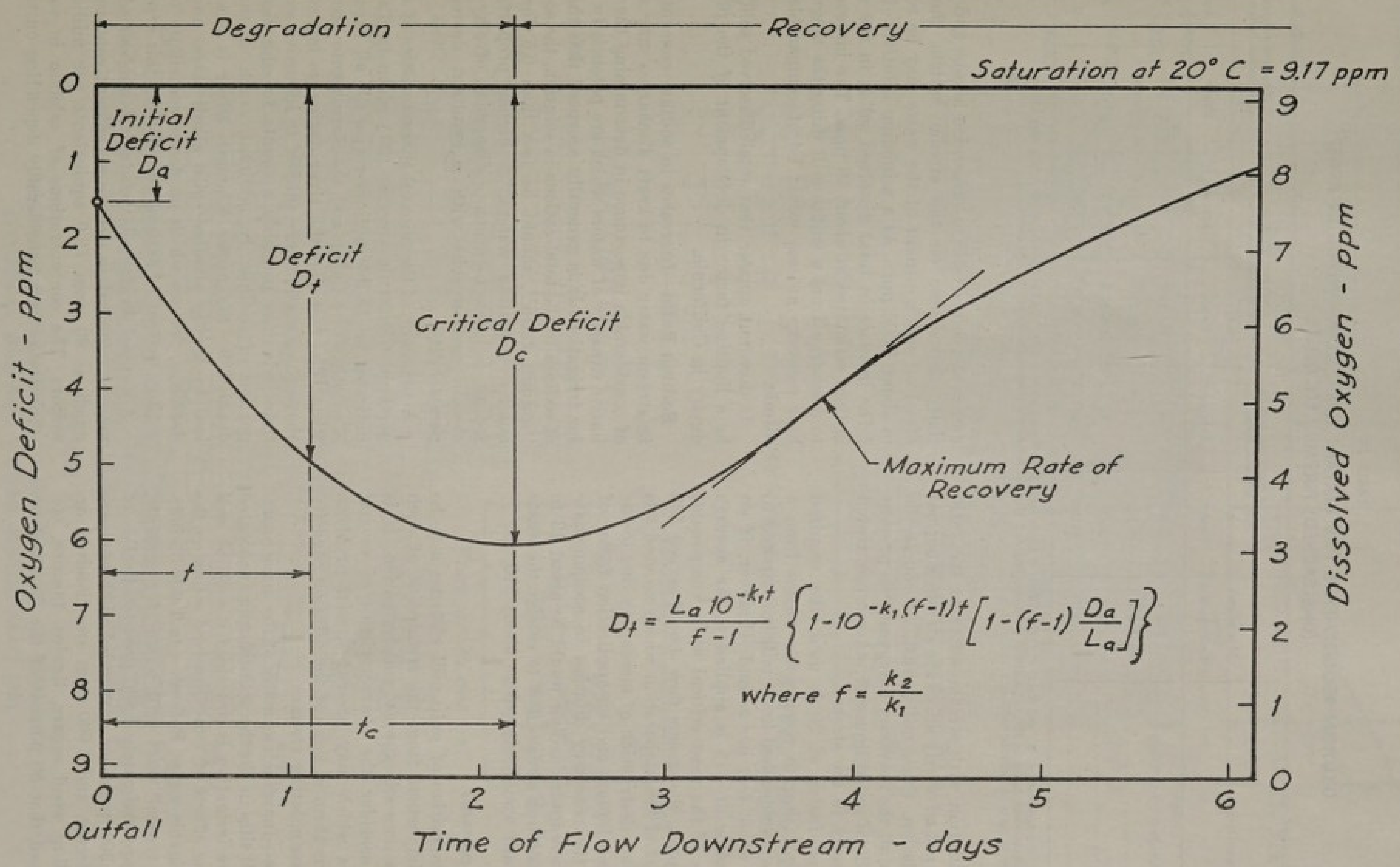


FIGURE 9

THE OXYGEN SAG—DEFINITION SKETCH

TABLE 38

DILUTION REQUIREMENTS FOR CERTAIN TOXIC COMPONENTS IN KRAFT (UNBLEACHED) PULPMILL EFFLUENTS *

Constituent	Minimum lethal limit† ppm	Probable concentration in mill effluent, ppm		Required dilution‡ no application factor		Required dilution application factor 1:5	
		Range	Average	Range	Average	Range	Average
Methyl mercaptan	0.5	1–10	4	1:1–19:1	7:1	9:1–99:1	39:1
Sodium sulfide	1.0	0–15	2	0–14:1	1:1	0–74:1	9:1
Resin acid	1.0	2–15	6	2:1–15:1	6:1	9:1–74:1	29:1
Sodium hydroxide	100.0	0–100	30	0	0	0–4:1	0.5:1

* After Van Horn, W. M., Anderson, J. B., and Katz, M, "The Effect of Kraft Pulp Mill Wastes on Fish Life," **TAPPI, 33:** 5, pp. 209-212, May 1950.
† Concentration of toxicant which failed to kill test animals (minnows, Daphnia, May fly larvae, and Chironomus larvae) in 120 hours.
‡ Parts of stream water to parts of waste by volume.

which after dilution with stream water in the ratio of 20 to 1 will not adversely affect the stream's normal aquatic population. Such mills must, of course, be equipped with all the necessary safeguards to prevent accidental spills of green liquor or other concentrated chemicals directly to the stream.

If a dilution factor of 20 is used, the required minimum stream flow to receive the wastes from a 400-ton per day unbleached kraft mill is computed to be about 274 cubic feet per second. However, if an application factor of 1:5 is applied to the average concentrations of the most critical waste component, methyl mercaptan, the stream flow should exceed 535 cfs. In a bleached kraft operation where no credit is given to possible destruction of mercaptan due to the action of bleach liquors and an application factor of 1:5 is used, the necessary dilution to accommodate the average mercaptan loading would be about 13 to 1. The corresponding stream flow to receive the waste from such a mill would have to be about 510 cfs.

Mineral Components

Mineral composition of pulp mill effluents may be particularly important from the standpoint of such water uses as domestic supply and irrigation. It is desirable to consider the characteristics of several typical wastes which may present special problems and to examine them in light of the dilution capacity of potential assimilating streams.

Total Solids—Inasmuch as many of the more promising pulp mill sites in Northern California are located in areas where irrigation is practiced it may be well to examine the effects of total dissolved solids on the quality of irrigable water. Reference to Table 35 indicates that a typical kraft mill waste, for example, may contain approximately 1,800 ppm total solids of which about 300 ppm are suspended, 500 ppm are dissolved minerals, and 1,000 ppm are dissolved organics including wood sugars, lignins, tannins, etc. If it is assumed that 50 percent of the dissolved organics are convertible to suspended humus and potentially depositable on the stream bottom the total dissolved solids content of the waste may be reduced to about 1,000 ppm. At a minimum dilution of 20 to 1 the increase in total dissolved solids in the stream is then estimated at about 50 ppm. The increase due to discharge from a sulfite mill using the magnesium base recovery process would be of comparable magnitude.

It does not appear that total dissolved solids will be a limiting factor in development of the pulp industry in California.

Sodium Ratio—Increases in sodium concentration in stream water due to kraft discharges may also be of considerable importance in determining the assimilative capacity of waters which are potentially useful for irrigation. It is generally accepted that the ratio of sodium to the total cations in solution, the so-called "sodium ratio", should be less than 0.5 for good quality irrigation waters. A higher proportion of sodium is liable to promote dispersion of clay particles in certain soils with a resultant decrease in permeability.

A summary of the mineral characteristics of several northern California streams (35) given in Table 39 indicates fairly low sodium ratios for all except the Klamath above Copco and the Sacramento above Rio Vista. The fact that the river drainages immediately above these stations are subject to intensive summertime irrigation probably accounts for the high proportion of sodium. In addition, much of the area drained by the upper Klamath River is characterized by highly alkaline soils, alkali lakes, and poor drainage, factors which no doubt contribute to high sodium content in natural runoff from this area.

A typical kraft mill producing unbleached pulp may be expected to deliver an effluent containing as much as 90 ppm (3.9 equivalents per million) of sodium. The concentrations of calcium in such an effluent may vary considerably depending on the effi-

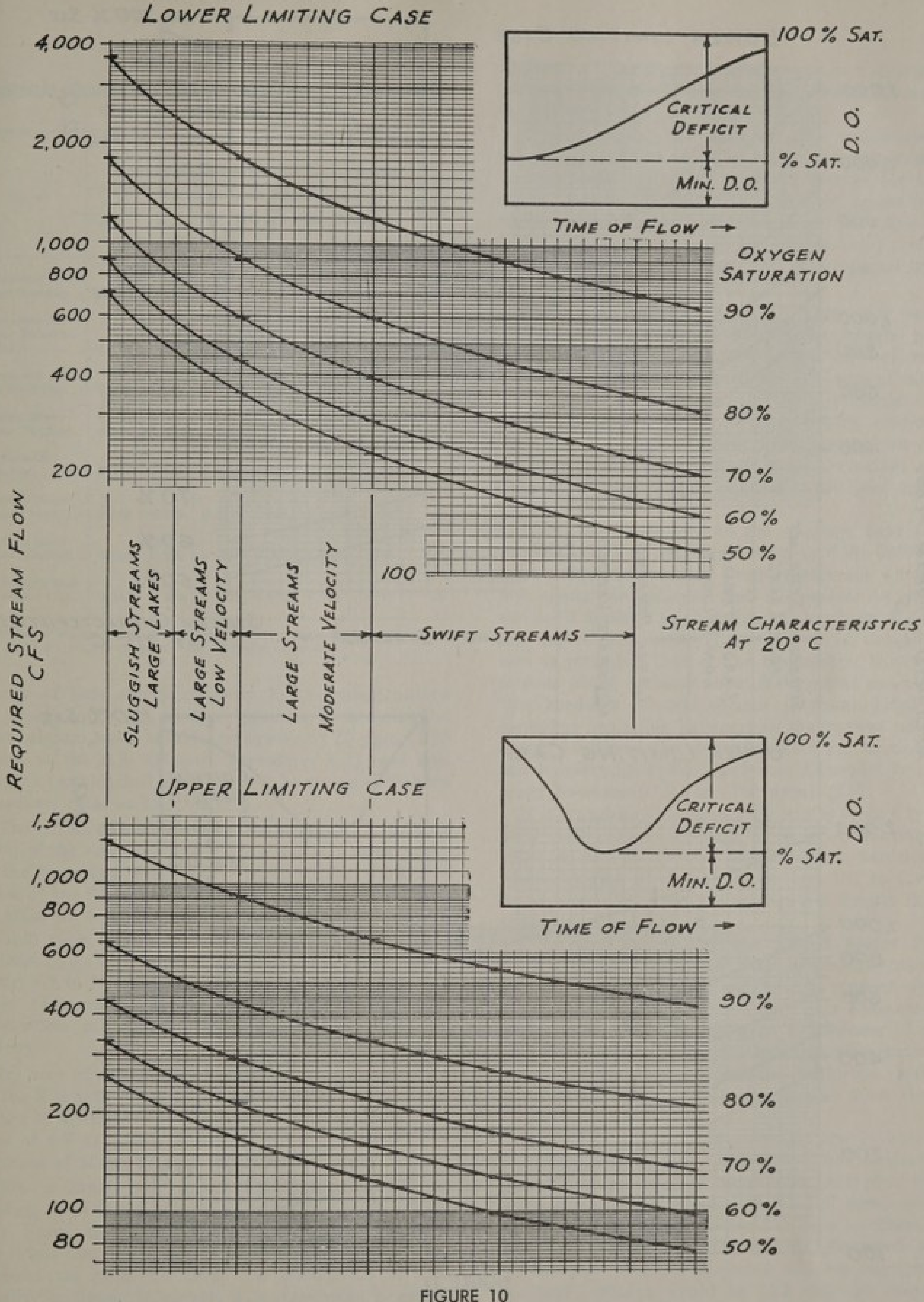


FIGURE 10

DISCHARGE REQUIREMENTS FOR MAINTENANCE OF DISSOLVED OXYGEN IN RECEIVING WATERS—400-TON KRAFT MILL

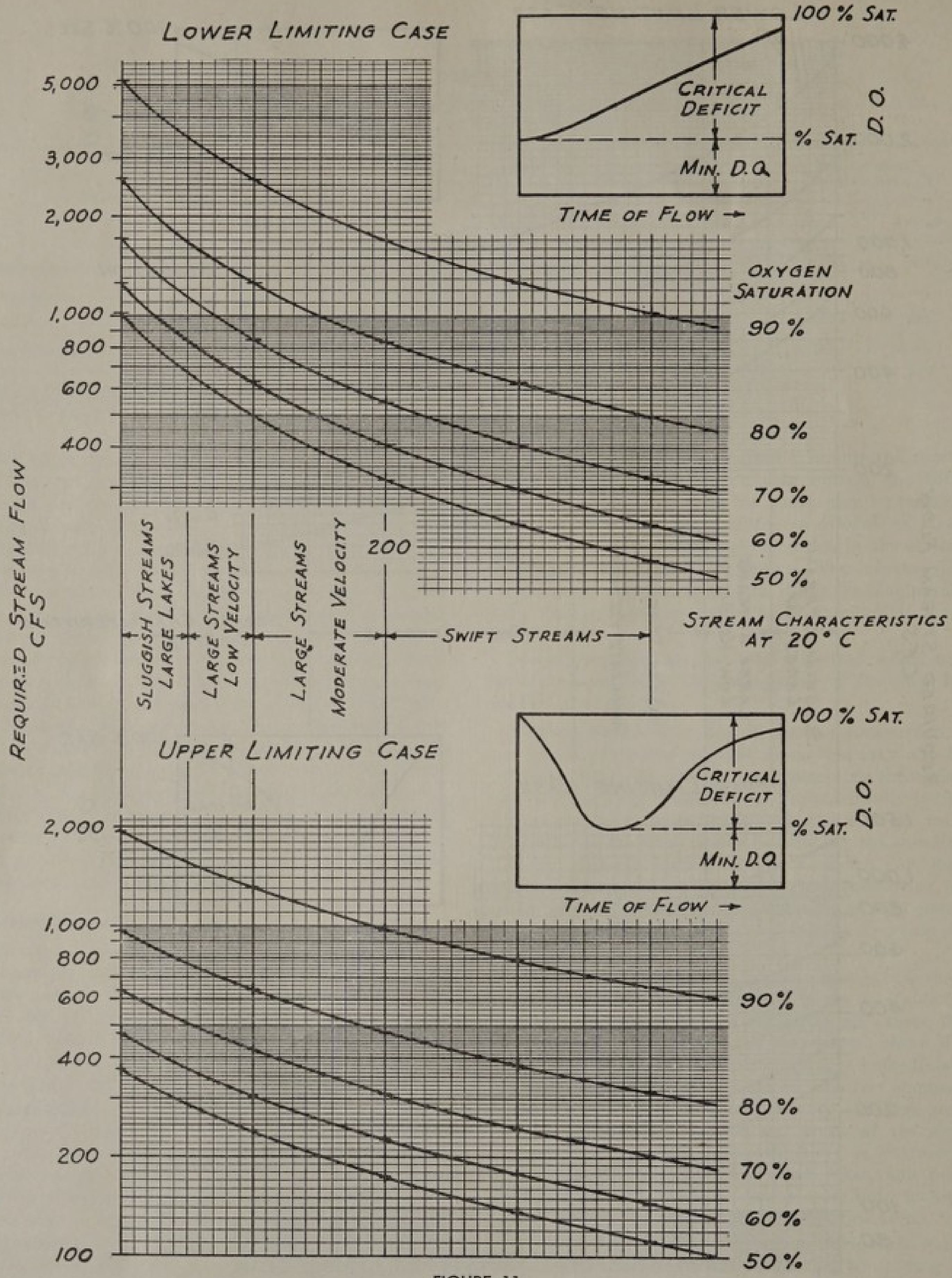


FIGURE 11

DISCHARGE REQUIREMENTS FOR MAINTENANCE OF DISSOLVED OXYGEN IN RECEIVING WATERS—400-TON BLEACHED KRAFT MILL

TABLE 39

MINERAL COMPOSITION OF NORTHERN CALIFORNIA STREAMS, SUMMER, 1954 *

Stream	Mineral constituents—epm					Sodium ratio	Hardness as $CaCO_3$
	Na	Ca	Mg	K	Total	$\frac{Na}{Total}$	
Sacramento River near Redding	0.234	0.574	0.271	0.025	1.104	0.21	42
Sacramento River near Hamilton City	0.301	0.537	0.350	0.029	1.217	0.25	44
Sacramento River at Rio Vista	0.912	1.913	0.524	0.035	2.384	0.38	82
Russian River near Hopland	0.344	1.080	0.722	0.029	2.175	0.16	83
Eel River at Scotia	0.420	1.788	0.809	0.033	3.050	0.14	130
Klamath River near Copco	0.643	0.529	0.439	0.068	1.679	0.38	48
Klamath River near Klamath	0.305	0.780	0.526	0.035	1.646	0.19	65
Smith River near Crescent City	0.148	0.390	0.827	0.009	1.374	0.11	60

* "Quality of Surface Waters in California, 1951-54." Water Quality Investigations Report No. 15, Department of Water Resources, California.

ciency of lime slurry recovery in the causticization of green liquor. In modern practice it is estimated that calcium losses would average about 25 ppm (1.25 epm) in the mill effluent. Therefore, a typical mill effluent (unbleached kraft) might be expected to have a sodium ratio as high as 0.75.

The effects of such a waste discharge on the sodium ratio of the receiving water are obvious. For example, if the receiving water had characteristics similar to those of the Sacramento River at Redding a minimum dilution of 4 to 1 would be required to maintain a sodium ratio of 0.5. If it was desired to maintain a sodium ratio of less than 0.4 a minimum dilution of about 8.8 to 1 would be needed. In order to meet this later requirement for a 400-ton mill a minimum streamflow of approximately 79 cfs would be required.

By way of contrast consideration of water quality in the Klamath River at Copco indicates that maintenance of a sodium ratio less than 0.5 requires a dilution of 6.7 to 1. For a sodium ratio less than 0.4 a dilution of about 97 to 1 would be necessary.

For a kraft mill producing bleached pulp the sodium ratio of the effluent is estimated at 0.4 (Table 36). Unless the requisite sodium ratio for stream water is less than 0.4 discharge of such an effluent should present no problems from the standpoint of this quality criterion. Moreover, it is reasonable to expect that for the unbleached kraft process the deliberate addition of lime slurry could be used as a convenient precautionary measure to insure a desirable sodium ratio in the receiving water.

It appears that the effect of pulp mill wastes on the sodium ratio of irrigable waters can be minimized by appropriate effluent treatment. Except for a few locations along the Upper Klamath and Lower Sacramento sodium balances for the larger northern California streams are generally good and could probably be maintained despite increased development of the fiber resources of these areas.

Hardness—The discharge of pulp mill wastes which contain calcium or magnesium may be potentially detrimental to some beneficial uses of receiving waters. Increases in hardness (the sum of calcium and magnesium expressed as $CaCO_3$) result in increases in soap consumption in laundry operations. In steam heating and steam power production excessive hardness often results in scale formation which reduces efficiency and requires additional maintenance expenditures.

With the exception of the calcium base sulfite process, which is not likely to be used in California, most pulping operations produce effluents which are low enough in calcium and magnesium to prevent serious difficulties in changing the hardness of receiving waters. The most critical effluent in this connection is probably that of the magnesium base sulfite process which contains about 300 ppm of magnesium. The hardness of this effluent is about 1,230 ppm assuming negligible hardness in the process water or about 7.7 times the desired maximum hardness of water divertable to the California Aqueduct from the lower Sacramento River (160 ppm) (21).

If it was desired to discharge wastes from a typical MgO mill into water with an original hardness of 150 ppm and to prevent increasing the hardness beyond 160 ppm a dilution of at least 107 to 1 would be required. This would necessitate a stream flow of approximately 2,100 cfs.

It is also noted that the United States Public Health Service indicates that in waters used for drinking purposes the magnesium content should preferably not exceed 125 ppm. This concentration of magnesium is equivalent to a hardness of more than 500 ppm. It is likely that any combination of pulp mill wastes and Northern California receiving waters which could result, could also meet this requirement.

Kraft mill effluents are generally low in hardness. The most critical situation arises when a bleaching operation is included in the process. A typical bleach kraft effluent may contain about 110 ppm. calcium (Table 36) or approximately 275 ppm hardness. Under conditions comparable to that described above for the MgO mill the minimum dilution required for the kraft effluent would be 11.5 and the necessary stream flow would be about 285 cfs.

It can be seen that so far as the kraft process is concerned there is little likelihood that hardness considerations will govern effluent requirements. In the case of the MgO process, however, abnormally high dilutions may be necessary if hardness increases must be kept within fairly narrow limits such as those likely to prevail in the lower Sacramento River because of diversions to the California aqueduct.

Chlorides—Use of waters for drinking purposes usually requires the maintenance of chlorides at levels which preclude an objectionable taste. The United States Public Health Service recommends a maximum of 250 ppm although many communities in the Southwest employ water with chloride contents of 500 ppm or greater. The board of Consultants for the California Water Plan (21) recommended that water diverted at the Sacramento delta have a chloride content not exceeding 100 ppm.

The most critical pulp mill effluents with respect to chlorides are those associated with bleaching operations. A typical bleached kraft pulp effluent may be expected to contain about 300 ppm chlorides. (Table 36)

As can be seen from inspection of Tables 33 and 34, and Figure 8 the upper Sacramento River is in an extremely favorable position with respect to chlorides. Even the lower reaches of the Sacramento River seldom experience concentrations exceeding about 75 ppm.

It is clear that there is considerable latitude for stream disposal of chlorides originating with pulping processes without seriously endangering the beneficial uses of waters of northern California.

Sulfates—The United States Public Health Service recommends that sulfate concentrations in domestic water should preferably not exceed 250 ppm while the California Water Plan reports a desirable maximum of 100 ppm in water diverted at the Sacramento delta.

Sulfate concentrations in pulp mill wastes from the kraft or MgO processes can generally be expected to average less than 200 ppm.

California receiving streams generally appear to have adequate reserve for the assimilation of sulfates. The present quality of the lower Sacramento River shows only occasional samples exceeding 50 ppm. Waste dilutions of 3 to 1 would probably achieve sufficient reduction in sulfate concentration to meet the requirements of the California Water Plan.

Aesthetic Considerations

The aesthetic degradation of receiving waters is extremely difficult to evaluate. It can never be accurately assessed in a quantitative sense. It is concerned primarily with the human senses, and the offenses rendered by alteration of the appearance, taste, and odor of waters but also involves the mental attitude of the persons concerned. All waste discharges including those of the pulp industry present some aesthetic problems.

If the receiving waters are to be used for domestic purposes a problem of *taste and odor* arising from pulp waste discharges may occur. It is generally desirable to maintain sufficient dilution of waste components so that critical thresholds are not exceeded. Since the senses of taste and smell are closely related the thresholds are usually defined to include both senses. Such thresholds vary with the individual concerned but can usually be prescribed to satisfy the majority of persons.

A critical component of kraft mill waste from the standpoint of taste and odor is methyl mercaptan. The threshold for this compound is reported to be about 0.02 ppm (32). Since the normal concentration of this component in a kraft mill waste is about 4 ppm (Table 38) it would be expected that a 200 to 1 dilution would be necessary to achieve the taste and odor threshold.

However, it should be recognized that mercaptans, as well as some of the other taste and odor producing substances in pulp mill wastes are inherently unstable and may be drastically altered upon discharge to the receiving water. Van Horn, et al (38) observed for example, that decomposition of mercaptans and sulfides in mill wastes may be reduced to one-third of original concentrations in as short a time as 10 minutes. It would be more realistic to expect that a dilution of 50 to 1 combined with the decomposition of the waste components and the effect of biological stabilization in the stream could achieve disposal within the requisite threshold values.

Color is also of considerable concern from the standpoints of both domestic and recreational water use. The board of consultants for the California Water Plan have recommended a maximum of 10 ppm for water diverted from the Sacramento River. For domestic purposes the U.S.P.H.S. recommends that water should not have a color which exceeds 20 ppm (platinum-cobalt scale). Recreational uses usually can tolerate higher levels.

Effluents from both Kraft and MgO processes may be expected to have color concentrations as high as 500 ppm. Assuming negligible color in the available dilution water the indicated dilution to meet U.S. P.H.S. requirements is approximately 25 to 1 and to meet the California Water Plan requirements, 50 to 1.

Floating debris is a primary concern in connection with recreational use of waters. Control of floating material is exclusively a matter of mill practice usually involving the use of screens and foam breakers. Modern practice seldom experiences any difficulty in achieving complete control of such waste components.

Hydrogen Ion Concentration

Hydrogen ion concentration has seldom been noted as a critical criterion in defining the assimilative capacity of receiving waters for pulp mill wastes. Most forms of aquatic life are not sensitive to changes in pH over comparatively wide ranges and most other beneficial uses will tolerate considerable fluctuation. In addition many natural waters exhibit properties which prevent drastic changes in pH with the addition of waste discharges.

The Kraft, neutral sulfite, and groundwood processes should present little or no trouble in waste assimilation from the standpoint of hydrogen ion concentration. Wastes from these processes normally fall within a pH range of 6 to 9 and with nominal dilution receiving waters are not likely to be adversely affected.

It has been previously noted that the sulfite process which produces very acid wastes (pH 3 to 4) has very little potential for development in northern California. A possible exception is the magnesium base process which incorporates a recovery operation and produces wastes which have a pH range of about 4 to 5.

Field studies have indicated that changes in hydrogen ion concentration in fresh surface waters due to sulfite waste liquor pollution are usually so small as to be virtually negligible when waste concentrations are great enough to cause a dissolved oxygen problem (37). In estuarial or ocean locations the buffer capacity of natural water would tend to further minimize pH changes.

Temperature

Most pulp mill effluents have temperatures in range of 65° to 80° F and could probably be expected to slightly increase the overall temperature of northern California receiving waters. With the minimum dilution essential for maintenance of aquatic life it is doubtful that the resultant increases could be damaging to the stream or the beneficial uses of water which it supports.

Contrariwise, in some locations an increase in water temperature may actually prove beneficial. For example, the ripening of rice crops in the Sacramento River Valley has been somewhat retarded in recent years as a consequence of decreased water temperatures due to regulation of stream flow by Shasta Dam. The desirability of increasing the temperature of rice irrigation water is apparent.

Methods for Increasing Assimilative Capacity of Streams

The success of a scheme for disposal of pulp mill waste to a receiving stream is dependent both on the peculiarities of the disposal practice for a particular mill and on a knowledge of the flow characteristics of the stream. In some cases effective disposal may be achieved by the simple mechanism of dilution, requiring only that the stream contain sufficient water to reduce waste concentrations after mixing to levels consistent with other beneficial uses of the water. In the extreme this practice implies that the mill does not resort to treatment of the waste and that the full potential of the stream is utilized. Actually, much can be done in such a situation to increase the potential of the particular mill site or to provide more latitude in the assimilative capacity of the stream.

Storage Lagoons to Facilitate Dilution—The assimilative capacity of many California streams may be critical from the standpoint of dilution potential only for a few months in the late summer when flows drop to their lowest levels. If a pulp mill was expected to maintain a certain minimum dilution of its waste in available stream water it might be obligated to curtail or even cease operation during the drought period. At least two alternatives are available, however; either the stream flow can be regulated by upstream storage thus assuring a satisfactory flow at all times or the mill may elect to impound a fraction of its waste output during the critical period for controlled release at times of adequate flow. The latter alternative probably represents the most attractive solution from the point of view of capital expenditure.

The design of storage lagoons is dependent primarily on the hydrologic characteristics of the particular receiving stream. A study of flow-duration curves such as those presented in Figure 6 can be very helpful in establishing the probable fraction of the total operating time when the flow can be expected to be less than the critical value necessary for dilution of the mill waste. Similarly, drought-duration curves such as those given in Figure 12 for the Eel River at Scotia are useful in establishing the critical operating period and the frequency of low flows as a function of time of year.

Perhaps the most useful type of hydrologic analysis for this particular problem is a runoff deficiency analysis similar to that shown in Figure 13 for the Eel River at Scotia. The application of Figure 13 is best illustrated by investigation of a hypothetical pulp waste disposal problem. Let it be assumed that a typical 125-ton per day groundwood mill is to be located near Scotia on the Eel River and that the management of this mill wishes to maintain a dilution of at least 1 to 100 of its waste in the receiving water. From Table 35 the average flow of such a mill is seen to be about 0.58 cubic foot per second which, at the desired dilution, requires a flow of 58 cfs in the river. It is apparent from examination of Figure 6 that the flow in the river is less than desired minimum about 7 percent of the time and Figure 12 indicates that the critical flow period will probably extend from July through November. If it is desired to design storage facilities to accommodate the excess waste flow

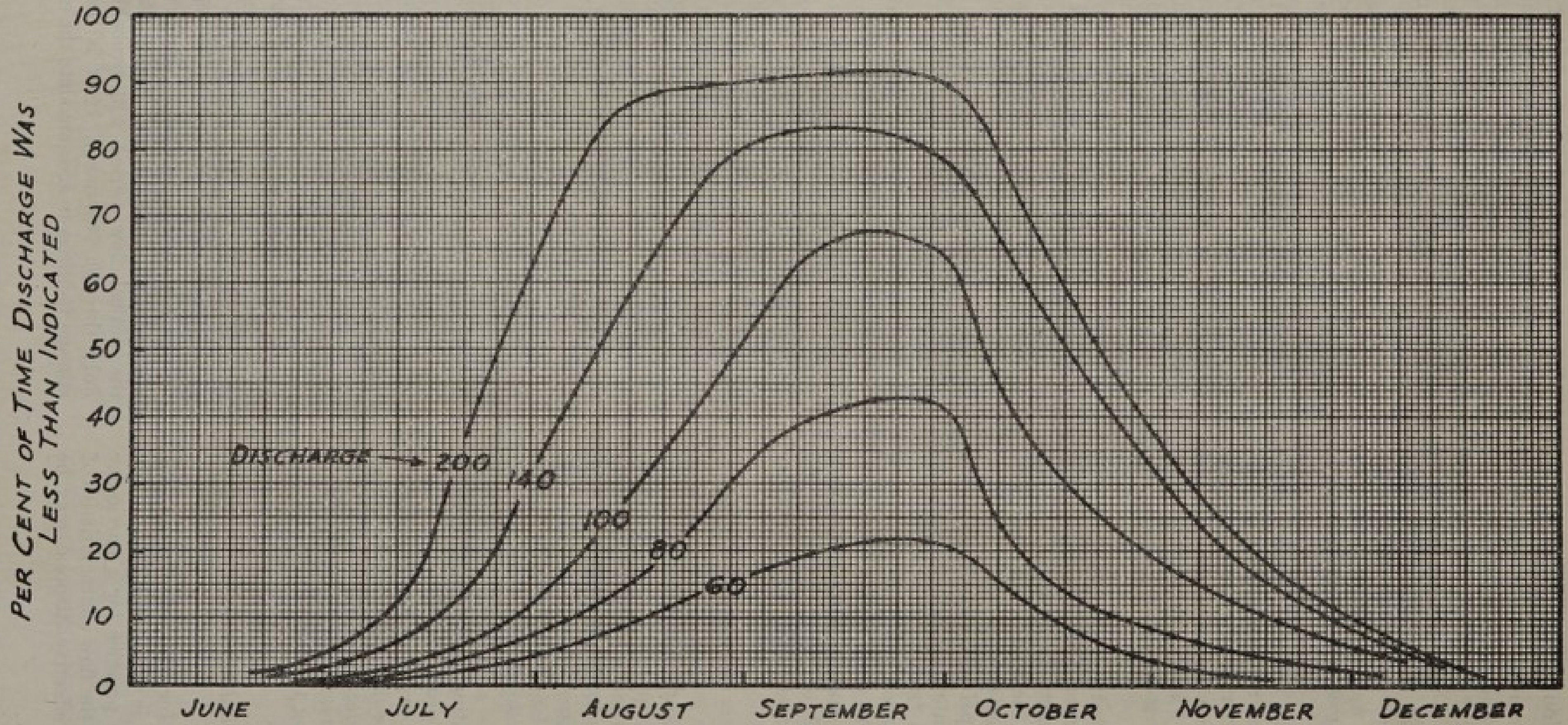


FIGURE 12

DROUGHT-DURATION CURVES FOR THE EEL RIVER AT SCOTIA, CALIFORNIA
1911-1913, 1917-1954

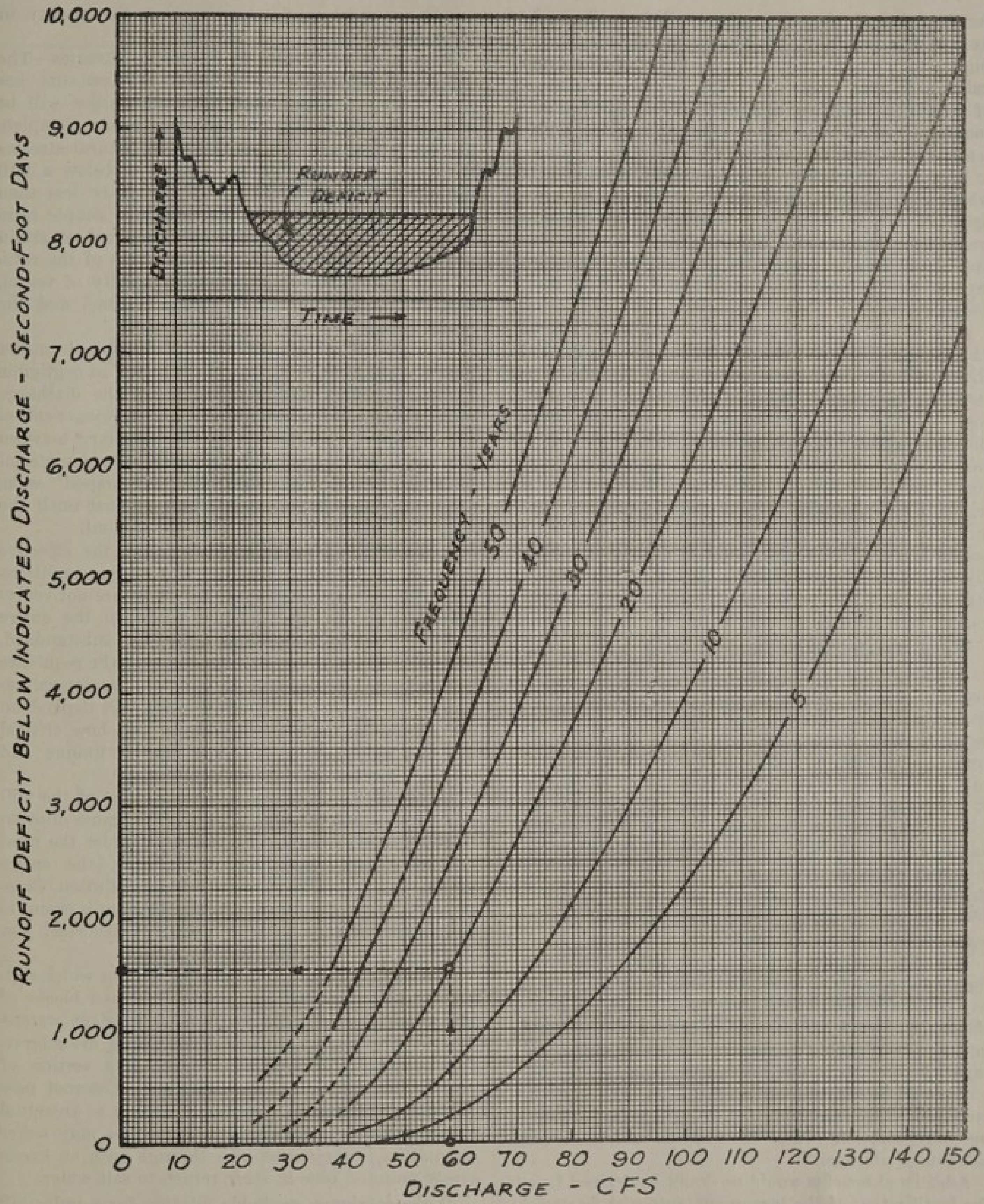


FIGURE 13

RUNOFF DEFICIT AS A FUNCTION OF CRITICAL MINIMUM FLOW—EEL RIVER AT SCOTIA, CALIFORNIA—1911-1913, 1917-1954 for droughts of 20-year frequency Figure 13 can be used to determine the probable storage volume. Entering the figure with a minimum discharge of 58 cfs and using a 20-year frequency results in the estimation of the runoff deficiency as approximately 1,550 second foot-days (SFD). Since this volume of water represents stream flow not available for dilution of waste at a ratio of 1 to 100 the corresponding waste volume which must be stored is about 15.5 SFD. At an average mill flow of 0.58 cfs a lagoon of this capacity would accommodate 26.7 days discharge. For 10-year and 5-year drought frequencies the mill would require lagoons having capacities for 10.9 and 3.8 days flow, respectively.

As a further example suppose a small kraft mill of 250-ton capacity was proposed for location on the Eel River and that lagoons accommodating 10 days flow could be constructed. What minimum waste dilution could be guaranteed for a frequency of 5 years? From the data in Table 35 it is estimated that 10 days flow from such a mill would require a storage capacity of $10 \times 8.56 = 85.6$ SFD. This problem necessitates a trial and error solution using Figure 13 such that the indicated discharge when divided by the mill flow produces a dilution factor equal to the runoff deficit divided by the required lagoon capacity. The solution indicates that the proposed storage capacity could guarantee a dilution of only 8 to 1.

Waste Treatment in Lagoons—It is particularly important to note that lagooning of pulp mill waste provides some additional important advantages aside from facilitating dilution. Of particular importance in alleviating stream pollution are the benefits of organic stabilization which may result during the holding period. Deliberate treatment of kraft wastes in oxidation ponds, which are really little different from storage lagoons, have resulted in BOD reductions generally exceeding 75 percent. In addition, retention of waste discharges in lagoons permits the stabilization of easily oxidizable mercaptans and sulfides, tending to reduce the toxicity hazards in disposal of this waste.

It is clear that storage for the purpose of reducing the stream's burden during the drought period would pay dividends in an overall improved quality of waste effluent. In fact, a mill possessing such facilities would find it advantageous to invoke their use at partial capacity throughout the entire year. The lagoon contents could be drawn down during high flows immediately preceding an anticipated drought period, retaining only sufficient waste to seed the inflow during subsequent storage.

Additional benefits would no doubt be derived from the fertilization of the lagoon contents with bacterial nutrients which are normally deficient in pulp mill effluents. It may also prove practical in some instances to incorporate preaeration or secondary biological treatment units to further improve the quality of waste discharges.

Dispersion of Wastes in Receiving Streams—The foregoing discussion of dilution requirements has necessarily presumed that waste discharges will be completely mixed with the receiving water. Complete mixing is not easily accomplished in natural streams with the result that for some distance below a mill outfall the actual dilution will always be less than the dilution computed on the basis of a simple ratio of flows. The time of stream flow required to attain effectively complete mixing is a function of the ratio of flow volumes, the distance and velocity of travel, and the geometrics of the stream channel and the waste outfall.

If waste discharge occurs through a single outlet near the bank of the stream dilution may be negligible for some considerable distance below the discharge point. Gradually, however, as stream turbulence causes the transport of water across the boundary between the waste and unpolluted water the waste material becomes diluted. A characteristic "fan-shaped" wake of pollution progresses across the channel until the waste concentration is uniform throughout.

A question arises here as to where the effective dilution should be evaluated. Obviously, conditions immediately below a discharging outlet are not representative of the effect of the waste on the entire stream. Locally, conditions may be substandard, whereas a short distance downstream all the requisites for adequate disposal may be satisfied. The determination of an appropriate control point will depend on the uses to be made of the stream and how critical the disposal problem is. Each case is unique and requires its own special investigation.

In general the best practice on the part of the mill concerned would attempt achieving maximum dilution in the shortest possible flow distance, under the most critical stream conditions. If possible, the entire stream flow should be effective in waste dilution. Careful attention to the details of outfall design is essential to insure maximum dilution within the shortest possible distance from the outfall.

It is of particular importance in streams which support anadromous fish populations to avoid blocks of either toxic constituents or oxygen deficient waters. If salmon or steelhead trout, for example, are migrating upstream for spawning purposes a section of stream through which they will not or cannot pass can deter the spawning run as effectively as an actual physical barrier. Also migrant juveniles may suffer mortalities if they must pass through such an excessively polluted zone in their return to salt water.

If the maximum available dilution for a pulp mill waste is especially close to the critical dilution at a particular site it is exceedingly important that the fullest use be made of available water. The usual

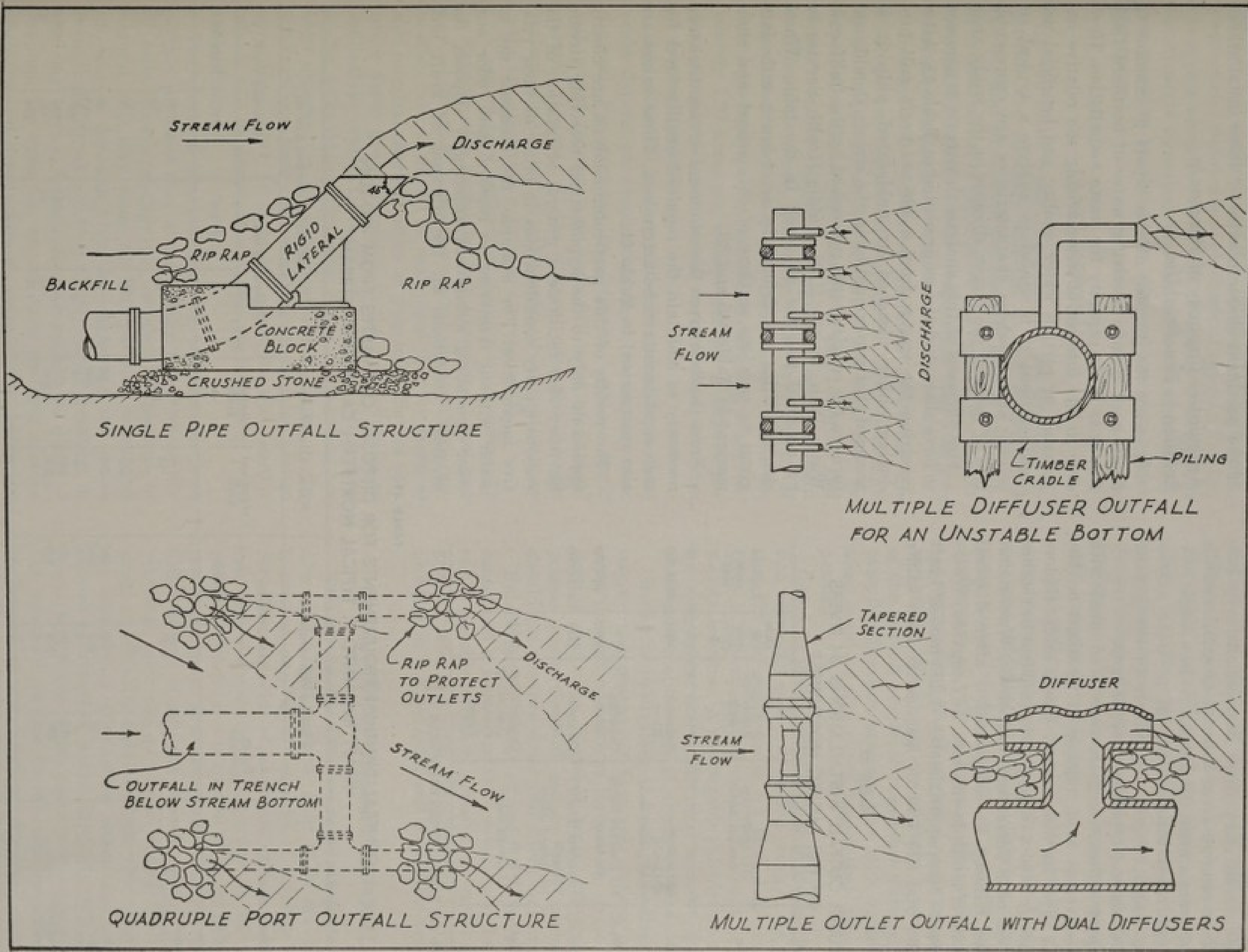


FIGURE 14

TYPICAL OUTFALL STRUCTURES FOR WASTE DISPOSAL INTO RECEIVING STREAMS method of accomplishing maximum dispersion of wastes in stream water involves the use of outfalls with multiple diffusers. Such installations may take many forms ranging from a series of small outfalls branching from a main discharge line to a single outfall line provided with a series of ports or nozzles along its length. Figure 14 illustrates the general features of several typical outfall designs.

Multi-port diffuser outfalls have been used with some effectiveness at a number of locations on the Columbia River in Washington. Waste sulfite liquors which have created a slime growth problem in reaches of the river near Camas and Vancouver, Washington have been reduced in concentration after disposal with the aid of multiple diffusers. At Longview, Washington wastes from approximately 1,200 tons of kraft production and 315 tons of magnesium base sulfite production are discharged to the river through two specially designed outfalls. Table 40 summarizes some of the pertinent characteristics of these installations.

TABLE 40

DIFFUSER OUTFALL INSTALLATIONS IN RIVERS OF THE PACIFIC NORTHWEST

Location	Mill production tons per day	Receiving water	Date of construction	Approximate cost
Camas, Wash.	320 sulfite[a] 420 kraft 40-60 ground wood	Columbia River	1951	$225,000
Vancouver, Wash.	110 bleached sulfite (Ca base)	Columbia River	1952	$40,000
Longview, Wash.	315 sulfite (MgO) 500 kraft 100 neutral sulfite	Columbia River	1951	$134,000
Longview, Wash.	700 kraft 76 ground wood	Cowlitz River at mouth in Columbia River	1951	--

[a] Sulfite wastes only discharged through diffuser outfall.

Assimilative Capacity of Streams in Relation to Beneficial Use

It is not the purpose of this report to examine in detail each specific receiving water of northern California as to its capacity for waste assimilation. However in the interest of summarizing the relative importance of certain water quality and beneficial use considerations it is useful to analyse a typical receiving stream whose characteristics are representative of most of the larger streams in the study area.

For purposes of this analysis the stream is assumed to have characteristics as presented in Table 41. After receiving the wastes from a 400-ton kraft mill producing either bleached or unbleached pulp it is assumed that water quality in the stream should conform to the requirements prescribed by the California Water Plan, by the U. S. Public Health Service or by accepted practice as noted in the table. Waste characteristics are defined in accordance with data given in previous sections of this report and summarized in Tables 35 and 36.

From the data given the minimum stream discharge necessary to maintain the required quality level for each constituent can be determined. These values are also summarized in Table 41.

The results of this particular analysis are clearly applicable only to the hypothetical receiving stream but they also facilitate a general orientation of the various quality considerations in order of their relative importance. For example, the domestic use of water without treatment to remove taste, odor and color producing substances apparently imposes the greatest restrictions on the disposal of kraft mill

TABLE 41

GENERAL DILUTION REQUIREMENTS FOR DISPOSAL OF WASTES FROM 400-TON KRAFT MILL INTO A TYPICAL NORTHERN CALIFORNIA STREAM

Constituents	Stream characteristics			Waste characteristics		Minimum required flow cfs			
	Before discharge	After discharge		Unbleached kraft	Bleached kraft	Unbleached kraft		Bleached kraft	
			USPHS				USPHS		USPHS
Toxic components	0	0		+	+	[f]274		[f]770	
Hardness as $CaCO_3$—ppm	60	[a]160		60	275	[a]0		[a]48	6
Sodium ratio	$\frac{0.3}{1.2}$	[a]0.5		$\frac{3.9}{5.2}$		[a]61		[a]0	
Sulfates—ppm	20	[a]100	250	200	80	[a]17	0	[a]0	
Chlorides—ppm	10	[a]100	250		300	[a]0		[a]85	
Taste and odor	0	0	0	[b]+	[c]+	686		963	
Color—ppm	5	[a]10	20	500	125	[a]1,345	384	[a]943	270
Total dissolved solids—ppm	120	[a]400	500	1,200	800	[a]39	25	[a]55	30
Dissolved oxygen at 20°C, ppm	9.2	5.0		[d]0	[e]0	155		255	

[a] In accordance with California Water Plan recommendations for water diverted to the California Aqueduct from the lower Sacramento River.
[b] Threshold 1:50. [c] Threshold 1:25. [d] BOD = 245 ppm. [e] BOD = 125 ppm. [f] 20:1 dilution.

wastes. Use of stream waters for support of aquatic life appears to be next in order of importance as indicated by requirements for dilution of toxic components and maintenance of dissolved oxygen. Finally, those uses which are concerned primarily with mineral constituents in waters are found in a comparatively low position in the waste disposal-receiving water spectrum.

LAND DISPOSAL

In the event water resources are not available to provide the necesary dilution during critical flow periods and when sufficient low-cost land is available, the construction of lagoons for the express purpose of disposal by infiltration or evaporation might be economically justified.

In semi-arid regions of northern California the potential average annual evaporation may run as high as 80 inches. About 40 inches of this total may be expected in the summer months of July, August, and September, the critical flow period for most northern California streams. Assuming total evaporation of impounded wastes over this three-month period the land area required for evaporation disposal is approximately 1.09 acres per million gallons. A 125-ton per day groundwood mill would require about 40 acres of disposal ground.

It is doubtful that any of the chemical processes could depend on evaporation alone for liquid waste disposal. For example, the "typical" 400-ton kraft mill would require more than 850 acres of disposal ground. However, if the disposal area was suitable geologically the additional benefits of infiltration may make the operation a little more reasonable.

A satisfactory infiltration basin should ordinarily be capable of a sustained rate exceeding 1 foot per day, or about 30 times the normal summertime evaporation rate. It should be recognized that the chemical and physical characteristics of pulp mill effluents may bring about gross alteration in the permeabilities of infiltration media. Intrusion of suspended solids into media voids during the early stages of operation has been observed to produce drastic reductions in the infiltration capacity of permeable soils during sewage spreading. (39) It is highly probable that similar effects will be produced with the application of pulp mill effluents.

The chemical characteristics of the effluents from certain processes may also influence the permeability of soils. Base exchange on the clay components of natural soils may cause the soil particles to expand on contact depending on the nature of the cation being substituted relative to the cation resident in the clay lattice. Substitution of sodium in place of calcium, for example, results in a swelling of clay particles and a reduction in permeability, hence the concern in irrigation practice over the "sodium ratio." The reverse process usually results in an improvement in permeability. The extent to which substitution is at all possible is determined by the relative proportions of the various cations (Na^+, Ca^{++}, Mg^{++}, K^+, and NH_4^+) in the liquid being percolated. Thus, it can be supposed that a kraft mill waste which is proportionately high in sodium will decrease the permeability of a clayey soil while a calcium or magnesium base liquor from the sulfite process might actually increase permeability.

Ordinarily the most efficient operation of infiltration basins involves alternate drying and wetting with periodic addition of soil conditioners. Some of the most successful soil treatments actually involve the application of pulp mill waste derivates to facilitate the aggregation of soil particles, thus increasing permeability. (40) It appears unlikely, however, in view of the adverse effects of suspended material, that the overall infiltration capacity even with optimum treatment could be maintained higher than about 0.5 foot per day.

Based on these conservative assumptions of infiltration capacity and evaporation rates it is estimated that the real requirement for land disposal of waste from a 125-ton groundwood mill would be approximately 1.4 acres. A comparable calculation for a 400-ton magnesium base sulfite mill indicates an infiltration basin requirement of about 48 acres.

Successful infiltration of kraft mill effluents would require maintenance of favorable sodium ratios, possibly through addition of lime sludge from the causticizing operation. Bleached kraft effluents normally possess proportions of sodium and calcium which should not produce structural alterations in soil.

Before land disposal of pulp mill wastes can be considered a feasible method, attention must be given to the possible effects of percolating wastes on underground water resources. Consideration is given to this problem in a subsequent section of this report.

BAY AND ESTUARY DISPOSAL

Because of convenient access to transportation facilities and world markets, pulp mills are frequently located at or near the mouths of principal streams. Situated at a point of maximum surface runoff a pulp mill may be considered to occupy an advantageous position with respect to control of water pollution. On the other hand, such locations often require a very different sort of analysis than is applied in the conventional approach to stream disposal. First, there exists a possibility of tidal effects which may influence the availability of dilution water and prevent the normal excursion of waste water seaward. Second, if the stream is one which receives other wastes during the course of its flow to the sea the pulp mill may be located at the "end of the line" with limited assimilative capacity remaining in the stream. The mill may be located at a point of lower critical loading and thus may be permitted the addition of only minimal quantities of waste. Finally, a new set of beneficial uses confronts the mill, those associated with brackish and salt waters; for example, the propagation of shell fish or the support of an anadromous fishery.

If the mill should locate on a bay which does not possess the benefit of receiving the runoff of an appreciable drainage the disposal problems which must be confronted can be even more troublesome. Without the flushing action provided by a continual inflow the mill must rely on tidal fluctuations alone to reduce waste concentrations to levels which protect other beneficial uses in the area.

It is the objective of this section of the report to present a brief summary and analysis of some of the more salient problems relating to the estimation of the capacity of bays and estuaries to assimilate wastes from the pulp and paper industry.

Tidal Influences

Tides along the Pacific Coast are of the diurnal type characterized by one major and one minor ebbing-flooding cycle each lunar day. Tidal fluctuations are greatly influenced by the action of wind, the configuration of bays and estuaries, and the stage of stream runoff. In addition, peculiar phenomena such as seiches or standing waves occasioned by unusual hydraulic or physiographic circumstances may be superimposed on or induced by tidal action. It is readily apparent that tidal behavior is at least very complex and often unpredictable.

The problem of estuarial flushing under the combined influences of tides and stream runoff and the determination of the excursion time of pollutants through the estuary has commanded the attention of oceanographers, hydrologists, and sanitary engineers for many years. The importance of a solution to this problem is obvious but it is equally apparent that no single solution will do justice to the peculiarities of every situation. A number of different approaches have been attempted with varying degrees of success depending on the assumptions made. These range from the simple tidal prism exchange concept and the more advanced theories of Ketchum (41) and Stommel (42) to the use of tracers for the estimation of excursion time (43, 44).

The tidal prism concept considers the case of the confined bay or estuary discharging to the open ocean on the ebb tide in such a way that no estuary water is returned with the next flood. Close approximations of this ideal case are seldom found in nature, the nearest comparable situation being that of a small bay which opens to an ocean with a prevailing longshore current. In application of the tidal prism method the assumption must also be made that the volume of water replaced on each tidal cycle (the inter-tidal volume) is completely mixed with the volume remaining in the bay or estuary. Similarly, it is assumed for purposes of determining the pollution buildup in the receiving body that waste discharges are also intimately mixed with the entire volume of receiving water.

If the volume of waste discharged to the bay is small relative to the available volume of dilution water the waste build-up, Q_w, can be estimated by the relation

$$Q_w = \left[\frac{1-(1-x)^n}{x} + (1-x)^n\right] q_w \tag{4}$$

where q_w is the waste volume discharged per tidal cycle and Q_w is the waste volume remaining in the bay after "n" tidal cycles. The factor "x", according to the tidal prism concept is simply the ratio of intertidal volume to the total volume at high tide. For equilibrium conditions equation (4) reduces to the identity

$$\frac{q_w}{Q_w} = x \tag{5}$$

The reciprocal of the ratio x in equation (5) is defined as the average excursion time of the waste through the tidal basin. A reasonable approximation of excursion time is necessary for predicting the effects of detention on wastes subject to decay, such as organic matter or chemically unstable waste components. Most of the methods currently available for estuarial analysis tend to overestimate the true time of excursion.

It is obvious from the assumptions inherent in the tidal prism concept that the condition described by equation (5) is seldom realized and that estimation of pollution buildup must depend upon a more realistic analysis of each individual situation. Other methods are available which may give closer approximations to the true value of x.

Ketchum (41) has proposed a step-wise analysis of complex estuary systems which embodies the same assumptions used in the elementary tidal prism theory. However, he divides the estuary into segments in such a way that the tidal prism in each segment is equal in volume to the net volume of fresh water or waste which is transported seaward in a given time interval. Each segment is then treated by the elementary theory assuming complete mixing of fresh and saline water and no net exchange of salt through the boundaries.

As might logically be expected the so-called "tidal flushing theory" of Ketchum gives a more reasonable estimate of transported water volumes through a long narrow estuary than does the single application of the tidal prism concept. It should be noted, however, that both methods tend to overestimate transported volumes in estuaries which tend to fan out or shoal as they approach the sea. Neglect of circulation, turbulence effects, and variation in velocity distribution probably accounts for these discrepancies.

Stommel (42) has proposed a theory which purports to account for the effects of turbulence through the introduction of the coefficient of eddy diffusivity into the steady state pollution equation. For pollutants which remain unaltered with time Stommel gives the relation

$$F(x) = Qc - SA\frac{dc}{dx} \tag{6}$$

where Q is the inflow to the section, c is the concentration of pollutant, A is the coefficient of eddy diffusivity, S is the cross sectional area of the section, $F(x)$ is the net seaward transport of pollutant, and x is the distance measured in a seaward direction.

Evaluation of the diffusion coefficient requires determination of the concentration of some other property of the estuary, for example, the concentration of fresh water, f, at various cross-sections. For cross-sections at intervals of "a" feet, "A" can be computed by the equation

$$A_n = \frac{Q2a\,(1 - f_n)}{S_n\,(f_{n-1} - f_{n+1})} \tag{7}$$

If the concentration of waste is also determined by the time of exposure to the receiving water then the total rate of pollution supply at the outfall ψ, is expressed by

$$\frac{d}{dx}F(x) + \frac{S}{\tau} = \psi \tag{8}$$

in which $F(x)$ is given by equation (6) above and τ is defined as the time required for the pollutant to decay from C_o *to* C_o/e. The time τ, is slightly larger than the "half-life" of the pollutant or

$$0.693\,\tau = \text{half-life} \tag{9}$$

Each of the methods outlined above has its limitations and at best can only be expected to yield estimates of probable pollution in estuaries. Wherever possible the use of an independent assay of the flushing action of tides and streamflow based on an actual tracer is recommended.

An evaluation of salinity gradients under steady inflow conditions has proven useful in several instances. Eriksen and Townsend (43) estimated the fresh water volume of Grays Harbor, Washington, using salinity data and Sylvester (44) conducted a similar investigation of tidal flushing in the estuary of the Willapa River, the site of a proposed kraft pulp mill. The latter investigation as well as a special survey of the Snohomish River estuary near Everett, Washington, (45) made considerable use of direct current measurements at various locations in the channels.

It is clear that any methods invoked for the study of estuarial pollution problems will require the utmost in care of execution and interpretation. No two problems are alike; the experiences gained from other investigations serve only as guides for the intelligent appraisal of each unique problem.

Hydraulic Models for Estuary Studies

Hydraulic models of complex bays and estuaries are useful in analysing particularly difficult pollution problems. For example, peculiarities in current behavior which could not ordinarily be accounted for in the analytical procedures mentioned earlier can usually be closely duplicated in carefully constructed and operated models. With the aid of dyes or other simulated pollutants the experienced researcher can trace the paths of contaminating substances through the model and evaluate the pollution build-up (equation 5) and the excursion time.

Some difficulties may be experienced in the investigation of pollution problems with models as a consequence of scale. It is never possible to construct a model that will satisfy simultaneously all of the laws of similitude. For practical reasons the model is usually designed so that certain forces are in the same ratio to one another in the model as they would be in the prototype. Other forces are either accounted for by mathematically correcting the results of model behavior or are neglected.

In estuarial models the forces of gravity, viscosity, and inertia of fluid masses are usually considered of primary importance. Surface tension forces are minimized by keeping the model size sufficiently large.

It is often impractical to scale both gravitational, viscous, and inertial forces if the fluid to be used is water. For studies of bays where frictional effects may be expected to be small in contrast to gravity and inertia effects viscosity can sometimes be neglected. In channels, on the other hand, viscous forces are very important while gravity forces can usually be neglected.

Since it is not possible to satisfy all primary force relations in a single model of a complex tidal estuary provisions are often made for adjustments to bring the model performance into line with actual observations in the prototype. Detailed studies of currents during known conditions of tide and stream runoff may be conducted on the prototype estuary in order that data will be available for verification of the model. Final adjustments usually involve a series of successive trial and error steps until the model faithfully duplicates the prototype for the parameter under investigation.

Estimation of sulfite pulp mill waste build-up in Alberni Inlet, B.C., was accomplished by Tully and his co-workers (46) with the aid of a hydraulic model. The model was constructed of plaster using scales of approximately 1 : 4,500 horizontal and 1 : 300 vertical or a distortion ratio of 15 : 1. It was reported that the model successfully duplicated water movements and salinity gradients. An estimation of pollution build-up of 85 percent of the total waste discharge per tide was considered accurate within the limits of observation.

An unusually intricate model of San Francisco-Oakland Bay has just been placed in operation by the U. S. Army Engineers at Sausalito, California. This model is built of concrete and covers an area of about one acre. It will be used primarily for investigation of sediment transport through the bay and the effects of tidal barriers but will find many other useful applications including the study of tidal flushing and pollution excursion.

A rather unique model which uses a variation on the tidal flushing theory of Ketchum (41) was constructed by the Weyerhaeuser Timber Company to study the potential pollution of Grays Harbor, Washington, by the effluent from a proposed 300-ton per day magnesium base sulfite mill (47). The model consisted of a series of interconnected tanks scaled volumetrically to represent various segments of the estuary and harbor. Tidal fluctuations were obtained by raising or lowering a discharge line on the final basin while supplying make-up water on the rising tide. River flows and mill discharges were regulated by dropping the overflows in supply reservoirs at a constant rate. By varying the position of the "mill discharge" the experimenters were able to determine the most probable of several alternate locations for the prototype sewer in order to obtain maximum dilution of the waste under the most critical flow conditions.

A comparison of model results and prototype investigations of salinity in the harbor indicated reasonable agreement despite the fact that the dynamic behavior of water masses were not reproduced in the model. The method is subject to the same general limitations that restrict the application of the tidal flushing theory. Its principal advantage rests with the economy of design and construction. For the purposes of the Gray's Harbor investigation it was apparently satisfactory.

In general, models permit an understanding of hydraulic behavior which can not be obtained from simplified theoretical studies. If the particular disposal situation is complex beyond convenient analysis and the future of a considerable resource is at stake the use of a good model is often the only reliable insurance.

Special Beneficial Use Considerations

A number of special considerations relative to the beneficial use of estuarial and bay waters arise in connection with the pulp and paper industry. These are primarily concerned with the sustainance of various forms of aquatic life indigenous to or which migrate through such waters. Problems associated with the support of an anadromous commercial or recreational fishery and the propagation of shellfish have been at the forefront; although the effects of pulp mill wastes on lower aquatic forms, particularly fish food organisms, have received considerable attention.

Much disparity of opinion among fisheries experts appears to exist as to the actual importance of certain pulp waste pollutants in relation to biological life. In some cases no apparent difficulties from toxic effects have been experienced at concentrations of waste higher than normally required to produce oxygen deficient conditions while in other instances waste concentrations barely considered detectable have been blamed for loss of important marine resources.

Oxygen Deficient Barriers—The more obviously critical problems which arise in estuarial pollution are those associated with the occurrence of oxygen deficiencies. Stream flows in the estuary are normally greater than at any other point on the stream and hence are normally capable of greater dilution. However, the influence of tides often results in current reversals which cause the same volume of water to be transported past the outfall point several times, each time receiving an additional burden of waste discharge. Such current reversals are common during the critical low flow periods of streams which reach the ocean on comparatively flat gradients. Most northern California streams are in this classification.

The migration habits of many anadromous fishes, particularly some of the salmonoid species, place them in the estuarial areas during the critical flow period. Occurrence of an oxygen deficient barrier across the stream at this point may prevent the consumation of the normal migration pattern. Ordinarily this type of barrier does not destroy adult fish which simply wait until conditions are more favorable or manage to survive short exposures to waters of substandard oxygen content. But, the young fingerling downstream migrants normally require a longer period of acclimatization to their new environment and may remain for considerable time in the brackish waters of the estuary. It is with this latter age level that fisheries' biologists seem to be most concerned.

Aside from waste treatment or abatement, alleviation of pollution load in the estuarial area is primarily a problem of providing more dilution water or providing it under circumstances more favorable to effective dilution. At least two methods have proven effective in the practice of existing mills.

Use of diffuser outfalls, which was discussed earlier in connection with stream disposal, prevents the concentration of waste at a single point and hence reduces the likelihood of a pollution barrier. This method has been very effective in eliminating a migration block which existed on the Snohomish River near Everett, Washington, during low flow periods

(48, 49). Two pulp and paper companies, both operating sulfite pulp mills, teamed together to construct a deep water diffuser line in Port Gardner Bay opposite the mouth of the river. The principal concentrated wastes of both mills are now discharged through multiple outlets in about 300 feet of water. According to a survey conducted by the Washington State Pollution Control Commission (49) this mode of disposal was effective in preventing the recurrence of critical oxygen conditions in the mouth of the river.

A second method involves the use of holding lagoons with capacity for waste storage through the critical flow periods. Such lagoons may operate on a season-long basis or may be designed for storage only during critical tide periods. Impoundment during flooding or slack tides and release during maximum ebb is usually the most favorable operating procedure.

A pulp-producing concern which operates a sulfite pulp mill at Hoquiam on Gray's Harbor, Washington, has effectively employed the seasonal lagooning procedure for many years. During the summer months when the flow in the Chehalis River is less than 2,500 cfs the mill impounds more than 80 percent of its concentrated waste liquor on an island in the river. In 1950 when the mill production was about 280 tons of dissolving pulp daily approximately one million gallons of waste water per day over a period of about four months each year were stored pending release under favorable flow conditions. The apparent success of this operation is reflected in the maintenance of a continuing prosperous salmon fishery supported by the Chehalis River system.

Shellfish Propagation—Much attention has been given over the years to the possibilities of damage to shellfisheries from pulp mill wastes. While there are indications that certain sulfite waste liquors in high concentration are damaging to various species of oysters the tolerance limits have never been conclusively established. Experiments to determine the tolerance of shellfish to waste liquors have served only to further confuse the issues. Studies by McMillan and his co-workers (50, 51) indicated that sulfite waste liquor in concentrations exceeding 100 parts per million was harmful to the presumably sensitive Olympia oyster. An investigation by the Washington State Department of Fisheries (52) purported to show that concentrations exceeding 13 ppm of S.W.L. were damaging. These observations were considerably weakened, however, by the fact that more than 50 percent of unexposed control oysters died during the test. Mortalities among the oysters subjected to 13 ppm of waste liquor were noted to be 20 percent higher than among the controls.

Recent unpublished research cited by Neale (53) indicates that Pacific oysters can be successfully grown in continuous concentrations of waste liquors for an entire growing season. In the experiments cited oyster mortalities were observed to be identical in (a) a sample plot in Willapa Harbor, Washington, (b) control troughs, and (c) troughs containing 70 ppm of sulfite waste liquor.

The effects of kraft mill effluents on shellfish culture has received some attention although this process has not been considered so objectionable because of the cooking liquor recovery techniques employed.

It is apparent that much work needs to be directed toward establishing the effects of pulp mill wastes on shellfish. This is particularly true with respect to the kraft process which is receiving the most attention from the pulp industry in its plans for future development of pulping potential in the United States.

OCEAN DISPOSAL

Direct discharge of pulp mill wastes to the open ocean is a mode of disposal which may provide a solution to some of the problems which face mills located on streams or estuaries. The likelihood of adverse effect on beneficial use is apparently lessened, partly because the uses of such waters are limited and partly because of the ease in divorcing the discharge location from the area of concentrated water use.

The advantages of ocean discharge are clearly evident in the experience of the pulp industry in Washington. Those mills which are located on the Strait of Juan de Fuca or in northern Puget Sound away from the mouths of salmon streams or oyster-producing areas have enjoyed comparative freedom in regulation of waste discharges. On the other hand, mills located on streams, estuaries or near the mouths of rivers have been faced with continuing problems of pollution abatement.

Despite the benefits derived from an ocean location, careful consideration is due the few liabilities which may result. The possible effect of mill wastes on the local shellfishery, either commercial or recreational, is still to be reckoned with. And the desirability of preserving the aesthetic qualities of a site which has recreational potential should be recognized. Oxygen deficient conditions almost never present a problem except in the immediate proximity of the outfall. Problems of color, taste, and odor are seldom of concern unless they should in some way be transmitted to fish or shellfish which frequent the area.

Invariably the solution to the ocean disposal problem is to provide maximum dilution through the medium of a deep water diffuser line. Proper construction and location of such an outfall requires a knowledge of the oceanographic characteristics of potential disposal sites and a careful study of meteorological conditions which may influence the effectiveness of waste dispersion.

An excellent discussion of oceanographic factors has been prepared by Pearson (54) in an exhaustive study of the problems of submarine outfall disposal of sewage and sludge. It is not the intent of the present discussion to duplicate the efforts of Pearson but in the interest of securing a somewhat complete coverage of pulp mill waste problems, a few of the more salient features are reviewed here.

Ocean Currents

Currents which prevail at a particular outfall site are usually induced by a multitude of effects. Tides, winds, bottom topography, coastal currents, and a surface runoff all influence current behavior.

The lateral transport of water masses with the rise and fall of the tide results in currents of complex form which are usually distinguished by their periodic nature. Tidal currents may be rotary or reversing, depending on the restrictions imposed by topography. Offshore tidal currents are likely to be rotary, that is, they will exhibit a continuous change of direction and magnitude. Close to shore or in confined bays or estuaries, tidal currents show less rotational tendency and are frequently observed to simply reverse direction with a change in tidal stage.

The magnitude of tidal currents in the open ocean is seldom greater than about 1.5 knots with an average of probably 0.3 to 0.4 knots, depending on location. In confined channels or estuaries, velocities exceeding 5 knots are not uncommon.

The frictional resistance afforded to prevailing winds by the water surface results in the production of waves whose height and period are functions of wind velocity and duration, the distance of wave generation, and the distance from shore. Attendant water transport and mixing of water masses by wind action may be exceedingly important in design of ocean outfalls.

In the case of waste discharges which are less dense than sea water (specific gravity approximately 1.025) the relationship between surface currents and wind velocities may be especially important. Ekman (55) has developed the following empirical expression relating wind velocity, surface current, and the latitude of the location

$$V = \frac{0.0127}{\sqrt{\sin \phi}} W \tag{10}$$

where V is the induced velocity of surface current, W is the wind velocity, and ϕ is the latitude. The ratio, V/W ranges from 0.0155 at Crescent City to 0.0161 at San Francisco.

Prevailing surface winds along the coast of northern California vary only slightly as to intensity with the season of the year. In the vicinity of Crescent City, for example, the resultant wind velocity averages less than 5 miles per hour over the year. According to Ekman's equation, the average wind induced current in this area is probably less than 0.1 mph.

The direction of prevailing surface winds along the California coast is very dependent on the season. During the spring, summer and fall months, winds are predominantly from the northwest while during the winter, the winds come from the south or southeast.

The angle of the current in deep water with respect to the set of the wind has been found to be approximately 45 degrees to the right in the northern hemisphere. As the depth of water decreases the deflection angle also decreases with the result that currents produced from wind action generally parallel the coast. This condition apparently exists for waters along the northern California coastline.

Coastal currents are usually indicative of the general drift of large masses of deep water and often parallel the coast line. The extent to which these currents are dependent on winds and other meteorological conditions is not always determinable. They are probably of little importance in controlling water movements in the depths of water which may be considered practical for outfall construction.

Longshore currents induced by the breaking of waves at an angle to the coast line may be particularly significant in the dispersion of wastes by ocean outfalls. The direction of such currents is primarily determined by the direction of wave movement and the rise in water levels due to mass transport of water in a shoreward direction by wave action. To compensate for shoreward transport subsurface current reversals and occasional rip currents may result. Figure 15 presents a sketch of an idealized nearshore circulation pattern.

The complexity of current movements prevents specification as to the most suitable location for submarine outfalls. It can be observed however, that extending the outfall beyond the breaker zone is necessary for minimum protection of the shoreline. Discharge directly onto the beach is generally undesirable in that dilution is only provided by nearshore return flows inside the breaker zone. Waste discharge inside of the breaker zone can be expected to be transported considerable distances by longshore currents until being released by rip currents.

A careful analysis of the current behavior at a proposed outfall site is certainly warranted to insure the most effective waste dispersion in sea water. Pearson (54) has summarized many of the techniques which are currently available for study of current movement and has suggested several methods for securing the reliable data necessary for an adequate appraisal. The interested reader is referred to his complete report on submarine outfalls.

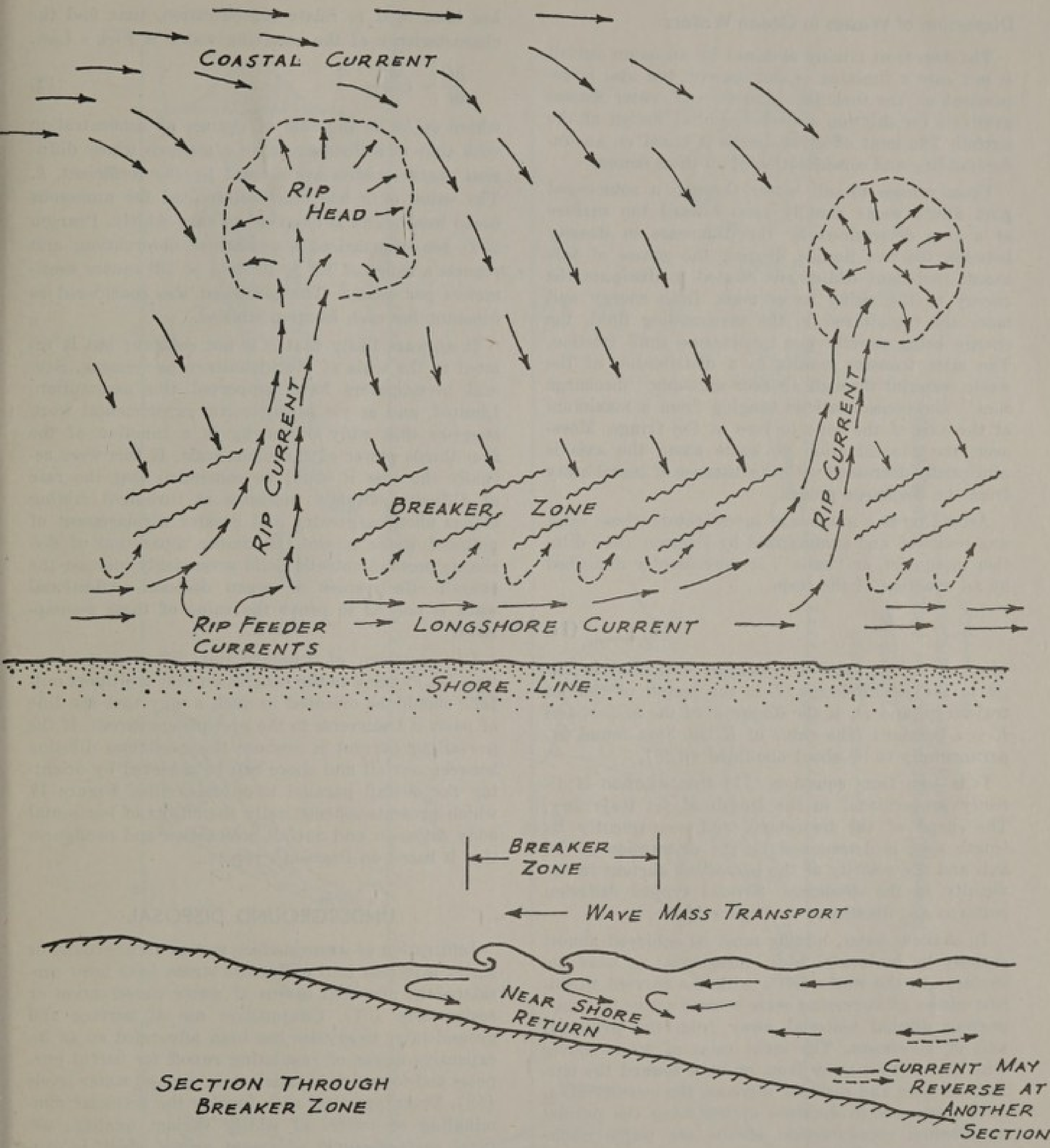


FIGURE 15

IDEALIZED NEARSHORE CIRCULATION IN OCEANS

Based on observations of Shepard and Inman (56)

Dispersion of Wastes in Ocean Waters

The degree of mixing obtained by an ocean outfall is not only a function of the current, but also is dependent on the turbulent structure of water masses available for dilution and the peculiar design of the outfall. The most effective design is based on an understanding and consideration of all these factors.

Upon release to salt water through a submerged port dilute waste usually rises toward the surface at a rate determined by the difference in density between the two liquids. During the course of this ascent turbulent eddies are created to dissipate the energy of the rising water mass. Both energy and mass are transferred to the surrounding fluid, the energy being rapidly lost by internal fluid friction. The mass transfer results in a distribution of the waste material through an ever-widening "discharge cone", the concentrations ranging from a maximum at the axis of the cone to zero at the fringe. Moreover, the concentration of waste along the axis is continually decreased with the distance of travel away from the discharge point.

According to a number of investigators whose work was reviewed and summarized by Pearson (54) dilution in the jet, or "cone", is conveniently described by an equation of the form

$$S_o = K \frac{L}{D_o} \tag{11}$$

where S_o is the ratio of discharge entrained in the jet to the jet discharge, L is the length of the jet trajectory, and D_o is the diameter of the orifice, and K is a constant. The value of K has been found experimentally to be about one-third (0.33).

It is seen from equation (11) that dilution is directly proportional to the length of jet trajectory. The shape of the trajectory, and consequently its length also, is determined by the orientation of jet axis and the velocity of the prevailing current in the vicinity of the discharge. Several typical diffusion patterns are illustrated in Figure 16.

In shallow water, mixing must be achieved almost entirely by horizontal eddy diffusion at or near the surface. As the waste drifts with the current turbulent eddies of increasing scale become active in transporting diluted material away from the principal axis of movement. The main mass of waste moves with the current away from or back toward the outfall. As time and distance increase, the concentration level continues to decrease approaching the normal equilibrium concentration of the sea water under steady state conditions.

The turbulence characteristics of the ocean mass, which are particularly significant in horizontal diffusion, are usually described by a diffusion coefficient, the coefficient of eddy diffusivity. An expression which has been used to relate concentration, time and the characteristics of the receiving water is Fick's Law.

$$\frac{\partial C}{\partial t} = k \frac{\partial^2 C}{\partial x^2} \tag{12}$$

where $\partial C/\partial t$ is the rate of change of concentration with time at a distance, x, in a medium whose diffusion characteristics are defined by the coefficient, k. The value of k has been determined for numerous ocean locales and is observed to vary widely. Pearson (54) has summarized a number of observations and reports a range of 1.9×10^3 to 4×10^8 square centimeters per second. The coefficient was considered as constant for each location studied.

It appears likely that k is not constant but is related to the scale of the turbulence phenomena. Several investigators have supported this assumption. Limited, and as yet inconclusive, experimental work suggests that eddy diffusivity is a function of the four-thirds power of turbulent scale. If this were actually the case it could be concluded that the rate of diffusion actually increases as turbulent mixing brings about a greater and greater displacement of polluted water masses. Maximum separation of discharge ports in outfalls could presumably increase the overall effectiveness of ocean disposal. Additional work is needed to prove the value of these assumptions.

Consideration of fundamental diffusion mechanisms led Pearson to the conclusion that multiport outfalls should be oriented in such a way that the line of ports is transverse to the prevailing current. If the prevailing current is onshore the maximum dilution between outfall and shore can be achieved by orienting the outfall parallel to the shoreline. Figure 17 which presents schematically the effects of horizontal eddy diffusion and outfall orientation and configuration is based on Pearson's report.

UNDERGROUND DISPOSAL

Infiltration of waste surface waters underground or direct injection into permeable strata have been considered as practical means of water conservation or reclamation (57). Conjunctive use of surface and groundwater reservoirs has been advocated as an inexpensive means of regulating runoff for useful purposes and to maintain satisfactory ground water levels (58). These practices each involve the artificial commingling of waters of widely variant quality; natural surface runoff of recent origin which is generally high in quality but may carry the waste effluents of the area and resident ground waters of considerable age which often carry high concentrations of dissolved salts and gases but no suspended matter.

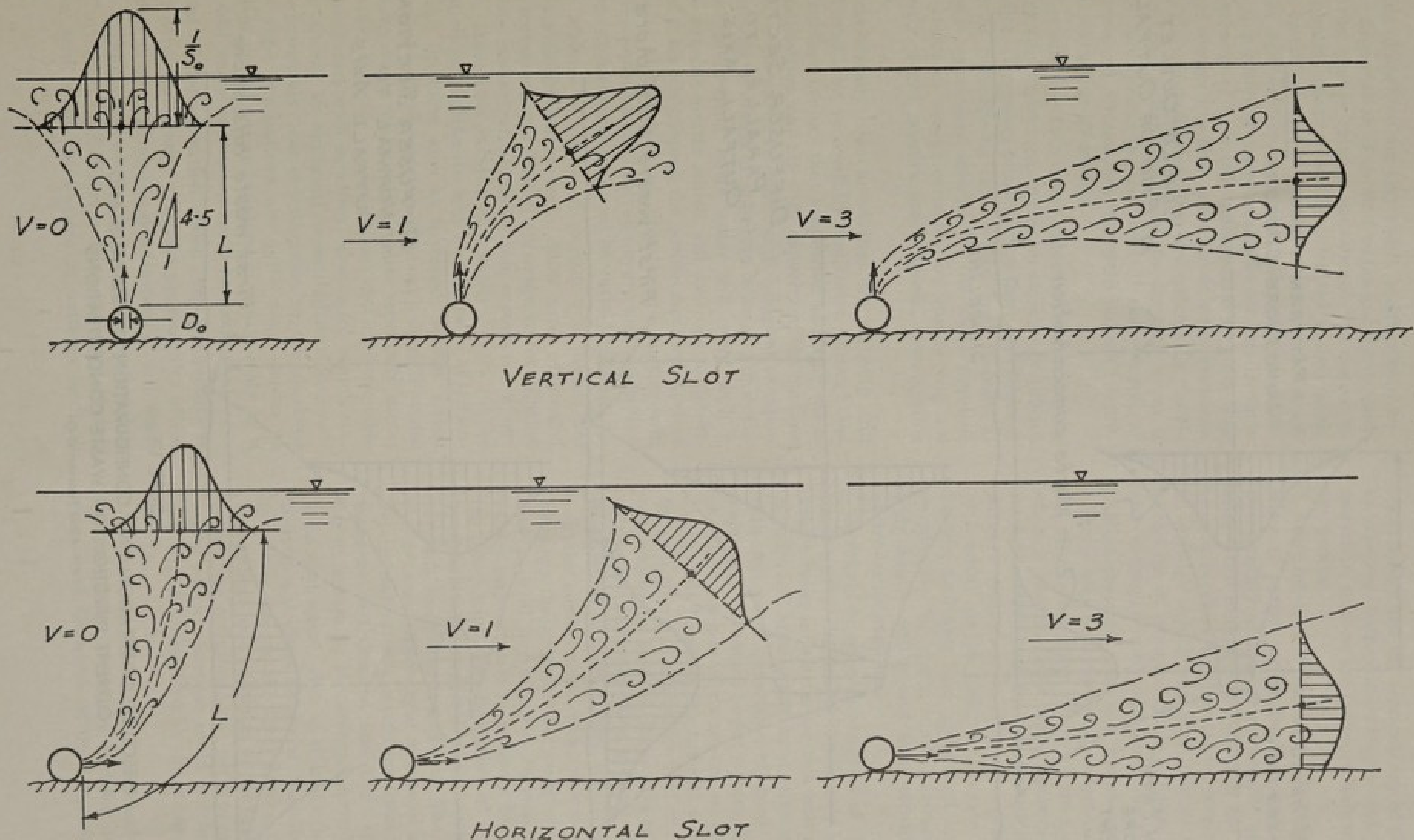


FIGURE 16

SCHEMATIC REPRESENTATION OF POSSIBLE DIFFUSER PATTERNS WITH VARYING CURRENT VELOCITY

After Pearson (54)

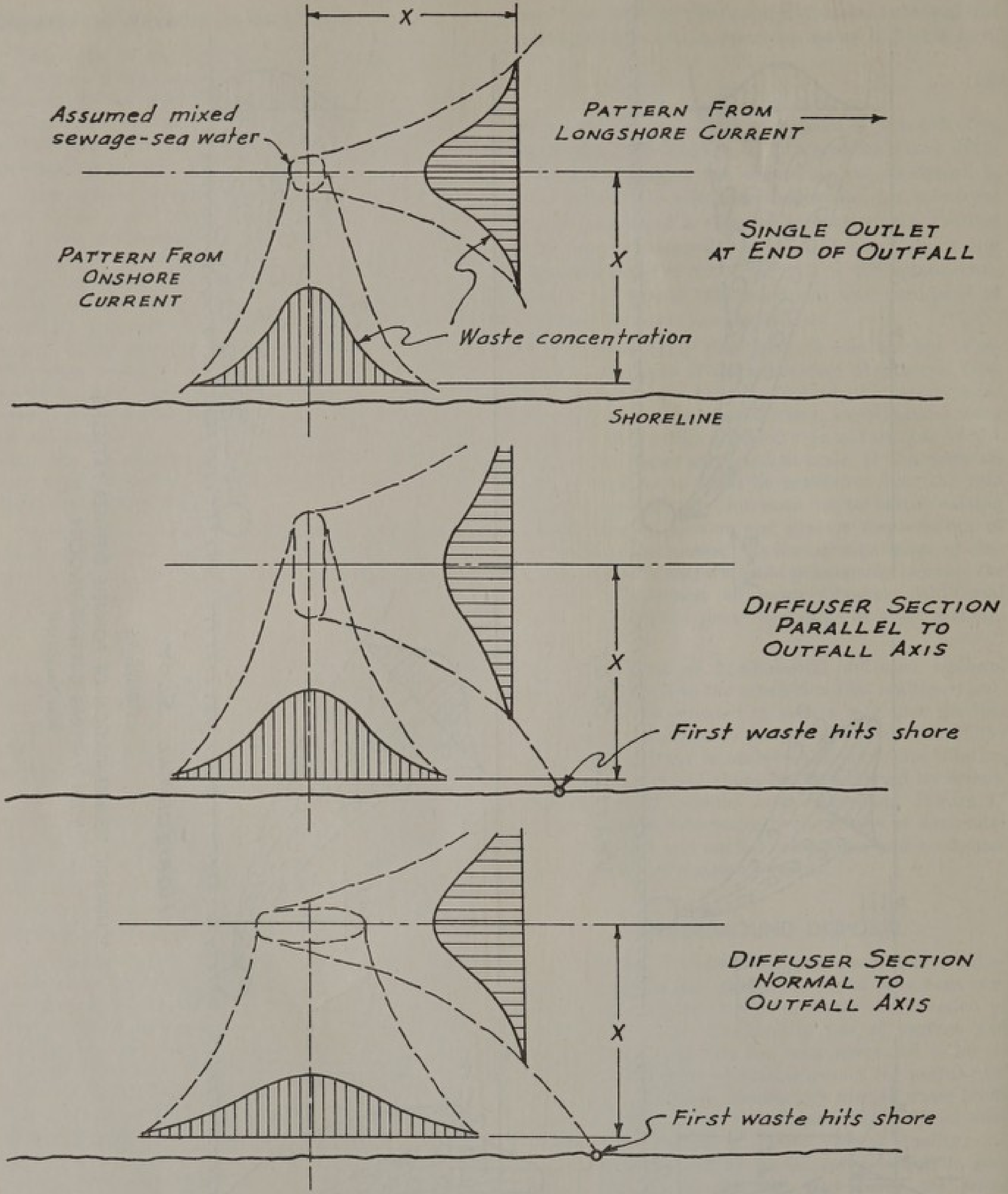


FIGURE 17

EFFECT OF ORIENTATION AND CONFIGURATION OF OUTFALLS AND CURRENT DIRECTION ON WASTE CONCENTRATIONS

After Pearson (54)

Mixing of such waters may result in either improvement or degradation of ground water quality depending on the quality criteria considered. The degree to which quality changes can be tolerated is dependent on the beneficial uses of ground waters and the advantages derived from artificial recharge by increasing the quantities of water available for use. In some areas recharge of depleted underground supplies with domestic sewage has been undertaken with some success. Certain industrial wastes are potentially usable for recharge, either incidental to disposal or as a planned enterprise. On the basis of the volumes of water involved, wastes from the pulp industry represent an attractive possibility.

The extent to which waste effluents from the pulp industry might affect ground water supplies is difficult to predict. It appears possible that there will be some incidental recharge in cases where land disposal is used as a convenient solution to the waste problem. Such situations would certainly be unique and undoubtedly would require much special investigation *in situ*.

It has already been noted that not all pulp mill wastes could be successfully infiltrated through natural surface media; that suspended solids or chemical composition may alter the capacity of the medium to receive the waste. In addition, it is logical to expect some special problems of pollution to arise. For example, the infiltrating waste water will carry with it soluble organic matter which will continue to decompose as it travels through the porous medium. Aerobic biological stabilization of this organic matter will result in depletion of dissolved oxygen and production of gases of decomposition, and bacterial cell material.

The absence of dissolved oxygen will permit anaerobic stabilization to begin. Slow rates of ground water movement and limited opportunity for dilution of waste concentrations make this occurrence a certainty. Anaerobic conditions usually result in the formation of odoriferous and aesthetically objectionable end products such as hydrogen sulfide. Large amounts of sulfur present in chemical pulp mill wastes would no doubt make this problem especially acute. Moreover, there is no indication that objectionable odor producers such as mercaptans, indol, scatol, etc., can be altered by biological decomposition into products appreciably less objectionable to the aesthetic senses. The implications are quite clear insofar as domestic use of ground waters in the vicinity of a pulp mill waste infiltration basin are concerned.

Gases of decomposition which may accumulate in media pores can greatly alter the permeability of the medium, thus reducing the effectiveness of any waste water recharge procedure. Experiments conducted at the University of California have indicated that if 10 per cent of the pore space in uniform media is occupied by gas, the permeability of the material may be expected to drop about 30 per cent. In non-uniform materials, such as are found in nature, the reductions are greater.

Accumulation of bacterial cell debris in the interstices of porous media can also lead to reductions in permeability of a more permanent nature. Once stabilized cell humus is deposited in the medium, it will remain resident until velocities become great enough to dislodge it and transport it to another location. A reduction in transmissibility appears to be an inevitable consequence of continued waste application.

Most chemical pulp mill wastes are highly colored, a factor which may seriously affect the aesthetic quality of ground water which receives direct discharge of such wastes. Some color components may be removed or reduced in concentration upon passage through natural soils. But experience with leaching of sawdust dumps and use of waste liquors for road binders indicates that lignin and tannin, which are responsible for much of the characteristic color of pulp wastes, will persist after considerable distances of travel through soil.

It should be noted in analysis of the ground water problem that the probability is very high of pulp mill wastes being soon returned to a natural water course. A pulp mill must locate in an area which is endowed with adequate quantities of good quality surface water, i.e., near some major stream. If the mill should choose to dispose of its wastes on land in proximity to the mill location, the migration of waste through the ground water in the direction of the normal gradient is virtually assured. In an area of intensive irrigation or normally abundant ground water, wastes may be expected to move toward the stream channel.

Under conditions in which the stream is serving to recharge the groundwater reservoir, as is often the case in arid or semi-arid regions, recharged waste waters may actually move away from the stream. On the other hand, the formation of a recharge mound by an infiltration operation can in itself result in local reversals in hydraulic gradient. The ultimate disposition of wastes discharged to ground water can only be determined after a careful analysis of all sources of recharge and demand and their effects on ground water motion in the area concerned.

Land disposal, even if it leads to ultimate stream pollution, is often beneficial. Stabilization of organic matter in the ground water during percolation to the stream and base exchange on the native soil can both reduce the pollution load; perhaps to a point where a waste which otherwise could not be tolerated could actually be assimilated by the stream without adverse effects.

Because of the effects of chemical pulp mill wastes on the quality of waters used for domestic purposes, the direct discharge of these wastes to groundwater cannot be regarded as a promising solution to the disposal problem. However, in some instances where local use of groundwater is not great, the conjunctive use of both underground and stream assimilative capacity may provide a solution to an otherwise insolvable problem.

The large volumes of waste associated with chemical pulping operations of moderate size preclude the use of underground disposal in areas where land values are high. In addition aesthetic considerations, in particular the problem of odor control, may militate against this mode of disposal.

In contrast, it would appear that the wastes from groundwood operations might be conveniently handled by infiltration ponds with comparatively little difficulty. Proportionately smaller waste volumes and the absence of strong odor-producing compounds give the groundwood process some advantage over the chemical processes. A higher B.O.D. in the effluent from a groundwood mill would probably require that additional attention be given to stabilization of the waste by biologic activity. Fertilizaton of infiltration basins with nitrogen and phosphorous, which are normally deficient in pulp mill wastes, may be a necessary operational procedure.

An incidental advantage of the infiltration basin lies in total elimination of suspended solids from the waste. In the case of the groundwood operation, which normally experiences higher fiber losses than the chemical processes, this aspect may be quite important in making the effluent acceptable for disposal.

ASSIMILATIVE CAPACITY IN RELATION TO NORTHERN CALIFORNIA WATERS

It has been the objective of the previous discussion on assimilative capacity of receiving waters to emphasize the importance of this consideration in defining the potential for the pulp and paper industry in California and to outline in a general way the methods of attack in solution of some typical receiving water problems. No deliberate attempts have been made to precisely define the capacities of any particular area, or any specific receiving water. In fact, if any feature of this section emerges as axiomatic, it is the observation that all pollution problems are unique, both in situation and solution, and are not susceptible to uniform treatment.

It is also clear that the future growth of California, both in population and industry, will impose continually increasing demands on the waste assimilative capacity of receiving waters. The capacity of the streams, bays, estuaries, and coastal waters to receive waste discharges is not unlimited but is determinable by standards set to preserve certain beneficial uses. To be sure, these standards are not rigid, but are dynamic and subject to revision as the requirements of beneficial water use change. Standards may be relaxed or tightened as the conditions warrant.

The equitable allocation of limited assimilative capacity among the various potential users, the waste dischargers, is a problem of extreme complexity. It requires careful consideration on the part of both the regulatory agency responsible for control and the industry or municipality which may contribute to pollution. It must consider all discharges, both present and future, and a variety of changing conditions.

It is possible to estimate the capacity of a particular water to receive a particular waste within the limits prescribed by some arbitrary standard. This can be done for wastes of the pulp and paper industry in relation to northern California waters. The procedures for accomplishing this estimation are presented on the previous pages.

Such estimation, however, cannot account for all the waste contributions from other industrial sources or from municipalities. It would have to be based on standards which may change with time and it could not account for modifications in process or waste treatment which may alter the waste characteristics. It would be useful for estimation of probable extremes and as an indication of future trends but could not be considered as a prognostication of the future.

In previous sections of this report, estimates have been given of the pulp tonnage which is potentially developable from the fiber resources of northern California. It would perhaps be desirable, from some points of view, to estimate the pulp tonnage which could be developed in terms of waste assimilative capacity of northern California waters. This has not been done in this report for the reasons which have been discussed above.

Information has been presented, however, which would enable the interested reader to examine many of the myriad combinations of waste and receiving water in greater detail if he so desires. Source data for additional analysis is cited in the general bibliography of this report.

SELECTED REFERENCES

FIBER RESOURCES

1. California State Water Resources Board, "Water Resources of California," Bulletin No. 1, 1951.
2. California State Water Resources Board, "Water Utilization and Requirements of California," Bulletin No. 2, 1955.
3. California Forest and Range Experiment Station, "Forest Statistics for California," Forest Survey Release No. 25, 1954.
4. U. S. Forest Service, "Timber Resource Review," 1955.
5. May, R. H., and Erickson, L. N., "Wood Residue from Primary Wood-Using Industries in California," Technical Paper No. 13, California Forest and Range Experiment Station, 1955.
6. Stanford Research Institute, "America's Demand for Wood," 1954.
7. Neubrech, W. L., "Waste Paper—Past, Present, and Future," U. S. Department of Commerce, 1954.
8. U. S. Forest Service, "Wood Pulp Mills in the United States," Washington, D. C., 1956.
9. U. S. Forest Products Laboratory, "Pulp Manufacturing Factors," Processed Paper No. 89, 1954.

WATER REQUIREMENTS

10. Stephenson, J. Newell, *Pulp and Paper Manufacture*, Vol. 1 New York: McGraw-Hill Book Company, Inc., 1950.
11. Sutermeister, Edwin, *Chemistry of Pulp and Paper Making*. New York: John Wiley & Sons, Inc., 1941.
12. Bjoorn, Erland O. (translated by J. P. Firrell, et al), "Woodpulp, a Technical and Commercial Handbook," Stockholm, Sweden: *The Swedish Timber and Woodpulp Journal*.
13. *The Pulp and Paper Industry in the U.S.A.*, report by a mission of European experts, Chateau de la Nuette, Paris: Organization for European Economic Cooperation, 1951.
14. American Pulp and Paper Association Reports 1949 through 1955, New York: Committee on Coordination of Research.
15. Mussey, Orville D., *Water Requirements of the Pulp and Paper Industry*, Geological Survey Water Supply Paper 1330-A, Washington, D. C.: U. S. Government Printing Office, 1955.
16. Gehm, H. W. and Moggio, W. A., "Conservation of Water in Kraft Pulp Industry." *Tappi 37*: 3, (1954).
17. Amberg, H. R., "Reuse of Water in Pulp and Paper Mills." *Tappi 38*: 11 (1955).
18. Gaudy, A. F., *Limitations Imposed on Industry on Basis of Water Supply*, Proc. 8th Annual Pacific Northwest Industrial Waste Conference, Wash. State Inst. of Technology, Pullman, Washington, 1957.

AVAILABILITY OF WATER

19. California State Water Resources Board, "Water Resources of California," Bulletin No. 1, 1951.
20. California State Water Resources Board, "Water Utilization and Requirements of California," Bulletin No. 2, 1955.
21. California State Department of Water Resources, "The California Water Plan," Bulletin No. 3, 1957.
22. California Department of Public Works, Division of Water Resources "Report of Sacramento-San Joaquin Water Supervision," 1946 through 1954 (9 volumes).
23. Rantz, S. E., "Surface-Water Hydrology of Coastal Basins of Northern California," United States Department of the Interior, Geological Survey, Water Resources Division, 1954.
24. United States Department of the Interior, "Surface Water Supply of the United States, Part II, Pacific Slope Basins in California," 1910 through 1954 (43 volumes).

WASTES FROM PULP AND PAPER PROCESSES

25. Phelps, E. B., *Stream Sanitation*, New York: John Wiley & Sons, 1944.
26. Gehm, H. W., "Pulp Paper and Paper Board Wastes," *Industrial Wastes*, by William Rudolfs, New York: Reinhold Publishing Corporation, 1953.
27. Haydu, E. P., Amberg, H. R., and Dimick, R. E., "The Effect of Kraft Mill Waste Components on Certain Salmonoid Fishes of the Pacific Northwest," *Tappi 35*: 12, (1952).
28. Van Horn, W. M., Anderson, J. B., and Katz, M., Trans. Am. Fisheries Society, p. 55, 1949.
29. Van Horn, W. M., National Council for Stream Improvement Technical Bulletin No. 16, 1948.
30. National Council for Stream Improvement, "The Effects of Kraft Mill Waste Liquors and Some of Their Components on Certain Salmonoid Fishes of the Pacific Northwest," Technical Bulletin 51.
31. State of Washington Dept. of Fisheries, "The Toxic Effect of Sulfite Waste Liquor on Young Salmon," Research Bulletin No. 1, December 1953.
32. *Water Quality Criteria*, SWPCB publication No. 3, State of California.
33. Curtis, Max L., "Methods and Results of Kraft Mill Sodium Balance," *Tappi 37*: 10, p. 187A.

POLLUTION CONTROL AND BENEFICIAL USE OF WATER

34. Dickey Water Pollution Act, (Chapter 1549, Statutes of California (1949) (Division 7 of the Water Code of California)
35. Department of Water Resources, "Quality of Surface Waters in California," Water Quality Investigations Report No. 15 (1951-1954)

ASSIMILATIVE CAPACITY OF RECEIVING WATERS

36. Fair, G. M. and Geyer, J. C., *Water Supply and Waste Water Disposal*, 1st Ed., John Wiley and Sons (1954).
37. Orlob, G. T., Anderson, M. D., and Hansen, D. L., "An Investigation of Pollution of Port Gardner Bay and the Lower Snohomish River," Washington Pollution Control Comm. Tech. Bulletin No. 3 (1949)
38. Van Horn, W. M., Anderson, J. B., and Katz, M., "The Effect of Kraft Pulp Mill Wastes on Fish Life," *Tappi 33*: 5, pp. 209-212, May 1950.
39. Orlob, G. T. and Butler, R. G., "Use of Soil Lysimeters in Waste Water Reclamation Studies," ASCE Proc., Sep. 1002, June 1956.
40. Schiff, Leonard, "Some Developments in Water Spreading," Prov. Rep. Soil Conservation Service U.S.D.A., 45 pp., Nov. 1953.
41. Ketchum, B. H. "The Flushing of Tidal Estuaries," *S&IW 23*: 2, pp. 198-207, Disc. 208-209, February 1951.
42. Stommel, Henry "Computation of Pollution in a Vertically Mixed Estuary," *S&IW*, 25: 9, pp. 1065-1071, September 1953.
43. Eriksen, A. and Townsend, L. D., "The Occurrence and Cause of Pollution in Grays Harbor," Washington Pollution Control Commission, Pollution Series Bulletin No. 2, June 1940.
44. Sylvester, R. O., "Pulp Mill Location Study in Regard to Water Pollution," *S&IW*, *24*: 4, pp. 508-521, April 1952.
45. Orlob, G. T., "Kraft Mill Waste Disposal Problem on the Snohomish River," Washington Pollution Control Commission Special Report, January 1952.
46. Tully, J. P., Hollister, H. J., Fjarlie, R., and Anderson, W., "A Working Model of a Tidal Estuary" (An unpublished report cited by R. G. Tyler), *S&IW*, *22*: 5, pp. 685-698, May 1950.
47. Bialkowsky, H. W. and Billington, P. S., "Pilot Studies to Predict Effects of Waste on Receiving Waters," *S&IW*, *29*: 5, pp. 551-569, May 1957.

48. Eldridge, E. F. and Orlob, G. T., "Investigation of Pollution of Port Gardner Bay and the Snohomish River Estuary," *S&IW*, *23:* 6, pp. 782-795.
49. Orlob, G. T. and Eldridge, E. F., "Deep Water Disposal of Pulp Mill Wastes," *S&IW*, *26:* 4, pp. 520-530, April 1954.
50. McMillin, H. S., U. S. Bureau of Fisheries, Bulletin No. 48 (1932)
51. McMillin, H. S., Galtsoff, Paul S., and Hopkins, A. E., Department of Commerce Bulletin No. 6 (1931)
52. Washington State Department of Fisheries Biological Report No. 49A (1949)
53. Neale, A. T., "Pulp and Paper Mill Waste Disposal Problems," Washington Pollution Control Commission Technical Bulletin No. 19 (1955)
54. Pearson, E. A., "An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge," California State Water Pollution Control Board. Pub. No. 14 (1956)
55. Ekman, V. W. "Om jurdrotationens enverkan pa vindstrommar i hafvet" Nyt. Mag. f. Naturvid Vol. 40 (1902)
56. Shepard, F. P., and Inman, D. L., "Nearshore Circulation," Proc. First Conf. on Coastal Engineering, Univ. of Calif. (1951)
57. University of California Sanitary Engineering Research Laboratory, "Studies in Water Reclamation," Bulletin 13 IER Series 37, 1955.
58. Clendenen, F. B., "A Comprehensive Plan for the Utilization of a Surface Reservoir with Underground Storage for Basin-Wide Water Supply Development: Solano Project, California," Thesis, D. Eng. Univ. of Calif. (1954)

printed in CALIFORNIA STATE PRINTING OFFICE

70277 2-58 1M

STATE OF CALIFORNIA

REGIONAL WATER POLLUTION CONTROL BOARDS

NORTH COASTAL REGIONAL WATER POLLUTION CONTROL BOARD (NO. 1)
1739 Fourth Street, Santa Rosa (P. O. Box 1436)

SAN FRANCISCO BAY REGIONAL WATER POLLUTION CONTROL BOARD (NO. 2)
1212 Broadway, Oakland 12

CENTRAL COASTAL REGIONAL WATER POLLUTION CONTROL BOARD (NO. 3)
1108 Garden Street, San Luis Obispo

LOS ANGELES REGIONAL WATER POLLUTION CONTROL BOARD (NO. 4)
Spring-Arcade Building, 541 South Spring Street, Los Angeles 13

CENTRAL VALLEY REGIONAL WATER POLLUTION CONTROL BOARD (NO. 5)
608 Thirteenth Street, Sacramento 14

LAHONTAN REGIONAL WATER POLLUTION CONTROL BOARD (NO. 6)
407 West Line Street, Bishop

COLORADO RIVER BASIN REGIONAL WATER POLLUTION CONTROL BOARD (NO. 7)
82-380 Miles Avenue, Indio (P. O. Box 277)

SANTA ANA REGIONAL WATER POLLUTION CONTROL BOARD (NO. 8)
3691 Main Street, Riverside

SAN DIEGO REGIONAL WATER POLLUTION CONTROL BOARD (NO. 9)
3441 University Avenue, San Diego 4