

# WATERWAY ENGINEERING

---

OTTO FRANZIUS

# **WATERWAY ENGINEERING**

**A TEXT AND HANDBOOK TREATING OF THE DESIGN  
CONSTRUCTION, AND MAINTENANCE OF  
NAVIGABLE WATERWAYS**

BY

**Dr.-Ing. e. h. OTTO FRANZIUS**

*Professor of Hydraulic Engineering at the Technical University  
of Hanover, Germany*

TRANSLATED BY

**LORENZ G. STRAUB, M. S., Ph.D., C. E.**

*First Freeman Traveling Fellow of the American Society of Civil Engineers  
Professor of Hydraulics at the University of Minnesota*

**THE TECHNOLOGY PRESS  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
CAMBRIDGE**

**1936**

COPYRIGHT, 1936  
BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

*All rights reserved. This book, or parts thereof,  
may not be reproduced in any form without  
permission of the publishers.*

First Published in Germany in 1927

By JULIUS SPRINGER, BERLIN  
under the title

DER VERKEHRSWASSERBAU

PRINTED IN THE UNITED STATES OF AMERICA  
BY THE MURRAY PRINTING COMPANY  
CAMBRIDGE, MASS.

## TRANSLATOR'S PREFACE

**A**LTHOUGH no political barriers are recognized in the engineering sciences, there are real or fancied obstacles which prevent the dissemination of knowledge to the busy designing engineer. One of the common barriers involves the differences in language. Every generation finds each outstanding civilized nation producing a number of individuals who might be called geniuses; and for the most part, the thought of these men is directed along the great scientific and social problems of the nation. Hence, the genius of one country may follow along entirely different lines of endeavor from that of another. America's expansive territory and its business enterprise made paramount the development of transportation and communication, resulting in a communication network far surpassing all others of the world. Until quite recently, however, this country has been comparatively little concerned with river regulation problems and in providing transportation facilities over its huge unimproved system of natural waterways; their rectification and regulation were considered unnecessary. The public now recognizes a great natural resource in its undeveloped system of water routes. As an indirect consequence thereof, many ingenious methods of regulation have of late been developed in America. This country is now on the threshold of what promises to be the greatest era of river regulation in history.

Europe, because of the density of its population, was forced to consider the matter of river regulation seriously several decades ago. Thus Germany began a systematic scheme of river improvement about the middle of the past century and has all but completed this work; she is now concerned chiefly with the *maintenance of river control structures* and in providing artificial connecting canals to link together the already improved natural system of waterways. It is only reasonable, therefore, to presume that a definite technique of river regulation has been evolved and that the methods used abroad are bound to include valuable suggestions for the American engineer. There is no intention or desire on the part of the writer to transplant German methods of river regulation in America, but rather to disseminate some of the knowledge of over a century's accumulation in a country where the improvement of waterways has been a paramount issue.

John R. Freeman, a foremost American hydraulic engineer, in consequence of his broad acquaintance and frequent contact with foreign

engineers, recognized the great value that might accrue to the profession by an exchange of thought. In his visits abroad he found that the application of experimental hydraulics to practical design had produced astounding results in facilitating and bettering the designs of hydraulic structures. With the desire of effecting this exchange of thought of Americans with foreign hydraulic engineers, he presented funds to three leading engineering societies (American Society of Civil Engineers, American Society of Mechanical Engineers, and Boston Society of Civil Engineers), the interest on which is to provide young hydraulic engineers with scholarship stipends for study and research abroad, and foster the diffusion of foreign knowledge of hydraulics in this country. Besides these funds, Dr. Freeman provided additional financial support to accelerate the realization of his plan of returning something for the advancement of the profession (hydraulic engineering) of which he was a member. The translation of this treatise from the German was thus conceived by Mr. Freeman and undertaken by the writer with the hope of bringing to light otherwise more or less inaccessible information concerning foreign practice in the design, construction, and maintenance of navigable waterways.

There are a number of excellent German books on applied hydraulics; this one was chosen largely because of its recent date of publication and the scope of its subject matter. It is to be hoped that other notable foreign writings in hydraulics will be published in English so as to be readily accessible to American hydraulic engineers.

An earnest effort has been made in the translation to retain the original viewpoint of the author. As is to be expected in any subject which borders on both art and science, diversities of opinion are bound to exist. All German hydraulic engineers do not agree with the author in all matters presented in this book; nor is it to be expected that all Americans in the profession will agree with him verbatim. This should not detract from the treatise; it is simply inherent in the subject. In places where it was deemed especially advisable the writer has provided explanatory notes calling attention to characteristic individualities.

Although the entire book of over eight hundred pages was translated into English and edited, after careful consideration of the subject matter it was decided to print only those parts which provide information not readily accessible to American engineers. In this way it was possible to present the salient information at a reasonable cost of publication, and lower selling price of the book, and at the same time avoid further duplication of material available in American treatises. The omissions in all cases consisted of entire chapters, including Parts I, II, VII, VIII, and XI. Part I of the German edition, entitled "Shipping — Its Nature

and Its Significance," contains nothing new or unavailable to American engineers. Part II, entitled "Water," treats of the general field of hydrology — a subject that already has been well developed in such books as "Hydrology" by D. W. Mead, "Elements of Hydrology" by A. F. Meyer, and "Stream Gaging" by W. A. Liddell. Part VII, "Dams," contains material which has been well treated in "The Design and Construction of Dams" by Edward Wegman. The subject matter of Part VIII, "Water Power Plants," is covered quite thoroughly by "Water Power Engineering" by D. W. Mead, "Water Power Engineering" by H. K. Barrows, and similar treatises. Part XI, entitled "Ports," is well treated by such books as "Port Development" and "Ports and Terminal Facilities," both by R. S. MacElwee.

The elimination of these chapters from the English edition does not greatly affect the unity or coherence of the subject matter inasmuch as virtually nothing has been omitted from the original treatment which concerns the construction and improvement of navigable waterways, with the exception of the development of port facilities. The latter forms an independent subject in itself.

The writer wishes to express his gratitude to all who have had a part in assisting with the presentation of this book in the English. He is especially indebted to the late Dr. John R. Freeman who, as founder of a group of fellowships for the study of hydraulic practice abroad, made it possible for the writer to spend two years in Europe where he could become familiar with foreign practice and German technical terms in hydraulic engineering, thus facilitating translation of the treatise; also for Mr. Freeman's complete financial support and sustained personal interest in this undertaking. The writer also wishes to express his appreciation to Mr. J. Rhyne Killian, Jr., Editor of the *Technology Review*, for his work in reviewing the entire treatise and for his valuable suggestions, constructive criticism, and close coöperation with the writer in the production of the English edition of this book.

L. G. S.

Minneapolis, Minn.

## AUTHOR'S PREFACE

**T**HIS treatise is intended to provide the designing and construction engineer with a condensed presentation of present-day knowledge of waterway engineering. It is not a book on transportation but rather one on that phase of hydraulics which serves transportation. The book is intended to be scientific, not in the sense that all theories are presented, but rather in the sense that the plausibility of various statements is critically analyzed. Antiquated methods have not been entirely disregarded because, according to experience, the antiquated methods of today may frequently be re-evaluated by ingenious changes. The older procedures, however, have been treated very lightly and in some cases have only been mentioned. The sources of information from which further data may be obtained have been indicated by footnotes. Inasmuch as the treatise is intended particularly for practical purposes, the development of the theories has been confined to a minimum space. It seemed more useful to present the theory in a condensed but well-analyzed form than to give extended developments thereof. In many cases new presentations or conceptions have been discussed. Thus, for example, the tables of water velocities have been presented in a different way than has been customary heretofore; methods of computation for shore walls, locks, lock gates, etc., were presented in a newer form.

The treatise is limited to the subject matter of waterway engineering, a profession which I have pursued in practice for twenty-five years and as a teacher for thirteen years. The treatment of questions of land reclamation as related to hydraulics has been avoided as far as possible. Discussion of the occurrence and movement of water has been condensed, the necessary practical information being emphasized. The book is not intended as a treatise for advanced training, but rather as an aid to the scientifically minded, practical engineer. In order to save space and maintain a systematic presentation, it was necessary to treat the more theoretical questions as a group; thus, for example, all questions concerning the occurrence and movement of water, regardless of whether river or ocean was concerned, were treated together. Locks of all types, canals, harbors, etc., have been discussed in individual sections, but have not been segregated according to divisions of river works, sea works, etc.

In the presentation of this treatise I especially acknowledge the valuable coöperation of my former assistant, Dr.-Ing. F. Collorio, and my

present assistant, Dipl.-Ing. Heinze. The former prepared most of the drawings, numerical tables, part of the data; the latter read proof with particular care. Furthermore, my assistant, Dr.-Ing. A. Streck, contributed materially to the book. All of these men have also aided greatly by a critical examination of the subject matter. Many firms and engineers have provided me with valuable drawings and discussions. Thanks are again expressed to all of these at this time. I want to especially acknowledge the coöperation of the publisher [of the German edition], Julius Springer, and thank him for his fine make-up of this book.

O. FRANZIUS.

Hanover, September 1927.



# TABLE OF CONTENTS

## PART ONE RIVER CONTROL

	PAGE
A. GENERAL.....	1
B. PRINCIPLES OF ECONOMIC REGULATION OF RIVER SOURCES.....	10
a. Influence of Forest and Agricultural Land upon Run-off.....	10
b. Natural and Artificial Means of Retarding Flow (Regulating Dams, Marshes, Glaciers, Natural Lakes, etc.).....	11
c. Obstruction of Torrential Streams.....	13
C. REGULATION OF UNNAVIGABLE RIVERS.....	18
D. REGULATION OF NAVIGABLE RIVERS.....	25
E. VARIOUS CONSTRUCTION METHODS: CUT-OFFS; RIVER FORKS; MOUTHS OF TRIBUTARY RIVERS; RAPIDS.....	35
a. Cut-offs.....	35
b. River Forks.....	37
c. Mouths of Tributary Rivers.....	40
d. Rapids.....	41
F. MATERIALS AND TYPES OF STRUCTURES USED IN RIVER REGULATION.....	43
a. Materials.....	43
b. Construction with Fascines.....	44
c. Wattlework.....	44
d. Dip-Layers.....	45
e. Dip-Trees, etc.....	46
G. TYPES AND METHODS OF CONSTRUCTION OF REGULATING WORKS ...	47
a. General.....	47
b. Groins.....	48
1. Purpose and Action.....	48
2. Construction of Groins.....	51
3. Construction of Sills.....	53
c. Parallel Works.....	54
1. General.....	54
2. Construction of Parallel Works.....	55
d. Movable Restriction Works.....	57
e. Shore and Bed Covering.....	59
f. Evaluation of Individual Construction Methods, Particularly Comparisons between Groins and Parallel Works.....	60

## PART TWO

## RIVER MOUTHS AND THEIR TREATMENT

	PAGE
A. GENERAL . . . . .	62
<i>a.</i> Purpose of the Correction of River Mouths . . . . .	62
<i>b.</i> Concept and Classification of River Mouths . . . . .	63
B. MOUTHS SUBJECT TO WEAK TIDES . . . . .	65
<i>a.</i> Relations of Current . . . . .	65
<i>b.</i> Correction of Direct Mouths Subject to Weak Tides . . . . .	67
<i>c.</i> Examples of Correction of Direct Mouths . . . . .	70
1. The Danube Mouth . . . . .	70
2. The Vistula Mouth . . . . .	72
<i>d.</i> Correction of Indirect Mouths . . . . .	78
C. MOUTHS WITH STRONG TIDES . . . . .	81
<i>a.</i> Behavior of Tidal Waves in Rivers . . . . .	81
<i>b.</i> High-Water and Low-Water Lines . . . . .	85
<i>c.</i> Action of Variations in Water Stage upon the River and Sea . . . .	87
<i>d.</i> Determination of Water Quantities . . . . .	88
<i>e.</i> The River Bed and the Means of Correction in the Lower Course . .	92
<i>f.</i> Examples of the Correction of Lower Courses of Tidal Rivers . . .	96
1. The Clyde . . . . .	96
2. The Seine . . . . .	98
3. The Weser . . . . .	102
<i>g.</i> The Outer Mouth District . . . . .	113

## PART THREE

EFFECT OF THE SEA ON THE COASTS; SEASHORE DEVELOPMENT;  
LEVEE CONSTRUCTION

A. NATURAL CHANGES IN THE SHORE . . . . .	120
<i>a.</i> Cause of Changes . . . . .	120
<i>b.</i> Steep Shores . . . . .	122
<i>c.</i> Flat Shores; Reefs; and Dunes . . . . .	123
<i>d.</i> Dune Protection and Culture . . . . .	125
<i>e.</i> Bays and Islands . . . . .	127
1. Bays . . . . .	127
2. Islands . . . . .	128
B. ARTIFICIAL ALTERATIONS OF SHORES . . . . .	131
<i>a.</i> General Considerations with Reference to Protection of Shores against the Attack of Water . . . . .	131
<i>b.</i> Adjacent Protection Works . . . . .	132
<i>c.</i> Protruding Protection Works . . . . .	137
C. MARSHES AND LEVEES . . . . .	142
<i>a.</i> The Arising and Cultivation of Marshes . . . . .	142

# TABLE OF CONTENTS

xi

	PAGE
<i>b.</i> Levees.....	145
1. Purpose and Classification of Levees.....	145
2. Position, Cross-Section, and Height of Sea Levees.....	149
3. Position, Cross-Section, and Height of River Levees.....	152
4. Material and Construction of Levees.....	154
5. Maintenance and Protection of Levees.....	158
6. Levee Ramps and Thoroughfares.....	162
7. Levee Locks; Sluices; and Siphons.....	163
<i>a.</i> Determination of Dimensions for Sluices.....	163
<i>β.</i> Construction of Sluices and Sluice Siphons.....	168

## PART FOUR

### WEIRS

<b>A. GENERAL.....</b>	<b>175</b>
<i>a.</i> Definitions.....	175
<i>b.</i> Purpose and Classification of Weirs.....	176
<i>c.</i> The Weir According to the Prussian Water Law.....	177
<i>d.</i> Discharge at Weirs; Effects above and below Weir; Buoyancy....	178
<i>e.</i> Location of Weirs.....	181
<b>B. FIXED WEIRS.....</b>	<b>182</b>
<i>a.</i> General.....	182
<i>b.</i> Rock-Fill Weirs.....	183
<i>c.</i> Mass-Masonry Weirs.....	184
<i>d.</i> Weirs Constructed of Sheet Piling; Hollow Structures with and without Fill.....	188
<b>C. MOVABLE WEIRS AND SIPHONS.....</b>	<b>193</b>
<i>a.</i> Classification.....	193
<i>b.</i> Bar Weirs.....	195
1. Stop-Log Weirs.....	195
2. Needle Weirs.....	196
<i>a.</i> Development of Needles.....	196
<i>β.</i> Movable Needle-Weir Trusses.....	199
3. Curtain Weirs.....	201
<i>c.</i> Gate Weirs.....	202
1. Trap Weirs.....	202
<i>a.</i> Trap Weirs which are Laid over by Headwater Pressure but are Raised Mechanically.....	202
<i>β.</i> Weir Traps which are Opened by Water Pressure and Closed by Counterweights.....	203
<i>γ.</i> Weir Traps which Operate Entirely Hydraulically.....	206
2. Sluice Weirs.....	210
<i>a.</i> Simple Sluice Weirs for Mill Channels and the Like.....	210
<i>β.</i> Newer Weirs with Movable Intermediate Supports.....	212
<i>γ.</i> Newer Weirs without Movable Intermediate Supports....	215

	PAGE
<i>d.</i> Cylindrical Weirs . . . . .	224
1. Segment Weirs . . . . .	224
2. Sector Weirs . . . . .	229
3. Roller or Cylinder Weirs . . . . .	234
<i>e.</i> Siphon Spillways and the Like . . . . .	240
<i>f.</i> Construction of Weirs . . . . .	241
<i>g.</i> Fish Passes and Fishways . . . . .	244
<i>h.</i> Comparison of Various Types of Weirs . . . . .	250

## PART FIVE

### SHIP LOCKS

A. GENERAL AND HISTORICAL . . . . .	251
<i>a.</i> Definition . . . . .	251
<i>b.</i> Historical . . . . .	251
B. CLASSIFICATION OF LOCKS . . . . .	255
<i>a.</i> Simple Locks . . . . .	255
<i>b.</i> Chamber Locks . . . . .	256
<i>c.</i> Double Locks and Train Locks . . . . .	258
<i>d.</i> Multiple Locks, Flights, Mechanical Lifts, etc. . . . .	260
C. LOCATION AND DIMENSIONS OF LOCKS . . . . .	261
<i>a.</i> The Location of Locks . . . . .	261
<i>b.</i> Dimensions of Locks . . . . .	263
D. DESIGN COMPUTATIONS FOR LOCKS AND DOCKS . . . . .	265
<i>a.</i> Magnitude of Operative Forces . . . . .	265
<i>b.</i> Distribution of Counterpressure on the Base of a Lock . . . . .	268
<i>c.</i> The Effect of the Inside Water Pressure upon the Bending Diagram . . . . .	270
<i>d.</i> Calculation of Maximum Floor Stresses . . . . .	275
<i>e.</i> Detail Computations . . . . .	278
E. EQUIPMENT FOR FILLING AND EMPTYING . . . . .	279
<i>a.</i> Various Arrangements for Filling and Emptying Locks . . . . .	279
<i>b.</i> The Time Necessary for Filling and Emptying . . . . .	284
F. CONSTRUCTION OF FLOORS, WALLS, SILLS, ETC. . . . .	286
<i>a.</i> Floors and Sheet Piling . . . . .	286
<i>b.</i> Construction of the Bays of Locks . . . . .	287
<i>c.</i> Construction of Lock Chambers . . . . .	290
G. LOCK GATES . . . . .	297
<i>a.</i> General . . . . .	297
<i>b.</i> Mitering Gates . . . . .	297
1. Strain of Walls, Inclination of Sill, etc. . . . .	297
2. Stressed Condition of Gate Leaves while Mitering . . . . .	301
3. Action of Mitering Gates during Suspension; Insertion of Air Chambers . . . . .	303
4. Heights of Gates; Protective Measures against Tidal Floods . . . . .	303

# TABLE OF CONTENTS

xiii

	PAGE
5. Post Gates or Girder Gates; Construction Procedure.....	305
6. Various Types of Bearings; Anchorage.....	308
7. Operation Appliances for Mitring Gates.....	313
a. Resistance to Movement.....	313
β. The Various Kinds of Gate-Operating Installations for Mitring Gates.....	314
c. Tumble Gates.....	322
1. Tumble Gates with Horizontal Axes.....	322
2. Tumble Gates with Vertical Axes.....	326
d. Segment Gates, Lift Gates, and Cylinder Gates.....	327
1. General.....	327
2. Segment Gates.....	327
3. Lift Gates.....	328
4. Cylinder Gates.....	329
e. Pontoons.....	330
1. Floating Pontoons.....	330
2. Sliding and Rolling Pontoons.....	331
3. Types of Pontoon Structures.....	332
a. Steel Pontoons.....	332
β. Roller Installations.....	337
γ. Operating Appliances.....	338
δ. Comparison of Mitring Gates and Sliding Gates.....	339
f. Special Construction Types.....	340
1. Hotopp Tumble Gate.....	340
2. Fan Gates.....	340
3. Sector Gates.....	341
4. Bascule Gates.....	343
g. Size of Operating Machines.....	343
H. SLUICES AND VALVES FOR FILLING AND EMPTYING LOCKS.....	343
a. General; Classification of Valves; Valve Shafts.....	343
b. Sluice Valves.....	345
c. Segment Valves.....	350
d. Cylinder Valves.....	350
1. High Cylinder Valves (Pipe Sluices).....	350
2. Single and Multiple Cylinder-Valves.....	352
e. Siphon Closures; Hydraulic Closures.....	357
1. The Hotopp Siphon.....	357
2. Proetel Type of Air Closure.....	358
f. Older Valve Systems.....	360
1. Butterfly Valves.....	360
2. Register Valves.....	361
g. Size of Operating Machinery.....	362
I. SYSTEMS FOR REDUCING WATER CONSUMPTION.....	362
a. General.....	362
b. Computation of Water Consumption in Thrift Locks.....	364
c. Newer Lock Systems.....	369
1. By-Pass Flights.....	369
2. Proetel Storage Locks.....	372

	PAGE
<i>d.</i> The Design of Thrift Locks . . . . .	374
<i>e.</i> Locks Requiring No Water Consumption . . . . .	379
1. Introduction . . . . .	379
2. Proetel Displacement Lock . . . . .	379
3. Proetel Float Locks Operated by Compressed Air . . . . .	383
<b>J. INCLINED PLANES AND MECHANICAL LIFTS . . . . .</b>	<b>386</b>
<i>a.</i> Inclined Planes . . . . .	386
1. General . . . . .	386
2. Longitudinally Inclined Planes . . . . .	387
3. Transversely Inclined Planes . . . . .	389
<i>b.</i> Vertical Lifts . . . . .	392
1. General . . . . .	392
2. Hydraulic Lifts . . . . .	393
3. Float-Actuated Lifts . . . . .	394
<i>a.</i> Lifts with Vertical Floats . . . . .	394
<i>β.</i> Lifts with Horizontal Floats . . . . .	400
<i>γ.</i> Diving Locks . . . . .	401
4. Mechanical Lifts with Counterpoises . . . . .	402
5. Drum Lifts . . . . .	405
<i>c.</i> A Comparison of Inclined Planes and Lifts, and a Comparison of These with Shaft Locks . . . . .	406
<b>K. FORE HARBORS; EQUIPPING AND OPERATION OF LOCKS . . . . .</b>	<b>406</b>
<i>a.</i> Location of Fore Harbors . . . . .	406
<i>b.</i> The Equipping of Locks . . . . .	407
<i>c.</i> Lock Operation and Maintenance . . . . .	409
1. Lock Operation . . . . .	409
2. Maintenance . . . . .	410

## PART SIX

## ARTIFICIAL WATERWAYS

<b>A. GENERAL . . . . .</b>	<b>411</b>
<i>a.</i> Classification and Purpose of Artificial Waterways . . . . .	411
<i>b.</i> Sea and Inland Ships . . . . .	413
<i>c.</i> Ship Resistance . . . . .	416
1. Influence of the Form of Cross-Section on the Resistance . . . . .	416
2. Magnitude of Ship Resistance . . . . .	420
<i>d.</i> Navigation Methods . . . . .	428
1. General; Drifting and Sailing . . . . .	428
2. Towing . . . . .	428
3. Towing Ships by Steamboat . . . . .	430
<i>e.</i> Computation of Freight Costs on Inland Waterways . . . . .	432
1. Ship Costs . . . . .	432
2. Navigation Tolls and Towing Costs . . . . .	436
3. Miscellaneous Costs . . . . .	437
<b>B. DEVELOPMENT OF BEDS FOR CANALIZED RIVERS AND INLAND CANALS . . . . .</b>	<b>439</b>
<i>a.</i> Shape of Cross-Section . . . . .	439
1. Canalized Rivers and Power Canals . . . . .	439
2. Canal Cross-Sections . . . . .	441

	PAGE
<i>b.</i> Bed Development and Shore Stabilization.....	446
1. Bed Development; Revetment; Concrete and Clay Water-proofing.....	446
2. Stabilization of the Canal Shore.....	451
3. Canal Location.....	453
<i>C.</i> WATER CONSUMPTION; SUPPLY AND DISCHARGE OF ARTIFICIAL WATERWAYS.....	461
<i>a.</i> Water Consumption.....	461
1. Evaporation and Seepage.....	461
2. Lock Losses.....	463
<i>b.</i> Relief Arrangements.....	471
<i>D.</i> SPECIAL CANAL STRUCTURES.....	471
<i>a.</i> Lock Entrances, Shunting Places, Turning Places, Guide Works, Dolphins, and Mooring Posts.....	471
<i>b.</i> Culverts and Inverted Siphons.....	472
<i>c.</i> Emergency Gates.....	476
<i>d.</i> Highway, Railroad, and Canal Bridges.....	476
1. Highway and Railroad Bridges.....	476
2. Canal Bridges.....	477
<i>e.</i> Canal Tunnels.....	480
<i>E.</i> EXAMPLES OF IMPORTANT WATERWAYS.....	480
<i>a.</i> Inland Canals and Canalized Rivers.....	480
1. General.....	480
2. The Midland Canal Project.....	481
3. Coastal Canal, Hansa Canal, and the North-South Canal.....	486
<i>a.</i> The Coastal Canal and the Hansa Canal.....	486
<i>β.</i> The North-South Canal.....	488
4. The Weser Canalization and the Weser-Main Canal.....	490
5. Development of the Rhine.....	491
6. The Rhine-Maas-Schelde Canal and the Aachen-Rhine Canal.....	493
7. Canal Plans for Southern Germany.....	495
<i>a.</i> Danube-Main Canal.....	495
<i>β.</i> The Danube-Neckar-Lake Constance Waterway.....	497
8. Connection of the Elbe and the Oder with the Danube.....	498
9. Further German Canal Plans.....	499
10. The Merwede Canal of Holland.....	501
<i>b.</i> Sea Canals.....	504
1. Open Sea-Level Canals.....	504
<i>a.</i> Suez Canal.....	504
<i>β.</i> Königsberg Sea Canal.....	506
<i>γ.</i> Other Open Canals.....	506
2. Closed Sea-Level Canals (North-Baltic Sea).....	506
3. Sea Canals with Variously Elevated Pools.....	509
<i>a.</i> The Manchester Sea Canal.....	509
<i>β.</i> The Panama Canal.....	512

# WATERWAY ENGINEERING

## PART ONE — RIVER CONTROL

### A. GENERAL

**T**WO entirely different problems must be dealt with in river control. One consists in attaining a good discharge, in which detritus movement is of interest only insofar as it affects the water movement. This condition must be brought about in cases where the combined interests of agriculture, power development, and city planning are of prime importance, but where large depth for navigation is unimportant.

The second problem is that of developing the greatest possible uniform depth in rivers, and necessitates a well-regulated detritus movement especially at LW and MW stages. For this purpose the scouring capacity of the river is extremely important, the movement of the water being of interest only insofar as it is the cause of scouring capacity. We are not concerned with a uniform movement of water but with equalization of detritus movement. Because of the lack of uniformity in various river sections, *this is possible only with variation of water movement*, and, therefore, with corresponding variation in the gradient. The development of uniform detritus movement is particularly important in streams where depth is the chief characteristic of the river; that is, in navigable streams.

Every natural river forms bends. Erosion takes place at the concave side of the bend. At the convex side, sand banks form because of the low scouring force. Submerged bar formations occur in the transitions. There is a medium scouring force at transitions, but it is usually too small to keep the channel deep enough for navigation. In order to effect uniform transportation of sediment the shoals must be deepened at the cost of the depth of the pools; that is, the depth must be made uniform. *The best solution is not obtained by making the gradient uniform, as is frequently still attempted, but by balancing the available scouring forces.* One adjustment, however, must be made in the water movement. This concerns the distribution of velocity in bends. The velocity must be lessened in the deep part of the pool and increased in the remainder of the section.



It can be demonstrated that the transporting force corresponds to the expression<sup>1</sup>  $S = atJ$ . The scouring force possesses a similar value. In spite of the fact that especially great depths occur at the pools, nature has taken care that the value of  $S$  does not become too large, the gradients at bends always being flatter than at transitions. Nevertheless, because of the great depths at bends, the scouring force there is usually much greater than at transitions. If the depth at the transitions could be mechanically increased, the scouring capacity would be augmented, but such a procedure would be of no avail since subsequent HW would again leave shoals. Furthermore, rapid improvement for navigation cannot be accomplished by dredging the sills.

Even good dredging does not alter the requirement that the river must be forced to scour out the shoals of its own accord. This is best accomplished by increasing the gradient over the shoals. Even a small diminution of the gradient in the pools, which are very long, makes possible a substantial increase in gradient at the transitions, because the steep gradient over the shoal begins only a comparatively short distance above the actual shoal crest, just as in the case of weirs. Toward the upstream side, the level of the backwater is affected far up the bend; downstream the steep gradient quickly adjusts itself to the flatter gradient of the following bend. Stretches having a flat gradient are thus very long, while the steep stretches over the shoals are comparatively short. In large rivers with excessive width, the width of the transitions should be narrowed down more substantially than has been done heretofore.

Just as detritus movement is dependent upon the kinetic energy of the water  $mv^2/2$ , resistance to navigation is likewise dependent upon this value. Doubtless an increase in velocity at individual short stretches causes very slight inconvenience which is acceptable to steamship operators if the usable depth of the stream at LW stages can thereby be increased. It is not even necessary to increase the power of the towboats to cope with the increase in gradient at the shoals. The towboats will simply travel somewhat slower at these locations in the case of properly regulated streams, but will be able to travel more rapidly in the bends because here the velocity of flow will be diminished. The total consumption of towing energy for propelling the ship, to be sure, will be slightly raised because of the increased irregularity in velocity of the water; the value of the stream for transportation, on the other hand, will become much greater since considerably heavier loading can be handled than could be otherwise.

<sup>1</sup> In this equation, when expressed in English units,  $S$  is the transporting force in pounds per square foot,  $J$  is the slope of the water surface,  $t$  the depth of the stream in feet, and  $a$  the weight of water in pounds per cubic foot.