Reprint. "Mastering Rivers in the Laboratory" Jan. 1930

Mastering Rivers in the Laboratory

by

JOHN R. FREEMAN

Reprinted from

THE TECHNOLOGY REVIEW

VOLUME XXXII, NUMBER 3 · JANUARY, 1930

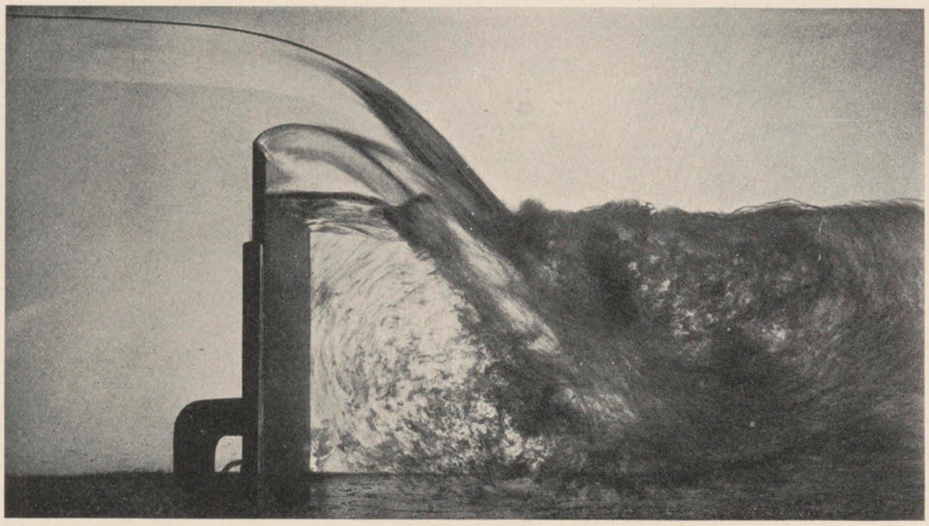
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS

MASTERING RIVERS

Progress in Hydraulic

By John

Illustrated from Photographs



THE RIVER-HYDRAULIC LABORATORY OF THE TECHNICAL UNIVERSITY AT KARLSRUHE, GERMANY. FLOW THROUGH SHARP-CRESTED SUPPRESSED WEIR

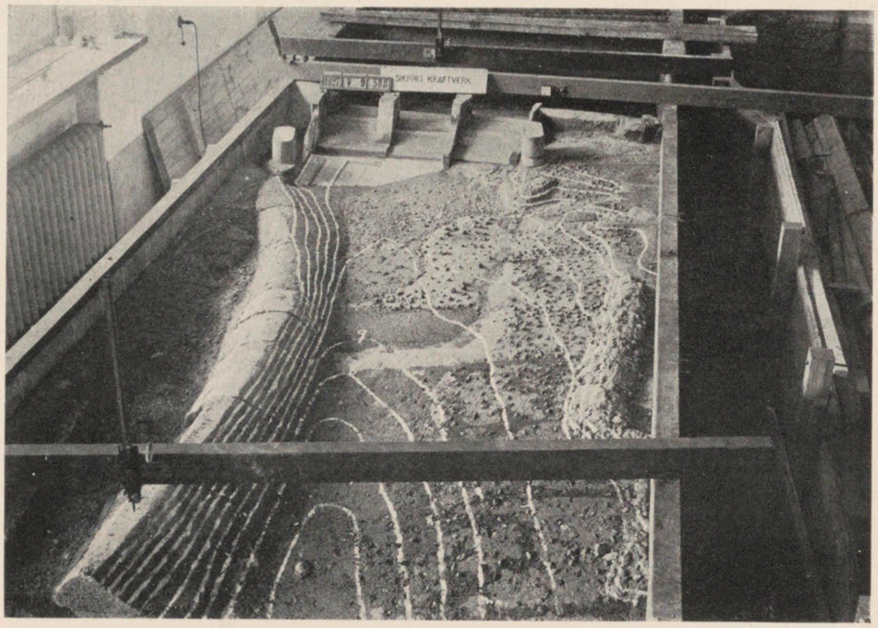
WITHIN the past few years there has been a remarkable advance in the methods of hydraulic experiment based on the Principle of Similitude set forth by the great English natural philosopher, Sir Isaac Newton, in a single paragraph of his monumental treatise, the "Principia," 243 years ago. The practical application of this idea to the flow of water in channels of various forms lay dormant until about 45 years ago, when it was applied to two important practical problems by two eminent English civil engineers. The first of these, Professor Osborne Reynolds of the University of Manchester, about 1885, invoked the Principle of Similitude and the use of scale models in the investigations of water flow of the tidal estuary of the River Mersey at Liverpool. About a year later, Sir William Vernon-Harcourt applied these principles in experimenting upon the improvements for navigation near the mouth of the River Seine in France. It is of interest to note that another great English hydraulician, Professor Gibson of Manchester, England, has recently constructed a new hydraulic laboratory named the "Osborne Reynolds Laboratory," at the University of Manchester, in which by means of a small-scale model he is now making researches relative to the effect of building a great dam across the estuary of the River Severn for the development of power from the flow of the tide.

It is remarkable how long a fruitful idea sometimes lies dormant and then suddenly bursts into great and widespread activity. This was true of the invention of the Mannheim slide rule, which for nearly a century lay dormant and then, suddenly within a decade, this instrument was found on the work table or in the pocket of every progressive engineer.

It was more than 175 years after Newton had stated this Principle of Similitude that the English naval engineer, Froude, applied it to researches for determining the best shape of a ship, by constructing a long narrow tank filled with water and drawing through this various small-scale models of ship-hulls at varying velocities, meanwhile measuring the resistance to traction at the various speeds with skilfully devised apparatus.

Although Froude, by the application of the Doctrine of Similitude to scale models, revolutionized the design of hulls in naval architecture, the complementary process of causing a current of water to flow past a fixed model of a structure proposed to be built within a flowing river or canal, was not actively taken up until another quarter century had passed.

Although Fargue in France, in 1875, was first to experiment with a scale model of a river with a view to learning what would happen in the actual river 100 times as large as the model, and Osborne Reynolds and Vernon



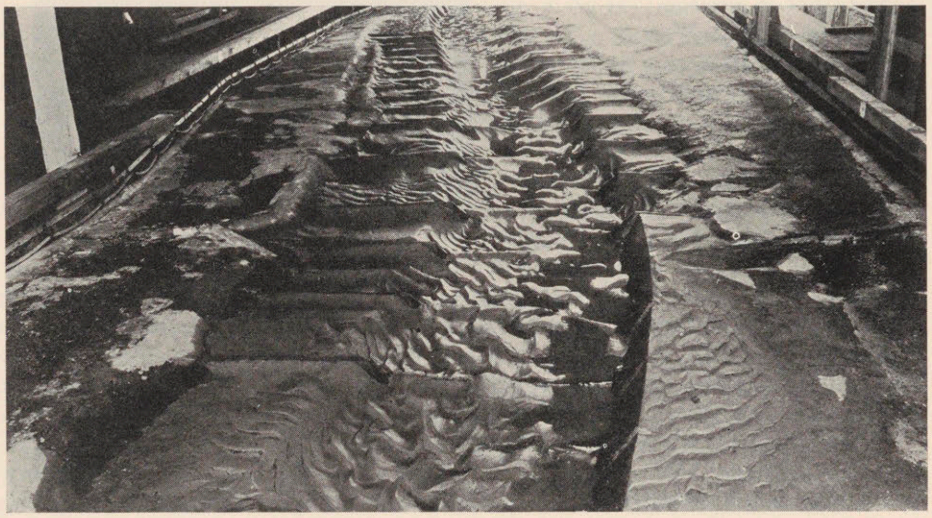
IN THE HYDRAULIC STRUCTURES LABORATORY OF THE ROYAL TECHNICAL UNIVERSITY AT STOCKHOLM, SWEDEN

IN THE LABORATORY

Laboratory Research

R. Freeman

Collected by Kenneth C. Reynolds



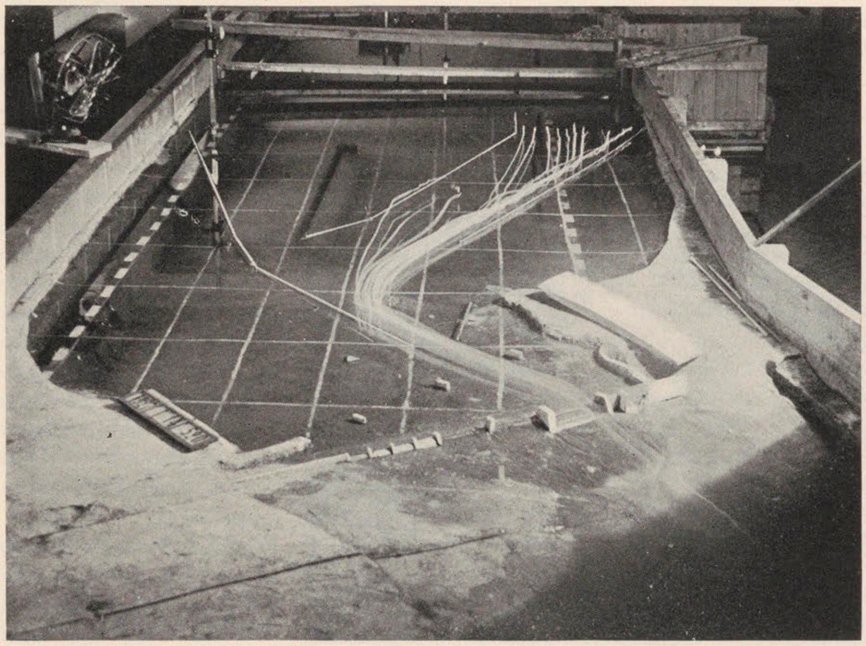
STUDY OF ELBE RIVER (SCALE: 1:200) AT EXPERIMENT INSTITUTE FOR HYDRAULIC ENGINEERING AND SHIPBUILDING IN BERLIN

Harcourt in England had made researches with scale models of river channels, this renaissance appears to have been due chiefly to Dr. Hubert Engels, Professor of Hydraulics at the Technical University of Dresden, Germany, who in 1891 began his hydraulic experiments with models.

His first permanent hydraulic laboratory was built-in in the old building of the Dresden Technical University in 1898. Dr. Engels gradually increased the range of his experiments and rebuilt his laboratory in larger form. The utility of the methods which he introduced quickly attracted the attention of the other German engineering colleges, where new and larger laboratories were built; guided often by the friendly personal counsel of Dr. Engels. The idea spread soon afterward to Austria, to Sweden, to Norway and to Italy, and the mathematical doctrine stated in outline by Newton somewhat obscurely in a single paragraph has been expanded and elaborated to cover a wide range of problems, all the way from water power turbine design to the improvement of harbors. Researches carried on by means of this principle relate to the improvement of both the efficiency and capacity of hydraulic turbines, to finding remedies for the evils of cavitation in turbines, to improvements in efficiency and capacity of centrifugal pumps and propeller pumps; also to improving the designs of spillways for water power dams; to the designing of great sluiceways so as to present a minimum loss of head, and to finding the best means of dissipating energy of flood waters flowing over a high dam and tending to cause disastrous scour in the river bed below the dam.

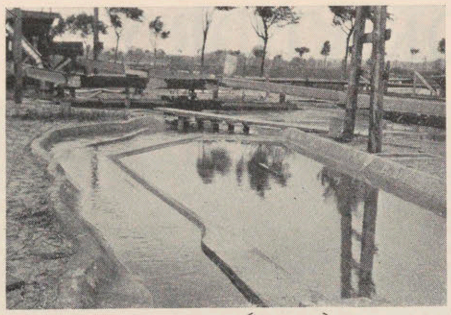
THE utility of the hydraulic laboratory also has been extended to studies of the movement of gravel bars in river channels, to finding the best forms of groins for regulating the course of rivers, and holding them to their proper channels, to the improvement of harbors and navigable rivers by controlling the deposit of sediment brought in by the tide from littoral currents or brought down by the river, and to methods of preventing seacoast erosion, — yet its great service to hydraulic science and to the hydraulic arts has hardly more than begun.

In brief, a new and most valuable lot of tools has been placed in the hands of the hydraulic engineer for solving a great variety of important problems. The working out of the mathematical laws of hydraulic similitude and the expressing of these laws in convenient formulas, makes it possible for the engineer to set up his laboratory apparatus, with great confidence that the behavior of water currents in river, harbor or structures for water power development will be for all practical purposes nearly enough the same as the behavior found in the laboratory model; which may have anywhere



HYDRAULIC STRUCTURES LABORATORY OF ROYAL TECHNICAL UNIVERSITY, STOCKHOLM, SHOWING 1:200 SCALE MODEL OF INDAL RIVER ABOVE HAMMARFORSEN POWER PLANT from one-tenth to one-hundredth part of the linear dimensions of the proposed structure.

Valuable suggestions as to the course of water through a large hydraulic structure can be had by merely watching its course, its eddies, its pulsations, and its deposits of sediment, in a small model, made either true to scale in all linear dimensions, or distorted in relations of width to depth; but if one would get the full benefit of hydraulic experiments made with models one must constantly be guided by the mathematical theories of dynamic and kinematic similarity, and this is the rule of procedure in these modern hydraulic laboratories.



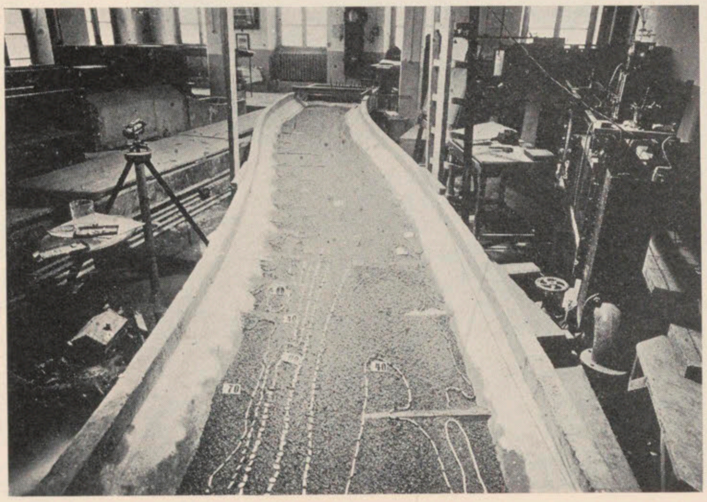
MODEL AT MARQUARDT (BERLIN) OF HENGSTEY SETTLING BASIN ON RUHR RIVER

The laws for governing the relation of dimensions and velocities in models are mostly of a simple form. For one example: The velocity in the model compared with that in nature should be in the proportion of the square root of the model scale, or with a model built to the scale of 1 to 100 the velocity should be 1/10th of that in nature; but this is not the place to discuss these relations at length. They have been worked out for a great variety of conditions and their development is still in progress.

In some cases one must depart from model proportions dictated by theory, particularly when dealing with the movement of sediments, because here the relations may be complicated by effects of surface tension on minute particles, or by skin friction, or by non-turbulent motion of water at low velocities. In many cases of river and harbor research one must have recourse to experiments for finding a sedimentary material of such size of particle and such specific gravity that its general behavior in formation of deposits and erosion cavities in the model will be analogous to that observed in nature in the far larger channel. Also sometimes a distortion of the scale of the depth or width of the model channel becomes useful and results become qualitative rather than quantitative.

In other words, for rivers and harbors, researches upon sedimentation and erosion by means of models must be carried on hand in hand with observations upon the natural river, harbor or other channel which it is desired to improve, and with the aid of varied experiments and matured judgment.

The glass-walled flume and the motion picture camera have been made most valuable instruments for study, particularly with regard to erosion of gravel in river beds and the travel of sand waves and gravel bars in river beds. By taking pictures at high speed and slowing them down in the projector, movements too rapid for the eye to follow can be studied at leisure. The laboratory at Karlsruhe, Germany, has been particularly active in this branch of research.



1:200 SCALE MODEL OF RHINE BETWEEN SONDERSHEIM AND MANNHEIM (TECHNICAL UNIVERSITY AT KARLSRUHE)

No reasonable doubt of the value of these methods in skilled hands can be retained after a study of the work accomplished in the laboratory of the German Navy Department at Wilhelmshaven with regard to remedies for objectionable sand deposits in the adjacent harbor, or after a study of many researches carried on at Karlsruhe, Charlottenburg, and other parts of Germany, Sweden and Austria and elsewhere, in relation to river erosion.

The value of the laboratory method of research has been so abundantly proved during the past 10 years at the older laboratories at Dresden, Charlottenburg, Karlsruhe, Darmstadt, Wilhelmshaven, and so on, that large new laboratories have recently been constructed at Delft, Holland; at Zurich, Switzerland; at the Walchensee near Munich, Bavaria; and elsewhere; devised in some cases to serve the double purpose of instruction to students and of fundamental research. A new laboratory that has greatly interested the author is that just completed at Tashkent, Russian Turkestan, by the Soviet government for the special study of the hydraulics of irrigation, which, from photographs and drawings appears beautiful in architecture and admirably planned.

Examples can be cited to show that where putting the question of how to improve the navigable quality or flood discharge of a river by experiment at full-scale in the actual river might cost $100,000 to $1,000,000 and require from one year to ten years for an answer, one can put the question to experiment by means of a series of laboratory models at a cost not exceeding the one-hundredth part of that of the full-scale experiment in the river, and thus in the laboratory receive a dependable answer in the course of from one to three months, which it would require many years to arrive at by the far more costly experiment on the actual river.

Examples can also be cited from experiences at various hydraulic laboratories, in which a saving in construction costs amounting to from ten to 100 times the cost of the model has been accomplished by experiments in qualified hands in a hydraulic laboratory.

The Director of the great hydraulic laboratory at Karlsruhe stated to the author that each of several major researches taken into the laboratory in recent years had been the means of making a saving in cost of the full-size structure greater than the cost complete of the model and the laboratory which contained it. The laboratory of the Technical University at Stockholm, Sweden, reports economies of a similar character.

In 1913, while visiting the great building exposition at Leipzig, Germany, the author's attention was called to models of some of Professor Engel's laboratory apparatus, which led him to visit Professor Engel's two laboratories, the old and the new. In 1924, he again visited Professor Engel's laboratory and several others, subsequent to attendance at the World Power Conference in London, and was amazed at the remarkable progress within 11 years, notwithstanding the impediments of the World War. This progress led him to make further investigation, which resulted in his pleading with the secretary of the German National Engineering Society and several of the leading professors of hydraulics in Germany, urging them to prepare a book which should contain descriptions of these laboratories and of their most noteworthy researches.

These gentlemen complied, and in 1926 the Association of German Engineers published a large and beautifully illustrated volume entitled "Wasserbaulaboratorien Europas," which in addition to the most noteworthy laboratories in Germany, with great breadth of view, included descriptions of noteworthy hydraulic laboratories in Austria, Sweden and Russia, and the researches made therein. This admirable recent work of these European scientists so impressed the writer that he arranged to have it translated into English, and in connection therewith he again in 1927 made a tour to the most remarkable of these European laboratories, including several in Italy and Switzerland.

The writer's first work in a hydraulic laboratory was more than fifty years ago, in connection with helping one of the most eminent of American hydraulic engineers to develop instruments for the measurement of flowing water and in determining the laws governing loss of head in conduits for water power development. For fifty years the author has been actively engaged in practice as a hydraulic engineer, mainly with large problems of water power development and the design of municipal water supplies for domestic purposes and for protection against conflagration.

In 1928, sharing the feeling of Bacon, the English philosopher, that, "every man is debtor to his profession," he came to feel strongly that one who had found great pleasure and the durable satisfactions of life in fifty years of practice should strive to *put something back* in partial payment of his own debt to the profession and to those who had gone before. Therefore he arranged for the publication of a translation of this German book, with extensions, comprising in all nearly 900 pages, which brought its researches up to date, containing accounts of the equipment and of the work in about forty of the most noteworthy laboratories in Europe and America under the title "Hydraulic Laboratory Practice." The care and labor connected with the publication of this book was kindly undertaken by the American Society of Mechanical Engineers as a contribution in promotion of engineering science and art. The writer of the present article refers all persons interested in the study of hydraulic problems by means of models to this book published by the American Society of Mechanical Engineers, as the most convenient means of learning of the vast scope of the investigations carried on in these hydraulic laboratories during the past ten years, their vast practical importance, and the warrants which they give for expecting great future progress.

It is of interest as showing present activities that although the author had collected all data available up to about one year ago, regarding the most noteworthy hydraulic research laboratories for inclusion in the book described above (exclusive of the small laboratories, used mainly for purposes of undergraduate instruction at engineering colleges), information of further progress has since been coming in at such a rate and so many new laboratories have been built that it has become necessary to publish an appendix, which is now in preparation.

There are still many researches of great importance to many branches of engineering awaiting proper laboratory facilities, among which are the following:

I. *Researches for promoting greater precision of measurement of flowing water. (a) By means of weirs of various forms. (b) By current meters of improved design. (c) By a "Standard Weir."*

(a) It is from the storage of flood discharge that most of our large hydroelectric power plants receive their motive power, and the historic records of measurement of flood discharge often are extremely crude. The best measurements of flood discharge of rivers are those made over spillways of dams. These dams present crests in great variety of form of whose precise coefficients of discharge we have no certain knowledge. It is desirable to have these coefficients of discharge accurately determined by means of models.

(b) The standard sharp-crested weir often has to be used under other than ideal conditions of approaching current. Turbulence in the approach to any sharp-crest weir affects the extent of contraction of flow beneath the jet, and causes inaccuracy in estimates of discharge made by the use of coefficients determined under ideal conditions. It is desirable to experiment with such weirs having various kinds of turbulence in the approaching current and to measure precisely its effect in lowering the value of the coefficient of discharge.

(c) It is highly probable that a new form of "Standard Weir" could be developed of greater accuracy under average conditions of use, than the present standard sharp-crested weir. To reduce the error in measurement this new standard weir ought to have a sloping approach and a rounded crest upon which the turbulence or slant of approaching current would have far less effect in changing the coefficient than it does with the sharp-crested weir. It is desirable to once for all find the best form, and to learn of the extent to which its coefficient may be modified.

II. *Precision of measurement by revolving fan-like current meters.*

(a) The precision of measurement by revolving fan-like current meters is adversely affected by turbulence of the current. It has long been obvious that some types are more accurate than others under these conditions. It is desirable to develop a new type, on which these adverse conditions shall produce the least possible impairment of accuracy, and which at the same time will possess the smallest liability to obstruction or error by catching upon its revolving propeller, weeds, grass or other matter suspended in the current. Also it is desirable to learn the percentage of error that may result from the measurement of mean velocity in the cross-section of a channel presenting turbulent or twisting eddying currents, by means of meters of ordinary types now in use.

III. *The Siphon Spillway, as a means of discharging surplus water from reservoirs or canals with exceedingly small excess of flood height above the ordinary working level.*

This is a device used occasionally during the past forty years in Europe and America. The author believes this device has never yet been put to use to the extent that its merit warrants. He believes that siphon spillway units can be constructed, each with a throat ten to fifteen feet wide by from ten feet to perhaps fifteen feet in height, each one of which under favorable conditions will discharge from 3000 to perhaps 5000 cubic feet per second, and that ten or twenty such units built of portland cement concrete, can be placed side by side, and discharge a flood of say 25,000 to 100,000 cubic feet per second while permitting the reservoir flood level to rise not more than one foot above the ordinary working level; thereby permitting a less high and costly dam, and obviating the need of using broad expensive areas of land for flood flowage. Meanwhile such a spillway will permit the power plant to function at any time with reservoir head up to within a foot of the flood level. A preliminary study with scale models in a series of say 1/24, 1/12 and 1/6 full-size, with a glass side wall permitting study of eddies, would lead to finding the shape giving the least eddy loss and least friction loss, and greatest coefficient of discharge; after which experiment should be made on a thin section perhaps only one foot in horizontal width on full-size vertical scale, to make sure that the maximum suction effect of atmospheric pressure in lifting the discharge to a height of ten feet or more above the crest, has been correctly worked out.

The siphon spillway presents one of the cases in which the small-scale model may not alone tell the whole story, because the atmospheric pressure acting on the model cannot be conveniently varied. Moreover, it is difficult to predict from the model just how high the water can be lifted above the reservoir level by the dragging out of the air from the top of the siphon chamber.

The results of these problems, having been once solved by any one of the full series of laboratory experiments above described, could serve for all time.

IV. *The hydraulic laboratory idea applied to river regulation.*

In the opinion of the author the hydraulic laboratory idea can render its greatest service to mankind in helping to work out and define the natural laws which control erosion of river beds and the deposit of sediments; and in helping to develop the most economical means for confining a straightened river to its prescribed new course, under the widely varying discharges from drought to flood, and over various kinds of gravel, sand, silt and other river bed material. To accomplish this the laboratory would need supervision by a veritable genius, an unprejudiced and persistent seeker after truth, quick to take a hint from minor things seen in the course of experimenting. He must alternate his studies first in the laboratory, then in the actual river, then back again, over and over again, and be patient in a task that might require ten years before he could safely generalize his observations into law.

The author is confident that many of our greatest rivers could be straightened and made to travel in the straight and narrow way and carry their burden of silt to the sea, through a channel tolerably free from obstruction to navigation by "cross over-bars" and with smaller flood rise.

Many of these problems could best be carried out in a great national laboratory, supported by the government with a fund of say $50,000 per year for staff, operation and maintenance. Germany has three great hydraulic laboratories supported by the general government devoted chiefly to researches upon problems of public works, apart from about half a dozen other hydraulic laboratories at its engineering colleges also under government support and control, and which divide their work between instruction of students and research on great out-of-doors problems of public works.

Ten years ago in China, at a gathering of high public officials, I recommended such a laboratory for problems of flood relief, and publicly stated my belief that *in proper hands* it would be made to return to that country dividends in results annually equivalent to a thousand per cent on its cost. This also may be true for other countries.

The Technology Review Reprint Series

REPRINTS of notable articles are distributed regularly by The Technology Review to supply a demand greater than that which it is feasible to fill with the more expensive complete editions of the magazine. The following reprints are available at 10c each:

FORESTALLING DEATH (November 1929; Page 21)
The cow's contribution to human longevity BY JAMES A. TOBEY

NEEDED: MORE SCIENCE IN FLOOD CONTROL (December 1927; Page 95)
A survey of the flood control methods utilized in the Mississippi valley and some pertinent recommendations (in particular, the establishment of a laboratory for the study of river hydraulics) for improved procedure BY JOHN R. FREEMAN

MASTERING RIVERS IN THE LABORATORY (January 1930; Page 136)
Progress in hydraulic laboratory research BY JOHN R. FREEMAN

PHYSICS AND MEDICINE (December 1928; Page 91)
With animadversions on certain methods of teaching each
BY EDWIN B. WILSON

HONORS STUDY IN ENGINEERING (January 1929; Page 147)
American education recognizes the exceptional student
BY RICHARD H. FRAZIER

PRIMITIVE THINKING (July 1929; Page 457)
The occult beginnings of authentic science BY TENNEY L. DAVIS

THE ENDOCRINE GLANDS (July 1928; Page 473)
The Public hears much speculation and little truth about endocrinology. This article summarizes some scientific facts
BY ALLAN W. ROWE

Address orders to the EDITORIAL OFFICES, ROOMS 11–203 *and* 11–205, M.I.T., CAMBRIDGE, MASS.