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CIVIL ENGINEERS

ADDRESS AT THE ANNUAL CONVENTION,
HOTEL WENTWORTH, NEAR PORTSMOUTH, N. H.,
JUNE 21ST, 1922

BY

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PAPERS AND DISCUSSIONS

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ADDRESS AT THE ANNUAL CONVENTION, HOTEL WENTWORTH, NEAR PORTSMOUTH, N. H., JUNE 21ST, 1922.

By John R. Freeman,* President, Am. Soc. C. E.

The By-laws of the Society require an address by the President at the Annual Convention. In nearly all scientific societies, the address of the President comes at the close of his term, which seems a more appropriate time. I awoke to this time of delivery too late to permit the development of my chief topic as I have desired. Before deciding on this topic and in order to learn the traditional scope and treatment, I read all the Presidential Addresses of the past 25 or 30 years. I found them mostly devoted to one of three subjects: (1) The Society; (2) the status and relations of the Engineer to the Public; and (3) a historical review of progress in that line of engineering to which the speaker had chiefly devoted his professional life.

While thus studying the proper topic and scope for a Presidential Address, my thoughts have been drawn in two directions: One, Progress in the Development of this Society and Its Possibilities for Greater Usefulness, and the other the Development of Hydraulic Science. I am particularly drawn to this topic, because it is now almost fifty years to a day since I began as a Junior Assistant Engineer in the office of the Water Power Company, at Lawrence, Mass., and my professional life has been chiefly devoted to Hydraulic Engineering.

Before proceeding with this second topic, I cannot, following forty years of membership in the Society, many years of membership in various other engineering and scientific societies, and five months in the closer view given by my present office, refrain from saying something about The Society and Its Progress.

As I recall my three years of service on the Board of Direction about 25 years ago, and compare the technical activities then and now, I find that the time and effort now given by the individual members of the Board toward the development of the Society has been vastly increased. Then, the Board could

* Cons. Hydraulic Engr., Providence, R. I.

finish its order of business in an evening, or, at most, in an afternoon plus an evening, and the proportion of Directors attending from a distance was much smaller than at present. Now, the Board requires at least two full days and an evening, four times a year, and this large amount of time is all spent in good hard work, in active discussion and thoughtful consideration of ways and means of promoting the efficiency and service of the Society to its members, and in carefully scrutinizing the records of candidates for membership, in order that the Society may do its share in maintaining the status of Engineering as one of the learned professions.

A few months ago, I was disposed to think it somewhat ridiculous that a Board meeting of the Society should take so many more hours than the Board meeting of a great business corporation, but now I see from the inside that this is not unreasonable. Settling matters in the Board meetings, instead of debating them in a general meeting, saves a lot of time to the members. The members of the Board represent different sections of the country having different problems and all of them are men of strong convictions, trained by their profession and by their daily tasks into a sense of responsibility. Many difficult questions of policy arise. I have heard suggestions from outside, more in jest than in seriousness, that so much time spent in meetings indicates that the Board is a divided body which spends too much time in "scrapping" and on petty detail, and so I will say that, in nearly a half year as Chairman, there has been not one word of acrimonious discussion, not the slightest manifestation of sectionalism, nothing but earnest forward-looking consideration of how best to achieve the purposes set forth in the Constitution. The 10 500 members should appreciate the spirit in which the busy men who constitute the Board of Direction leave their important responsibilities and give their valuable time to these matters. Twenty-six out of the twenty-eight Directors were present at the meetings at Dayton, Ohio, on April 3d and 4th, 1922, and twenty-four Directors are present at this Annual Convention, three of whom came from the Pacific Coast. The Board thus functions from a broad National viewpoint, while the great majority of members present at the midwinter meeting, or at the midsummer convention, always are from relatively near-by.

All members may well be pleased with the Society's progress as shown in the character and extent of the papers published during the past year, in the steady growth in membership, in the activities of 34 Local Sections scattered through almost every important section of the country, in the 45 Student Chapters—one at substantially every important engineering school—and in the arrangements for Technical Divisions specializing in Power Development, Sanitary Science and Public Health, Irrigation Engineering, and Highway Engineering, provided for at the meeting of the Board of Direction held on June 19th, 1922. It is intended that, henceforth, when "birds of a feather flock together", there will be a place for their flock inside the Society with no need for them to form a little new society outside. One of the many pleasing features of the Dayton meeting was the innovation of the presence, by invitation, of a large group of students from two of the Ohio Engineering Colleges, whose professors had suspended their lectures, in order that the students might attend the technical session held at that meeting. We hope this may be repeated in each State where we meet, wherever there is sufficient seating capacity in the convention hall.

Above all, the members should be pleased with the earnest work for the advancement of engineering arts and science now being conducted by the Special Committees. I fear that too few appreciate the time now being given to this committee work by busy men—the most eminent and best fitted men that we can find in the United States, or in Canada, for each special task—at great personal sacrifice of their time and comfort, and in earnest spirit of service to the Engineering Profession. The mere payment of the traveling expenses of the members of these Committees to a common meeting place, although it makes something of a hole in our budget, is the merest pittance in proportion to the service rendered to the public, to engineering, and to the members of the Society collectively. In the rapid development of Engineering, this kind of committee work may well be increased, and the Committee on Special Researches, of which A. N. Talbot, Past-President, Am. Soc. C. E., is Chairman, is working to get together half a dozen new committees in special fields.

The Constitution states that the main objects of the Society are:

(1).—"The Advancement of Engineering Science". This is done mainly by committee work such, for example, as that on structural standards, and by contributing data and experiences in papers.

(2).—"The Professional Improvement of Members". This is done through the maintenance of high standards for the admission of members and by bringing the Junior into friendly contact with the Senior.

(3).—"The Encouragement of Intercourse". As seldom more than 3 to 5% of the 10 500 members, scattered all over the United States and throughout the world, attend either the Annual Convention or the Annual Meeting, and as less than 1% attend the monthly meetings, this intercourse obviously must come mainly through Local Sections and through the published *Proceedings*, or perhaps through a new bi-monthly, containing more matters of current interest to members and to the younger members in particular.

(4).—The fourth great objective stated in the Constitution, "The Establishment of a Central Point of Reference for the Preservation of Data", is obviously met by the share of this Society in the establishment and maintenance of the great Engineering Societies Library—but because of the wide distribution of membership, this fourth objective must be mainly attained through the files of *Transactions* in each member's office or home.

Let us now briefly consider possibilities of greater service by the Society toward the better attainment of each of these four objectives.

In Engineering, Science often lags far behind the Constructive Arts. Watt built engines without knowing much about thermodynamics. Arches and trusses long preceded stress diagrams. Portland cement has been used a hundred years, and its chemistry is not yet well understood, and great bridges have been built with little knowledge of the metallurgy of steel. The pioneer is, of necessity, often wasteful with his factor of safety, or knowing the risk must, of necessity, take a chance, as with the early sheet-iron water pipes of the

California miners, and "through our failures we achieve success". Then Science comes and shows the way to economy, reducing wasteful cross-sections, combining experiences, deducing theory from successful practice, and giving confidence for projecting structures to longer spans, higher pressures, and new lines of attack. Textbooks and published data often lag far behind the information collected here and there by some one under stress of circumstances. The *Proceedings* and *Transactions* of Engineering Societies provide convenient places in which to record these forward steps.

One great service of the *Proceedings* of technical societies is the collection, preservation, and early dissemination of these experiences and newly discovered facts, so that they may be available to engineers and to writers of textbooks.

Our Society machinery does not yet seem particularly well organized for scanning the horizon, discovering, and systematically bringing foward and publishing these new data. The busy worker has his hours so full of responsibilities that commonly pressure must be brought on him to sacrifice his time to prepare a paper, through the appeal of rendering service to others. Some of the best papers of the past year have been thus obtained, more can be done in this line and Object No. 1 of the Constitution thus better attained.

The Engineering Foundation was established to aid in advancing Applied Science, and to aid in developing new data, by a far-seeing engineer who intended his own gift to be merely a nucleus to which others by adding might testify in a substantial way to the help they had received from association in the Engineering Societies and the researches of their predecessors; or, if they had prospered, might pay in like manner a part of their debt to the Profession.

Cannot our Society take a more active part in making this great idea bear more fruit, both in increment to this fund and in adding to data for the practical engineer? Would it not show a finer spirit of appreciation toward those who build up this Foundation fund, if every dollar of its income from endowment was devoted to its main purposes, while the four National Societies took on themselves the whole expense of its administration?

On the second topic, "Professional Improvement", and on the third, "Encouragement of Intercourse", does not our present opportunity for doing more lie chiefly in a stronger and better organized support for each of the Local Sections? For the Board of Direction simply to frame some permissive rules for the Sections and then to give back $1 per year of the $20, or more, of dues collected, is not enough attention by the Parent Society. The Student Chapters also may well be given much more attention, and a strong effort put into the active development of the newly provided for Professional Sections within the Parent Society.

On this topic of intercourse, I take this occasion to express my regret at my inability to accept many of the hospitable invitations to address Local Sections and Student Chapters. I have gladly done so, as far as practicable, but with 34 Local Sections and 45 Student Chapters, it is obvious that some new means of showing proper attention from the home office to these scattered, distant bodies should be devised.

These second and third ideals of the Constitution—Professional Improvement and Intercourse—could be better satisfied by a larger membership. In his

Presidential Address,* eight years ago, Hunter McDonald, Past-President, Am. Soc. C. E., stated that the engineering development of the United States was then such that outside our Society there were three or four times as many qualified by the standards for membership, as there were inside the Society. Most of us who have broad contacts with what is going on in the United States, will on reflection agree with him, and agree that all three of the first aims of the Constitution, "Advancement of Science", "Professional Improvement of Members", and "Intercourse among Engineers", will be better satisfied when more of those now outside are quietly made to see that they should be inside the Society; not so much for what each can receive, as for what all can give in the maintenance of professional ideals.

By no means should the requirements for admission be lowered or less rigidly observed. The Constitution and By-laws make plain the intention to restrict membership to the specially educated, skilled, and supervising class and to young men who are educating themselves for high responsibilities. We owe it to ourselves and to the public to maintain Engineering as one of the learned professions.

All four of the objectives of the Constitution of this Society can be promoted through continually improving the quality of the publications. Civil Engineering presents the broadest field and opportunity of any branch of engineering for valuable papers and discussion, because of the scale of work, the variety of its field, and its many and broad public relations. A large proportion of the membership is in the direct service of the public, as City engineers, State engineers, public health administrators, railway administrators, and in various other branches of public service. Therefore, it is not strange that, in the course of the present year (1922), the Society is publishing a greater number of technical papers and more square inches of discussion of technical papers than any one of the other three National Societies (although less than the National Society of Chemical Engineers and Chemists which I hope will some time be in the United Engineering Society group).

While thus fulfilling the specifications of the Constitution, does not our monthly publication now partake too exclusively of the character of a cold storage warehouse, filled with valuable material, to some of which each member will certainly want to refer in the future, but not all of which is particularly interesting just now, particularly when one is a thousand miles away from the Engineers' Club.

The quality and the tonnage now going into this storage warehouse are admirable, but cannot we work in between these valuable papers more pages of immediate human interest to the junior members and to the thousands of distant members who pay their dues, 90% of whom can neither attend an Annual Convention nor enter the Society House in New York City.

Cannot the *Proceedings* (or preferably perhaps an intermediate journal) carry more pages about what is going on just now in the engineering world, more of its inspiring story of current general scientific research, better book reviews by eminent practitioners, or teachers, which will give the young engineer a better guide to what he should add to his working library, out of

* *Transactions*, Am. Soc. C. E., Vol. LXXVII (1914), p. 1737.

his modest salary? Would it not be well to let each issue carry a few small half-tones and biographical sketches of engineers prominent in notable works of the day, thus adding more of the touch of human interest and should not we find means for sending out better abstracts of current technical literature?

If the present ten issues per year become too bulky, split the material into twelve or twenty-six issues. Due regard for the distant member suggests that the issue should not be suspended two months in summer.

Such improvements, as suggested, cannot all be made at once, and to live up to present-day opportunities and to provide the right personnel for additional work will require more money than is carried in the present budget. How to obtain this is another pressing and important question.

I will now proceed to the second topic, Hydraulic Science, and present some notes on its development and some suggestions of further development.

Old books on Science are always interesting and suggestive. I have found this true of Hydraulic Science and as I have taken books from the shelves of ancient libraries, I have found that although the art of the Hydraulic Engineer is old, his science is young, and some parts of it now appear to be in a state of arrested development. If this development is lagging, let us join in starting something!

Progress in Hydraulic Science

"Irrigation is the oldest branch of Applied Science in the world,"* says Sir William Willcocks, famed for hydraulic works and studies in Egypt and the Holy Land. One of the most remarkable pieces of ancient art that has been preserved in all the world, is a head, beautifully sculptured in obsidian, of the Egyptian king who completed Lake Moeris, greater than any irrigation reservoir since built, more than 4 000 years ago.

Thus, when the Mechanical Engineer, in pride of ancient lineage, points to Tubal-Cain or to the Artificer in Iron whom the wise Solomon seated at his throne, the Hydraulic Engineer may point to the important work of his ancestor who had charge of the canals in the Garden of Eden. For Sir William also says: "The events recorded in the early chapters of Genesis had their origin in a rainless land where life depended upon irrigation." He quotes from the second chapter of Genesis: "Out of Eden came a river which watered a garden", and says that, in the course of his explorations, he has discovered the precise spot. Also, he tells us how these rivers in the Holy Land have eroded their beds and impaired their possibilities for service since Biblical days.*

Speaking precisely, it was only an Art and not a Science by which, in those early days, water was regulated as it flowed down hill or was guided as it sought its level. The Arts of controlling water were pre-historic, but Hydraulic Science did not have its birth until thousands of years after the dawn of history, or until about 300 years ago. Its birthplace was along the rivers of Italy.

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* "From the Garden of Eden to the Crossing of Jordan", by *Sir* William Willcocks, Spon & Chamberlain, New York.

Until very recently, all the Constructive Arts have been far ahead of their Sciences, as we now differentiate the terms, Art and Science, and most of the inventors and great builders of the past have not been scientists. The special mission of Science—the organization of knowledge, the discovery of natural law, and its expressions in formulas—has been to bring safety and economy into the Constructive Arts, and only very recently, and mainly in the new fields of Chemistry and Electricity, have Science and Mathematics yet accomplished very much in pointing the way to progress in the arts.

Very curiously, the old Roman, with all his skill in architecture and aqueduct building, seems to have had no conception of measuring velocity as a factor in quantity of flowing water, because he had no instrument with which to count seconds; therefore, he measured the discharge of his aqueducts in "quinaria", a sort of ancient "miner's inch",* of double the California quantity, determined by the diameter of a short outlet tube. His state of mind was much the same as that of the practical man of to-day who says, "as much water as a 6-in. pipe will deliver", or that of the country lawyers who drafted certain old water-power leases in which the water right was measured by the diameter of the penstock.

More than 250 years of slow earnest painstaking work by the greatest engineers and scientists of the Middle Ages was required to work out the simple fundamental formula, $V = \sqrt{2\,g\,h}$. The writings of Vitruvius, Frontinus, and even those of that greatest of all men of inventive genius, Leonardo da Vinci, reflect few, if any, glimmerings of exact science in the laws of flowing water, and it was not until about 300 years ago that a pupil of Galileo worked out his formula that the discharge from an orifice varied as the square root of the head. It was not until about 125 years later, in 1738, that the mathematician, Bernoulli, put the gravity factor into this formula and gave engineers the present fundamental hydraulic formula of $V = \sqrt{2\,g\,h}$, with which Hydraulic Science really began.

Tennyson says: "Science moves but slowly, slowly; creeping on from point to point", and Hydraulic Science moved very slowly and almost not at all until about 200 years ago, when there came a beginning of precise observation and experiment, and a development of Hydraulic Science, in both Italy and France. 150 years ago, the fundamental formula for the flow of water in canals, aqueducts, and pipes, that is in general use to-day (the Chezy formula), was developed at the water-works of Versailles; and, about 100 years ago, the French engineers had developed the mathematics of hydraulics to nearly the point where they stand to-day. In the next 50 years, there was much progress, but this has since lagged and it is now high time we gave Hydraulic Science a new impetus.

Eighty-three years ago, fresh from his studies at the French School of Bridges and Roads, the late Charles S. Storrow, Hon. M. Am. Soc. C. E., of Boston, Mass., the best educated American engineer of his generation, wrote "A Treatise on Water-Works" which at that time was by far the best in the English language and was so clear, so complete, and so condensed, that it might serve as

* A "quinaria" was probably equivalent to about 2 miner's inches, or to 5 000 to 6 000 U. S. gal. per 24 hours.

a college textbook to-day and lead no one into serious error by its methods of computing flow through orifices and pipes or over weirs. His introductory chapter contains one of the best brief historical reviews of the development of Hydraulic Science that has yet been written, and his earnest plea—that engineers in charge of hydraulic work add to experimental knowledge—continues worthy of repetition to-day.

It was from 60 to 70 years ago that Francis made the greater part of his famous Lowell hydraulic experiments and published his book thereon, which is a classic in clear description and in detailing precision of measurement. He was the first in the world to design his experimental hydraulic apparatus of a size that could deal with full-sized specimens. Until his time, the orifices, weirs, and conduits used by the scientists to develop and prove their formulas were but very few inches in diameter, and the fact that they got a fair degree of accuracy should give confidence in the laws of hydraulic similitude when we seek the laws of river flow in a laboratory. Francis' formula for discharge over weirs, his methods of testing turbines, and his methods for measurements of the discharge in canals by floats, remain standards for precise work to-day.

It was from 60 to 70 years ago that Humphreys and Abbot wrote their great book on the "Physics and Hydraulics of the Mississippi".

Although the past half century has been a period of marvellous development for all kinds of structures within the field of Hydraulic Engineering, and dams, aqueducts, municipal supplies, power developments, reclamation works, and canals have reached really wonderful dimensions in many parts of the world, particularly in America, experiments and systematic observations for increasing knowledge in important branches of the Science of Hydraulics have lagged behind the development of the art.* In the important field of training rivers, erosion of river beds, and in laws governing the deposition and transportation of sediments as affecting problems of relief from floods† this branch of Science has mostly slumbered, except at one or two small laboratories in Germany, of which I will speak later, although Fargue, in France, and Engels, in Germany, and a few others, have worked diligently to formulate observations on the fixing of locations of gravel bars on rivers of the European types, for the benefit of navigation. For example, the six rules of Fargue chiefly relate to stabilizing a navigation channel, to keeping the shoals so placed that the pilot will know where they are.

Most of the studies and books on river training have had navigation as their aim, while in these later years protection against floods and reclamation of fertile lands have become of relatively greater importance.

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* Most of the college textbooks on Hydraulics fail to show that even the root given in the fundamental Chezy formula is probably wrong and should be written as ⅔ or ¾ instead of ½, the correction being now made in the variable coefficient. They give little warning that ordinary types of current meters in disturbed water may show velocities far from the truth. Their back-water formulas are not readily applicable to real rivers. They give no intimation of the twisting currents often found in circular penstocks and fail to note that the curve of distribution of velocity does not follow the parabolic law near the conduit wall in pipes or in river beds, but is greatly retarded. They say almost nothing about precautions for accuracy in application of formulas, etc., etc.

† The erosion and transportation of sediment probably has been studied more by English engineers on the great irrigation canals in India than anywhere else in the world, but their knowledge appears far from being yet organized into Science. A good résumé may be found in Buckley's "Irrigation Pocket Book" (Spon & Chamberlain, 1920).

What we now chiefly need is to find out how to control the sediments and improve the carrying capacity of rivers to the sea, so that with all possible speed and facility the main trunk will take away the water delivered into it by the branches.

We need to find out how best to make a river dig its bed deeper, instead of obstructing itself by rolling up its gravel bars into dams at every "cross-over" in the early stages of a flood. The late Professor J. B. Johnson, M. Am. Soc. C. E., stated the case well in 1884, in the *Proceedings* of the American Association for the Advancement of Science, in the language of a former Secretary of the Mississippi River Commission: "The first work of a flood is to impede its own discharge and the impediment outlasts the flood." Johnson cited observations at Columbus, Ky., comparing heights on the river gauge when the river was rising, with heights for the same number of cubic feet per second (1 100 000) on a falling stage, showing an average increase of 2.1 ft., and a total increase in flood height of 5.5 ft., due to gravel rolled up on to the bars.

This stagnation and need for a new departure in hydraulic experimentation and science was forced upon my attention, a few years ago, when I was reviewing the literature of river training, in preparation for my studies in China, and recently has been brought to my attention during a recent tour of inspection, first along the Missouri River, near Omaha, Nebr., to inspect those "Retards"* shown by Roy N. Towl, M. Am. Soc. C. E., in moving pictures at the Dayton meeting of this Society on April 5th, 1922; which "Retards" are permeable elastic spur-dikes, built of trees, for training the river to avoid bridge abutments and to turn it away from eroding valuable farm lands; and it was still more forcibly impressed upon me only a few weeks ago when I inspected the threatened and the flooded regions along the Lower Mississippi at many points from Memphis, Tenn., to below New Orleans, La., including the crevasses near Ferriday and Poydras, the near crevasse at Tunica, and the threatening of a crevasse at Stanton, La.

Since that inspection, I have been reading the story of the Mississippi levees and jetties and proposed spillways in the library of river and harbor literature collected by the late Elmer L. Corthell, Past-President, Am. Soc. C. E., and as I have learned more details of the many controversies and of the diametrically opposite opinions of high authorities about river training, protection against floods, and about maintaining channels for navigation, which controversies have centered around the outlet of the Mississippi and certain harbors of the Gulf States, and the divergent views that prevail to-day in New Orleans about safe-guarding the future of the city, both as to floods and as to navigation, I have become more and more impressed with the idea that this branch of Hydraulic Science in particular is still in the stage of argument and opinion, rather than that of precise observation and determination of facts; and that the science of current control, particularly in rivers carrying large loads of sediment and flowing over beds of deep alluvium,

* A brief description of these retards is given in the paper by Mr. Towl, entitled, "Missouri River Bank Protection at Omaha, Nebraska", *Proceedings,* Am. Soc. C. E., May, 1922, p. 1185.

is now very much where chemistry was before the universal use of the balance, or where electricity stood prior to the centimeter-gramme-second units.

On the Lower Mississippi, they have just been having the highest water ever known, and no one can appreciate the frightful conditions of threatened and ruined homes, of tens of thousands of square miles of the most fertile land in the United States, worth, literally, hundreds of millions of dollars, threatened by inundation and by the loss of a year's crops, until he has been on the ground during high water and has seen this mighty river, ½ mile wide, 100 ft. deep, 50 ft. above its normal stage, rushing along with its surface within 6 in. of the top of thin soft earth dikes, from 12 to 18 ft. high, and here and there threatening to cut through them by a new eddy or swirl of the current; or until he has seen the temporary protective works hastily built by thousands whose homes and properties were threatened.

There are two distinct problems along the many miles of levees: One, that of designing and building a strong impervious dike to a proper height; the other, that of guiding and controlling the direction of the swift current so that it will not undermine and cut into and rupture the dike or "levee". One who is rash enough to risk an encounter with the authorities, American, French, and German, many venture to ask if there is not a third problem, namely, that of training the river to dig its bed deeper; and in New Orleans substantial citizens are asking that a fourth problem, many years old, that of spillways through the levees, be again considered.

Revetment of all the hundreds of miles of threatened banks against possibility of erosion is hopelessly beyond limits of expenditure. Advances in both the Art and the Science are needed.

For ten years past, I have been thinking of the benefits that might come from a hydraulic laboratory, built on a large scale, in which sundry important observations could be made, and nine years ago, I visited the new Flussbau Laboratorium of the Technishe Hochschule at Dresden, Germany. Three years ago, I urged the value of such a laboratory on a group of members of the Society gathered at lunch in San Francisco, Calif., urging that, if established at their great University of California, it would contribute greatly to the economic solution of some of the problems of the Sacramento River and of the problems presented by some of the torrential streams that at times rush down the Pacific delta cones.

On several occasions, I have suggested the value of such a laboratory *somewhere* in the United States, and what I have seen and read during the past few weeks has led me to believe that *now is the time* to urge the importance of immediately constructing a National Hydraulic Laboratory, on a larger scale, in some locality where it will be in a scientific atmosphere (for, in addition to many simple matters of experiment and observation, there are some very obscure phenomena of intricate hydrodynamics, colloidal physics, and other abstruse matters to be considered), which shall be at the service of whatever branch of the Government that may need it. First, for a season, say, in the service of the River and Harbor Engineers; next, perhaps, of the Hydrographic Branch of the U. S. Geological Survey; next, possibly, for some months, in the hands of the U. S. Reclamation Service; and, next, perhaps, serving the Department of Agriculture; and sometimes serving a special purpose outside the Government service. Such a laboratory, operated in close parallel to studies on the real river, can be made to give a new impetus to several extremely important branches of Hydraulic Science, and give precise data which we lack in important fields. More about an hydraulic laboratory will be said later.

Resuming the story of progress, the Outlines of History of Hydraulic Science must be greatly condensed in an address of this kind, because to tell all the development that is of interest to an hydraulic engineer, would require some hundreds of pages.

Commonly, we forget how young all engineering science is. In most branches, it began its rapid development only about 100 years ago, or at most, 150 years, and followed close upon the greatest of all of man's inventions, the manufacture of power by the steam engine. It is hard for me to realize that my own engineering experience of 50 years covers one-third (one almost might say one-half) of the whole history of these great engineering activities, and that I knew personally the chief engineer of the earliest railroad in New England and the author of the earliest American book on Hydraulics, and that the greatest public work constructed by our National Government up to 90 years ago was the stone dry dock at the Charlestown Navy Yard, built from designs of Mr. Loammi Baldwin.

Although the Science is young, its Arts are old. The art of irrigation was highly developed in pre-historic times in many lands, in Egypt, Chaldea, India, China, and other parts of the earth. At the dawn of history, the flood waters of the Nile were regulated and stored for irrigation in Lake Moeris—far larger than any present-day storage reservoir—into which the waters of the Nile were led by the Canal of Joseph. In Szechuan, China, the present irrigation channels, watering many thousands of acres, are said to have been admirably designed and regulated, some thousands of years ago, by an engineer who worked out matters in great detail, set monuments for regulating the depth to which water might flow, and prescribed good rules of operation that are said to be still faithfully observed.

The arts of river control and canalization also received attention in those ancient days. Back in the half legendary days, about 4 000 years ago, China's most famous hydraulic engineer, the great Yu, is said to have successfully regulated rivers by dikes, guiding them into new channels, so that the people got along fairly well for 1 000 years, while his rules were followed. Many temples were built in his honor. The Grand Canal of China was built in part 2 400 years ago.

The Suez Canal retraces a small canal of many hundred years ago. There was a canal dug from the Nile to the Red Sea in the reign of one of the Pharaohs, more than 1 450 years before the Christian era. The "fresh-water canal" used by the French engineers of 1863 to convey fresh water from Cairo to Suez had been in use for 2 500 years. Along the Tigris and Euphrates, large canals were in use for irrigation and for boats, 350 years before the Christian era, the ruins of which show them to have required much engineering skill.

In Greece, at Corinth, the American School of Archæology has excavated the remains of ancient fountains and conduits, which, as I inspected them, gave me much respect for the skill of the workmen of 2 000 years ago; but it was art and architecture that were in evidence rather than engineering design. In many places in the Old World one finds remains of wonderful aqueducts, tunnels, and foundations built by the Romans about 2 000 years ago; and to me the most beautiful of all their structures, more beautiful than temple or palace, amphitheatre or forum, is that aqueduct bridge, the Pont du Garde, near Nismes, France.

Vitruvius, in his ten books on Architecture, written nearly 2 000 years ago, devotes the eighth book to Water Supply, but almost the only engineering data in its many pages of forgotten lore are some directions for constructing an accurate leveling instrument, the rule that aqueducts should not slope at a less gradient than 1 part vertical to 4 800 in length, or slightly less than 1 ft. per mile, and rules for the weights of lead water pipes. Caution is given about providing air vents and suggestions for laying clay water pipe with tongued ends, perhaps somewhat like that now made near Akron, Ohio. Vitruvius was wise in his sanitary precautions and strongly warns against poisoning from water conveyed in lead pipes, giving preference to pipes of clay; but in spite of its author's manifest effort to tell all that was worth knowing, it is really surprising to see how little this eighth book of Vitruvius contains of what we would call scientific information.

About 250 B. C., Archimedes, the great Greek scientist of ancient Syracuse, invented the screw pump, discoursed on principles of flotation of solids, detected spurious gold by determining its specific gravity in water, and is said to have discovered fundamental principles about the flow of water, but just what these were, I have not found recorded. Vitruvius quotes him as knowing that the earth was round and that a broad water surface had a curvature corresponding to its radius.

Julius Frontinus, Water Commissioner of Rome, about 70 A. D., left in his writings an admirable account of the aqueducts of Rome and their management. This account has been made available in English by Clemens Herschel, Past-President Am. Soc. C. E., in his excellent volume,* in which the translation of the original treatise is supplemented with a great deal of Mr. Herschel's own analysis of the ancient records, by a brief history of the development of early Hydraulic Science, and by many illustrations of appliances used by the Romans in distributing their domestic water supply. Frontinus seems to have been a faithful administrator rather than an engineer, but he compiled many notes and records, and had there been extant in his days any Hydraulic Science, beyond the simple facts that water would flow at about the right speed down an aqueduct having a declivity of about 1 ft. or 2 ft. per mile, and that it could be metered in a common-sense way by the area of the stream, or by the area of pipes leading out from the aqueduct, he would have told us all about it.

Outside the books of Vitruvius and Frontinus, as far as I have been able to learn, hardly anything can be found written on Hydraulics until about 425 years ago, when Leonardo da Vinci, engineer, artist, architect, poet,

* "Frontinus and His II Books on the Water Supply of the City of Rome, A. D. 97."

sculptor, and foremost of experimenters—greatest genius of all time—wrote on the "Motion and Measurement of Water" and invented, or first constructed, the navigation lock, which gave a new impetus to canal building. Some years ago, I visited the site of this first lock, as one visits a shrine. Although water still runs down the canal, it now serves to generate electricity for Milan.

With all his genius and his art, and his wonderful skill in mechanical invention, Leonardo did not add so very much to Hydraulic Science, and, after his time, it seems to have slumbered for 100 years, until the days of Galileo and his pupils, Torricelli and Castelli, each of whom was a real scientist and began the development of precision of measurement and the systematic arrangement of facts expressed by mathematical laws.

The experiments of Galileo on efflux appear to have been begun in efforts to construct a water-clock, measuring time by the flow of water through an orifice, which should be a more accurate timepiece.

It was Castelli, working under the direction of Pope Urban VIII, in 1628, who appears to have first published a treatise on rivers, and he appears to have been also the first to introduce velocity as a factor in measuring the discharge of rivers; but he supposed wrongly that discharge varied *directly* as the head.

In 1643, Torricelli discovered that water issuing from an orifice followed the law of falling bodies, on which his master, Galileo, had experimented at the Tower of Pisa; but although he got the idea of "the square root of h" all right, it was not until nearly 100 years later that the factor "$2g$", was put into the equation by mathematicians. Torricelli appears to have been the first who argued that the acceleration of rivers was due to the slope down which they ran.

Forty years later than Torricelli, in 1684, the French physicist, Mariotte, gave a new impetus to Hydraulics by his observations on flow from tubes and orifices, and he also wrote a treatise on the movement of water.

In Italy, there was great need to study means of relief from the floods of torrential mountain streams that brought not only floods, but also débris and sediment that clogged the river beds and added to the woes of the people, particularly along the lowlands of the River Po. Therefore, it is not strange that river science had its birth in Italy.

In 1697, Guglielmini published the first part of an elaborate work, "Della Natura de Fiumi", the second part of which was published in 1712, after his death. He appears to have been one of the earliest scientists to grasp fundamental principles and made many contributions to Hydraulic Science, probably more than all the others who had preceded him, but he went sadly astray about a few of them, for example, in his notion of the distribution of velocity at various depths. His work is spoken of very kindly by authors of a century later. Undoubtedly, he was the pioneer in River Hydraulics and the old quotations from his works show that he started several important questions that are not settled to-day, and to answer which we need a National Hydraulic Laboratory.

Mathematical science by this time was well expressed in algebraic equations, also the application of calculus to Science was receiving great development, and the great mathematicians seem to have been fascinated with the problems of flowing water, but made a bad mess of trying to devise their laws from *a priori* reasoning instead of by observation in field or laboratory. Sir Isaac Newton, the greatest of all these mathematicians, tried his hand at formulating laws about flowing water, but found no great success in this field, although he developed some beautiful equations in the "Principia", published about 1714. Soon after 1714, there came a rapid succession of authors on Hydraulics.

In 1718, Marcus Paulini experimented on the discharge through orifices and discovered that it could be increased by adding a short tube. Frontinus had previously stated that this principle was known in Rome, and that thrifty Roman water takers had applied it to increasing the discharge from the aqueduct into their premises by adding an enlarged tube to the official nozzle.

In 1730, Pitot, member of the French Academy of Science, invented the Pitot tube which in more elaborate form we use to-day, for measuring velocity and disproved Guglielmini's ideas on the distribution of river velocities at various depths, although his precision of measurement was crude.

In 1732, experiments made on the flow of water in the pipes leading to the Versailles Fountains, were reported to the French Academy.

In 1738, Daniel Bernoulli, and, in 1742, John Bernoulli, father and son, began the establishment of sound mathematical theory as a basis of Hydraulic Science and developed the doctrine of living force.

In 1743-52, d'Alembert, another great mathematical physicist, made important contributions.

In 1764, Paul Frisi, Professor of Mathematics at the University of Milan, wrote his celebrated treatise on the "Nature of Torrents", quoting largely from Guglielmini's observations and giving proof in many ways of being an earnest seeker after truth. Other Italian writers on the flow of water flourished about this time, their interest being aroused by the flood problems of the Po and other Italian rivers. In 1765, Lechhi, of Milan, also wrote an elaborate treatise.

In 1768-71, Euler, the great mathematician, published, at St. Petersburg, a treatise in which he attacked the problem of the flow of water and made useful mathematical contributions.

Up to about this time, or as recently as 150 years ago, the sum total of contributions to theory, other than the one formula for efflux, $V = \sqrt{2\,g\,h}$, was of little practical importance, because of the lack of care to test theory by experiment, and from the lack of precision in measurement; but from about 1764 to 1774, the experimental era was inaugurated, and both in Italy and in France the hydraulicians had reached the conclusion that formulas must come from experiment and not from pure mathematics. Within the following hundred years, the science was developed nearly to where it stands to-day.

In 1775, Chezy, as already stated, gave us his extremely valuable formula for the flow in conduits, but without much discrimination as to the effect of roughness of the wetted surface.

In 1782, Belidor wrote a monumental work on hydraulic architecture, copies of which I have found in three of the early American engineering libraries.

In 1784, the Academy at Toulouse, France, reported experiments on the discharge of orifices and some notes on the junction and separation of rivers.

In 1779-86, Dubuat reported his results of ten years' reports and experiments. Some of his data on the transportation of débris are still reported in textbooks of to-day, as if his data were of practical value—which they are not, because of having been obtained by experiments on the effect of a current of water in moving sand and pebbles lying loosely on the smooth bottom of a little wooden trough only 18 in. wide and less than 1 ft. deep.

I would not leave the impression that I have laboriously read the works of all of the previously named authors, but from time to time I have turned the pages of many of them and have found much of interest in tracing parts of this history in certain old libraries, particularly, in the Locks and Canals Library at Lowell, collected mostly about 75 years ago by the late James B. Francis, Past-President, Am. Soc. C. E., and in the remarkable library of Mr. Loammi Baldwin, who has been called "The Father of Civil Engineering in America", the collection of which was begun about 100 years ago. Baldwin's library was doubtless the best possessed by any engineer in America in his day, and it is extremely interesting as illustrating the breadth of culture of this early engineer. It is particularly rich in the French hydraulic works of 100 years ago, and contains also a few books in the Italian language, notably a treatise, in three thick volumes, on the motion of water, published at Parma in 1766, the second volume of which is entitled "Della Natura d'Fiumi: Trattato Fisico Matematico dell Dottore Dominico Guglielmini", etc.

The Baldwin Library also contains a copy of "Noveaux Principles d'Hydraulique Appliques à tous Objets d'Utilite et particulierment aux Riviéres", published in 1687. It is interesting to note this author's good words for Guglielmini, the author on river hydraulics of nearly a century before. On page 3 of its Introduction, this book contains a very interesting reference to Galileo's opposition to straightening the Bisenzio, and his seven principles, derived *a priori,* in opposition to Bartolotti, who proposed straightening the river. The author states that "Galileo had the misfortune of making his opinion prevail in spite of the truth." (This remark reads like some of those made 235 years later in the controversies about the Mississippi.)

The Baldwin Library contains also a copy of the work, "Recherches sur la Construction la plus Avantageuse des Digues", a prize essay published by the Toulouse Academy, written by Citoyens Boussut et Viallet in 1772, which, in certain of its diagrams, illustrates that groynes and retards for the protection of river shores had been used more than 150 years ago.

In this library is also to be found a copy of De Prony's work, of 1822, on the Pontine Marshes, which he had studied as member of a commission in 1810, as well as a copy of "Essai sur la Theorie des Torrens et de Riviéres, par Citoyen Fabre, Ingenieur en Chef des Ponts et Chaussées", published in 1817; also a book of 280 pages, entitled "Les Moyens les plus Simples d'en Empecher les Ravages d'en Retrecir le Lit et d'en Faciliter la Navigation" ("The Most Simple Means of Restraining the Ravages of Rivers, of Narrowing or Straightening the Bed, and of Facilitating Navigation").

The library also contains the work of MM. Poncelet et Lesbros on the discharge of orifices, published in 1832. It contains many other books of interest to an engineer, showing the state of these arts and sciences 100 years ago.

Incidentally, it may be of interest to remark, as showing the broad culture of "The Father of Civil Engineering in America", that in addition to many scientific works in English and French, and a few in Italian, Mr. Baldwin's library was rich in classic literature and in works on Natural History, for which apparently he spared no expense, for we find here an original set of Audubon's celebrated volumes, "Birds of America", with hand-colored plates, which was published at $1 000 per copy. The scientific part of the Baldwin Library is now at the Massachusetts Institute of Technology, but the parts relating to general literature and Natural History are still in the old Colonial mansion of the Baldwin family at North Woburn, Mass.

A copy of the celebrated treatise of Paul Frisi, on "Torrents", may be found in the Library of Brown University. This English translation is of interest, having been made more than 100 years ago by an English engineer officer for the use of the English engineers in India in their early days of developing the vast Indian systems of irrigation. Few in America appreciate the present magnitude of those Indian irrigation works or the early day at which England began this beneficent work in India. This conscientious engineer-translator visited Italy to check up the general accuracy of the statements in the original work. The book was dedicated to Warren Hastings. It is a beautiful sample of the printer's art of 100 years ago, contains many references to the investigators who had gone before, and raises several important questions about which there is still controversy, such, for example, as the raising of river beds by diking their floods. There are chapters on the subsidence of the sea coast, and on deposits of sediment, and experimental proof that gravel stones could not be ground down into sand during their passage down the whole length of a river, wherefore those brought in by mountain torrents must accumulate and raise the bed of the river near the foot of its steeper slopes; and on the raising of certain up-stream sections of the beds of Italian rivers within the historic period, he presents much proof. He also shows that the débris dams of California were anticipated several hundred years by those of Italy, which were not always successful, etc. All of this shows Paul Frisi to have been such an earnest seeker for scientific truth that we wonder he could not find more of it. This book of 168 years ago details controversies between the highest authorities over the flood problem of the Po and other Italian rivers, which very much resemble those that have raged up and down the Lower Mississippi and the Sacramento and, thence, have spread to Washington, during the past 50 years, and are still unsettled. They were then, 168 years ago, violently discussing the efficacy of cutting spillways in the dikes to take off their floods, somewhat as at New Orleans to-day.

From the accounts of Pliny and Tacitus, they seem to have been discussing and trying out the same ideas in Rome (with poor success), 1 600 years before. Frisi quotes Tacitus as recording a dictum of the Roman Senate concerning straightening the Tiber, "Nature has known how to provide for our wants much better than Art in assigning to rivers those courses, boundaries, and limits, which are most apposite". This reminds one of those recent authors who oppose training rivers to straight courses "because Nature always guides them on curves", without reflecting that Nature's purpose was largely that of delta-building, while Man's is flood protection or navigation.

As an engineering treatise, this book of Frisi is chiefly interesting in showing the state of the art at that time and the small amount of accurate Hydraulic Science that had been made sure of 100 years ago. Nevertheless, it is a wonderfully interesting book and raises many questions, and shows that its author had traveled widely and studied diligently. It illustrates better than any other old treatise on Hydraulics, the slow process of organizing knowledge into Science.

It is interesting to read Frisi's criticism of the absurdities into which mathematicians, even the great Sir Isaac Newton, had been led by efforts to develop laws *a priori* from mathematical reasoning, and Frisi's declaration that Hydraulics is a branch of physics rather than of mathematics, and that he especially renounces the hypothetical calculations of his predecessors. Nevertheless, like much that has been written on river science down to the present year, 1922, and is still current, Frisi's own writings are largely flavored with speculative philosophy.

The first clearly written and concise treatise which I have found anywhere is that by the late Mr. Charles S. Storrow, previously mentioned, which was written 83 years ago.

Bennet's translation of D'Aubuisson's "Hydraulics" was another good American book of many years ago, written, I have been told, by a man of exceptionally fine character, mostly at home in the evenings and late at night, while he was trying to cheer up an invalid wife by faithful companionship.

An admirably full bibliography tracing the development of the hydraulic theory of flow in rivers from the earliest times down to 62 years ago, with an appreciation of the contributions to the science by each author, can be found in Chapter III, pages 187 to 228, of Humphreys' and Abbot's "Physics and Hydraulics of the Mississippi." Perhaps the most noteworthy contribution to river training since that time is that of Professor James Thomson on the travel of detritus diagonally across rivers at bends, reported to the Royal Society in 1877 (page 356), or 45 years ago.

It was 65 years ago that the publication of Henri Darcy's researches on flow of water in pipes called attention to the remarkable differences in loss of head, or slope, caused by different degrees of smoothness of the walls of pipes, and developed the parabolic law of distribution of velocities in pipes by means of the Pitot tube; but the remarkable series of experiments on open canals by Darcy and Bazin was not published until 1863, or two years subsequent to the publication of the investigations of Humphreys and Abbot.

These experiments on flow of water in straight pipes and straight open artificial canals, made in France, at Government expense, by Darcy and Bazin, with thoughtfully designed apparatus and special attention to observing the effect of smoothness of conduit wall upon resistance to flow, and measurement of the distribution of linear mean velocities, are a fine example of service of a well equipped laboratory to Science and the Constructive Arts. The scarcity of similar examples shows that research of this kind must be financed by the Government, or mostly remain undone. Bazin made subsequently some important contributions to data on weir flow, but the data of the epoch-making Darcy and Bazin laboratory researches have not been added to in the sixty years that have followed to anything like the extent that one might expect, nor has the work so admirably begun by Humphreys and Abbot been followed up as the importance of the subject deserves.

Nearly 50 years ago, we had the excellent translation of Weisbach's Hydraulics (first published in German 76 years ago), by our fellow member the late Eckley B. Coxe, M. Am. Soc. C. E., and many admirable college text-books on Hydraulics have been published since, especially notable among which are those of Professor Mansfield Merriman, M. Am. Soc. C. E., Professor Irving P. Church, Affiliate, Am. Soc. C. E., that of David A. Molitor, M. Am. Soc. C. E., giving refinement of formulas, Professor W. C. Unwin, Hon. M. Am. Soc. C. E., the late Professor Bovey, of Montreal and London, Hughes and Safford, and the recent book of Professor William H. Durand dealing with flow in pipes. Revy has described his researches on the great rivers of South America. Cunningham and Gordon, Kennedy and Buckley have written excellent books giving fragmentary observations on the rivers of India, and Thomas and Watt, United States Assistant Engineers of long experience, have published a monumental treatise on the improvement of rivers, dealing mainly with structural designs. I do not find, however, in any of these books the theories, or the data, that we need in training rivers for relief from flood; nor do I find it in the excellent work of Professor Van Ornum, formerly a U. S. Assistant Engineer, or in the works of those authors experienced in the special problems of India, Belasis, Strange, Buckley and Parker, although the two latter present some suggestive data from the Indian works. These latter manuals are intended for the practicing engineer rather than for the college student. Spring's "Training of Rivers on the Guide Bank System", also gives many fruitful suggestions, as does also the development of the "Bell Bund" guide dikes at several Indian bridges.

The reports of the several International Navigation Congresses of the past 20 years give many interesting opinions and some highly useful observations, but as I have read them, the impression has been vivid that they were concerned chiefly, as the title shows, with river training for Navigation, not for Flood Relief. Although the preponderance of authority is for training rivers along the curving lines of Nature, I do not find that the engineers of the great irrigation canals of India which have to take care of some of the worst sediment-carrying waters found anywhere in the world, lay them out on other than the straightest practicable lines. Their problem (like ours in training rivers for flood relief), is the *conveyance of water,* not its navigation, or the fixation of shoals for the convenience of pilots.

In Germany, Professor Hubert Engels has published an admirable treatise dealing with river and harbor structures, of which a new addition is just out, which appears to give a résumé of all recent European writings on river training. In France, Fargue has written much of interest in trying to formulate laws of river control; but all these treatises have had to deal with scant data, and many of the fundamental scientific laws governing erosion, transportation and deposition of sediments, and the art of river training, are not yet well established. Even Kennedy's laws and rules for silt control in canals and rivers, derived from many observations in India, while heartily approved by many experienced engineers, are questioned or doubted by others.

Three years ago, as previously stated, in preparation for my work in China, I arranged with Hardy Cross, Assoc. M. Am. Soc. C. E., then Assistant Professor of Civil Engineering in Brown University, to make a thorough search for everything in recent contributions to the science and art of river training, which seemed worthy of an abstract, in the principal libraries, beginning with the Corthell Library at Brown University and covering the Libraries of Harvard, the Massachusetts Institute of Technology, Boston Public Library, New York Public Library, Engineering Societies Library, and the Library of Congress, also including the *Minutes of Proceedings* of the Institution of Civil Engineers and the *Transactions* of this Society, and of the several International Congresses for the improvement of navigation and many recent French and German publications. He compiled, with excellent judgment, about 1 000 typewritten pages and photostat copies of abstracts, classified them, and brought them into parallel for my use.

My general impression, born of weariness, after laboriously reviewing his many papers, was that we had collected mainly a mass of conflicting opinions, with a comparatively small amount of new data. This first impression was too severe, for much was found that is interesting and valuable, which I would like sometime to arrange more fully and publish as a volume of classified topical abstracts containing perhaps 500 pages, for the convenience of other students and in the hope that the state of uncertainty thus revealed would stimulate a new departure in research in laboratory and river, that would lead to certainties instead of merely a collection of conflicting opinions.

There is promise of some noteworthy additions to the literature of river training in the near future. Col. C. McD. Townsend, U. S. A. (*Retired*), M. Am. Soc. C. E., for many years Chairman of the Mississippi River Commission has ready for publication a new book, in which all who know of his many years of great interest in river and harbor problems, may hope to find much information of value.

J. A. Ockerson, Past-President, Am. Soc. C. E., reported in the course of his recent address at Dayton, Ohio, on "Flood Problems of the Mississippi",* that work is now in progress on the task assigned to a special committee of its members, "of preparing a full report of the work done under the Mississippi River Commission and the results attained, 'in order to bring together with a view to publication and make available the great mass of valuable data relating to river hydraulics, covering the physical investigations of the varying elements that make up regimen of the Mississippi River, as well as the instrumentalities that have been developed and tried out by the Mississippi River

* *Proceedings*, Am. Soc. C. E., May, 1922, p. 1184.

Commission and its assistants in channel improvement and flood control of the river'."

It is to be hoped this report will be published soon and that it will bring together the valuable views and opinions scattered through the reports issued annually for the past forty years by the Mississippi River Commission, and also all the important data from reports published from year to year as sections of the general report of the Chief of Engineers, U. S. Army, who is charged with all work performed on rivers and harbors under appropriations by Congress.

Although the Science of Hydraulics has made small progress in the past 50 years, the Arts of hydraulic construction have been wonderfully developed in many structures built on a stupendous scale.

The recent Catskill Aqueduct, in a single conduit, has nearly ten times the combined capacity of all the nine aqueducts of Ancient Rome. We now have no occasion to build such magnificent architectural structures as the Pont du Garde, because thanks to the progress in manufacture and the low cost of structural steel, we get far more capacity for less money in a 10-ft. steel siphon. The Los Angeles Aqueduct in boldness of conception far outranks anything of olden time. Moreover, it supplies to the community not only water, but from this water as it flows to the city, it provides electric power and light, which services were not dreamed of even a half century ago. The Hetch Hetchy Aqueduct, now in progress of construction, is on an even more stupendous scale. The Boston Aqueducts, although now outranked in size and length, should not be overlooked, for it was in their construction under the late Joseph P. Davis, M. Am. Soc. C. E., the late Alphonse Fteley, Frederic P. Stearns, and Desmond FitzGerald, all Past-Presidents, Am. Soc. C. E., that a school of scientific water-works construction was established in Boston, the influence of which has spread around the world; as has also the influence of Boston and Massachusetts in safeguarding the purity of domestic water supplies, under the devoted leadership of the late Hiram F. Mills, Hon. M. Am. Soc. C. E., who, shunning all publicity, gave the best that was in him to the service of his fellow men, without fee or salary, during the larger part of his working hours for 30 years.

In power development, also in turbines, the scale of construction has become truly wonderful. About twelve years ago at Keokuk, Iowa, the Mississippi River Power Company had designed a single hydraulic turbine having a power capacity about two-thirds that of all the eighty turbines in Lawrence, Mass., or to all those in Manchester, N. H., and then placed fifteen of these huge units in a row. A few months later, even larger units were put into service at The Cedars, on the St. Lawrence, and now near Niagara, on the Canadian side, there have just been put into service, single units, each of which has a power capacity about equal to the sum total of the developed turbine capacity at Lowell, Lawrence, and Manchester, the three great power cities on the Merrimack, which were three of the greatest water-power centers in the world only a half a century ago. In these great modern water-power developments, the hydraulic turbine yielding more than 90% of the theoretic power in water fall, has been brought as near to perfection as can ever be hoped for.

Meanwhile, water-power development in icebound latitudes has been greatly helped as the outcome of a research in pure science, by Dr. Howard T. Barnes, Professor of Physics in McGill University, who has shown us how to conquer anchor-ice troubles, by raising the temperature of the water less than 0.01° Fahr.

The art of building great dams, both of masonry and of earth, has been developed on the great municipal water supplies for Boston and New York City, and, particularly, for the U. S. Reclamation Service, until now it is proposed to build on the Colorado River, a concrete dam, having its crest 605 ft. above the present low-water surface or higher than the Washington Monument. Its proposed height above bed-rock foundation is 745 ft., or about the same as the topmost pinnacle of the Woolworth Building above Broadway.* In recent years, several masonry dams have been built that are much taller than the Bunker Hill Monument, the granite shaft of which, in Daniel Webster's day, was considered a wonderfully tall masonry structure.

In irrigation works, the hydraulic engineers of the United States, particularly those attached to the U. S. Reclamation Service, under A. P. Davis, Past-President, Am. Soc. C. E., have developed works far beyond even the conception of the Ancients, although they have as yet hardly equalled the acreage brought under the service of water in India during the past century by English engineers.

The canal construction at Panama and the solution of its important hydraulic problems are so well known to all engineers that no especial mention of them is needed here.

Doubtless, I will be criticised for having intimated, in the face of all those stupendous works, that Hydraulic Science has been moving too slowly. In partial answer, it may be said again that it is not the art that has slumbered, but important parts of the science, notably river hydraulics and the means of training rivers to flow peacefully and to carry their load of sediment to the sea, and to dig themselves deeper, if the character of the bed and the general situation permit.

Some explanation for this lack of progress may be found in the fact that some of these American river problems are larger and more difficult than those in other parts of the world, and that it is the American habit to go ahead with the construction without waiting to develop the scientific theory to the utmost nicety. We can build good aqueducts and safe dams notwithstanding uncertainty about the root of h in the Chezy formula or the precise value of the coefficient of discharge for a round crested weir, and can develop power without waiting to untangle all the vagaries of preliminary stream gaugings. Progress in construction is often more profitable than precision, and, for example, at Panama, the Federal Government was wealthy enough to stop the slides by simply digging away everything which it seemed might sometime slide, instead of taking the chances involved in delay while profound studies were being made on the increasing frictional stability of earth by the abstraction of water, or by other means. Nevertheless, in the long run, waste

* See "Problems of Imperial Valley," U. S. Senate Doc. 142, 67th Cong., Govt. Printing Office, 1922, Plate IV, following p. 21.

results from all such lack of knowledge, and this seems particularly true with regard to river training and protection from floods.

Many of these great works just mentioned, have added valuable engineering data. Precise measurements giving the relations of flow, slope, and area, have been made in these great modern aqueducts. Messrs. Fteley and Stearns utilized the Boston Sudbury Aqueduct for their weir experiments. The late Hamilton Smith, Jr., M. Am. Soc. C. E., contributed experiments on pipes in California and on orifices at Holyoke, Mass. Herschel has given the results of experiments on flow in the great steel pipes of the East Jersey Water-Works, etc., and the U. S. Department of Agriculture has given us new and valuable data on the coefficients of flow in irrigation canals and flow in drain tile, which add more patches to that wonderful piece of hydraulic patchwork, the Kutter coefficient for the old Chezy formula. This formula with a coefficient, somewhat ragged after 53 years of wear, still covers fairly well most problems of the construction engineer, but it is high time we had something better.*

Moreover, within these recent years, the art of gauging flowing water has been much improved. Past-President Herschel, in his Venturi meter, transformed an ancient curiosity into a most valuable invention, and recently has partly developed and applied for a patent on a new gauging instrument of remarkable simplicity and promise in his new method of measuring the head and area by means of a perforated pipe on a round crested weir, and B. F. Groat, M. Am. Soc. C. E., has developed the art of Chemi-Hydrometry for which he has received the Norman Medal of the Society.† Meanwhile, the electric generator has given a far more convenient absorption dynamometer for measuring output in water-power turbine tests than the old Prony brake.

A National Hydraulic Laboratory

Early in this address, I mentioned the hydraulic laboratory at the Dresden Engineering School which, although small, has been helping to solve problems of river training, under the skilful management of Professor Hubert Engels, who has devoted his life mainly to studying and teaching Hydraulic Engineering and is the author of one of the best books yet written descriptive of the problems and works of the hydraulic construction engineer.‡

About 20 years ago, Professor Engels established a small laboratory for experimenting on models of rivers and worked out mathematical relations between small and large streams, and demonstrated that the model could give dependable results. In 1913, on the moving of the College to a new site, a new Flussbau Laboratorium was built on a larger scale. This new laboratory was still unduly limited by the space left for him by the architect

* Twenty-nine years ago, hoping to add something to Hydraulic Science, the speaker made elaborate experiments of wide range and great accuracy on loss of head corresponding to a wide range of velocities in all commercial varieties of iron water pipe, tees, and elbows, from ⅛ in. to 8 in. in diameter; also, on new, especially smooth brass pipe, from ½ in. to 4 in. in diameter; also on the loss of head in pipes given the roughest possible interior by lining them with expanded metal lath, and on a great variety of elbows, tees and curves of different radii. He greatly regrets that he has not yet found time to prepare these observations in proper shape for publication, but hopes to finish the reductions and drawings within the coming year. His own shortcomings in failure to publish, make him charitable toward others who might have helped the good cause.

† *Transactions*, Am. Soc. C. E., Vol. LXXX (1916), p. 951.

‡ "Handbuch des Wasserbaues", Leipzic, 1921.

in the basement of the new college building, and hardly a third part as wide or as long as the dimensions that I would suggest for the American National Hydraulic Laboratory. Nevertheless, by the aid of these small models, Professor Engels has worked out various practical problems for rivers and harbors in Germany. A similar laboratory has been built at the Civil Engineering School at Karlsruhe and still another at Berlin. Also, there have been small-scale models built in England and in France for studying river and harbor improvements, and these have been discussed by eminent authorities. After a partial examination of what has been written about them and a review of various discussions of the use of models in the study of river problems, this German type seems best suited for our present needs and promises results of great value *if properly used in parallel with studies on the real river.*

The principal apparatus in the new Dresden Laboratory comprises two canals, or tanks, each about 75 ft. long, the principal canal being about 6.5 ft. wide with an annex, or wing, giving a total of about three times the normal width, within which river bends can be modeled. One tank has a fixed support at one end while the other end rests on jack-screws by which the whole length can be set at various degrees of inclination.* Within this long, tilting tank, a model of the river channel to be experimented on is built up, with all its sinuosities and variations of cross-section. Sometimes the model river bed is built up of earth and sometimes it is made with a base of plaster of Paris, which either can be left bare or can be veneered with earth of the quality under experiment. Sometimes, in studying the deposit of sand-bars, in order to obtain greater visibility, pulverized coal is used to represent the sedimentary deposits, because of its special visibility through the muddy water against the white plaster-of-Paris background.

The same water is circulated over and over again down the model river channel and back through a pipe. By means of a centrifugal pump and by regulating the slope of the tank any desired rate of discharge can be obtained. There are elaborate devices for checking pulsations in the delivered flow, and the experiment can be made with various velocities. After the water has run under a given condition for a time, the model channel can be emptied, and the state of erosion and of deposition of sediment can be observed and photographed.

In Professor Engels' recent publications, the model is shown as arranged for experiments on the Rivers Weser, Rhine, and Danube, and illustrations are given of experiments preliminary to harbor improvements at Düsseldorf, Ymuiden, etc. Also, experiments are described on scour and deposition of sediment caused by various designs of spur-dikes or groynes, some pointing up stream, some down stream, and some squarely across, with photographs showing the deposition of the sand waves developed by the eddies around the ends of these groynes and in the adjacent channel bed. So far as they go the results shown in his publications seem remarkably instructive, considering the small dimensions of his model rivers. He prefers a depth of water not exceeding about 8 in., because with greater depth of sediment-laden water, the motion of the sand grains along the bottom cannot be observed. I am led to believe that

* A recent publication shows the river tank set up on rigid supports.

more convincing results could be had from the larger tank that I would now propose and in which either small or large depths could be used.

I beg that I be not misunderstood as claiming or suggesting that the several problems of river training, and erosion and sand-bar deposition, can be completely solved in such a laboratory. Tests on the model stream, seldom of more than 2 ft. in depth or 10 ft. in width, would be suggestive rather than conclusive, and should be supplemented constantly by reference to the full-size specimen. The mathematical laws of correspondence seem to have been fairly well demonstrated in Professor Engels' laboratory, but by this frequent comparison they would soon become well established. It needs no extended argument to prove that variants in form of dike, jetty, or in slope of river bank, or seashore and bulkhead, and all the varying relations of velocity to erosions, transportation, and deposition of sand and gravel, could be tried out far more quickly and economically in the model, than on the river or shore, and that thereby the number of years through which the threatened communities must wait for relief could be shortened and the deepening of harbors hastened.

My conception of such a laboratory for America, is that it should be National in scope and available for the use of any one of the branches of the service that has problems of the kind that it could help solve. After serving for studies of river flow, coefficients of pipe flow, and crest discharge, it could be quickly refitted to help solve problems of shore protection against wave wash, like those of the New Jersey or the Santa Barbara shores, and when the series of experiments was completed, the apparatus could be maintained at very small expense until the next problem came.

It is not necessary to locate this National hydraulic laboratory on a flowing river or at a water-fall. There are certain advantages of regulation and precision of measurement which can be best secured by circulating the same water over and over again, by pumps of the centrifugal type. One main requirement is a convenient source of electric power, commonly about 50 h. p., seldom more than 100 h. p., for a few hours, intermittently. If the laboratory is further developed with apparatus for new determinations of accurate data for the discharge over large weirs and various forms of dam crests, up to 5 ft. in depth, there might be sometimes a brief call for 1 000 h. p. or more for a brief experiment that could be performed at night or at off-peak hours. The two canals and the main tanks should be housed for winter use and for protection from wind and rain.

In a preliminary and tentative way (but subject to revision after conference with others interested), I am proposing that the tilting tank for the model river be about 250 ft. in length, 20 ft. in width, and about 3 ft. in depth, with a broad wing giving a width of, perhaps, 50 ft. for laying out river bends, and that this tilting tank be fixed at one end at a permanent elevation on a fulcrum or pivot, while it is supported elsewhere by a series of jack-screws about 25 ft. apart, all actuated by worm wheels of varying pitch, proportional to the movement during inclination, so that all can be actuated from a single shaft and motor and the model tank quickly set at any desired gradient, from horizontal to, say, 3 per cent. After a run at one slope, the inclination can be changed in a moment's time by these screws without other-wise disturbing the model. The same apparatus could be quickly adapted for tests on models of jetties for harbor entrances and for studies of shore protection.

Within this tank, a rough foundation of any convenient material could be shaped to represent a river channel, say, from 5 to 10 ft. wide by 2.5 ft. deep, or smaller, and this base veneered, or covered over, with earthy material from the river in question; or, sedimentary material of the kind carried by this particular river could be stirred into the water while one watched its collection into shoals or sand-bars, and the laws of deposition in eddies behind spur-dikes or retards could be studied. Also, one could study the law of re-distribution of sediments in the bed of a river during floods, by which, in many critical places, material is eroded during a flood from the pool near the concave shore and deposited along the bar, at the point of contraflexure.

One could also develop further information on the respective merits and disadvantages of straightening a channel that has many big bends, which topic has been under dispute since the time of Galileo, and on which I will say more later.

A large amount of much needed information could also be had on the best radius or curvature for the end of spur-dikes placed in series, for maintaining a straight-line channel. There can be no doubt that there is an optimum radius for such curvature and that a dike, with its end curved down stream on a long radius, can be formed so as to lessen the irregularities of the sand waves in the channel bottom and lessen the tendency to undercut the end of the spur-dike or groyne.

Obviously, it is far cheaper to begin the development of the best form of groyne in a small, cheap model than to build a groyne of full-size in the river; moreover, the effect of changes in outline can be far more quickly studied as the experiments progress. One can perhaps cover as wide a range of experiment for finding which is the best form in 6 days on the model as he could cover in 6 months on the river. Nevertheless, studies on the small model and on the large river should go on almost simultaneously, and the distribution of velocities in eddies and the capricious forms of sand waves in river, and in model, must constantly be compared, in order that the tests on the small model may not lead one astray.

The admirable experiments on the transportation of sand and river débris, carried on by Professor Grove Karl Gilbert, of the U. S. Geological Survey, at the University of California, in 1914, could be extended.

The most difficult requirement of all in establishing a National Hydraulic Laboratory, is that of finding a director who shall have a clear head, a broad experience in the field, and a devotion to science like that of the late Professor Gilbert.

Last, but not least, is the matter of swirls and eddies and sundry obscure forms of vortex motion in the water, which some of us who have been observing watercourses for many years, believe are at the bottom of many of the problems of erosion and transportation of sediments. The swirls and eddies of the big river could be studied in parallel with studies in a laboratory of the dimensions proposed. I believe that by glass plates in the walls and powerful illumination of a thin optical section by means analogous to those used with the ultra-microscope and with the use of bright sand grains and a high-speed motion picture camera, much could be learned about this vortex motion.

The tank in the laboratory of Professor Engels has been used for a variety of other experiments, for example, studies have been made relative to the shaping of jetties at harbor entrances on coast lines where great quantities of sand are swept along by the tidal currents and clog the entrance to the harbor; and studies also have been made of varients in the outline of these harbor jetties, for lessening the deposits, or of disposing of them so as to lessen their obstruction to navigation.

Other trials have been made in Professor Engels' laboratory on the effect of various forms of bulkhead or sea-wall in resisting the action of storm waves, and for obtaining a shape of the vertical cross-section of the embankment or sea-wall that will leave the sand carried by waves and littoral currents in good shape. In order to simulate wave wash on the shore, a volume of water is held back by a gate at the up-stream end of the tank, which gate is lifted suddenly, allowing a symmetrical wave to advance with uniform speed down the channel and impinge on the model of sandy foreshore and bulkhead.

Obviously, this tilting tank could be applied to a great variety of investigations, for example, for an extension to larger sizes of the experiments for determining the laws of flow in drainage pipes, made a few years ago by the U. S. Department of Agriculture. The pipe or conduit to be experimented upon could be blocked up by supports from the bottom of the tilting tank and the water could be run through it at any desired slope, from zero up to 3%, by quickly re-setting the screw supports, which could be done in a moment's time without disturbing the alignment. Such a series of experiments would give much valuable new data on the discharge of partly filled drains and sewers up to cross-sections 5 ft. or more in diameter.

Alongside this tilting-tank canal, I would propose building a parallel canal with concrete walls, say, 240 ft. in length, 15 ft. in width, and 15 to 25 ft. in depth, in which experiments could be made on the flow over models of dams and weirs of various forms, and in which other experiments could be made for determining new methods of precise measurement of velocity in disturbed currents. For certain tests, the current could be given a twist by inclined shear boards attached to the bottom or sides of the tank. In large, filled, circular conduits like turbine penstocks, there is often a surprising amount of twist in the current and sometimes it is present in deep rectangular canals.

There is abundant proof that some supposedly accurate measurements made by ordinary current meters in streams having deeply disturbed currents, have been seriously in error, and the use of such an experimental channel, it is believed, would be of great advantage to the Hydrographic Department of the U. S. Geological Survey, and to many other institutions, in educating its young men in the avoidance of errors in gauging, in addition to other uses in developing new and accurate methods.

In this second proposed experimental channel, provision should be made for weir experiments, with many varieties of shape and roughness of crest, and at greater depths than any heretofore made. A preliminary design for this second experimental canal has been largely repeated from one prepared by myself ten years ago for a proposed large Hydraulic Laboratory for the Massachusetts Institute of Technology, which was crowded off the campus. This design proposes to circulate quantities of water as great as 600 cu. ft. per sec. by means of centrifugal pumps and to make possible the precise measurement of rates of discharge in a tank, with a limit of error within one-tenth of 1 per cent. It provides for experiments with 5 ft. in depth over a round-crested weir, 15 ft. in length, by utilizing a quick-swinging gate, somewhat after the idea used by Francis in his famous weir experiments, by which in a fraction of a second the weir flow can be diverted from one channel into another and the interval of tank-fill timed by an electric chronograph. This capacity of 600 sec-ft. could be used for experiments at greater depths over the weir by narrowing the sluiceway, also, various much needed data could be obtained on the coefficients of flow through sluices and over drowned weirs. Also, the new method of measuring depth on a round-crested weir, devised by Past-President Herschel and partly tested under a grant from the Engineering Foundation,* could be thoroughly tested.

Many years ago, I became convinced that a standard round-crested weir could be developed that would be superior to the sharp-crested weir and that precision of measurement, particularly in inexperienced hands, can be greatly improved by thus avoiding the disturbances due to eddies and the irregularities in the contracted vein due to swirls and irregular motion in the channel of approach.

Certain preliminary experiments made by the late Mr. Mills, on a "Venturi flume", at Lowell, Mass., indicate that a very instructive series could be run on such a piece of apparatus in this new laboratory, which might develop considerable utility in the constructive arts.

The laws of the so-called "hydraulic jump", which has lately come into prominence as an absorber of energy and thus a safety device for protecting the undermining of dams, could be much better worked out. Through the mathematical investigations of Karl R. Kennison, Assoc. M. Am. Soc. C. E., reported to the Society,† we know that the time-honored formula is wrong and a series of experiments with varying forms of pit and with various forms of deflectors, at the foot of the fall, would aid greatly in showing how best to absorb energy in the friction of eddy currents with maximum structural economy. The absorption of energy at the "jump" comes largely from the friction losses in the violent churning and swirling of the waters in the small open chamber immediately down stream from the jet.

When a set of tests has once been worked out understandingly and carefully, the results are good for all time, within the limits tested, like the weir experiments made by Francis 60 years ago.

This proposed National laboratory would be essentially for experiments on a large scale, leaving to the small-scale college laboratories, about 50 in number, built in recent years, the researches within their capacity.

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* *Transactions*, Am. Soc. Mech. Engrs., May, 1920.

† *Transactions*, Am. Soc. C. E., Vol. LXXX (1916), p. 338.

In order to give an example of the capacity of such a river laboratory,* let us consider the biggest problem possible, that of the Mississippi. Problems of German rivers have been studied in laboratory tanks of one-third the linear dimensions here proposed, and let us run an experiment from the point of view of flood relief rather than improvement of navigation.

In the beginning, however, let me say that if this experiment to be next described, was successful in the model, no means yet exist for carrying out such a plan of cut-offs and straightening on so grand a scale as the Mississippi would require. Groynes or retards cannot yet be built capable of holding a river bank 100 ft. high.

If the principle should prove good, there are many smaller rivers on which it could be tried. If the test failed, there might be achieved the valuable result of settling an argument that has been going on since the days of Galileo and of Ancient Rome.

Let there be modeled in the proposed tilting tank a winding stream with a soft or sandy bed, in form analogous to the Lower Mississippi, on a horizontal scale of 1 to 1 000 and a vertical scale of 1 to 100. This distortion of scale probably would not seriously disturb the results. It would be analogous to experimenting on the discharge over a section of dam crest only 3 ft. long, where the entire structure had a crest 30 ft. long. The test could be repeated on natural scale.

Our 200 ft. in length of experimental tank would then represent 200 000 ft., or about 40 miles, along the valley, and its 20 ft. of width would accommodate a bend with an ordinate of nearly 4 miles, while the broad part of the tank would take in a bend of nearly 10 miles ordinate.

Corresponding to the 100-ft. flood depth of the Mississippi, we would have a 1-ft. depth flowing in the tank, and instead of a main river channel, 3 000 or 4 000 ft. in width, the channel in the tank would be 3 or 4 ft. wide.

The slope of the tilting tank would be readily adjusted by the screws to give a velocity, somewhere near to that of the actual river; or such velocity that there would be an analogous slow process of erosion at bends and of deposition of sediment on the nearly opposite convex shoal, with an established regimen showing no important scour or fill along the straighter portions. Although swirls and vortices that exist in the large river, which have much to do with scour and transportation of sediment, might not be found fully represented, there doubtless would be some analogous action in the model stream.

The rise and fall of a flood could be represented by varying the discharge at the pump. Various percentages of sedimentary material could be put into circulation. The formation of bends and action of sand waves could be studied and a great variety of instructive observations made.

After having made various precise quantitative observations on the behavior of the model of the curving, sediment-carrying river in flood, let a section of channel comprising one or two bends be straightened by cutting off the bends and training it to the straightest practicable line, giving it the same average depth as before and holding it from spreading, or wandering horizontally,

* Outline designs for this laboratory are in course of preparation by the speaker, *pro bono.*

by means of dikes and projecting spur-dikes or groynes, which preferably should make the flood channel, say, 10 to 20% narrower than before, in order to encourage the scouring to greater depths.

At the down-stream end of this straightened section let the water be restrained from changing its surface elevation, as by discharge into the Gulf, and at the up-stream end of the section straightened, restrain the bed from being scoured deeper by the swifter current by a "sill", analogous to that built at the head of the Atchafalaya outlet from the Mississippi to prevent its scouring deeper, or analogous to those built at the head of the "Passes".

During this rectifying of channel and enlarging of the cut-off trench some additional head for scour could be had temporarily, if needed, by the water backing up over the sill into the section next up stream, until erosion had lowered the bed.

In addition to increase of velocity and scouring force caused by increased slope, increased depth, of itself, tends to cause increase of velocity with increase of power to erode.

If under the original condition of the curving river, scour and sedimentation were in equilibrium and the regimen thus established over the erodible bottom, then under the new condition this increased current will dig the bed deeper than before, unless the river has a hard resistant bed.

As erosion of the bed progresses the elevation of the water surface along the middle and up-stream part of the straight section will progressively become lower, because of the decreased slope needed to convey the water in the deepened channel. Rapids will be established over the sill placed previously at the head of the section, of increasing height and steepness, until equilibrium is established; and, finally, the current would probably settle down to nearly the same mean velocity all along the straightened river as that originally found in the crooked river; because with a given quality of bed material the control and establishment of a permanent regimen depends on attaining the bottom velocity which is not great enough to dig and is too great to permit deposition. There is commonly some margin between these limits.

The feature of greatest interest and apprehension of trouble is the possibility that with the lessened obstruction from building up the crossing-bar in the curved channel, there would be substituted in the straight channel trouble from sand waves, moving irregularly here, there or anywhere down stream at the rate of only, perhaps, a mile per year. The experiment with the model might give some very useful suggestions. River observations have generally shown that the sand wave did not extend all the way across the channel, like the "crossing"-bar.

The final longitudinal section of the straight river, after regimen is established, probably would differ substantially from that of the natural curving river which works itself into a succession of pools and shoals, deep pools in the bends, with their line of maximum depth following along near the concave shore, which pools are separated by bars of sediment, or coarser gravel, deposited at the place of reversal of curvature—the "cross-over", as the pilots call it—where the channel shifts to near the other bank. In the straight river, the transverse section of the channel will be more nearly of uniform depth and there will be no occasion for gravel bars to accumulate at the cross-over, for there will be no such strongly marked cross-over. Possibly much of this coarser material might find lodgment in the depths of the old pools. With the meander stopped, the supply of coarse material which now builds up the cross-over bars, would be lessened.

In the straight river it is probable that the flood would dig the deposit of sediment more deeply and more uniformly all along, and that the increase of flood height caused by these submerged dams rolled up by the current during a flood, would be substantially reduced.

After one section of model river (or actual river) had been thus trained and its bed lowered, the section next up stream could be undertaken, and the restraining sill between the two sections removed. At each successive stage up stream there would be greater forces available for hastening the excavation, because the amount of fall over the successive sills would be cumulative; and the cumulative change of fall due to the lessened resistance to flow in a straight deep uniform channel and slope possibly would dig the bed enough deeper so that in the upper reaches its floods would no longer reach the top of the banks, and levees no longer be needed.

The reported experience of the past 20 or 30 years with the Atchafalaya channel, below the outlet sill from the Mississippi, indicates that the test would be successful.

The many disastrous effects recorded as resulting from cut-offs of bends in the Mississippi, in past years, seem to have been caused by lack of control. Things simply have run wild under the increased slope of the shortened piece of river. New bends have been eroded, banks undercut, vast areas of fertile land ruined, the products of scour deposited on bars down stream and previously established regimen disturbed, it is said, for more than 50 miles, the disturbed length extending both above and below the cut-off, and the river has not appeared satisfied until the original excess of length has been restored. All this appears to be Nature's method of building deltas and fertile bottom-lands with material eroded from the hills, but after man arrives and needs to cultivate these bottom-lands for a food supply, a change of program may be entirely reasonable. If a cut-off is to be beneficial, it must be under most carefully planned control, with sills, groynes, etc.

As stated previously, however, no practicable type of groyne has yet been developed, that could safely protect and restrain the 100-ft. depth of the Lower Mississippi. Apparently, there now is one that can cope with the Missouri and the Platte, and such laboratory test, therefore, would be applicable to those rivers and many others.

There are a hundred important problems that I have not space here to mention, the solution of which a laboratory on this large scale could hasten. Thoughtfully devised experiments in the laboratory compared with observations on the big river, would develop new lines of analogy, test theories, and surely bring benefits and economies far outweighing the cost of the laboratory, and give basis for deduction from observed facts, instead of mere personal opinions, speculation, and philosophical discussion.