Reprint. "To Establish a National Hydraulic Laboratory..." Sept. 1922

TO ESTABLISH A NATIONAL HYDRAULIC LABORATORY

HEARING

BEFORE A

SUBCOMMITTEE OF THE COMMITTEE ON COMMERCE UNITED STATES SENATE

SIXTY-SEVENTH CONGRESS
SECOND SESSION

PURSUANT TO

S. J. RES. 209

TO ESTABLISH A NATIONAL HYDRAULIC LABORATORY

SEPTEMBER 8, 1922

Printed for the use of the Committee on Commerce

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

11077

COMMITTEE ON COMMERCE.

WESLEY L. JONES, Washington, *Chairman.*

KNUTE NELSON, Minnesota.
BERT M. FERNALD, Maine.
WILLIAM M. CALDER, New York.
IRVINE L. LENROOT, Wisconsin.
CHARLES L. McNARY, Oregon.
WALTER E. EDGE, New Jersey.
FRANK B. WILLIS, Ohio.
OVINGTON E. WELLER, Maryland.
COLEMAN DU PONT, Delaware.
DUNCAN U. FLETCHER, Florida.
JOSEPH E. RANSDELL, Louisiana.
MORRIS SHEPPARD, Texas.
FURNIFOLD McL. SIMMONS, North Carolina.
NATHANIEL B. DIAL, South Carolina.
THADDEUS H. CARAWAY, Arkansas.

J. H. DAVIS, *Clerk.*
HAZEL E. JONES, *Assistant Clerk.*

SUBCOMMITTEE ON SENATE JOINT RESOLUTION 209.

CHARLES L. McNARY, Oregon.
COLEMAN DU PONT, Delaware.
JOSEPH E. RANSDELL, Louisiana.

CONTENTS.

NATIONAL HYDRAULIC LABORATORY.

FRIDAY, SEPTEMBER 8, 1922.

United States Senate,
Subcommittee of the Committee on Commerce,
Washington, D. C.

The subcommittee met pursuant to call at 10.30 o'clock a. m. in the committee room, Capitol, Senator Joseph E. Ransdell, of Louisiana, presiding.

Present: Senators Ransdell, McNary, and Du Pont.

Senator Ransdell. This is a hearing on Senate Joint Resolution 209, introduced by myself, to create a national hydraulic laboratory.

(The joint resolution under consideration by the subcommittee is here printed in full, as follows:)

[S. J. Res. 209, Sixty-seventh Congress, second session.]

JOINT RESOLUTION To establish a national hydraulic laboratory.

Whereas floods are causing increasing losses along many of the streams of the United States; and

Whereas there is great lack of information on this matter which is of vital concern to the people in various sections of the United States; and

Whereas there is disagreement among the best authorities on fundamental practices involved; and

Whereas systematic research and comprehensive study of flood-control experience and practice in all ages and in all countries promises to be helpful in meeting problems on streams in the United States: Therefore be it

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That a national hydraulic laboratory be established in the District of Columbia, in connection with such bureau as the President may designate, for the conduct of research, experiments, and scientific studies in connection with the problems of river hydraulics, and an appropriation of $200,000 is hereby authorized for that purpose.

Senator Ransdell. Our first witness this morning will be Mr. Morris Bien. You are connected with the Reclamation Service, are you not, Mr. Bien?

Mr. Bien. Yes, sir.

Senator Ransdell. Now, Mr. Bien, if you will state in your own way anything you desire to say upon this resolution we will appreciate it.

STATEMENT OF MR. MORRIS BIEN, ASSISTANT DIRECTOR RECLAMATION SERVICE, WASHINGTON, D. C.

Mr. Bien. Mr. Chairman and gentlemen of the subcommittee, Mr. Davis, who is in charge of the office, is in the West at the present time, so I am appearing before the committee for the Reclamation Service. I merely wish to call attention to the work that the service has done on one phase of hydraulic investigations, namely, such as are essential to the construction, management, and operation of the irrigation works which we have been building for nearly 20 years in the irrigated country of the West under the reclamation act of June 17, 1902 (32 Stat. 388). In connection with such work a great deal of information is essential regarding the flow of water in canals, the flow of water through outlets, the flow of water over dams, and many other conditions of that kind. We have spent a small amount of money on such studies, but we have been limited to what was absolutely essential for the particular work required by the reclamation law, because the bulk of our money must be spent for irrigation works.

In the Reclamation Record, which we publish monthly, in the issue of December, 1920, page 578, we have printed a report on the engineering investigations of the service. I would like to mention a few headings to give an idea of the scope of the work of these investigations:

Seepage losses from canals.

The value of Kutter's formula, which is the means by which we compute the flow of water in channels and canals.

The effect of stilling basins and chutes to decrease the power of water in dropping to a lower level.

Coefficient of discharge through head gates.

Intake and outlet losses of flumes and canals.

The various functions affecting siphon losses.

The form and method of construction of drops of various kinds where water must be dropped to a lower level.

We have also investigated the value of Kutter's formula for discharge in metal flumes; the friction of bronze on bronze in gates for outlets; transition losses in concrete-lined canals, that is, where it passes through a change of size or shape in concrete-lined canals; the sag in metal flumes which affects the discharge; friction coefficients for gate leaves and bronze seats; coefficient of discharge for overflow dams; discharge coefficients through head gates; and the effect of alkali on concrete.

A great deal of our work has been based on information obtained by other bureaus. We have had available much information, published or unpublished, from the Geological Survey, the Bureau of Standards, and other bureaus. We have been limited in these investigations, because it was incidental, as we had no special appropriation and used a small amount of our regular appropriations to carry them out. The importance of these investigations is evident, because as a result we can save water, and therefore save expense to the water users on our projects. It costs a large amount of money to get water to the land where it is used, as we must often carry it long distances. We have spent about $160,000,000 on our irrigation works, and the law requires the settlers on the land to repay it. It is therefore our effort to perform the work in the most economical and efficient way, so as to reduce the burden on the settlers who not only have to repay the cost but they must usually produce it out of the soil. I think that is all I have to say, unless you desire to ask some questions.

Senator RANSDELL. As a result of your studies, do you believe that the work contemplated by this hydraulic laboratory would be of very material assistance to the Reclamation Service?

Mr. BIEN. I am satisfied of that, because we would be glad to spend more money on this work, but we do not feel justified in diverting any more from the actual construction work. I know that it would be a great advantage to the work, as it would assist us in making more economical use of water and, directly or indirectly, reduce the cost to the settlers who by law are required to repay it. So we are strongly for it. Mr. Davis, our director, is much interested, and he has helped in carrying the idea along.

Senator RANSDELL. Have you any suggestion to make as to which branch of the service should have charge of it if it be created by law?

Mr. BIEN. I am not sufficiently familiar with the work of all bureaus to answer that; but the Bureau of Standards and the Geological Survey have trained observers for this kind of work. Whether it would be feasible to divide the work between them I don't know. There are certain classes of work in this line that the Bureau of Standards can do rather better than the other bureaus, but much of it could be handled by the Geological Survey.

Senator RANSDELL. Could you leave out entirely the Engineer Corps of the Army?

Mr. BIEN. My understanding of their work is that many of the problems in which we are interested do not come up in their work.

Senatod DU PONT. What do you come in contact with?

Mr. BIEN. The flow of water in rivers and in artificial channels and outlet structures.

Senator DU PONT. Have you any laboratory now in your department?

Mr. BIEN. No; but we have this advantage, that we can do the experimental work on the actual structures.

Senator DU PONT. You do your actual experimenting by making notes of what happens, from practical results of the finished work?

Mr. BIEN. We study the way water flows in canals and outlets of various kinds.

Senator DU PONT. Those are new works and improvements?

Mr. BIEN. New works and improvements. We have devoted two or three thousand dollars the last few years to that special study.

Senator DU PONT. Experimenting?

Mr. BIEN. Experimenting.

Senator DU PONT. You did that in the field?

Mr. BIEN. By our managers who are handling the works.

Senator DU PONT. They collect the data?

Mr. BIEN. They collect the data. It requires regular visits and reading gauges to know what happens from time to time. We have forces varying from half a dozen men on the small projects to 50 or 60 on the large projects, and we can do this with little expense. We would be glad to cooperate in any investigations of any bureau that would operate under this law and would give them opportunities to use our structures. We cooperated with the Bureau of Standards in their investigation of the effect of alkali water and alkali soils on concrete.

Senator DU PONT. Is there any laboratory connected with any of the departments now which would be of any use in these instances?

Mr. BIEN. Not to my knowledge. Our work has been done in the field. Of course, a laboratory study would be beneficial in many of the problems.

Senator DU PONT. An irrigating canal is a small laboratory in itself?

Mr. BIEN. Yes, sir. Nearly every structure has an outlet into a gate or tunnel and would afford means of making a study.

Senator RANSDELL. I understood you to say that you have spent around $160,000,000 on irrigation work.

Mr. BIEN. That is the total expenditure for our irrigation work.

Senator RANSDELL. About how much more have you in contemplation?

Mr. BIEN. The amount which may ultimately be spent can not easily be estimated, and depends largely on the length of time Congress continues to authorize it.

Senator RANSDELL. There is really a great deal more to be done; you would say that anyway?

Mr. BIEN. There are many acres of arid lands to be irrigated and a great many engineering problems to be solved. The land largely exceeds the water supply.

Senator RANSDELL. You don't intend to confine yourself to arid lands? They have some wet lands down my way that we have been trying to look after.

Mr. BIEN. Of course, very similar methods would be necessary in connection with the drainage of wet lands, but our authority under the law hasn't gone that far. In irrigating lands the farmers have a tendency to use too much water. Frequently in the beginning a large amount of water is necessary to get production started, and that has had the effect of water-logging considerable areas, so that after we have furnished the water for the dry lands we may be required to build drainage works to take off the surplus.

Senator RANSDELL. As you view the situation, this hydraulic laboratory would be very helpful in reclaiming wet lands as well as irrigating dry lands?

Mr. BIEN. Very much so. There is not very much difference in the problems.

Senator RANSDELL. Senator McNary, do you care to ask any questions?

Senator MCNARY. I am interested in the western irrigation projects, but I do not see any connection between them and this proposition. I didn't follow you, Mr. Bien, in what you said about a drop in water in canals. Do you mean a drop in seepage?

Mr. BIEN. No, sir; when water in a canal is being carried through country that has a much heavier grade than is suitable for the canal, or where it is necessary to reach much lower land in a short distance, special structures are necessary to drop it to the next level.

Senator MCNARY. That is, a water canal; not a boat canal?

Mr. BIEN. No, sir.

Senator MCNARY. I didn't just get what you meant by "drop in the water." You had irrigation canals in mind, and I thought you were referring to a drop in a navigation lock.

Mr. BIEN. The resolution as drawn relates only to river hydraulics. I think its scope should be enlarged to cover artificial structures for the carriage of water, because the problems can be studied by the same personnel, and their study would be of great value in the work of several bureaus or offices dealing with questions of irrigation and drainage, and other matters concerning the conveying of water.

Senator RANSDELL. Thank you, Mr. Bien. Now, Mr. Freeman, will you state your full name, your office in the American Society of Civil Engineers, and in a general way your experience in matters bearing upon the subject of this bill?

STATEMENT OF MR. JOHN R. FREEMAN, CIVIL ENGINEER, OF PROVIDENCE, R. I.

Mr. FREEMAN. My full name is John R. Freeman. I am a civil engineer who has specialized in hydraulics for more than 45 years. Although at the present time I happen to be president of the American Society of Civil Engineers, I am appearing here as an individual and I do not assume to represent the society in this matter. But I know from personal conferences that many eminent engineers, members of that society, are strongly in favor of such a laboratory as is now proposed.

To-day there does not exist on the American Continent even one laboratory for the study of river-training problems.

I have come here to speak in favor of such a laboratory mainly because of my observations of the terribly threatening conditions during a tour of inspection along the lower Mississippi a few months ago during the highest flood ever known and because of my profound belief that such a laboratory would be extremely helpful toward better, cheaper, and broader protection against flood disaster by giving to American engineers more precise scientific knowledge than they now possess upon the operation of water currents in eroding, transporting, and depositing sediments; in causing river banks to cave and thus breaking down levees, and in creating bars of sand and gravel which obstruct navigation.

The chief objects of this proposed laboratory are the promotion of economy in certain large expenditures and greater safety to life and property.

This proposed laboratory is an intensely practical matter and is very far from being primarily a place for the mere pleasure of making new discoveries, or for recreation of scientists, or for promoting philosophic discussion.

In the course of my discussion of this proposed laboratory with Senator Ransdell and other friends there has been no thought of creating a new scientific bureau with this laboratory as a center, but solely a proposal to find a home in some existing bureau here in Washington, and on land now owned by the Government, for a single one-story building or shed, and under this roof to build one or two large pieces of testing apparatus, and put them for safekeeping in the hands of one custodian of high scientific training, assisted by two or three young engineering graduate students and one or two mechanics.

The purpose of placing this apparatus under some established Government bureau in or near Washington is that it may be at the service of the engineers of either one of the departments of the Interior, Agriculture, Commerce, Army, or Navy, for a day, a month, or half a year, upon any special problem of importance, or available for water-power problems or those of municipalities or State commissions or of individual engineers. This apparatus would be used for the benefit of all—for example, like the great machine for testing strength of materials at the United States arsenal at Watertown, Mass.

THE USES OF THE PROPOSED LABORATORY.

Tests with models in the laboratory are proposed to be used hand in hand with observations in the field or river, "on the full-sized specimen," as a means of obtaining the underlying scientific fact or law of nature with greater precision. The river training problems to my mind are just now the most important among the many for which this laboratory would be useful.

The laboratory method is a most useful adjunct to observation upon the actual river, because it permits exact control of conditions and permits elimination of many disturbing circumstances found out of doors—one does not have to wait for wind, weather, or for special flow of sediment, or for some special flood velocity of current. The great floods which threaten widespread damage come only about once in 10 years. The Government can not profitably organize an observing staff and fit it out with apparatus to sit down and wait for an opportunity to observe the effect of flood velocities; and when the flood does come, the able engineers of the district will have their hands too full of matters of protection and relief.

In the laboratory one can create the precise special condition that he desires to observe and watch its effects on sand erosion or transportation or deposition, etc. Field observation and laboratory test must continually supplement one another for the best results; and having worked out the probable law in the laboratory, the engineer-scientist can quickly test its application in the field.

The steamboat pilot on the river and the scientist in the laboratory each has certain advantages in his point of view. Much of our river-training work in America has been of that scientific quality that might be expected to be produced by a committee of steamboat pilots without special training in exact science.

There is an important distinction which is recognized more and more from year to year between the experience and skill of the constructive art and the underlying scientific theory by knowledge of which we can make improvements. For example, for many years until very recently road builders had no use for a highway laboratory. Now this has become recognized as highly important for economy and durability of highway construction.

I profoundly believe the proposed expenditure is a measure of economy, in view of the many millions of dollars that are being expended year by year in these United States on hydraulic works.

The amount proposed to be expended upon this laboratory is extremely small in proportion to the expenditures which it would help economize. The Federal Government spends more than a million dollars a year in the upkeep of its river-training structures along the Mississippi, and so far as I can learn the Mississippi River Commission has in recent year been concerned chiefly with structural details and badly needs the aid of science.

The United States Government has expended more than $100,000,000 upon the improvement of the Mississippi and has expended $16,000,000 on the South Pass Entrance to the Mississippi alone, without yet getting it to stay open. About $10,000,000 has been expended for improving the navigation of the Missouri River between Kansas City and St. Louis, and hardly more than a beginning made in stopping the caving of its banks and the shifting of its channel.

The farmers of the lower Mississippi Valley desire their States and the Federal Government to join in expending $40,000,000 or $50,000,000 on completing the levees to full height. I understand that the Mississippi River Commission desires about $300,000,000 more to complete the protection of the Mississippi banks below St. Louis against erosion. Upon all of that work I believe scientific study in this laboratory would aid in economizing and in the production of more permanent results. I have been told that repairs on river-bank revetment cost now more than a million dollars a year on the Mississippi, and that it would require several million dollars to put back into good condition these works on the Missouri River that had to be neglected during the World War.

The city of New York has expended many millions on its water supply, and to-day, as one of its consulting engineers, I now know of a problem where a few days' work in this laboratory would be extremely helpful in drafting a particular specification for a new conduit.

The city of New Orleans just now is actively discussing anew a problem many years old, of a river spillway about 5 miles downstream from the city, to cost three or four million dollars, about which there exists great diversity of opinion and on which problem a few weeks' work with a model in this laboratory supplementing certain observations on the river, would be extremely helpful and might avert disaster. Without exact scientific knowledge about the different kinds of sediment near top and bottom, there is danger that skimming off the top water by this spillway might concentrate the remaining coarse sediments in bars, where force of current would be smaller after the diversion than before the spillway existed, so these sediments might obstruct navigation up through the mouth of the river at the South Pass or Southwest Pass and prevent the big ships from coming to New Orleans.

I am strongly inclined to believe that the Mississippi is seldom or never saturated with all of the sediment that it might be made to transport; but we need experiments in a laboratory to discover the laws and conditions that govern this.

There are urgent problems of seashore protection, west and east, at Santa Barbara, Calif., and on the New Jersey coast, upon which problems this laboratory could help economize.

There are many harbor inlets obstructed by deposits of drifting sand which this laboratory might show how to deposit outside the fairway.

There are certain so-called "dry washes," or gravel "delta cones," in California down which mad torrents sometimes rush with great disaster. I am sure this laboratory could teach how to train them to flow safely.

It cost the Southern Pacific Railroad more than a million and a half dollars to close the break of the Colorado River into the Imperial Valley. The Imperial Valley of California is still threatened by the Colorado River, and notwithstanding the Boulder Canyon Dam is built and controls the floods of the upper river one must still reckon with the floods of the Gila River, and the depression into which the Colorado below Yuma has recently been diverted by a cut-off will soon be filled with sediment, and I believe that a few weeks' work in this laboratory on the most economical and efficient shape for groynes or "retards" would make possible the building of a new permanent levee for keeping the river away, which levee would not be sideswiped and destroyed before a year old, like that built there in 1910–11, with expenditure of about a half million dollars of United States Government funds, and whose failure I find described in the Transactions of the American Society of Civil Engineers in connection with the story of the closing of the great break.

The State of California, in partnership with the Federal Government, is now expending several million dollars on a flood-relief channel for the Sacramento Valley, which also presents extremely important problems of erosion, transportation, and deposition of sediment, and as illustrating differences of opinions in solving such problems it may be mentioned that six different plans were proposed to the board of engineers, some by men of large experience and showing wide divergence of opinion.

Also there are big flood-relief and channel problems awaiting attention on the San Joaquin and also along some of the southern California delta cones, like the San Gabriel wash, for one example, in all of which a combination of laboratory studies with field studies would be useful. There are problems of the pros and cons of river straightening and the resulting benefits or damages of straightening versus curvature to flood disposal or navigation could be measured and weighed more accurately than heretofore, and the seemingly endless discussion about cut-offs could perhaps be brought thus to a reasonable conclusion.

The Reclamation Service of the United States Interior Department and the Forest Service of the United States Department of Agriculture in its water-power studies have many important hydraulic problems in which a large, well-equipped laboratory would be helpful.

Also there are problems of back water from dams, and of the obstruction of bridge piers; of minimizing the loss of head in canal sluiceways, in devising and rating more perfect appliances for gauging large flows of water, and in devising improved means for preventing scour and undermining at the downstream base of overfall dams and spillways (like those which suffered disaster at Austin, Tex., and at Austin, Pa., at both of which I inspected the ruins and concluded the disaster might have been prevented).

There are many other important problems, all awaiting the service of such a laboratory.

I believe there are enough important problems to keep such a laboratory with a staff of from 2 to 6 men busy for 5 or 10 years on investigations which ultimately will pay abundant profit by promoting smaller factors of safety and in developing improved methods of designs.

And, entirely apart from these matters of flood protection and river training, there are many problems of great importance in municipal water supply, in conservation of water for power development, in the safe design of bridge abutments and piers; problems in design of canals and pipe conduits for irrigation, in tests for improving the shape of boats, in developing more accurate apparatus for measuring velocity of currents, in the more precise formulation of certain hydraulic theories, etc., in which such a laboratory could be extremely useful.

A few moments ago I was greatly interested in listening to the statement of Mr. Bien, Assistant Director of the United States Reclamation Service, in favor of a Government hydraulic laboratory, because of my personal contact with their work during some of my summer-vacation tours, when I have accompanied the Director of the Reclamation Service on a part of his round of inspections and have discussed with him some of their problems in Idaho, California, and Arizona, for which better scientific data was needed. For example, I recall the problem of unwatering the site of the Arrow Rock Dam in Idaho—to-day the highest dam in the world—where a change in plant that I suggested, of substituting a particular type of bell-mouth tunnel entrance, with which I happened to have had some experience, in place of the ordinary precedent of a timber flume, saved the Government, as I recall, more than $100,000 and more than a year's time. I mention this now merely to illustrate that such things as "coefficients of discharge," which might seem only of theoretic interest, may have an immediate practical application that can save a great deal of money.

SOURCE OF PRESENT DATA.

The hydraulic coefficients and formulas for flow in rivers, canals, and conduits used to-day in engineering designs and computations all over the world were mostly derived in temporary hydraulic laboratories set up many years ago by the French Government. In these laboratories Dubuat, Poncelet and Lesbros, Darcy and Bazin, and others experimented primarily for aid in the design of structures to be built by the famous French engineering corps of Ponts et Chaussess, but they generously gave their results to the world. In England the Royal Society and other scientific organizations have supplied Prof. Osborne Reynolds and others with limited means for experiments on river and harbor models, and their national physical laboratory now provides a large naval tank for researches on ship models.

In America, save for the Humphreys and Abbott Mississippi investigation of 60 to 70 years ago, the advancement of hydraulic science has chiefly been fostered by certain water-power corporations, as, for example, the Locks & Canals Co., of Lowell, Mass., which gave to the American engineers the celebrated Lowell hydraulic experiments and the Francis weir formula; also the Holyoke Water Power Co., which made its testing flume available to all, primarily for turbine development, but also for certain important experiments on weirs and orifices. Certain American college hydraulic laboratories, particularly that of Cornell, have made notable contributions.

It now seems highly appropriate that the American Federal Government, with its many efforts for improvement of navigation channels, protection of river banks, aids to agriculture by drainage, storage of water for irrigation, conservation of water power in the national forests, etc., and its vast expenditures year by year on hydraulic structures in these various public services, should contribute some new data by means of a national hydraulic laboratory built on a worthy scale, and this seems particularly appropriate, since a large amount of money will undoubtedly be saved as a result of new information thus obtained.

I have been interested in what Mr. Bien, Assistant Director of the United States Reclamation Service, has just said about reclaiming dry lands. There is also a wonderful opportunity to reclaim wet lands along the lower Mississippi. During my studies in China I learned that hundreds of years ago the Chinese reclaimed vast areas of salt marsh that previously had no value whatever by first throwing up a very cheap dike around the outer edge of one trace after another, each of a few square miles in area. They then allowed the sediment-laden water of the Yellow River to flow over that land and to deposit its sediment, while the clarified water flowed off on the opposite side into the sea. By these deposits of sediments they brought the land several feet above the level of the sea and made it excellent for purposes of agriculture, for the river sediments make extremely fertile land.

It has seemed to me as I have studied the map of Louisiana and as I have looked over the country alongside the river near the Gulf below New Orleans that there is a great opportunity for that kind of reclamation alongside the lower Mississippi, and that this laboratory and the studies made in connection therewith would be useful for helping that kind of work along. Before beginning that work we need a better scientific basis than we now have regarding the classification, transportation, and deposition of Mississippi sediments, and better information about how to take out or how to deposit the heavy sediments.

Senator McNary. Do you contemplate taking up under this resolution various forms of reclamation, drainage, irrigation, flood control, river training, and the various problems involved in the storage of water for developing hydraulic energy? I am wondering how comprehensive your plan is. I have myself studied certain of these matters relating to western reclamation problems and understand that most of that work is done by the various bureaus in the most practical way, and I am wondering how far you intend to go into these various schemes. This resolution as it now stands is apparently limited to flood-control problems.

Mr. FREEMAN. My conception of this matter is that the work of this laboratory should not be limited to flood-control problems, and that it should not interfere with any work now done by these several bureaus, but that this laboratory should help them all in obtaining more precise scientific data; that it should be at the service of first one bureau and then of another in obtaining precise scientific data, and thereby help all in economizing the cost of works and in improving their efficiency.

For example, our Army Engineers might occupy this laboratory for several months for certain experiments on river training, next it might be used by the Hydrographic Division of the United States Geological Survey or by those engineers of the United States Department of Agriculture who are now making hydraulic experiments with reference to farm-drainage problems, also it could in turn be used by the United States Reclamation Service on problems like that of by-passing the water while building the Boulder Canyon Dam.

The United States Department of Agriculture now proposes carrying on experiments in the hydraulic laboratory of the University of Iowa, on the flow of water in pipes, for distributing it for irrigation. The Department of Agriculture a few years ago made experiments across the Potomac from Washington on the discharge of drainage channels, which perhaps could have been done in one-tenth part of the time if this proposed laboratory had then been available. My idea of the advantage in locating the laboratory here in Washington is that it would be at the service of whichever department of the Government had any problem to be worked out.

As a further illustration of the service of such a laboratory I may state that there are many problems, as for example, upon the best form of river bank "groynes" or spur dikes or "retards" for river-bank protection where one could obtain more definite information during one week in the laboratory than he could obtain in six months' experiment alongside the river, and by making most of his experiments on small models they would be performed at less than one-tenth the cost of experiments on a full-sized specimen.

From my contact with engineering problems in many parts of this country I believe it would be a great advantage to have here in Washington such a laboratory on a larger scale than the hydraulic laboratories of the engineering colleges, and I am confident that whenever the Government can release the laboratory for tests by civilian engineers it can be of great use to them, just as the testing machine at the Watertown arsenal has been, they of course paying the Government for the cost of its operation meanwhile.

In the course of working out my own engineering problems I have long realized our poverty in certain lines of precise hydraulic data where we are compelled often to rely on coefficients determined, perhaps 50 years ago, somewhere in France, England, or Germany, from petty apparatus, all out of proportion to present-day problems; and a few years ago, while getting together information for a trip to China to study certain river and canal problems for the Chinese Government, I realized more plainly than before the great differences of opinion that existed between high authorities upon certain important problems over which there was lively controversy, such, for example, as the Eads jetties, the Galveston harbor works, the Aransas pass, and the relative merits of bends and cut-offs, and such as the problem of the flood spillway now being actively promoted in New Orleans.

Senator RANSDELL. Since I am author of the resolution, I would like to say that I did not intend to confine it to flood control although as the resolution is worded, it might seem that flood control was its only purpose. Flood control is the principal thing in my mind but I certainly expected the laboratory to assist in solving all sorts of water problems.

Senator MCNARY. Mr. Freeman has set forth in a general way that which I expected he would, that it is a large undertaking. Of course it might save duplication of work and unnecessary scientific research, but I think the Army Engineers and our several Departments of Agricuture, Commerce, the water power board, and the Reclamation Service are now doing about everything that can be done from a practical standpoint, although they may not have the laboratories sufficient for doing a lot of those things that scientists like to do.

Mr. FREEMAN. My work all my life has been on the practical side of engineering and not in the college atmosphere, but nevertheless I believe it is of the utmost importance to have much of the basis of practical work tested out in a scientific atmosphere, and I have had experience in many cases where results of the highest value to the practical man have come from experiments in pure science; but I will not take the time of the committee to go into these matters now, although I could cite many interesting cases.

As to Senator McNary's suggestion that this laboratory idea might result in building up quite a bureau, that is not my own conception of it at all. My idea is that the one collected group of apparatus shown in these drawings in a one-story building about 73 feet wide by 385 feet long would suffice for pretty much everything that I have in mind and for ten years to come I do not believe that any substantial additions would be needed. Certainly I have nothing in mind beyond what is shown in these drawings. To care for all this I have no idea there would be needed more than a single chief custodian whose duties would be similar to those of Mr. Howard while he was custodian of the great machine for testing strength of materials at the Watertown arsenal. He knew how to use the machine without injury to it. This chief custodian should be a man of high scientific attainment who could act as scientific advisor on matters of theory to the practical construction man and field engineer. His assistants would be a few young men recently graduated from an engineering college who would be paid the modest salaries prevailing for such young men in the several scientific departments of our Government.

Whenever the Department of Agriculture, the Department of the Interior, or the Department of Commerce, or the Army Engineers, or the naval architects had any special problem for this laboratory they would send over their engineer specialist and perhaps he would take along two or three assistants. I can now see no occasion for more than 10 men in this building at one time to care for the most lively experiment. I have not the slightest idea of building up any new bureau or any new department.

Washington seems much the best place for such a laboratory. Yesterday I had intended going out alongside the Washington Aqueduct to see if there was a space where the laboratory could be conveniently located, and will go there later. I did find time yesterday to go to the grounds of the Bureau of Standards and asked Doctor Stratton if they had a place where a structure of this kind could be put up and if they had electric power enough for running the necessary pumps.

He took me to two places within their grounds on either of which there was ample room to place this structure on land that is owned by the Government and now unoccupied except by small trees. One of these places is right alongside the special hydraulic flume built 8 or 10 years ago and regularly operated whenever required by the Bureau of Standards for testing the river gauging meters used by the United States Geological Survey. This present flume or "laboratory" is narrower but is a little longer than either of the new flumes proposed for this laboratory. It is now covered by a light shed roof so that current meters for the Geological Survey can be tested in it at any time of year, and when I was there there were two or three young men making one of these tests.

Possibly this present testing flume could be covered under the same roof with the proposed new flumes, and I have no doubt that the engineers of the United States Geological Survey would find the new flumes just about as useful as they do the present flume, whenever they could get a chance at them, or whenever some of General Beach's junior officers were not trying out experiments in them for the Army engineers.

Senator McNary. I did not understand fully that you contemplated using this laboratory in that practical way. That is very much better than I had assumed from the wording of the resolution.

Mr. Freeman. I would like to say in this connection that I have no particular ax to grind except advancement of science and the public welfare. I am not looking for a job or for a contract or for a fee from any Government bureau, or anything of that sort. The work that I have done for the Government in the last 10 years has been done without any fee whatever. My last trip to the Panama Canal as a member of a special scientific committee to study the slides under special appointment by the President of the United States was without fee, and all my work for the Government during the war has been without a fee.

I went down along the Mississippi River about three months ago purely as an engineering tourist, at my own expense, to see what I could learn about the flood conditions there. I happened to be in the office of General Taylor, who is General Beach's right-hand man on rivers and harbors, when reports were coming in telling how fierce those floods were, and through the kindness of General Taylor or General Beach I was given a letter of introduction to the president of the Mississippi River Commission, who gave me a general letter of introduction to the Army engineers in charge of the several stations down river. All were very kind to me, and in that connection my personal friends in civil life also helped me by boats and by automobiles to see the sights at the danger points all along, near Memphis, Greenville, Vicksburg, Natchez, Baton Rouge, and New Orleans, with visits to crevasses and near crevasses, and I never was more intensely aroused in my life than I was then, by seeing the fearful conditions down there, and that is why I am here now with these plans.

No man unless he has been along the river when it is in high flood, and has seen that torrent tear along at 5 or 6 miles an hour, lapping at the very tops of the dikes along the Yazoo Basin and also gnawing perhaps at their bases, can realize what it means.

It was only by the most heroic work that the whole Yazoo Basin, of more than 5,000 square miles, was kept from being put under water, with property loss of probably $25,000,000.

I visited the crevasses that had occurred near Ferriday and Poydras, and no man can appreciate what a crevasse means until he has seen those hundreds of thousands of acres of land covered by water with just the roofs of the houses sticking out of the water. These sights, on top of what I had seen of flood conditions in China and my previous researches in hydraulics and my knowledge of the scant scientific data yet available, intensely aroused me and on my way back North I saw Senator Ransdell and told him I thought something ought to be done to study these things in a more scientific way, and in a more intensive and accurate way than they had heretofore been studied; that is, with the aid of the best scientific apparatus that could be devised, and that now is the time to found this laboratory while memories of the recent terrible experiences are fresh.

This particular branch of hydraulic science, the scientific laws controlling the erosion, transportation and deposition of sediments, and the science of river training in general, seems to have been comfortably asleep in America for many years past, but meanwhile some investigation has been aroused at a few river-training laboratories in Europe, notably at Dresden and Karlsruhe.

In order to show that I am not going off at half-cock on a hasty emotion, I trust I may be pardoned for some personal experiences, giving the background of my present plea for this laboratory.

It is now a little more than 50 years since I began as a junior engineer with the water power company that developed and controlled the flow of the Merrimack River at Lawrence, Mass.; and from that time until now I have specialized in hydraulic engineering and in lines which have brought me into close contact with many problems of flowing water.

My duties at Lawrence for 10 years brought me into close contact with several of the foremost hydraulic engineers of that time, Hiram F. Mills, James B. Francis, and Charles F. Storrow, all now dead. Under Mr. Mills, as his principal assistant engineer, I spent many months—I might almost say years—in scientific investigation and laboratory experiments on many matters connected with the flow of water and in measuring the supply of water power to the factories; while also having immediate charge of the daily measurements of the Merrimack flow. Also I had much incidental work under Mr. Mills along the Merrimack and Connecticut Rivers relating particularly to power development, at Lawrence, Lowell, Manchester, Concord, and Bellows Falls.

In my subsequent engineering work for the past 35 years I have had many problems in the control of water for domestic water supply, power development, and navigation improvements. Twenty-five years ago I was the engineer member of the Massachusetts Metropolitan Water Board, organized to build new works for the Boston district; also, I have served the cities of New York, Baltimore, Hartford, City of Mexico, San Francisco, Los Angeles, and others as consulting engineer on large water-supply problems, chiefly the developing of new sources. The new Hetch Hetchy works of San Francisco are now being built mainly from my plans. Three times I have visited Panama on service as member of a special engineering committee under special appointment by the President of the United States to study important features of the Panama Canal.

I have served the Canadian Government on many investigations for developing river water powers, also many power corporations on large work in the United States, Canada, and Mexico; on the St. Lawrence, the Mississippi, and on tributaries of the Sacramento and the San Joaquin in California. I had charge of the extensive scientific investigations made nearly 20 years ago for damming the tidal estuary forming a part of the harbor between Cambridge and Boston, Mass. My special interest in problems of river training has been stimulated by my recent work for the Chinese Government, connected with the rehabilitation of their ancient Grand Canal and the control of the Yellow River, which river carries larger quantities of sediment than almost any other large river in the world. These investigations in China incidentally led me to make cursory examinations of work of the English engineers in India for improving river navigation and bridge crossings, some of which works I have inspected.

About 10 years ago I was requested to prepare outline plans for the new plant at Cambridge of the Massachusetts Institute of Technology, and in preparation for this I investigated the educational plants and laboratories of many prominent engineering colleges in America and some in Europe. Incidental to this work of planning outlines for buildings and grounds, I prepared preliminary designs for a hydraulic laboratory on a larger scale than any yet in existence, which should be adapted for several much-needed researches, in addition to serving for the instruction of students.

Also at about that time I inspected the river-control laboratory of the German Engineering College at Dresden and was greatly impressed with its possibilities for usefulness. My plans for this laboratory at the institute of technology were not completed because of lack of building space following radical changes in ground plans made by the architect.

Early in the present year, in course of some remarks at a dinner of the technology alumni association and a subsequent dinner of the Washington (D. C.) Engineering Society, while briefly tracing the history of the development of hydraulic science and showing certain of my recent discoveries about the way the Yellow River of China digs out its bed during a flood and refills it as the flood subsides, I suggested that the training of great rivers to themselves by their own power dig their courses deeper and carry their burden of sediment out to sea had long been slumbering, and I then suggested the desirability of a national hydraulic laboratory in America, somewhat like those in Germany, but on a larger scale, and also larger than those now in existence at the American engineering colleges for studying a limited few of these important questions, and Mr. Wallace, secretary of the American federation, thought the idea good and gave it considerable publicity. I did nothing more about this until my recent observations along the Mississippi, which fanned these smouldering ideas into new activity.

The foregoing will show that the views now presented are not a notion hastily conceived as the result of a temporary excitement.

Some five or six years ago while traveling in China I became greatly interested in certain of their river problems, which are second to none in the world in importance from the viewpoint of relief to suffering humanity and of scientific interest, and about four years ago I was put in charge of extensive researches upon modernizing the ancient Grand Canal of China, which has been ruptured and put out of business by an outbreak of the Yellow River. This work required my making the first scientific study that has been attempted of that remarkable river, which probably is the muddiest great river in the world and also has the distinction of having killed by outbreaks more human beings than any other river. Some extremely interesting facts were discovered, although the work is yet far from complete. It was found that in a most remarkable way this great river digs its bed deeper in the delta deposit during floods in order to get more waterway and that it gradually refills this excavation as the flood subsides, all apparently in a very law-abiding way. Apparently we now have this record of the effect of a flood on the bed of a sedimentary river in better form in some respects for that far-off river in China than we have for rivers in the delta lands of America.

In these Chinese delta deposits, which are far more uniform in their grain and of much finer grain than the deposits along the lower Mississippi (except perhaps in its last 100 miles) it appeared that the river abhorred a mean velocity greater than about 7.5 feet per second, and that whenever the flood rose and the mean velocity increased much beyond 4 or 5 feet per second the river immediately dug deeper and got more space so that the velocity seldom or never exceeded 7.5 feet per second.

As I drifted down that river in a small boat, studying the shore protection, the levees, the spur dikes for protecting the banks, and the sand waves found under the water all along, and as I subsequently studied the maps and hydraulic data collected by our engineers who surveyed the river, it became strongly borne in upon me that these facts about Yellow River erosion and refill during the rise and subsidence of a flood, might have a most important practical application in the training of any rivers flowing through soft delta deposits and that they were worthy of immediate and intensive study, part of which could best be done in a laboratory, to supplement observations on the actual river; and I then recommended the construction of a small hydraulic laboratory to the officials of the Chinese Government.

INTEREST QUICKENED BY INSPECTION OF "RETARDS" NEAR OMAHA.

In April of the present year the American Society of Civil Engineers held at Dayton, Ohio, a convention devoted to the discussion of flood problems, in which, among others, there were important reports of conditions and progress on the hydraulics and flood problems of the Mississippi, and those of the Colorado River of Arizona, as effecting the safety of the Imperial Valley of California. Also there were shown moving pictures of caving river banks along the Missouri with a story of rapidly wasting farm land, which were very impressive; but the speaker, Mr. R. N. Towl, C. E., of Omaha, also showed pictures of recent devices for protecting these banks, particularly near railroads and bridges, by means of permeable spur dikes called "retards," built of cottonwood trees, which grow like weeds on the river bank; these trees being tied together and anchored in a new way to deeply submerged posts of reinforced concrete about 16 inches square and 20 feet long, sunk by the hydraulic jet process to bedrock, or to far below flood scour, with their top ends, say, 40 feet below the ordinary river bed.

Although this idea of bunches of trees anchored along shore was similar to that of the so-called "Brownlow weed" devised years ago for protection of river banks in India, the newly-invented form of anchorage by wire ropes to a pile submerged far below the river bed, appeared an improvement of great practical importance.

I was so greatly interested in the pictures and in the story that soon afterwards I personally inspected these works of bank protection along the Missouri River in company with the engineer of the contractors and certain railroad engineers who had used these "retards" with success.

The oldest of these "retards" are only 1 or 2 years old and it remains to be seen how long they will withstand high floods and general wear and tear of ice, or the deep scour of a flood rolling over them. Some experienced river engineers doubt their permanence. Perhaps after all they will go the way of the "Stickney bankhead." But the apparent success of the work that I inspected again aroused my interest in river training and this interest was fanned into a burning flame by what I saw a little later along the lower Mississippi. I concluded that if we had a laboratory in which to experiment on the action of currents and sediments and floods around these retards, and could thus get some more of science into the art of building them, one could possibly improve the details and finally get a cheap structure that would not fade into oblivion like the many previous devices tried out along the Missouri.

Permeable spur dike current retards of many forms have been tried out along the Missouri River during the past 25 years. Many of these were described in one of the reports on the Missouri River by the United States Engineer officers in charge—I think in the report of the Chief of Engineers of about 1911—some of them have promised very well at first and have performed excellently for a while and finally have succumbed to ice or been undermined by the current or swallowed up by the deep bed of sand. A lot of money has been lost in these practical experiments, though the total probably is small in comparison with the value of the farm lands eaten away by the Missouri, and the point that I would press is the economy of doing some of the preliminary experimenting on models in the laboratory.

The theory of all retards is to cause the current to slacken so it will deposit a sand bank quickly. This endures up to certain stages of high water and everybody is pleased until a still higher stage or a different twist comes in the current over the top or around the end, and the structure sinks deep into a newly scoured hole, and finally is swallowed up and the way cleared for a new invention.

I am strong in the belief that with the aid of the proposed laboratory an economical and enduring structure can be invented. I hope that the Chicago, Burlington & Quincy Railroad engineers have found a permanent device in the Woods Bros.' "retards," anchored by the "Bignell pile." If not, I shall still believe that "Through our failures we can achieve success."

While I was greatly impressed with the apparent success at the end of one year's exposure of the retards shown me near Omaha on the Missouri, I do not believe those structures would suffice on the lower Mississippi with its far greater depths of water, its different concentrations of sediment, and its more powerful eddies.

I am confident that the fundamental idea is all right in "Brownlow weeds," in "Stickney bank heads," French "gabions," and in Woods Bros.' "Tree retards" and the deeply set Bignell pile, and are full of promise, but we need the laboratory to help in finding just where the trouble is, and in order to perfect the details.

Although the cost of the laboratory may seem large at a time when Congress is trying to economize, this cost is very small in proportion to the expenditures which it would help safeguard and economize on the Missouri River alone; this is small in proportion to the present annual waste of farm lands or in proportion to the cost of river-bank protective works which the Government is building right along, year by year, and many of which are now calling for vast sums for repairs. The willingness of the farmers along the Missouri bottoms to burden their future with millions of dollars of bonds of reclamation districts, and the thousands of acres of farm lands that actually are being eaten away year by year, which they seek to protect by these retards and other devices, prove the urgency of the problem.

The Missouri is nearly 400 miles long from its mouth up to Kansas City and on improving this, chiefly by attempts to protect its banks, about $10,000,000 has been expended by the United States Government in the past 11 years, and about twelve and a half million dollars are estimated as required to complete the existing project.

From Kansas City to Sioux City is about another 400 miles, and on this the Federal Government has expended about $3,000,000 in bank protection and snagging for navigation, and within about a year past the farmers have expended about $170,000 in "retards" for saving their farms from being washed away.

What I have seen along the Missouri convinces me that on rivers of this size and type success is within reach, although it may be a long step thence to some of the problems on the lower Mississippi.

Senator McNary. You know the great damage wrought by the floods on the Mississippi. Do you think any problems now known could be worked out in a laboratory such as you suggest?

Mr. Freeman. I am certain that many things not now known could be worked out in the special kind of hydraulic laboratory that these drawings show. I have followed the work done in various European hydraulic laboratories and I am certain our American scientists would go much further than the European engineers have gone if given a chance. Science has progressed in recent years in methods of attack, and our American problems are larger.

Our American laboratory should be on a larger scale than either of the river-study laboratories that have been built in Europe. I know that those several European laboratories have produced valuable practical results. I have visited some of them and have studied their reports. I am sure as can be that this proposed laboratory, in the right hands, could be extremely helpful in preventing flood damage and in saving money. Many scientific facts and laws and formulas of highest practical utility have been worked out in hydraulic laboratories.

One thing I want to call your attention to as showing the value of science to these practical problems is that when they began at Dayton, Ohio, to study how to get flood relief for all future time, one of the first things they did was to call over the professor of hydraulics from the University of Iowa, and he and his associates in studying flood relief for the Miami Valley found it necessary to construct a small hydraulic laboratory to solve some of these Dayton problems.

I understand that certain of the rules that the American Army Engineers are now following for the laying out of channels were devised with the aid both of a temporary laboratory and observations on the rivers in France many years ago by a French engineer—Fargue—for the improvement of the River Garonne and the harbor of Bordeaux. General Beach can tell you about this better than I.

I was in France last summer with a group of French engineers inspecting some of their recent river works and power developments, and I know that in France, England, and Germany the most eminent men are believers in these laboratory methods for supplementing observations on the actual river; although over there in their past hydraulic laboratory studies navigation and power development and general scientific data have been in view more than flood relief.

Hydraulic laboratories as a means for the study of problems of river training are highly esteemed among the skilled engineers of Europe.

The six rules of Fargue, to which I alluded a moment ago, were finally established or tested out in a crude sort of a laboratory in France, in which the engineers built temporary channels and trained the river to run on courses of various curvature between plank side walls, over a bed of sand, feeding these channels from a near-by canal.

In connection with the improvement of the River Seine many years ago certain English engineers were called over to France and they immediately built a model of the river upon the shore in which to experiment upon the currents and sediments.

The first permanent laboratory designed for working out a variety of problems of this kind was that established by Professor Engel in Dresden about 20 years ago and rebuilt in an enlarged and improved form about 9 years ago. I know of no book in the English language on river training that in scientific treatment equals Professor Engel's book. I think the reason for his vision is that he has had this laboratory in helping him work out his problems. And I believe with this proposed American laboratory we would get a new departure in the science of river training and some good new textbooks.

Senator du Pont. The fundamentals are understood?

Mr. Freeman. I think they are hardly understood at all. There are radical differences of opinion among the most prominent authorities. In the fundamentals of the art of building revetment probably no corps in the world excels our American Army Engineers, but in the scientific fundamentals, the physics of erosion, suspension, transportation, and deposition of sediments there remains a lot to be found out, and the authorities disagree.

I estimate that I have recently read at least 3 cubic feet of literature on those subjects in trying to make sure of the latest and best teachings, and I find both poverty of exact data and a conflict of opinions.

A CONFLICT OF OPINIONS.

Preliminary to my recent studies of the improvement of the Grand Canal and the Yellow River for the Chinese Government, I got Mr. Hardy Cross, associate professor of civil engineering at Brown University, an exceptionally capable man and a graduate both of Harvard and the Massachusetts Institute of Technology, to go through all the literature that could be found on the subject. He spent eight months on it, beginning with the library of the late Elmer L. Corthell, formerly principal assistant to Captain Edes on the South Pass Jetties and later himself one of the most distinguished harbor engineers of the world. Mr. Corthell accumulated a great library, which he left to his alma mater, Brown University. Professor Cross went through that library; he went through the library of Harvard College; he went through the library of the Massachusetts Institute of Technology; he went through the great public libraries of New York and Boston; he went through the Engineering Library of New York, which now is the leading engineering library in the world; and we went through the Library of Congress and the library of the United States Geological Survey, seeking everything of importance written on the science of river control.

Whatever seemed important he had transcribed on the typewriter. He thus accumulated several thousand pages of typewritten notes of what most of the eminent engineers all over the world, including the United States Engineering Corps, the United States Geological Survey experts, and many others, including those who attend the international navigation congresses that are held every few years, had to say on the different features of river training.

Then he condensed these abstracts into a sort of concordance, bringing together what had been said on each important topic. For example, here in this 700-page volume, No. 1, I turn to "Topic B. Sediment," and find 60 pages of condensed statements by different authorities—everything he could find printed from good authority on the subject of how much sediment water will hold in suspension at any given velocity, etc. He has here statements from Captain Eads about this, and from men all over the world, including men in the United States Engineering Corps, engineers in England, India, and including Mr. Ockerson.

I worked on this compilation more or less with Professor Cross. I felt that before attempting anything on a great river problem like that of the Yellow River I would like to find out what eminent engineers had done anywhere in the world under similar circumstances; therefore I had this review prepared and took these volumes on the steamer to study on my way over to China. I soon found that you could get from these volumes diametrically opposite opinions on almost every important question and from equally eminent authority.

Senator Ransdell. The doctors didn't agree?

Mr. Freeman. The doctors didn't agree at all. Some of these present-day differences of opinion about straight versus crooked rivers, and about flood spillways, etc., have been debated since the days of ancient Rome.

Senator du Pont. Generally speaking, isn't it true that hydraulic engineering for the past four or five thousand years has been an art and that until the past, let's say, 100 years, it hasn't been a science?

Mr. Freeman. That is absolutely true. To-day, although there have been marvelous developments in the art, the science slumbers, and should be awakened to guide improvements in construction.

OPINIONS ARE STILL DIVERGENT.

During my recent tour along the Mississippi I found extremely divergent opinions held by men of high standing and great experience as to matters of safeguarding levees and as to utility of flood spillways, and I became so impressed with the importance of increased scientific knowledge about the action of river currents that in June of this year I made the need of a national hydraulic laboratory a leading topic of the annual address which the president of the American Society of Civil Engineers gives each year on some of the broader matters of engineering.

FLOOD PROTECTION VERSUS NAVIGATION.

Within the past few weeks I have been rereading this compilation of opinion of eminent authorities on river training made by Professor Cross. It was made with an earnest purpose to impartially collect everything that seemed worth while and to in no way take sides while recording.

It plainly appears from the record that the attention of engineers here in the United States and in Europe who have written upon river training and in particular those who have attended navigation congresses have been focused mainly on the problems of navigation and of how to fix sand bars and shoals so that they would remain in the same place for a season, and so that the pilot could have the least difficulty in getting past them; rather than on the problem which is of a hundredfold greater importance in the United States at the present time, of training a great river so it will carry its burden of flood water and sediment to the sea with all possible dispatch and with least possible damage to the adjacent agricultural land or city plat; or the extremely important problem of how best to train a great river to dig its channel deeper, by its own power, and transport this burden of sediment to the deep sea.

The engineer bent on improving the low-water channel of a river flowing between beds and banks of silt or sand and gravel has a radically different problem from the engineer bent on flood relief, and intent upon compelling the river to stop cutting away its bank and compelling it to transport its burden of water and of sediment to the sea with all practical dispatch and with the least practicable elevation of its flood surface. Neither the textbooks nor the technical publications appear to recognize or to emphasize this difference as they ought, and I fear that roots of the deep-seated original navigation idea sometimes obstruct progress in the more recent flood-relief idea.

As showing that others have found similar lack of dependable data, I may state that when the California Débris Commission asked the United States

Geological Survey to aid them with scientific data, Doctor Gilbert, of the Survey, one of the foremost geologists in the world in field studies, was assigned to this investigation. He first collected and published a big, thick monograph containing all of importance that he could find already published. He found in all of this such a lack of really dependable data for guidence on the design of the important work proposed that he next had to establish a special hydraulic laboratory at the University of California, in which he and assistants worked for months. Then a second volume was published by the Geological Survey, which is much more valuable than the first, because now he had begun to find out the underlying scientific facts about the laws of sediment and débris transportation by water. He built three different small temporary laboratories on the grounds of the University of California, in which he tried out his experiments. He published a valuable monograph of the results of these experiments, but he hardly more than got started. He was getting on in years and has since died.

Strange as it may seem, these were the first real scientific experiments that had been made in that line for 100 years.

The eminent French hydraulician, Dubuat, who worked 100 years previously, in a little hydraulic laboratory provided by the French Government, had made his experiments on transportation of sediment, in a wooden trough about 14 inches wide and a foot deep by running a current of water at various velocities through that trough into which he dropped in grains of sand of various sizes, to see what velocity was necessary to carry them along. You will find the data from those Dubuat tests repeated in various engineering textbooks to-day. Instead of information it is misinformation. This lack of definite, dependable information about sedimentation has stood in the way of various important public works.

DISTINCTION BETWEEN FINE AND COARSE SEDIMENTS.

This is of vast practical importance and one is liable to be misled by the records maintained at municipal water supply pumping stations which take their samples near the surface and obtain no information as to the density, concentration, or size of particles drifting along close to the bottom of the river.

All through in the literature of river hydraulics and in the discussions found in the transactions of technical societies there is a great lack of data about the distribution of sediments in the upper and lower strata of the flowing water.

The sand bars which obstruct the flow of the river and cause pretty much all of the trouble as to navigation and impeded flood discharge are probably caused by material so coarse that a sample taken near the surface gives no proper idea of its quality. It is the local gravel and coarse sand from caving banks which causes all of the trouble about river training and it is not the fine-grained sediments such as brought in by the Missouri.

Nearly 20 years ago I was in charge, for the Massachusetts Legislature, of an investigation of the problem of the damming of the tidal estuary forming part of the harbor between Cambridge and Boston. One of the great questions which had delayed that work for 40 years was the fear that if the velocity of the harbor currents was lessened the main harbor would be shoaled. I couldn't find any experiments along that line and I had to go to one of the water power canals, at Lawrence, Mass., and make certain observations in that canal. Like Professor Gilbert, I found there had been almost no real scientific work along that line for 100 years.

I am sure from what I have dug up in my reading, that certain of Captain Eades's ideas, particularly his idea on the maximum quantity of sediment that can be carried in suspension at a given velocity, was wrong. There is nothing approaching saturation of water by sediment along the Mississippi. A proper laboratory, supplemented by field tests, would settle a lot of these important questions for all time.

As to the present great problem of a flood spillway at New Orleans, I think the authorities are liable to run into disaster instead of avoiding disaster, if they begin on the lines now proposed without scientific experiment. The newspaper reports seem to overlook the fact that there are two very different kinds of sediment in the Mississippi River. One, the fine mud from the Missouri, that is carried in suspension evenly mixed from top to bottom. The other kind of sediment is coarser and comes from local cutting away of banks by the current, and never shows near the top of the water.

From what I am told by newspaper reports, they have got out the records of the New Orleans waterworks as to the percentage of sediment day by day, and from these records they conclude that the amount of sediment would not interfere with the spillway project. The waterworks naturally take their water where the sediment is the least and of finest grain, and perhaps it is different from the sediment that comes rolling along the bottom of the river, which builds the bars and delays the opening of the Southwest Pass. Possibly there are sediments that would not be drawn off at the top by a spillway, which would be thus concentrated and deprived of propelling force by the water abstracted. The transportation of heavy sediments is very sensitive to decrease in velocity. This matter needs investigation, in which the proposed laboratory would help.

There is a good account of the source of the coarse sediments in the report of survey of a 14-foot waterway by the Board of Army Engineers in 1909. The trouble and obstruction at the gravel bars that cross the river between pools at places where direction of curvature is reversed, seems all caused by a kind of sediment that you don't see near the top—a sediment entirely different from that which comes down the Missouri River. I have had charge of building a dam on the upper Missouri River, and I have watched the river at Glendive, Mont., near where the Missouri gets its great load of fine-grained sediment. This is a different kind of material from that which causes the trouble and forms bars at the crossings between the long curved pools on the lower Mississippi. That coarse sediment travels away down so deep that you don't know anything about it without a special and rather difficult investigation. It is probably all of local origin, coming into the river from the washing away of ground deposited tens of thousands of years ago when the river was far larger and more powerful, due to the melting of the continental ice cap.

Senator du Pont. Relatively you have a greater percentage of sediment in the bottom water?

Mr. Freeman. Yes; I have no doubt that is true. I have read everything that I could find published about sediments in the reports of the Army engineers, and once in a while they get out a most interesting technical document, like that of 1909, although commonly some economical rule prevents them from publishing technical details.

In this laboratory that is now proposed one could experiment with these sediments in many ways. For instance, I have sketched here a model of a channel which might represent the Mississippi on a scale of 1 to 1,000. On that scale it could represent 50 miles in length of this river, or upon a scale of 1 to 100 the model would represent 5 miles. The laboratory should be worked in parallel with observations on the actual river.

The great advantage of the laboratory over the real river is that in the model you could carry any concentration of sediment that you desire and study what happens more conveniently. The apparatus shown in these drawings provides for a separate return of the muddy water, which can be circulated by the pump and used over and over again. You can make your temperature just as you want it, and you can exepriment with 1 per cent of sediment or with 10 per cent of sediment. You can experiment with sand grains of any size you want. You can bring a carload of sediment right from the dredger on the Mississippi River and put it in the laboratory. You can control your conditions in the laboratory in a way that you can not control them in the field, and probably can find out just how the current gnaws at the bed or bank and under what conditions it will dig, and under what conditions it will drop its burden.

Moreover, in time of great floods the river engineers have all their energies focussed on preventing crevasses and not on scientific observation.

While the recent great flood was in progress I asked General Taylor or General Beach what scientific data they had secured on this recent flood, about the increase of depths in the pools and the building up of sediment on the bars, etc., and he replied, "We will find that out later. Our men are all busy looking at the points where crevasses are threatened."

You will nearly always find that to be the case in any flood. The Army engineers will feel it their first duty to protect life and property. Meanwhile the opportunity for scientific observation is lost, unless as it happened 40 years ago, in 1882, when the Mississippi River Commission had five survey parties in the field making surveys and current observations when the flood happened. They kept observing harder than ever; merely because they happened to be already on the job. This seems not to have happened again, and so some of the most complete data yet available is 40 years old, with little scientific study then or since that time into the phenomena of the rivers' behavior down deep during a flood.

These big floods only happen about once in 10 years. An organization can not be ready and waiting to observe. The laboratory can be used at any time. You can do certain kinds of work much better in a laboratory than you can in the field.

My opinion, after studying the literature of river training as diligently as I know how, is that our science of river control to-day is just about where science of chemistry was before they used the balance and weighed things carefully or just where electricity was before the modern "C. G. S." units of electrical measurements were established. Chemistry and electricity had been the subject of interesting discussion and much argument for many years, but no great advance until exact observation and real precision of measurement.

With a laboratory, if the right man can be found to supervise its use, if you can find another man of the late Professor Gilbert's quality, the whole outlook on many of these very important river problems could soon be changed.

Although the principal data used by hydraulic engineers all over the world to-day—in the United States or in India or wherever you go—for designing nearly all their works was founded on tests in hydraulic laboratories built by the French Government about 60 years ago, in which Dubrat, Poncelet, Lebros, Darcy, Bazin, and others experimented, America also did some of the very best early pioneering.

Somewhere about 70 years ago the United States Government, through Humphreys and Abbott, started one of the finest pieces of scientific work in connection with river-flow work that had ever been done anywhere in the world up to that time. Two young lieutenants—Humphreys and Abbott—of the Army Engineers came out of West Point with a broad horizon and the enthusiasm of youth and planned a wonderful piece of work on the "Physics and Hydraulics of the Mississippi." They published their big volume in 1861, but the Civil War interrupted their work, and the study of physics and hydraulic science on the Mississippi pretty nearly ended with Humphreys and Abbott's work 61 years ago. Science along that river seems to have been slumbering while the art of bank protection by mattress and concrete revetment has been concentrated upon by the Army Engineers until they have developed the most perfect (and perhaps the most expensive) bank revetment built anywhere in the world. There is a distinction between science and mechanical arts, and science should now be awakened.

Humphreys and Abbott 61 years ago can hardly have said the last word about the "physics and hydraulics of the Mississippi."

Right after them came a French hydraulic laboratory with the great researches by Darcy and Bazin, already mentioned, which were of incalculable value in showing effect of roughness of the bed of the stream upon its velocity of flow. The weir experiments of Bazin followed later.

As previously stated, the advancement of hydraulic science in America, apart from river hydraulics, has chiefly been fostered by certain water power corporations, as, for example, the Locks & Canal Co., of Lowell, Mass. About 65 or 70 years ago James B. Francis established a temporary hydraulic laboratory in Lowell in which he made many investigations on measuring the flow of water and established rules and formulas of inestimable value to engineers, and which are the standards to-day.

Later the Holyoke Water Power Co. built a testing flume for turbines, etc., another name for one kind of hydraulic laboratory, greatly extending and improving the experimental facilities over the previous Emerson flume, and the art of turbine building was fostered by accurate experimental work here until now America leads the world in the manufacture of water-power turbines, and some of the most progressive American water-wheel builders have recently built special hydraulic laboratories of their own, so well proved is the value of scientific research in the laboratory. The Holyoke flume also has served for various other researches, by the late Hamilton Smith, jr., and others.

Later came the hydraulic laboratory of Cornell University, which has been utilized by the United States Deep Water Ways Commission for tests on discharge of water over dam crests, and which is admirable for the range of work within its capacity. I have utilized it myself in important researches. It is utterly unsuited for many of the researches that the advance in hydraulic science and the science of river training now require. I am familiar with the other principal college hydraulic laboratories and their limitations. The country needs something bigger and with special adaptation to river problems, but I am very strongly of the belief that it must be in a scientific atmosphere, and that Washington, D. C., is the best place for it.

If I may say a word on that, I think Senator McNary has a little misapprehension as to my ideas on the advantages of the scientific atmosphere.

Senator McNary. I think I understand your position.

Mr. Freeman. Just by way of illustrating how the investigator in pure science sometimes can help the practical engineer, I would like to mention one experience. When I was working on water-power development on the St. Lawrence River I found progress blocked by the clogging of anchor ice or "frazil," and I called to my aid Professor Barnes, from McGill University, who had developed in his laboratory a most remarkable electric thermometer that could show a difference in temperature of only a thousandth part of a degree. He had probably the most delicate thermometer in the world. With this he discovered that the sticking together of anchor ice was caused by "undercooling" of the water a few thousandths of a degree below the freezing point of 32° F., and that if water could be warmed by blowing in a little steam at relatively small expense the needle-like ice crystals would cease to adhere and agglomerate and would cease to clog the intake screens and the turbines. This work in pure science by a physicist who had no practical experience in water-power engineering, who experimented first in his laboratory and then on the river—I was out with him at temperatures of 15° below zero—solved this anchor-ice problem and removed one of the greatest obstacles to water-power development in northern latitudes without interruption from anchor ice.

My conception of the utility of this national hydraulic laboratory is that it will make use of science to help forward the art of river training and promote economy and efficiency in the construction of works costing many million dollars, which works the country, the States, the cities, and the corporations have got to build anyhow.

More of science and more preliminary experiments in a river-training laboratory such as is now proposed might have prevented the waste of half a million dollars on the Ockerson Dike below Yuma and have given real protection there instead of nothing at all.

Or it might have shown how to space the excellent "Stickney bank-head" structures built on the Missouri so near together that the current would not have cut in between them and got back of them. I have an idea that Colonel Stickney was on track of an exceedingly meritorious invention which needed a laboratory to perfect it.

I haven't any desire to show up anybody's mistakes or to try to prove to anybody that he is wrong, or anything of that sort. Mistakes, if followed up in the right spirit, often prove to be merely milestones on the road to success.

Some poet has said, "'Tis through our failures we achieve success."

I have a notion that if Colonel Stickney's "bank heads" were each cut into two or three parts and these parts, with their easy radius, set inclined to the current and placed, say, 250 yards apart, they probably would have proved a great success; and if the Ockerson Dike had been built from borrow pits on the land side instead of from the river side and had been guarded by short inclined spur dikes with stone piles at their extremities, set, say, 200 yards apart, and with willow plantings between, my best guess is that it would not have been so promptly side swiped and cut all to pieces, although any structure of these kinds needs continual oversight and maintenance. I believe that some preliminary laboratory tests would have helped Colonel Stickney and Mr. Ockerson, and that by its aid successful structures could be built next year or the year following on the same sites and from similar materials.

Senator du Pont. In any industry to-day all of the leading and most successful concerns are doubling their laboratory forces and trebling them.

Some of the men on our road commission in Delaware were complaining that our engineering costs for road building were four times as high as those of some States and the highest of any State, but by careful laboratory inspection these costs were in three years' time greatly reduced and in four years they were less than half those of any State.

Mr. Freeman. Since the benefits to highway building of scientific and laboratory methods have been mentioned, I may say that I was greatly interested when I recently visited the State College at Ames, Iowa, to find that the Iowa Highway Commission had practically gone to the laboratory of the college to find out how to build their roads. By these scientific investigations they are finding out a lot of things as to why concrete roads break down that no one knew before, and to-day the Iowa road builders in the field are working hand in hand with the scientific men in their laboratories.

Senator du Pont. You are in favor of the resolution?

Mr. FREEMAN. I am most heartily.

Senator RANSDELL. The amount proposed to be expended is $200,000.

I have in my hand a table furnished me by the Weather Bureau of the Government showing the loss of life and property by floods in the United States from July 1, 1902, to June 30, 1922, inclusive. This table shows a total loss of 1,561 human lives in the United States by floods during that period.

Senator DU PONT. That is for a period of 20 years?

Senator RANSDELL. Yes. The total property loss is estimated at $624,052,651. There is one exceedingly interesting fact that I am tempted to bring out here, and that is that out of a total of 1,561 human lives lost in 20 years only one life was reported lost on the lower Mississippi River. But there were many lives lost by floods and over $600,000,000 in property loss by floods. If you could help us save even a small percentage of that enormous loss, it certainly would be worth while.

Mr. FREEMAN. Speaking of the lower Mississippi, Senator Ransdell's constituents, and his friends across the river in the State of Mississippi, were exceedingly lucky that their losses in the recent floods were not a hundredfold greater than they were. Crevasses which might have inundated the great St. Francis and Yazoo Basins, of more than 12,000 square miles combined areas, were prevented only by the most energetic and heroic work and then only by very narrow margin. I was along the river studying conditions while the water was still high, and men who had been in the thick of the fight with the river told me of the narrow margin of success.

If, for example, the river had gotten in at Tunica, about 20 or 30 miles below Memphis, last April or May, the damage would have been more than $25,000,000 in the Yazoo Basin alone, and there were chances of equally great damage on the other side of the Mississippi in the St. Francis and Tensas Basins.

Probably I will arouse a protest from some of my friends who have worked hard many years on improving the navigation of the Mississippi and Missouri when I venture the opinion that navigation has ceased to be the paramount question along the Mississippi River.

The proper viewpoint has completely changed since the days when the Army engineers were given charge and since the date, 40 years ago, when the Mississippi River Commission was created.

The increased value of those rich delta lands along the Mississippi and also in the Sacramento and San Joaquin deltas has within the past 20 or 40 years become so vastly increased by the drainage of swamps and the building of high levees as to completely overshadow the values of the channels for navigation except near the river's mouth.

The building of railroads parallel to the river and the change in the currents of commerce also have greatly changed the outlook in the past 40 or 60 years.

The improvement of navigation at the Federal expense was the original and fundamental reason for placing the improvement of these rivers in the control of the Army engineers, and while the ascendancy of flood control over navigation is no reason why the Army engineers should not continue in charge, it should be made plain to everyone that flood control is now and henceforth the paramount issue and navigation subordinate to it.

The navigation problems are chiefly low-water problems. The protection of the present vast agricultural values is chiefly a high-water problem. The problems have vastly changed since Humphrey's and Abbott's time. I have not the shadow of a doubt that both of these interests, agriculture and navigation, can be served far better than in the past and that the laboratory will help them both.

The two points of view lead to different lines of treatment. Navigation calls chief attention to the low-water channel. Flood relief requires the best possible high-water channel, and in some way the two are antagonist c, and one of the grounds of conflict is the respective merits of straightened versus a crooked river or of cut-offs at bends.

The textbooks and the papers at the International Navigation Congresses, the "Six Rules of Fargue," etc., have chiefly in view the fixing of the low-water channel. Fargue's rules for training a river on a gently curving course in low water have for their object making it easy for the pilot or captain to know where the sand bars are. Along a gently curving concave bank one knows that he always will find deepest water near the bank, and that the bars will be located diagonally at the reversals of curvature, and that the length of the course in shallow water will be short, with long pools between. In most of the year the river's winding course will be a succession of long, deep, curving pools with short, shallow crossings between. The pools will be nearly level and the fill concentrated at the crossing bars.

If you straighten a river you develop a different condition. Instead of fairly permanent bars of sand or gravel at crossings extending the entire width of river you will soon have "sand waves" projecting out one-fourth or one-half way across, slowly changing their location, moving downstream all the time. The navigator will find them first at one side and then on the other side, with a sort of zigzag channel in between, which may not be as easy to navigate.

The great flood volume follows a more direct, shorter course than the low-water channel. It submerges and sweeps across the sand bars that project from the banks.

If you want to convey a great volume of water most rapidly to the sea you would best make a straight channel, and plan something different from the course commonly laid out by river-training engineers.

For navigation alone the curving channel sometimes may be superior where flood relief would call for the straightened channel; and flood relief having become most important, its needs should prevail.

The presence of sediment does not forbid a straight course. Recently, along the River Durance, which carries a vast burden of sediment, French engineers have built a great water-power canal, 10 miles, more or less, in length. Last summer I motored in southern France inspecting this river and this canal, and I noted that they built this canal as straight as possible, notwithstanding this sediment.

For the purposes of the navigator the gently curving river may be better than a straightened river because of the great length of ample depths that may be depended upon in the pools along near the concave shore, from the bank of which the spiral current digs and transports the sediment. The total length to be traveled at the crossover bars between the pools at the reversals of curvature is very short in comparison with the length of the curves and their deep pools, and if one can protect the river bank near the apex of the curve by a few hundred thousand dollars worth of willow mattress and concrete blocks so it will no longer erode, and can assist nature by dredging a low-water channel through the crossover bar, the work of improvement for navigation is minimized and the cost of improving navigation is lessened.

On the other hand, in a river like the Mississippi below St. Louis, where a considerable amount of coarse sand and gravel is brought into the channel by the undercutting and toppling over of the banks, this everlasting supply of new material for building up the bars greatly complicates the problem of securing a greater depth for navigation over these bars than was provided by nature. The much-desired 14-foot channel to St. Louis from the Gulf can not be brought within practical limits of expenditure so long as the river continues to cut away banks and bring in a fresh supply of material with which channels dredged across the bars at the reversals of curvature in the crooked channel during the low-water period are promptly filled up by each year's flood.

This disadvantage of the curving river with caving banks and a changing meander, as compared with a straightened river, does not seem to have been brought forward so prominently in the discussion of the 14-foot channel as its importance warrants. A straight channel for navigation probably would behave better and it would be extremely instructive to carry out simultaneous experiments on the two, one downstream from the other in the proposed laboratory.

On the other hand, for a flood-relief channel it appears plain that the straight channel will carry the same discharge of quantity with much less declevity, both on account of being shorter and also because of the greatly lessened resistance to flow upon a straight course in comparison with a curved course containing eddies and internal turmoil. It may be argued that the straightened river has greater length of bank to be protected—two banks instead of one; yet it must be remembered that a convex bank is not always safe from undercutting and the inviting of a crevasse as at Stanton, Tunica, and Ferriday, also, in low water and upon a river varying greatly from high to low the straight river presents less concentration and less permanence of the navigation channel, for the straight channel accumulates its sediments in the form of sand waves, slowly traveling downstream and without fixed location, composed mainly of those particles of sand and gravel which are too large or too heavy to be taken and distributed through the water in true suspension. Between these sand waves the low-water current of a river that is straight in the flood season, travels on a zigzag course which frequently changes.

However, the sand wave presents the advantage of extending only halfway across the river; whereas, on a curving river the crossing bar goes all the way across from bank to bank and presents more of an obstacle to the discharge of a flood volume.

I have mentioned this confusion of claims only to illustrate some of the problems in which a study of models in the laboratory would be helpful in clarifying ideas.

STRAIGHT RIVER VERSUS A CROOKED RIVER.

The Mississippi River Commission and the Army engineers appear to have 40 years ago stopped debating the question of the respective merits of curved and straightened channels which had been debated since the days of ancient Rome and to have accepted as a settled fact that a curved channel was better for the purposes which they were to safeguard—i. e., primarily navigation; secondly, flood relief—40 years ago. Probably they are still right for the case of the lower Mississippi, because of the Herculean labor required to straighten it and the lack of well-proved devices for holding it straight, but there may be smaller streams in the United States, and perhaps some as large as the Missouri, where the straightened river may be best for present purposes, particularly in view of a permanent interest in flood protection as against the interests in navigation which have become relatively insignificant.

There are still able engineers full of confidence that a straightened river would in many cases be better, while there are other able and experienced engineers equally confident that it is highly dangerous to disturb the bends placed in the river by nature, and the United States Government for many years has been spending millions of dollars in building revetments to hold the Mississippi to its extremely crooked course, and does all in its power to prevent cut-offs.

Also the question has been discussed more or less in France, Germany, and England, and their river work of the past 40 years have gone on apparently with a somewhat changing policy; first a general tendency to train rivers into straighter courses, so far as the substructure of beds and topography of banks would permit, but in later years the tendency, largely under the desire to improve low-water navigation, seems to have more generally favored a gently curving channel without any such consideration of flood protection as is required in many cases along American streams.

The sand-wave proposition at low water also appears to have influenced this European practice, chiefly from considerations of navigation which do not now obtain in America.

The European rivers under improvement mostly are relatively short. Their delta courses, even those of the Rhine and Danube and Po, are extremely short in comparison with that of the Mississippi, and from what I have personally observed along the Rhine, the Seine, the Rhone, and the Danube these European rivers carry a larger proportion of coarse gravel, and therefore may very properly be trained under different rules than these soft-bed rivers of America. Obviously they present conditions very different from those found along the great deltas of the Yellow River and the Yangtze, where the sediment is substantially all composed of particles that can be carried in suspension and do not have to be rolled along the bottom.

Several of the most careful students of conditions on the Mississippi below Cairo have called attention to the fact that the crossing-bar obstructions are built up from material that has been transported only a short distance and not by the extremely fine-grained sediment that comes down the Missouri.

Those who have spent years along the Mississippi and the Missouri, particularly those who have had charge of dredging operations, have far better information on these matters than it has been possible for me to obtain, but from the little that I have seen and from all that I have been able to find written I am strongly inclined to believe that on a river carrying mainly fine-grained sediment and where the importance of flood relief greatly outweighed that of low-water navigation, a straight channel would be better than a curving channel. Moreover, what I have seen accomplished along the Missouri River near Omaha by the spur-dike "retard," and what I have seen of holding the Yellow River by inclined solid spur dikes, tends to convince me that for many rivers of the size of the Missouri it would not be a relatively difficult or expensive matter to train the river on any desired straight course and hold it there.

Regarding river straightening, the eminent English engineer, Bindon B. Stoney, has said:

"I am frequently struck with the manner in which past generations of engineers, when engaged in training rivers, somewhat slavishly followed the curve which nature delighted in, in place of boldly marking long, straight reaches, even at the appearance of opposing nature but in reality controlling her. Their idea, and it seems to prevail still to a certain degree, was apparently that long sweeping curves were more easily maintained than straight reaches."

When the matter of prime importance is the conveyance of large quantities of water, as for example, in large canals in India for irrigation, wherever topography permits and notwithstanding that waters are far more heavily charged with sediment than those of the Mississippi, the engineers appear to have laid out their canals on straight lines.

All over the world it will be found that intelligent engineers, when designing a channel to carry the maximum quantity of water with the minimum of fall, will lay it out on straight lines, notwithstanding this water is heavily charged with sediment. When considering a river primarily as a flood discharge channel the same consideration should prevail.

Nature's chief purpose in curving a river is plainly that of delta building and of spreading broadly and evenly, by means of the meander of the river, the sedimentary material eroded from the hills.

The Mississippi banks are 10 feet, more or less, higher than the ground level some miles back from the river near the bluffs. Some prominent writers on Mississippi problems have urged that man makes a mistake in interrupting the effort of nature to level up the land back from the river by building it up with sediment from overflow of banks.

Nature's processes are slow, and computations probably would show that it would require tens of thousands of years for it to complete this process of sediment spreading all the way across the lower Mississippi Delta, so as to bring it to a level east and west cross section. Man, with the records before him of the brevity of the historic period of civilization and with evidence accumulating of a present-day revolt against civilization in several parts of the world, has a more immediate interest in himself and his descendants being safe and comfortable during the next hundred years than in working toward a perfection of topography to be attained 10,000 years hence.

In all of these problems that we have just been discussing experiments in the hydraulic laboratory now proposed would be extremely instructive.

In regard to making cut-offs and straightening any part of the lower Mississippi I am well aware of the trouble described as having been brought about by previous cut-offs in increased erosion of bank and obstruction of low-water channel by vast additional quantities of coarse sand or gravel brought in and which builds up the crossing bars during the flood, and at the present time I know of no certain or dependable means within economic reach by which the river in these great depths could be held to a straight course, but in view of the remarkable progress in construction methods during the past 50 years and the more powerful instruments now in our hands, he would be rash who would claim that the next 10, 20, or 40 years will not find and prove some method of control, and one step toward such improvement would be a more intensive investigation of the science of river erosion and sedimentation carried on with the laboratory supplementing work in the field.

Purely as an interesting speculation I have been interested in considering what might happen if the river could be straightened and held straight. This "if" is a big one and perhaps insurmountable, but it is of interest to work out the theoretic possibilities and find that when thus straightened the river upstream from Natchez or Vicksburg, all the way to Cairo and possibly to St. Louis, would have no further need of levees and in a flood as great as the recent one would not rise so high as the "bank-full stage." The present ever-present danger of a crevasse in a levee of standard section would then entirely disappear and the permanent prosperity of the region and the market value of some 20,000 square miles of farm land would be vastly improved.

I was afraid to mention this beautiful dream out loud until finding that Captain Eads had had the same dream.

In 1875 he said:

"A correction of the high-water channel by reducing it to approximate uniformity of width would give uniformity to slope and current, almost entirely prevent the caving of is banks, and its present shoals which now constitute a resting place for its snags there would be navigable depth in low water equal to that which now exists in its bends.

"By such correction coupled with a few judiciously placed cut-offs of flood slope can be safely and permanently lowered above each cut-off and in this way the entire alluvial basin from Vicksburg to Cairo can be lifted as it were above all overflow and levees in that part of the river rendered useless. There can be no question of this fact and it is well for those most deeply interested to ponder it carefully before rejecting it, for the increased value given to the territory thus reclaimed can scarcely be estimated."

While, as above stated, this ideal result may be beyond practical reach, it certainly is worth again studying, and the study of the physics and hydraulics of the Mississippi so auspiciously begun 65 years ago and interrupted by the Civil War certainly should be resumed.

Senator RANSDELL. I have always understood, and I have been studying the Mississippi very closely for certainly 30 years, that it is the duty of engineers to maintain the regimen of the river and to allow the channel to meander around as nature seems to have provided. That has been the practice around here. You take issue to that practice to some extent, do you?

Mr. FREEMAN. Yes; but I want to study into it further before taking any strong stand. I am now raising these questions in order to show the need of further study. Meanwhile I venture to say that the engineers in charge of the Mississippi haven't yet found out everything that should be known about the real needs of maintaining so crooked a river.

DANGERS THAT REMAIN AFTER LEVEES ARE ALL COMPLETED.

If every lineal foot of levee now planned along nearly 2,000 miles of river front downstream from Cairo were forthwith built of the full standard section to full height at the additional cost of about 40 or 50 million dollars, after all of this expenditure, and millions more spent in upkeep and in extending the revetments at concave banks of bends year by year, there is no real safety or insurance against sudden disaster from some apparently stable part of the levee being under-cut without warning by a new swirl or twist of the swift current, thus opening a crevasse which no human power can prevent from rapidly enlarging to half or three-quarters of a mile in width within a few days, with the result of putting 5,000 square miles of fertile farm land under water, in either the Yazoo, the St. Francis, or the Tensas basin.

This land is potentially worth when drained, more than $100 per acre, wherefore 5,000 square miles has a potential value upward of $300,000,000, and when this is developed by drainage, as it soon will be, the damages by flooding a year's crop and driving the inhabitants from their homes might readily be $25,000,000 in either the Yazoo or the St, Francis basin, and if all three basins were flooded the damage might reach $75,000,000 in a single flooding.

The grand total of the area of six lower Mississippi delta basins is reported to be 29,790 square miles, divided as follows:

St. Francis	6,706	Tensas	5,370
Yazoo	6,648	Atchafalaya	8,109
White River	956	Pontchartrain	2,001

At present, under conditions of a high flood, there are a hundred or perhaps a thousand ever-present possibilities of a crevasse developing as suddenly as those at Ferriday, Poydras, Tunica, or Stanton, and against which there now is no substantial precaution or defense whatever if the current down deep takes a new swirl against the bank which supports the levee.

The fact that in all the 1,400 miles of river bank between Cairo and Ferriday, near Natchez, there was not a single crevasse during the flood of 1922 is to be credited first to a kind Providence and second to the energy with which thousands of men hastily erected temporary safeguards at points which their watchful eyes saw were threatened.

By far the most immediate and important use for a national hydraulic laboratory would be the development of more precise knowledge about river currents and their hidden method of attack upon a bank supporting a levee and the means by which such attack can be prevented.

To make my point plain I will later cite a few object lessons.

There are problems of the lower Mississippi where I am confident this laboratory would be helpful. These relate to flood relief and to navigation, to straightening and to bank protection, to economic deepening at the passes into the Gulf, to reclamation of salt marsh, and to the spillway method for lessening flood height at New Orleans.

Values involved in treating the problems of the lower Mississippi according to methods heretofore proposed are on a scale of stupendous costs. When I was along the lower river a few months ago I was told they proposed to ask the Federal Government for forty or fifty million dollars with which to complete the levees to the standard height and section prescribed by the Mississippi River Commission, but when you have the levees completed you have only completed the least expensive part of the whole job.

There is something like 750 to 1,000 miles of river bank that is subject to erosion—some on the east bank, some on the west, according to the local curvature. The maps that accompanied the engineers' report of 1909 showed 750 miles of actively eroding river bank. After you have completed your levee you are liable any time during a great flood to have a short piece of bank somewhere cut out from under it in the middle of the night, causing a crevasse that might submerge the whole of the Yazoo Basin, the Tensas Basin, or the St. Francis Basin.

The only effective remedy yet developed by the engineers in charge is the revetment of the eroding banks by willow mattresses or blocks of concrete, involving the expenditure of $200,000, or perhaps $300,000, per mile of bank protected.

These revetments for some years past have been built at the rate of about 3 miles per year, and at that rate it would require about 250 years to complete them and the cost would add more than $200,000,000 to the cost of the levees. I believe it is true economy to study the science of river currents and of bank erosion in the laboratory as well as in the field and try to find some quicker and less expensive methods.

Senator RANSDELL. You mean the banks?

Mr. FREEMAN. I mean the banks. Revetment by willow mattress or concrete is the only remedy used along the Mississippi below the Missouri at the present time. According to recent reports of the Chief of Engineers, they are putting in about 3 miles a year at a cost of about $250,000 a mile. It cost more than that during the war. If Congress gave the Army engineers more money they could put in more miles per year, and from reading reports it seems there are yet 750 miles to be revetted.

The need for supplementing levee building by all of this bank protection is not generally understood, though it is well known that often a long piece of good standard levee has to be abandoned and a new levee built farther back, sacrificing the present level and the valuable land between it and the new levee; sometimes the river shifts its cutting current too quickly to give time to build a new back levee. I can illustrate this sudden danger at an unsuspected place by what happened 6 miles below New Orleans, at Stanton plantation, on the west bank, nearly opposite Poydras crevasse, during the recent flood. As they told me the story down there, they didn't expect any trouble there at Stanton. It was on a convex shore with levee well back from river, and no sign of trouble. A little girl in a house near the river, looking out from a second-story window, saw a familiar tree on the broad flooded foreshore sink down below the surface of the river. She rubbed her eyes wondering whether she was just seeing things, and then saw another tree disappear. Quite excited she ran and told her brother or father that she had seen the trees sink down below the water. Instantly they knew what it meant. It meant that down deep the current had taken a new twist and was eating its way at the foot of the submerged bank rapidly toward the levee. The river here was about 80 feet deep. They summoned a great force of men who set at work immediately to build a new dike back of the main dike, so that they would be safeguarded if the main dike was completely undermined and let go. Fortunately the river fell before it had cut entirely through the old levee, but the incident illustrates how these crevasses may come suddenly at places where no one is looking for them.

Everyone is thankful and happy over the fact that in the recent flood, the highest ever known, the levees had been so far completed that in more than 1,500 miles of river bank on both sides all the way from Cairo or St. Louis down to near Natchez there was no crevasse, but reviewing it now calmly we find that the Ferriday crevasse and the Poydras crevasse came suddenly where they were not expected. If in a high flood a gap 30 feet wide is made, no power of man can stop it from quickly becoming 3,000 feet wide and from flooding thousands of square miles.

SOME OBJECT LESSONS IN UNDERCUTTING OF BANKS.

These hidden dangers can be illustrated by repeating what was told me at several places along the river, of happenings during the recent flood. I have already described what happened at Stanton, which near crevasse was close to the main river channel on the convex shore, where undercutting seldom occurs.

A second object lesson about these dangers is found at Ferriday (or Weecame) crevasse, where I was told that no one expected serious trouble along here, because the levee was a mile back from the main river, with a broad expanse of willow-covered sediment deposits between, and only a relatively small old channel or slough known as Lake Concordia between this high-water island and the levees. I was told that this break came with such a suddenness that nothing whatever could be done by those living near, except to move out in a hurry, taking families and live stock to the higher land of the levee itself until removed by boats, while the broad back plain was slowly submerged. So far as could then be learned this crevasse originated in a sand boil, which very rapidly enlarged until about 40 feet of the levee fell into the hole, after which the crevasse widened at the rate of several hundred feet per day until at the time of my visit it was about 3,500 feet in width and still being cut away at both ends, while a territory, said to be 1,000 square miles was submerged, partly by backwater, but mainly from the volume pouring through this crevasse, estimated roughly at 200,000 cubic feet per second, or about equal to the whole flow of the St. Lawrence River.

The third illustration is at Tunica, about 30 miles below Memphis, near the head of the great fertile Yazoo Basin, which has an area of 6,600 square miles. Here also the levee was a long way back from the main river and shielded by broad, high-water islands of sediment, covered with large trees.

A big bend with a circuit of several miles carried the river far away to the west and this long detour naturally caused a concentration of fall across the neck of the bend which, obstructed as it was by the growth of trees and general shallowness of the sedimentary deposit, was not considered threatening, although an eddy of this small back stream had years ago dug out a considerable cavity near an angle where an old levee joined the new levee. Suddenly as the flood rose this harmless looking back current developed greater velocity and the whirling eddy evidently started gnawing at the foot of the levee, and only by most skillful and strenuous efforts of hundreds of men who suspended long "snakes" of sand bags, bound in series to ropes and built out a short-timber diverting spur, was this undercutting and down-sliding of the top of the levee resisted and a widespread inundation prevented, which otherwise might have cost, say, $25,000,000.

Fourth. At the Myrtle Grove crevasse, 35 miles below New Orleans (which I did not visit), the break is said to have occurred in the middle of the night and to have been due to a sand boil.

There were several near crevasses at various points along the 1,500 miles of river front, where disaster was averted only by wonderfully quick and able work.

Good fortune can not be always relied upon to wait upon energy of men to this extent, and my best guess now is that once in 20 years for a hundred years to come, with works as heretofore proposed, there will be a crevasse somewhere along the Yazoo, St. Francis, or Tensas Basins, causing a property damage of $25,000,000.

LEVEE "SETBACKS" ARE EVIDENCES OF DANGERS.

Along many parts of the river, as one traverses the top of the levee or motors by the good roads just inside the levee at its foot, one notices setbacks in the alignment of 500 feet, more or less, where a new levee has been built and the old is no longer depended upon because of an observed tendency of the river to shift its channel and attack the bank beneath the old levee. Hundreds and thousands of acres of fertile land and many miles of levee are thus sacrificed by the slowly changing position of the river channel. True, a corresponding strip of nearly the same area is slowly built upon the opposite shore, but it is outside the protection of the levee.

THE SMALL PROPORTION OF BANK REVETMENT.

The river is continually changing its meander in nearly all this thousand miles of crooked course between Cairo and the Gulf. The sole and only attempts that have been made, or that are being made, to restrain it or hold it in any particular location are those widely separated spots of a few thousand feet in length where revetment of bank and adjacent bed has been built in recent years, under the supervision of the United States engineers, at the sharp bends or near large cities, or in a sharp bend where the continued erosion on the upstream side of a long oxbow has threatened to make a cut-off.

The sum total of all the revetment work thus far accomplished by about 40 years' continuous effort does not exceed about 100 miles, which it will be noted is an extremely small proportion of the 2,000 miles of river bank between Cairo and the Gulf, and the rate at which this has been going in, after all the improvements in process of manufacture during the past few years, is only about 3 miles per year, and at a cost varying in different localities and with different types, but averaging before the World War not far from $35 per linear foot, or $180,000 per mile, and since the war costing about double this. At $50 per foot, or say $250,000 per mile, revetment for only half the shore line from Cairo to New Orleans would cost about $250,000,000, and maintenance of the older revetment requires large annual expenditure for repair.

Few can believe that the whole length of the river bank, or even one-half of it, will ever be revetted with mattress or concrete, and it is obvious that in all this 2,000 miles there will for 100 years to come be many places remain open to some such attack as the three that I have described above, unless engineers can devise some simpler and less expensive means of holding the river to its course.

The attacks on a bank obviously are more violent on a sharp concave curve than on a straight river, but that even convex banks are not immune, and that situations remote from the main channel are not always safe is shown by the recent happenings near Stanton, Ferriday, and Tunica.

In the 1,500 miles of levees above Ferriday there were plenty of chances where there might have been a crevasse, notwithstanding all their vigilance and heroic energetic labors during the flood. Many near crevasses were stopped by summoning everybody from the plantations for miles around and doing wonderfully energetic work. Plantation bells were rung at midnight; motor trucks loaded with men and grain sacks for making sandbag dams. They got the ex-service Army men to take charge of the commissary. It was one of the most thrilling stories of a great fight that I have ever heard. They were successful all along the Yazoo, the St. Francis, and the Tensas, and I think it is wonderful they were successful, but this success is no guaranty of complete sucess in the next big flood.

FUTILITY OF RESERVOIRS.

This particular flood of 1922 demonstrated what the Army engineers have been saying for years—that you can not protect the lower Mississippi River districts by reservoirs on the headwaters of the Mississippi. The rains which caused this 1922 flood pretty much all fell on drainage areas located downstream from any of the proposed great reservoir sites. General Beach can tell you more about details than I can. But this last flood, which was the highest ever known, came into the Mississippi mostly below where any reservoirs had been proposed. This proposed reservoir system for preventing Mississippi floods on the lower river is thus proved an iridescent dream.

St. Francis Basin would make an enormous reservoir, but is potentially far too valuable for reclamation, drainage, and agriculture; and if one can devise bank protection that will supplement levees and so afford thoroughly dependable protection, instead of being worth $100 an acre, much of this delta land would be worth $200 and $300 an acre because of its wonderful fertility.

In telling of the immensity of these problems I have been getting away from the laboratory idea. In returning to it, let me say once more that I don't think the laboratory will do the whole thing, but I do believe it could be made a powerful instrument in the right hands for finding out more quickly and cheaply how to do things right.

Senator RANSDELL. Pardon me, but you have gotten away from the matter of straightening that river. Have you said all you want to say on that?

Mr. FREEMAN. There is a lot more that I would like to say at the proper time and place in favor of straightening, but just now it might seem to partake of the character of academic discussion. I am strongly inclined to believe that a lot of good could be done by river straightening under certain circumstances, but I hesitate to raise false hopes until some one can put the idea to test on a laboratory model. This straightening is a far-reaching subject that must be studied from a broad horizon, with an outlook of 10 or 20 years' systematic improvement in view.

The classic story that always brought into the discussion of river straightening on a large scale is that of the River Theiss, in Hungary, which was straightened upstream from the city of Szegedin so that it brought down the floods to that point in greater force and volume than before. The city fathers of Szegedin seem to have been reactionary. They opposed or delayed the improvements urged by the engineers for removing obstruction and improving the flow past their city. The flood came and piled up at this obstruction and washed out and destroyed a large part of the city.

While the advocates of a crooked river cite this as a horrible example, the advocates of the straight river say the incident proves nothing except that the improvers began at the wrong end of the job, and that the city fathers invited disaster by delaying improvement past their city.

The general subject of river straightening opens up some remarkable possibilities if carried far enough, but to go a little way on construction and then stop might, as the poet said about a little learning, be "a dangerous thing."

I may say that now it seems abundantly demonstrated from experience, with the present schemes and methods of improvements for maintaining a 9-foot navigation channel up the Mississippi to St. Louis, that if you cut off a few of the bends there would for several years afterwards be an awful job on hand in digging out the crossing bars to maintain this 9-foot channel after the quickened current had cut the concave bends deeper and this cutting and caving had brought in vast quantities of sand and gravel, which in each flood would be swept onward from the deep curving pool onto the crossing bar.

But in a long range, systematic treatment of the Missouri, and perhaps even in some places on the lower Mississippi, there appear to be some possibilities well worth studying into. In any such work of river straightening one should begin at the downstream end.

Senator RANSDELL. Have any eminent engineers, so far as you know, in this country argued for a straightened Mississippi to some extent?

Mr. FREEMAN. One conspicuous case I can think of is that of Capt. James B. Eads, who probably knew more about the moods and the mysteries of the Mississippi currents than any man of his day and generation. He says in some of his papers that a few judicious cut-offs would be a good thing.

There are possibilities which one can figure out on paper to the effect that by a system of cut-offs and straightening and with control sills like that at the Atchafalaya outflow, the river's maximum flood line upstream from Vicksburg could be lowered and the bed so lowered that levees would be henceforth unnecessary and the river would never afterwards overflow the banks.

The present insurmountable obstacle is the lack of a cheap, efficient, dependable form of spur dike or bank head or training wall for holding the river securely in its course. It is going too far to say that such a device can never be invented.

I don't like to get into that too deep now for fear I will be misunderstood and called visionary, but I will say it is worth while to search here faithfully for the truth, and let the truth lead us where it will. In this matter of straightening bends, there may be a pot of gold at the end of the rainbow, which I would take a chance on chasing this rainbow a little way, but please take notice that I hold out no glowing promise of success in this quest, just suggested.

Senator RANSDELL. You could chase your rainbows with this laboratory?

Mr. FREEMAN. Yes, sir; and do a lot more besides.

Senator RANSDELL. If you could straighten that river, what would be the effect ultimately on the channel deposits in your judgment?

Mr. FREEMAN. If you could first of all hold the bank securely it would be an entirely different problem than the problem we have today. The great and immediate problem is a study of bank erosion and bank protection.

From all that I have thus far found in the books and papers, with what little I have been able to observe personally, the lower Mississippi carries two very different kinds of sediment, which come from entirely different sources and which produce very different results.

The first is the extremely fine grained sediments from the Missouri. This doubtless gives most of the muddy appearance and color to the water below St. Louis and Memphis, but probably causes little or none of the trouble at crossing bars. It probably has relatively small part in obstructing navigation or in building those submerged dams across the river which obstruct the flood discharge. Much of it probably has a grain less than a thousandth part of an inch in diameter—some is like clay and carried in colloidal suspension. All of this fine-grained portion can be distributed from top to bottom in true suspension by the vortex currents and the general internal turmoil of the flowing water. I have examined the cooarsest grains that can be found in the sand piles of the contractors who dredge sand from the river bed at Kansas City for mortar sand, and find this all is even too fine for the best quality mortar sand.

The coarser sand and gravel, which probably causes most of the trouble in the lower Mississippi, is of local origin. Probably nearly all of it comes from the caving in of the thousands of acres that are yearly undermined and washed into the river. This is scoured from the banks into the pools and mostly is too coarse grained to be taken up by the water into true suspension and evenly distributed from the bottom to top by ordinary velocities. When a flood gives high velocity this is dragged from the pools and left on the bars. If you could stop the erosion of the banks and the vast annual destruction of farm lands on the river margin, you would soon cut off the fresh supply of coarser sands and gravels from which bars are built that obstruct navigation and cause floods, and after that the maintenance of navigation probably would be easy in a straightened channel.

If after the river cut too deeply, after it was rigidly narrowed and straightened, this could readily be controlled by dams perhaps 40 miles apart, provided with flood sluiceways and a lock as at Keokuk, similarly giving slack-water navigation and water power enough to pay for the dam. This may be a rainbow, but it is worth thorough study, and my main idea is that the search would cross the path of something substantial.

The first thing a flood does is to obstruct its own discharge by building up submerged dams on the crossing bars out of the sands and gravels that have accumulated in the pools from the caving of banks along the pool.

Some of the most distinguished members of the Mississippi Commission have advised that if you could stop the caving of the banks then you would stop the obstruction of navigation by the bars.

These coarser sands which form the obstructing bars were probably brought down and deposited to form a large part of the so-called "bottom lands" between the river bluffs tens of thousands of years ago when the continental ice cap and the great continental glaciers were melting and the Mississippi and Missouri carried perhaps a hundredfold greater volume than ordinarily to-day and flowed full from bluff to bluff, with greater transporting velocity than now. The Director of the United States Geological Survey, whom I see in here this morning, could give some very interesting information about this.

I would like to investigate this matter of relative coarseness and distribution of sediments further before saying too much about sand bars in a straightened channel. I would like to sample the sand dug by the dredgers at various places along the river. I can not find much printed information about its fineness of grain or distribution in the water.

Personally, I have made superficial observations along these rivers, noting their sediments at Glendive, Holter, and Hauser in Montana; at Omaha, Kansas City, and Keokuk, and at the eroding bluffs at Natchez, but as yet I have arrived only at the stage of asking questions about these sediments. I believe a more scientific study than has yet been made would be profitable.

The curious fact is abundantly demonstrated that a Mississippi flood obstructs its own progress by piling up submerged dams built of sediments swept forward from the pools, so that with precisely the same discharge in cubic feet per second the river stage is from 2 feet to 5 feet higher after the peak of the flood than before. I recall some observations made years ago at Columbus, Ky., where a discharge of the same quantity required a river stage of 4 or 5 feet higher on the falling that on the rising river, because the river during the flood had built up a new series of submerged dams at the crossing bars at reversals of curvature all the way down. There are perhaps 40 places along the course of the river where sediments thus collect during floods and obstruct the flood discharge.

One may ask why the present curving Mississippi piles up these sediments at the crossing bars during floods and slowly digs them out during the following low-water season.

The explanation is that in the low-water season the whole river is a succession of nearly level, long, deep, curving pools, with short shallow diagonal "crossing bars" of sand and gravel between the bends at points of reversal of curvature, over which bars most of the river's declivity occurs. The subsiding river, after a prolonged period of flood, digs readily into the high, water-softened banks, chiefly at the sharp concave bends. The spiral current drags this mixture of eroded silt, sand, and gravel into the pool, where the coarser material mostly lies dormant until swept forward by the higher velocity of the next flood.

Curiously the river is much wider at these places of reversal of curvature than in the curves, and although more shoals, has a cross section of more uniform depth of cross section, than the triangular cross section at the bends. Thus it happens that at the crossover the area of cross section is greater and the velocity slower, and so the sediment is dropped here, from lack of propelling force and forms the crossing bar. By observations on the model in the laboratory we could work out and demonstrate these problems more precisely. The rivers course in flood is somewhat different and more direct than in low water. As the flood rises, it overflows many of the small sand bars projecting from the convex banks and runs with swifter velocity.

Senator du Pont. I have two or three problems I would like to take there myself.

Is there any doubt in your mind or in the minds of competent engineers to-day that the upkeep or maintenance of a laboratory has generally shown beneficial results?

Mr. Freeman. Absolutely no doubt whatever, in my own mind.

Senator du Pont. There is no question about that.

Mr. Freeman. The greater part of our recent progress in science and in the arts has been made by taking problems from outdoors into the laboratory, then coming back out of doors with the result, and working the theoretical and the practical side by side.

Senator du Pont. Wouldn't it be your judgment that any competent engineer to-day would say that a laboratory is a cheap investment from the standpoint of operating and maintenance of large works?

Mr. Freeman. I would say yes to that most emphatically for myself; for others, I can not speak. This thick volume of compilation of engineering opinions upon the various branches of river hydraulics shows that there are equally eminent engineers on both sides of almost every question. If they had had the opportunity to go with their problems to laboratories, I believe many of these differences of opinion would not now exist.

The great advances in naval architecture of recent years, in the shape, power and speed of ships, had their chief impetus in the laboratory experiments of Froude in England. By means of a model of a ship's hull in a laboratory containing a long tank filled with water you can work out a proper model for a ship at a mere infinitesimal fraction of the cost and time of building and experimenting with a ship over the measured mile.

There are now two or three of these naval tanks in the United States—one here in Washington at the navy yard—one at the University of Michigan, but nowhere in America have we yet a river training laboratory comparable with those in Germany.

That reminds me to state that either of the two flumes shown in these drawings of the proposed national hydraulic laboratory could be used for tests on swift boat or steamer models with certain great advantages over any existing naval tank, because the boat model can be held at a fixed point while the water runs. You can work with a model of a boat with flowing water instead of experimenting hastily over a short quickly finished course in a tank as they do in the present naval tanks.

Senator du Pont. Anchor the boat and let the current run by?

Mr. Freeman. Anchor the boat and let the current run by. And the beauty of this method is that you can have more time for observing. If you try to run the model at high velocity in the existing naval tanks you get to the end of the tank before you have had time to do much observing; moreover, you sometimes haven't the time to establish what they call "regimen."

In this proposed flume you can do with the ship model just what they do with the airplane model in the wind tunnel at the aviation field at Dayton or at the big wind tunnel at the Bureau of Standards, and you will have time enough to make observations.

I am inclined to think that when you have established this laboratory and the Navy Department finds out about it, they will want quite a long inning.

Senator RANSDELL. Would this amount, $200,000, if the bill carries, be sufficient to construct a laboratory such as you have designed?

Mr. FREEMAN. I have tried very hard to get this design within that appropriation and was delighted on going out to the Bureau of Standards to learn that they have some available land now not used, so that no part of this appropriation would have to go into land or into a power plant. And if you couldn't build the whole laboratory at first, I would build half of it, comprising the river flume and the smaller pumps, leaving out some of the expensive features. Perhaps temporarily you could borrow a pump for a month or two, preliminary to some great drainage job, and use it at this laboratory for the few large discharge experiments on weirs and dams; using it on the way from machine shop to final destination.

Senator DU PONT. I understand, then, that the $200,000 would not include any land cost, nor would it include any maintenance or operating costs?

Mr. FREEMAN. That is true. I haven't had the time to make up as detailed an estimate as one might like. I tried first to design apparatus that was right. I redrew these designs entirely after I learned the amount of the proposed appropriation in Senator Ransdell's bill, and after my first estimate of quantities I redesigned it and tried to reduce the quantities, so as to get a start and possibly complete the structure within the proposed appropriation.

Senator RANSDELL. You don't contemplate in any way creating a new bureau of the Government, but simply to create an instrumentality which in your judgment will be helpful to a number of the existing bureaus and departments and which from time to time they can use?

Mr. FREEMAN. That precisely is my proposal.

Senator DU PONT. A laboratory for all the departments.

Mr. FREEMAN. Yes. I thought out this matter of location gradually on my way up and down the Mississippi. I had been very much impressed with the hydraulic laboratory at the Iowa State University, where the Department of Agriculture is making some experiments this summer; there was a question in my mind about locating it at some educational institution in the Mississippi Valley, but after reviewing the whole from many points of view my final answer is that it ought to be placed here in Washington.

The proposed laboratory can be used for many purposes besides experiments on river training.

The Dresden laboratory also has been used to study problems of seashore protection, such as they have at Santa Barbara, where they are wondering what to do to prevent their beach from being washed away. They have similar problems along the New Jersey coast, which are now causing much anxiety and much expense.

A sudden tidal wave is released to run down the steeply inclined flume, like a roller coming in from the sea, and is arrested by model sea walls of various forms, trying first one form and then another to see which is best.

I have somewhat hastily written out a list of topics on which this laboratory could give useful information, which I will present later.

This laboratory would serve many departments of the Government, and before the Government departments had found out all they wanted to find out I believe that many civilian engineers would be waiting to take their problems there.

I am pretty sure Mr. Hoyt, whom I see here, has some problems on which he could use this laboratory to advantage, and that Mr. George Otis Smith, whom I see here, has some. And I can suggest a lot of questions that water-power engineers would like to have this laboratory help solve.

Senator DU PONT. It ought to be in an atmosphere of science; there is no question about that.

Mr. FREEMAN. Absolutely. Pure science often has come to my assistance and helped me out of a bad hole. I am certain beyond a doubt that this laboratory ought to be in a scientific atmosphere. I am very strongly of the opinion that the custodian should be a mathematical physicist with a training in engineering. If I may say a word further on this, I think it ought to be in the custody of some man who could stick right there year after year and accumulate experience, as Mr. Howard did on the big Government testing machine at

Watertown, so as to be able to give valuable suggestions to those who bring their problems.

With great advantage to public service later, his assistants might be young officers of Army or Navy, or hydrographers from the Geological Survey, or young engineers from the Department of Agriculture. These men could get training here, and a lot of ideas valuable in their future work, and move on; but the man in charge should be a real scientist, a mathematical physicist, who could be a consultant and helpful by accumulated experience to all who brought their problems to the laboratory.

Senator RANSDELL. Mr. Freeman, will you glance at your memorandum there and see if there are some other points you would care to bring out? I have read the memorandum with a great deal of interest. We would be very glad to have you add to or elaborate upon anything you have said.

Lieut. S. S. Leach, when secretary of the Mississippi River Commission, in Appendix E, Report of 1882, page 111, stated: "The first effect of an approaching flood is to impede its own discharge, and the impediment outlasts the flood."

Plates 14, 15, 16, and 17 of the Humphreys and Abbort Report of 1861 give many beautiful and convincing demonstrations of this fact in its discharge diagrams of rising and falling rivers.

The late Prof. J. B. Johnson, of Washington University, St. Louis, whose early engineering experience was gained by several years on Mississippi River surveys covering the great flood of 1882, in a very instructive paper printed in the Proceedings of American Association for Advancement of Science, 1884, page 276, also made plain the great fact that one of the first actions of the Mississippi, the Ohio, and Missouri Rivers in time of flood is to build up a barrier in the river bed which impedes its discharge. It does this by digging out material from the deep pools of the concave bends and piling up this material (largely gravel) to increase the height of the gravel bars at the crossovers, or points of reversal of curvature from one bend to another.

Professor Johnson makes the surprising statement, Journal of Engineering Society, July, 1884, page 173 et seq.: The mean velocity of the water in great floods at some of these reversals of curvature is only half the velocity in the deep pools of the bends; and says that this reduction of velocity is the cause of the dropping of the gravel and sand here. One naturally pictures the deep pool as having the slower velocity. The pool, however, is deep only at its outer cutting edge; the opposite edge is shallow; the straight reach at the crossover is broader and more uniform. He pictures the whole river as a series of alternating pools and shallows, with a succession of a reach of swift motion with erosion and then a reach of slow motion with deposition, and states that these deposits on the bars are not of fine sand, such as may be transported a long distance, but of coarse gravel coming from near-by erosion. I was myself surprised to note the coarseness of some of the strata of gravel in the steep, high river bank at Natchez. Plainly part of this material now being worked over by the river in its modern meandering is not river silt from the Missouri, but is the gravel of an earlier geologic epoch.

Johnson says: "The Mississippi River bed is a succession of narrow, deep, and long pools and short, wide shoals, the pools being generally in the bends and the shoals on the crossings at low stages. At high stages the more rapid current is in the narrow pool and the slower in the wide crossing. The variation in velocity from pool to shoal and from shoal to pool is enormous."

Obviously, this continued succession of acceleration and retardation and the eddying and turmoil of current around the succession of sharp bends causes a large increase of friction and fall over that required for the same velocity in a straight channel, which naturally would shape itself to greater uniformity of cross section.

Professor Johnson, in his paper on the Proceedings of the Association for Advancement of Science, pages 276–286, cites an example on the Mississippi at Columbus, Ky., about 20 miles below Cairo, showing that, comparing heights of river surface before and after the flood with the same number of cubic feet per second flowing, the water surface, soon after the peak of the flood had passed, by the average of four determinations, was 2.15 feet higher while the flood was subsiding than when the flood was rising.

This 2.15 feet difference was for stages near top of flood. After the water had fallen to a normal low stage the difference was far greater. The surface elevation was then 5.5 feet higher than for the same quantity discharging prior to the flood, due to the deposit of gravel dug from the curved pool, raising the height of the bars at the crossings from one bend to another.

These bars concentrate the fall at low stages and the rapid flow over them slowly cuts them down to about the level at which they previously stood.

The Humphreys and Abbott report, in plates 14, 15, 16, and 17, presents abundant proof of these facts, from which we take a few cases, as follows:

At Carrollton, near New Orleans, the increase of river stage or elevation of surface due to the building up of these submerged dams by one great flood of 1858 was about a foot, and in another about 2.5 feet. Here the river is deep, there are fewer reversals of curvature downstream, and pesumably the sediments contain less coarse gravel for building a resistant bar.

At Baton Rouge the increase varied from 3 feet to 4 feet at lower stages.

Farther up river, at Natchez, the increase in stage from rising to falling discharge curve averaged about 1.8 feet, and in another flood the increase was about 2 feet to 3 feet at lower stages.

At Helena the increase was about 2 feet at high stages and about 2 feet at low stages.

At Red River Landing the increase was about a foot, perhaps being influenced by the large outflow through the Atchafalaya.

At Columbus, 20 miles below Cairo, in addition to the condition noted by Professor Johnson, the comparison over a long range at about half flood height, shows a raising of the river stage by about 5 feet, which nearly all disappears when the water has again subsided to lowest stage, due probably to the submerged dam having become cut out by this time by the current over it and the absence of the supply of gravel rolled up by the higher velocity of the flood.

Professor Johnson, as a result of his personal experience along the river and his later careful studies, presents the following interesting conclusion: "If the river flowed between straight parallel banks, such as Captain Eads has constructed at the mouth of the river, then there could be no such thing as this discontinuous transportation of sediment, and hence no alternate scour and fill. The concentration of volume would be beneficial and would ultimately lower the river bed."

Professor Johnson, writing nearly 40 years ago, concluded that this treatment of the Mississippi could never be accomplished and that therefore levees would be harmful by raising the river bed and a far greater volume forced down its channel. The river has since been leveed along substantially its whole length and on the whole has become deeper. That far more deepening has not resulted probably is due to these causes that Professor Johnson pointed out, although he overestimated their power.

It will be interesting to learn if the hundred miles of revetment of river banks placed during the past 30 years has lessened the gravel supply so that the floods of 1912 and 1922 built up smaller obstructions than the flood of 1858.

Judge R. S. Taylor, of the Mississippi River Commission, has said that "If the caving banks were all revetted, the bars would all be starved out," and that the bar-building sand or gravel is substantially all of local origin.

By means of a laboratory containing a model river on a small scale this matter could be carefully studied under a great variety of conditions and with precise control and could then be checked up by various observations on the river during and after floods. The study in the laboratory would point the way to planning just how and where observations should be made during the limited period while the flood is in progress and would hasten the finding of dependable and useful facts.

SCOUR BY SPIRAL CURRENTS.

One of the most important hydraulic discoveries of the past 40 years is that worked out in a laboratory by Professor Thompson, reported in the Proceedings of the Royal Society of London, 1878, page 356, which explains the procedure by which the sediment eroded by a swift current in a concave bend is transported by a sort of spiral motion of the water downward and across the bottom of the channel, because of the centrifugal force of the water near the surface moving with high velocity, being greater than the centrifugal force of the slower lower strata. This centrifugal force raises the head of water in the apex of the bend to greater height than the water surface on the opposite side of the river—I have personally seen the water level a foot different on the two sides of the St. Lawrence—and at the same time produces a twisting spiral current downward along the bank which is being eroded, and across the bed of the river which drags the eroded sand grains away and across to form sand bars a little farther downstream. There is dispute among the eminent authorities as to whether the sand grains cross the channel to the opposite shore or lodge farther downstream on the same shore.

Contrary to popular opinion, Professor Thompson says that the swiftest current is not around the concave bend, but near the convex shore where fall is steepest.

This principle of spiral currents at bends is but lightly dealt with in American hydraulic textbooks and many do not mention it at all, but it is made much of by Professor Engel, the director of the Dresden river-control laboratory, in his excellent treatise on river hydraulics, and the principle might well be much further developed by experiment and observation in a laboratory and in the real river.

SOME PRODUCTS OF THE DRESDEN RIVER-TRAINING LABORATORY.

Professor Engel, in his great treatise on structures for water (Wasser Bau, Leipzig, 1919, 3 vols.) also explains the relation of pools in the bends and shoals at the points of reversal of curvature in a more instructive way than any American textbook or any in the English language, largely, I presume, because of the facilities that he has had for studying these matters in his laboratory; and there are a multitude of similar phenomena relating to river flow, to vortex motion, to eddies, to erosion, and deposition of silt, which, with great ultimate advantage, could thus be studied in detail in the laboratory, where conditions are under immediate control, and then checked up by observations in the river.

In many of his experiments with laboratory currents on a carefully proportioned small scale Professor Engel prefers to have the water not more than 8 inches deep, so that he can watch the course of dark-colored sand grains over a white plaster of Paris bed and study the whirls and eddies and laws of transportation and deposition.

Professor Engel's textbook, in describing river-bed formation, stands alone among textbooks, so far as I recall, in repeating the idea published by Colonel Leach and Professor Johnson—quoted a few pages later—which he seems to have checked up in his laboratory. He says, page 323, as translated:

"In general, high water has, by raising the ridges at the fords, increased the hindrances to outflow, and by deepening the washouts lying upstream has created places at which the living force of flowing water is consumed in inner motions at the expense of its propelling force."

He says on page 238, in effect:

"Because of the impossibility of tracing the particles of gravel and sand in their course along a deep and turbid river the only means of research open is by experiment on a small scale in the laboratory."

And says further that he entered on such a course of experiment about 30 years ago, and 22 years ago built his first hydraulic laboratory, in which he has proved the path of the particles and found agreement with the results on the real river, and thus disproves the preconceived opinions of Grebenau.

Engel discusses and compares at much greater length than we can follow here the observed positions and movements of detritus banks in straight and curved channels of the Rhine and Danube with results found in the laboratory.

So far as I have followed his argument, I find nothing adverse to a straight channel for flood relief of a river carrying sand and gravel, although so long as new material is supplied it moves along with alternating sand bars first on one side and then on the other with a winding low-water channel between.

It is worthy of note that there is a vast amount of vagueness of description of the size of sand grains and gravel in nearly all published descriptions of river-training works, also little about the stickiness or colloidal quality of the silt. These are highly important factors and may utterly vitiate the application of experience on one river to the problems of another. For example, the gravels on the Garonne, which were particularly investigated by Fargue and was apparently the stream chiefly in mind when formulating his rules, the gravel is reported to have been about the size of walnuts.

Obviously a river with its bed and bars composed largely of this material would follow different rules from one like the Yellow River, with sand grains one-thousandth of an inch in diameter, and different from one flowing over a bed of silt like that carried in suspension by the Missouri, or like the bed of the Mississippi near New Orleans. Colloidal or other qualities causing adhesion in some masses of river sediments gives vastly different conditions of resistance to erosion from those found where silt or sand of fine grain has nonadherent particles.

In addition to the hydraulic laboratories at Dresden and Karlsruhe and the American laboratory of Professor Gilbert and these experimental channels of Fargue there have been others. The English engineer, Hearson, following the great success with the naval tank of Froude, was one of the first to propose laboratory models for rivers and deduced mathematical laws for their proper relations.

Prof. Osborne Reynolds, one of the most distinguished of English scientists, also proposed their use and discussed their mathematical relations to a tidal basin (see British Assoc. Adv. of Science, 1887, p. 555).

Eger, Dix, and Seyfert made experiments at Berlin on a model of the river Weser (see Zeitschrift Bau Wesen, vol. 56, 1906, p. 323) and adopted a scale of 1 to 100 for horizontal dimensions and depths. Vernon Harcourt, one of the most prominent English authors, used a model of the mouth of the Seine.

Kennedy, one of the most famous of English observers on sediment in channels, used various large artificial canals in India as his laboratory for discovering the laws of silt scour and deposition known by his name and popular with English engineers in India.

The Miami conservancy district in Ohio had need for accurate information on some of its problems of back water and dissipation of energy not to be found in the books and engaged Prof. Sherman H. Woodward, of the University of Iowa, to make theoretic analysis and practical application. A small temporary laboratory was set up supplied with water from public mains and circulated by pump driven by a 50-horsepower electric motor in which a large amount of valuable information and checking of theoretic work was obtained. This related chiefly to problems of dissipating energy in a stream from a large sluiceway in a flood detention dam, and while it does not pertain particularly to present problems it illustrates the great advantage of the laboratory method of treating such problems.

FLOOD RELIEF AND LAND RECLAMATION VERSUS NAVIGATION.

From New Orleans to the Gulf it is of highest importance to maintain a deep and safe channel for great ocean steamships. Spillway channels for flood relief of 2 or 3 feet at New Orleans must wait on proof that the depth in the pass to the Gulf will not be injured.

Upstream from Natchez, Vicksburg, or Greenville navigation channels are of steadily diminishing importance. From Memphis to Cairo or St. Louis their commercial importance is just now almost negligible and likely to remain so in the ratio of 1 to 100 in comparison with protection of the agricultural interests of the broad rich delta basins from overflow.

The value of all these 29,700 square miles of delta basin is potentially more than a billion dollars, and its yearly product more than a hundred millions. In comparing the number of families that can be supported by each, the navigation interest fades into insignificance beside agriculture. In the early years of planning river improvements the vast potential values of these rich delta lands was not appreciated.

The 14-foot channel from St. Louis to the sea for conveying vast quantities of produce toward a European market seems to be hopelessly beyond economic limits of costs of construction and maintenance until some means can be devised for stopping the never-ending fresh supply of coarse sand and gravel that comes from erosion of the shores in the ceaseless meander of the river, and which each high flood digs up from the depths of the pool and rolls along into a submerged dam at the crossover at reversals of curvature filling up time after time the channel dredged during the previous low water.

Originally the justification for the Federal Government in spending many millions for river improvements here was the improvement of navigation, and the inertia of this old idea still persists. It now seems that if by blocking all the crossings from navigation during, say, 25 years, the river could in any way be straightened and its flood plain lowered materially all along, the country as a whole would be the gainer and, in the end, in the straightened river the 14-foot or possibly even a 20-foot channel to St. Louis might become more certain of attainment.

It is stated in reviewing the admirably comprehensive reports of the Board of Engineers upon a 14-foot waterway from Chicago to St. Louis and to the Gulf, made in 1909:

"Until caving banks can be stopped on the Mississippi below St. Louis, either entirely or to a large extent, it is practically hopeless to expect any improvement of low-water conditions in the open river.

"The bank erosions must continually bring new conditions of river bends and river channels, and the loosened material as it goes down river must continue to form obstructing bars shifting with every change of water condition and requiring constant removal."

But, as said before, the obstacles to straightening in any large way now seem insurmountable and not worthy of absorbing time in speculation until more immedate problems are studied.

The report of the Board of Engineers on a survey of the Mississippi River from St. Louis to its mouth (61st Cong., H. Doc. No. 50) contains a wealth of information on the navigation problems of the Mississippi, and Appendix No. 1, prepared by the recorder, gives a remarkably complete description of the characteristics of the river, addressed particularly to the construction engineer. It repeats the survey on caving banks of 1892, which tells a remarkably impressive story of the enormous quantities of silt, sand, and gravel thrown into the water each year.

Page 127 states that during the low-water season of 1907 a survey showed that a channel length of 790 miles presented a total length of actively caving banks aggregating 749 miles.

Page 48 estimates the total volume coming into the river from caving banks along the Mississippi and lower Missouri is equivalent to a volume a mile square and almost 1,200 feet high, and this amount must necessarily be picked up by the water currents of the Mississippi below the mouth of the Missouri and carried down the river until it is deposited by some freshet at other places above low-water level or reaches the Gulf of Mexico.

This report of 1909 appears to have, for the time being, put an effective quietus upon the promotion of a 14-foot channel under the present conditions of a crooked river with caving banks and constant upbuilding in floods of the vast succession of submerged dams at the crossovers between the pools.

Without in any way questioning the information or the data set forth in this excellent report, the point that I would now make is that it was a study addressed to the point of view of the construction engineer, without any particular attempt at an intensive scientific study.

In other words, I think what is now needed most of all is a resumption of study on "Physics and Hydraulics of the Mississippi," particularly the physics, and it is interesting to note that this was the title under which Humphreys and Abbott began their remarkable investigations 70 years ago, and that the point of view of physics seems largely to have disappeared in the later investigations and should be resumed in connection with a laboratory such as now proposed.

Another matter occurs to me—the cause of sand bars at river outlets into the sea.

In studying the charts of outlets to San Francisco Harbor and the outlet of the mouth of the Mississippi, and in fact at the point of discharge of any sediment-laden water into the sea, I am impressed by the fact that when the fresh water laden with sediment mixes with salt water the sediment is soon precipitated.

When, as chief engineer of preliminary investigations, I was studying at Boston Harbor the proposed dam across the tidal estuary between Boston and Cambridge, I called to my aid various scientists, and among them was a chemist, notwithstanding this appeared to be strictly an engineering problem. I had noticed the comparative clarity of salt water compared with river water and noted how quickly sediments would subside in salt water. I asked this chemist to make some experiments on the muddy rain water flowing in the street gutters of Boston by mixing it with salt water to see what would be the result, and found that the salt water appeared to act as an electrolyte and precipitate fine suspended matter.

In this proposed laboratory I think it would be wise to extend the scope of activities to investigate matters of the kind when studying the formation of sand bars at river outlets. In other words, I think the functions of the man in charge of this laboratory should be extended to permit him to take up any item of that sort, even though he could not put the experiment into one of these two flumes shown in the drawings. The engineer might often be helped in the experiments in this laboratory by calling to his aid a chemist or other scientist. There are many intensely practical problems continually arising beyond those described in engineering textbooks, in which the viewpoint of various specialists in science is helpful, and that is why this laboratory should be in a scientific atmosphere here in Washington.

Senator RANSDELL. I wonder if there is anyone here who would like to ask Mr. Freeman any question while he is on the stand, any of you gentlemen of the Bureau of Geological Survey or any other department.

I will state that the way my resolution is at present worded confines it largely to flood control, but what I had in my mind was the beneficial effects to any branch of the Government resulting from a study of rydraulics. Mr. Freeman's conception of the problem is much broader than my resolution. I certainly want to treat it along the broadest lines and will so modify the resolution before it is reported to Cogress, if we decided to report it.

General BEACH. As I understand the matter, Mr. Freeman has submitted a diagram of the laboratory as he conceives that it would be built, and can be built within that sum of $200,000?

Senator RANSDELL. Yes, sir. That diagram is here and it will be printed with the hearing.

Senator McNARY. Before Mr. Freeman goes I want to be sure that I am right in my understanding of his position, and that is that this laboratory is necessary and would be useful in the study of hydraulic-engineering problems, not merely flood control, and those of river erosion and of the formation of sand bars, but also general hydraulic-engineering problems.

Mr. FREEMAN. That is my idea, Senator.

Senator RANSDELL. Do I understand, Mr. Freeman, that this page 56 of your typewritten memo, presenting a list of about 60 problems, conveys your idea of the possibilities of this laboratory?

Mr. FREEMAN. Yes; that list was written out, as far as I could think of such problems, in two or three hours. I have no doubt other subjects would come up, some of which should properly take precedence of these listed.

Senator RANSDELL. Suppose I read this list so that these other gentlemen can hear it and so that it may go into the record. [Reading:]

SOME STUDIES IN WHICH THE PROPOSED LABORATORY COULD BE USED.

First will be listed briefly some of those for which the river flume would be useful; on a following page will be listed some for which the weir flume could be used. These lists were hastily written and could be extended.

1. An investigation of Thompson's theory of scour at river bends due to spiral flow.
2. An investigation of the path of material scoured out from the concave shore at a bend, whether moved across the river or to a downstream sand bar.
3. Study of straight versus curved river channel for Missouri River conditions.
4. Study of curved versus straight channel for a deeper river as for certain bends on the lower Mississippi.
5. Best inclination to bank and best shape of end for spur dikes in a straight river channel for producing minimum scour at ends of spur and best shape for preventing undermining a submerged spur by scour.
6. Relative merit of permeable and impermeable spur dikes of various forms.
7. Best form for subsurface dike reaching from bed to slightly above low water but submerged at high water, and thence extended up the bank by thicket of willows or other trees.
8. Development of shape and construction of cross section of spur dike faced with stone riprap for minimum cost.
9. Necessary distance between spur dikes in relation to width of river for maintaining straight alignment and protecting shore between spurs.
10. Formation and travel of sand waves in straight and curving rivers and relation of same to navigable low-water channel.
11. Study the effect of the coarseness of grain as between fine sand and coarse gravel in its relation to the upbuilding of cross-over bars on curved rivers.
12. Study the action of the Haupt reaction jetty and its limiting curvature for efficient action.
13. Study for economizing cost of bridging a river by construction of "Bell-Bunds" similar to those developed in India, with study of minimum distance between abutments and proper curvature of alignment.
14. Investigation of obstruction and backwater caused by bridge piers and of tendency to undermine same by swift current.
15. Form of bridge pier base and abutment for producing minimum scour on the bed, combined with a maximum of stability.

10. Miscellaneous studies in training a river like the Missouri or Platte, within erodible banks and bed, in the most economical way for flood relief, by causing it to dig itself deeper, so as to minimize need of levees, and to carry its sediment forward to the sea with minimum deposition en route.

17. Best form of harbor jetties to minimize obstruction of entrance by littoral currents carrying sand.

18. A study of maximum bottom velocities consistent with the stability for various sizes of sand grain and various qualities of adhesion.

19. Transportation of larger débris by rivers, and extensions of the Gilbert California experiments to broader conditions, larger pieces of débris, and higher velocities.

20. Investigation of the truth of Kennedy's law on movement of sand and silt in suspension.

21. Develop the law of back-water effect from dams and obstructions in straight or curving channels.

22. Investigation of fluid-filament theory of parallel flow versus vortex motion near sides at various velocities.

33. Distribution of velocity for various qualities of roughness of surface, particularly near sides and bed of stream or flume.

24. Study of vortex motions and boils caused by obstructions at bottom or by collision of currents.

The following experiments, which could be made in the river flume, relate to flow in artificial channels, such as canals, flumes, sewers, culverts, and large pipes partly filled:

25. An extension of the Darcy and Bazin experiments of 60 years ago to other shapes of channel and to greater velocities of flow and with various definite forms of roughness of surface.

26. Effect of twisting or spiral currents upon loss of head.

27. Loss of head with water carrying nearly a maximum load of sediment, in comparison with clear water.

28. A text of the Eads theory as to the maximum percentage by weight of sediment of various sizes of sand grain which can be transported at a given velocity. (The probabilities are that nowhere on the Mississippi or even upon the Missouri is the water saturated with sediment, and that much higher percentages of sediment could be carried in a regular channel, if only it could be dug up from the bottom by the velocity and kept moving, in a straightened river.

29. Determine the relative proportions of sediment that can be carrid in suspension at various high velocities when walls of conduit are relatively smooth and when roughened or thrown into eddies by spur dikes.

30. Determine more precisely the relations of roughness to laws of flow. (This can be readily done with tilting trough, over a wide range of velocities, by changing the depth, or the speed of pump, or by control by its discharge valve.)

31. Develop formulas of discharge for sewers, or conduit pipes, partially filled to various depths.

32. Effect on velocity or loss of head caused by various percentages of the wetted perimeter much smaller than the whole, being rough.

33. Laws of loss at sudden enlargements.

34. A study of tidal rivers in which the action of the rising tide on the river flow is simulated by water introduced at downstream end of flume.

35. Test the effect of wave transmission for various depths and forms of channel, and study effect of pulsations of flow upon sand waves and sand-bar formation.

36. Determine the law of flow for the "bore," or "cloud-burst" type of flood wave, at various inclinations of bed.

37. Repeat the J. B. Francis "white-wash experiment" under various conditions, for determining course of threads of current.

38. A model of the mouths of the Mississippi on a horizontal scale of about 1 to 100 might prove very instructive in studying out the most efficient means of making the South Pass available for deep-draft steamers with a minimum of dredging.

39. Possibly also some extremely useful information could be had by experiments on the model of the spillway proposed 6 miles below New Orleans, from the Mississippi to Lake Borgne, as to the results that would be achieved in flood relief and subsequent silting or absence of silt in the river mouth.

40. From the printed descriptions of what has happened and is liable to happen again in the delta of the Colorado River below Yuma, Ariz., in relation to a change of the river's course that might endanger the Imperial Valley, some experiments on a model of a portion of this river, with a dike protected by "groynes" or "retards" might be very useful for determining the cheapest and most resistant form. The writer believes it highly probable that a dike could be built at little larger cost, protected by stone-faced spur dikes inclined downstream, aided by willow plantings on the spaces between groynes, that would stand secure and protect the Imperial Valley if given a moderate amount of attention and repairs from year to year.

WIER FLUME.

For the weir flume the following immediately suggest themselves:

41. Extend the Francis Weir formula by new experiments to greater depths up to 5½ feet with crest 15 feet long, or to higher depths with shortened crest.

42. Try out in great variety the effect upon accuracy of measurement of swirls and irregularities of flow in the current approaching a standard weir.

43. Determine the coefficient of discharge for various forms of round-crest weir and, incidentally, experiment to develop a new standard form of weir for measuring water discharge which shall be less subject to error from disturbance in approaching currents and disturbed contraction than is the sharp-crest weir.

44. Determine form of crest for maximum discharge, or least depth over a dam.

45. Test effect of submergence and backwater on weirs at various depths and proportions of backwater to a depth of 5 feet on crest. More extended experiments on this are greatly needed for practical use.

46. Test thoroughly the new Herschel type of weir and depth measurement.

47. Determine the coefficients for discharge over models of many dam crests actually in use and now utilized for metering the flow of American rivers.

48. Check up and extend the deep-waterway dam-crest experiments made some years ago at Cornell University.

49. Determine coefficients for various types of sluiceway, some of which are utilized in gauging the discharge by the hydrographic department of the United States Geological Survey.

50. Make a series of experiments on ordinary canal headgate sluices of different forms, for determining the coefficient of discharge for various heights.

51. Test the effect of various forms of twisting and disturbed flow in channels upon the precision and accuracy of measurement by current meters of various types. There is great need of additional data on this. Certain types of current meter are much more accurate than others in disturbed currents.

52. Develop best type of current meter for accuracy in the disturbed currents found over a cobblestone or other rough bottom.

53. Develop and test an improved portable type of pitot-tube velocity meter and study the errors that may be caused on this under practical conditions by waves and twists of current.

54. A study of the hydraulic jump or standing wave phenomena.

55. A study of "fall increaser," for use in economizing water power on rivers subject to high backwater in floods.

56. Study of various types of energy absorber for the foot of overfall dams, to lessen danger of scour on soft river beds downstream therefrom.

57. Develop best type of baffle piers, for foot of an ogee overfall.

58. Develop a venturi type of sluice gate for the head gates of irrigation canals and other waterways.

59. Develop the best form of bell mouth for tunnels for the by-pass of dams.

60. Determine the most efficient angle of divergence for a venturi tube, both with smooth current of approach and with disturbed and twisting currents of approach, as in the draft tube of a water wheel. It is possible these studies would aid in the economics of power development.

61. Study the limiting conditions for precision of measurement with venturi meters of various types with disturbed currents in the approach.

62. Experiment on the laws of centrifugal pump discharge over a wide range of velocities and with throttled inlet and throttled outlet.

63. Determine the overturning effect of currents at various high velocities upon bridge piers and similar structures of various shapes.

64. The weir flume would be useful as a naval test tank for certain conditions of currents, where holding the model still while the current flowed swiftly past. It would be particularly instructive for cases of high velocity and too brief a run in the ordinary naval tank.

DRAWINGS ILLUSTRATING A HYDRAULIC LABORATORY.

Mr. Freeman. In order to present something definite I have drawn up some designs of such a structure as I believe would meet the present needs and have brought here four sheets of the preliminary drawings of this structure, which I will now present. The entire laboratory proposed and all of its apparatus could be covered by a 1-story shed roof about 73 feet wide by about 385 feet long. In designing this apparatus I have, for purposes of economy of construction and efficiency of operation, combined into one structure a variety of apparatus intended to give new information in several different lines of hydraulic problems, and have tried to keep the cost within the appropriation.

The four sheets of plans now presented each show two long flumes standing side by side, within either of which a large quantity of water (600 cubic feet per second or less) can be circulated at any desired speed over and over again, by means of centrifugal pumps, or by a device like the propeller of a steamship or airplane.

The flume shown at the far side of the building called the river flume can be adjusted at any desired slope and is primarily for experiments on models of rivers and canals. Sheet No. 1 shows the model of a crooked river outlined within the flume.

The flume shown at the near side of the building called weir flume is rigidly built of concrete and is primarily for experiments upon the flow of great depths of water over dams and for testing measuring weirs and various other apparatus with which the flow of a river can be gauged, so as to know how much water is available for storage in reservoir for irrigation, or for domestic water supply. Also this weir flume gives means for finding out the best form of dam crest for discharging the maximum quantity with the minimum increase in height of water, and would give accurate formulas for computing the flow over drowned weirs or submerged dams. Large rectangular reservoirs can be connected with either flume, within which reservoir the volume of water flowing can be accurately measured.

As to which of many problems should first receive attention in this laboratory I am led to believe by what I saw along the Mississippi and by what I have heard of the present menace to the Imperial Valley of California, that the problems of river control should come first; that is, the problems of preventing rivers from gnawing at their banks and caving them in, and the problems of training a river to stay where put, and to dig its own channel deeper, and to carry its burden of sediment out into the sea.

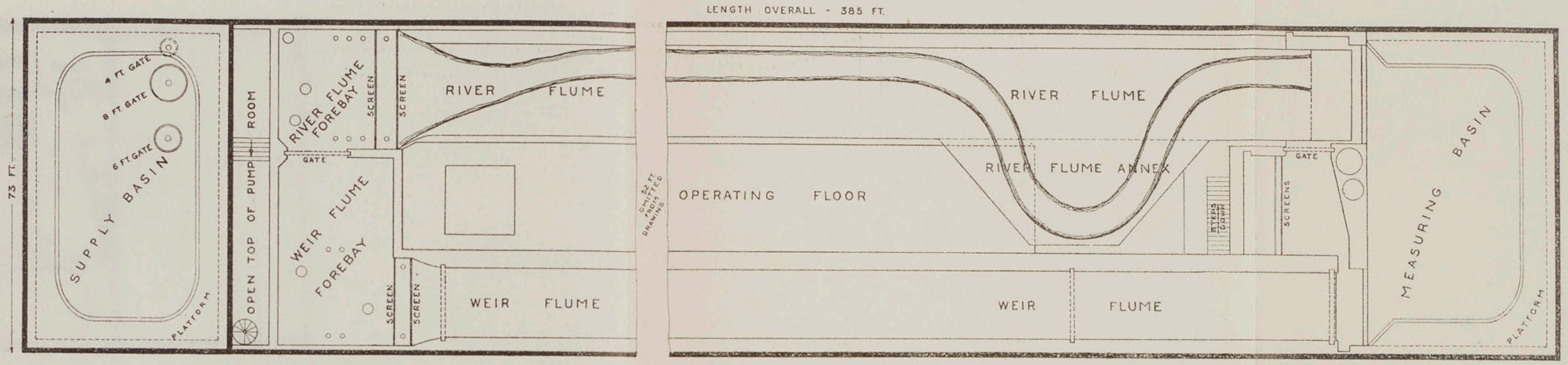
Senator Ransdell. With the consent of the committee I will include those drawings and the technical explanation, without asking Mr. Freeman to give it all orally here.

(Mr. Freeman then exhibited drawings shown on pages facing.)

DESCRIPTION OF DETAILS OF LABORATORY.

Mr. Freeman. The several plans and sections presented in these four sheets of drawings have been lettered so plainly as to need but little description of detail. There are some minor features of the design, such as the quick-swinging gate, the interlocking reservoir gate, and the details of jack screws, which have not yet been drawn up, although sufficiently sketched in pencil to make sure of practicability.

There are two flumes built side by side, one marked "River flume" for experiments upon river models of many kinds, and especially for learning the underlying scientific laws of nature which govern the erosion of river banks and the transportation and deposit of sediments of various degrees of coarseness and great range of velocity of water. This tilting river flume also can be used for adding to scientific knowledge of laws of flow in conduits with various kinds of shapes and surface and a great range of velocity. The other is marked "Weir flume," and is designed for adding to our knowledge of the laws of flow over weirs and dams, particularly submerged dams, and for developing new and more convenient form of weirs for accurate measurement of discharge.



TOP VIEW OUTLINE - SCALE 1 IN. = 10 FT.

-QUANTITIES-

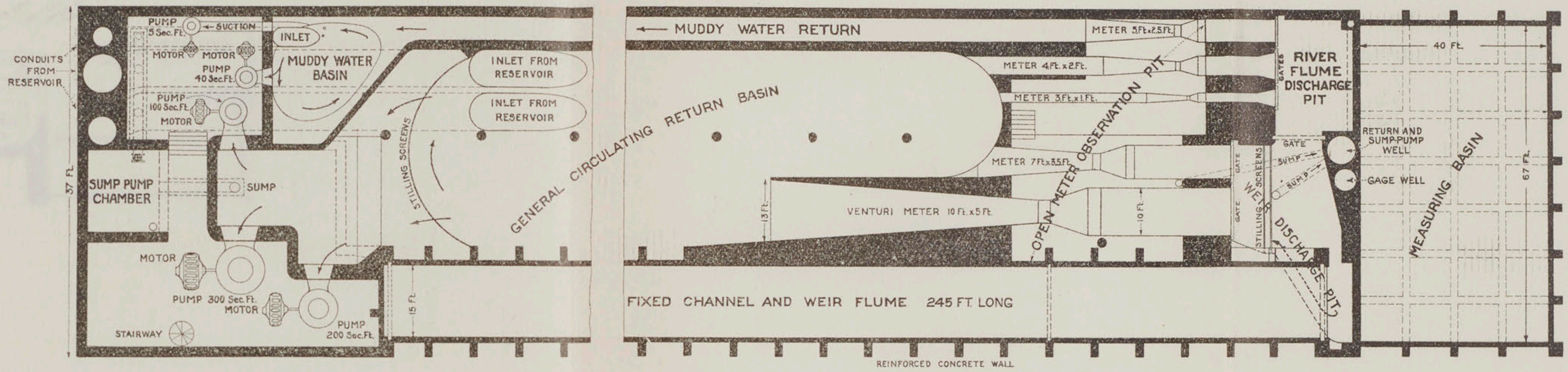
CONCRETE	4750 CU. YDS.
STEEL- RATIO TO CONCRETE=1.5%-	470 TONS.
FORMS	175 M.B.M.
EXCAVATION	11,500 CU. YDS.

NOTE THAT HORIZONTAL REINFORCEMENT FOR PREVENTING TEMPERATURE AND SHRINKAGE CRACKS SHOULD EXCEED THE VERTICAL.

-ALL SUBJECT TO REVISION-

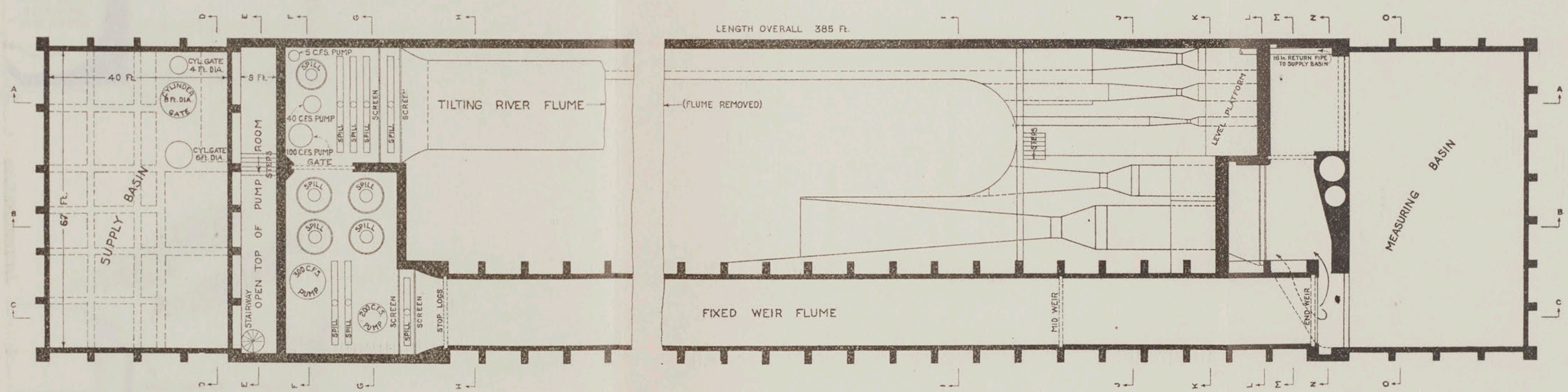
STUDY FOR HYDRAULIC LABORATORY
By- John R. Freeman C. E.
August - 1922 Scale- 1 In. = 10 Ft.
GENERAL PLAN SHEET No. 1.

11077—22. (Face p. 40.) No. 1



HORIZONTAL SECTION NEAR BOTTOM AT (ABOUT) ELEVATION 80

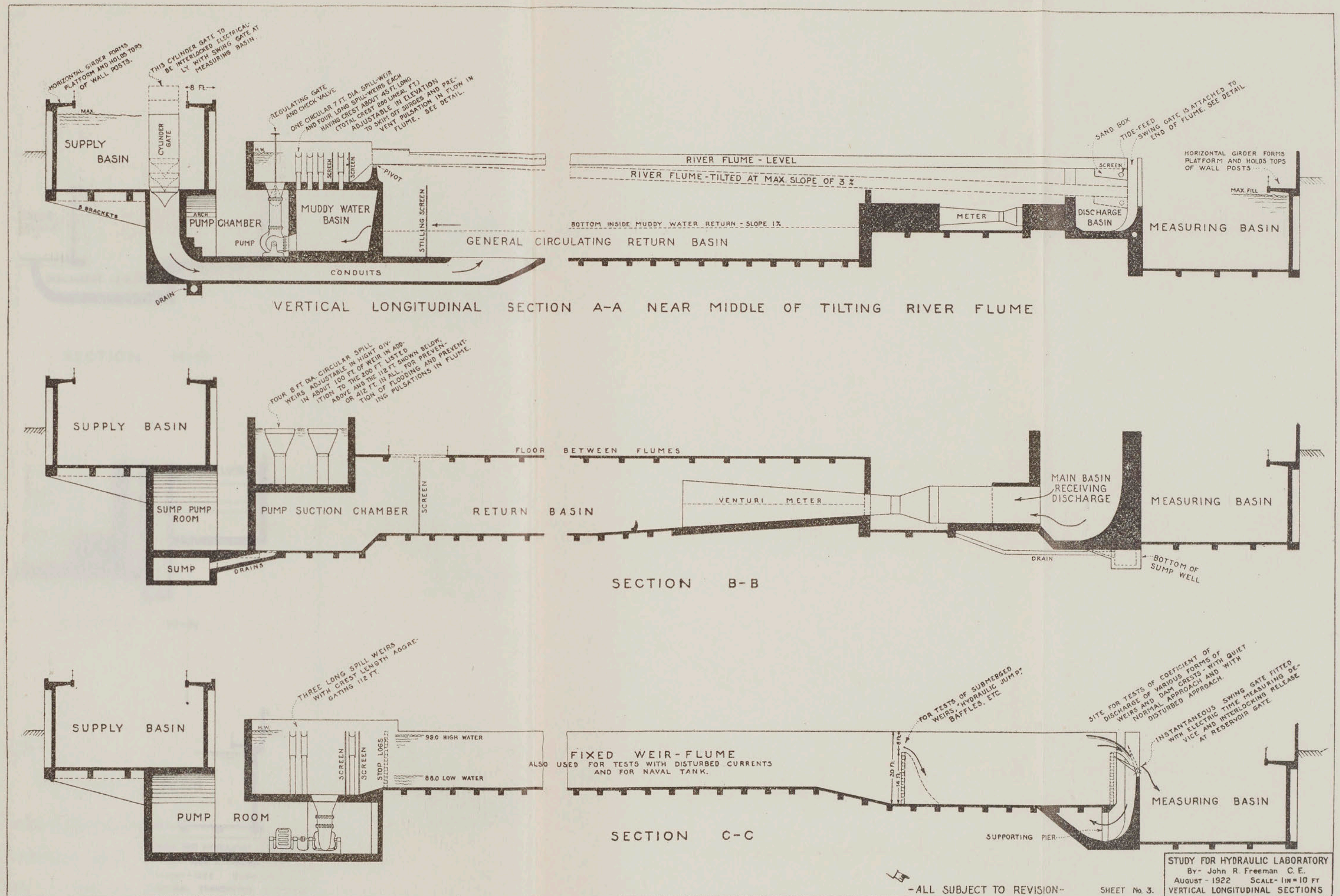
NOTE THAT WHOLE OUTPUT OF ALL PUMPS (about 655 cubic feet per second) CAN BE CONCENTRATED IN EITHER FLUME.

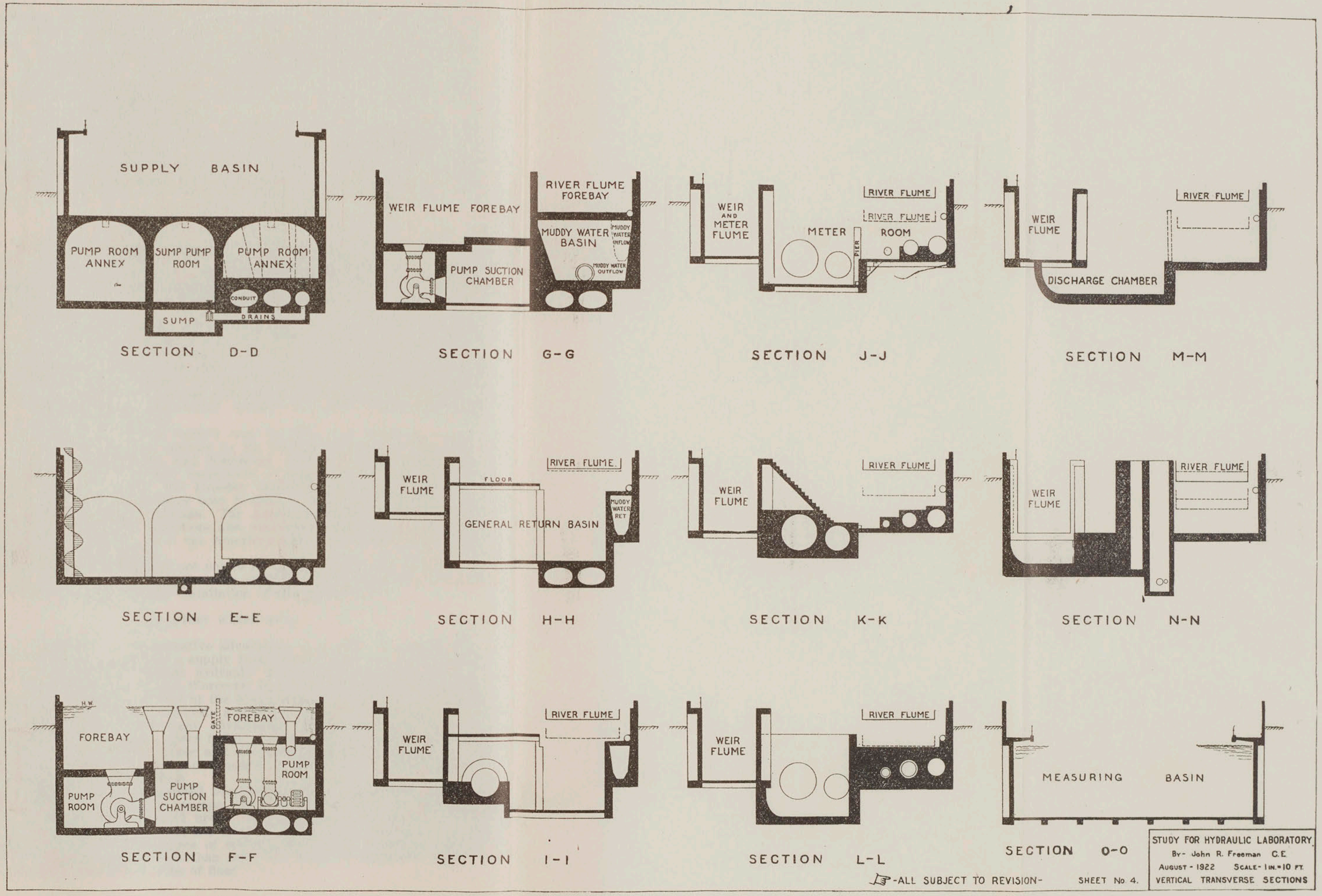


HORIZONTAL SECTION NEAR TOP AT ELEVATION 100

-ALL SUBJECT TO REVISION-

STUDY FOR HYDRAULIC LABORATORY	
By- John R. Freeman C.E.	
AUGUST - 1922	SCALE - 1 IN. = 10 FT.
GENERAL PLAN	SHEET No. 2


HORIZONTAL GIRDER FORMS PLATFORM AND HOLDS TOPS OF WALL POSTS.
THIS CYLINDER GATE TO BE INTERLOCKED ELECTRICALLY WITH SWING GATE AT MEASURING BASIN.
8 FT.
MAX.
SUPPLY BASIN
CYLINDER GATE
5 BRACKETS
ARCH
PUMP CHAMBER
PUMP
REGULATING GATE AND CHECK VALVE
ONE CIRCULAR 7 FT. DIA. SPILL-WEIR AND FOUR LONG SPILL-WEIRS EACH HAVING CREST ABOUT 45 FT. LONG (TOTAL CREST 200 LINEAL FT.) ADJUSTABLE IN ELEVATION TO SKIM OFF SURGES AND PREVENT PULSATION IN FLOW IN FLUME. SEE DETAIL.
H.W.
SCREEN
SCREEN
PIVOT
MUDDY WATER BASIN
STILLING SCREEN
RIVER FLUME - LEVEL
RIVER FLUME - TILTED AT MAX SLOPE OF 3 %
BOTTOM INSIDE MUDDY WATER RETURN - SLOPE 1 %
GENERAL CIRCULATING RETURN BASIN
CONDUITS
DRAIN
METER
SAND BOX
TIDE-FEED
SWING GATE IS ATTACHED TO END OF FLUME. SEE DETAIL
SCREEN
DISCHARGE BASIN
HORIZONTAL GIRDER FORMS PLATFORM AND HOLDS TOPS OF WALL POSTS
MAX. FILL
MEASURING BASIN
VERTICAL LONGITUDINAL SECTION A–A NEAR MIDDLE OF TILTING RIVER FLUME
SUPPLY BASIN
FOUR 8 FT. DIA. CIRCULAR SPILL WEIRS ADJUSTABLE IN HIGHT GIVING ABOUT 100 FT. OF WEIR IN ADDITION TO THE 200 FT. LISTED ABOVE AND THE 112 FT. SHOWN BELOW, OR 412 FT. IN ALL, FOR PREVENTION OF FLOODING AND PREVENTING PULSATIONS IN FLUME.
FLOOR BETWEEN FLUMES
SUMP PUMP ROOM
PUMP SUCTION CHAMBER
SCREEN
RETURN BASIN
VENTURI METER
SUMP
DRAINS
MAIN BASIN RECEIVING DISCHARGE
MEASURING BASIN
DRAIN
BOTTOM OF SUMP WELL
SECTION B–B
SUPPLY BASIN
THREE LONG SPILL WEIRS WITH CREST LENGTH AGGREGATING 112 FT.
H.W.
SCREEN
SCREEN
STOP LOGS
99.0 HIGH WATER
88.0 LOW WATER
PUMP ROOM
FIXED WEIR-FLUME
ALSO USED FOR TESTS WITH DISTURBED CURRENTS AND FOR NAVAL TANK.
FOR TESTS OF SUBMERGED WEIRS, "HYDRAULIC JUMP," BAFFLES, ETC.
20 FT.
14 FT.
6 FT.
SITE FOR TESTS OF COEFICIENT OF DISCHARGE OF VARIOUS FORMS OF WEIRS AND DAM CRESTS - WITH QUIET NORMAL APPROACH AND WITH DISTURBED APPROACH.
INSTANTANEOUS SWING GATE FITTED WITH ELECTRIC TIME MEASURING DEVICE AND INTERLOCKING RELEASE AT RESERVOIR GATE
MEASURING BASIN
SUPPORTING PIER
SECTION C–C
-ALL SUBJECT TO REVISION-
SHEET No. 3.
STUDY FOR HYDRAULIC LABORATORY
By- John R. Freeman C. E.
August - 1922 Scale- 1 in = 10 ft
VERTICAL LONGITUDINAL SECTIONS


SUPPLY BASIN
PUMP ROOM ANNEX
SUMP PUMP ROOM
PUMP ROOM ANNEX
CONDUIT
DRAINS
SUMP
SECTION D-D
WEIR FLUME FOREBAY
RIVER FLUME FOREBAY
MUDDY WATER BASIN
MUDDY WATER INFLOW
PUMP SUCTION CHAMBER
MUDDY WATER OUTFLOW
SECTION G-G
WEIR AND METER FLUME
RIVER FLUME
RIVER FLUME
METER ROOM
PIER
SECTION J-J
WEIR FLUME
RIVER FLUME
DISCHARGE CHAMBER
SECTION M-M
SECTION E-E
WEIR FLUME
FLOOR
RIVER FLUME.
GENERAL RETURN BASIN
MUDDY WATER RET
SECTION H-H
WEIR FLUME
RIVER FLUME
SECTION K-K
WEIR FLUME
RIVER FLUME
SECTION N-N
H.W.
FOREBAY
GATE
FOREBAY
PUMP ROOM
PUMP ROOM
PUMP SUCTION CHAMBER
SECTION F-F
WEIR FLUME
RIVER FLUME
SECTION I-I
WEIR FLUME
RIVER FLUME
SECTION L-L
MEASURING BASIN
SECTION O-O
-ALL SUBJECT TO REVISION-
SHEET No 4.
STUDY FOR HYDRAULIC LABORATORY
By- John R. Freeman C.E.
August - 1922 Scale- 1 in. = 10 ft.
VERTICAL TRANSVERSE SECTIONS

This weir flume will serve for a great variety of experiments, as for example, determination of conditions affecting the accuracy of current meters in disturbed currents, experiments on sluiceways for economizing loss of head, including one on the Venturi principle; experiments upon best form of bellmouth for increasing the discharge of tunnels used in by-passing river dams during construction, etc. And this fixed flume also can be used as a naval tank in which boat-model stands still, while the current moves past it at much higher velocity than possible in the existing naval tanks, and with a much longer run for precise observations.

This weir flume is rigid, but the river flume pivots at its upstream end, where the metal work unites with the rigid concrete by flexible sheets of steel. The variable slope of this river flume is obtained by its support on a double line of jack screws placed about 20 feet apart and all driven from a common shaft and motor so that this flume can very quickly be adjusted to any desired declivity from 0 to 3 per cent, and meanwhile maintain a straight and rigid alignment.

THE DEVELOPMENT OF THE PRESENT DESIGN.

For nearly 10 years past I have been thinking of the possible uses and benefits of such a laboratory, and occasionally sketching out a design, and a few months before the beginning of the German war I visited the river-training laboratory at the Dresdon Engineering College—presided over by Professor Engel. Professor Engel has since sent me various papers describing some of his researches.

Recently I have got out my old sketches and had them redrawn several times with certain improvements and in the effort to lessen the cost, and now present them to illustrate what a national hydraulic laboratory should be like.

These drawings have been made after reviewing the descriptions of previous hydraulic laboratories in France, England, Germany, and America, and after reviewing the statistics of dimension and capacity of all hydraulic laboratories connected with American engineering colleges and after having personally visited the most important ones.

By these studies I came to believe that the type best suited for present needs is very similar to that adopted by the German scientists in their river-flow laboratories at Dresden and Karlsruhe, but on a much larger scale commensurate with the greater magnitude of American river problems and American hydraulic works. The Dresden laboratory would have been on a larger scale had not the designer been limited to the space in the basement of one of the new college buildings. The American hydraulic laboratories at colleges with two or three exceptions also have been limited in size by reason of space or cost, and no one of the American laboratories has apparatus for experiments on river training.

The drawings now presented are not to be taken as final, and if funds are scant the river-flow half of the structure could be built now and sundry other parts deferred, particularly the installation of the largest pump.

LABORATORY WATER SUPPLY.

While considering the comparative advantages of a reservoir supply circulated by centrifugal pump and a supply from lake or river, I have personally looked over the largest college hydraulic laboratories, including those at Cornell, University of Iowa, and Worcester Polytechnic, which take their supplies from river or lake, and that at the Massachusetts Institute of Technology and that at Dresden, which circulate a pumped supply. It appears that the pumped circulation presents many advantages for studying river problems, one main reason being that it gives better control of the percentage by weight of sediment carried by the water and also presents superior conditions for controlling the temperature and the transparency of water in certain important tests of vortex motion and eddies.

With a tank supply, replenished occasionally by a 4-inch pipe from the public main and circulated by pumps, any desired percentage or quality of sand grain can be experimented upon. This sand material can be brought in barrels to the laboratory from any river in question and can be sifted into the current to any desired degree of concentration, from 1 part in 1,000 to 1 part in 10, which will no more than cover the range of muddiness found in typical American streams in time of flood.

The pumped circulation also is helpful in making the hydraulic laboratory part of a scientific plant comprising various other kinds of apparatus and it permits the operation at any time of the year and with any desired temperature from 32° to 90° F.

ELECTRIC POWER FOR CIRCULATING THE WATER.

This laboratory should be placed where electric power can be had to any desired extent from a normal draft of 50 to 100 horsepower up to a rarely occasional draft of about 122 horsepower for a few hours. Such a supply is feasible in almost any American town or city by connection to the public service system or by building the laboratory in connection with some institution or plant having a large electric plant for other purposes, from which the rarely occasional large demand can be taken in off-peak hours.

For the rixer-flow experiments the power draft commonly would be small.

Care has been taken to shape the designs both for the river flume and for the weir flume so as to minimize the lift of the pump and the consumption of power.

In a model river channel, say, of 10 square feet cross section, larger than which would rarely be used, a velocity of 5 feet per second with 10 feet lift calls for, by computation, 57.6 theoretic horsepower and with pumps of best ordinary efficiency this would call for nearly 100 brake-horsepower of motor, or 75 kilowatts.

At the weir flume during the brief series of experiments for determining coefficients of discharge with maximum depth over the crest of 5.5 feet, or say 600 cubic feet per second of water discharged over a weir 15 feet in length with a lift of 12 feet at the circulating pumps, the theoretic power figures at 817 horsepower and with a pump efficiency of 70 per cent this would call for 1,167 brake horsepower. This could be drawn at night when other regular demands were small. A few weeks of experiment with these extremely large flows would give about all the new data needed.

PRECAUTIONS FOR ACCURACY.

Great care has been given in the design of this apparatus in order to secure freedom from pulsation during the experiments and to permit of precise measurements. The writer years ago spent many months on precise hydraulic experimentation and thus came to realize the need of extreme precaution in these matters. The enormous length of development of spillway crest shown in the forebays (200 linear feet) is provided for this purpose.

Regarding pulsations, moreover, the writer, while carrying on extended current meter measurements nearly 20 years ago in the main ship channel of Boston Harbor opposite the Deer Island Lighthouse, was much impressed with the rythmic variations in the tidal current as revealed by the clicking of the electric current meter register. This gave evidence of a pulsating scouring force for the movement of sediment much greater than indicated by the mean velocity recorded near the bottom by the current meter. Having this laboratory apparatus so as to give an extremely uniform current for most experiments it will be easy to cause pulsations of any desired amplitude for special study.

POSITIVE QUANTITY MEASUREMENT.

All need of indirect measurement of rate of flow or discharge is avoided by providing a measuring basin and a quick-swinging gate so arranged that the time of fill can be measured by an electric chronograph to the fiftieth part of a second. Provision also is made for measuring the height of water in the measuring basin before and after experiment to within the thousandth part of an inch and altogether it is expected that a large discharge can be readily measured in this tank to within one-tenth of 1 per cent and that the several Venturi meters through which the return current commonly flows can be rated with corresponding precision.

Measuring a large discharge in a basin with precision is a somewhat arduous task, therefore the apparatus is arranged to avoid the necessity of frequent repetition of tank measurement by providing Venturi meters of various sizes adapted to different rates of flow which can be recorded continuously by simple automatic devices, thereby relieving the experimenter and lessening the number of observers required.

MISCELLANEOUS TESTS.

This so-called river flume also can be used for a great variety of other experiments in straight and curved channels with rigid walls of various degrees of smoothness, for developing formulas, for measuring the flow or loss of head in partially filled sewers and aqueducts, for wave motion, vortex motion, seacoast protection, backwater effects, resistance of bridge piers, testing of current meters, and other velocity-measuring devices in the disturbed current over a cobblestone bottom, etc.

THE RIVER FLUME.

This river flume will be built of structural steel channels and plates about five-sixteenths-inch thick, its downstream end will carry a sand-catching box also available as a tidewater inlet. At its downstream end the flume structure also supports a quick-swinging gate by which the discharge can be shifted instantaneously in and out from the measuring basin. The inclination of the river flume can be made as steep as 3 per cent, giving a drop of 7½ feet in its 250 feet of length. So great a declivity as this is not needed for river experiments but will be useful for a great variety of other determinations, as for example an extension of the Darcy and Bazin experiments and for improving on the Kutter formula.

With smooth walls this high inclination could give mean velocities up to from 16 feet to 25 feet per second, according to the depth. Obviously the flume can be narrowed by partitions, or drain tiles or other conduits can be erected temporarily on its floor. The entire pump capacity of 600 second-feet can be turned into the river flume for special experiments.

The changes in inclination would be effected very easily and within a very few minutes by means of the cast-iron supporting screws similar in quality of mechanism to the cheap jackscrews used in building construction. These screws would not rotate, but their nuts would be formed in worm wheels driven by a shaft common to the whole line of support actuated by a small electric motor. The different amounts of elevation at the different supporting points corresponding to the straight line slope would be obtained by differences either in pitch or in gear ratio.

The bed of this tilting tank is 20 feet broad, with possibilities for adding a bay 40 feet or 50 feet wide within which a large river bend or harbor entrance can be modeled.

The model river under experiment rarely would exceed 5 feet in width by 2 feet in depth, and this greater width of 20 feet between the walls of the tank permits giving it a sinuous course, while the bay permits modeling a big bend, comparable with those on the Mississippi.

TYPICAL EXPERIMENTS.

On the floor of this river tank sand could be placed and shaped to represent any desired form of river bed, and on top of this a veneer a few inches in depth could be placed composed of sand of any desired quality or fineness. Then, upon starting the pumps and tilting the tank to any appropriate delivery for producing erosion, the general laws governing erosion and the redeposition of sediment could be studied. The depth of water in the model river could be quickly increased or diminished by means of the outlet gate on the pump or by changing the speed of the pump. At the close of an experiment the water could be drawn out and photographic record made of the condition in which sand bars and erosion had reformed the river bed.

Obviously a great variety of sand from different river beds could be used, in some of which the grains were adherent from colloidal quality and in other cases nonadhesive.

In connection with this river flume the various passageways for the supply, discharge, and return of water can be kept separate from the main circulation chamber, so that water with any desired degree of concentration of sediment can be circulated over and over again without necessity for providing an excessive volume. It can be kept running steadily any number of hours while erosion of bank or bed and the building up of sand waves or crossing bars at reversals of curvature are studied.

OPTICAL STUDIES OF VORTEX MOTION.

In certain experiments clear water can be circulated, into which relatively few dark-colored sand grains of various sizes are sifted and let flow over a contrasting bed of white plaster of Paris wash, and special illumination in an optical plane similar to that used with the ultramicroscope can be employed in connection with a high-speed motion-picture camera to study the intricate laws of vortex motion and the formation of such swirls and vortices as often are observed on the surface and which appear to come from some obstruction at the bottom.

STRAIGHT VERSUS CURVED CHANNELS.

A special study of the advantages and disadvantages of gently curving channels versus straight channels, both for navigation and for flood relief, can be made, observing the crossing bars built up in one case and the sand wave in the other case. A straightened river would require better means of holding it securely in position than we now possess. While the forms of revetment by willow mattress and concrete block now built by the United States Army engineers are admirably efficient, they are hopelessly expensive for protecting the whole length of both banks of a great river, and this has led to many inventions, most of which have failed.

Means of bank protection by rows of concrete piles deeply jetted down below the river bed could be developed and studied; also varients of the Stickney bank head, developed about 20 years ago on the Missouri River, with various curvatures; also varients of the Brownlow Weed protection developed in India.

SPUR DIKES

The comparative merits of various shapes for the ends of spur dikes and their inclination to the bank could be tried out, and perhaps as much learned about them in six days in the laboratory as could be found out by six months' experimentation on the actual river and at one-twentieth part of the cost. Professor Engel's experiments on the shape and inclination of groyne appear to have successfully demonstrated the utility of the laboratory test.

EITHER SMALL OR LARGE MODELS USED.

For certain quick changes of river bed, etc., experiments, whenever desired, could be run in a model bed on a smaller scale or of the same dimensions as used in the German laboratory. In contrast to the German laboratory and in order to give an example of the capacity of the American laboratory now proposed let us consider what could be done in it on a model of our greatest river—the lower Mississippi—and let the experiment be run with quantities representing the highest flood instead of representing low-water condition and improvement of navigation, such as most of the experiments carried on in the German and other foreign laboratories.

EXAMPLE OF LARGE SCALE EXPERIMENT.

For example, let there be modeled in the river flume a winding stream with a soft sandy bed in form representing accurately to scale some part of the lower Mississippi, with horizontal dimension, all on the ratio of 1 foot in the model to 1,000 feet in the actual river. The vertical scale can either be the same or could be increased and made on the ratio of 1 foot depth in the model to 100 feet in the river. Probably this distortion would not seriously disturb the results in certain important experiments. It would be analogous to experimenting on the discharge over a section of dam crest only 3 feet in length where the entire structure had a crest 30 feet long. A check test could be run subsequently on natural scale.

Our 250 feet length of experimental tank would then represent 250,000 feet, or nearly 50 miles along the valley in a straight line, and 20 feet of width would accommodate a river bend with an ordinate of nearly 4 miles, while the broad tank could take in a bend of nearly 10 miles ordinate.

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

The slope of the tilting flume would be readily adjusted by the screws to give a velocity somewhere near to that of the actual river, or to give such velocity that there would be an analogous slow process of erosion of bend and of deposition of sediment upon the nearly opposite convex shore or perhaps farther downstream on the same side with the concave shore, and with an established regimen showing no important scour or fill along the straighter portion.

RELATION OF MODEL TO ACTUAL RIVER.

Notwithstanding we might not obtain representation of all the swirls and vortices that exist in the large river, which have much to do with scour and transportation of sediment, there doubtless would be some analogous action in the model stream. Professor Engel and others who have made use of these model laboratories in Europe testify to finding in general a remarkably good correspondence in effect upon erosion, transportation, and sedimentation.

In considering this proposal to use a model, it is to be constantly kept in mind that it is proposed to always work in parallel with observations upon the actual river and thereby, step by step, find out what correspondence and what divergences exist.

The rise and fall of a flood could be represented in the model by varying the discharge at the pump. Various percentages of sedimentary material could be put into circulation and the water frequently drawn out between experiments and the formations studies. Perhaps during this drawing off of the water it might be found necessary to lessen the inclination of the tank to avoid cutting.

The writer believes that a great variety of useful information could be obtained in the course of such experiments by an engineer or physicist thoroughly familiar with the vagaries of motion and sediment along the actual river. This out-of-doors experiment is highly important to success.

THE WEIR FLUME.

The so-called weir flume is shown on the opposite side of the building. This is about 15 feet wide by from 15 to 20 feet in depth and 240 feet long. This is built throughout of rigidly supported reinforced concrete and will generally be used for a different class of experiments from those made in the river flume, such, for example, as determining the coefficients of discharge over various forms of dam crest and discharge over submerged weirs and dams of various shapes and for developing a more accurate and more convenient form of weir for general measurement purposes. One of its important uses would be to extend the range of the Francis and Bazin weir experiments to greater depths, such as frequently are met in practice.

An uncommonly high percentage of reinforcing steel would be used in all these concrete structures of flumes, basins, and circulating tanks in order to minimize the danger of leakage through temperature cracks or shrinkage cracks.

Both tank and basin would be housed as cheaply as possible against weather and wind, and so as to permit the experimenting to go on day or night without disturbance at any time of year.

The effects of wind velocity upon currents of water could readily be studied by laying a light covering of board or canvas over either flume and circulating air at a given velocity by a large fan.

Senator RANSDELL. We are indeed very much obliged to you, Mr. Freeman. Mr. R. H. Downman, of New Orleans, is here. Mr. Downman is a very prominent citizen of our State and is eminently successful in the business world. He is not an engineer or a technical man in any sense, but is intensely interested in our flood problems down there. Won't you please just say a word, Mr. Downman, as to what you think of this bill

STATEMENT OF MR. R. H. DOWNMAN, NEW ORLEANS, LA.

Mr. DOWNMAN. I haven't read your bill, Senator, but have listened with a great deal of interest to Mr. Freeman's address. Of course, I heartily commend the idea, but feel that Mr. Freeman has made his estimate of the amount that this great Government should put into this proposition entirely too low. I believe the amount of the appropriation should be no less than $1,000,000.

Senator RANSDELL. You mean, Mr. Downman, if that is necessary; but if the proposed appropriation of $200,000 would do the work you would be satisfied to begin with that?

Mr. DOWNMAN. Certainly, Senator.

Senator RANSDELL. You understand this appropriation is for the purpose of establishing a hydraulic laboratory.

Mr. DOWNMAN. Yes, Senator; but I don't believe that amount will do the work. The little organization that I am connected with in New Orleans has spent over a million dollars the past several years in the development of its business through investigation, laboratory work, etc. Now, if we, a small coterie of business men, feel that we are justified in spending that much money, surely this great Government ought to be willing to appropriate at least as much. As a business man I don't think $200,000 is going to do the work, if you expect to get anything like tangible and satisfactory results.

Senator DU PONT. Isn't this what you mean—that this Government first ought to expend whatever amount of money is necessary to establish this hydraulic laboratory, so that we can get at the facts and know how to deal scientifically with these flood-control problems?

Mr. DOWNMAN. Yes. Of course, I am not an engineer, but we all know that when the crevasse at Poydras occurred, some 15 miles below New Orleans, during the last flood in May of this year, that the flood level of the water in front of New Orleans was lowered nearly 2 feet in four days, but this crevasse being controlled it resulted in spreading the waters over the entire territory east of the levees on the Mississippi River from New Orleans to the Gulf, which created tremendous damage to the farmers, planters, truck gardeners, and others, as well as spreading disease. If the water which passed through this uncontrolled outlet or spillway had been confined between levees running from the river to a debouchment into the Gulf, this damage and distress could not have occurred. I think that the results of this crevasse are so self-evident that it would not be necessary to have a hydraulic laboratory to decide whether or not control spillways or outlets were necessary for the relief of the people in the lower reaches of the Mississippi River during flood periods. I have no doubt that with the assistance of the proposed hydraulic laboratory we would be able to solve a great many of the problems in the action of the waters of the Mississippi River, which is suggested by Mr. Freeman. Not only would the hydraulic laboratory be used to help solve the problems of the Mississippi River but of all other rivers and watercourses throughout the United States which are subject to flood conditions periodically.

Senator DU PONT. How much lower is that ground than the overflow; that is, lower than the bed of the river in normal times?

General BEACH. The bed of the river is about 120 feet at the point of the crevasse.

Mr. A. L. VUILLEMOT (New Iberia, La.). It is 127 feet and 5 inches. I worked right on the very spot you are talking about and I measured it myself.

Senator DU PONT. How much lower is it than the normal height of the river?

Mr. VUILLEMOT. I suppose about 10 or 12 feet. I should judge 12 feet. I worked on that very ground, but I couldn't go into the details further than that.

Senator RANSDELL. You have answered the question very satisfactorily, Mr. Vuillemot. We are much obliged to you. It is always necessary to differentiate between the low-water plane of the river and the surface plane at flood times and the bed of the river. Of course, the bottom of the stream is just the same substantially in low water as it is in high water, but a great many people confuse the plane of the high-water surface with the bed of the river, and that is incorrect. Now, gentlemen, we will resume this hearing at 2.30 o'clock this afternoon.

(Thereupon, at 12.30 o'clock p. m., the subcommittee recessed until 2.30 o'clock p. m. of this day.)

AFTER RECESS.

The subcommittee reconvened at the expiration of the recess.

Senator RANSDELL. Mr. Ockerson, will you please give your full name, address, and present occupation?

STATEMENT OF MR. J. A. OCKERSON, MEMBER OF MISSISSIPPI RIVER COMMISSION AND PAST PRESIDENT AMERICAN SOCIETY OF CIVIL ENGINEERS, 1307 INTERNATIONAL LIFE BUILDING, ST. LOUIS, MO.

Mr. OCKERSON. My name is J. A. Ockerson; address, St. Louis, Mo. I am a member of the Mississippi River Commission and past president of the American Society of Civil Engineers.

Senator RANSDELL. How long have you been a member of the commission connected with the work on the Mississippi River, Mr. Ockerson?

Mr. OCKERSON. I have been with the commission for 43 years.

Senator RANSDELL. That is, you mean since it was created in 1879?

Mr. OCKERSON. Yes, sir.

Senator RANSDELL. Are you familiar with the resolution we have under consideration to create a national hydraulic laboratory? And if you have any ideas in connection with it, we would be pleased to hear you state them.

Mr. OCKERSON. I have read the resolution carefully on the trip from St. Louis, and the idea I get of it is that it is to provide a hydraulic laboratory to consider matters relating to rivers; that is the purport of the bill. I am here at the instance of the Chief of Engineers, United States Army, and of the Mississippi River Commission, representing a majority of the commission that met in New Orleans last week.

Senator RANSDELL. We will be glad to hear you make a statement on the subject that you desire.

Mr. OCKERSON. I have stated that we met in New Orleans last week.

The impression seemed to prevail there that an extended series of laboratory experiments is needed in order to secure data necessary to arrive at a solution of the problems relative to the regulation and control of the Mississippi River.

After 43 years of active work by a corps of scientific men in nature's own laboratory, the river itself, it is believed that the commission has accumulated a volume of data covering practically all of the varying phases of the physics of the Mississippi River which are necessary to a full understanding of the regulation and control of the river. There is no "woeful lack" of data, as has been charged.

It is believed to be wholly impracticable to obtain any further useful data regarding the Mississippi River problems by the use of laboratory models, and the reason for this belief is to be found in the following briefs of conditions to be met with.

When I speak of "models" I speak of the whole scheme of hydraulic laboratory work.

1. The river is so gigantic in all its elements that a practicable model would be too small to duplicate the many elements of the regimen of the river. Then, too, the regimen must be thoroughly understood before it can be incorporated into a model, and this means an exhaustive study of the river itself.

2. The horizontal and vertical scales should be the same, as variations in the proportions give different results. This would give depth and slopes too small to be satisfactorily measured.

The importance of having the proportions of the scale correct is indicated by recent experiments in regard to the Gilboa Dam, where variations in the relative proportions gave quite different results.

Senator RANSDELL. Where is that dam, please?

Mr. OCKERSON. That is in New York State, connected with the water supply of New York City. It is described in a late paper of the American Society of Civil Engineers, September number of Proceedings, 1922.

3. The present condition of the bed of the river is the resultant of a long period of changes in stage and volume, passing through many succeeding cycles of high and low water, and a knowledge of all these must be had before intelligent conclusions could be drawn as to the lessons shown by its present condition.

4. In order to reach a fair understanding of the physics of the river it is important that studies should cover a number of cycles of extreme high and low water, and the period of such studies can not be materially curtailed without vitiating the results and involving the conclusions in doubt. This would make the study through models impracticable.

5. The regimen elements are constantly changing. The stage is in a constant state of change, moving up and down, never at rest; so is also the volume and the relative amount and character of sediment carried in suspension. The slope and the hydraulic radius are undergoing constant changes and the thread of the current is restless and shifting. These conditions could not be duplicated in a model.

6. The common conception of the flow of water in streams is that the water flows in parallel filaments, which is far from true. The Mississippi and other large streams are filled with boils, whirls, and eddies, and as the flowing water impinges on the banks in the bends it piles up and in a measure turns over in its bed. These conditions could not be duplicated in a model.

7. The banks of the river subject to erosion are very different in different localities and the changes as to character are apt to be sudden and frequent. A section of the bank at a given locality may be composed of layers of clay, sand, silt, etc., and in an adjacent locality may show solid sand or clay. Laterally the changes are equally sudden and a knowledge of all of these conditions covering hundreds of miles is necessary. It is impracticable to duplicate these conditions in a model or even a small fraction of them. Even if they were it would be applicable to one limited locality, whereas these conditions are duplicated many times along the length of the river.

8. It is not believed that there is a "great lack of information" so far as relates to the flood control of the Mississippi River that could be met by the use of laboratory experiments. And furthermore it can be said that there is less "disagreement among the best of authorities" with regard to the Mississippi River flood control than any other problem of equal magnitude that I know of.

9. That the floods are not "causing increasing losses" along the Mississippi River is established by the fact that in 1882, 1883, and 1884, all high-water years, there were 712 breaks in the levees. In the great flood of 1922 there were no breaks in the commission levees from Cairo down for a distance of 700 miles, then for another distance of over 200 miles there were no breaks, and this with an incompleted levee system. In short, over 20,000 square miles were protected from the flow.

10. Much study has already been made of "flood-control experiences" in other countries through published reports and data gathered by Government agencies, and all such data is helpful in meeting problems of our own on the Mississippi. We have gathered a vast amount of literature covering these subjects, and we are still doing the same thing, trying to find out all we can, and we are still continuing the experiments on the Mississippi River.

In 1880 the commission employed an engineer of high scientific attainments and certain familiarity with river hydraulics to study the problems which then were new to us. He was to study the problems as to the carrying of sediment, the formation of sand bars, etc., the caving of banks, and all matters like that. He was to devote his whole attention to it and make a report thereon to the commission. He did so, and in starting out he undertook to duplicate the conditions found on the river and made some model experiments. He carried that on for a considerable time but finally abandoned the idea of models as leading to rather doubtful results and substituted therefor a discussion of the data which we had on hand, which, to a certain extent, was mathematical and theoretical and made quite an interesting report of that.

Senator Ransdell. Who made that report, may I ask?

Mr. Ockerson. R. E. McMath was his name.

One reason why the commission takes this matter up is the impression, apparently, that they have in New Orleans that the work that is being done should wait now until we establish a laboratory and get a lot of data that they think we do not have in our possession. The commission is confident that they have gone through the subject very thoroughly and that the data are exceptionally complete, probably better and more complete data than exists in relation to any other river in the world.

Senator Ransdell. Will you not elaborate that a little. You say something about an impression existing in New Orleans, though I did not quite catch your point.

Mr. Ockerson. It is the general impression existing among some people in New Orleans to the effect that what we need is the results that we might get from laboratory experiments. I do not think that there is any necessity, so far as we are concerned, for anything of that kind.

Senator du Pont. So far as straightening out the river is concerned, or making it better for navigation or perhaps to study the rolling up of the bars, will the laboratory be of any value in that direction? I mean, aside from the flood question.

Mr. Ockerson. I do not think so.

Senator du Pont. You think there is such a great difference between the actual river conditions and the laboratory conditions that the results obtainable in a laboratory would not be conclusive?

Mr. Ockerson. The changes are so frequent and so sudden that while you may——

Senator du Pont (interposing). I am not speaking of flood damages now.

Mr. Ockerson. No; navigation conditions.

Senator du Pont. I refer to the average run of the river, rolling up sand bars.

Mr. Ockerson. The river below Vicksburg and below Natchez—those sections are entirely different.

Senator du Pont. And you think a model would not in any way help to study the normal conditions?

Mr. Ockerson. I can not conceive that it would.

Senator du Pont. And the building of jetties to divert the water?

Mr. Ockerson. We have a giant to handle in problems of that sort on the Mississippi River.

Senator du Pont. You think you could not gain any knowledge in that way?

Mr. Ockerson. We would find, we think, that we could not begin to tackle it at all.

Senator du Pont. I mean, would a model jetty in a laboratory be of any use?

Mr. Ockerson. No. You suggested straightening the river.

Senator du Pont. I did not suggest straightening it; I suggested whether or not straightening out the river would make it better for navigation.

Mr. Ockerson. No. We have current enough now so that the force of the water is active in the erosion of the banks in the bends. If we could lengthen the river so as to establish an equilibrium between the stability of the banks and the velocity of the current, that would be the ideal condition. First, if you straighten the river you would increase the velocity and increase the tendency to tear down the banks.

Senator du Pont. Unless it scoured out the bottom it would not stay straight?

Mr. Ockerson. No; it would not stay straight.

Senator Ransdell. Your commission, Mr. Ockerson, has always contended that you must maintain substantially the regimen of the river that you found there when you were created 43 years ago.

Mr. Ockerson. That is the only thing we can do. We can not go beyond that very well, with the small means at our disposal.

Senator Ransdell. Even if you had additional means, would you not contemplate maintaining the river substantially as it was?

Mr. Ockerson. We would try to maintain the regimen of the river as it is.

Senator Ransdell. Taking the ground that if it is shortened materially, as you just a moment ago said, it would increase the current so much as to tear the banks to pieces above and below.

Mr. Ockerson. It would affect that very materially and it would change the regimen. If we made a cut-off where there was a long bend and cut through the narrow neck of land it would change the condition for many miles below and above.

Senator Ransdell. Is it possible that straightening the river would deepen the channel a great deal?

Mr. Ockerson. I doubt it very much. It would tear down so much material and move it a certain distance and begin to deposit it—in fact, we find cases of bad bars, so far as navigation is concerned, lie ordinarily below rapidly caving banks; that is, the bars are moving all the time; they are traveling down the river, and while it might be better in this place [indicating] it would be worse in the other place near by.

Senator du Pont. Generally speaking, they are just below the heavy erosion, in most instances.

Mr. Ockerson. Yes; that is true.

Senator Ransdell. I believe your commission has always contended that if you were given money to build the levees according to the section and grade which you have adopted, and then sufficient funds to hold the banks and to prevent the rapidly caving banks, that the whole problem would be solved.

Mr. Ockerson. That would solve the problem undoubtedly, and the holding of the banks would tend to deepen the river as well.

Senator Ransdell. Can you tell us what caused the trouble, for instance, at Tunica. Mr. Freeman dwelt pretty strongly on the situation at Tunica, up in the upper Yazoo, this morning, and painted the great dangers which existed there, how hard everybody had to work to save it. What caused that, and why did not your commission or somebody prevent that from occurring?

Mr. Ockerson. That is entirely off our line. It is a mile from the river, where the flood ran across a narrow neck of land. The angle of the levee was protected by a dike which proved to be too short and the water whirling around the end thereof caused excessive scour. It was an entire surprise to everyone. Nobody thought there was any special danger there, and the danger developed very suddenly.

Senator Ransdell. It is not on the main river, and not under your jurisdiction?

Mr. Ockerson. It is not under our jurisdiction. We do not do anything in way of levee building in that district, but do operate our revetment plant to prevent destruction of levees by bank erosion by use of funds contributed by the district.

Senator Ransdell. As a matter of fact, you have jurisdiction over the entire river, but I believe that particular section has been handled by the engineers of the upper Yazoo Levee district.

Mr. Ockerson. Yes; it was not a caving bank along the river front but at a point fully a mile inland.

Senator Ransdell. But it was a very difficult situation, was it not, Mr. Ockerson?

Mr. Ockerson. Apparently. It took a great deal of very prompt work in order to save the day.

Senator Ransdell. Which might have done a great many millions of dollars of damage.

Mr. Ockerson. It undoubtedly would. Being in the upper end of the Yazoo Basin it would have flooded both the upper and lower Yazoo districts.

Senator Ransdell. I suppose there is no doubt but that the problem has not been solved in that river yet? Whether it is due to the lack of money or not, it has not been settled yet?

Mr. Ockerson. Oh, no. There are miles of banks to revet and hold and miles of levees to be built up to grade yet, but the plan is to continue them until the work is completed. So far as I know there will not be any great change in the scheme of work, but there ought to be a great change in the amount of work that could be done in a year.

Senator Ransdell. I have said repeatedly that I have understood the Mississippi River Commission would have accomplished all that it had set out to do long ago if they had been given the money. It is a question of money and not of engineering. Am I correct in that?

Mr. Ockerson. I think so, entirely.

Senator Ransdell. But, unfortunately, they have not been given the money, and we have before us now a very, very long stretch of that river—several hundred miles—which must be revetted. Could you tell us about how many miles have got to be revetted right now?

Mr. Ockerson. Several hundred miles, of course; that is, one side or the other practically the whole length, you might say from Cairo down.

Senator Ransdell. About how many miles, Mr. Ockerson, are there, and about what would it cost a mile to revet that river?

Mr. Ockerson. The cost now is about $60 per running foot.

Senator Ransdell. Over $300,000 a mile?

Mr. Ockerson. Over $300,000 a mile, under present conditions, because of the cost of material and labor. Pre-war cost was about $35 per running foot, or $185,000 per mile.

Senator Ransdell. And about how many miles?

Mr. Ockerson. Well, as I say, I am refering now to the river below Cairo.

Senator Ransdell. Yes, I am speaking particularly of that.

Mr. Ockerson. It would be, I think, about 600 miles.

Senator Ransdell. And it would cost $300,000 a mile. That is $180,000,000, provided the costs remain as now.

Mr. OCKERSON. Yes. There is this to be said about it, though: The revetment of a bend at a given point changes the condition of revetting in the next bend below, and just how far that would reduce the amount of revetment as a whole would be difficult to say.

Senator RANSDELL. It might increase the mileage or decrease it?

Mr. OCKERSON. It might diminish the mileage; that is, preventing caving here [indicating] would lessen the caving there. So the total cost would be affected by that process.

That is based on our experience so far. Of course, what we have to do now is to take an emergency point where the greatest interests are threatened and hold that. We can not go at it systematically and revet the entire river, beginning, say, at Cairo.

Senator RANSDELL. About how fast would you like to prosecute that work of holding these caving banks by bank revetment?

Mr. OCKERSON. With the plant we have now we count on about 20 miles a year.

Senator DU PONT. It would require 30 years to do it, then?

Mr. OCKERSON. Yes.

Senator RANSDELL. That is, assuming you would get the necessary money?

Mr. OCKERSON. Yes.

Senator RANSDELL. That is, a good deal more than you have been getting?

Mr. OCKERSON. Oh, yes. We have attempted to build up our plant so that we would have in each district a plant that they could put in about 5 miles each season. That would be, for the four districts, 20 miles.

Senator DU PONT. You have four plants?

Mr. OCKERSON. Yes.

Senator RANSDELL. And good business warrants the prompt expenditure of that money, does it not, Mr. Ockerson?

Mr. OCKERSON. It seems to me it is inevitable; it must be done.

Senator RANSDELL. It would be very unwise, would it not, to spend vast sums to build the levees there unless we are going to maintain the permanence of the banks so that the levees when built will stay there?

Mr. OCKERSON. You would have to protect them in that way. The levees up to the standard grade and section are so high and so expensive to build that we could not afford to let them go into the river.

Senator RANSDELL. And the disaster is so great if one of them caves in?

Mr. OCKERSON. The disaster would now be so much greater on account of the country being settled up—much more than when we began, for one thing. You see, when we began the water flooded an area about 60 miles wide. We brought the levees together and carried the floods down between levees that in some places are only 2,300 feet apart. That means, of course, that flood raised very materially. But it has been carried past Natchez, where the distance is only 2,300 feet in width, for many years without any disaster at that particularly narrow place.

Senator RANSDELL. Have you a memorandum of the results and the enhancement of values in the valley since the Mississippi River Commission was created in 1879, giving the increase of population and assessed values and things of that kind? If so, please state it, or if you have not it will you please insert it in the record when you revise your remarks?

Mr. OCKERSON. I prepared a copy of that character, which I will insert, as you suggest.

(The data referred to was subsequently furnished by Mr. Ockerson, and is here printed in full, as follows:)

THE SUBSTANTIAL BENEFITS RESULTING FROM FLOOD-CONTROL WORK.

[Extract from paper on subject of Flood Control prepared by J. A. Ockerson, member Mississippi River Commission, and read before the commission on December 8, 1921.]

There have been extraordinary developments in what was formerly the area subject to overflow in the States bordering on the lower Mississippi River, which must be largely credited to successful flood-control work.

Without such work even moderate development would have been impracticable.

In order to ascertain the extent of the benefits due to flood control under the Mississippi River Commission, data has been derived from the United States census reports of 1900, 1910, and 1920 covering the increase in farm areas, farm values and population, as compared with like items in the non-Delta portions of the States which are above the reach of Mississippi River floods.

The counties lying wholly or largely within the overflow basins of Missouri, Arkansas, Mississippi, and Louisiana are included in these investigations. The census data are given by counties, a few of which contain considerable hill areas, and a sharp line as to flooded area alone, which is by far the major part of the area considered, can not be drawn.

At the lower ends of the Delta basins, the Upper St. Francis, Lower St. Francis, Yazoo, White, and Tensas, where tributary streams enter the Mississippi River, the levees are not yet completed and the Delta lands are subject to overflow to a certain extent from backwater, but the counties covering the same are included in the general investigation of benefits.

Keeping these limitations clearly in mind, the favorable results of the work done should be highly gratifying. The Delta counties lie in the area formerly overflowed from the Mississippi River.

The State of Missouri has 114 counties, 6 of which lie in the Delta known as the St. Francis Basin.

The total value of "all farm property" of the six Delta counties in 1900 was $25,118,167 and in 1920, $170,079,705, a gain in value of $144,961,538. The percentage of increase is about two and a half times that of the State at large.

The total acres of "improved lands in farms" in the six Delta counties in 1900 was 604,475 and in 1920, 1,072,133, a gain of 467,658 acres, which is more than one-fifth of the gain in all the other counties of the State combined.

The average price per acre of "land in farms" in the six Delta counties has increased from $19.72 in 1900 to $101.37 in 1920, while in the State at large the increase has been from $20.46 to $74.60.

The six Delta counties have increased 55,912 in population in the same period, while 89 counties show a decrease in population and over one-fifth of the total gain for the entire State, including cities, belongs to the six Delta counties.

The State of Arkansas has 65 counties, seven of which lie along the Mississippi River, largely in the Delta district, but also embrace considerable areas of hill lands.

The total value of "all farm property" in these seven counties was $22,-602,988 in 1900 and $168,390,215, a gain of $145,787,227, which is about one-fifth of the increase for the entire State.

The total acres of "improved land in farms" in the seven counties was 592,151 acres in 1900 and 1,024,946 in 1920, a gain of 432,795 acres, which is about one-fifth of the increase for the entire State.

The average price per acre of "land in farms" in these seven counties was $12.32 in 1900 and $77.34 in 1920, while in the State at large the increase was from $6.32 to $34.86.

These delta counties increased in population from 120,079 in 1900 to 220,442 in 1920, a gain of 100,363, which is about one-fourth of the total gain for the entire State.

These delta counties increased in cotton acreage from 341,222 acres in 1910 to 539,550 in 1920, with an increase of 69,493 bales of cotton in same period.

The State of Mississippi is divided into 82 counties, 12 of which lie in the delta.

The total value of "all farm property" in these delta counties was $60,071,432 in 1900 and $442,481,342 in 1920, a gain of $382,409,910, which is equal to one-half the gain for the entire State.

The total acres of "improved land in farms" was 1,466,413 in 1900 and 2,067,384 in 1920, a gain of 600,971 acres, which is equal to one-third of the gain for the entire State.

The average price per acre of "land in farms" was $17.29 in 1900 and $121.61 in 1920, while the State, as a whole, gives $6.30 per acre in 1900 and $35.27 in 1920.

These 12 delta counties have increased 107,850 in population from 1900 to 1920, while 49 of the counties show a decrease. The State at large shows an increase of 293,348, including the cities, 38 per cent of the gain being in the delta counties.

These delta counties increased in cotton acreage from 1,023,353 in 1910 to 1,209,639 in 1920, or a total of 186,286 acres and a gain of 64,026 bales of cotton in same period.

The lower end of the Yazoo Basin is subject to backwater overflow, as the controlling levee line lacks 18 miles of completion, which has been so long deferred that a considerable area of cultivation has been abandoned. This and the ravages of the boll weevil have greatly reduced the development below that which would have been realized under normal conditions.

The State of Louisiana can not be analyzed in the same way as the other lower Mississippi River States, because one-third of its area is alluvial or delta land, because its years of settlement are measured in centuries, and because some measure of flood control has prevailed for a like period. At the same time there are about 2,000,000 acres of land still subject to overflow from the Mississippi River, so the full benefits from flood control will not be realized until this vast area has also been reclaimed.

The benefits thus far belong largely to more substantial levees which give added security to lives and property occupying the lands that have long been in use, rather than any great extension of new farm land areas.

The benefits are reflected in the farm-land values, which have increased from an average of $15.05 per acre in 1900 to $46.51 per acre in 1920 as derived from 15 parishes fronting on the Mississippi River.

Senator RANSDELL. Mr. Ockerson, I have always been impressed with the idea that there is a great deal to be learned on all imaginable subjects, and especially such a subject as that of the mighty Mississippi.

Mr. OCKERSON. Undoubtedly.

Senator RANSDELL. And in introducing this bill I was fully aware of the magnificent work of the Mississippi River Commission. I do not believe it has a better friend in public life than myself, and I was hopeful that this hydraulic laboratory, if created, might help to solve some of your problems. Do I understand you now to say that you do not believe it could do any particular good at all; that you believe you have all the lore that can be evolved in regard to that river?

Mr. OCKERSON. I am sure we have not got all the lore, because we are still studying it, Senator. We are still trying to find out and verify the things that were discovered prior to our time and see whether they are correct or not. We find that in a good many cases they were not correct; further examination showed that they were in error, due to the lack of sufficient observation, and so on.

As far as the hydraulic laboratory experiments are concerned, I can not conceive of anything that it could do that would materially modify the plans that are now under way.

Senator RANSDELL. Understand, this plan, as suggested to me by Mr. Freeman, which I am thinking to have embodied in this bill, does not contemplate the creation of a new bureau to take away any work which is being done by the Mississippi Commission, nor by the engineers of the Army, the Geological Survey, or the Bureau of Standards, or any of the Government bureaus. But it does contemplate having this agency or laboratory, or whatever you choose to call it, located here at the seat of government as an aid to all those different bureaus and governmental agencies. So that if you wish to try out anything experimentally in this laboratory it would be at your service, or at the service of any other bureau of the Government. That is the thought back of it, and that was elaborated very fully by Mr. Freeman here this morning.

Mr. OCKERSON. The bill states that it is to be devoted to studies in connection with the problems of river hydraulics. That limits it——

Senator RANSDELL (interposing). You have had a good deal to do with legislation in your time; and this bill is only a starter. We want to modify this bill and get it so that if we obtain a hydraulic laboratory it will do something for water in America—I do not care what use you put the water to, it is the use of water as it may be helped by a laboratory. That was my thought. Frankly, as you know, I had my whole heart and soul wrapped up in the lower Mississippi. I was in hopes this laboratory would do something to help you gentlemen down there. But I also believe it could do something to help the floods in other places. I put in a document here this morning showing that we had 1,591 lives lost by floods in 21 years and $621,000,000 of damage. There was only one life lost on the lower Mississippi according to that report and a little over $100,000,000 of damage. But there was terrible loss by flood throughout America, and I was in hopes that some of these other floods might possibly be assisted by such a laboratory.

There are several other branches of the Government that think they would be aided. I have letters from the Bureau of Standards and the Geological Survey saying that they think they would be very much aided. The chief attorney for the Reclamation Service testified here this morning that he would be delighted to have it established.

Mr. OCKERSON. My statement is not an objection to a laboratory; it is simply a statement to the effect that we do not think it would help our problem materially.

Senator RANSDELL. That is what I wanted to know. In other words, you gentlemen think that you can handle your problem there just as efficiently as it can be handled without any assistance from a laboratory?

Mr. OCKERSON. We hope to improve our methods all the time as we have in the past, and we hope to continue that, and if the proposed laboratory could help that situation of course we would be very glad to accept the result.

Senator RANSDELL. You were connected once, if I mistake not, with the floods on the Colorado and Salton Sea?

Mr. OCKERSON. Yes.

Senator RANSDELL. That was a tremendous flood problem out there. Do you imagine that those problems could be aided at all by such a laboratory, Have you thought of it at all in that connection?

Mr. OCKERSON. That was an emergency. No laboratory could help that. That had to be done at once, and could not wait for experiments, nor would any experiments that might have been made in the past have had any bearing whatever on that situation. And that is the trouble with the most of the problems we are up against. They are problems that come suddenly, and we have to meet them at once with what facilities we have.

Senator RANSDELL. Mr. Freeman spoke this morning about a very interesting matter that we have had a good deal of testimony on before this committee—the Wood Brothers retard on the upper Missouri. They seem to have accomplished pretty good results; at least they have convinced the Commerce Committee they have. That is something new in engineering, and something that seems to be beneficial in the way of protecting those eroding banks on that great river. I do not say that system could be successfully worked below, but is it not possible that a continuation of that system which they evolved out there might help you to solve some of these awfully expensive bank protections on the lower river? Is it not true that they do check the eroding banks on the Missouri and do it at a comparatively small cost?

Mr. OCKERSON. I can say this: That the whole principle, with the exception of the method of anchoring them, was tried on the Mississippi at Memphis over 40 years ago. The general principle is not new. They were used on the Rhine upward of a hundred years ago. All kinds of things come before the commission. You can not imagine the number of them, all of which are given consideration. The retards have not been tried on the Mississippi River recently, but the levee board proposes to try a section near Caruthersville, Mo. (See reference to this type of work in Transactions American Society Civil Engineers, 1898, p. 236.)

Senator RANSDELL. They have been a success on the Missouri, have they not?

Mr. OCKERSON. I do not know. I suppose they are all right in shallow streams, where I should think they would be effective. It may be that they are effective in deeper streams also, but I do not know. As an illustration of the economy of that type of work the Frisco Railway had some trouble at Memphis at the bluffs. Their freight line runs close to the edge of the bluffs and now and then they have slides there that take away some of their property. They asked the retard people to see what they could do with it. The slide is only about 1,200 or 1,500 feet in length. They were asked to make a bid, and their bid for that work was $435,000. We would consider that pretty expensive revetment work.

Senator RANSDELL. They probably had not evolved proper methods for that kind of deep-water problem. But I have understood they have accomplished effective work and cheaply on the Missouri.

Mr. OCKERSON. I have heard so.

Senator RANSDELL. I have heard so, too. I am simply using that as an illustration to show that there was one solution of the big problems connected with eroding banks on an enormous river that does seem to have been worked out by somebody in the last few years, and I was in hopes that we might get some additional aids in the solution of this awful problem on the lower Mississippi.

Mr. OCKERSON. I hope so.

Senator RANSDELL. I wanted to ask you a little about levees. You spoke about the tremendous expense under your commission of holding the banks. About what would it cost, if you have any figures, to build the levee system up to the full commission section and grade, including the levees on the tributary streams below Cairo in so far as they are affected by flood waters of the Mississippi?

Mr. OCKERSON. I have never gone into that phase of the protection of the tributary streams, so far as they are affected by back water from the Mississippi. I think that Colonel Potter covered that ground; but to complete what we call a controlling levee system, which is along the Mississippi River front, would take about 100,000,000 yards.

Senator RANSDELL. At about how much per yard?

Mr. OCKERSON. Well, we generally figure about 25 cents. If we do it by machine, we can do it cheaper than that; if we do it by contract, it may run a little more than that, but 25 cents would not be a bad figure to use.

Senator RANSDELL. That would be $25,000,000. Some engineers figure higher than that. The State board of Louisiana have figures which were higher than that.

Mr. OCKERSON. I think their figures were 37½ cents.

Senator DU PONT. Do you see how much of that retard could be discovered in a laboratory? Would a laboratory be of any benefit in developing the retard?

Mr. OCKERSON. The best laboratory in the world is right on the Missouri, where they are using it.

Senator DU PONT. Would it have been possible to have developed the retard system in a laboratory?

Mr. FREEMAN. I think you could do much toward determining the best angle for the stream and the best contour for maximum effect and for preventing scour at its outer end.

Senator DU PONT. If the retard were developed outside, the experiments could be continued on a small scale?

Mr. FREEMAN. I think so; and with economy. It seems to me that a retard could be built to serve the same purpose at considerably less cost. My whole thought of the laboratory was as a means of economizing these enormous expenses.

Senator RANSDELL. Is it not possible, however, if we were to get this laboratory and start experimenting with it, the brightest engineering minds in the various bureaus of the Government might discover something, just exactly as the German chemists discovered lots of wonderful things when they got to delving in coal tar, where they found many things they did not expect to find and things from which humanity has been wonderfully benefited? Is it not possible, if we create this scientific agency and go to working at it, that the Government will benefit a great deal more than $200,000 which we estimate it will cost?

Mr. OCKERSON. If they could develop a scheme to jet cement into the banks so as it would stay there and not cave, it would be worth the $200,000 right quick.

Senator RANSDELL. Mr. Freeman, would you like to ask any questions of Mr. Ockerson?

Mr. FREEMAN. I would like to get some information on a few points where I have not been able to get it, and perhaps Mr. Ockerson can give it to me. Have you any idea on the character of the sediments in the Mississippi River down below Cairo as to the relative quantity of different sizes—that is, how much is in real suspension and what percentage is dragging along the bottom?

Mr. OCKERSON. We have had some extended experiments on all those things in the early days. We are not continuing those experiments, because we have regarded those problems as settled.

Mr. FREEMAN. About how many years ago was that?

Mr. OCKERSON. We began in 1880 at New Orleans with daily observations of sediment and discharge and so on. We had near Lake Providence a party examining the sand waves and at the same time the material held in suspension. The reports covered all of those things. But, as I say, after we have determined certain phases of the problem we do not think it is necessary to continue. The expense is hardly justified after the principle has been once established by a long series of observations. So far we have felt confident that the results are correct.

Mr. FREEMAN. I have seen a record of some experiments made, I think, about 40 years ago. Have you had any made since that time?

Mr. OCKERSON. Oh, very much later than that; yes.

Mr. FREEMAN. Is there on record any place to which you can refer me the percentage of sediments of different sizes and qualities?

Mr. Ockerson. I could not tell you that offhand.

General Beach. Mr. Chairman, I can answer that as to the mouth of the Mississippi. Experiments have been made there in great detail within the last few years, and we can give the exact proportions of each possible division of the material in suspension, and that moving along the bottom also.

Senator Ransdell. You can furnish that to Mr. Freeman, can you?

General Beach. It can be furnished for the mouth of the river.

Mr. Freeman. That is, for the Southwest Pass?

General Beach. Yes, sir.

Mr. Freeman. That would be substantially the same as at the city of New Orleans in connection with the spillway, as to the percentages?

General Beach. There is no opportunity to get anything else into the river after it passes New Orleans and only one or two opportunities to get anything out. But there is no reason to believe that what goes out at the other apertures is any different from what goes out at the Southwest Pass.

Mr. Ockerson. I can say this: That the observations taken at New Orleans for a year or more are plotted with the relative saturation, the velocity, the stage, and all those matters, so as to show whether it conforms to the stage in a measure. That was the question brought up by the spillway people and records obtained which I think were taken for the whole depth of the river, so that it conforms in a measure to the variations in stage.

Senator Ransdell. There is hardly any erosion of the banks of the river below New Orleans, is there?

Mr. Ockerson. Yes; in places they are more apparent because the levees are built right on the brink of the river and when they go, they go all at once. There has been erosion down to Fort Jackson to a considerable extent—we do not call it exactly erosion; it is a sloughing of the banks.

Senator Ransdell. That would deposit something in the river that would have to be carried off?

Mr. Ockerson. That will make a sand wave passing down clear through the jetty to the Gulf.

Senator Ransdell. There is nothing like as much erosion below the mouth of Red River as there is above, I believe?

Mr. Ockerson. Oh, no; nothing like it. In fact, when our attention is called to erosion below Red River it looks insignificant compared with the erosion we have to contend with above there. But it is accentuated all along there from Red River down, from the fact that the levees are right on the brink of the river, you might say, whereas above they are a considerable distance back. I would like to say something about the impression that a good many people have that the floods are rising all the time.

Senator Ransdell. We will be glad to have you do so.

Mr. Ockerson. As I explained a while ago, we started our work with a river flooding an area of sixty-odd miles wide. We have brought it down until it is less than 1 mile wide. The real test of whether one flood is bigger than another is the volume of discharge and not the stage. Of course, the stage, so far as the levee is concerned is the important thing. So, a good many people get a wrong impression due to that fact. The increase in height of water is due to confining the floods more and more each year.

Senator Ransdell. Congressman Wilson, would you care to ask any questions?

Congressman Wilson. No; I believe not.

Senator Ransdell. Are there any other points, Mr. Freeman, which you care to bring out?

Mr. Freeman. If I think of any I will write the Senator or ask Mr. Ockerson direct.

Mr. Ockerson. I would not like you to get the idea that the commission has finished studying the river problem. It is always at it, but the big end of the problem we have pretty well solved.

Senator Ransdell. What you need now is money?

Mr. Ockerson. We need money; yes. But what I mean is we are trying to improve on our plant. When we build a new plant we expect to build it better than the other one, because we have tried out the plant and know what the weakest points are and know what the necessary points are that should be developed in another direction.

In the same way with reference to the levees. As you know, the levee machines we have built in recent years are being improved on all the time, reducing the cost of levee building very materially. It is the same way with regard to dredges. When constructing new dredges used in channel work we try to build much better than anything we have had before. Consequently, those problems in economy are constantly before the commission.

Mr. FREEMAN. I would like to ask Mr. Ockerson if the new levees built by machines at this cheaper price are really as good as the old levees built by teams; that is, as I was along the river during the recent floods we would find sometimes a stretch of 2 or 3 miles where the water was percolating from the top to the bottom of the levees in little streamlets, so that they had to cut gashes down the side to prevent scouring. A mile from that, where I could not see any difference in the soil, I would find a levee absolutely tight and not a sign of water percolating through. The impression I gathered was that those tight levees were built in the old-fashioned way by teams driving up over the levees, depositing in layers, and more or less solidifying it as they put it down, and that the looser levees were built in the cheaper method by these magnificent machines.

Mr. OCKERSON. There is another explanation for that which is entirely different. We have found by experiment that the hydraulic gradient of the water soaking through the levees is about a certain angle in the general soils we have on the Mississippi River. In consequence of that we build banquettes so that the angle will fall well within the base of the levee. When you do that then you do not see those little streams and little drains that they put there on the surface of the levee at all. That is really the saving thing about banquettes. We have had cases in the last flood where if it had not been for banquettes the levees would have failed; the floods would have taken out the levees. But with banquettes there is not much trouble about that. In the levee machines the dirt is raised considerably higher than the levee when it is dropped and comes down with a great deal of force and it is packed extremely well. It should be remembered that levees must be built from the material found on the ground and there is limited opportunity for selecting it.

Senator RANSDELL. Those machines handle about 5 or 6 yards to a load, do they not?

Mr. OCKERSON. Yes, they handle about 8 yards, which is dropped at one time.

Senator RANSDELL. And it drops with great force?

Mr. OCKERSON. Yes.

General BEACH. There are some types, if you will allow me, that handle 10 yards.

Senator RANSDELL. It is a very heavy impact and about as great as a mule walking over it would amount to?

Mr. OCKERSON. Oh, yes; much greater. We have used tractors to haul up the dump wagons. We found, however, that the tractors were really much more expensive than the other method, for the reason that the material gets into the bearings and wears them out very quickly. We adopted the tractor because the quartermaster had more than he knew what to do with and we could get them for nothing. We are trying them out still, and instead of using mules we use tractors, and the tractor itself, then, packs it pretty well.

In my remarks throughout where I have referred to the Mississippi River Commission I have had in mind also the district engineers from the Engineer Corps of the Army and the civilian assistants, all of whom have rendered valiant service in our efforts to solve the many difficult problems involved in the gigantic work of flood control and channel improvement of the Mississippi River.

Senator RANSDELL. Thank you very much, Mr. Ockerson. Mr. L. W. Wallace, executive secretary of the Federated American Engineering Societies, Washington, D. C., desires to make a statement.

STATEMENT OF L. W. WALLACE, EXECUTIVE SECRETARY FEDERATED AMERICAN ENGINEERING SOCIETIES, 24 JACKSON PLACE, WASHINGTON, D. C.

Mr. WALLACE. Mr. Chairman and members of the committee, Federated American Engineering Societies was organized and is being operated for the purpose of enabling engineers to render public service in relation to problems of public moment of an engineering aspect. The study of river flow and flood problems are intrinsically engineering questions. Floods which result in disaster to hundreds of thousands of American people are questions of great importance to the public in general. The prevention of floods or their alleviation are inherently engineering in aspect. It is clearly within the purview of the Federated American Engineering Societies to take such action as its board of directors might advise concerning any matter that has bearing upon this public question. Aside from the public aspect of the study of river flow and flood prevention, there is a scientific and technical feature which also comes within the scope of interest of Federated American Engineering Societies.

There are two fundamental reasons why the Federated American Engineering Societies is concerned with the bill proposing the establishment of a national hydraulic laboratory.

First. It has a bearing upon an important public problem of an engineering aspect.

Second. The establishment of such a laboratory will materially increase scientific knowledge concerning many phases of river hydraulics.

It is felt that neither of these two items have received the scientific study that their importance demands. It is well known that many phases of them have not been adequately studied from a scientific point of view, and by the term "scientific" is not meant a theoretical study or investigation, but that scientific study which would lead to a practical solution of many of the difficulties.

It is our information that in a large measure the principal phases of planning river improvements of to-day are based upon Fargues laws, which were the result of some observations made some 80 years ago on a few kilometers of a small river in France. Some additional work has been done in a laboratory in Germany, but there has been no scientific study made in the United States whereby the planning of river improvements and control can be adequately undertaken. This clearly indicates that there is a great need for such a laboratory as proposed. No more evidence of the need is required than to make a casual observation of the serious losses of property, and indeed of human life, that occurred in various localities of the United States in recent months.

It has been in view of the consideration referred to that the Federated American Engineering Societies has become actively interested in the passage of the proposed bill. It earnestly hopes that Congress will realize the great need and will make available the necessary facilities for meeting the need by the passage of the designated bill.

Senator RANSDELL. Thank you, Mr. Wallace.

(The following letter from Mr. Clemens Herschel, the eminent hydraulic engineer, was introduced and made a part of the record:)

NEW YORK, N. Y., *September 6, 1922.*

Hon. JOSEPH E. RANSDELL,
Chairman Committee on Commerce, United States Senate:

Responding to your valued invitation of August 28 to present my views either in person or by submitting a written statement to be embodied in the record bearing on the establishment of a United States hydraulic laboratory, I have to say:

To the Holyoke Water Power Co., of Holyoke, Mass., belongs the credit of having built and operated the first modern hydraulic laboratory in the United States, or for the matter of that (at least so far as I have ever heard), in the world. This was in 1881, and reference is made to the well-known "Holyoke testing flume." As hydraulic engineer of the company at the time, I had the honor to design this flume and to supervise its construction; also to have charge of its operation until 1890. The company needed such a laboratory from time to time in the conduct of its business, and it was thought that by offering its use and the services of the engineers accustomed to operate it, between times, to serve the public in an impartial and exact manner, the undertaking would at least occasion no loss on the investment made.

This testing flume, as it was popularly called, has been the scene of important work. Principally used to test the mechanical efficiency of hydraulic turbines (more frequently called water wheels) it has been of incalculable benefit in the development of water-wheel construction in the United States. Practically all of the wheel builders of the country have used it, and of late years have had to await their turn to get the use of it. When it was built, hydraulic turbines seldom attained 300 horsepower in the United States, and some 1,300 horsepower (a wheel in Italy) was perhaps the maximum-powered wheel in the world. Wheels were mostly cast-iron contrivances, turned out in quantity like shelf hardware. Every wheel builder had a wheel yard attached to his foundry or factory and purchasers selected their wheels from the stock on hand so as to meet, as well as might be, their immediate needs. If the wheel did not have the speed wanted, it was geared up or else geared down to meet requirements, while to-day wheels are built to meet exactly the ever-varying demands of the site in question, and wheels of 80,000 horsepower, not 300 as formerly, are in process of construction.

This development of a useful and highly beneficent art could not have been brought about without the agency, open to the public, of a modern hydraulic laboratory, wherefor I have been thus explicit in describing it and the changes it has been the means of producing.

Other useful work has been done at this same testing flume, not counting the services of the flume in the conduct of the business of the Holyoke Water Power Co.

For instance, there was created the Venturi water meter, the only practical meter to measure and record large quantities of water, such, for instance, as the daily water supply to the city of New York.

New York has three meters capable of measuring up to 800,000,000 gallons daily, and many more of smaller capacity. The diameter of the conduit leading to the meter is nearly 18 feet (a good-sized railroad tunnel), while at the same time such meters of only one-fourth inch in diameter have been in service. The Venturi meter is used all over the world, and on its records is based the operation of innumerable water supply works, such, for example, as those of the Metropolitan Water and Sewerage Board of Massachusetts, supplying Boston and about 20 adjoining municipalities, some 75 or 80 large meters being at work here.

Without a hydraulic laboratory at hand, like the Holyoke testing flume, no such invention could ever have been effected.

My argument is, and long has been, that there are needed in the United States several endowed hydraulic laboratories in which experiments and observations may be made and taken continuously, and by trained observers making this their life work, precisely as kindred work is done on astronomical lines in astronomical observatories; and I am hoping that the United States Government will make a beginning in this direction, principally for the use and benefit of its government departments.

The resultant benefits to the conduct of the affairs of these departments will, it is believed, follow as assuredly as such have followed from the operation of the first built public hydraulic laboratory, a part of whose work and the consequences flowing from it have been above described.

If this much be granted, there remains the broad question of location and operation.

On this point I quote from the presidential address of Mr. John R. Freeman, American Society of Civil Engineers, who, I understand is to appear before your committee. He says: "Now is the time to urge the importance of immediately constructing a national hydraulic laboratory, * * * 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 United States Geological Survey; next, possibly, for some months, for that of the United States 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 [the present writer says, "will 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."

In this forecast of the work awaiting a national hydraulic laboratory, I agree in the fullest manner. Such an institution would at once be in demand for all of its time and probably would grow as the country grows, and with the needs of the several departments of Government.

Let me say in this connection that since 1881 I have had considerable experience in these matters in general. I have called the Holyoke testing flume the first modern hydraulic laboratory. There were such before 1881, but they were of so modest or minute dimensions that they failed to produce results suited to, certainly, modern practice. And yet the demand for knowledge to be produced by a practical research in hydraulic science is a very old one. Galileo, who was born in 1564, complains in one of his essays that he could find more in books about the attributes of the heavenly bodies than he could about those of the waters that flow on the earth which he inhabited. Even to-day most of the hydraulic laboratories to be found in schools and colleges are much too small to be of adequate service for aught but the giving of primary instruction.

Next following the Holyoke testing flume, in order of time, came the Cornell University hydraulic laboratory, built by the State of New York in 1898. It also has done good work, but is handicapped from not having an endowment to keep it in operation; that is, not being able to work continuously and in a manner that will exhaustively reply to the questions put to it. The combination of teaching students and making exhaustive, practical, research studies has generally, I believe, not been found to be a happy one.

About 1910, on the occasion of the then contemplated hydraulic laboratory for the Massachusetts Institute of Technology, the late Professor Sabine, of the institute, and I visited all the hydraulic laboratories in the United States we then could hear of and procured plans of all we could hear of as existing in Europe. In this way, and taking note of those constructed since 1910, it would be working from assured precedents, and no untried experiment, now to design a United States hydraulic laboratory for the use and service of the several United States departments and bureaus whose work could be furthered by the operation of such an establishment. In Senate Joint Resolution 209 only flood drainage prevention is mentioned or emphasized as such prospective work, but this does not present the only questions of the sort we are now endeavoring to answer. In fact, the promotion of low-water navigation in rivers and estuaries will probably, as I am viewing it, demand more research study and experiment from a United States hydraulic laboratory than will the study of flood damage prevention; and a multitude of other questions are constantly arising in the conduct of many of the Government bureaus, whose proper answer can only be given by a laboratory such as we are considering.

The conclusion I wish the subcommittee to come to is that a United States hydraulic laboratory should be made one of the permanent institutions of the country, as fully as and even more than a United States astronomical observatory, and that Senate Joint Resolution 209 should pass.

All of this is respectfully submitted.

CLEMENS HERSCHEL.

Senator RANSDELL. Unless there is something else, the subcommittee will now stand adjourned. We thank you gentlemen very much for your statements.

(Thereupon, at 4.10 o'clock p. m., the subcommittee adjourned.)

×