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DESIGN OF NATIONAL HYDRAULIC LABORATORY

COPIES OF PLANS, ESTIMATES OF COST, AND MEMORANDA RELATING TO THE NATIONAL HYDRAULIC LABORATORY AT THE UNITED STATES BUREAU OF STANDARDS, WASHINGTON, D. C., PREPARED BY JOHN R. FREEMAN, CONSULTING ENGINEER, PROVIDENCE, R. I.

PRESENTED BY MR. HEBERT

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DESIGN OF NATIONAL HYDRAULIC LABORATORY

PROVIDENCE, R. I., *June 24, 1930.*

Hon. JOSEPH E. RANSDELL,
United States Senator.

Hon. ROBERT P. LAMONT,
United States Secretary of Commerce.

Dr. GEORGE K. BURGESS,
Director of United States Bureau of Standards.

GENTLEMEN: Four weeks ago in Washington I learned that plans had been prepared under the direction of a member of the laboratory staff at the Bureau of Standards for the National Hydraulic Laboratory. I called on Doctor Burgess, who gave me a copy of this outline plan, which I understood was about to be turned over to the architect for further elaboration.

On studying this outline design prepared at the bureau, I became greatly disturbed lest the good cause of the National Hydraulic Laboratory for which, with Senator Ransdell, I had worked so diligently for eight years past, was to be imperiled by lack of facilities for fundamental hydraulic research on a large scale, such as I believed were contemplated by the act of Congress, and which had been plainly described by me before the Senate Committee of Commerce, at a public hearing in 1922, and plans presented, which were reproduced in the printed report of the hearing.

Thereupon, I started to revise the plan which I presented to the congressional committee in 1922, in the light of information that I had gained during two subsequent tours of European hydraulic laboratories, in 1924 and 1927, and which are set forth in the book published by the American Society of Mechanical Engineers one year and a half ago, entitled "Hydraulic Laboratory Practice," copies of which book were presented to various members of the United States Senate and to each member of the House Rivers and Harbors Committee.

Unfortunately I have been under very great pressure during the past four weeks, having been compelled to delay my European trip in order to present my testimony before a master appointed by the United States Supreme Court, in the matter of the diversion of the head waters of the Delaware River for the supply of New York City. This testimony made necessary much preparation and rereading of old reports. It was completed on Wednesday of last week.

In the meantime, my assistants have worked diligently over my notes and sketches, with such supervision as I could personally give, and have prepared the plans now presented.

The preparation of such extensive plans in such a short time was rendered possible only by the plans of an equally generous scale, which I presented at the congressional hearing eight years ago, and by a still earlier set of large-scale studies that I had made 17 years ago, and by my familiarity through more than 50 years with hydraulic engineering designs on a large scale.

During the preparation of these plans we endeavored to keep the cost of the principal structures within the congressional appropriation, therefore, I have been much pleased to-day at the result of conferences of my assistant engineer with the estimating staff of Charles T. Main (Inc.) (which is one of the largest and most experienced engineering offices in New England familiar with the construction of industrial plants), and with the estimators of the Turner Construction Co., which built the present industrial building and also the east building at the Bureau of Standards.

The figures from these two independent sources are presented herewith. Those of the Turner Co., total $341,715 were made up on a generous basis of quantity estimates in order to cover any uncertainties, as were the estimates of Charles T. Main (Inc.), which total $354,885 which were based on the same quantities but using slightly different unit costs.

I have not had time to get figures for cost of electrical motors, internal combustion motors, and auxiliary pumps, but I am confident that enough can be saved out of these items, estimated, totaling $341,715, to cover the cost of putting a laboratory into active service.

The ordinary architectural fee of 6 per cent which would amount to about $20,000, need not be expended, because the plans now submitted with the addition of a few details, are sufficient for purposes of a firm bid and for construction purposes. I cheerfully contribute them cost-free for the good of the cause.

I believe no one acquainted with my work, will seriously question my ability to prepare designs of this character.

I have prepared several sets of the blueprints and also several sets of photostats, for the convenient study of Senator Ransdell, Secretary of Commerce Lamont, Doctor Burgess, and members of the advisory committee.

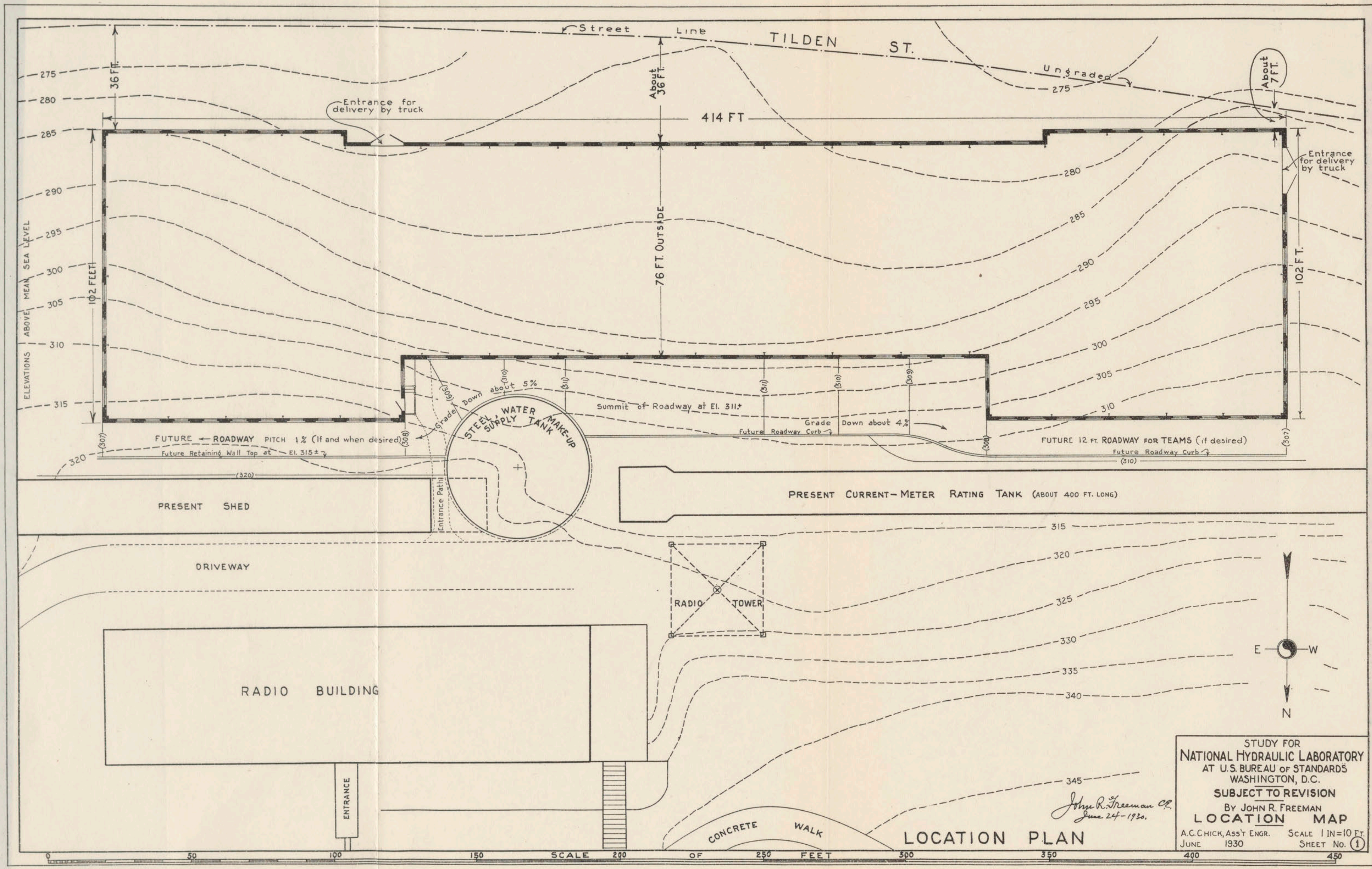
Because of my sailing for Europe next week I regret that I can not be present at further meetings of the advisory committee. I may, however, state that I had previously arranged to meet Professor Gregory, of the advisory committee, in Germany, to inspect some of the larger and more recent laboratories, and that I expect to devote the greater part of the month of July to such inspections and to a discussion of the plans now submitted with some of the most eminent laboratory experts in Europe.

I respectfully submit that the public interests would not suffer by delaying action until Professor Gregory and myself can report on what we find in Europe.

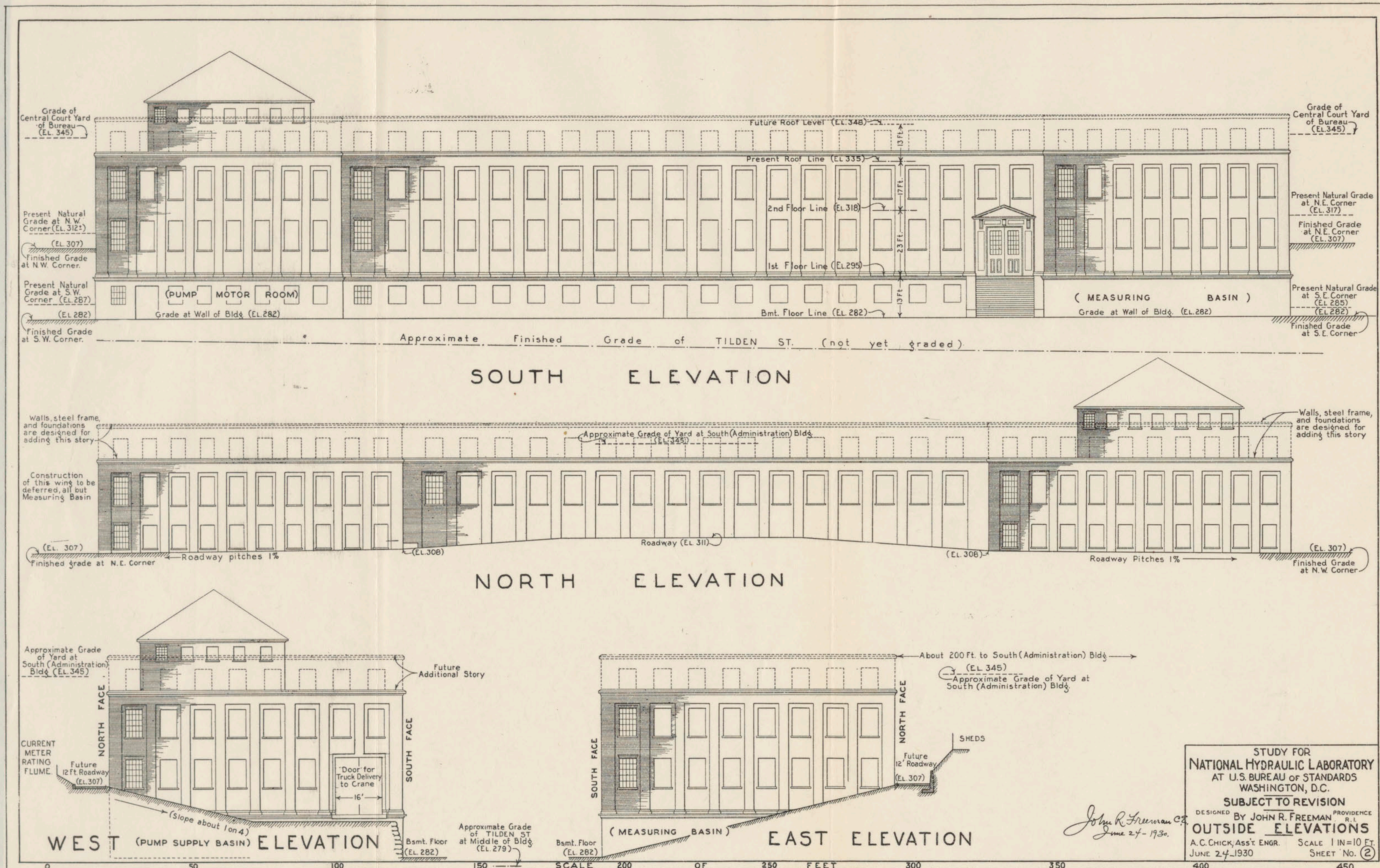
Attached herewith are small-scale photostats of the plans, also copies of the two independent estimates of cost, and some memoranda that I have dictated hastily for the use of the advisory committee and Doctor Burgess, as to the motives of the design now submitted.

Respectfully submitted.

JOHN R. FREEMAN.



121057—30. (Face p. 3.) No. 1



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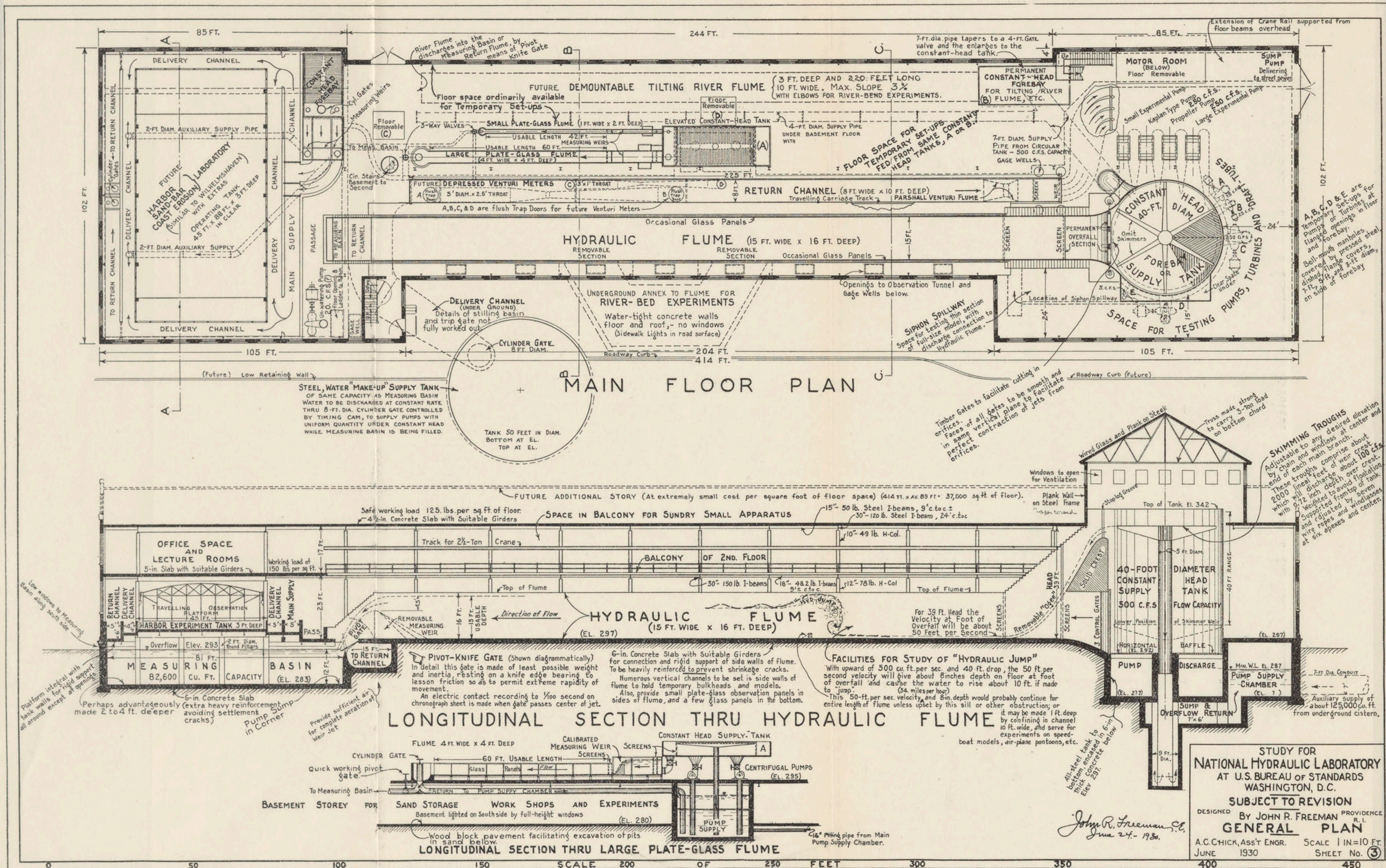

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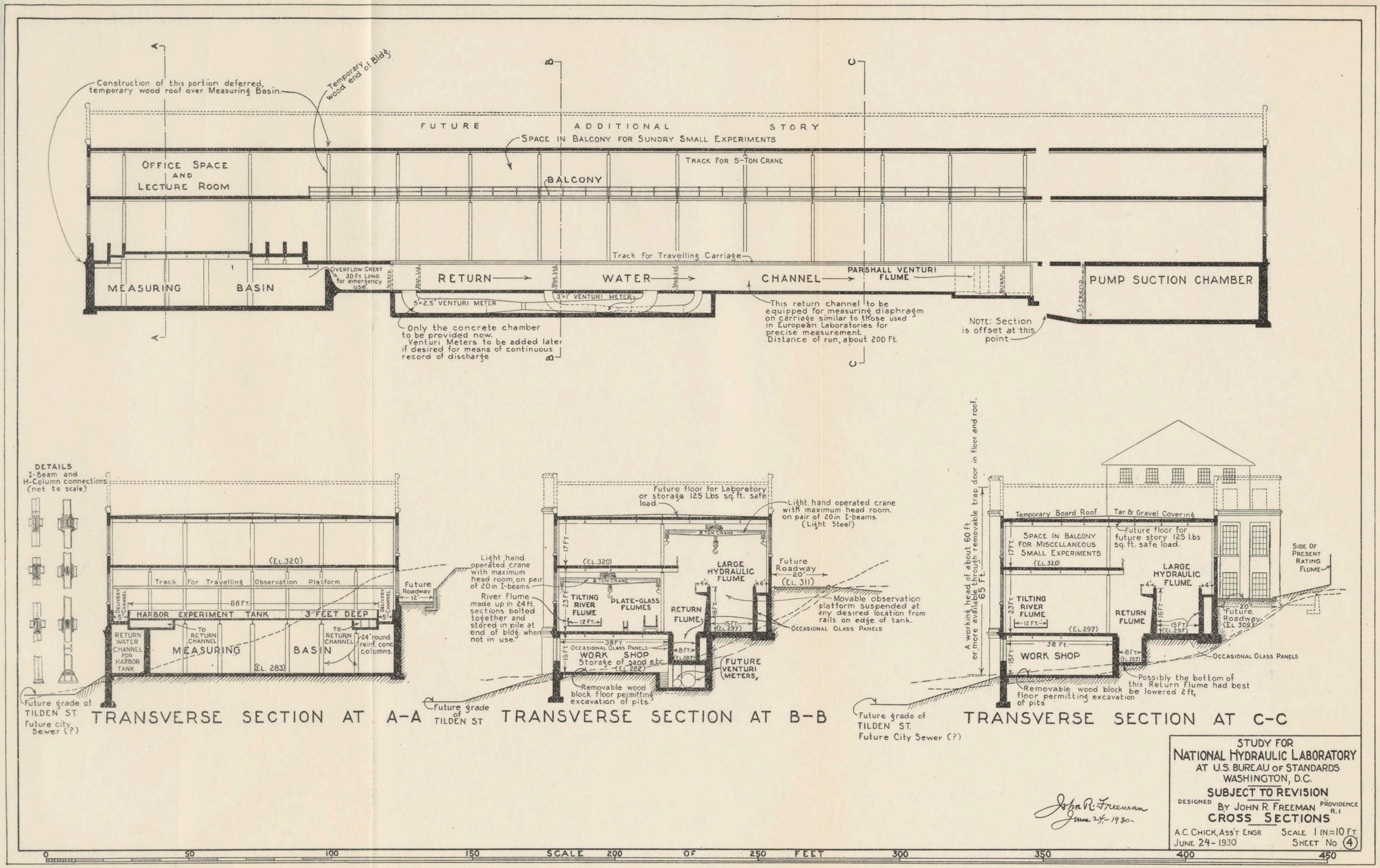
Construction of this portion deferred, temporary wood roof over Measuring Basin.
Temporary wood end of Bldg.
FUTURE ADDITIONAL STORY
Space in Balcony for Sundry Small Experiments
Office Space and Lecture Room
Track for 5-Ton Crane
Balcony
Track for Travelling Carriage
Measuring Basin
Overflow Crest 30 Ft. Long for emergency use
RETURN WATER CHANNEL
PARSHALL VENTURI FLUME
PUMP SUCTION CHAMBER
Screens
5×2.5' Venturi Meter
3×1' Venturi Meter
Only the concrete chamber to be provided now. Venturi Meters to be added later if desired for means of continuous record of discharge
This return channel to be equipped for measuring diaphragm on carriage similar to those used in European Laboratories for precise measurement. Distance of run, about 200 Ft.
Note: Section is offset at this point
DETAILS I-Beam and H-Column connections (not to scale)
(El. 320)
Track for Travelling Observation Platform
88 Ft.
Harbor Experiment Tank 3 Feet Deep
Delivery Channel
Return Water Channel for Harbor Tank
To Return Channel
Measuring Basin
24" round reinf. conc. columns.
(El. 283)
Future Roadway 12'
Future grade of TILDEN ST.
Future city Sewer (?)
TRANSVERSE SECTION AT A-A
Future grade of TILDEN ST
Light hand operated crane with maximum head room, on pair of 20 in I-beams
River Flume made up in 24 ft. sections bolted together and stored in pile at end of bldg. when not in use.
Future floor for Laboratory or storage 125 Lbs sq. ft. safe load.
Light, hand operated crane with maximum head room, on pair of 20 in. I-beams. (Light Steel)
2 Ton Crane
17 Ft.
23 Ft.
15 Ft.
Tilting River Flume
Plate-Glass Flumes
12 Ft.
Large Hydraulic Flume
Return Flume
Future Roadway 20'
(El. 311)
Movable observation platform suspended at any desired location from rails on edge of tank.
Occasional Glass Panels
38 Ft.
Work Shop Storage of sand etc.
(El. 282)
(El. 297)
Future Venturi Meters,
Removable wood block floor permitting excavation of pits.
TRANSVERSE SECTION AT B-B
A working head of about 60 ft. or more available through removable trap door in floor and roof. 65 Ft.
Temporary Board Roof
Tar & Gravel Covering
Space in Balcony for Miscellaneous Small Experiments
Future floor for future story 125 Lbs sq. ft. safe load.
Side of Present Rating Flume
Future Roadway (El. 309)
Possibly the bottom of this Return Flume had best be lowered 2 ft.
Removable wood block floor permitting excavation of pits
Future grade of TILDEN ST.
Future City Sewer (?)
TRANSVERSE SECTION AT C-C
STUDY FOR NATIONAL HYDRAULIC LABORATORY AT U.S. BUREAU OF STANDARDS WASHINGTON, D.C.
SUBJECT TO REVISION
DESIGNED BY JOHN R. FREEMAN PROVIDENCE R.I.
CROSS SECTIONS
A.C. CHICK, ASS'T ENGR
JUNE 24 - 1930
SCALE 1 IN.=10 FT.
SHEET No. 4
John R. Freeman June 24 - 1930
0 50 100 150 SCALE 200 OF 250 FEET 300 350 400 450

OUTLINE DESIGNS FOR A NATIONAL HYDRAULIC LABORATORY

AT THE

UNITED STATES BUREAU OF STANDARDS

By John R. Freeman

Estimate No. 1

Summary of estimate of cost

[Based upon design by John R. Freeman. Estimate by A. C. Chick, assistant engineer, in conference with Mr. Taylor, chief estimator for Turner Construction Co., of Boston]

	Quantity	Unit cost	Total
Excavation, including, backfilling, and shoring	22,100 cubic yards	$1.00	$22,100
Concrete foundation walk, basement interior walls, basement floor, large hydraulic flume, return flume, etc.:			
Concrete only	4,100 cubic yards	10.50	43,000
Reinforcement, including all reinforcement for entire building.	200 tons	90.00	18,000
Forms (straight work, some specially accurate for flumes)	87,600 square feet	.30	26,300
Curved forms	6,000 square feet	.50	3,000
Granolithic finish for concrete surfaces	15,000 square feet	.12	1,800
Concrete for floor slabs:			
Concrete only	934 cubic yards	10.50	9,800
Forms (allow for use 4 times)	60,000 square feet	.18	10,800
Granolithic finish	do	.12	7,200
Two 2-ton cranes (hand operated), crane track, brackets, etc	30 tons	90.00	2,700
Structural steel, including all beams, columns, etc	430 tons	90.00	38,700
Temporary board roof over third floor (1-inch boards with tar-and-gravel cover).	27,300 square feet	.30	8,200
Outside brick walls, windows, complete with caps, sills, lintels, trim, etc.	28,700 square feet	1.50	43,000
Temporary wood roof over measuring basin (2-inch plank, tar and gravel, on suitable wood timbers).	9,000 square feet	.60	5,400
Steel forebay supply tank	67.5 tons	125.00	8,500
Skimmer weir apparatus			6,000
Roof house over steel forebay:			
Wall area (copper-covered plank on steel)	4,800 square feet	1.00	4,800
Roof (plank on steel, wire-glass skylights)	3,500 square feet	1.75	6,200
2 stairways ($12 per riser)			1,500
Ornamental doorway			500
Heating (radiators and piping only)	1,000,000 cubic feet	.15	15,000
Toilets and washrooms			5,000
Lighting (ordinary equipment)	60,000 square feet	.15	9,000
Underground concrete cistern for 125,000 cubic feet supply water			20,000
Steel make-up water tank, 50 feet diameter			10,000
Kaplan type pump, adjustable blade, 250 cubic feet per second capacity.			8,215
2 small plate-glass flumes, etc			5,000
Total			341,715

Note.—All quantities have been estimated liberally to meet any uncertainties. With more refined design a substantial saving in these quantities can undoubtedly be made.

ESTIMATE No. 2

Summary of estimate of cost

Stem	Quantity	Unit price	Total
Excavation	22,100 cubic yards	$0.60	$13,260
Foundation and basement, concrete:			
Main foundation walls, concrete	1,410 cubic yards	18.00	25,400
Floors (all resting on earth) and interior columns of measuring basin.	353 cubic yards	16.00	4,650
Pump-room floors, etc., in west end of building	193 cubic yards	20.00	3,860
Forms for outside basement walls	36,320 square feet	.30	10,900
Interior basement walls	554 cubic yards	18.00	9,970
Forms for interior basement walls:			
Measuring basin	5,080 square feet	.40	2,040
Basement—			
Straight-form work	4,100 square feet	.30	1,230
Curved-form work	6,100 square feet	.50	3,050
Temporary wood roof over measuring basin (2-inch plank on suitable floor timbers).	27,000 board feet	100.00	2,700
Tar-and-gravel covering	9,000 square feet	.15	1,350
Return flume and adjoining tunnels, concrete, etc	510 cubic yards	18.00	9,170
Forms:			
Flume	13,900 square feet	.40	5,550
Adjoining portions	4,290 square feet	.30	1,290
Main hydraulic flume:			
Concrete	1,075 cubic yards	20.00	21,500
Forms—			
Side walls of flume	21,380 square feet	.45	9,600
Upper portion of upper end walls	2,450 square feet	.40	980
Steel forebay or supply tank for large hydraulic flume	134,500 pounds	.12	16,150
Skinner weir			6,000
First floor:			
Concrete	311 cubic yards	16.00	4,970
Forms	16,760 square feet	.25	4,180
Steel beams (12.8 pounds per square foot)	215,000 pounds	.05	10,750
Steel columns	21,800 pounds	.05	1,090
Second floor:			
Concrete	243 cubic yards	16.00	3,880
Forms (use first-floor forms)	15,750 cubic yards		
Steel beams (12.8 pounds per square foot)	189,500 pounds	.05	9,470
Steel columns	9,820 pounds	.05	490
Two 2-ton steel hand-operated cranes complete with track, etc			5,000
Third floor (present roof):			
Concrete	380 cubic yards	16.00	6,080
Forms	27,280 square feet	.25	8,200
Steel beams	292,000 pounds	.05	14,600
Temporary wood roof covering	30,000 board feet	75.00	2,250
Tar and gravel covering	27,280 square feet	.15	4,100
Outside walls of building (13-inch brick)	490,000 brick	60.00	29,400
Windows	7,000 square feet	1.00	7,000
Parapet cap	760 linear feet	1.00	760
Steel for columns in outside wall of building	128,100 pounds	.05	6,400
Temporary wooden end for east end of building	4,000 square feet	100.00	400
Roof house over large steel forebay			15,000
Heating (radiators and piping only)	1,000,000 cubic feet	.15	15,000
Toilets and washrooms			5,000
Lighting (ordinary)	60,000 square feet	.15	9,000
125,000 cubic feet underground concrete cistern for auxiliary pump supply.			20,000
82,000 cubic foot steel make-up water tank			10,000
Kaplan pump, adjustable blade, 250 cubic feet per second			8,215
2 small plate glass flumes, etc			5,000
			354,885

NOTE.—All quantities have been estimated liberally to meet any uncertainties of ground, etc. With more refined design a substantial saving in these quantities can undoubtedly be made.

SCOPE OF DESIGN

(1) The attached drawings speak for themselves, but the following statement will aid in understanding the motives of the design:

The accompanying plans are designed to meet the purposes specified in the act of Congress of May, 1930, and to fulfill the promises of usefulness to the public set forth by Senator Ransdell, of Louisiana, and by various engineers, and others, at the several hearings before committees of the House and Senate, and presented in the printed reports of the hearings:

(2) The bill as passed reads:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be established in the Bureau of Standards of the Department of Commerce a national hydraulic laboratory for the determination of fundamental data useful in hydraulic research and engineering, including laboratory research relating to the behavior and control of river and harbor waters, the study of hydraulic structures and water flow, and the development and testing of hydraulic instruments and accessories.

Three distinct lines of useful research are authorized:

1. The discovery of fundamental hydraulic data, such as coefficients of weir and orifice discharge, with greater accuracy than now known.
2. Testing of instruments and accessories.
3. Experiments of immediate practical application to the design of structures proposed for the development of water power, flood control, irrigation, domestic water supply, and the improvement of rivers and harbors for navigation, by means of studying the movement of water in relation to small models of the proposed structures, which models may be readily changed in trying out different ideas.

From observations upon these models the action of the proposed full-size design may be accurately foretold, and changes made for improving its efficiency or lessening its cost.

(4) The accompanying plans are designed with a view to presenting facilities for hydraulic research on models, and for developing formulas for estimating the discharge in proportion to depth, form, or velocity for many forms of weirs, orifices, and channels on a large scale, and with a high degree of precision, better than can be found anywhere in the world, and for redetermination of many fundamental hydraulic coefficients with such certainty and accuracy that they may stand unchallenged for a hundred years.

(5) They have been prepared in the light of my experience of more than 50 years in large problems of hydraulic engineering, and after many months of personal experience in several hydraulic laboratories in years gone by; also they are designed after personal inspection and review of substantially all the foremost hydraulic laboratories in Europe, as they existed three years ago. Laboratory research has since made large advances abroad, and very possibly I might change certain details after the tour of the three latest and largest European laboratories, on which I start next week, and after conferences with the eminent engineers in charge.

(6) In general, the fundamental hydraulic laws, coefficients, and constants for weirs, orifices, open channels, and pipes, now chiefly relied upon, have not been determined with the precision, nor over the range, required by present-day engineering, but have been developed piecemeal from apparatus of small capacity and often of imperfect adjustment. For example, the data on coefficients of orifices were largely determined by Poncelet and Lesbros 100 years ago, with precision marvelous for the times, with orifices only 2 decimeters (8 inches) in width and heads only up to 2 meters (6.6 feet). That these old researches leave much to be desired is shown by the critical review of Hamilton Smith, jr., Hydraulics, New York, 1886, page 27, et seq.

It is of particular importance that new tests be made upon water measuring weirs—rectangular, sharp-crest, round-crest, and V-notch—of many forms and large dimensions.

(7) The very small scale of most of the apparatus with which many important hydraulic constants and coefficients now in use were determined requires for their extension to modern practice, wonderful faith in the laws of hydraulic similitude, which may not be fully justified. Recent admirable experiments under the supervision of Professor Thoma at Munich, for developing the effects of changes in weir crests, reported in 1929 under the title "Sources of Error in Weir Measurement," are extremely instructive, but were made with great precision on extremely small apparatus, with a length of weir crest of only 6 inches and a depth over the weir of from 1½ inches to about 4 inches.

CONFIDENCE VERSUS DISTRUST

(8) I believe there is a growing feeling of distruct among engineers familiar with the movement of water about the precision obtainable in applying coefficients, constants, and hydraulic laws, derived from apparatus and in depths of these small dimensions, to practical problems where the depth may be thirty or forty times as great, and the discharge a thousand times greater.

(9) In the paper to be presented during the present week at Toronto, before the summer convention of the American Institute of Electrical Engineers, Mr. Karpov, the chief hydraulic designing engineer of the Aluminum Co., which is now building the largest hydroelectric station in the world, on the Saguenay River, and another large station in Tennessee, reports after a recent tour of European power developments and hydraulic laboratories:

> Two different opinions predominate [in Europe] in the question of the scale on which models such as of rivers, channels, locks, dams, etc., should be made and tested.
>
> One opinion that is best represented by the hydraulic laboratory of the Prussian State in Berlin is that the models have to be as large as possible; the other opinion, best represented by the hydraulic laboratory of the Technical University of Karlsruhe, is that the models are to be reasonably small, depending on the character of the problem to be studied.
>
> The Berlin laboratory in logical development of its idea went so far as to start to build an out-of-doors laboratory outside of Berlin, in order to remove the limitations that are put on the scale of the models by the size of a building. In this laboratory models as large in scale as 1:40 are built and tested.
>
> In order to work on still larger scales, this laboratory goes so far as to build and test models with different horizontal and vertical scales.
>
> The Karlsruhe laboratory stresses the importance of the refinement of measuring and observation methods, and believes that a small model can be tested out much more thoroughly, by making a larger number of tests under different conditions, a procedure that would be prohibitive on account of time and cost in a large scale model.
>
> Both laboratories have the support of outside technical opinion. The Berlin laboratory is starting a number of model tests on river regulation problems in Soviet Russia which are to be run on out-of-door models of large scale.
>
> The Karlsruhe laboratory is finishing a special building where the regulation problems of the Rhine River are to be solved on models of much smaller scale (1:200). The tests are to be run on a number of separate models, each representing consecutive stretches of the Rhine River about 10 km. long.

The out-of-door hydraulic laboratory recently completed at the Walchensee, near Munich, was promoted largely because of doubts about accuracy with very small models.

IT IS HIGHLY IMPORTANT TO HAVE FACILITIES BY WHICH "SCALE-EFFECT" CAN BE TESTED, AND A PROPER DEGREE OF CONFIDENCE GIVEN

(10) Illustrating this, I may say the recent measurements of the flow, about 11 feet deep, over the actual crest of the dam across the Mississippi, at Keokuk, Iowa, recently measured with great care by a group of engineers from the hydraulic laboratory of the University of Iowa, resulted in finding a discharge nearly 10 per cent greater than that which I had deduced about 20 years ago from the best experimental data then available.

FACILITIES FOR RESEARCHES FOR BOULDER DAM—UNITED STATES GEOLOGICAL SURVEY, DEPARTMENT OF AGRICULTURE, UNITED STATES ARMY AND HARBOR ENGINEERS, ETC.

(11) In the design now presented for a national hydraulic laboratory, in addition to facilities for determining fundamental laws and coefficients, facilities also are provided for other practical experiments and tests with models on smaller scale, in great variety, so as to fully meet the conditions prescribed in the hearings before Congress, and fulfill the promises made which led Congress to grant the appropriation, and for fullest cooperation with the United States Army engineers.

(12) The general layout is shown in the accompanying plans of a building, not all of which is to be built at once. The foundations of the whole should be planned from the beginning, so as to contain the flumes, supply tanks, and measuring tanks necessary for future large scale operation, in determination of fundamental laws and coefficients.

(13) The drawings now presented have been worked up in a great hurry to fit the site at the bureau, and are subject to revision. I believe that by conferences with eminent hydraulicians in my prospective tour of the largest, latest, and best European laboratories during the next two months, I could learn how to substantially improve many details.

(14) Once more I emphasize that the entire structures shown are not all to be built immediately. After a more precise estimate of construction costs, possibly I would desire to readjust some features so as to surely keep within the appropriation of $350,000 for buildings, plus $50,000 per year for operation and apparatus.

(15) The present outline design has been assembled to fit the local conditions, with the elements of flumes, tanks, pumps, and measuring basin laid out with the purpose of first of all making these elements of the maximum size desirable for the greatest possible utility of the laboratory.

My assistant engineer, Mr. Chick, has carefully estimated the quantities of excavation, concrete, steel, brick, roofing, windows, etc., and has discussed cost of the various elements with the chief estimators of C. T. Main (Inc.) and the Turner Construction Co., concerns particularly experienced in the design and construction of industrial buildings, and has thus reached the figures shown in the attached table. There has been insufficient time to precisely work out all details, or to get firm prices on pumps and electrical apparatus.

The experienced Swiss engineer, Doctor Meyer-Peter, spent more than six months, with a corps of experienced structural designers, on the details of design of the hydraulic laboratory very recently completed at Zurich.

An architect in the ordinary sense is the last man needed in planning a laboratory of this kind. The external shell is the smallest and least difficult part of the work, and its planning naturally comes after the layout of the big apparatus has been all worked out.

(16) If I had another month, subsequent to getting firm contract prices on the present building plans and apparatus, I would probably slightly modify certain features, and change some dimensions of the building, but from many years familiarity and several previous designs I believe these are about right.

SCALE OF MAGNITUDE AND PRECISION

(17) The design contemplates the discharge of water in quantities as large as 500 or 600 cubic feet per second on rare occasions, and the layout is designed so that quantities even up to this large size can be measured with certainty such that the margin of error will not be greater than one-tenth of 1 per cent, which is fivefold to fiftyfold better than heretofore commonly attained.

(18) These very large quantities will very rarely be used under more than 20 feet head on the pumps. The heads of 40 feet are for rare and brief experiments on full size syphon spillways, hydraulic jump, energy destroyers, pontoon models, etc. Possibly in order to get uniform distribution of velocity throughout the cross section, the discharge for pontoon models will have to be made from a bell-mouth gate, instead of over the ogee.

The quantities of water to be circulated by the pumps in the main flume ordinarily will be from 2 to 5 cubic feet per second, under only about 15 feet total head, including friction, thus requiring but a small amount of electrical power and a small pump.

MEASURING EFFECT OF IMPERFECTIONS UPON DISCHARGE

(19) It is proposed to create definite disturbances on weirs, orifices, channels, and dams, and accurately measure the effect. Practical conditions often prevent the perfection of form assumed in the application of ordinary formulas. For example, the edges of the orifice, or the crest of the weir, may be slightly round instead of precisely sharp. Also the walls of the orifice or weir may have the roughness of ordinary masonry, instead of the polished surface of the original apparatus, and of even greater importance is turbulence, vortex motion, or inclined approach in the channel feeding the measuring weir or orifice.

(20) There are almost no data by which the effect of these disturbances can be estimated, but certainly these apparently minor defects sometimes lead to important errors in estimates.

For illustration, I have been told that when the discharge of the 24-inch Venturi meter in the mechanical engineering laboratory of the Massachusetts Institute of Technology was tested by the Francis type weir into which its conduit leads, an error of about 8 per cent was found. This subsequently was traced to the disturbance immediately upstream from the Venturi, induced, first, by the turbulence from the pump, and, secondly, by a right-angle elbow.

The type of current meter most commonly used by the water resources branch of the United States Geological Survey and by the Reclamation Service is well known to be subject to error caused by turbulence, or twist, in the approaching current. Also it is known that certain other types of meter, the Haskell meter used by the United States Army engineers, and the Ott meter used in Germany, are less subject to these errors due to turbulence and twisting currents.

I am told that in Germany the American type of meter is ridiculed in some quarters because of this imperfection. It continues in use in American because of its remarkable ability to resist deterioration from rough usage in transportation, and the gritty water necessarily encountered in field service.

I believe that given opportunity for mechanical improvement of current meters by tests with running water, in which turbulence and twisting currents can be introduced to any desired extent, also in the irregular currents over cobblestone stream beds, these defects can be remedied.

GUIDES FOR COLLEGE LABORATORIES

(21) There is a strong forward movement among American engineering colleges toward establishing hydraulic laboratories for purposes of instruction and also for research, but obviously, as with the great majority of laboratories at the engineering colleges in Europe, the scale of operations of these new American college laboratories will be necessarily cramped by financial and architectural considerations.

(22) It has seemed to me of the highest importance that this national hydraulic laboratory should be laid out with a scope sufficient to settle many of these important questions about scale error, "Reynolds number," wall friction, etc., for a hundred years to come, and I believe this can be done under the present appropriation of $350,000, with $50,000 per year provided for management, operation, and new apparatus if the original layout is properly made.

(23) The plans now submitted are with the above facts in view. This national laboratory could derive the precise coefficients and formulas for the most exacting work, leaving to the college laboratories such tests as can readily be made on smaller scale.

BACKGROUND OF THESE TENTATIVE DESIGNS

(24) I may add that my own hydraulic laboratory experience began actively more than 50 years ago in two of what were at that time doubtless the best hydraulic laboratories in America, where I worked off and on for 10 years, and continuously for many months, on very precise researches on developing apparatus for measuring the water drawn from canals of the power company by the factories at Lawrence, Mass., at Manchester, N. H., etc., and in supplementary researches on the accuracy of piezometers, and upon the flow of water in pipes, penstocks, sluiceways, flumes, and open channels. I have myself conducted researches on discharge over models of dams at Cornell University, and had charge for nearly 10 years of measuring the water drawn for power by all of the factories at Lawrence,

and for a time at Manchester, N. H., and have supervised the making of designs for several large water-power developments and municipal water supplies, having to provide for enormous flood discharges, etc.

I also made a long series of experiments on gage errors due to capillarity.

I have personally made the most extensive series of researches ever made on height of jets, discharge of nozzles, and hydraulics of fire protection.

Some years ago I carried out the most extensive and precise series of researches on the flow of water in pipes that has yet been attempted anywhere in the world, but which unfortunately remain unpublished because pressure of other matters has prevented the desired critical review of the results.

My uncommon experience in laboratories and in practical work have made me painfully aware of many of the difficulties involved in great precision of hydraulic measurement, because of air traps, capillarity, turbulence, pulsating heads, etc., and I have tried to take advantage of this experience in the layout now presented.

Above all I have sought to avoid cramping the scale of future research, by building foundations with proper regard for scale effect.

ESTIMATES OF FLOOD FLOW OVER RIVER DAMS

(25) In dozens of problems of water-power development, municipal water supply, irrigation, flood relief, etc., the best information available about flood flows that can be stored in great reservoirs, when traced back, rests on some sort of an estimate of discharge over a dam corresponding in depth, and the determinations commonly are of doubtful accuracy. New experiments over dam crests of great variety of form are greatly needed.

The tests made 25 years ago at Cornell University on a few typical forms of dams, are of doubtful precision.

LARGE MEASURING BASIN

Particular attention is called to the large measuring basin, the elevation of water within which can be measured with certainty to within 0.0001 part of a foot by Hook gage, or to within less than 0.05 of a foot by a 1-inch glass-tube gage.

It is designed to base quantities discharged upon this previse cubical measurement in connection with a chronograph recording to hundredths of a second of time, and by these means to calibrate or test other water measuring devices, such as the standard weir, the V-notch weir, the Venturi meter and standard orifices, which will thereafter be used with greater facility in the ordinary course of experimenting and testing in this laboratory.

CONSTANCY OF HEAD

Unusual precautions are taken for great constancy of head in the forebay, or supply tank, by means of a skimmer weir presenting about 2,000 feet in length of overfall crest, by which any momentary increase of delivery and head by the pumps will be "skimmed off" and returned to the suction chamber. It is estimated that a sudden increase of 100 cubic feet per second in pump delivery could not increase the operating head by more than 1 inch.

The designer's many personal experiences in various hydraulic researches have taught him the difficulty and the necessity of extreme precaution in matters of providing constant head, if one would measure depths over weirs and upon orifices and pipes with the utmost precision.

TURBULENCE AVOIDED

Precautions against eddies and turbulence in the approach to apparatus under experiment has been the most common source of error in precise hydraulic research. Therefore, I have taken great precautions to provide means by which one can screen out all such irregularities, by adjustable screens, beyond which uniformity of distribution of the current throughout the cross section will be insured, and by a forebay and connecting channels of ultragenerous size.

LARGE DISCHARGE CAPACITY

The water-discharge capacity of 500 second-feet is more than double that understood to be available at the latest and largest laboratory in Europe (the Walchensee), and is nearly four times that available at the newest large indoor laboratory at Zurich, the designer of which assured me of his opinion that most of the then existing laboratories were cramped in the quality of certain important researches by lack of adequate scale of operations.

I believe from experience that this large capacity is not an extravagance. So much will rarely be called for, and then only for brief periods.

To circulate 500 cubic feet per second of water with 20-foot total lift, including friction losses, will call for 1,500 horsepower on pumps, at 75 per cent efficiency, but this large power demand will be only for a very few hours.

In the laboratory for which I made tentative outline designs for the Massachusetts Institute of Technology 17 years ago, I also provided for 500 to 600 cubic feet of water discharge per second, mainly for the purpose of establishing coefficients of weir discharge at great depths, with high accuracy for important conditions often met in practice.

This 500 cubic feet per second on a sharp-crest weir, without end contractions, 15 feet in length, will develop an overfall of about 4.5 feet in depth; or, if the channel is narrowed to a 10-foot length of weir, will present a depth of about 6 feet. Should the pumps prove capable of 600 cubic feet per second, a depth of about 6.8 feet can be maintained over a weir 10 feet long.

The Francis standard weir of 75 years ago had a maximum crest length of 10 feet, and a maximum discharge depth of about 1.6 feet. The many experiments of later years by Fteley, Stearns, Bazin, or those at Karlsruhe, Cornell, etc., have mostly been with smaller dimensions and smaller depths. The caution by Mr. Francis that his formula was not expected to be accurate for depths greater than 2 feet, or less than 0.5 foot often has been forgotten.

The slightly more complicated Bazin formula is now preferred by many careful engineers for use outside these narrow limits.

The best brief discussion of limitations of weir formulas that I have seen is that by Hazen and Williams in their admirable Hydraulic Tables, pages 63 to 75. An earlier, excellent discussion of the uncertainties in weir discharge is presented in Hamilton Smith's Hydraulics, page 89 et seq.

Both of these critical reviews fail to deal with the most common source of error, which is turbulence or twisting motion in the approaching channel, and scant depth.

The recent European experiments by Rehbock and others, and the recent Cornell experiments, fail to agree within about 1 per cent.

LARGE APPARATUS FOR DETERMINING SCALE EFFECT

One most important purpose of the great range of size of models and quantity of discharge permitted in the proposed design, is for thoroughly testing the question of scale effect, about which there has been much doubt in the minds of practical men.

It is important to settle this question for all time, also to discover rules of percentage allowance necessary in transferring from one scale to another, and rules controlling the accurate use of distorted scales.

ORDINARY ROUTINE WORK WILL BE IN SMALL FLUMES

Glass flumes similar to those in Professor Rehbock's laboratory at Karlsruhe are provided for researches upon models which will permit the scale of experiment common in the European laboratories. These smaller flumes will service for three-quarters of the routine experiments.

Ample floor space is provided for temporary tests on models, or on structures of many kinds similar to those made at Charlottenburg on temporary models.

In any of these experiments it is obvious that quantities of water can be used as small as desired.

TESTS WITH SMALL DISCHARGE

It is expected that research in the large flume, with full capacity of apparatus, will, in most cases, be preceded by experiments on a small scale in either the Rehbock flume or in small special apparatus temporarily erected on the floor and supplied from any one of the numerous outlets on pipes connected with the main fore bay, which will give pressure under extremely uniform head.

The first work of the laboratory will doubtless be with the small flumes—the Rehbock flume and small, special apparatus—on problems for the Boulder Dam, Reclamation Service, Geological Survey, and the Department of Agriculture, in which no great discharge of water will be needed, and no extreme precision.

Nevertheless, this laboratory, being of national scope, should be laid out in its flumes, foundations, large supply tanks, and measuring basin on a scale for determining fundamental hydraulic coefficients competent for service in designing the largest engineering works and the most exacting researches.

In order to provide the United States Army engineers, whose cooperation in this laboratory is expected, with facilities for laboratory researches upon sand-bar formation in harbors, or at their entrances, space is provided for the duplication of the harbor-model tank at Wilhelmshavén, Germany, which was Germany's great naval base, and presented particularly difficult problems of shoaling by drifting sand. So far as I could learn this particular laboratory (the second near the same site) is the best special tool for this kind of problem ever yet built. It was designed after long study of other laboratories, and seems to have served its purpose well. (See Hydraulic Laboratory Practice, p. 374.)

MEASURING ERRORS DUE PRACTICAL DEFECTS

One of the most important features of the present laboratory design is the provision for testing the percentages of error caused in the discharge of weirs and orifices, by various disturbances of measured dimensions, such as turbulence, inclined or twisting currents, roughness of crest or wall of orifice, etc. Often these defects of form are unavoidable in practice.

Shear boards for producing definitely inclined or twisting currents in the approach to various types of weir (sharp crest, notch weir, and round crest) can be introduced as desired, and the effect noted in percentage of error due to incomplete contraction of jet, etc.

The proposed new form of standard round-crest weir is expected to show much less error due to such causes.

The effect of various definite degrees of roughness in the side walls of orifices or in the crests of dams will be measured as produced by covering these surfaces with expanded metal lath, etc., thus simulating the rough surface of masonry.

The Fteley and Stearns experiments on effect of slightly rounding the weir crest and on various breadths of weir sill, and the Bazin experiments on various depths in front of weir and various velocities of approach, and on correction for various velocities of approach will be greatly extended.

NEW FORM OF ROUND-CREST STANDARD WEIR

Since my personal tests 30 years ago at the hydraulic laboratory of Cornell University for determining the rate of flow at various depths over a full-scale model of the Croton Dam and since my researches of 40 years ago upon "the nozzle as an accurate water meter" I have been convinced that a form of weir crest giving greater precision of measurement under ordinary practical conditions than the common sharp-crested weir now in use and less liable to error due to turbulence or shallow channel of approach can be made.

The layout presented for this laboratory is adapted to determine this particular matter, once and for all, up to the large depths of 6 feet on crest and with precise measurements of the effect upon accuracy of disturbing conditions.

FURTHER DESCRIPTION OF DETAIL

The attached plans show a laboratory layout comprising:

(*1*) *Large flume.*—This is a very large flume about 16 feet deep by 15 feet wide, within which experiments can be made with a discharge of large volumes (500 cubic foot-seconds) of water over weirs of various types and dam models of various shapes.

Current meters can be rated at various velocities in currents purposely disturbed to definite amounts.

Venturi meters up to 3 feet or more in diameter can be set up downstream from a bulkhead built within the flume at any convenient point, and tests made on disturbed currents from elbow and other causes. Also, experiments can be made upon the limiting conditions of maximum efficiency as determined by the upstream and downstream Venturi taper. Experiments on effects of bell-mouth and curving tapers, both upstream and downstream, can also be made to advantage, for use in confined situations.

(*2*) *Fore bay.*—At the upstream end of this large flume stands a steel tank fore bay, about 40 feet in diameter and 40 feet high. This has been designed with an adjustable skimmer-weir for maintaining, with the utmost precision, a constant head on apparatus fed from this fore bay, while also avoiding turbulence in head and velocity due to possible variations in rate of delivery of the pumps. An adjustable horizontal perforated screen stops eddies from the discharge of the pumps.

The forebay is made of this large diameter in order to permit a new series of fundamental determinations of the coefficient of discharge from large orifices of various kinds opening from the flat, smooth, vertical surface of its wooden bulkhead, comprising the three gates which close the three main openings.

(3) *Deep erosion and revetment research.*—The large flume will present an excellent opportunity for certain types of experiments on river-bed erosion, both in straight and crooked channels, and to uncommon depths. It is believed that by this means much valuable information can be obtained relative to rip-rap revetment deposited in a mass along the bank in readiness to roll down and give protection as undermining and undercutting of the bank occurs, as has been practiced from time immemorial in river bank protection in China and Italy.

The large flume also will afford better opportunities than ever believable for researches on the transportation of large-size gravel and boulders, along river beds, at high velocities.

An observation platform carried by rails on the top edge of side walls of the large flume permits convenient observation at low-water levels.

(4) *Small return flume.*—The return current from the large flume is brought back to the pumps by a small flume at the lower level, which also can be used to great advantage for a large number of experiments with current meters, etc. In many cases two simultaneous sets of observations can be maintained, one at relatively low velocity in the large flume, and another at three or four times the velocity in the small flume.

The small flume is to be fitted for the moving diaphragm method of measuring, common in the European laboratories, and excellently described in the bulletin of the Engineering Experiment Station at the University of Wisconsin, Paper No. 672, June 10, 1914, by Mr. C. R. Weidner. It will be of interest to compare precision of measurement and facility of measurement by moving diaphragm, with other standard methods.

(5) *Pitot tube researches.*—Within both the large and small flume the Pitot tube as a water-measuring instrument can be developed and tested. This was highly developed by Darcy about 70 years ago, and was further greatly improved by the late Hiram F. Mills, of Lawrence, Mass., 50 years ago, who developed various forms for regular use in measuring the large quantities of water drawn from the canal by the various factories. These forms developed by Mr. Mills have never been publicly described, and some, doubtless, are capable of great practical utility.

(6) *Ogee dam model.*—Attached to the forebay is an ordinary section of ogee dam, 15 feet in length of crest, over which the water can be discharged and flow down the ogee, presenting at the bottom a velocity of about 50 feet per second and presenting excellent opportunities for large-scale experiments on the hydraulic jump as an energy absorber, and on various other forms of energy absorbers. This will permit a testing out of the scale effect for various types by means of similar tests on small models.

It is highly possible that this swift current would continue with a shallow depth for nearly the whole length of this flume, unless interrupted by some low form of sill for starting the jump. This sill can be placed at any desired point.

This current of swift velocity will also serve the useful purpose of testing models of speed boats and models of pontoons for naval airplanes. For this purpose, the discharge can be made through a bell-mouth orifice of the full width of the bottom of the flume, and at any velocity desired, up to about 50 feet per second.

(7) *Bottom orifice discharge.*—By temporarily narrowing the bottom of the flume to a width of 10 feet or less, greater depth can be obtained. This discharge through a smooth bell-mouth orifice will present a very advantageous condition of uniform distribution of velocity throughout the cross-section useful in many researches on boundary-layer effect.

It is believed that much useful data can be obtained by experiments similar to those made with air currents in wind tunnels.

(8) *Venturi meters for continuous use.*—Beneath this small return flume a space is provided in which two Venturi meters of widely different size can be installed in future, whenever desired, and maintained as a convenient ordinary means of automatically recording the rate of discharge, while experiments on river models, etc., are going on in either the large or in the small flume.

(9) *Measuring basin.*—This measuring basin comprises a large concrete tank permitting precise cubical measurement of volume for the precision of approximately 0.01 per cent, although commonly there would be no need of precision more than 0.1 per cent, which is the general limit aimed at in the design. An outside gage pit permits the quick use of a glass-tube gage of 1 inch internal diameter, quickly read by a vernier for avoiding capillarity, and also permits arrangement for Hook gage.

By means of a pivot gate of small inertia, capable of instantaneous movement and chronographic record, the water can be diverted into and out from this measuring basin in a fraction of a second, and the time of filling precisely recorded by the chronograph, to within less than 0.02 second.

This large and precise means of measurement will permit more accurate rating of discharge over new standard forms of weir, either horizontal, sharp-crest, round-crest, or V-notch types, with far greater depth than have ever yet been made, and can reconcile the differences now found between the researches with small apparatus made by many experimenters.

The large scale of the measuring basin, flume, and forebay, are all adapted to the precise measurement of quantities up to 500 cubic feet per second.

(10) *Auxiliary make-up tanks.*—One of the chief difficulties encountered in the design, for accurately controlling and measuring such large quantities, when delivered from a pumped supply, is found at the time of deflection of current into the measuring basin, because immediately thereafter the lessened delivery into the return channel supplying the pump increased the pump suction head which would quickly cause some variation in the rate of flow. This obstacle can, I believe, be successfully overcome by a supplementary supply tank 50 feet in diameter by 40 feet in height, located near the measuring basin, which is to be provided with a trip gate interlocking with the pivoted diversion gate, so as to be opened wide in the return flume to the pump supply tank at the instant following the diversion into the measuring basin. I have not had time to work up the final details of this device, and the tank as shown is subject to modification.

The rate of discharge from this make-up tank will be made substantially constant by means of a cylinder gate, previously adjusted so as to give a discharge substantially equal to that in the experiment, and raised automatically by the action of a large float during the descent of the level in the make-up tank, so as to give substantially a constant discharge. The distance away from the return channel of the disturbance caused by this switching of one current away from, and of another into it, is so far away from the pumps that it is believed that no important disturbance of constant head upon the weir, or orifice, under experiment, need be caused by the switching.

In order to fill the big forebay, or supply tank, in some few experiments, with this filled near its top, another outside auxiliary tank or cistern will be needed, of somewhere near the capacity of a cylindrical tank 40 feet in diameter by 40 feet deep. A circular cistern 80 feet in diameter by 10 feet deep near the west end of the main building would serve this purpose.

(11) *Water supply.*—The total quantity of water for filling the auxiliary tanks, the pump suction chamber, the large hydraulic flume, the forebay, and the make-up tank, and all accessories, for those few experiments demanding the largest quantities, will be about 200,000 cubic feet, or 1,500,000 gallons, which can be slowly drawn from the present city water mains through pipes not necessarily more than 6 inches in diameter, which at a draft of only 500 gallons per minute, or 30,000 gallons per hour, would fill the tanks in about 50 hours, and would cost, at an ordinary charge of 10 cents per 1,000 gallons, only about $150. This water would be used over and over again,

so that the tanks would not need to be refilled more than once or twice a year, and possibly less often.

(12) *Pumps.*—It is expected that the large quantities of water will be supplied by the use of propeller pumps, in order to save cost of apparatus.

In observing the marvelous efficiency of the speed-boat propellers developed during the last few years, the writer believes that pumps can be developed for this type, useful in many situations and to a greater extent than heretofore. It is proposed that one of these large pumps shall be of the Kaplan type, a sort of reverse Kaplan turbine with its high-speed propeller blades, adapted to have their angle of advance changed while in operation as in the turbines.

Ample space is also provided for many varieties of centrifugal pump.

It is proposed that some of these experimental pumps be driven by extremely high-speed internal combustion engines as used in airplanes. The demand for experiments with extremely large quantities of water will be infrequent and brief, and it is desirable to save the cost of an unnecessary plant for pumping these large capacities.

The fore bay and pump room also permit a great variety of experiments relative to the efficiencies of pumps or turbines which can be attached to bell-mouthed openings, ordinarily closed by flanges. Apparatus for studying cavitation similar to some of that recently found in European laboratories can be attached to one of these.

(13) *Harbor flume.*—Arrangements have been made for duplicating the apparatus developed at Wilhelmshaven, Germany, through many years of experiment, for the special study of harbor problems. From inspecting this special harbor laboratory, I believe that it has a wide adaptability, and that it might be extremely useful to the United States Army engineers in studying various problems of sand-bar erosion, of channel straightening, of effects of groynes, retards, etc., and many other devices pertinent to harbor improvement.

From all that I have been able to learn, this special German laboratory was found of great utility in saving cost of dredging continuously at the entrance to the great German pre-war naval base, (harbor of Wilhelmshaven), and in improving the harbor entrance at Helgoland. I believe it well worth while of further study, and am proposing to again visit the Wilhelmshaven laboratory the coming summer, although, since the war, its activities have greatly declined.

(14) *Tilting flume.*—The original Engel's river flume, which I saw at his first laboratory about 17 years ago, was of the tilting variety, his later flumes are of the fixed variety, but I note that as large a tilting flume as space permits has been installed in the new Zurich laboratory.

I believe that an exceptionally long flume of this kind can be made of great utility for determining accurately the hydraulic laws governing the flow in open channels. Also, that a series of much needed experiments on partially filled conduits can be made therein; therefore, I have provided for it. I have designed it to be in sections of steel plate that can be stored in small quarters when not in use, or be bolted together, presenting a channel 220 feet in length, capable of being turned to any angle from zero up to a 3 per cent slope. Still greater length could be provided; also a somewhat greater angle of slope.

When not in use, and piled up in storage, the large vacant floor area adjacent to its site, would be open and free for other experiments.

Large size is of no important disadvantage, except first cost. The large pump would not be run, except rarely, for large-scale experiments. The large dimensions of the tilting flume and of the hydraulic flume are of no disadvantage, all permit temporary structures to be built inside to meet various special conditions. Access by the observers can very readily be had for studies of small depths flowing at the bottom of the flume from a platform suspended either from the traveling crane or from a light carriage traveling on the top edge of the flume.

This great depth in the hydraulic flume permits additional experiments on the laws controlling the hydraulic jump, which is a principle largely discussed during the past 10 years and not yet fully solved, which one may judge from a paper received June 19, 1930, from the Technical University at Charlottenburg, comprising extended experimental studies by Dr. Ingr. Kurt Safernez, of the construction firm of Julius Berger, and supervised by Professor Ludin, entitled "Untersuchungen Uber Den Wechselsprung." (Researches on the Hydraulic Jump.)

SAND AND SILT EXTRACTOR

While inspecting conditions on the silt-laden Colorado River at the irrigation canal intake near Yuma, Ariz., on several occasions, and also while studying conditions along certain silt-laden rivers in China, I have been impressed by the great importance of developing simple, effective, and cheap apparatus for extracting the major part of the burden of silt from the water by means of an apparatus involving very little mechanism and small loss of head.

I have also been greatly impressed while watching the marvelous performances of certain cyclone-dust extractors in extracting fine cotton-lint discharged with large volumes of air from napping machinery, by the application of the principles of centrifugal force, and have been led to believe that the useful device for this purpose could be designed for extracting the principal burden of sand and silt at intakes from rivers carrying a large silt burden, and have provided space in this national laboratory, wherein such apparatus of large dimensions and capacity can be conveniently set up for trial. (A pencil sketch of this has been prepared, but there has not been time to trace it.)

VENTURI FLUME AND PARSHALL FLUME

Nearly 40 years ago, I made many experiments on the discharge of hydraulic nozzles with a view to utilizing them for metering water, and was greatly impressed by their merit for certain conditions, and by the relatively small effect which turbulent approach had in modifying their discharge. On the other hand, I noted the errors caused by turbulence in the discharge of sharp-crested measuring weirs.

At that time I desired opportunity for the development of a measuring flume on the Venturi principle, but the opportunity did not present itself. Some years later my former chief, Hiram F. Mills, chief engineer of the water-power developments at both Lawrence and Lowell, Mass., made what, so far as I know, were the earliest experiments on a crude sort of a Venturi flume, and showed me the results.

His experiments had reference particularly to the design of certain new sluiceways at the head gates of one of the Lowell canals, with a view toward lessening the loss of head at entrance. These were intended as merely preliminary to further experiments on a more elaborate and precision scale which I discussed with Mr. Mills, but which were never carried out.

Eight years ago I suggested Venturi-flume development as one of the objects of the hydraulic laboratory. I have since been greatly interested to read of the admirable progress made by Mr. Parshall in developing a measuring flume for irrigation purposes on this principle, which for certain situations is better than any measuring instrument for this purpose heretofore devised.

The Parshall flume is designed first of all to be cheaper, and of such simple outline that it can be put together by any ordinary carpenter and used for measuring as accurate as is needed by the ordinary farmer. I believe that the principle could be applied with great advantage in a more refined form, which would give greater precision, and that this offers to be a useful adjunct in hydraulic engineering. I have, therefore, provided for experiment with Venturi flumes of various form and various sizes up to one of large dimensions conveying 500 cubic feet of water per second and for determining the discharge of each with great precision. Meanwhile, tests would be made by various forms of disturbances, twisting, and of turbulent currents, and of the effect of obstructions of gravel accumulated at the upstream side of the sill in case this were elevated above the general bottom.

The large hydraulic flume also permits of a wide range of experiments upon the erosion and transportation of river débris, such as sand, gravel, and cobblestones, and would permit a most useful extension of the partially completed researches by the late Carl G. Gilbert, made some 15 years ago at the Institute of California, with the assistance of Mr. Gerard Matthes, in small flumes with small quantities.

Professor Meyer-Peter, the eminent engineer and professor of hydraulics at the Technical University of Zurich, Switzerland, has told me of his earnest belief in the necessity of experiments on the hydraulic laws covering the transportation of gravel and small bowlders with much larger flumes and with much larger quantities and velocities of discharge than have heretofore been available in laboratories. I have sought to make ample provision for this in the hydraulic flume.

EROSION EXPERIMENTS

The most difficult and important question in economic control of the Mississippi River lies in the subject of erosion and deposition of sand and gravel after considering various plans of relief at various times, after observing erosion effects left at some of the great crevasses on the Mississippi, particularly at the site downstream from the Weecama crevasse of 1922. I have come to believe that fundamental experiments relative to rip rap are greatly needed, which experiments will fail of their untility unless carried out in a flume of about the size and depth here provided.

Along the Yellow River (Hoany Ho) in China and along the Po River in Italy as developed by centuries of practical experiments, I have observed precautions against the undermining of levees comprising, in brief, a deep mass of irregular fragments of stone and from one-half to 3 cubic feet in size deposited at the foot of a sloping bank with the expectation that when, if ever, a current should cut deeper and threaten the undermining of the bank at this point, this mass of stone would gradually roll down the steepened slope and deposit itself so as to prevent further erosion. I am led to believe that experiments on this made at the laboratory on a gradually increasing scale, would develop the principles under which the experiment within the river itself on full, natural scale, could be much more effectively carried out.

TILTING FLUME

A tilting flume of a large size and length is regarded in several of the leading European laboratories as a very desirable piece of research apparatus, but in nearly all cases they are much smaller and shorter than would be most advantageous. In Professor Engel's earliest laboratory, which I saw in connection with the Leipzig Exposition, about 17 years ago, a tilting flume was his principal apparatus for the study of river hydraulics, and his new laboratory at Dresden at first contained a large apparatus of this kind, which could be quickly adjusted to any convenient angle.

In his later remodeling of his laboratory at Dresden, the tilting flume has been omitted, and his models are built upon the bottom of a fixed flume, similar to the hydraulic flume now proposed, but very much smaller in width, depth, and hydraulic capacity.

I noted with great interest that in the new laboratory at Zurich Professor Meyer-Peter was planning as large a tilting flume as his floor space would permit.

It has seemed to me, during much consideration of problems of river regulation in China and in the United States, that a tilting flume could be made an extremely useful instrument for many kinds of research, and therefore I have reserved ample space for one of large dimensions, which would, however, not be installed until the special demand comes for research with its aid. Primarily, this will be extremely useful in studying the possibilities of making cut-offs in river bends in the Mississippi and other meandering streams. Also useful in studying the best form of groyne or dike for deflecting an erosive current away from a bank which it threatens to otherwise undermine.

The tilting flume can also be useful for estimating on a more firm and precise basis than is now given in the textbooks, or that has ever yet been possible, the fundamental laws of flow in open channels of various shapes of cross section and with various hydraulic radius.

FLOW IN PARTIALLY FILLED CONDUITS

Large conduits for drainage, sewage, and water supply of the cut and cover type carry their discharge without being completely filled. For some purposes, as for the conveyance of sewage and storm water highly charged with sedimentary material, it has been found to be advantageous to give these an ovate cross section diminishing toward the bottom so that in periods of low flow the velocity should not be abnormally diminished beyond that which would move the sediment.

The hydraulic laws covering such conditions are very poorly established; this tilting flume would permit establishing them once and for all, and very possibly would develop facts of much economic importance.

WATER CUSHIONS BELOW OGEE DAM

One of the subjects as yet very much unsettled and greatly discussed in current technical literature is that of the most effective and economic means for distributing surplus energy at the foot of the overfall of a high dam.

Much research with small models in European laboratories has been devoted to this subject, and there is some uncertainty in the application of these model experiments to practical conditions on a very much larger scale and with extremely variable depths of discharge. I have therefore provided an overfall similar to a dam crest at the top of the main supply tank, in which conditions governing flow and the discharge over a high dam can be simulated. The upper portion of the slope is made permanent, the lower part is made removable so that it can quickly be changed in form, either being taken out or put in by the overhead crane.

At the foot of this slope various forms of baffle piers can be used, such, for example, as those similar to the piers downstream from Gatun spillway, which I have from the first believed were not as advantageous a type as could be devised by laboratory experiments.

By means of continual cutting and trying I believe the most advantageous form of baffle pier could be developed once and for all.

Also, a large depth of the hydraulic flume at this point, the large quantity available, from 300 to 500 cubic feet per second, and the high fall of about 40 feet, permits a great variety of experiments on different so-called water cushions and energy absorbing basins, which would supplement the experiments on the hydraulic jump made by Professor Woodward for the Miami conservancy and other similar experiments.

THE SIPHON SPILLWAY

This is a device of very great economic importance in the development of water-storage reservoirs, which has never yet come into such great use as its importance justifies. I believe that I have supervised the design and construction of the largest battery of siphon spillways ever yet constructed. To get some of my data I had experiments made by Professor Smrcek in his laboratory at Brno, Czechoslovakia, which foreshadowed experimentally the results attained in a practical test of the completed structure. But I believe that I certainly could have prepared a still better design with laboratory facilities.

The spillways just mentioned had a height of 8 feet in the contracted area, six in number side by side, over the crest and a width of 10 feet, and each discharged approximately 2,000 cubic feet per second. Each was provided with an automatic flashboard device at the throat. I have since designed others which were not built, in which the established discharge of each unit was 4,000 cubic feet per second, and with 20 of these units side by side, the head of the contracted area over the crest being 10 feet. I have reason to believe this depth could readily be increased to 12 or 15 feet. Small-scale models are incapable of indicating this maximum, because of complications relative to the atmospheric pressure.

These large siphons, just mentioned, present great advantage in permitting the passage of driftwood, trees, even of logs 40 feet in length, and their use gives a safeguard not dependent on human control in case of sudden flood or the bursting of a dam or reservoir farther upstream. It permits waste of storage space now almost universally requisite for flood discharge over a thick, permanent dam crest, and permits the reservoir to be normally used for storage up to within 1 foot of the maximum flood height.

I have deemed this matter of such great importance for the conservation of this country's water resources that I have devised means for making practical tests with a siphon throat up to the maximum possibilities, 12 or 15 feet above the permanent crest, and over a section equal to the whole atmospheric pressure.

PROPELLER PUMPS

The laboratory has been laid out for extensive research on single pumps with motor blades ranging from multiblades to a single pair of blades like those in an airplane propeller. Pumps of the propeller type, of great capacity and a lift of about 10 feet, as I remember it, were introduced nearly 40 years ago by the E. P. Allis Co. for promoting circulation in a canal at Milwaukee, but the type has never yet received the professional attention which I believe it merits. The type can be further developed in the form of a reversal of the Kaplan turbine, with adjustable blades, and I have provided that the propeller pump for large quantities and low lifts in the laboratory should be of this type, permitting a wide range of research on the controlling principles.

There has been a remarkable development of the propeller type of turbine water wheel, particularly of the Kaplan type in Europe during the past five years with very great economic advantage in permitting the use of high-speed, electric generators directly attached to turbines acting under very low heads. There is good reason to believe that high-speed low-head pumps on the propeller principle have great economic merit, and I believe this laboratory could be of great service in developing the principles of design.

I have been much impressed with these possibilities while a passenger observing the performance in various light, high-speed skiffs, provided with outboard motors, and more recently in observing the propeller in a speed boat belonging to my son, capable of about 35 miles per hour, at from 2,500 to 3,000 revolutions per minute, driven by a gasoline motor of about 125 horsepower. This application of extremely high speed to boat propellers is a most remarkable development, and the reverse application merits immediately earnest attention.

It is possible that with various modification of the apparatus much could be learned useful in the aeronautic propeller from the hydraulic propeller, because the controlling principles of hydrodynamics and aerodynamics have much in common. One of my friends, eminent in aeronautics and a great mathematical genius, assures me that the design of aeroplane propellers could be helped by studies of small model propellers immersed in mercury.

CENTRIFUGAL PUMPS

Ample opportunity for testing single-stage centrifugal pumps up to heads of 40 feet has been provided for, and with discharges up to about 300 cubic feet per second.

About 40 years ago, I became greatly interested in the design of centrifugal pumps in connection with a factory organized for their manufacture at Lawrence, Mass.; subsequently, 35 years ago, I induced Mr. Carson, chief engineer of the Boston metropolitan sewer system, to modify his proposals for pump equipment, which had been drafted as solely enormous reciprocating pumps, so as to admit of the centrifugal design, and myself bid and tend red on four large pumps of this type. I was slightly underbid by the Allis-Chalmers Co., and so lost the opportunity for engag ng in pump manufacture. But the results demonstrated the principle of superiority of the centrifugal pump, which now, 35 years la er, has become well established.

Many years ago, while on engineering work in Mexico, I had opportunity to experiment with a small centrifugal pump made, as I recollect, by Sulger Bros., in Switzerland, which developed such great discharge capacity for its size and weight that it convinced me that here was a great field for research.

I believe that the national hydraulic laboratory could do a great service by developing the true principles of design for obtaining either maximum discharge or maximum economy with a minimum quantity of cast iron.

Therefore I have provided ample space around the main forebay where pumps of various types can easily be set up.

Obviously, these same outlets and inlets, which ordinarily would be covered by simple, dished-flange plates held on by bolts, could be utilized for the testing of turbines of various types and sizes under heads of up to 40 feet.

COMPARISON OF PRESENT PLANS WITH THOSE PRESENTED AT HEARING BEFORE SENATE COMMITTEE EIGHT YEARS AGO

(1) These earlier plans were described in the report of the hearings of September 8, 1922, calling attention to the drawings following page 40, reproduced on a small scale from those which I presented at the original hearings.

This original report contemplated: (1) A discharge of about 600 cubic feet of water per second; (2) about 1,167 brake-horsepower, on rare occasions for brief time; (3) a weir flume 15 feet wide by 15 to 20 feet deep by 245 feet long; (4) a tilting flume about 200 feet in length; (5) a concrete measuring basin of about 50,000 cubic feet capacity; (6) a supply basin of about 50,000 cubic feet capacity; (7) several large Venturi meters; (8) many items of large-scale fundamental research.

(2) The present layout is substantially for the same scope of operations as that of eight years ago, with provision for 500 second-feet of water instead of 600, and with building slightly larger in plan and

design especially to fit the site on the steep hillside at the southerly side of the bureau grounds near Tilden Street.

(3) In my plans now submitted, the design has been modified to fit the ground, and also modified to meet conditions developed during the eight years since the first hearing, and improvement found during my two tours of hydraulic laboratories in Europe, and in course of my compilation of the book entitled "Hydraulic Laboratory Practice."

But in my later plans I have taken scrupulous care to provide for research on the same scale set forth in my report to Congress of eight years ago and in subsequent reports.

In the report of eight years ago the appropriation asked for was $200,000.

(4) The appropriation in the bill recently passed being nearly double, permits more stories and more floor space than recommended eight years ago; but in my recent designs scrupulous care has been taken to keep within the limits of this appropriation of $350,000 intended to cover building and the fundamental apparatus, comprising flumes, supply tanks, and pumps sufficient to immediately begin work on a most comprehensive scale, in meeting the objects set forth in the bill recently passed and the hearings precedent thereto, for both fundamental research and the practical tests desired immediately by other departments of the Government. I have not included the cost of tilting tank distinctly marked as "future," nor the "future" Venturi meters. Otherwise substantially all problems suggested at original and later hearings can be studied by means of the apparatus now provided.

(5) To make certain of thus fulfilling the promised researches by an expenditure within the appropriation, I have had detailed estimates of cost prepared by estimating the quantities in foundations in great detail, including the principal flumes, measuring basins, supply tanks, pumps, etc., so that a far closer estimate of cost can be had than by the very rough method based on an assumed number of cents per cubic foot of total cubical space contained in the buildings, which cubic method is extremely unreliable for a special structure of this class, in which the building foundations, etc., are integral with the chief apparatus, or flume and measuring basin, etc.

(6) These estimates did not include the construction of the harbor laboratory in the east wing for special research for the United States Army Engineers, which I proposed to study further in Germany during the coming summer after conference with the Chief of Army Engineers, and after further studies to be made by Lieutenant Kramer of his corps, arrangements for whose studies of laboratories in Europe have already been made.

(7) The estimate did, however, include foundations of an exceptionally heavy character, sufficient to support one or two additional stories at some future time, giving additional convenient floor space for the use of any of the varied purposes of the bureau, at the extremely small additional cost of about $1.50 per square foot of floor space, by reason of the roof in the present plans being designed as a future floor suitable for carrying a working load of 125 pounds per square foot; this floor roof to be temporarily covered by a watertight and weatherproof roofing material of standard Barrett specifi-

cations, upon temporary boards, cost of which is included in this estimate.

(8) Because of the peculiarities of this hillside location, the one of two future stories provided for in strength of foundations, walls, and columns might properly be considered as not wholly a charge on the laboratory appropriation, since these one of two additional stories are peculiarly advantageous in their location close to the administration and other buildings, and being at very nearly the upper courtyard level, the hydraulic laboratory proper being mainly below the top of the hill. No other location on the bureau grounds will give floor space for general at so low a cost.

(9) The drawings now submitted have been worked out in such detail that work might immediately be begun under an ordinary form of cost-plus contract, frequently used by industrial corporations, or they can quickly have further details added, within from two to four weeks' time by one or two skilled designers, at an additional expenditure of, say, $1,000 for wages, including forms of contract and specifications suitable for the competitive bidding now required on Government buildings.

(10) From much experience I have entire confidence that with a moderate amount of trimming and reshaping certain features (such, for example, as substituting a steel tank at a cost of only about half that for the underground reinforced-concrete reservoir at the west end, carried in the present estimate at $20,000), that the structure can be put into working shape so that within the limits of the appropriation several important lines of research could be started within eight months from the present time.

(11) It was not at any time expected during the recent hearings that all cost of all future apparatus would be covered within the $350,000 appropriation, because a large part of this apparatus will be made by the bureau's mechanics, especially to fit the research in hand, under the annual allowance of $50,000 per year.

(12) Most of the laboratories in Europe had been badly cramped in their scope of operations by insufficient laboratory space and by having to crowd apparatus into rooms that were too small and were ill adapted in shape. It is of the highest importance that first attention be given to having the fundamental apparatus of proper size and built integral with, or prior to, the outside walls.

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