The Role & Contributions of Hydraulic Testing Labs: Part II, World War I to World War II

Hydraulic testing laboratories have played key roles in advancing the science, practice and teaching of fluid mechanics. One on-going laboratory has made far-reaching contributions in the field.

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At the beginning of the twentieth century, the theory relating to hydropower was advancing. R.D. Johnson published his analytical treatment on surge tanks in 1908.[1] Many colleges started including courses on hydropower. At Worcester Polytechnic Institute (WPI), student assignments relating to power at the Alden Hydraulic Laboratory (AHL) at Chaffinville were extensive. For example, a list of experiments for mechanical engineering students for the period from 1904 to 1909 is shown in Table 1.

Charles M. Allen, Head of the Alden Hydraulic Laboratory since 1906, also became active in the "politics" of hydraulics in the early part of the twentieth century. On January 14, 1914, Clemens Herschel sent the Boston Society of Civil Engineers (BSCE) a letter recommending that a national testing flume be built in Washington, DC, and be operated by the US Bureau of Standards. In a March 9 letter to Herschel, Allen indicated that he had started the ball rolling in favor of the Government Testing Flume. Similarly, in the late 1910s, when there were 7 million horsepower of developed water power and an estimated 30 million to 60 million of undeveloped horsepower, Allen lobbied six influential members of Congress to increase the appropriations for the construction of river and stream gauging stations. The argument was made that information from these gauging stations was required to build new hydroelectric stations that would decrease the use of more expensive coal stations and, thereby, preserve dwindling coal reserves. (Along the same lines, it is interesting to note that Allen served as a

TABLE 1.
Experiments Undertaken by Mechanical Engineering Students

Boiler Inspection	Torsion
Efficiency of Screws	Valve Setting-Vacuum Pumps
Efficiency of Chain Hoists	Calorimeters
Platform Scales	Friction of Flow
Pump Sketching	Belt Testing
Safety Valve & Gage Testing	Pump Testing
Clack Valve	Steam Engine Testing
Tension Tests of Steel Tests of Cast Iron	Boiler Tests
Engine Clearance	Gas Engine Tests
Indicator Testing	Compound Steam Engine Tests
Steam Traps	Walpole Pumping Test
Boiler & Engine Room Piping	Cross Bending of Wood
Inspection of Hydraulics Laboratory	Current Meter & Pitometer Tests
Pitometer Tests at Chaffinville	Pipeline Friction, Venturi & Weir Tests
Friction in Pipe Line	Bending Tests of Steel Beams
Current Meter	Compression of Steel Columns
Pitometer Tests	Water Wheel Tests
Governor	Structural Steel Tests
Pelton Wheel	Compression of Wood, Long & Short Columns
Belt Losses	Valve Setting-Corliss Engine
Power Tests	Steam Engine Testing
Friction of Oils	Overshot Wheel
Shearing Bolts & Rivets	

field engineer for the Fuel Administration during World War I, made a number of inspections of manufacturers, and recommended coal conservation measures that were of great value to the Commonwealth of Massachusetts.)

During World War I (1914-1918), the great increase in the cost of coal and the uncertainty of its delivery due to strikes had a marked effect on the desirability of water power development.2 Congress took comprehensive action and passed the Federal Water Power Act of 1920 (also amended in 1921). This act fundamentally altered hydropower development by placing the licensing of plants on navigable streams under the control of the Federal Power Commission. The function of the commission was "to provide for the improvement of navigation, the development of water power, and the use of the lands of the United States in relation thereto."

Also, the National Defense Act of 1916 authorized the federal government to construct dams for nitrate munitions plants. These plants were designed so that they could be easily transformed to produce fertilizer once the war was over. The Wilson Dam at Muscle Shoals on the Tennessee River was to provide power for one such plant. However, the dam was not completed until after World War I. (A great debate would last for 15 years until President Franklin Delano Roosevelt resolved the issue of what to do with publicly built plants that would be in competition with privately owned utility companies. Senator George Norris of Nebraska fought a "give-away" sale of this asset to Henry Ford or others. Because the facility was supposed to produce fertilizer, all proposals for the "sale" came before Norris' Committee on Agriculture and Forestry. In the meantime, no power was generated, and the Tennessee Valley languished in poverty generally without electrification until the mid-1930s.)

During this time, the notion of area-wide electrical grids, or "superpower zones," came into vogue. H.K. Barrows believed that comprehensive water development would alleviate electrical power shortages and interruptions.[2] A long-term overview of the growth in installed capacity for hydropower is shown in

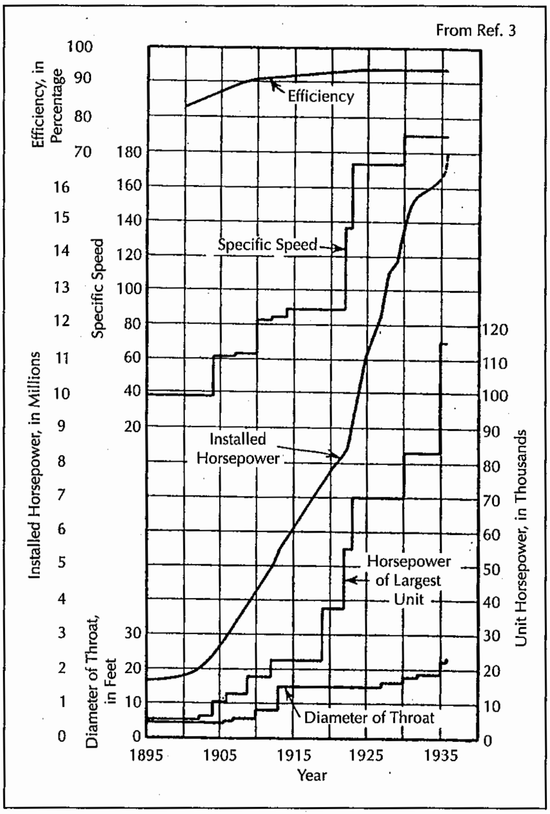


FIGURE 1. Installed capacity and progress of the hydraulic turbine in the United States from 1895 to 1936.

Figure 1. Before World War I, power was generated primarily for lighting and manufacturing plants. Most manufacturers owned and operated their own power plants. However, by 1936, industry was purchasing over half of its power. While in 1914 the price of energy for domestic use averaged 8.2 cents per kilowatt hour, by 1936 the price had declined to about 4.5 cents per kilowatt hour, a decline of 45 percent over a period when inflation was approximately 40 percent. The economy of scale and the lowering of prices were accelerating the use of power, except during the worst depression years. There were few regional companies prior to World War I, and a 5 megawatt unit was considered large, and a 50 megawatt plant was confined to major load centers. With little grid interconnection, reliability required installed capacity 50 to 100 percent over peak winter load.

Early Measurement of Large Flows

In addition to the required technical information regarding river flows, the hydropower industry needed better flow measuring capabilities by the mid-1910s. From the time of the founding of the Hydraulic Laboratory at WPI, the population of the United States was growing at an average of 14 million people per year, and the use of water power was growing at an average rate of 288,000 horsepower per year. The maximum size of water turbines, however, was increasing exponentially at a rate of 1.7 times every five years. The largest turbine output 5,000 horsepower in 1895, 20,000 horsepower in the 1910s, 38,000 horsepower in 1920 and 70,000 horsepower in 1925. No longer was it possible to test such large turbines in the Holyoke, or other, test flumes to establish the flow rate to the gate setting relationship. Since flows had become too large to use weirs in many places, flows were determined by using current meters, pitot tubes, Venturi meters, the color velocity method and the moving screen method. The color velocity and moving screen methods are no longer used. The color velocity method basically consisted of visually observing the elapsed time between injecting a dye and observing it at a downstream point. By knowing the distance and the pipe area, the flow could be calculated. All of these methods of large flow measurement had disadvantages either due to their high cost or because they resulted in inaccuracies greater than most engineers would tolerate, especially in turbine acceptance tests.

The first breakthrough in measuring large flows was described in a lengthy 1916 paper by B.F. Groat presented to the American Society of Civil Engineers (ASCE) and entitled "Chemi-Hydrometry and Its Application to the Precise Testing of Hydro-Electric Generators."[4] This technique became known as the salt dilution method of flow measurement, and is generally the same as the tracer (often dye) dilution method that is used today. In this method, a known concentration of salt solution is injected into the flow stream. After complete mixing in the flow, a sample is extracted. By knowing the initial and final salt concentrations, the flow rate can be determined. Allen used this technique for acceptance tests conducted on a

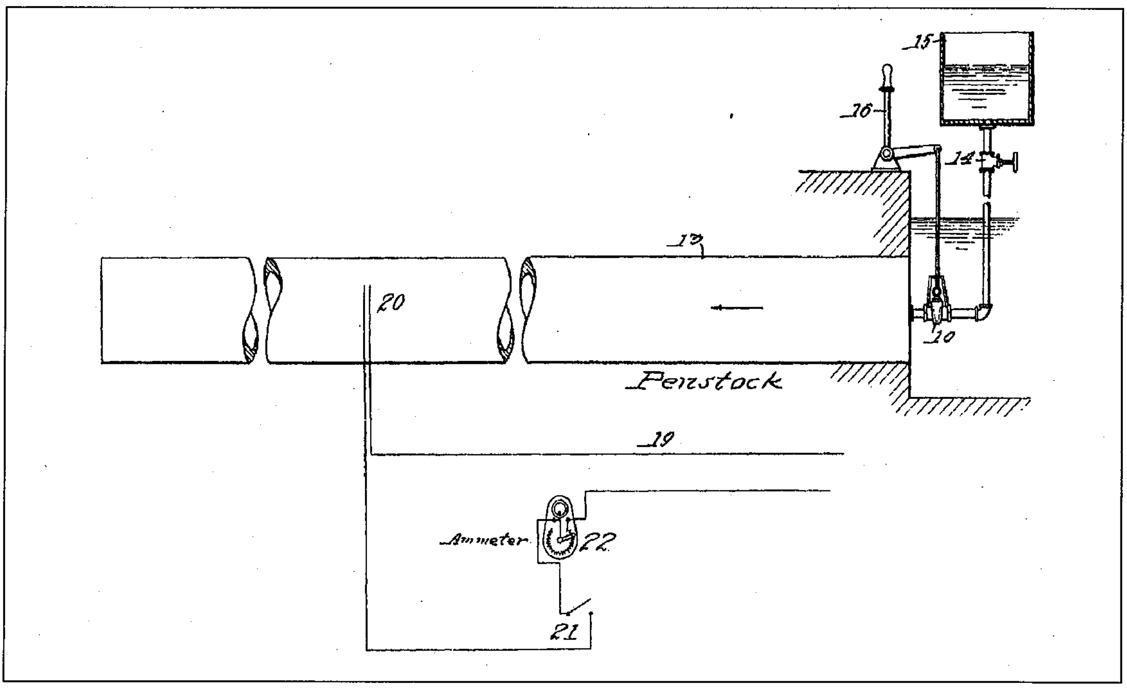


FIGURE 2. Allen's early salt velocity patent drawing (1926).

3,540-horsepower turbine for a power company in Hiram, Maine, on September 25 to 28, 1917. Allen had first proposed doing pitot tube traverses in the 11-foot diameter penstock to obtain the flow rate. However, because the power company would only pay for the turbines based on the results from the tests, the manufacturer only consented to the salt dilution method.

Allen secured the services of Professor Fredric Bennet, Jr., of the WPI Chemistry Department to perform the necessary chemical work for the tests. One ton of salt per test was used in a 15- to 20-minute run. Many salt-water samples were collected during each run. The salt concentration was obtained by evaporating a water sample using a hot plate, and then weighing the remaining dry salt. At the end of the test, the manufacturer was paid the agreed price for the turbine, based on achieving the 89 percent efficiency as specified by the power company.

It is pertinent to note that Groat's extensive paper dealt in detail on errors and methods that are taken for granted today.[4] Allen probably had numerous ideas based on his experience with Groat's salt dilution method. Multiple distribution points, multiple sampling points, mixing and other factors were all considered.

Salt Velocity Method

In 1916, the same year that Groat gave his paper on salt dilution, Allen began experimenting with a similar technique, which was later called the salt velocity method. This technique was based on the fact that salt increases the conductivity of water. If you could accurately measure the time it takes a salt cloud to go from the injection point to a measuring station, and you could measure the volume between these two points, you could determine the volumetric flow rate in the penstock. The time at which the salt cloud reached the measuring station could be determined by continuously measuring the conductivity of the water.

It was not until five years later that the first salt velocity tests were conducted at the laboratory. During the initial testing, the injection station was located at the intake of the penstock into the laboratory. A turbine was set at different gate openings. The electrode that would measure the conductivity of the water was connected to an ammeter and consisted of two copper strips 2 inches wide separated by wooden

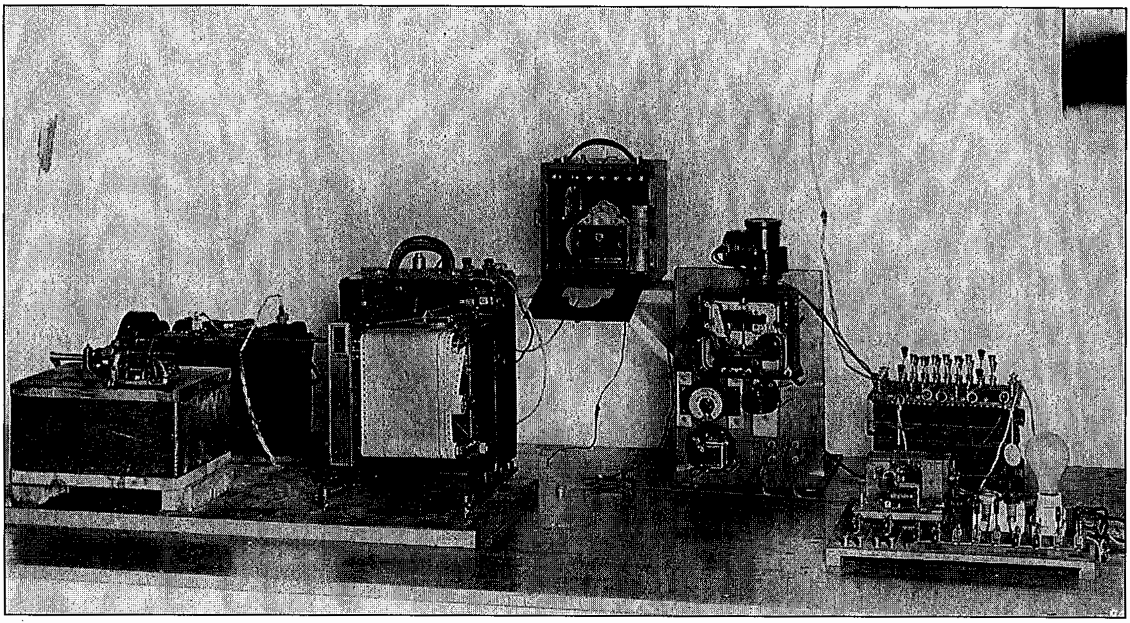


FIGURE 3. The recording apparatus used for Allen's salt velocity method.

blocks. The flow rates were measured with a 12-foot weir located in the basement of the laboratory.

The first test consisted of throwing a bag of salt in the intake, starting a stop watch, running down to the electrode and stopping the watch at the indication of the first appearance of the salt. This crude injection technique was refined twice. First, a hinged box containing a quantity of salt was lowered to the mouth of the intake and the salt was released by using a string attached to the hinged cover. The second refinement, which ultimately was implemented for all salt velocity tests, consisted of a quick-acting valve located at the intake centerline and connected by a 2-inch pipe to a mixing tank elevated above the surface of the pond. Allen's 1926 patent drawing reflects these improvements (see Figure 2).

Soon after the first few tests, a telephone line was installed between the pond and the laboratory that replaced the operator who had to sprint from the intake. Timing was also changed to include both the time of the initial and final indication of the salt passing by the electrode. Figure 3 shows the apparatus used for recording the test data.

About 400 charges of salt were used in 30 runs at different gate settings of the turbine during these initial tests. The results of each individual test were within 1 percent of the weir measurements. In addition to the weir, the color velocity was used to check the flow rate. In this method, a red aniline dye was injected at the penstock inlet, and the dye was observed in an open-ended 2-inch glass pipe containing a white background. By taking the mean time between the initial and final appearance of the color, these results correlated very closely with the results obtained by the salt velocity method.

The first field tests using the salt velocity method were performed in 1920 by Professor S.M. Woodward of the State University of Iowa for measuring dredge pipe velocity in flood prevention work near Dayton, Ohio. Allen's first test was for a hydropower plant in Berlin, New Hampshire, on September 10 to 15, 1921. The tests were conducted on two units located on 13-foot diameter wood stave pipes 1,400 feet long. In addition to the salt velocity tests, current meters and the color velocity method were also employed during some of the tests. After the tests, which Allen termed successful, he returned to the laboratory and continued to work on improvements to the technique. (Even after hundreds of tests had been conducted by Allen and his successors [Professors Leslie J. Hooper and Lawrence C. Neale], the routine was al-

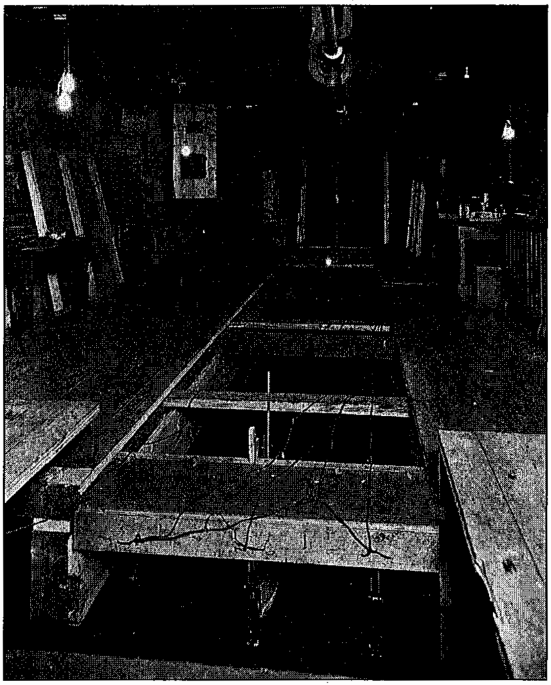


FIGURE 4. Measuring open channel flow using the salt velocity method.

ways the same after each test — namely, to return to the laboratory and try to improve the technique. To that end, test lines were almost always available at the laboratory for experimentation during the five decades that followed Allen's development of the method.)

Allen also experimented with using the salt velocity method in open channel flow (see Figure 4). A clock pendulum indicated time and multiple injection points were used.

A formal presentation of salt velocity work, "The Salt Velocity Method of Water Measurement," was presented in the 1923 American Society of Mechanical Engineers (ASME) *Transactions* by Allen and his brother-in-law Edwin A. Taylor, who had helped in the original testing and development.[5] An example of efficiency test results conducted by Allen and Taylor using the salt velocity method is shown in Figure 5. Coincidentally, another paper appeared in the same publication, entitled "The Gibson Method and Apparatus for Measuring the Flow of Water in Closed Conduits," by Norman R. Gibson, which outlined the impulse-momentum principle.[6] Both methods were successful and were later adopted as official methods endorsed by ASME and other worldwide technical organizations for measuring flow in large pipes.

Allen's creative skills, as demonstrated by the salt velocity method of flow measurement, and his other inventions, along with all his testing experience, teaching, and common sense, enabled him to formulate what he called *fundamentals* that he observed important in engineering practice:

- If you stay with a problem long enough, you will get an answer. It may not be the one you expected, but the chances are it will be the truth.
- The truth is the only thing that does not vary.
- If you really want to learn anything from an experiment, change only one condition at a time.
- Never hesitate to try a hunch. If it turns out OK, the theoretical chap will tell you why.
- If practice and theory do not agree, investigate the theory.
- Every engineer has the right to use his or her brain.
- One cannot work long with natural laws without having great respect for the "powers that be."

Hydraulic Modeling & Major Historic Events

Hydraulic models were not yet commonly accepted in engineering practice in the United States, but river modeling was used in Europe. In 1918, B.F. Groat extensively discussed similitude and advocated hydraulic scale modeling.[7] Groat used a model having proper similitude for designing submerged baffles to improve flow conditions at a hydro intake while ice was deflected. Since "seeing is believing," Groat's favorable model-prototype comparison of flow patterns on the St. Lawrence added to the modeling momentum. The prototype data were recorded by John R. Freeman in 1904.[7] It is pertinent to note Groat's correct insight on factors that can influence similitude. He discussed viscous effects, surface tension, roughness and other factors for free surface models.

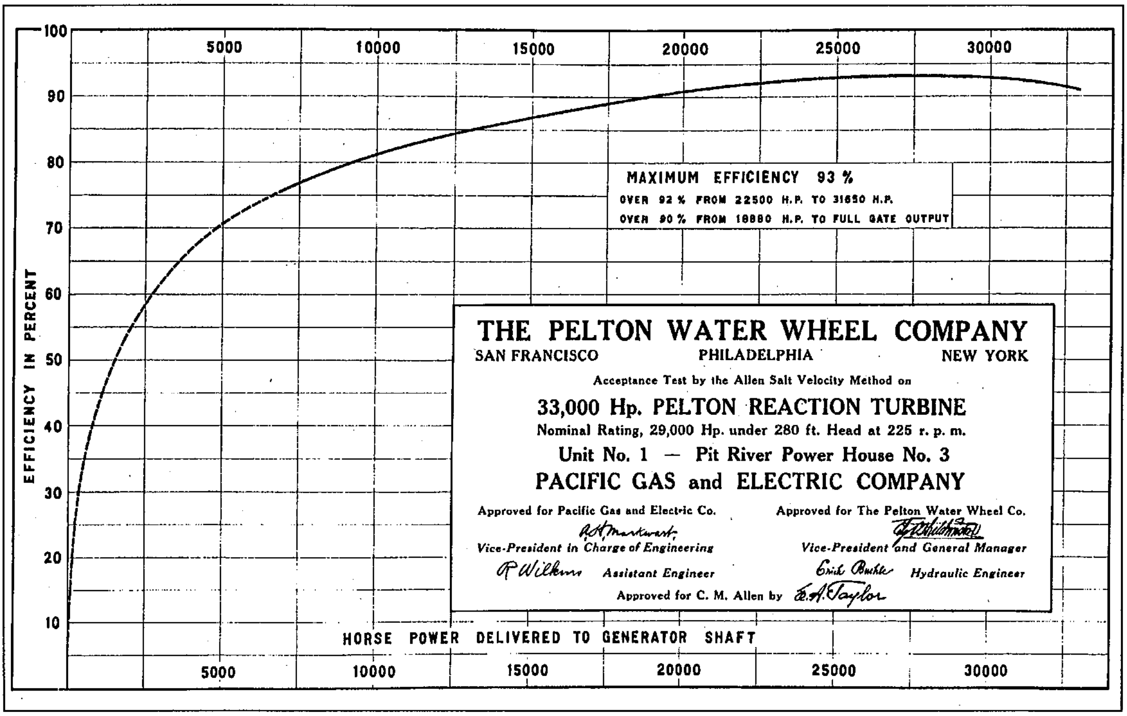


FIGURE 5. Acceptance test data using Allen's salt velocity method.

The Alden dynamometer at AHL (part of the original testing equipment at the lab) continued to be used for many other activities. Allen's 1919 files showed the dynamometer (see Figure 6) being used to test the efficiency of a gear box. Apparently, the bearings for the worm gear failed during the test or at some other time.

During the period from 1910 to 1920, major flood control works were being undertaken in the United States, prompting innovation in all phases of civil engineering, hydrological analysis, equipment design and model testing. The severe Ohio River flood of 1913 resulted in a system of flood control dams by the Miami Conservancy District in Ohio.[8] This agency developed the basic concept of the hydraulic jump pool (stilling basin) for energy dissipation, lending further credence to scale model testing. Also, major water supply projects were being developed for metropolitan areas. Models were used for the spillway for the Boonton Dam in New Jersey and models were contemplated for the Schoharie developments of the Catskill water system.

Farming in the early 1900s, and earlier, was a struggle. Rural areas were the last to be electrified, "modern" soil conservation methods were either not readily accepted or known, and large-scale efficiency had not yet started. However, during World War I there was extensive farm expansion to supply food for the war effort and export. This need combined with somewhat higher than average rainfall in marginal farm land in areas of the West and Midwest resulted in farming in areas never before having sod plowed. After the war and through the 1920s, these areas would "hang on" as adequate moisture levels continued on the Great Plains.

World War I fundamentally changed the US government and changed how most people viewed the role of the federal government. The national government became very much involved with business. The railroads were nationalized, and the War Industries Board, War Food Administration, War Finance Corporation and other such agencies made people tolerant of major new government activities as well as the centralization of authority.

During this time, other major civil-hydraulic works were completed. The Panama Canal opened in 1914. The need to combat malaria and yellow fever during its construction

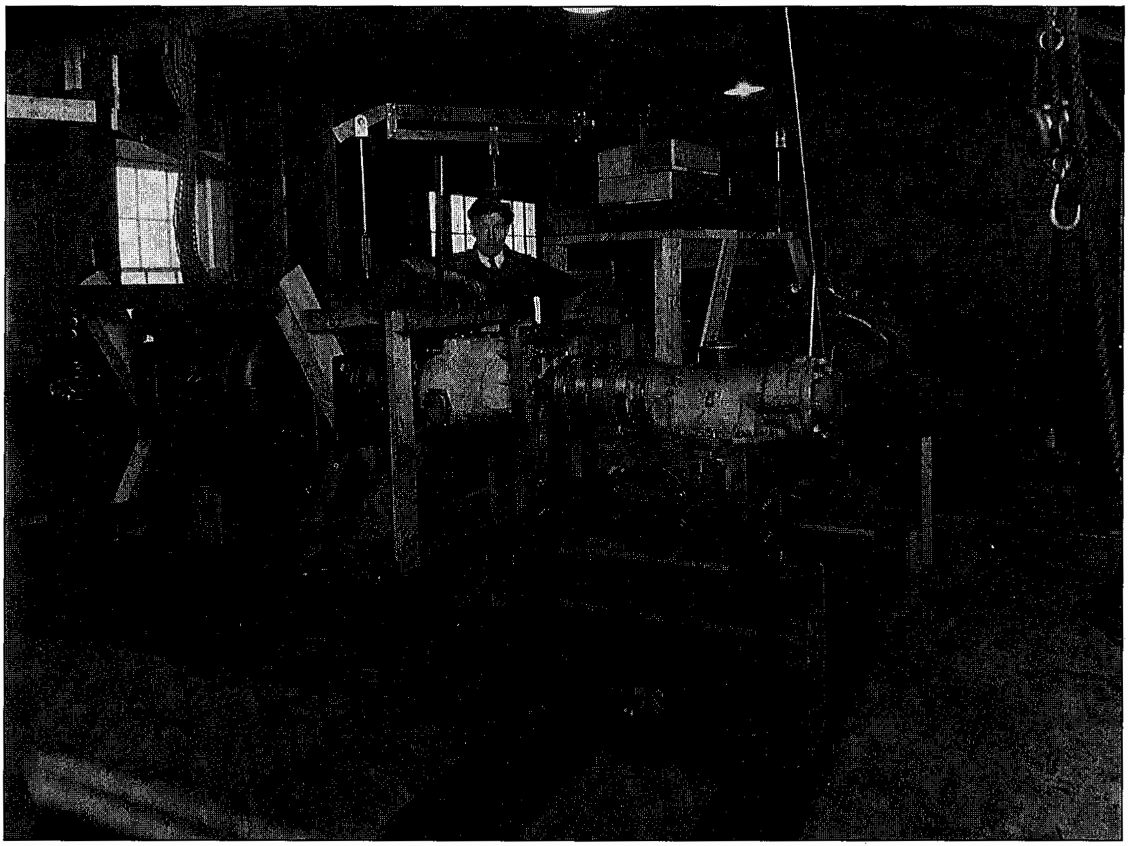


FIGURE 6. Gear box testing at the WPI Hydraulic Laboratory.

helped foster large-scale, concerted public health projects. In addition the worldwide influenza epidemic that killed 20 million (one half million in the United States) pushed public health agendas to the forefront.

Sea-borne traffic between New England states and other eastern states was very extensive. Finished products were going south, and coal and other raw materials were coming north along Cape Cod through Nantucket Sound. Fog, shoals and treacherous currents led to many ship losses. In 1870, Clemens Herschel analyzed the situation and recommended a sea level canal without locks. After 250 years of surveys and false starts, the Cape Cod Canal was completed in July 1914. Because of high currents, narrowness and a poor approach from Buzzards Bay, the original canal would be widened, deepened and improved in the 1930s. At that time, the present-day car bridges and vertical lift counterweighted railroad bridge were completed.

The post-World War I years became known as "The Roaring Twenties." The United States was not interested in the League of Nations (which had been created after World War I in order to avoid another world war), but a return to normalcy. For the Alden Hydraulic Laboratory, this decade began one of growth and one in which field testing became the consulting domain of individuals (for example, Allen) and laboratory testing was concerned with modeling and flow meter calibration. Going into the 1920s, the staff at the laboratory was quite small, with most dedicated to student instruction.

Floods

Although the "The Roaring Twenties" was coined to describe the social aspects of the American scene following World War I, a similar name could be applied to one natural hydraulic phenomenon that touched thousands of Americans during the 1920s — floods. Although there had been floods in the past, the floods of that decade seemed more severe and impacted many lives in the United States.

To help communities, especially along the Mississippi River, the US Congress passed legislation in 1917 to build levees. This legislation provided that at least one-third of the cost of levees built by the US government be borne by the local authority. Although the legislation was instrumental in helping build numerous flood protecting levees, it had two drawbacks. The first drawback was its funding requirement. The more populous cities, towns and districts had the most funds and, therefore, could afford to pay the one-third duty imposed by the act. Secondly, while the levees constructed protected those areas, the flood waters also rose higher and flooded areas that were unprotected by levees (some of these areas had not previously been affected).

In 1922, parts of the 1,240,050 square mile area of the Mississippi River watershed were hit with large floods that caused considerable damage. Larger floods were experienced in the same watershed in 1927 when 20,000 square miles were flooded, leaving 380 dead and 700,000 homeless. (By comparison, the floods of June to August of 1993 in roughly the same areas caused 50 deaths and left 70,000 homeless. The week of November 3, 1927, also saw the greatest flood in New England since 1869.)

Partly as the result of floods such as these, and from his own work and the work of others, John R. Freeman began to promote hydraulic model testing and the construction of a national hydraulic laboratory. In his 1922 address at the ASCE national convention in New Hampshire, he discussed the need for such a laboratory.[9] A technical paper written in 1924 outlined what equipment and buildings would be required for a national laboratory. Freeman even included 65 different hydraulic problems that the national laboratory could pursue.[10]

In the same year, Freeman visited numerous European laboratories to learn about their methods and techniques. He persuaded the leaders of these laboratories to write technical descriptions of their facilities and the methods used in their testing. All of this information was gathered and published, first in German and then enlarged in 1929 in English, in an 868-page book entitled *Hydraulic Laboratory Practice*.[11] Included in this book was a straightforward discussion on similitude. With Freeman's stature, the profession started to pay attention. Also, the great cost saving associated with modeling was evident. Many millions had been spent in a haphazard manner (some would say) on flood protection along the Mississippi River. At this time there was still limited experience with the performance of new large projects, and many engineers were concerned with the various aspects of river modeling.

Freeman was so convinced that the United States should have a national laboratory, and adopt modeling techniques such as those used in European laboratories, that he established traveling scholarships in 1924, 1925 and 1926 to study these overseas laboratories. (Seven decades after their establishment, Freeman Scholarships are still available for studies of hydraulic-related topics.)

Physical Hydraulic Modeling & Laboratory Expansion

In the 1924 *Transactions of the ASCE*, when John Freeman was pleading the economic need and value of a national laboratory, B.F. Groat, formerly a professor at the University of Minnesota and at the time a consulting engineer in Philadelphia, firmly stated his support.[10] Groat described the results of a 1:100 scale model that was used for a temporary stone closure across the South Sault Channel of the St. Lawrence River. The stone was sized from the study, and the model was vindicated. Groat even described a model-prototype comparison of behavior when the project superintendent, having no large stone, started the work with smaller stone that washed away. Groat proposed: "One use for a laboratory . . . is the publication of the physical laws by which correct interpretations may be placed . . . relative to the action of the full size river. Many such laws are now known to a limited number of engineers . . . The National Hydraulic Laboratory (should) prove these laws and publish the information."

Allen was also attuned to the future need of model testing. In the early 1920s, he had Gleason H. McCullough, a future head of WPI's Mechanical Engineering Department, draw up plans for a new and larger main laboratory

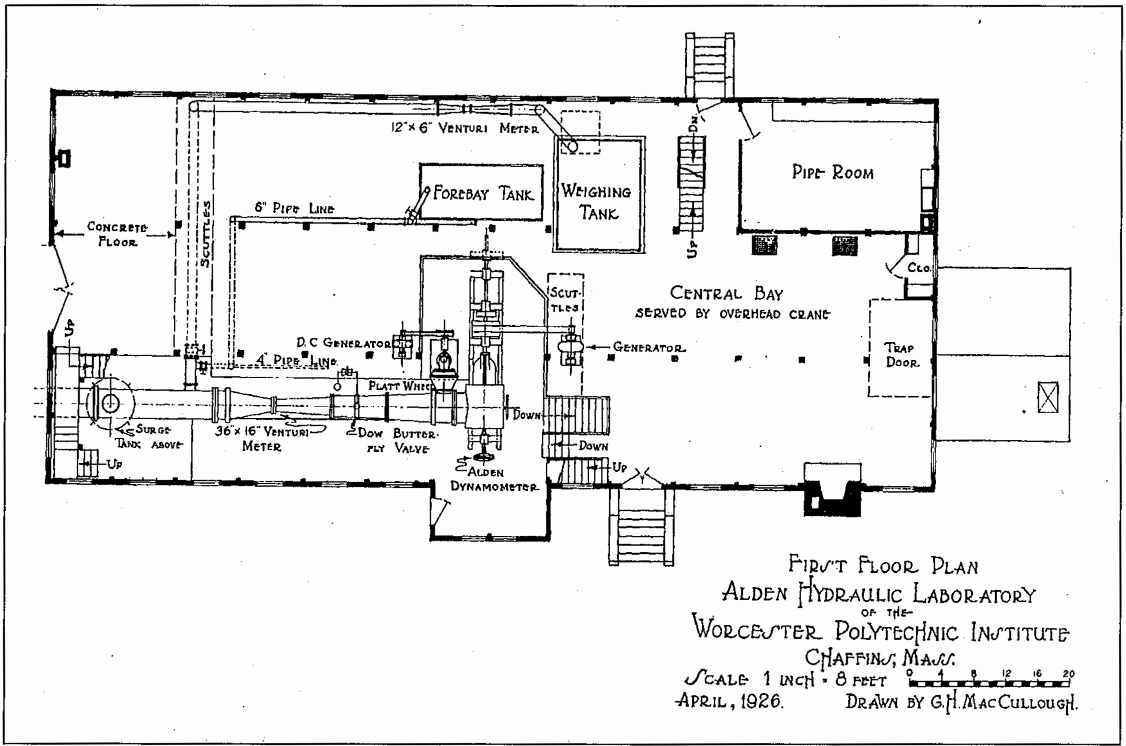


FIGURE 7. Layout of the first floor of the Alden Hydraulic Laboratory (1926).

building using the existing building as a starting point. In 1924, thirty years after the start of AHL, Allen saw that it was time to expand and renovate. In the summer of 1924, the foundation for a new facility (now Building 2) was erected around the existing Hydraulic Testing Station. In the fall of that year, Allen took Alden (the founder of the laboratory) out to see the new foundation and hoped to convince him to furnish funding for the new building. Alden agreed to the funding, as a provision of his will. Using the old building as a staging, a new building was built during the next year and a half at a cost of $42,000. The dedication of the facility was on May 7, 1926. The building represented the last direct gift from Alden to the laboratory since he died four months later on September 13, 1926.

The new main laboratory building at that time was 110 feet long by 45 feet wide, with two towers — one for head measuring water columns and the second tower for a surge tank. Other existing buildings included the low-head lab, a small office building, a storehouse and a wood shed. The total floor space of all buildings was approximately 19,000 square feet. The layout of the first floor of the Alden Hydraulic Laboratory in April 1926 is shown in Figure 7. The surrounding land included over 100 acres of woods. An aerial view of the area is shown in Figure 8.

In 1922, a resolution was introduced in the US Senate for a national hydraulic laboratory, but the US Army Corps of Engineers blocked it. Not until 1928, when a great flood occurred on the Mississippi with tremendous loss of life and property, did the Corps of Engineers (directed by Congress) recommend (as a self-protective move) the establishment of a hydraulic laboratory under its own auspices.

Feverish Modeling & Consulting

The Alden Hydraulic Laboratory was a point of interest to many engineers during this period. In his 1923 report to the president of WPI, Allen mentioned that "during the past year we have had as visitors all of the Chief Engineers of all the Water Wheel Companies, as well as a large number of consulting hydraulic engineers not only of this country but from Canada,

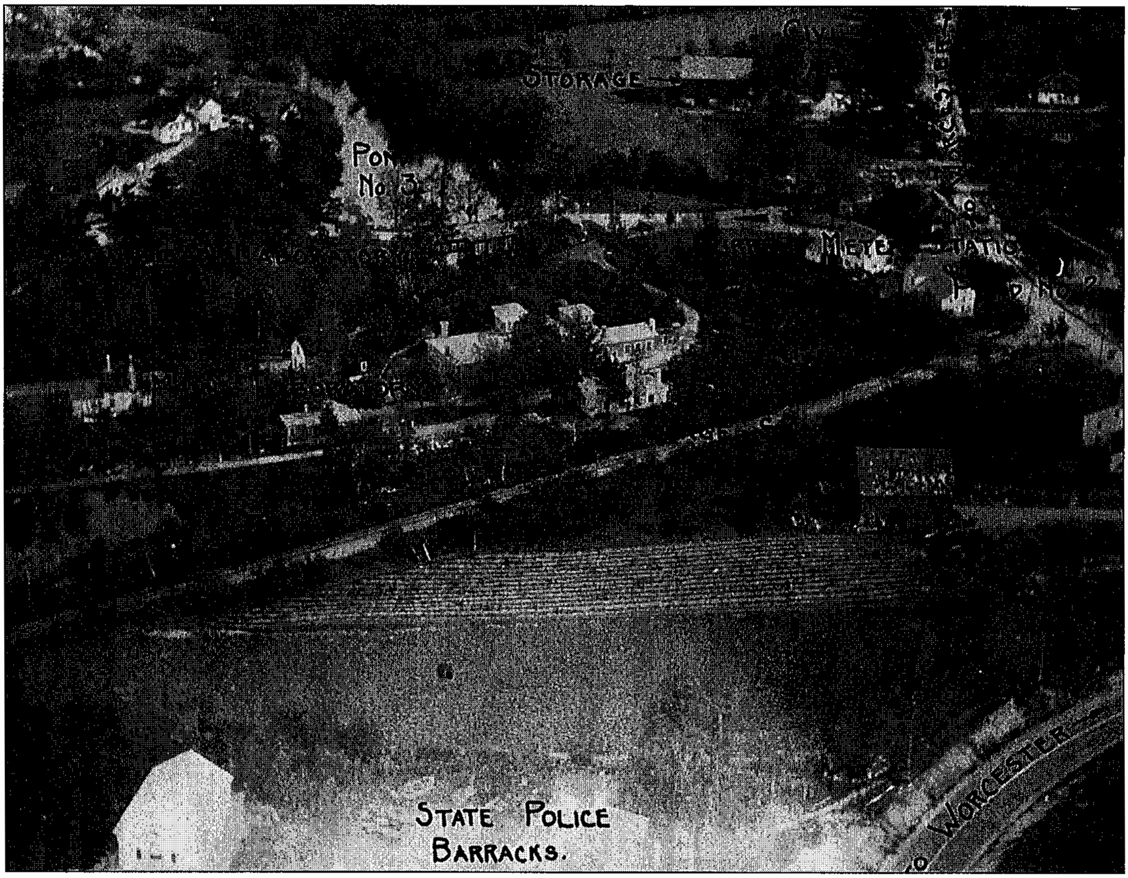


FIGURE 8. An aerial view of the laboratory and surrounding area (1930).

England, Sweden, etc." These visits enabled Allen and the visitors to discus various aspects of hydraulic engineering, thereby keeping abreast of current national and international practices. These practices included the use of various materials for simulating roughness and shape. In one of Allen's spillway models, for example, equal portions of sawdust and cement were used for easy shaping using carpenter's tools.

The model activities at AHL involving power production and flood control were so numerous in the 1920s that, of the 26 most important power projects in the United States listed in the magazine *Power* in January 1930, nine had been modeled at the laboratory. The total installed capacity of the 26 projects was 2.2 million horsepower. The nine projects studied at AHL had an installed capacity of 1.1 million horsepower. In the late 1920s, rivers flowing (by proxy) at the laboratory included the Androscoggin, Penobscot, Kennebec, Presumpscot, Deerfield, Connecticut, Westfield, Ware, Hudson, Susquehanna, Osage, Columbia, St. Lawrence and St. Maurice. During this period, Allen was also continuously refining his salt velocity flow measurement technique.

A power company in New England had studies conducted for the Fifteen Mile Fall power site (also called Comerford) on the Connecticut River (see Figure 9) and on the Davis Bridge Dam power project on the Deerfield River, a tributary of the Connecticut. A power company in New York had canal model studies done on the Spiers Falls site on the Hudson River. At this time, physical models were either tested in open channels, in the low head laboratory or in the basement of the main laboratory. The Davis Bridge project involved a novel spillway (previously used in Europe) that was called a "morning glory" because of its shape. As far as can be determined from existing files,

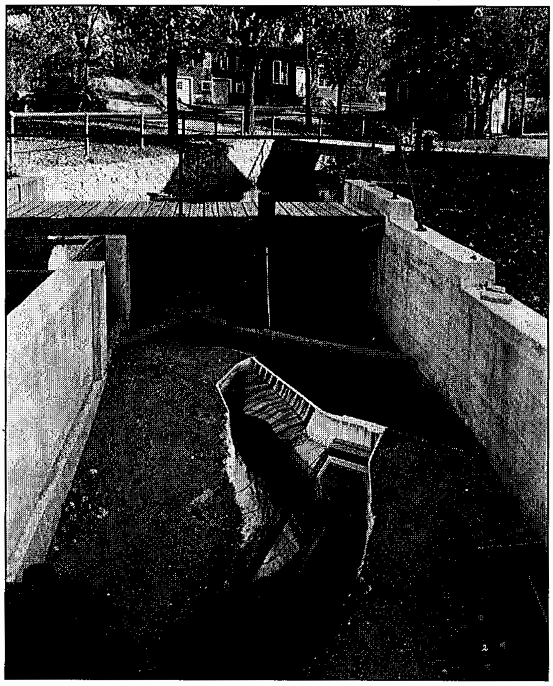


FIGURE 9. Fifteen Mile Fall model.

the 1922 testing of the 1:36 geometric scale Davis Bridge "morning glory" intake was the earliest hydraulic model test at AHL. This shaft spillway was designed for 27,000 cfs and would have to pass this maximum flood without any entraining air that would reduce capacity. A rendition of the Davis Bridge Project is shown in Figure 10, and the capacity of the spillway based on the 1:36 scale hydraulic model is shown in Figure 11.

The Davis Bridge Project was a record 200-foot high hydraulic fill dam on the Deerfield River at Davis Bridge (now called Harriman Station) in Whitingham, Vermont.[4] The hydroelectric plant was constructed from 1922 to 1924 and had many special features including a 13,000-foot long, 14-foot diameter power tunnel with a surge tank. The plant had a total capacity of 38.5 megawatts, for three units operating with a head of 340 feet.

The first Davis Bridge intake tests simulated the intake crest and tunnel, which was located in a deep pool that did not have any channel effects. The actual channel shape was designed so that part of the spillway was fronted by deep water while the other half had a special channel. Model roughness similitude was a concern in the 1:36 model. These tests indicated satisfactory flow capacity with limited air entrainment. Subatmospheric pressures were meas-

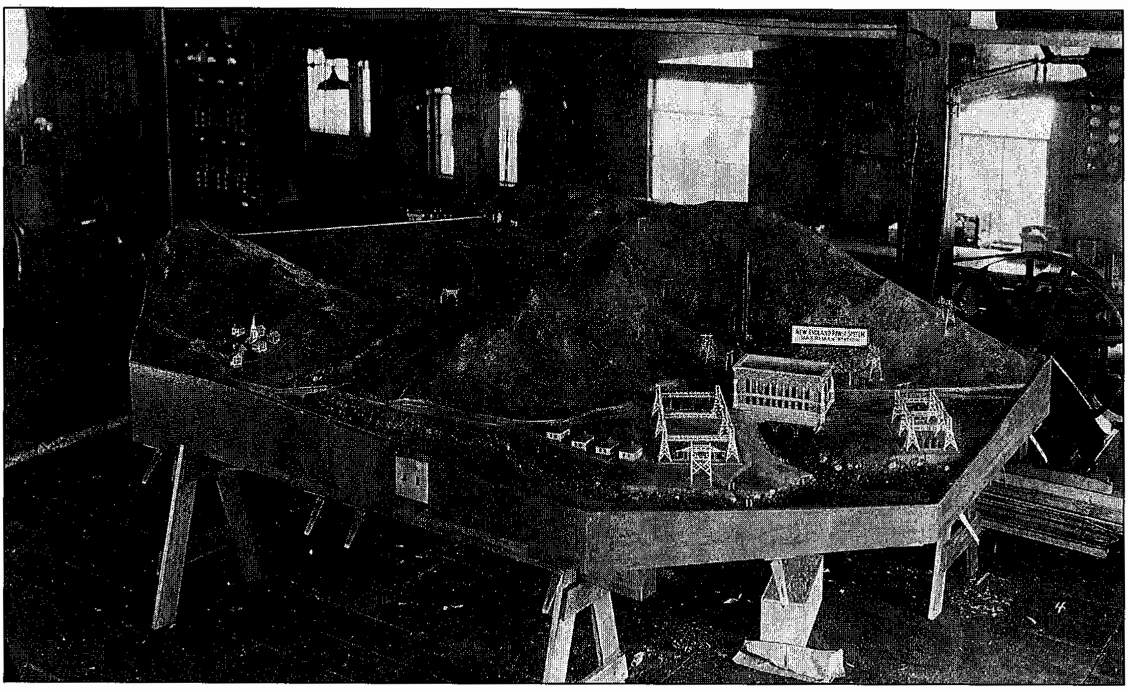


FIGURE 10. An architectural model of the Davis Bridge Project.

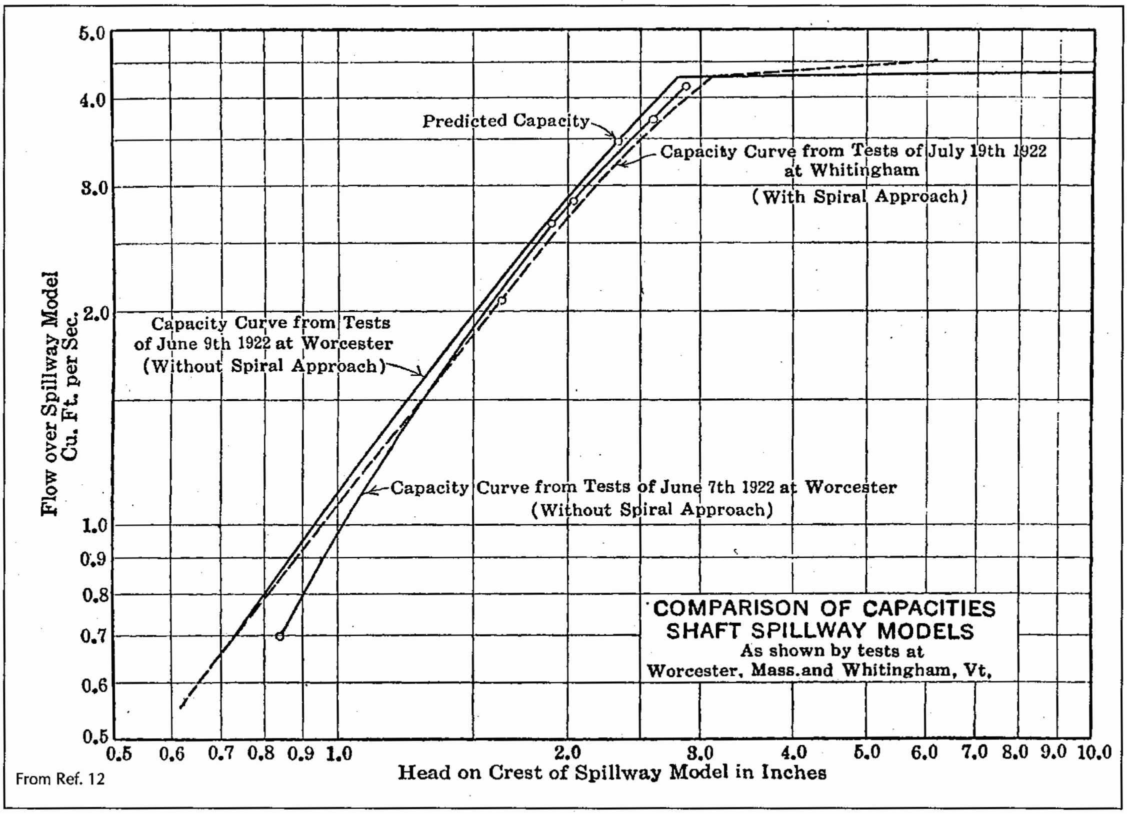


FIGURE 11. Davis Bridge "morning glory" spillway capacity.

ured on the spillway crest profile. Overhead photographs were taken to show flow patterns. The model was later tested at the Massachusetts Institute of Technology (MIT), and a discussion of the paper by Fred Kurtz touched on similitude limitations of air entrainment.[12] Another early study was done in 1924 at AHL for an outlet stilling basin of a twin-pipe bypass between the Middle and Lower Canals in Rumford, Maine.

Most projects involved power production and the safe control of flood water. The Conowingo, Holtwood and the Safe Harbor studies on the Susquehanna River for an electric power company in Philadelphia were important to the power development and flood control on this river. Various aspects of the Conowingo Project would be evaluated by the laboratory over the years (even up to the present). These studies would include spillway flow capacity, fish passage and turbine flow measurement. For a 1927 model study, the focus was to design an apron so that erosion adjacent to the toe of the dam would be minimal. A 1:30 scale section of the dam was constructed in a flume (see Figure 12) and numerous apron designs were evaluated. It is interesting to note that large crushed rock was used to conservatively represent the large blocks of granite in the actual river. In an *Engineering News Record* article written five years later, a favorable comparison is made between the model and prototype erosion.[13]

Draft Tube Modeling

In the south, a large power company had a major facility completed — Mitchell Dam — which required hydraulic investigations that were conducted at the power company's own hydraulic laboratory. This project would have a major impact on turbine design and Allen. Hydropower was becoming a major study area in civil engineering. In 1921, a hydroelectric option was offered at MIT,[2] and water power engineering courses were being offered at WPI.

The Alden Hydraulic Laboratory in the 1920s was not only doing work in modeling

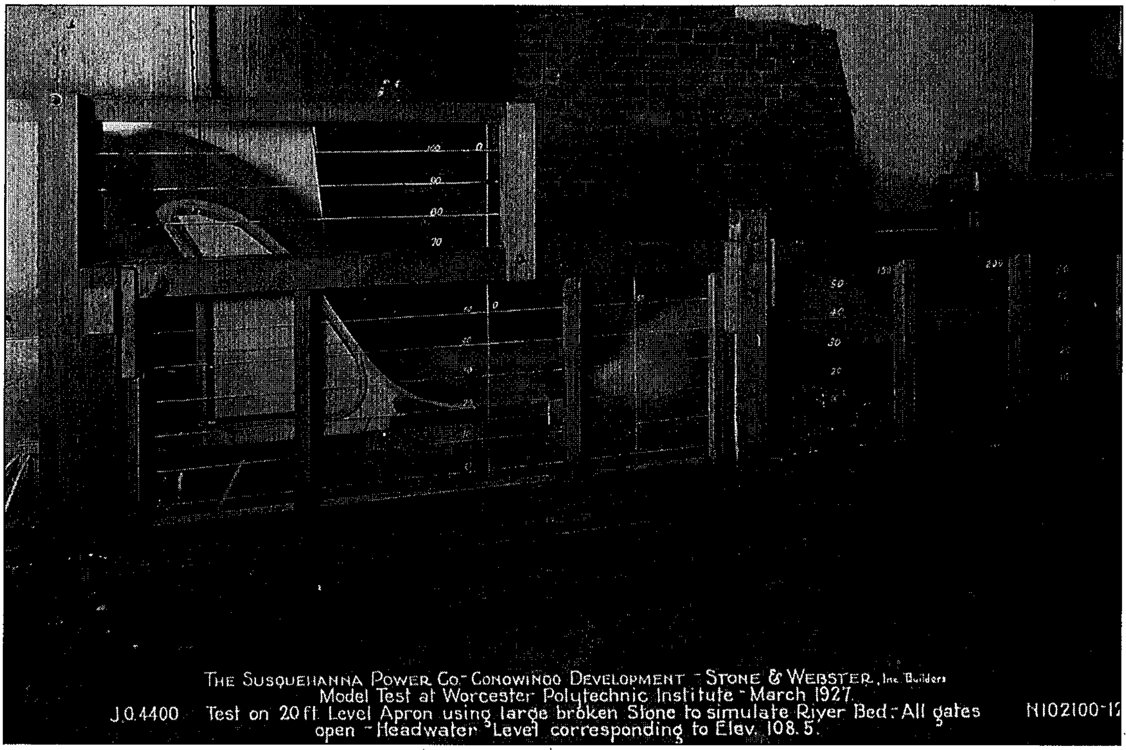


FIGURE 12. Model of the Conowigo spillway apron.

power and flood protection projects, it was also performing extensive modeling to improve draft tubes for two power companies. In 1922, classic experiments were conducted at the laboratory on 12 experimental draft tubes.[14] A Francis-type model runner was used for the tests. It is interesting to note that of the 12 draft tubes, six were designed by the manufacturers, three by one of the power companies and three by Allen and I. A. Winter, a hydraulic engineer for one of the power companies. The test facility layout is shown in Figure 13 and typical data are shown in Figure 14. A technical paper entitled, "Comparative Tests on Experimental Draft Tubes,"and written by Allen and Winter, was presented to ASCE in 1923.[14] This paper prompted much discussion and further established Allen and AHL in the field of hydraulics and turbine testing. The paper also was awarded the ASCE James Laurie prize in 1925 for the best paper in hydraulics. Winter was also involved in developing the Winter-Kennedy method for measuring flow using pressure taps on the scroll case of Francis or Kaplan turbines.

Growth of the Power Industry & Cities

In the early 1920s, the efficiency and scope of the US electric power industry led to real national growth — there was an increase in gross national product accompanied by less hours of labor. In many ways, this increasing competition and efficiency should have produced falling prices and increased economic benefits. However, consolidation (some said monopolization) came about in various industries, including companies that generated electric power. Engineering companies also were growing to meet design needs. For example, by 1920, in addition to all of its varied engineering, construction and appraisal activities, one company provided management services under contract to 59 utility companies in 18 states.

Upon the death of President Harding, President Coolidge in 1923 permitted economic concentration, which led to the formation of holding companies, especially in the power industry. These holding companies issued stock that became vastly overinflated in value.

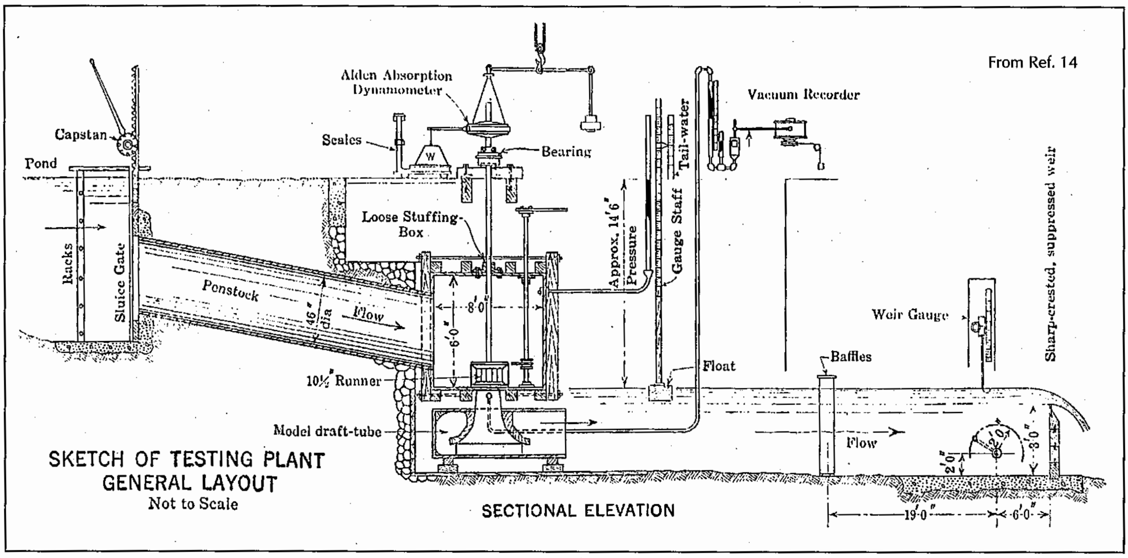


FIGURE 13. Draft tube testing plant layout.

Oversimplifying, there were holding companies for holding companies, and, in the end, few could understand this "pyramiding." By someone owning a few shares in a holding company, financial power became centralized. The shares of these holding companies were bought "on margin" with as little as 25 percent downpayment. The rest of the payment to the stock seller were borrowed from banks based on the "value" of the stocks. But the value of the stocks was inflated by the holding companies far above the worth of the operating companies. In such a climate stock speculation flourished.

By the end of the 1920s, ten large utility companies had absorbed three-fourths of the total electric light and power business. Electric power companies had very substantial economic and political power, and were not hesitant to use it. By June 1929, one engineering firm reported that during the previous six years the utility industry had sold about one-fourth of the total new stock offered to the public.

Besides the need for power and flood control, the expanding population of the United States required more drinking water. Boston, Massachusetts, for example, was outgrowing its 63-billion gallon Wachusett Reservoir which was built in 1906. At that time, that reservoir was described as the largest of its kind in the world. Frederic P. Stearns, in his 1895 report to the city, had envisioned that the Boston system would expand to the Ware, Swift, Westfield and Deerfield river valleys located in the western portion of the state. In 1920, Boston started to look at expanding the system. As part of the study, the Metropolitan District Commission Water Supply Section commissioned AHL in 1928 to study the flow and energy dissipation for Shaft No. 8 on the Wachusett-Colebrook Tunnel. Water from the Ware River was to be diverted some 240 feet vertically into the tunnel and to have a minimum of energy when it reached the tunnel. Two methods to achieve energy dissipation were studied. The first used a double pitch helical "thread" to dissipate energy by rotation, and the second had metal fins attached to the circumference of the shaft. The metal fin technique (see Figure 15 on page 21) was found to be the best method for conducting the flow to the tunnel with the least amount of energy. The shaft was constructed from wood, and narrow vertical windows were used for flow observation. Depending on the flow, 76 to 88 percent of the available energy was dissipated by the "cork screwing" flow. Prototype details of the Ware River intake are shown in Figure 16 (on page 22).

Large coastal cities were developing in the 1920s, and there was concern with the practice of offshore sewage disposal. The reclamation of sewage for fertilizer in Los Angeles was considered, but the proposal was defeated in

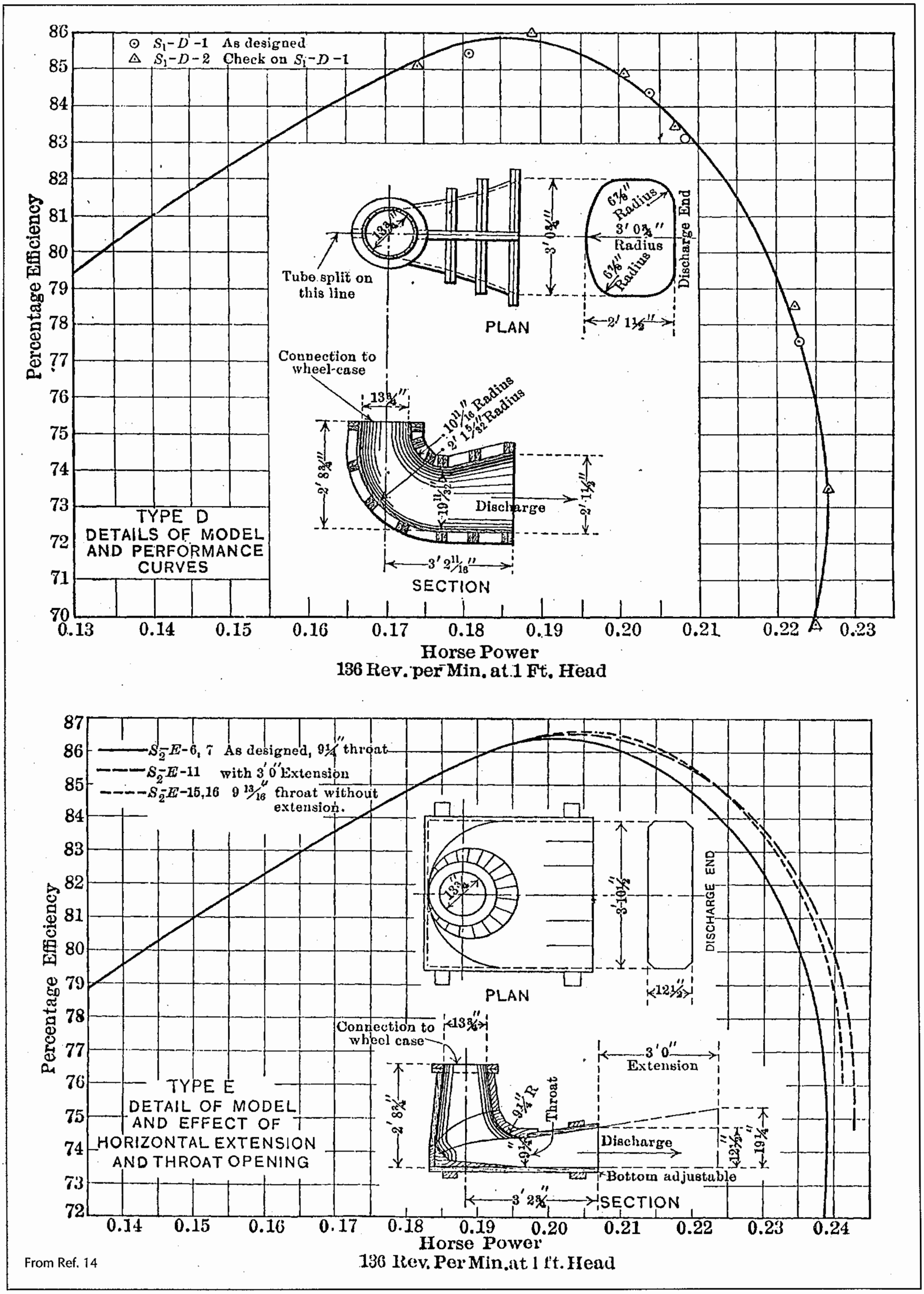


FIGURE 14. Comparative draft tube test data.

1921.[16] While the wastes were treated with chlorine, dispersion of the effluent continued to pollute the beaches. Eventually, Los Angeles constructed a 5,093-foot long, 7-foot diameter pipe along the sea bottom. The wastes were discharged offshore using two 5-foot diameter branching tunnels. However, problems developed due to fruit and vegetable canneries overtaxing the system. Gasoline and oil discharges were not permitted, and some consideration for the disposal of industrial wastes was being considered. The concept of distributing discharges over a large area eventually led to the diffuser for dilution of wastes (and waste heat) as proposed by Rawn, Bowerman and Brooks.[17]

Ocean travel was also popular in the 1920s. Ship log pitometers were instruments being used to measure the speed of large ocean liners. In those days, AHL calibrated many of these pitometers. In 1926, in nearby Auburn, Massachusetts, Dr. Robert Goddard showed the practicality of liquid fueled rockets. In 1927, Charles Lindberg was the first to fly across the Atlantic.

Special projects at Alden Hydraulic Laboratory were ongoing. One study in 1929 related to the efficiency of a portable fire pump that was driven by the wheel of a car. Allen's report states:

> "The pump was bolted to the running board of a Peerless six cylinder automobile and adjusted so that the pump pulley came tight against the tire on the left rear wheel... The car was jacked up and blocked... The first set of curves show the discharge of the pump at various pressures, each curve being plotted for a different speedometer reading... The effect of greasing the pump is shown... The tire which was driving the pump was smooth with the tread practically worn off... With a new tire the pump would certainly run better."

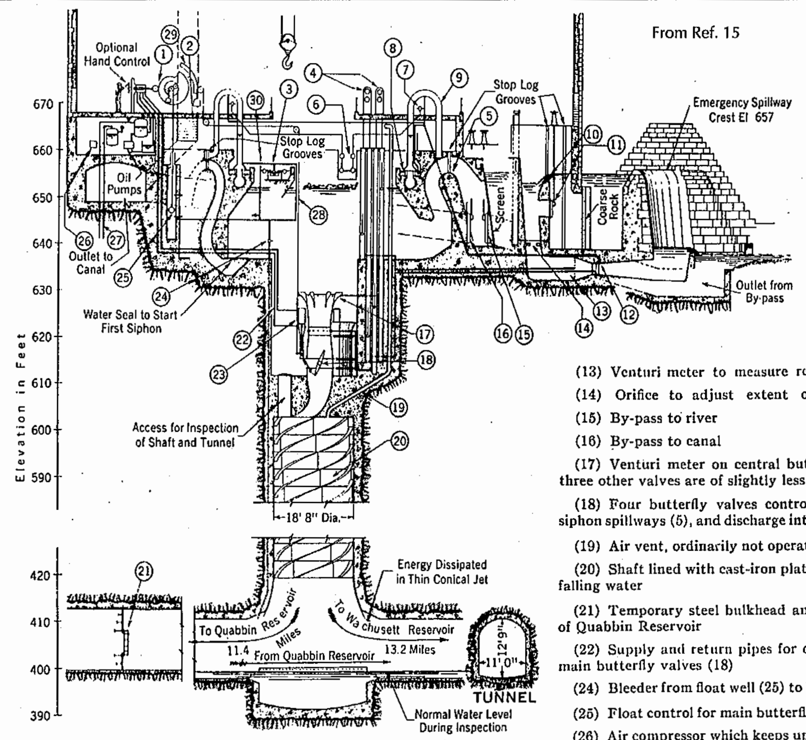
The tests were made by Clyde Hubbard, and selected data are shown in Figure 17 (on page 23).

The electric power industry was evolving, and production costs were relatively low. There was also the realization that hydropower could be adapted to carry peak load. Conowingo, Safe Harbor and Fifteen Mile Falls were described as peak load plants complementary to large steam plants. At this point in time, transmission voltages reached 330 kilovolts, and the length of transmission extended to 265 miles.

FIGURE 15. A close-up view of a section of the model of Shaft No. 8 showing fin-ribs.

Changes at the Laboratory

Throughout the 1920s, Allen managed to run the Alden Hydraulic Laboratory as a state-of-the-art facility. In 1922, he lined the 50,000-pound weigh tank with copper to reduce leakage and to improve the accuracy of calibrating flow meters. By the late 1920s, Venturi meters ranging in size from 1.5 to 12 inches were being calibrated. In the spring of 1924, a model river gauging station was built on the stream flowing through the property downstream of the main laboratory. The station was equipped with a small concrete dam containing a triangular weir and a building with an automatic water level recorder. In 1925, a mess hall for the staff was constructed using lumber from the old laboratory. An equalizing pond below the laboratory was developed by building a dam



(1) Four cams, float-controlled, which actuate oil sleeve valves to open and close main butterfly valves (18)

(2) Louver to maintain atmospheric pressure inside building under fluctuating water level

(3) Compensating weir for automatic regulation of flow to float well (25) for control of main butterfly valves (18)

(4) Float-operated meter registers to record rate of diversion through (17) and release through (13)

(5) Nine siphon spillways with a crest at elevation 656—six of 360-mgd capacity under maximum 9-ft head, and three smaller. Order of priming determined by sensitive float switches (6) operating solenoid valves (7) on vacuum connections. Order of breaking of siphons determined by surface contact (8) of siphon break pipes (9)

(10) Pond level at diversion limit for release of 85 mgd fixed at elevation 656 by adjustable weir crest (10) or sluice gate (11)

(12) Vacuum pipe connected with Venturi meter (13) for rapid priming of siphons (5)

(13) Venturi meter to measure release to river

(14) Orifice to adjust extent of backwater on weir crest (10)

(15) By-pass to river

(16) By-pass to canal

(17) Venturi meter on central butterfly valve of 620-mgd capacity. The three other valves are of slightly less capacity and are unmetered

(18) Four butterfly valves controlling water level in valve pit, head on siphon spillways (5), and discharge into shaft

(19) Air vent, ordinarily not operative on account of vacuum in shaft

(20) Shaft lined with cast-iron plates with helical vanes to absorb energy of falling water

(21) Temporary steel bulkhead and flap gates in use pending completion of Quabbin Reservoir

(22) Supply and return pipes for oil pressure cylinders (23) operating the main butterfly valves (18)

(24) Bleeder from float well (25) to bottom of shaft

(25) Float control for main butterfly valves (18)

(26) Air compressor which keeps up required pressure in water and oil tanks and supplies air for air-lift water supply (27)

(28) Steel cable connecting each butterfly valve to compensating arm (29) on oil valve control

(29) Compensating arms to prevent hunting in opening and closing of main butterfly valves (18)

(30) Air vent

Fig. 1. Diagram of Ware River Intake Works

FIGURE 16. The Ware River intake works.

on that site in 1928. An addition to the carpenter shop was built in 1929, as well as a permanent building to store idle apparatus.

Always attuned to new technology, Allen convinced R.D. Johnson to design a differential surge tank (a relatively new concept) to protect the main pipeline to the laboratory. The inner portion of this tank was constructed so it could be hoisted up in the air and, thereby, convert the surge tank to a simple surge tank. Thus, the tank could be utilized by students to study full-size surge tank designs. This tank was one of the prides of Allen, and he frequently demonstrated it to visitors. On one occasion, Allen had sent his visitors to the surge tank tower to observe the oscillating water level. Unknown to Allen, the surge tank had been set up to act as a simple tank. With the waterwheel going at full power, Allen quickly shut down the flow by closing the turbine's wicket gates. Suddenly, he heard the water overtop the tank, and a group of wet visitors came down from the tower none too happy about the demonstration. Needless to say, from that time on, Allen always checked the position of the internal riser in the surge tank before giving demonstrations. In addition, a student used the surge tank for a thesis to determine the effectiveness of measuring the transient level during turbine closure to accurately predict flow. It is interesting to note that in 1929 a model of a surge tank for the Cobble Mountain Development was tested to determine the discharge coefficient through the throat leading to the tank.

Allen's drive to stay up to date with technology is indicated by a 1927 student thesis that compared "an apparatus similar to Gibson's in its essentials, although much cheaper, can be used to give an accurate measurement of water flowing through a turbine." The ingeniousness

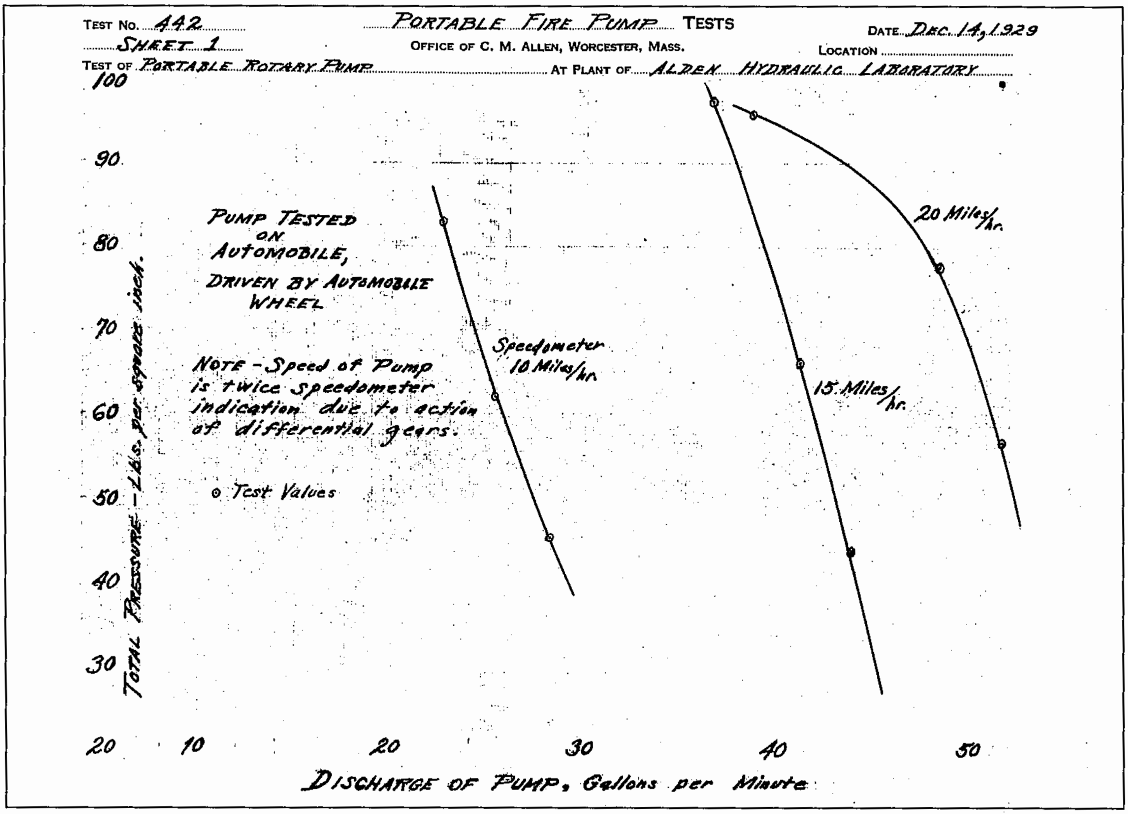


FIGURE 17. Portable fire pump test data.

of the apparatus and instrumentation is particularly noteworthy because they were all constructed at the lab. The 1927 thesis acknowledged R.D. Johnson's advice and criticism. In a similar vein, in Allen's October 1926 report to Hardy S. Ferguson, the salt velocity method was used for turbine efficiency tests in Rumford, Maine, and to calibrate permanent meters (a reducing section at the entrance to the scroll case) for measuring discharge.[18] The details of the piezometer plugs and piezometer ring are consistent with present-day practice.

In the 1920s, Allen was faced with the challenge of building a spillway on the low head pond at AHL. The exit from the pond was very narrow and, thus, precluded building a standard spillway capable of carrying the required capacity. Allen had heard of an ingenious type of spillway — a "side channel spillway" — designed by John Vaughan, a consulting engineer. In talking with Vaughan, Allen concluded that this type of spillway (a double-sided channel with a steep chute) would be exactly what was needed at this location. (Today, some seventy years after its construction, the Vaughan spillway is still active and has successfully passed every flood during its existence.)

A model valve, designed by E.A. Dow, a power company employee, was tested at AHL during the same years. After the study, Dow gave the laboratory a 36-inch Dow valve, which was used to control the flow in the 36-inch line located in the basement of the laboratory. (The valve has since been motorized and is still in use today.)

Activities at AHL in the 1920s were not limited to sponsored projects. Since about 1905, civil engineering students had used the grounds for their Railroad Surveying Camp. Numerous experiments were conducted by WPI students, as well as students from Tufts University and other colleges, to supplement classroom teaching. The main laboratory was both a study and testing area, and was heated by resistance coils powered by the hydraulic turbine. In addition, 52 students worked on 26 senior theses as part of their graduation requirements. Two of the students who did their theses at the lab returned to work there. Clyde W. Hubbard graduated in 1926 and started teaching and working the same year. Leslie J. Hooper graduated in 1924 and began working in Sao Paolo, Brazil, as a test engineer. His job was to measure the efficiency of the many hydraulic turbines owned by his employer. From his undergraduate days at WPI, Hooper had become familiar with the salt velocity method of flow measurement, and he proposed using the technique in Brazil. He corresponded with Allen frequently regarding the method and probably was the first to use the method in the field aside from Allen. In 1927, Allen persuaded Hooper to return to WPI to study for an advanced degree and to work at the lab.

Recognition for the Alden Hydraulic Laboratory & Allen

Recognition for AHL in the 1920s came in the form of awards to Allen for his significant contributions in several areas of hydraulics. In addition to the 1925 ASCE award for best hydraulics paper, Allen was named president of BSCE, received the Clemens Herschel Award from BSCE in 1928 and was presented with an honorary Doctor of Engineering degree from his alma mater, WPI, in June 1929.

Freeman wrote in *Hydraulic Laboratory Practice* describing three notable US laboratories: "namely those at Cornell University, the University of Iowa, and Worcester Polytechnic Institute. . . in addition to their use in the instruction of undergraduates [they] have led all others during the past 10 or 20 years. . . [being] broadly useful to engineers."[11] Freeman's enormous stature as a hydraulic engineer and his belief in scale models, plus growing experience in modeling and similitude, accelerated the use of modeling throughout the United States in all irrigation, power and flood control activities. Freeman's list of Unsolved Problems in River Mechanics was probably like a "call to arms."[11] This growing use of modeling was also prompted by difficulties occurring at various sites such as the costly repair work at Wilson Dam at Muscle Shoals in 1927 where extensive erosion resulted due to the lack of an adequate stilling basin.

When Allen became president of BSCE, it was no surprise that his address at the annual meeting was titlted "Water." For background information, during the 1920s, the cost of coal was soaring and there were coal car shortages and labor problems (in 1919, 3.2 pounds of coal were consumed per kilowatt hour) — factors that promoted the use of water power. Allen commented on the use and conservation of natural resources, water power and Niagara Falls:

"*Use of Water Power*. I would not feel justified in writing this paper if I did not say a few words on the use of water power. I believe that all the water power should be developed that can be shown to be financially economical, and I believe we should go even a step beyond, in view of the probable increase in the cost of coal and also to save all we can. If we don't use water power, we lose it; while if we don't use coal, we save it!

"Furthermore, I believe we should look ahead a bit and imagine what our descendants are likely to call us for using up and wasting so many of our natural resources.

"One of the best ways to conserve coal is *not* to use it — by using water power instead. I believe the time will come, and not so very far distant, when as a nation we shall arrange with Canada to use all of the water at Niagara for power purposes. If I am correctly informed, something must be done before long to prevent the Falls from automatically wearing out. To my mind the simplest way to prevent a thing from wearing out is not to use it. Therefore, why not use the water for power purposes, and incidentally save the Falls for exhibition purposes on Sundays and holidays? I realize the howl that would go up if such a proposition were really put forward in earnest, especially from people who believe that the Falls were put there to be looked at. As comparatively few people ever see the Falls, why not distribute their beauty (although in another form) by putting more horse power behind each individual in the country? This would enable a wider distribution of the good things of life."

During the 1920s, the Alden Hydraulic Laboratory effectively bcame a national resource for developing the hydraulic aspects of the many projects being constructed for power and flood control. Until the early 1920s, the laboratory was mostly used for undergraduate instruction and as a resource for WPI staff in their consulting and applied research. In the mid-1920s, research files began appearing in the name of the laboratory rather than in the name of an individual. Prior to this, most of the work is documented in the files of Allen. With the hiring of both Hubbard and Hooper, the laboratory also acquired its first full-time professional staff.

Many of the lab's clients (engineers) were involved with some day-to-day testing. A 1929 letter from Allen to a client regarding a manifold with a pump for the Rocky River Station in Connecticut, the first pumped storage plant in the United States, indicates the major ongoing activities. Various other manifolds were being tested or bid upon.[19] Unit prices in the bid for a 1:17 manifold with an actual dimension of 1 foot for the penstock are noted in Table 2. Allen's estimate was $2,000 to $3,000, "unless you have a problem different from what I think necessary."

TABLE 2.
Unit Prices for a Manifold Under Test

Expert laboratory assistance doing the setting up and conduct of tests: $25/day

Expert mechanic and model maker: $20/day

Assistant mechanic: $15/day

Common labor: $0.70/hour

Personal services on supervision and consultation: $100/day

Laboratory fee: 25 percent of total of above items

Rock Island Dam & Fishways

An extensive model study was commissioned in 1929 to research the flow conditions on the Columbia River at the Rock Island dam site that included the dam, spillway and powerhouse. The 1:100 scale model was constructed using a sand, cement and sawdust mixture. The prototype contour map had been enlarged on 6-foot square sheets of brown paper using a reflectoscope. Dowel pins were used in the model to get the exact elevation. According to newspaper articles, the model cost $15,000, while the initial dam and powerhouse were estimated to cost about $15 million. The model was constructed so that the dam could be quickly installed and visitors could see the site with and without the dam on the same day. Apparently, a major function of the model was to study the number of fishways to be installed. At that time, full-grown returning salmon on the Columbia River weighed 15 to 20 pounds. Based on the visit to the model, the US Commissioner of Fisheries required a third fish ladder to be installed. The newspaper articles also indicated that hydraulic models were used less in the United States than in Europe, but that financiers of large hydro projects had discovered their value. This study even included an architectural model of the powerhouse to follow the construction of that building.

Depression

In the mid- to late 1920s, some areas of the country were prospering while others were severely depressed. The 1928 election of Herbert Hoover, a very successful mining and consulting engineer, brought to the White House an individual who thought that economic concentration was desirable. Also, he believed that government should generally not be in the power business to compete with private industry. In Hoover's March 1929 inaugural address, he said, "I have no fears for the future of our country." (Subsequently, the shanty towns that developed all over the country were called Hoovervilles.)

In October 1929, the stock market collapsed. Throughout the stock market boom of 1929, utilities led the way. People believed that utilities were the safest of investments, and everyone could see electric power use increasing. As this was happening, Senator Norris of Nebraska was fighting the power industry to prevent a giveaway of the Muscle Shoals facility on the Tennessee River.

The Alden Hydraulic Laboratory entered the Great Depression with an outstanding reputation, excellent client contacts in the electric power industry for hydraulic modeling, Allen's steady work in flow measurement, some basic research work and a demanding requirement for academic-related activities. There was also work for municipalities (water supply and transmission) and government agencies (flood control). This effort was accomplished with a small staff. Allen continued to split his time evenly between academics and consulting. The staff was multi-disciplined so everyone "pitched in" to get a project rapidly completed. The staff included a carpenter, machinist, instrumentation technician and one or two construction helpers. Based on various correspondence, it is believed that the clients' engineers often came to assist in the testing.

During the Depression, power companies were a source of jobs and, some say, the life blood of politics at the time. During this ten-year period, power demand was doubling every six years (a 12 percent annual compounded rate).

After the Great Depression started, the holding companies symbolized to many the entrenched economic power of the Northeast because electric rates seemed to be unjustly high. Utilities refused to run power lines to rural areas because they claimed they could not get a decent return. Later studies showed that the utilities greatly inflated their cost estimates and only wanted to generate power for densely populated areas where their rate of return was higher. The abuses of the utilities led to various federal stock, financial and utility legislation in the 1930s.

Financial Crisis, Migration & Politics

As late as 1935, many rural areas, including nine out of ten farms, were not electrified. The lack of refrigeration and powered equipment caused great hardship. Manufacturers were scrambling to maintain production and artificially supported prices by offering attractive credit terms. However, the average wage-earner could not afford many of the products. Banks were enthusiastically lending money for stock purchases. Samuel Insull's power holding companies extended into 32 states from Maine to Florida. In 1932 in Texas, Insull (a former private secretary to Thomas Edison) was building the largest dam of the time. When his empire collapsed in 1932, investors lost virtually everything.

As the United States entered the 1930s, there was a national depression unlike anything that had happened in the past. In terms of length, severity and number of people affected, only the Civil War had been worse to this point in time. With no national social security, private charities and local governments tried to meet the needs of the jobless. In 1932, public land was turned over to the unemployed for gardens and almost 300,000 homeowners lost their properties by foreclosure. New construction fell 60 percent between 1931 and 1932. Unemployment would exceed 25 percent (the unemployed would reach 10 million) and millions had their wages substantially reduced. In Worcester, some office workers had their wages cut from $15 to $10 per week. In central Massachusetts, Quabbin Reservoir was built in the mid-1930s and workers were paid 25 cents per hour. It was estimated that total national income dropped 50 percent between 1929 to 1932. Five thousand banks permanently closed and nine million savings accounts were wiped out. A relief meal cost about 6 cents, but states could not afford to feed the hungry. With all of this, floods and drought still occurred.

In the Midwest, reduced rainfall began on the Great Plains in 1930. With the drought in 1933 came the wind and the dust bowls. From the Dakotas to Texas, east to the Alleghenies, wind stripped the farm land and forced the implementation of land conservation practices. Thousands of families were affected on a long-term basis, more than those affected by the floods and hurricanes of the period. From about 1935, a great migration occurred from Oklahoma, Texas and Missouri to California.

President Hoover was a conservative leader who generally believed in conventional economics. Change would have to wait for a new leader. As the Depression deepened in 1930, the Hawley-Smoot Tariff on foreign imports aggravated the crisis. Farmers and industrialists, many of the latter with near monopolies, were crying for protective tariffs on imports. Hawley-Smoot provoked retaliation by European countries on goods made in the United States. To do business in other countries, some industrialists built plants overseas. It was also in 1930 that initial funding for Boulder (later called Hoover) Dam passed in Congress.

An overall philosophy of the Alden Hydraulic Laboratory during the 1930s can be obtained from words written by Allen in early 1940:

> "The motto of the Alden Hydraulic Laboratory was chosen from an article written some time ago by Bruce Barton: 'When you are through changing you are through.' This motto has fitted conditions at the Alden Hydraulic Laboratory ever since its beginning. It has been especially applicable during the past decade. Although the laws of gravitation and of flowing water remain unchanged, viewpoints and ideas continually change with increasing knowledge. It is, therefore, the object of the Laboratory to provide the best possible facilities for further investigation of the phenomenon of flowing water and for sane instruction in the field of hydraulics."

It was also during the 1930s that staff from the laboratory first became involved with the American Society of Mechanical Engineers' (ASME) Power Test Codes (PTCs). This association would continue for about 50 years. In 1938, Allen, Norman Gibson and others were involved with writing PTC No. 18 on hydraulic prime movers. In 1948, Allen, Leslie Hooper (by this time assistant director of the laboratory) and Clyde Hubbard (by then a principal assistant engineer for a paper manufacturer) were all involved with updating PTC 18.

John R. Freeman's active devotion towards the building of a national laboratory during the 1920s was thwarted by the politics of the day. The US Army Corps of Engineers could see no need for such a facility, and at every opportunity opposed the creation of a national laboratory. The Corps anticipated infringement on their activities and the diversion of funds. It was not until Herbert Hoover was president that this dilemma was resolved. Hoover appointed Major General Lytle Brown to head the Army Corps of Engineers, knowing full well that Brown favored a national hydraulic laboratory and a Corps laboratory. Finally, in May 1930, Hoover signed a bill establishing a national laboratory with a restriction that the laboratory could not do work in the field of any other agency. This provision was probably one reason for the laboratory's failure to thrive. (Eventually the four-story national laboratory became a part of the Bureau of Standards of the Department of Commerce.) Ironically, Freeman's detailed plans for the national laboratory, presented free of charge, were never used and Freeman withdrew completely from any activities dealing with the laboratory. This disregard for a well respected authority who had for a decade advocated a national laboratory seems cruel and unjustified. Later, the federal government established the Bureau of Reclamation laboratory, which began testing in 1930 in Fort Collins, Colorado, at the Agricultural Experiment Station. This facility had been established in 1912 by Ralph Parshall. In addition, shortly after the Tennessee Valley Authority (TVA) was established, their hydraulics laboratory was developed in 1934 in Norris, Tennessee, the construction town for the Norris Dam.

Army Corps of Engineers' Hydraulic Laboratory

The Army Corps of Engineers laboratory was established by Congress in 1928. The site for the laboratory was Vicksburg, Mississippi, the location of the Mississippi River Commission. In 1930, Major General Brown employed Allen as a consulting engineer to meet with him in Washington, DC, and to visit the laboratory site in Vicksburg, to look over the plans and layout, and to make recommendations. This consulting work reflected the respect that people had for the work being done at the Alden Hydraulic Laboratory. In taking the assignment and completing it to the best of his ability, Allen showed his integrity and honesty since both AHL and the Corps laboratory were, in effect, competing for the same work. In the days that the Corps lab was being established, many projects for the Corps were being tested at AHL.

In Allen's consulting report to Brown, he wrote:

- The choice of Lieutenant Herbert Vogel to head the laboratory was excellent in view of his enthusiasm and knowledge of modeling. (It should be noted that Vogel had been assigned to study modeling tech-

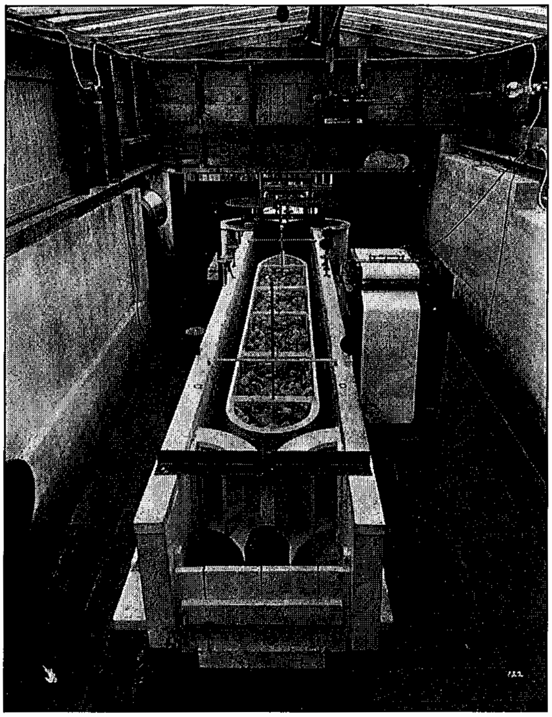


FIGURE 18. The navigation lock model for the Passamaquoddy Tidal Power Project.

niques for one year in Europe, and he joined several of the Freeman Fund Scholars during their second year in Europe. One of their major activities was visiting principal European laboratories.)

- In view of the large models that might be built, it is suggested that undeveloped land adjacent to the laboratory be acquired.
- Initially, work on models should go slowly because it would take time to get organized and to purchase the required equipment.
- There was a need for ample storage area. (This recommendation probably arose from Allen's experience with storing idle equipment.)
- To obtain the most benefit from the models, it was suggested that a good field man should be with the lab staff during the setup and testing of the models.

Corps Testing at the Alden Hydraulic Laboratory

While the Corps laboratory was being established, many of their projects were tested at the Alden Hydraulic Labaoratory. One of the biggest of these projects tested at AHL was the Passamaquoddy Tidal Power Project in Maine, a project that a half-century later is still mentioned as a possibility to produce tidal power. Six different aspects of the project were studied. Discharge flows through various gate designs were investigated using model flow rates of 23 cubic feet per second (10,350 gallons per minute). The application of sector gates for filling and emptying the proposed navigation locks was also studied. As part of the lock filling process, recorded measurements of all restraining forces on a ship in the lock were made (see Figure 18). A study was also conducted of three different methods of constructing a rock-filled dam under conditions of reversing flows. A final investigation involved plotting underwater rock trajectories during the construction of the underwater portion of the rock-filled dam.

Up until the time of World War II, the Alden Hydraulic Laboratory would conduct 11 more studies for the Army Corps of Engineers. The prototype projects were located in all the New England states except Maine. As the result of the 1927 New England floods (the worst since 1869), the spring floods of 1936 and the great hurricane of 1938, the emphasis of the studies was on flood control. Spillway calibrations as well as tunnel exit flows (outlet works) were studied for Union Village, Vermont; Knightsville Dam and Northampton Dike, Massachusetts; and Surrey Mountain, New Hampshire. In addition, flows through conduits and/or tunnels were investigated for Union Village, Vermont; Mill River, Massachusetts; and Park River, Hartford, Connecticut.

Model Testing in the 1930s

Dam and spillway studies were not only precipitated by floods but also by the need for more electric power. On May 18, 1933, the Tennessee Valley Authority (TVA) was established to control and develop the Tennessee and the Cumberland river valleys. These projects provided much work in these hard economic times and may also have been an inspiration to promote other hydropower sites in the United States.

Model spillway studies were also conducted for the Bills Brook Project in Hartford, Connecticut; the Molly Falls Project in Marshfield, Vermont; and the Holtwood and Safe Harbor projects in Pennsylvania. In 1936, a cone-valve outlet model was tested for the Hartford, Connecticut, Metropolitan Water Bureau District Commission. These tests were to prove correct design and ensure the absence of cavitation. For Holtwood, also in 1936, an outside test flume was used to determine pressure distributions on the crest and the spillway discharge coefficient. An outside model was used for Bills Brook.

The limitations of conducting model testing outside would continue for several decades. Alden Hydraulic Laboratory was unique in the large size of projects undertaken. Models were constructed in early spring for testing until the following winter. Wind breaks were used to minimize wind-induced currents.

An interesting study in 1935 involved the use of the Rock Island model that had been dormant for five years. A lawsuit had been initiated relative to damages below the dam and powerhouse. To provide information for the case, river flows were investigated with and without the dam and powerhouse in place. The diversion of flow around Rock Island in the channel below the island was also observed. The re-use of models after the initial study had been concluded occurred a number of times at AHL over the years, and this possibility is given as a reason for retaining a model for a few years after tests have been concluded.

From 1937 to 1938, New York City was investigating the expansion of its water supply system. Intake control works for a roundout on the West Branch Tunnel and a diversion tunnel on the Lackawack Dam were studied using models to ensure proper hydraulic conditions. Clyde Hubbard was very much involved with these and other tests. In correspondence between the New York City Board of Water Supply, Allen suggested — and apparently this was done — that the work be separated into two contracts and staggered in time so the total cost of the first project would be known prior to starting the second project. In Allen's words, "in this way, the overall safety margin in the bid would not be excessive and the lowest possible price would result." The extent of the tests for the control works is notable because of the complexity of the model and the concerns with capacity, efficiency of operation, minimizing air entering the tunnel and the prevention of cavitation in the full size structure. At the end of this period, Leslie Hooper became assistant director at AHL, and Clyde Hubbard left the laboratory to enter the US Navy.

Other than theses studies, the 1930s were rather quiet at Alden Hydraulic Laboratory, perhaps due to the economic times. However, pitometer, ship log and current meter calibrations continued to be performed. Flow calibrations were also performed on 20- and 24-inch Kennison flow nozzles and 12- and 20-inch Venturi meters. Flow meter calibrations were also performed for a company in Philadelphia, Pennsylvania. At least as early as 1931, AHL was doing head loss tests for various types of valves.

Consistent with the Alden Hydraulic Laboratory's philosophy of studying all types of fluid mechanic phenomena, the lab was contracted to study the best designs and features for a rowing tank for Yale University's Payne Whitney Gymnasium using a 1:5 scale model. The actual tank, powered by two 100-horsepower pumps, was first used in the winter of 1931 and 1932 to train the Yale rowing crews. Two more practice tanks were constructed at Yale using some refinements of the original tank. (Allen must have enjoyed this study that came three decades after his thesis on an oarsman's indicator.)

Further Laboratory Expansion

During the 1930s, Allen did not neglect the expansion of laboratory facilities. Using money donated by the Alden Trust Fund, Allen continued to maintain up-to-date facilities. In 1936, an addition was made to the main laboratory. It included a lecture hall on the top floor and a basement laboratory. This laboratory was later called the "student laboratory" because of the large number of student experiments that were conducted in that facility. At the same time, a steam heating system was installed, and the main building was completely equipped with a sprinkler system for fire protection. In 1937, the "river laboratory" was constructed (see Figure 19). This facility was surrounded on three sides by windows that provided adequate light for

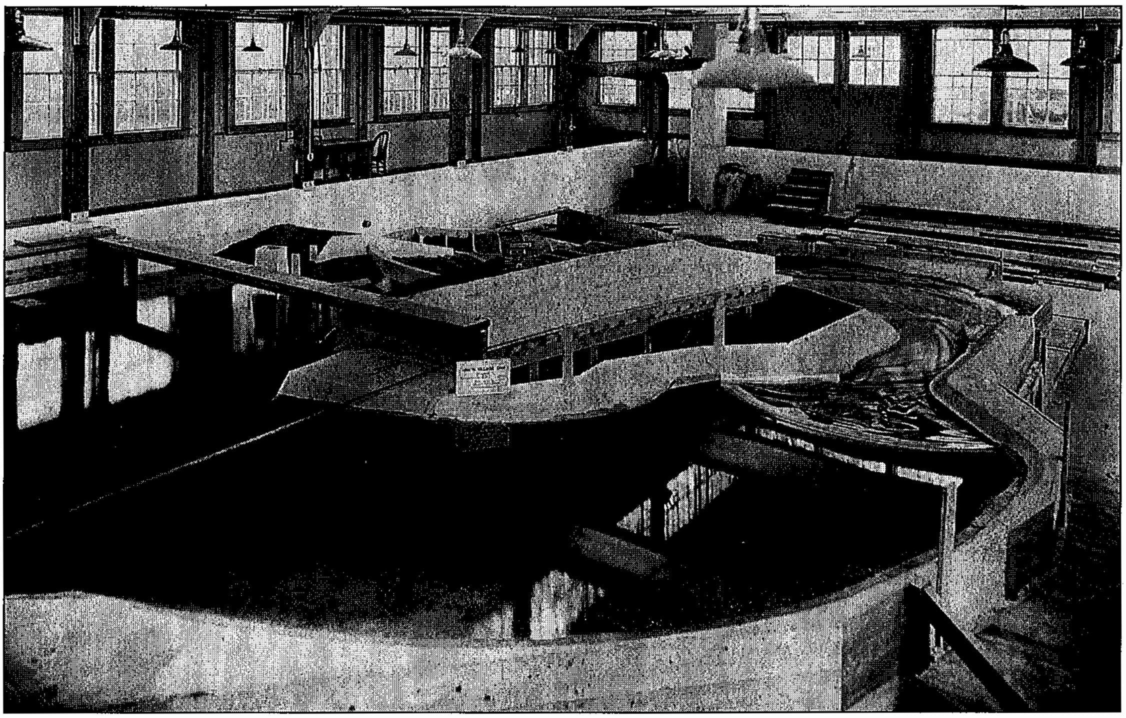


FIGURE 19. The river model laboratory.

photographing models. In addition, this heated facility allowed fairly large model studies to be performed during winter.

In 1930, the WPI trustees voted to expand AHL by acquiring the Fairbanks farm that adjoined the laboratory property. Expansion was required because the existing facilities were so cramped with models and equipment that room for student use was almost non-existent. The farm's barn was used to store "idle equipment," while the farmhouse was converted to drawing rooms and dining facilities for the Civil Engineering students who held surveying classes at the laboratory during their fall practice. The students lived in tents in the fields surrounding the farmhouse.

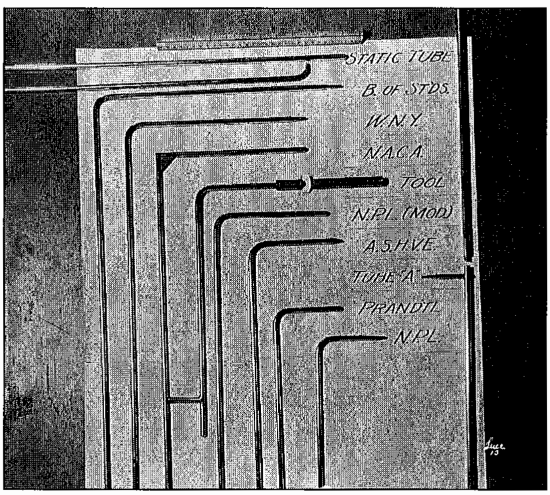


FIGURE 20. Pitot tubes studied by Hubbard.

Alden lab staff also provided instruction for WPI students. Teaching of all hydraulic courses was assigned to the laboratory and was carried out in this period by Allen, Hubbard and Hooper. During one half of the first semester, a senior laboratory was conducted three afternoons a week, and there was also an all-day waterwheel test each week. During the second semester, advanced hydraulic laboratory and thesis work represented the students' activities. During the summer months, WPI sponsored a program called Techniquest, which was designed to show high school students various aspects of engineering studies. Part of this program was staged at the laboratory where Allen delighted in showing the prospective WPI students the models and various projects at the facility. One of the highlights of Techniquest was

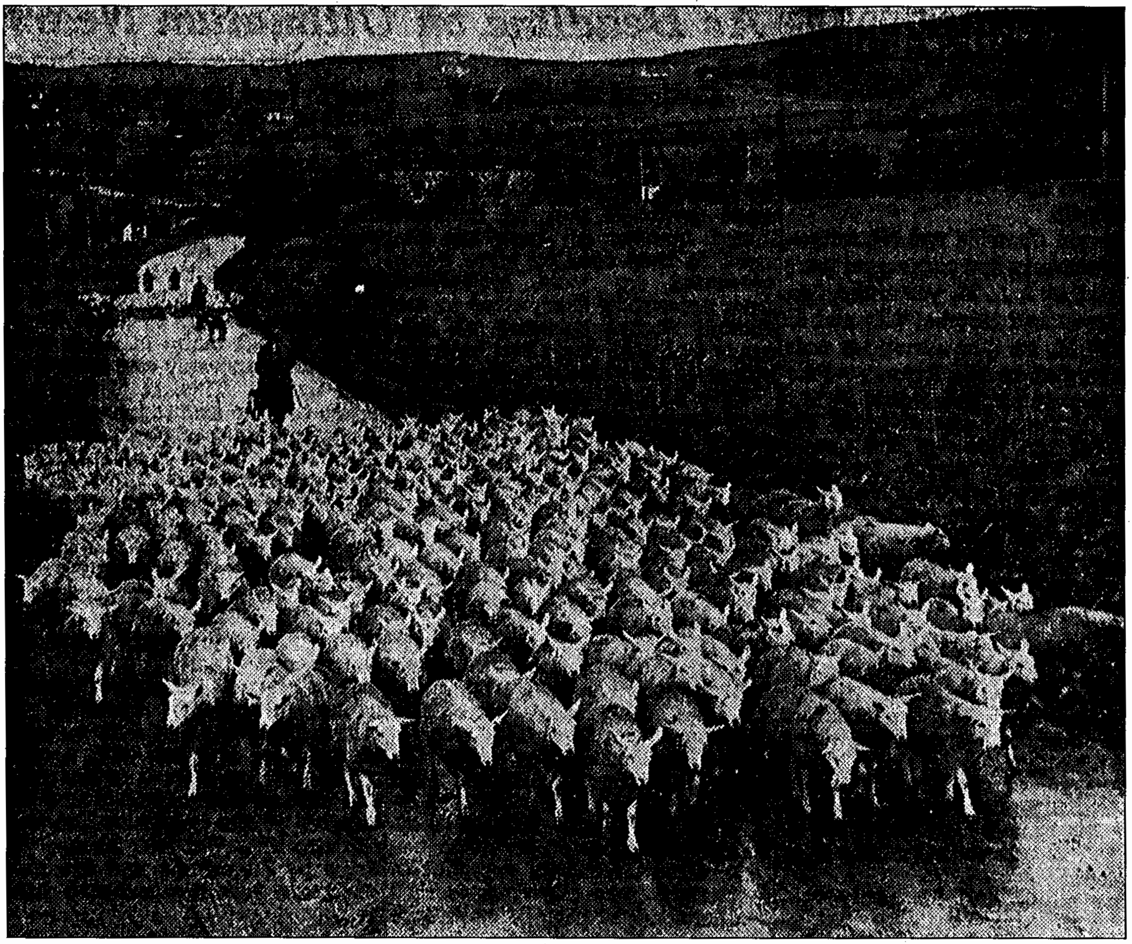


FIGURE 21. Allen's sheep nibbling on grass example of velocity profile.

a picnic at the Fairbanks farm. Allen's teaching style was much appreciated by students because of all the stories he told to illustrate significant points.

Applied Research

When Alden Hydraulic Laboratory staff were not busy with student or project responsibilities, they engaged in research of their choice. Hooper was involved with investigating pressure measuring errors due to variations in piezometer features. He published his findings with Allen in 1932 in an ASME paper entitled "Piezometer Investigation."[20] To this day, it is used as a reference in this area. Hubbard concentrated on examining errors in using pitot tubes. His paper, "Investigation of Errors of Pitot Tubes," was also published by ASME and explained a variety of ways by which pitot tube measurements could be in error.[21] Many pitot tubes were tested (see Figure 20).

Allen continued with his flow measurement studies. In 1934, he published "How Water Flows in a Pipe Line."[22] His discussion of turbulence using the analogy of sheep nibbling on grass is classic (see Figure 21). (In 1947, it became a part of a laboratory Christmas card.)

The 1930s were enjoyable for the laboratory staff, and provided full-time employment in difficult economic times. However, there were some anxious moments. The laboratory had some peculiar financial arrangements with WPI, some of which included getting paid only after a project was completed. This practice occasionally was a hardship for the staff so Allen often paid them from his own pocket and was reimbursed when the funds came through.

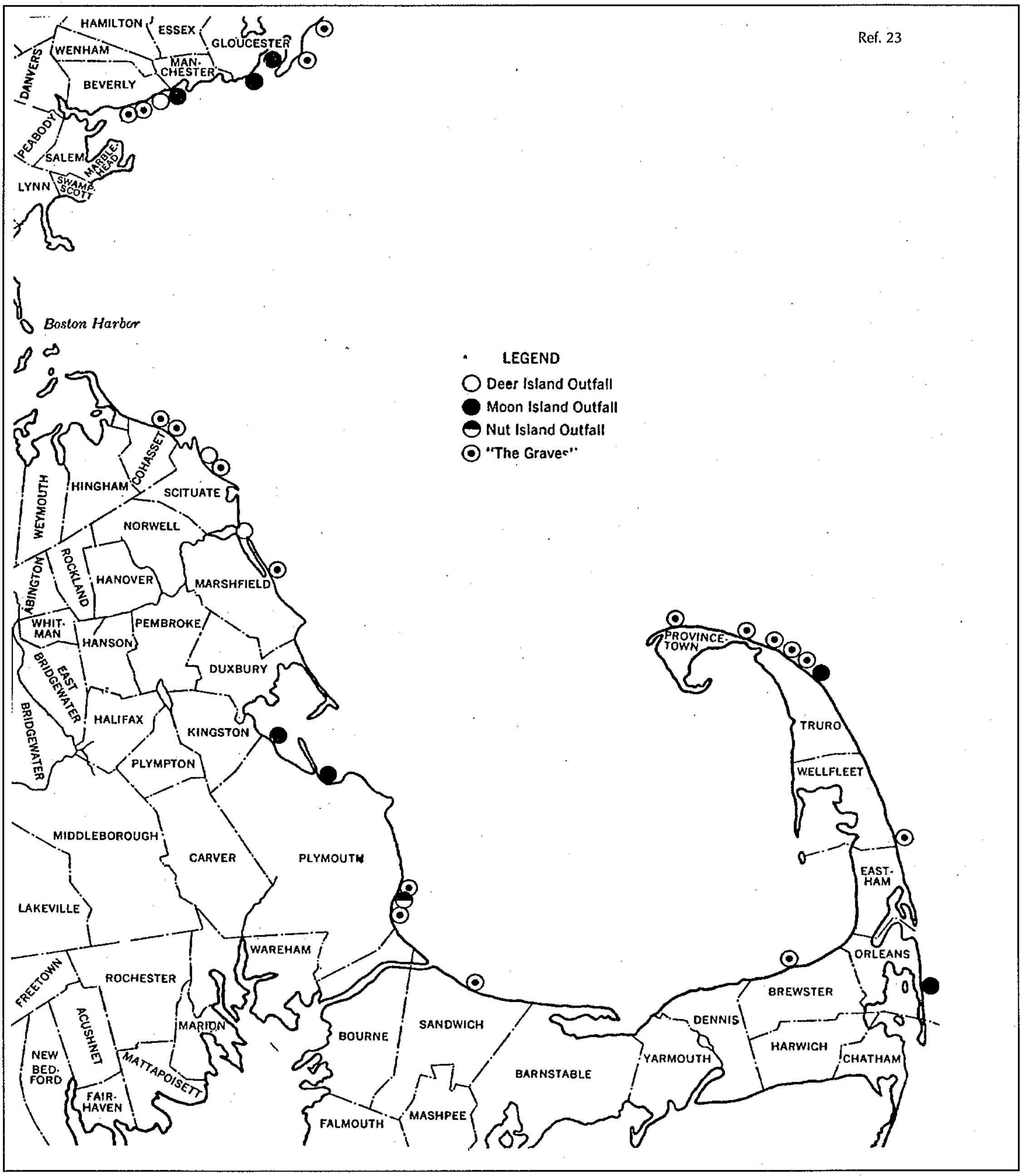


FIGURE 22. Pickup points for float chips dropped at various points in Boston Harbor.

Boston Harbor

At the end of this period, one local concern was the cleanup of Boston Harbor. Prior to 1940, rather comprehensive studies had been performed to determine harbor flow patterns and any changes that resulted with the dredging, filling and construction of Logan Airport. Pollution had not yet depleted the oxygen in tidewaters sufficiently to cause an odor nuisance, but there had been increasing aesthetic demands because of sleek waters and beach pollution. Flow tests in 1935 and 1936 were used to follow discharged material. Surface and deep submergence floats along with chips were used to get current patterns. Figure 22 indicates the distant locations where some surface chips were found. Various solutions were promised, and experimental treatment plants were established on Deer Island. These plants consisted of fine screens, a settling tank and a pre-aeration tank to aid grease removal. Other experiments were conducted to remove suspended solids. The sanitary concept of the time was to determine the capacity of the waters in which the effluent was to be discharged in order to replenish the oxygen that would be consumed by the bio-chemical purification processes.

An outfall sewer (tunnel) having multiple outlets discharging in the Boston's outer harbor near The Graves was considered but eliminated because of cost. Furthermore, based on float tests, engineers realized that it would still be necessary to remove grease and floating matter. The float chips (patterns) indicated that some flow at The Graves would return to the harbor and other coastal points, which would be objectionable to beach activities.

The New Deal & Electric Power Industry

As the Great Depression deepened to its low point in 1932 and 1933, the people of the United States focused their attention on a new president. Hoover was not able to rally the country or make the changes necessary to get the economy going. The election brought Franklin Delano Roosevelt into office and fundamental changes came to all aspects of US life. Industries including banking, securities, electric power and others were altered. Unions, work place job security and retirement were also affected.

Roosevelt was elected in November 1932, carrying all but six states, four in New England. During the lame-duck period that extended into March (in accordance with the Constitution), the conditions in the country deteriorated since Hoover and Roosevelt were unable to come to any working agreement. (The 20th Amendment to the Constitution was speedily proposed by Congress in March 1932 as a direct result of the experience with the Hoover-Roosevelt transition. That amendment, which changed the date the new President assumed office to January, was ratified by February 1933. Prohibition also ended in 1933.)

The country had to withstand two serious shocks. As the lame-duck period was ending, the nation's banking system was in a state of collapse. Panicky citizens were holding cash to the point that some cities were printing script for local use. Also, about two weeks prior to Roosevelt's assuming the office on March 4, an assassin's bullet killed Chicago's mayor Anton J. Cermak and just missed the President-elect.

In his first 100 days in office, Roosevelt brought about the New Deal. The New Deal legislation brought Social Security, the Works Projects Administration (WPA), the National Industry Recovery Act (NRA), the Tennessee Valley Authority (TVA) Act of 1933, and others. The most far-reaching in terms of the electric power industry was the Security-Exchange Act in 1934 and the Public Utility Holding Company Act in 1935. These two acts set up numerous financial safeguards, and passed a "death sentence" against all far-flung utility holding companies by 1937, except those servicing a "geographically and economically integrated system."

The TVA Act had several purposes, one of which was fostering competition and general rate reductions. The TVA was to serve as a yardstick by which to measure the cost of private power. Some utilities had regularly lowered rates. In fairness, a cost comparison between a public and private enterprise can be very difficult because of allocations for various activities such as flood control, navigation, soil rehabilitation and finance costs. However, whether due to the Depression, efficiency in scale and design, competition or other factors, rates and profits in the utility industry did go down during this period throughout the country. The average residential rate for the whole country declined from 5.5 cents per kilowatt hour in 1933 to 3.67 cents in 1942. The price of TVA power was about 3 cents per kilowatt hour.

Ongoing power supply costs also decreased. In 1934, Barrows noted that "steam plants at public utility plants now average only 1.5 pounds of coal per kilowatt hour and large plants at tidewater can produce power at 0.75 cent per kilowatt hour and less."[24] By comparison, in 1919, 3.2 pounds of coal was consumed per kilowatt hour.

While the price of power charged to the consumer in terms of production cost may or may not have been excessive, the simple fact is that most people (if able and connected to a system) were more than willing to pay the price for the convenience and improvement in life. Industrial usage dropped, but residential use increased substantially. Without increased residential use, many utilities would have failed because towns and cities were not paying their bills. One of the ingredients that allowed some utilities to meet their revenue needs was the greatly increased load due to refrigeration. In the system serving greater Philadelphia approximately half of the residential customers discarded their ice boxes between 1933 and 1938.[25] The average yearly residential power usage increased from 499 kilowatt hours in 1929 to 959 kilowatt hours by 1938.

Roosevelt saw the TVA as a multi-purpose regional planning agency for a seven-state poverty stricken area that had been abandoned by private utilities. Less than 2 percent of the area was electrified. He envisioned that products made in the region would be transported out by the navigation system and, thereby, the entire area would become self-supporting.

The charter for TVA promoted "flood control, navigation, electric power production, power distribution, proper use of land and resources, and the economic and social well being of the people." Even though Roosevelt criticized the private power industry, the TVA was created as a corporation vested with the power of government but operating with the flexibility and initiative of private enterprise.

Private utilities saw public power agencies as a real threat to survival and tried to block parts of the New Deal in the federal courts. These cases lasted for years, and the Supreme Court would generally rule in Roosevelt's favor on these matters.

The private electric power industry was undergoing great turmoil. With the Supreme Court's ruling upholding the Public Utility Holding Company Act of 1935, as of December 1, 1938, all holding companies were required to submit proposals for the integration and simplification of their properties.

Another threat to the private utilities was the Rural Electrification Administration (REA), which was started in 1935 because 90 percent of farms did not have electric power. In some areas, private utilities quickly responded by wiring large areas and bringing new customers on-line. These customers added needed revenues to hard-pressed utilities.

In the first 100 days of the New Deal, numerous reforms and programs in banking, finance and public works were started. Programs in public works were designed to put people back to work. One of the most far reaching was the Works Projects Administration (WPA) under Harold L. Ickes, Secretary of the Interior. The purpose of the WPA was to stimulate heavy industry via the authorization and construction of large public works. One WPA project, the Boulder (Hoover) Dam was completed two and a half years ahead of schedule with work going on around the clock. Bridges, military airports, hospitals, water supply works, dams, canals, sewers, flood control and irrigation projects, wind tunnels for plan design, housing, and some naval warships (later limited by Congress) were constructed. WPA built parts of the TVA, Grand Coulee Dam, Bonneville Dam on the Columbia River, Fort Peck Dam, Boulder Dam and other projects.

The success of the TVA gave rise to authorization of more limited river development projects not having the completely integrated regional planning. In 1937, "projects" were authorized for various regions including the Arkansas River Valley and the Lower Colorado, Ohio, Missouri and Red rivers. In hindsight, knowing the tremendous power needs in World War II and the special role of the TVA region, for many reasons the United States was fortunate that the TVA was created. In addition, the TVA would eventually grow to be the largest generator of electric power in the United States.

Prelude to Another War

At the end of the 1930s, the world was in chaos with Hitler conquering one country after another in Europe and the Japanese doing the same in Asia. When the United States went to war in December 1941, the Alden Hydraulic Laboratory was nearly a half-century old as it embarked on new work related to helping the United States defeat the aggressive forces of the Axis.

In 1939, the US government initiated a program that would use science to aid military efforts should the country enter the war. Aside from the Manhattan Project to develop the atom bomb, a large part of the funding for military developments was spent to finance experimental equipment at existing government facilities, such as the Naval Ordnance Test Station in China Lake, California. Some of the funding was made available to universities and private institutions to conduct basic research for military applications. As part of the program, Columbia University was contracted by the Office of Scientific Research and Development to organize research at various institutions in the fields of medicine, nutrition and weapon development. In 1941, the Alden Hydraulic Laboratory was approached to perform preliminary feasibility tests in the field of hydroballistics. When approached by the US Navy, the laboratory agreed to help and signed an open-ended contract that lasted until 1975.

The electric utility industry, as all other industries in the United States, rallied during the 1930s and 1940s to meet the nation's electric energy needs. National defense spending, lend-lease to England and a general build-up started in about 1939. Finally, the Depression ended virtually everywhere in the United States during the beginning of World War II — when Poland was invaded on September 1, 1939, when France fell in June 1940 and when the Battle of Britain began.

Power Industry & Engineers Respond

The TVA system went through an enormous, rapid expansion. In 1940, four new dams were completed and another three more were under construction. By mid-1942, TVA had 12 dams in operation and a steam plant under construction. TVA employment reached 42,000. Records were set by construction forces working around the clock to build plants and produce energy for several critical needs.

In 1942, Oak Ridge, Tennessee, was adopted as the location for a mysterious undertaking that later would be called the Manhattan Project. The site was selected for its remoteness, generally low population, distance from the coast and potential bombing, and available power. Numerous specialized facilities were needed on a "crash" schedule and a city for 75,000 people had to be constructed. Critical manufacturing plants were located in adjacent valleys so that shielding was provided by the hills against premature explosions.

Three-fifths of the elemental phosphorous for incendiaries, smoke screens and other uses also came from the TVA. In addition, aluminum plants in the valley ran continuously.

Engineering and construction companies built all of the facilities needed to equip the miliary in its global needs — munitions plants, foundries, rubber plants, refineries, chemical plants, shipyards, naval bases, refineries, pipelines and other facilities.

Electric power systems underwent expansions and were faced with war-time shortages and allocations. The manufacture of civilian commodities ceased. Turbines necessary to meet power demand were allocated to the war effort, with naval carriers having first priority. In general, there were no electric power shortages, but instances of restrictions and brown outs (voltage reductions) did occur. In February 1942, Congress enacted wartime daylight savings to reduce the evening peak power demand. In the East, power restrictions were most severe around Christmas 1943 when decorations and lighting were discouraged. The war effort also taxed power plant workers and some strikes and labor unrest occurred. The Los Angeles municipal power system (the largest city owned public utility) was shut down in February 1944 due to workers protesting a small wage increase. Ten days later, the US Army took over the system.

Hydroballistics — Water Entry

By the beginning of World War II, the Alden Hydraulic Laboratory staff was beginning to change. Lawrence C. Neale, a WPI graduate and a future laboratory director, was hired in 1940. Clyde Hubbard left in 1941 to work with a well known consultant, Joel B. Justin, co-author of a popular book on hydropower, first published in 1927.[26] In 1942, Hubbard was commissioned in the US Naval Reserve and, due to his experience at AHL, was immediately assigned as the officer in charge of the design and construction of the circulating water channel for the David Taylor Model Basin. As the war effort was stepped up, other WPI personnel, especially in the area of electrical engineering, were added to the laboratory staff.

During World War II, student work continued at AHL, and many of the students were part of the US Navy V-12 program. Private test and consulting work essentially came to a standstill during this period since all the staff were involved in the experimental Navy program. The open-ended Navy contract paid the laboratory $40,000 per year to quickly solve problems by testing. The contract enabled various agencies to obtain experimental results without going through a lot of red tape. The work at the Alden Hydraulic Laboratory was generally related to thewater entry of ballistic weapons. At the beginning of the war, many torpedoes and bombs entering water from the air experienced instabilities of their underwater trajectories and were, therefore, ineffective. Studies in this area became an AHL specialty. Testing in this area was developed from scratch since none of the facilities or equipment needed to perform this work existed when the original Navy contract was signed.

Most of the work in water entry involved the use of high-speed photography. At the start of the contract, Leslie Hooper, the Alden Hydraulic Laboratory Director, had contacted Victor Sepavitch, an electrical engineer at a textile factory in Worcester, Massachusetts. Previously, Sepavitch had worked at the laboratory when he was a graduate student at WPI. Hooper knew that Sepavitch was studying the motion of looms using high-speed photography and strobe lights — a method recently developed by Harold Edgerton at MIT. This technique, Hooper thought, would be perfect to study ballistic missile behavior during water entry and during the initial stages of air cavity formation behind the projectile in the water.

The first photographs were stop-action, strobe-lighted pictures taken in the 50,000-pound weigh tank in the main AHL building in late fall of 1941. These photographs were a success, but the tank did not lend itself well to photographing the phenomenon since the tank did not have glass sides that permitted easy viewing of the projectile models. In the winter, Hooper consulted with both Sepavitch and Edgerton (who was later known as "Papa Flash") regarding high-speed photography and methods that were being implemented and considered for the Navy work. At this time Japan bombed Pearl Harbor, and the United States formally entered the war. The military research programs were accelerated, and the laboratory became more active in its studies of the water entry of ballistic projectiles.

In 1942, Hooper, Neale, Professor Hobart Newell (from the WPI Electrical Engineering Department) and some technicians began water entry work at the MIT swimming pool. Edgerton had offered the use of his high-speed strobe lights, 16-mm movie cameras, technicians and facilities for developing and processing the film. It was felt that doing the work at MIT was easier because the photographic equipment was readily available and the pool had a glass port on its side that could be used to photograph water entry. However, the MIT pool was required during the day for the Navy V-12 program. Alden Hydraulic Laboratory staff were only allowed to use the facility from 10:30 p.m. to 6:00 a.m. and had to erect and dismantle their equipment every day. Travel to Boston every day, plus the odd hours and the added work of daily equipment set-up and removal, took its toll on everyone concerned. Edgerton then suggested that he could lend the laboratory a spare 16-mm movie camera and could rig a few lights that could be used in Holden.

Testing began at AHL with the equipment loaned by Edgerton, augmented by Sepavitch's strobe lights. Edgerton had supplied Newell with circuit diagrams that he could use to maintain the system. Newell improved on many of the circuits, increasing the efficiency of taking photographs. The equipment was initially set up in the basement of the main building, using a 3-foot deep glass-sided flume to observe the water entry process. It was soon apparent that this facility needed improvement because of its limited size.

Hooper investigated other nearby facilities and obtained permission to use the US Navy's submarine escape training tower in New London, Connecticut. This facility was a 50-foot high circular tower with glass-sided ports. After some initial work, it was decided that the

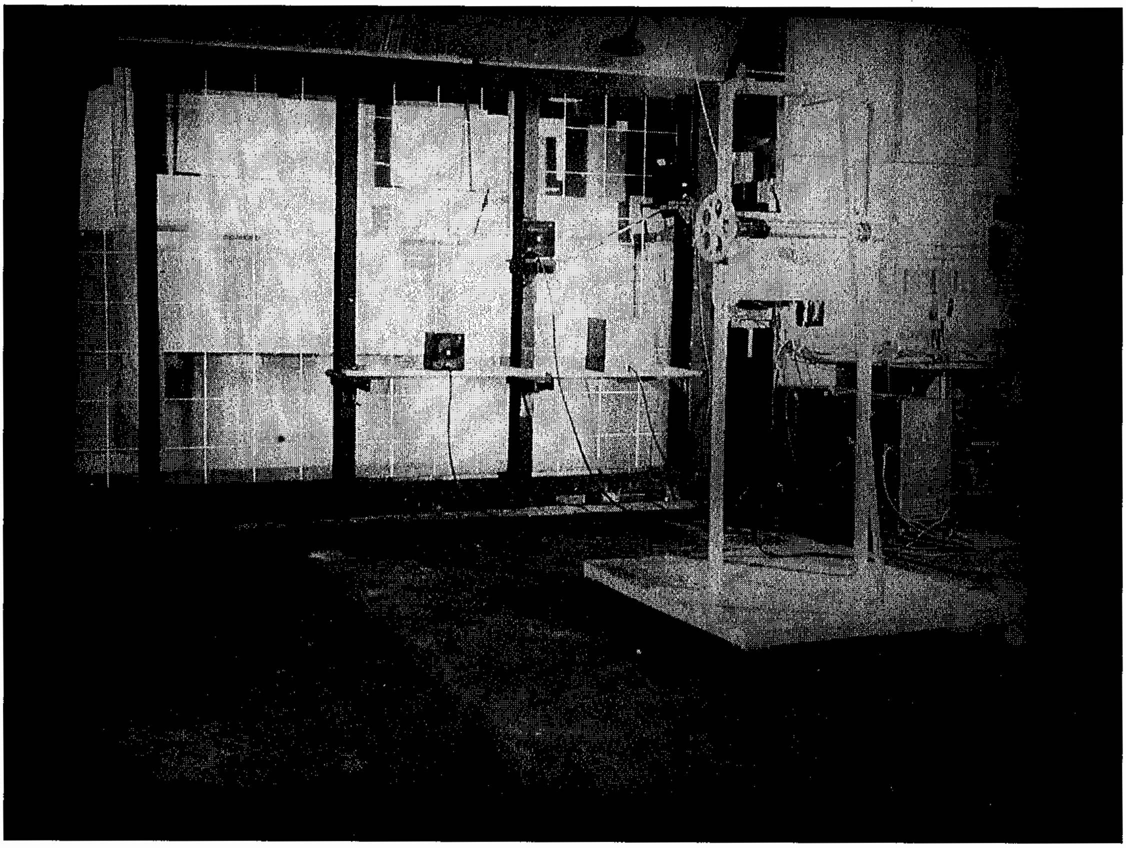


FIGURE 23. Glass-sided tank for entry studies.

same problems encountered at MIT were present in New London; therefore, testing there was discontinued.

In the late spring of 1942, plans were made at Alden Hydraulic Laboratory to erect a glass-sided tank (see Figure 23) for entry studies in the relatively new "river laboratory." Due to security, and for photographic reasons, all the windows that had been installed in this laboratory were covered. The "river laboratory" only had a brief existence. The tank that was installed was 9 feet high by 5 feet wide by 16 feet long. It consisted of a steel frame with four 4-foot by 9-foot by 1-inch thick annealed glass plates in the front and redwood for the rest of the tank. (In the late 1950s, the wooden portion was replaced by steel plate.)

The equipment necessary to conduct the studies consisted of a camera, strobe lights, model launchers and electronic circuitry. The 16-mm camera that had been borrowed from Edgerton had the disadvantage of being slow and its film was small, which reduced sharpness when enlarged prints were made. Hooper designed a new camera and had it built by Carl Anderson, a laboratory machinist who had come to AHL from WPI. The camera consisted of a lens and a drive mechanism of two wheels with slightly raised rims, and used 70-mm unperforated film in a roll. One wheel of the drive mechanism was driven by an electric motor and the other wheel was connected to an electric solenoid. The film was threaded between the rollers and, upon actuation of the solenoid, the rolls pinched the edge of the film and drove the film past the lens into a receiving container. The strobe lights acted as the shutter while the film was in motion. The problem with the camera was that it tore the film from the roll during the initial film acceleration, but this problem was solved by the insight of a student working at the laboratory after returning from a Christmas party. He suggested that the film be removed from the roll and configured like Christmas

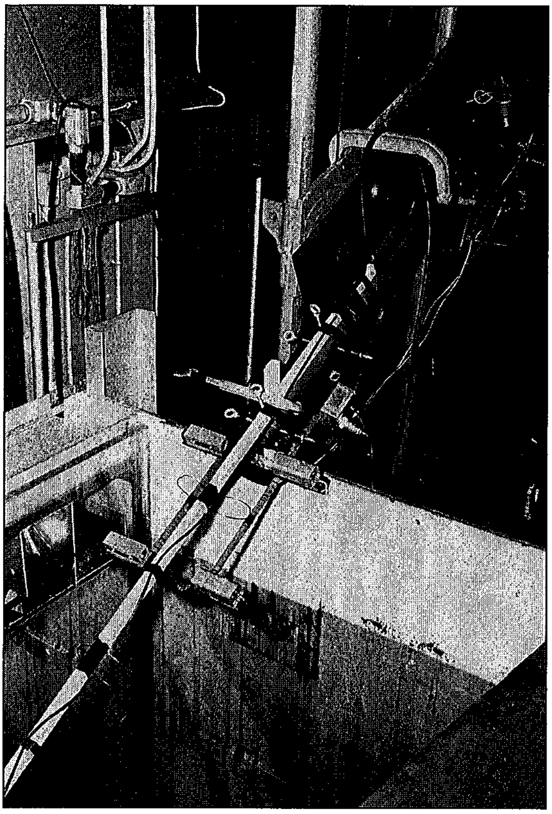


FIGURE 24. Pneumatic blow gun with barrel, velocity indicator apparatus and antenna.

candy ribbon in a separate container. By so doing, only a small section of the film would be accelerated at a time. The scheme was tried and it worked like a charm.

The strobe lights used were originally from Edgerton. Newell rigged new lights that were extremely bright for very short durations and required huge banks of capacitors. To keep moisture from harming the capacitors, they were placed in a separate room adjacent to the river laboratory.

Initial water entry studies involved dropping the models in the tank. This technique sufficed at first, but it lacked the flexibility required for a thorough evaluation of critical phenomena. To study vertical as well as angled water entries, a pneumatic-type blow gun (see Figure 24) was designed by Hooper, assisted by one of his WPI classmates, Ray Tower, a chief engineer and owner of a paper box plant. The gun used carbon dioxide gas as a propellant and operated as a differential piston. The original gun had problems with the escaping gas creating a disturbance on the water surface. This problem was quickly remedied by a spool attached by a rod to the piston that stopped in guides just before the model was released.

The models used in this gun were normally 1.25 inches in diameter and were quite sophisticated. They were usually constructed of more than one kind of material. Besides modeling the shape and total weight, the center of gravity and the moment of inertia needed to be properly scaled. Numerous nose and tail pieces were needed as replacements for those pieces that were damaged during errant trajectories. Most pieces of the models were machined on equipment that was normally used to work on watches. The threaded parts of the models fit so perfectly that it was often impossible to tell where one piece ended and the other began.

For proper operation, the principal requirement was a system that synchronized all components so that they would work exactly when required. Professor George Stannard of the WPI's Electrical Engineering Department designed and constructed a sophisticated timing system, consisting of 76 electronic tubes, fans, relays, variable resistors and motors. This system enabled the operator to automatically initiate a sequence of events, starting with the firing of the guns, followed by the start of the camera, with the strobe lights starting to flash just prior to the model ordnance entering the water (see Figure 25) and reflected, as sometimes occurred. The number of strobe pulses could also be scheduled on the timing system, varying anywhere from one to one thousand pulses per second. The resulting cavities were compared (see Figure 26 on page 40). The total system was so unique that engineers from a major camera and film manufacturer visited to inspect the facility.

To supplement information from the main tank, a 3-foot diameter vertical drop tank was erected in the north corner of the main laboratory. This tank permitted no access with which to photograph water entry; instead it was used to confirm some values of velocity and acceleration observed in the large tank. Ordnance models tested in this smaller facility were

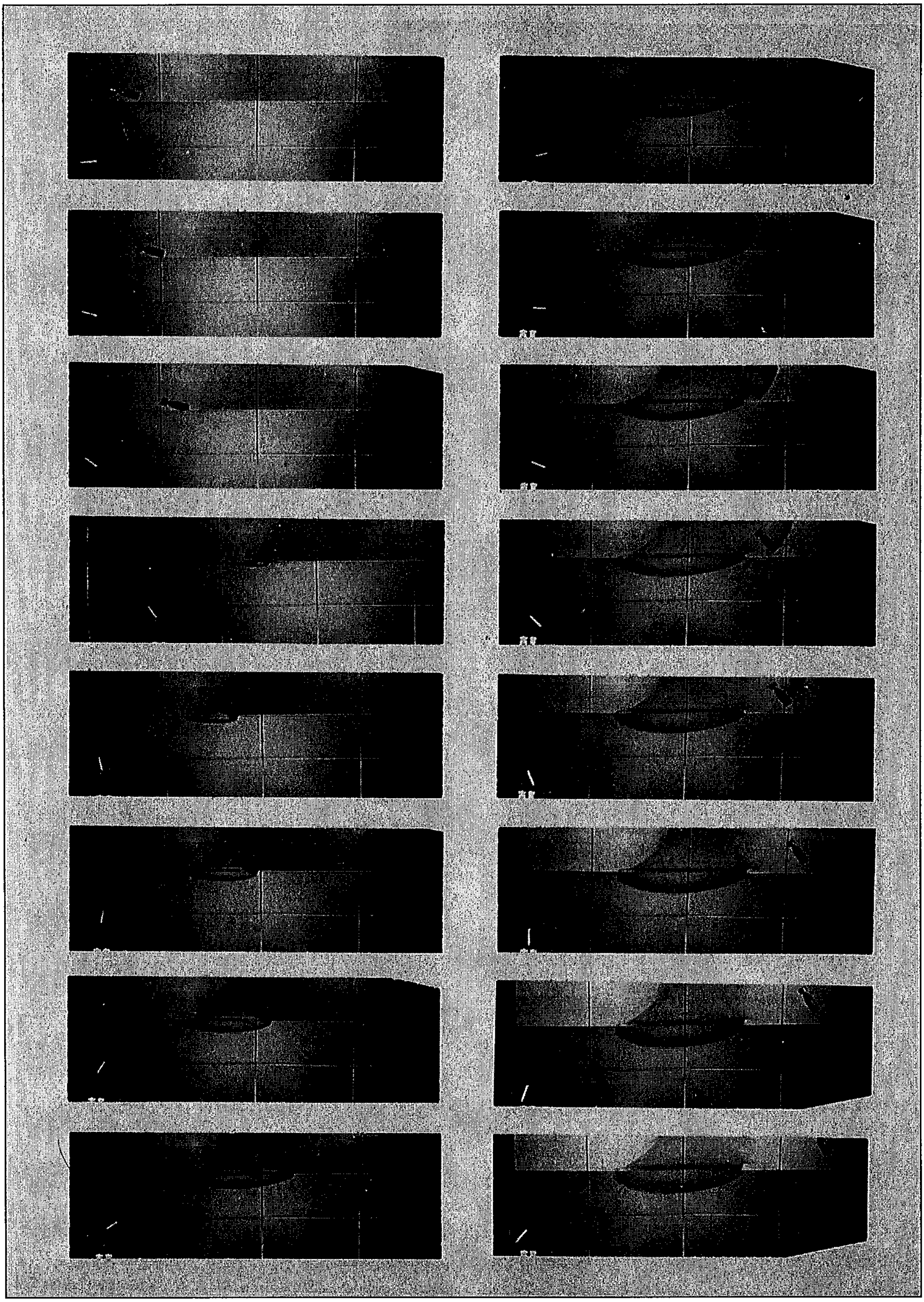


FIGURE 25. A projectile reflecting from the water surface.

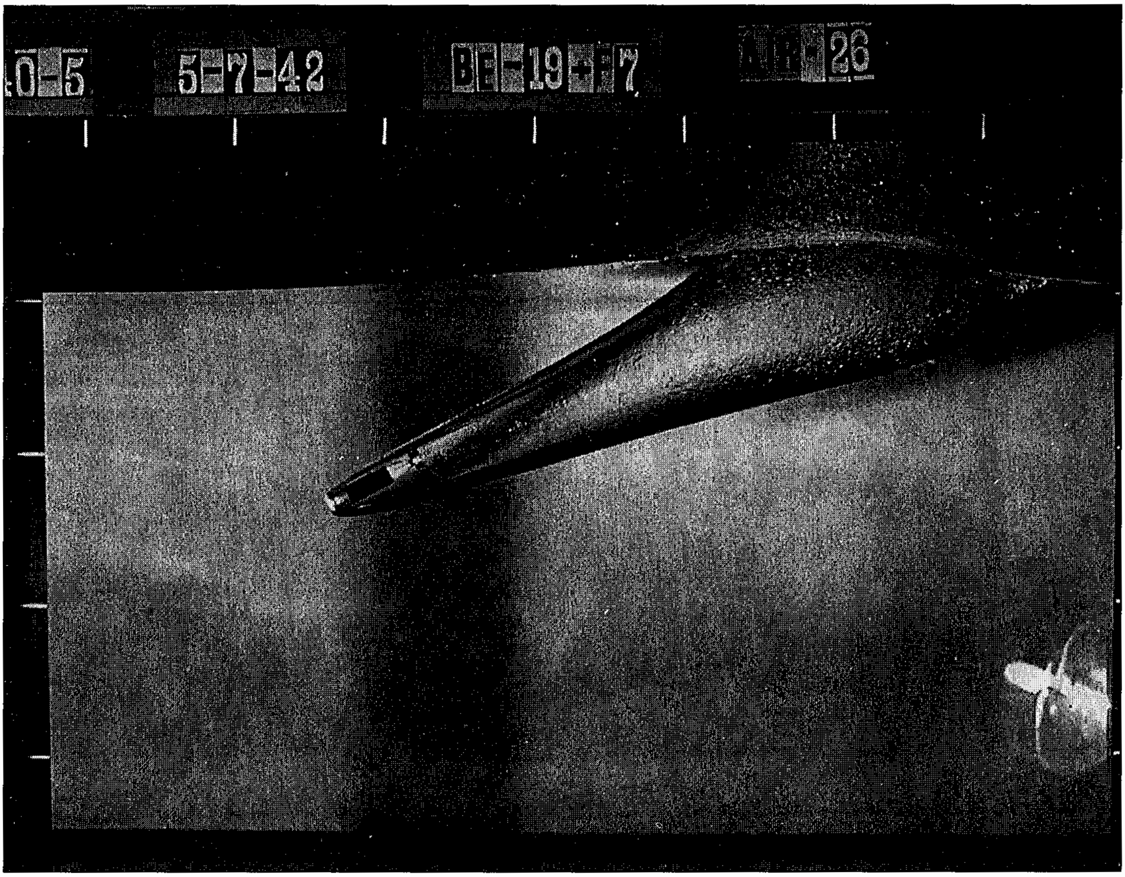


FIGURE 26. The cavity formed at entry.

equipped with a magnet, and a system of coils was mounted vertically every 2 feet in the tank. The coils sensed the model as it went by and sent a signal to a chart recorder. From these tests, accurate time-distance diagrams were obtained and used to plot the velocity and acceleration of the models. In the main tank, this information was obtained by hand-plotting model position frame by frame using the photographic film.

In 1943, another test tank was added to the river laboratory. This tank was 4 feet high by 5 feet wide by 18 feet long and was used to study high-speed water entry. The gun used in this facility was a converted 50 caliber gun. Hand loading of the ammunition allowed obtaining the various entry velocities. Models were mounted in specially designed plastic sabots that would break and release the model prior to entry; a special container caught the sabot parts, preventing them from entering the water.

Among the ordnance types tested at the Alden Hydraulic Laboratory during World War II were depth charges, plunge bombs, jet-propelled devices, bullets and buoyant devices. Thirty-five different models of depth charges were studied. A few of these had better trajectories and faster depth penetration than those used by the Navy, but they were never produced for actual use.

The plunge bomb model was a device made using drawings obtained from the capture of a German experimental facility. Reports captured with the plans described the bomb as having excellent water entry characteristics. Because of this feature and since the bomb seemed to be simple to manufacture, the Navy wanted the shape tested. All of the tests at AHL failed to confirm the claims. In fact, most of the models displayed extremely unstable behavior at water entry with a tendency to tumble after entry. (It was not until after the war that the truth was learned. At a scientific meeting in Europe, Neale met one of the scientists who had worked at the German facility. When they discussed the project, the German scientist indicated that they were allowed to live at the facility with their families provided they were productive. The facility was considered reasonably safe, and scientists did their utmost to remain there. When it became evident that Germany was losing the war, some scientists falsified data and reports to prevent their removal and that of their families to more dangerous zones.)

The buoyant devices were to be mounted near the bottom of a harbor and released when an enemy ship moved overhead. The models used in this study were made of balsa wood and were released by a person sitting on the bottom of the tank. That person was equipped with a homemade diving helmet fabricated from a pail, a small compressor and a garden hose.

One project worked on at AHL was a type of bomb that the British planes used to sink the German battleship Tirpitz off the Norwegian coast in 1944. The devices were dropped from high altitudes. Upon entering the water, they followed a curved path under the ship and exploded near the unarmored underside, blowing a large hole in the hull.

The rotating boom at the laboratory was also used during World War II for studies on ship logs (a device for measuring speed), hydrophones and paravanes. Two different types of ship logs were studied. The first was a propeller-type log, where the rotation of the propeller was an indication of the ship speed. Besides calibrating ship logs, a 500-hour endurance test was conducted on two propeller-type logs. The officer in charge at the US Navy Bureau of Ships indicated that the tests were done at AHL because it had the only facility in this country capable of making continuous runs. The second type of log was a pressure-sensitive plate where the force on the plate indicated ship speed. The hydrophone studies involved minimizing noise from the turbulent flow around the noise pick-up through use of various shields. Paravanes were devices used to sweep moored mines. They resembled inverted wings and were towed out the side of a ship at the end of a wire. When the ship snagged a mine, it slid down the wire and detonated at the paravane.

Hooper was also active during the war, traveling to numerous Navy facilities in Washington DC, the California Institute of Technology, the China Lake Naval Test Facility in California and the Naval Underwater Test Facility in New London, Connecticut. His expertise was sought after in various aspects of fluid mechanics. In some facilities, he was part of a project team studying ballistic or flow problems. On numerous occasions he left Worcester on one night in a sleeper car, arrived in Washington early the next morning, attended a meeting all day, and returned that evening on another sleeper car to Worcester.

NOTE — *This article is the second in a multi-part history of the Alden Research Laboratory. Part I appeared in the Vol. 14, No. 1, Spring/Summer 1999 issue.*

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