HYDRAULICS IN THE UNITED STATES

1776 - 1976

BY

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PREFACE

There is said to be a bit of a snob in each of us, and it was probably something of the sort that led me to avoid England when I first went abroad to study, because I did not consider the English sufficiently foreign. (I was so wrong!) Much the same thing occurred when I wrote the final version of our *History of Hydraulics:* though I then gave full credit to British contributions, I treated our own as if they were of secondary importance. However, in a 1971 after-dinner talk to the effect that "Hydraulicians Are Human Too!" fully half of the fourteen men that I discussed happened to be Americans—four native-born, three immigrants by choice. And according to an article that I drafted in 1973, "Hydraulics' Latest Golden Age," people from the United States seem to have played as large a role as any in bringing about this century's renaissance of their profession. Whether I am actually biased pro or con, the temptation to help celebrate the bicentennial of our country's founding by devoting a whole book to American hydraulics has been too great to resist. True, the basic principles of hydraulics had all been formulated before the United States came into existence, and our earliest projects were really carried out almost completely as an art. But we eventually showed an inborn ability to apply the scientific principles that others had developed, and within the past four decades the fluid-mechanics approach to hydraulics has been advanced as far in this country as anywhere else in the world.

Just what is meant by "hydraulics" varies greatly from person to person, even within the one professional field. To some it signifies the use of the underlying principles in engineering design, and to others the discovery of the principles or their amplification. Still others think primarily of model testing, or of flow measurement in the field. Were this book to cover everything relevant to the term itself, it would have to be a multi-volume work. To me, the term refers to the science rather than to its application, though there is admittedly no sharp borderline between the two. Perhaps the factors on which I place the greatest emphasis are investigation and publication. In the opening chapters, of course, I have had to deal with the practical aspects of water supply and disposal, because that was all that existed. But as the principles came to be recognized and applied, advancement by cut-and-try processes could be given less and less prominence, and finally attention could be centered on research and analysis, as I have sought to do in the later chapters of the book. Even there the treatment has not been simple and straightforward, for the advancement of the subject has depended upon a diversity of influences: the people, first of all, and their associations with each other; such matters as wars, migrations, and study abroad; the professional societies, the federal agencies, and the variable largesse of the government. Whereas these influences might appear to have played a minor role in the early history, it has sometimes seemed to me that my present writing deals almost too much with people (particularly the ones I have known) and too little with hydraulics, even though the latter has been my primary interest for nearly half a century!

While this span of years has given me a broad overview of what has occurred in the States during the last two generations, the viewpoint is necessarily a subjective one, biased in the direction of my own experience. Events of at least the past decade, of course, are too recent to be seen in proper perspective, but they are included to round out our second century of endeavor. Items from the more distant past I have been able to recall to some degree from conversations with still older people, many of whom are no longer alive, but the material from over a century ago stems primarily from the literature. The stories of particular localities I have acquired to some extent from historically minded colleagues—such, for example, as Joe Johnson of Berkeley, who has done much to preserve the record of hydraulics in California's golden years. Nevertheless, many gaps must still remain, and some of my statements may well be inaccurate. Nine months ago I hence deemed it wise to send the prologue and subsequent chapters of the provisional manuscript (the epilogue was then still unwritten) to some twenty of my friends who knew various aspects of the story better than I, in the hope of producing a final result with which all would be reasonably well satisfied. The same material was submitted to the Freeman Fund Committee, Boston Society of Civil Engineers Section, American Society of Civil Engineers, which honored me four months ago with its first Freeman Hydraulics Prize. The revised manuscript is now to be published serially by the BSCE Section, and by the Iowa Institute of Hydraulic Research as an illustrated book.

Though I will have given some four years to the writing of the book and must accept final responsibility, during that period many of my colleagues have had the opportunity to provide additional input, whether of factual or illustrative material, for which I am very grateful. Particular thanks are due the following: M. L. Albertson, J. W. Ball, P. C. Benedict, E. F. Brater, F. R. Brown, J. E. Cermak, E. S. Cole, J. S. Cragwall, J. W. Daily, R. L. Daugherty, D. G. DeCoursey, J. B. Drisko, R. A. Elder, R. G. Folsom, A. H. Frazier, D. R. F. Harleman, R. Hazen, G. H. Hickox, L. J. Hooper, J. W. Howe, T.-K. Hung, G. D. Johnson, J. W. Johnson, J. F. Kennedy, C. E. Kindsvater, D. L. King, M. Kranzberg, G. Kulin, E. Layton, G. B. Lyon, Mary H. Marsh, L. C. Neale, A. J. Peterka, M. S. Petersen, E. B. Pickett, C. J. Posey, T.

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Iowa City, 29 March 1976 HUNTER ROUSE

PROLOGUE

European Antecedents

By the time the American colonies began functioning as a unit, other civilizations had already existed from a few hundred to many thousands of years. The New World was thus still in the position of a receiver rather than a contributor in virtually all aspects of civilized life. In this study of American hydraulics, therefore, it would seem in order at the outset to assess the state of the profession elsewhere at that time, and then to estimate what portion of the existing knowledge was readily available to the colonists—and how much of this actually reached more than a very few of those who could appreciate it.

Like other engineering sciences, that dealing with the flow of water necessarily began as an art, its general principles still to be formulated millenia later as the result of experience acquired over countless centuries of practice in the field. Indeed, hydraulic engineering is among the most ancient of professions, for the need of providing water to drink and to irrigate crops is older than civilization itself—and, in fact, often influenced its course. There is still evidence of extensive canalization systems having diverted river flows in the Middle and Far East well before recorded history. Written evidence from Egypt, China, and Greece attests to the construction of reservoirs, wells, canals, and tunnels of surprising size several thousand years before the Christian era, and ships of that time are known to have ranged far and wide. Later writings of Vitruvius and Frontinus describe Roman systems of water supply and drainage of vast proportions.

During the millenium that followed the fall of Rome, ground was lost in many ways, for major structures were permitted to deteriorate, and practically nothing new of a scientific nature was discovered till the present millenium had begun. On the other hand, water mills increased in number (as well as windmills after the 12th century), land was drained or irrigated, and the size and range of sailing vessels advanced in proportion. By the time of the great upsurge in accomplishment marked by the Renaissance, hydraulic engineering was as ready as any profession to take its proper part.

The elements of hydrostatics, of course, had been known from the time of Archimedes in the 3rd century BC through successive translations of his works from Greek to Arabic and then to Latin and the more modern languages of Europe. His teachings were gradually amplified by the observations of Leonardo da Vinci, Stevin, Galileo, and Pascal in the 15th, 16th, and 17th centuries. Of considerably more interest at the moment, however, are the simultaneous contributions to principles of hydrokinetics and to hydraulic practice in general. Da Vinci, around 1500, not only first formulated the principle of continuity (the inverse relation between velocity and flow section) and conceived such devices as miter gates for canal locks and parachutes (akin to sea anchors), but he planned and supervised the construction of extensive canal and harbor works in Italy and France. Unfortunately, many of his writings and drawings disappeared for several centuries after his death, and his accomplishments hence had limited influence on the course of technology. Galileo and his followers, Castelli and Torricelli, had considerable effect a century later upon various aspects of experimental hydraulics (continuity, efflux of jets, pump suction), and Galileo is also rumored to have advised an engineer against river cutoffs, though apparently in vain. Drainage of Italian marshlands was then (and for centuries thereafter) of considerable importance, and open-channel hydraulics progressed apace. Domenico Guglielmini, who was born a few years after Galileo's death, was the first to write as well as practice in this field, and his works were widely read.

Although Italy was thus responsible for the naissance of hydraulic theory, other countries in turn soon took the lead. A contemporary of Guglielmini, Edme Mariotte of France, contributed as much to laboratory experimentation as the former did to field observation. Mariotte was interested in the shape of jets and the force they exert on deflecting surfaces, the resistance of bodies to the flow of air as well as water, and the compressibility of air; and a book containing his findings was published after his death. His German and English contemporaries Otto von Guericke and Robert Boyle (the latter of whom apparently coined the word "hydraulics") were also interested in the weight and compressibility of the air, as was Mariotte's compatriot Pascal. Later in the 17th century the Englishman Isaac Newton formulated in his *Principia* . . . the equality between the impulse of a force acting on a body and the rate of change of momentum that it produces, and he applied it to the motion of the planets, experimenting with various kinds of fluid resistance to prove (contrary to the belief of Descartes) that the planets moved through a void; he also developed an initial form of the calculus. Shortly thereafter the German Gottfried Wilhelm von Leibniz likewise invented the calculus, and just a year in advance of Newton's *Principia* introduced the equality between work and the change of energy that it produces (though without the factor ½ that eventually had to be applied to the kinetic term). Cries of plagiarism from the colleagues of both led to a rift between continental and island science that was to persist for generations. Johann Bernoulli and his son and pupil Daniel contributed to the application of Leibniz' calculus as well as to the principles of continuity, momentum, and energy in their books *Hydrodynamica* (by Daniel in 1738) and *Hydraulica* (by Johann in 1743); for want of the pressure term, however, neither truly included the primary theorem of hydraulics now known by their name. The spatial variation of pressure was first truly understood by Johann's pupil and Daniel's classmate (and fellow academician at St. Petersburg), Leonhard Euler, who first derived the so-called Bernoulli equation in 1752; primarily a mathematician, Euler laid the true foundation of hydrodynamics (including unsteady, nonuniform flow in conduits), in the course of which he also designed a primitive reaction turbine.

Mariotte's early efforts at hydraulic experimentation were followed by a series of related discoveries in various parts of Europe. Robert Hooke built in England in 1683 a vaned mill for air flow and a screw for use on ships' logs, sounding devices, and current meters. Henri Pitot discovered in France in 1732 a "machine" to indicate the speed of flowing water, consisting of an L-shaped tube pointing upstream and a straight one normal to the flow, with an interconnecting valve to be closed before withdrawing the instrument from the flowing water. Daniel Bernoulli in his St. Petersburg laboratory improved on Pitot's crude manometer (the normal tube) by inserting it in the conduit wall; he also discovered and analyzed the principle of jet propulsion. In England Benjamin Robins introduced in 1746 the rotating arm for gaging the resistance of bodies. In 1759 his countryman John Smeaton described the first scale-model tests, to determine the performance (i.e. efficiency) of both windmills and water wheels. The Frenchman Jean-Charles Borda less than a decade later used the rotating arm to compare resistance measurements of similar bodies in air and water. And his compatriot Charles Bossut wrote in 1771 the first textbook on "fluid mechanics" (actually hydraulics, with one volume on theory and one on experiment).

Indicative of the scientific ferment occurring in the 17th century was the formation of small groups of people interested in the advancements that were taking place. As a result of meetings held as early as 1645, the Royal Society of London was established by 1660, and both Hooke and Newton became active participants. The *Académie Royale des Sciences* came into existence in 1666 for similar reasons, and it was to have an equally great influence on scientific progress. With these as models, many other European countries followed suit in the century that followed. The learned publications of most of these societies received wide circulation.

By the beginning of the 18th century, engineers in France were held in considerable esteem. The national *Corps des Ponts et Chaussées* stood in high repute from the time of its establishment in 1716, and in 1747 the world's first engineering school was founded in its name. Members of the *Corps*, and eventually graduates of its school, were responsible for all the civil engineering works in the country, including the development of canals. Antoine Chézy, one of its outstanding graduates, devised in 1768 a similarity method of predicting the resistance of one channel from that already known for another, which today is still in use; however, the fact attests to the ability of the *Corps* members more than it speaks for the basic hydraulics principles then at hand, as Chézy's report was lost in the files of the *Corps* for many years.

By 1776 all of the books that have been mentioned were readily available—those by Guglielmini, Mariotte, the Bernoullis, and Bossut—as well as the many reprintings of other authors that had become the custom in Italy. There was no lack of bibliographies, moreover, for it was common practice for each successive book to review much that had gone before. A set of books also worthy of mention was the four-volume *Architecture hydraulique* by Belidor, published at Paris between 1737 and 1753, which was a descriptive compilation, beautifully illustrated, of existing engineering works of every sort. Unfortunately, none of these books had been translated into English, and the works originally written in English were limited in number. Those by Boyle, Robins, and Smeaton, of course, were readily available. A few treatises on hydrostatics were almost naively elementary. Three more extensive works, however, are worthy of mention: Stephen Switzer's *An Introduction to a General System of Hydrostaticks and Hydraulicks, . . .* (London 1729), which reviewed most of the books already listed; Martin Clare's *The Motion of Fluids* (London 1735); and Charles Vallancey's *A Treatise on Inland Navigation, . . .* (Dublin 1763), based on the works of Guglielmini, Belidor, and others.

While settlers of the Colonies also came from France, Holland, and Germany in limited numbers, by far the majority were of English ancestry, and it is pertinent to examine the state of 18th-century civilization in at least London (where one-tenth the English population was concentrated and which by mid-century had overtaken Paris in population) for clues as to what practical knowledge of hydraulics the migrants could have brought to America with them. Three aspects of the subject will suffice to depict the general state of things: water supply, sewage disposal, and shipping, together with a general remark on the social status of engineering.

Contrary to the situation in France, where the *Corps des Ponts et Chaussées* was a government organization containing even members of the nobility, construction in England was a trade, and no one in trade could possibly be a gentleman. (Though not gentlemen, it is to be noted, the inventors of the steam engine were all Englishmen—Thomas Savery, 1702; Thomas Newcomen, 1712; and James Watt, 1769—and the primary use of their machines was the pumping of water.) There were, of course, a few exceptions to this rule among the architects, city planners, and bridge builders, but John Smeaton (1724-1792) seems to have been the only noteworthy person among the hydraulic engineers.

He designed and built various English harbors, drainage works, steam-driven pumps, and—the project for which he was best known—the Eddystone Lighthouse, on which two previous contractors had failed. He was also an inventor (the hydraulic ram being among the devices attributed to him), a writer on various fields of mechanics, and a medal-winning member of the Royal Society of London.

Use of the River Thames for shipping, drinking water, and sewage disposal had probably occurred from time immemorial, and by the 18th century all three practices were inextricably associated. In the course of this century the number of ships belonging to the city grew from perhaps 1200 to nearly 2000, and tonnages as high as 1500 were involved in the India trade. Most of London's water supply—80,000,000 gallons per day by the end of the century for a city of nearly a million—came from the Thames, in which a series of tide-driven undershot wheels had powered piston pumps since Elizabethan times. However, neighboring streams (such as the Fleet and the Lea) were used as well, particularly as the system of inland waterways was developed during the Industrial Revolution into a network of canals for the barging of coal and timber. Springs and wells in the hills to the north were also tapped, and in the course of the century some 40 miles of conduits containing several hundred wooden aqueducts were built, with bored-elm-log pipes providing the final distribution. Iron pipes were tested as early as 1756, but well over half a century was required to bring them into wide use.

Sewage disposal was wholly unorganized. Streets drained into ditches and ditches into canals and streams; garbage and offal were dumped into one or another. Indoor and outdoor privies, many directly over the banks of ditches, canals, and streams, were the norm. Such sewer pipes as had been installed, following advent of the water closet late in the century, usually leaked, and what with the cesspools that existed in even the best of quarters, the odor in the basements was comparable only to that on the river banks at low tide. The York Building Water Works, which operated from 1675 to 1829, provided unfiltered water from a point in the Thames 600 feet offshore; this was preferred to another source because its water cleared faster! In 1755 Marchants Waterworks placed its intake pipe near the river bank not far from a sewer outlet. Both companies, to be sure, also drew from reservoirs fed by springs, but this did not prevent contamination of their supply. It is perhaps relevant that through much of the century the death rate exceeded the birth rate, though some blame the deaths not so much on the pollution as upon the quantities of gin drunk by the lower classes to overcome the stench. In any event, London's population increased markedly only as the result of migration from the countryside and other parts of the world. At intervals such streams as the Fleet "Ditch" were cleaned up and made navigable, but they rapidly reverted to conduits for garbage, offal, sewage, and silt, and eventually were covered over. The banks of the Thames, once tidal flats, gradually filled in so badly from such deposits as to impede shipping. Late in the century the banks were dredged for the construction of new docks, and the waste material was used to fill in the old Chelsea Waterworks reservoir. In 1796 it was proposed that several bends in the river below London be straightened to provide further docking area, but this sound engineering proposal came to nothing.

In much of its hydraulic engineering, England borrowed from or sought to emulate the French, who were then technologically far superior. Had the situation been reversed, colonial technology might have advanced more rapidly than it did.

Colonial Inceptions

Though civilization in 18th-century America had only as many hundreds of years to develop as that in England had thousands, it was the migrant English who determined in large part the course which colonial developments took. Thus, whereas the outposts of the Colonies might have seemed very primitive in comparison (as indeed they were, mainly for lack of roads or waterways for communication), the larger towns along the Atlantic seaboard, with their considerable ocean traffic, came to resemble those of the mother country more and more. Philadelphia, the largest, but New York and Boston no less, actually had much in common with the London cited in the Prologue to provide an example of the times, as a glance at the situation in New York toward the end of the Colonial period will suffice to show.

The population of New York, a bare 2000 only a century before the Revolution, was nonetheless growing at an exponential rate, roughly doubling each quarter century and reaching some fifteen times 2000 by the year the Revolution began. Shallow wells—first private and later public—were sunk for domestic and fire-fighting use, and gutters and outdoor privies served for waste disposal. So long as the population was small, the water was good, but the more finicky residents were gradually forced to go to springs north of town. The so-called Tea Water Well, a spring at what are now Chatham and Roosevelt Streets, was mentioned in the literature by 1750, and shortly before the Revolution it was capped by a pump and the area made into a garden, from which carts used to deliver water—for a price—to a more central distribution point as well as to private homes. As the yield became insufficient (and the water further into town more distasteful), the first of countless efforts was made to improve both the quantity and the quality of the municipal supply. Collect Pond, not far from the Old Tea Water Pump, might have alleviated the need for a while had it not become used instead as a sink rather than a source. In 1774 the Irish civil engineer Christopher Colles (1738-1816) proposed and built a well and reservoir east of Broadway between the present Pearl and White Streets, using one of Newcomen's atmospheric pumps to lift the water, a system of hollow logs to distribute it to the main streets, and bonds known as Water Works Money for financing. But the supply was still insufficient, and the Revolution put an end to the project.

Boston and Philadelphia evidenced much the same hydraulic problems, and they are of particular interest because the former was the birthplace and the latter the adopted home of Benjamin Franklin (1706-1790), who played a notable role in both colonial and post-colonial developments. The Boston Water Works Company had been formed in 1652 to develop what became known as the Conduit, a distribution reservoir fed by bored logs from nearby wells and springs. The Boston fire of 1711, for lack of adequate water, left a hundred families homeless. Philadelphia was not only densely settled for its time, but clustered its wells, privies, and graveyards far too closely for good health. Smallpox and yellow fever resulted in thousands of deaths, but their causes were only vaguely sensed. It is therefore interesting to note that Franklin was to bequeath one thousand pounds to each city, to be invested at 5% compound interest, one hundred thousand pounds of the total sum anticipated at the end of a century to be spent for public works, not the least of which was a good water supply!

In 1743, somewhat less than a century after the establishment of the Royal Society of London, Franklin published "A Proposal for Promoting Useful Knowledge Among the British Plantations in America," and later that year he was instrumental in founding the "American Philosophical Society," but interest therein soon lagged. In 1766 a group of Quakers organized "The American Society for promoting and propagating useful knowledge, held in Philadelphia." The following year it too began to decline, but The American Philosophical Society was then revived and considerable rivalry developed. In 1768 the two united under the rather bulky title, "The American Philosophical Society held at Philadelphia for Promoting Useful Knowledge." Franklin became its first president in 1769 and served till his death in 1790. Though it was not to receive its charter till 1780, its *Transactions* have been published continuously since the 1769 volume appeared in 1771. Other cities eventually followed suit in the development of such organizations, but in the meantime the one at Philadelphia played a very strong role in establishing the reputations of the Colonies in the field of science, in no small way through Franklin's writings. Though these were first almost insultingly spurned by the Royal Society of London, their worth was soon recognized by the

Académie Française, and the Royal Society later bestowed upon Franklin its Copley Medal (the award previously received by Smeaton) and elected him to full membership.

While Franklin is well known for his electrical discoveries (not to mention his political and diplomatic activities), a review of his extensive correspondence reveals an extremely great breadth of interest, not the least of which had to do with fluid motion. His concern with the weather stemmed very likely from his kite experiments. His frequent voyages across the Atlantic led him to study the course and ponder the cause of the Gulf Stream. In a letter of 1761 he discussed the fate of rivers leading to the sea, speculating on the amount of fresh water that evaporated before it could mix with the salt. In a letter of 1769 he considered the flow of air in houses and chimneys in both winter and summer. But it was his letter of 1768 to Sir John Pringle that is now of greatest import, for it describes the first towing-tank tests of ship resistance—conducted, to be sure, in England, but conceived and carried to completion by an American—nearly a decade before those of Bossut, d'Alembert, and Condorcet at Paris, not to mention the subsequent ones of the Englishman Mark Beaufoy. The letter deserves reproduction in full:

> SIR, *Craven-Street, May 10, 1768*
>
> You may remember that when we were travelling together in *Holland,* you remarked that the track-schuyt in one of the stages went slower than usual, and enquired of the boatman, what might be the reason; who answered, that it had been a dry season, and the water in the canal was low. On being asked if it was so low that the boat touch'd the muddy bottom; he said, no, not so low as that, but so low as to make it harder for the horse to draw the boat. We neither of us at first could conceive that if there was water enough for the boat to swim clear of the bottom its being deeper would make any difference; but as the man affirmed it seriously as a thing well known among them; and as the punctuality required in their stages, was likely to make such difference, if any there were, more readily observed by them than by other watermen who did not pass so regularly and constantly backwards and forwards in the same track; I began to apprehend there might be something in it, and attempted to account for it from this consideration, that the boat in proceeding along the canal, must in every boat's length of her course, move out of her way a body of water, equal in bulk to the room her bottom took up in the water; that the water so moved, must pass on each side of her and under her bottom to get behind her; that if the passage under her bottom was straitened by the shallows, more of that

water must pass by her sides, and with a swifter motion, which would retard her, as moving the contrary way; or that the water becoming lower behind the boat than before, she was pressed back by the weight of its difference in height, and her motion retarded by having that weight constantly to overcome. But as it is often lost time to attempt accounting for uncertain facts, I determined to make an experiment of this when I should have convenient time and opportunity.

After our return to *England* as often as I happened to be on the *Thames,* I enquired of our watermen whether they were sensible of any difference in rowing over shallow or deep water. I found them all agreeing in the fact, that there was a very great difference, but they differed widely in expressing the quantity of difference; some supposing it was equal to a mile in six, others to a mile in three, etc. As I did not recollect to have met with any mention of this matter in our philosophical books, and conceiving that if the difference should really be great, it might be an object of consideration in the many projects now on foot for digging new navigable canals in this island, I lately put my design of making the experiment in execution, in the following manner.

I provided a trough of plained boards fourteen feet long, six inches wide and six inches deep, in the clear, filled with water within half an inch of the edge, to represent a canal. I had a loose board of nearly the same length and breadth, that being put into the water might be sunk to any depth, and fixed by little wedges where I would chuse to have it stay, in order to make different depths of water, leaving the surface at the same height with regard to the sides of the trough. I had a little boat in form of a lighter boat of burthen, six inches long, two inches and a quarter wide, and one inch and a quarter deep. When swimming, it drew one inch water. To give motion to the boat, I fixed one end of a long silk thread to its bow, just even with the water's edge, the other end passed over a well-made brass pully, of about an inch in diameter, turning freely on a small axis; and a shilling was the weight. Then placing the boat at one end of the trough, the weight would draw it through the water to the other.

Not having a watch that shows seconds, in order to measure the time taken up by the boat in passing from end to end, I counted as fast as I could count to ten repeatedly, keeping an account of the number of tens on my fingers. And as much as possible to correct any little inequalities in my counting, I repeated the exeriment a number of times at each depth of water, that I might take the medium. And the following are the results.

Water	1½ inches deep	2 inches	4½ inches
1st exp	100	94	79
2	104	93	78
3	104	91	77
4	106	87	79
5	100	88	79
6	99	86	80
7	100	90	79
8	100	88	81
	813	717	632
	Medium 101	Medium 89	Medium 79

I made many other experiments, but the above are those in which I was most exact; and they serve sufficiently to show that the difference is considerable. Between the deepest and shallowest it appears to be somewhat more than one fifth. So that supposing large canals and boats and depths of water to bear the same proportions, and that four men or horses would draw a boat in deep water four leagues in four hours, it would require five to draw the same boat in the same time as far in shallow water; or four would require five hours.

Whether this difference is of consequence enough to justify a greater expense in deepening canals, is a matter of calculation, which our ingenious engineers in that way will readily determine.

I am, &c. B. F.

Franklin's interest in ship resistance was indicative of the progress that was being made in colonial shipbuilding, which had already become competitive with that of England itself. Not only were American craft being produced more cheaply than those in the mother country, but they were smaller, sleeker, and faster. On the other hand, had Franklin devoted more of his time to contemplation of fluid motion, American hydraulics would surely have profited accordingly. Moreover, had more Americans spent as much time in France as Franklin did, this country would have had more of a French scientific heritage. True, such leaders as Adams and Jefferson followed in Franklin's diplomatic footsteps, but not his scientific, and as a result European hydraulicians of the 18th century were almost unknown in the Colonies. Aside from Newton's contributions, which were read by the well-educated few, there was much less scientific knowledge to be transmitted to the Colonies from England than from France, and the major English technical influence was that of such engineers as Smeaton, whether this was exerted by colleagues who migrated westward or by American engineers who visited England.

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CHAPTER I

THE FIRST HALF CENTURY

Although the Revolution and the accompanying change from colonialism to independence represented a discontinuity of normal activity and even considerable change in its direction, in some ways life thereafter—for at least the remainder of the 18th century—seemed simply a resumption of what had gone before. Franklin continued to write his many friends in Europe, one of his most pertinent letters being that of 1785 to David Le Roy, ostensibly composed on board ship and known as his "maritime observations." Therein he philosophized at length on such matters as the resistance of sails, storm anchors, jet propulsion (in which connection he not only referred to Bernoulli but improved somewhat on his very primitive design), air propellers (and their potential hydraulic counterpart), stability, drag experiments in an improvised air jet, free fall, flotation, buoyancy, inertia, and wind shear. And the success of Franklin's American Philosophical Society prompted John Adams and a group of other Harvard graduates to form at Boston in 1779 the American Academy of Arts and Sciences, which was chartered the following year and began publishing its *Memoirs* in 1785.

Though American-built ships of frigate class and below had not yet attained their full degree of effectiveness, it is interesting to note that the last quarter of the 18th century brought a related American contribution—the steamboat—definitely to the fore. James Watt, to be sure, had proposed as early as 1770 that his improved steam engine be connected to a propeller and used to drive a ship, but nothing came of it. However, the general idea was definitely in the air. In 1788 James Rumsey (1743-1792) of Virginia claimed to have applied to a small boat the Bernoulli principle of jet propulsion, as described in a certification provided by one of his friends:

> The boat was finished in the fall of the same year (1783). Her hull was built by Rumsey's brother-in-law, Joseph Barnes, who was a carpenter by trade. The estimated capacity of the boat was about six tons burthen. Her boiler was a primitive affair, being simply an iron pot or kettle, such as is ordinarily used in the country for culinary purposes, with a lid or top placed on its mouth and securely fastened there with bands, rivets and soft solder. The engine, which was constructed partly by the village blacksmith, but principally by Rumsey himself, was upon the Newcomen or "atmospheric" principle, its power being obtained by the weight of the air, pressing on the piston beneath which a vacuum had been created by the condensation of the steam. The

> mode of propulsion was by means of a pump, worked by steam, which, being placed toward the forward part of the boat, drew up at each alternate stroke of the engine a quantity of water, which, by the return or down stroke, was forced through a trunk at the bottom along the Kelson, and out at the stern under the rudder. The impetus of the water rushing through the trunk against the exterior water of the river, drove the boat forward; the reaction of the effluent water propelling her at a rate of speed commensurate with the power applied.

A further certification was given by George Washington, who had witnessed tests on a working model in 1784:

> I have seen the model of Rumsey's boats, constructed to work against the stream; examined the powers upon which it acts; been eye witness to an actual experiment in running water of some rapidity, and give it as my opinion (although I had little faith before) that he has discovered the act of working boats by mechanism and small manual assistance against rapid currents.
>
> That the discovery is of vast importance, may be of the greatest usefulness in our inland navigation, and if it succeeds (of which I have no doubt) the value of it is greatly enhanced by the simplicity of the works which, when seen and examined, may be executed by the most common mechanic.

Washington's paradoxical comment in a later letter is equally significant, as will soon be seen:

> . . . The counteraction being proportioned to the action, it must ascend a swift current faster than a gentle stream, and with more ease than it can move through dead water. But in the first there may be, and no doubt is, a point beyond which it cannot go without involving difficulties that may be found insurmountable . . .

In 1785 Rumsey wrote Washington that he had "taken the greatest pains to perfect another kind of boat upon the principles I mentioned to you in Richmond in November last . . . ." This boat was completed and tested in the Potomac with four friends as the sole witnesses, apparently in March 1786; an improved form was given a public demonstration on 3 December 1787, eventually making a speed of four miles per hour against the current. That winter Rumsey went to Philadelphia, where interest in his steamboat resulted in the formation of the Rumseian Society, with Franklin as president, and in his setting sail for England in the spring to promote further interest in the venture. There he died two years later, after building and demonstrating a still larger craft.

Whether the jet-propulsion idea was communicated by Rumsey to

Franklin or vice versa is still not clear. It is pertinent to note, however, that Rumsey's rival, John Fitch (1743-1798) of Connecticut, at one time thought to discard his original idea of paddle boards on continuous chains for the jet-propulsion idea proclaimed by Franklin in his "maritime observations," which were included in the minutes of the American Philosophilcal Society of 1785. (A posthumous claim was also made that he had once experimented with a propeller-driven boat on the Collect Pond of New York.) But he was persuaded by his mechanic to adhere to the original paddle-board idea, though this was soon changed to a system of crank-mounted paddles driven by a self-designed steam engine. A skiff so propelled made its first short trip on the Delaware with the two fabricators as passengers toward the end of July 1786, and an improved craft was demonstrated publicly the following year. A year or so later a better-streamlined boat with stern rather than side paddles was built, and by 1790 Fitch was operating a passenger and freight service between Philadelphia and Bordentown. Like Rumsey, Fitch sought exclusive patent and operating rights for his steamboat from various states, essential to which was the proof of priority of invention. For this he turned to Washington, Franklin, and many others, but in vain. Rumsey apparantly had the better claim (or at least the stronger backing), but to remove all doubt a bit of skulduggery seems to have been introduced by his supporters if not by Rumsey himself. The model that Washington certified was apparently a mechanical device not utilizing steam at all, as should be apparent from his forthright comments; and the other certification evidently describes the boat of 1786, for it agrees in detail with Rumsey's own description of 1788. Though Fitch secured many affidavits correcting such misstatement, Rumsey seems to have won his case. Dissatisfied with the recognition he received in the States, Fitch sought support in France, but with even less success. Plagued by unfortunate personality traits and bad luck, he returned home a bitter man.

The question of priority or even practicability is of less moment in these pages than the fact that both inventions were largely original, the one involving jet propulsion being well before its time and the one imitating hand-manipulated canoe paddles not warranting further attention. But two other American engineers soon brought the approach into line with future trends. One was John Stevens (1749-1838) of New Jersey, after whom the Institute of Technology at Hoboken was named. In 1802, with the financial collaboration of Robert Livingston (1746-1813), Nicholas Roosevelt (1767-1854), and the French migrant Marc Brunel (1769-1849), Stevens experimented with boats having at first a single steam-driven propeller and later two counter-rotating propellers. The date is particularly noteworthy, since the man who usually is given credit for introducing the propeller into American shipping—John Ericsson (1803-1889)—had not even been born. Credit for the steamboat as a practical means of transportation, of course, usually goes to Robert Fulton (1765-1815) of Pennsylvania. A man of many talents, in his youth he was both an expert gunsmith and a portrait painter. From 1787 to 1797 he lived in England, not only painting but studying their canal systems and inventing new methods of construction and operation. In 1797 he moved to France, where he sought to sell Napoleon on the use of a submarine for the placing of explosives under the hulls of enemy (i.e. English) ships. While in France, Fulton made the acquaintance of Livingston, who was there as minister plenipotentiary from the States. Now Fulton had experimented in 1793 with the propulsion of surface craft by means of pivoted paddles and paddles mounted on wheels (a device already known for a hundred years or more), though driving his submergible boat by a hand-cranked propeller; he had also had the opportunity to observe the endeavors of Rumsey in England and Fitch in France, and to study the experimental findings of the Abbé Bossut and of the Englishman Mark Beaufoy. Livingston, in turn, had been interested in steamboats for a number of years, and in 1798 he had even secured a New York grant of sole rights to steamboat operation within the state for a twenty-year period. It was therefore only natural that he and Fulton should join forces.

By 1802 Fulton had made model tests in a channel nearly 70 feet long to determine whether "paddles, skulls, endless chains, or water wheels" were superior, and later in the year he and Livingston signed a deed of partnership calling for the construction of a 120-foot 60-passenger boat powered by an English steam engine. An experimental boat with paddle wheels and a makeshift steam engine was built for trial on the Seine in 1803; Napoleon assigned a committee of such men as Bossut, Carnot, and Prony to report to him on its performance, once the first runs had been successful. Thereafter Fulton ordered the agreed-upon engine from Boulton, Watt & Company and moved back to England to follow its fabrication—and to promote rival interest in the submarine devices that Napoleon had not purchased. Near the end of 1806 he returned to the States for the construction of the projected boat (plus an effort to sell his ideas for submarine warfare to his own country). The new boat had both its trial run and its public demonstration in August 1807, and—eventually christened the *Clermont*—began regular service on the Hudson, making the 150-mile trip between New York and Albany in 30 to 36 hours. Fulton was obviously not the inventor of the steamboat, but he was surely the one who made it practicable. It was not long before steamboat traffic spread across the country, from New York to New Orleans, along the Ohio and the Mississippi, and through the Great Lakes. In the meantime John Stevens (who had declined an invitation to collaborate with Fulton and

Livingston) was the first to take a steamboat on the open sea. The first steam-equipped sailing ship to cross the Atlantic (the *Savannah,* in 1819) was also American. However, the general application of steam power to ocean ships was primarily an English undertaking, though Marc Brunel (and in particular his son) had a large part in it after his return to Europe.

While pre-revolutionary engineering projects of a public nature had been scattered and of very minor importance, in the remaining quarter of the century such activity increased in a notable fashion—if not in actual undertakings, at least in the serious discussion of them. In New York, plan after plan for a municipal water supply was submitted to the city administration, but each was rejected for one reason or another, usually political. Christopher Colles, the Irish engineer who had constructed the inadequate well and reservoir system for New York just before the Revolution, next proposed to clear the Mohawk, the Ohio, and other rivers for purposes of navigation, and to connect Lake Ontario and the Hudson through a combination of natural and artificial waterways. The English engineer William Weston (1752-1833) was requested just before the end of the century to prepare plans for damming the Bronx River and delivering a flow of 6 cubic feet per second to a Manhattan reservoir. His plan (which involved the advanced idea of a sand filter for improvement of the water quality) was opposed by a group that included, interestingly enough, both Alexander Hamilton and Aaron Burr, the former for reasons of public economy and the latter for private gain. Although banks in those days were in strong public disfavor, Burr and several colleagues succeeded in 1799 in obtaining a bank charter under the guise of a waterworks organization known as the Manhattan Company. The bank thrived (it still exists under a slightly different name) but produced only enough water to maintain its charter. Some thirty-odd years of maneuvers prompted by general dissatisfaction with the situation were still to be necessary before a satisfactory solution was found.

Other 18th-century ventures should be mentioned at this point: The Potomack Company, established in 1785 to improve navigation on that river, functioned under the leadership of Washington, and Rumsey served for a time as secretary. The Santee Canal Company was chartered shortly thereafter, to connect Charleston and Columbia in South Carolina. The promotion of New York canals began with the formation of the Western and Northern Inland Lock Navigation Companies in the 1790's. More or less concurrent were schemes to build the Susquehanna, Conewago, and Schuylkill Canals in Pennsylvania, and the South Hadley and Middlesex in Massachusetts. The former was notable for its use of a tank car on an inclined plane for lifting boats in place of the more customary lock. The Middlesex Canal, built to connect the Merrimack and Charles Rivers, contained 20 locks and 8 aqueducts in its 27-mile length. In many of these projects—particulary the latter—William Weston had a guiding hand. Another English engineer who was to exert a strong influence on American developments was Benjamin Henry Latrobe (1764-1820), who had studied in Germany, worked in England under Smeaton, and migrated to the States toward the end of the century; extremely versatile, his interests ranged from hydraulics to architecture to shipbuilding (in partnership with Fulton, Livingston, and Roosevelt); it was he, moreover, who most strongly urged the provision of clean water for Philadelphia to reduce the spread of disease.

Though capable engineers were definitely at a premium for the planning of new projects—not to mention their ultimate execution—and though Latrobe recommended repeatedly that they be sought abroad, not only did the Americans usually hesitate to utilize foreign authorities, but the foreigners themselves were difficult to attract across the ocean. At the same time, self-educated American engineers began to appear on the scene, some of whom had profited by training—or at least inspection trips—abroad. Their approach to practice was decidedly varied: some were surveyors, some contractors, some entrepreneurs, and some simply opportunists. Three, however, deserve mention at this point as well as in the following pages: Loammi Baldwin (1745-1807) of Massachusetts, James Geddes (1763-1838) of Pennsylvania, and Benjamin Wright (1770-1842) of Connecticut, the last two moving to New York State while still young. Baldwin, who instigated construction of the Middlesex Canal, worked originally as a surveyor, but during the Revolution he saw duty both as a military engineer and as an officer, and thereafter as a hydraulic engineer (not to mention as developer of the Baldwin apple). He was thus one of the first to demonstrate to his compatriots that both military and civil engineering have much in common.

This similarity became the clearer with the founding of the U.S. Military Academy at West Point in 1802, under the strong sponsorship of President Jefferson among others. Ostensibly for the preparation of military engineers, the Academy eventually came to train as many men for civilian life as for the army. In 1812, for example, the administration provided specifically for a professorship of civil and military engineering. One of West Point's early graduates was Sylvanus Thayer (1785-1872), of the class of 1808, who had previously studied at Dartmouth College and was eventually to return there to found the school of engineering now known under his name. After service in the War of 1812, Thayer was sent to Europe by President Madison to study the theory and practice of fortification design. In 1815-16 he had the opportunity of observing instruction at the *Ecole Polytechnique* in Paris, where mathematical analysis was (and still is) paramount, and his observations there were to play a considerable role in his development of the West Point curriculum. In 1817 he was appointed superintendent, and during his 16-year incumbency both science and engineering were greatly strengthened. The French engineer Claudius Crozet (1790-1864), a graduate of the *Ecole Polytechnique,* had preceded Thayer at West Point by a year and been given charge of the engineering department. Much of the instruction was patterned after the French system, in particular the strong emphasis on mathematics. Though there was periodic external criticism of teaching civil as much as military engineering, and of producing more engineers than the Army itself could absorb, it was invariably decided that this policy was salutary rather than misguided. For nearly two decades after its founding, West Point was the only American organization giving formal training in technology, but in that period it contributed well over a hundred engineers to civilian practice, and graduates remaining in the Corps of Engineers were also frequently given leave to supervise civilian works. In 1820, however, Norwich Academy began the teaching of a course in civil engineering, and Rensselaer School (later to become Rensselaer Polytechnic Institute) was established only four years thereafter. It is interesting to note that Norwich, founded by a disgruntled former acting superintendent of West Point, claimed to have more flexibility than the latter both coursewise and timewise, whereas at Rensselaer it was even held that no mathematics above arithmetic was required, because engineering training had to be practical rather than theoretical!

The first decade and a half of the 19th century was very much a continuation of the 18th so far as canal construction was concerned—considerable planning but little accomplishment. The South Hadley Canal had to be rebuilt in 1802. An attempt to build the Chesapeake and Delaware Canal failed in 1806. And in 1808 the Union Canal Company took over both the Delaware and Schuylkill and the Schuylkill and Susquehanna projects. But with the Peace of 1815, much of the earlier planning seemed to reach fulfillment. There had been agitation for longer canals in New York as early as 1804; in 1808 the legislature had requested a survey for the Erie project originally proposed by Colles; and in 1810, with the strong political support of DeWitt Clinton (who resigned a seat in the U.S. Senate to become mayor of New York City and then governor of the State), a commission was appointed to finalize the plans. Six years later Geddes, and then Wright, were each given authority over portions of the undertaking, and within two years Geddes had also been appointed chief engineer of a related project, the Champlain Canal. Nearly a decade was involved in the completion of the two. The Erie, 40 feet wide and 4 feet deep, with a total length of 363 miles and an elevation difference of some 500 feet, was not historically record-breaking, to be sure, but a most noteworthy achievement for so young a country. In fact, many constructional innovations—such as stump-removing and earth-moving equipment—came to be utilized that were unheard-of even in England, where hand shovels, picks, and wheelbarrows were still in common use. Above all, the operation is often said to have rivaled West Point in its production of engineers—the Erie School, it is frequently called—who learned on-the-job and soon came to be in demand in other parts of the country. The number of civilian engineers doubled in this period; it is estimated that some seventy-five became available, two dozen of whom were of high caliber. Probably the most notable of these was Canvass White (1790-1834) of New York, who among other things developed the first American hydraulic cement, a very essential element in lock and bridge construction.

The undeniable success of the Erie Canal naturally led to greatly increased activity in canalization around the country, generally involving the services of Geddes, Wright, and those like White whom they had trained. In 1824-28 the Blackstone Canal was built between Providence and Worcester, and in 1825-35 the Farmington Canal between New Haven and Northampton. There was also marked activity in Pennsylvania, Virginia, the Carolinas, and Ohio. Loammi Baldwin Jr (1780-1838), a lawyer-turned-engineer, made the survey for a projected canal from Boston to the Hudson River in 1825, but the project was abandoned because of the need for a tunnel through the Hoosac Mountain in the Berkshires. It is significant to note that a railroad later followed the same course, tunnel and all. As a matter of fact, the development of the railroad as a competitor of the canal for the economic transporation of goods began soon after this time, barely a half century beyond the birth of the nation, and this led to the gradual decline of canal construction. Though hydraulics was still involved only so far as drainage was concerned, construction for transportation by rail used much the same technical skills, and the engineering profession continued to thrive. West Pointers, in particular, were in their element. If steam power played a negligible role in promoting canal traffic, it did have much to do with its demise, for the adaptation of the engine to the powering of train locomotives proceeded apace, with John Stevens again taking a prominent part.

As has already been indicated, dissatisfaction with the water supplied by the Manhattan Company of New York was to continue unalleviated throughout the first quarter of the 19th century. Though Aaron Burr was soon deposed from leadership in the organization, many another politician succeeded him; among them was DeWitt Clinton (whose name is usually mentioned more charitably in connection with the Erie Canal). Many a stopgap measure to provide water was tried by the company, including the digging of cisterns to collect the rain and the sale of the water-supply aspects of its business to the city. But little improvement was noticeable, and fires and fevers continued to plague the inhabitants.

Other cities were to fare better, all but one of which—paradoxically enough—favored private companies like that of New York. Even as early as 1798 the Boston Aqueduct Corporation tapped Jamaica Pond's excellent water, and the Baltimore Water Company in 1804 pumped a new supply from nearby Jones Falls to a central reservoir, from which it would be distributed as usual by log pipes. In New York State, moreover, some twenty-five new aqueduct associations were formed—to be sure, among the smaller towns. By far the largest system, on the other hand, was the single public one at Philadelphia. Designed by Benjamin Latrobe, and utilizing steam-driven pumps fabricated by Nicholas Roosevelt, the system conveyed water from the Schuylkill River to two engine houses, the second of which—the Centre Square Works—was in the classic style usually favored by Latrobe the architect. Unfortunately, yellow-fever epidemics continued to occur, and the supply of water again became inadequate. Much of the latter difficulty lay in the log-pipe system, with blame being shared by the inaccuracy of the available flow formulas, the clogging of the pipes, and their gradual deterioration through misuse or lack of maintenance. At the instigation of Latrobe's assistant Frederick Graff (1774-1847), it was decided in 1817 to adopt cast iron for replacements, but wood was used for another year. Then in 1818 two miles of 20- and 22-inch iron pipe was laid, with such an improvement in performance that at least two more miles of it per year was installed through the next decade. In 1820, moreover, the Schuylkill River was dammed to increase the supply. The accompanying feud between the domineering Schuylkill Navigation Company and the city administration was a significant sign of the times.

The first half century of United States history has been seen to bring a series of developments of sorts that—with a bit of hindsight—might well have been anticipated. At the outset much that happened was simply a continuation of the pioneering endeavors of colonial times. Most of the colonists had come from the working classes, and their contributions were highly practical. Noteworthy among these were the inventions and writings of Oliver Evans (1755-1819) of Delaware, who had been apprenticed to a wheelwright as a youth. In later years he greatly improved mill machinery, developed a non-condensing steam engine, and wrote *The Young Steam Engineer's Guide* and *The Young Mill-Wright & Miller's Guide.* The latter contained such sections as "Mechanics and Hydraulics," "Rules for applying theory to practice," and "Directions for construction," including many numerical examples and diagrams in its 400-odd pages. But whereas such developments were often innovative, they were surely not what one would call scientific.

The relatively few who first participated in such organizations as the American Philosophical Society were surely familiar with English (and, to a far lesser degree, French) literature, but there is little indication—beyond Franklin's mention of Bernoulli and Evans' of Smeaton—that writings on hydraulics of that time were known.

Before the end of the century (1796) the American Fulton published *A Treatise on the Improvement of Canal Navigation,* but this was done in England rather than the States. Mention has been made of the towing tests of Bossut in France and Beaufoy in England, yet even the latter were to have no influence in America till Fulton returned to the States after the turn of the century. The same is true of books by the Frenchman Du Buat, the German Woltman, and the Italian Venturi, all of which appeared in the quarter century after the Revolution (it has been said that the English translation of Du Buat's second edition brought him the compliments of George Washington, but the existence of an English translation cannot be verified). An English translation of Venturi's 1797 booklet on flow expansions by William Nicholson in 1799 was published by Thomas Tredgold in his *Tracts on Hydraulics.* The early 19th century brought three more publications—a three-volume posthumous edition of Du Buat, and new books by the Frenchman Prony and the German Eytelwein, the last of which was also translated by Nicholson. At least the second was probably known to men like Latrobe, who recommended turning to Prony for aid in attracting engineers to the States. This period was also marked by the return of Americans such as Fulton and Thayer from abroad, bringing with them not only acquaintance with the English and French technical literature but copies of the books themselves. Though Loammi Baldwin Sr never went abroad, he is said to have collected a representative assortment of civil engineering books; many were destroyed by fire, but the remainder are in the library of Harvard University. Loammi Baldwin Jr began his very extensive collection of engineering works during an 1824 trip to Europe; it is now in the library of the Massachusetts Institute of Technology.

The first truly American books on engineering as such were by coincidence published the same year. One was by the physician and botanist Jacob Bigelow (1786-1879), who graduated from Harvard College in 1806 and in 1816 was the first to be appointed to its distinguished Rumford professorship. For some ten years he lectured at Cambridge and Boston under the terms of the Rumford grant on "application of the sciences to the useful arts," and then amplified his lectures in a book called *Elements of Technology*—a term which he appears to have coined. The Massachusetts copyright of Bigelow's book was dated 9 July 1829. On 2 March, however, Zachariah Allen (1795-1882) had secured a Rhode Island copyright on his *Science of*

Mechanics, which covered much of the same field though in a totally different manner. Whereas Bigelow was primarily a descriptive scientist, Allen—a graduate of Brown University at Providence—was a practical combination of lawyer, businessman, and inventor. Prior to writing his book, he had traveled in England and France to study their manufacturing practices, and his treatise compares those of all three countries. Bigelow discussed the technology of the times in wholly descriptive terms, devoting about ten percent of his 500-page manuscript to hydraulics; reference was made to essentially all of the European writers mentioned in the foregoing pages and many more. Allen, on the other hand, showed little familiarity with the foreign authorities, but devoted an even larger percentage of his somewhat shorter text to hydraulics, and sought through tables and numerical examples to permit the reader to obtain useful quantitative results. Though the two books together still lacked much of the hydraulic detail already available in the continental literature, they marked a very respectable start.

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CHAPTER II

EARLY WRITINGS AND INVESTIGATIONS

Apparently some fifty years of gestation were necessary to bring the citizens of the United States to the point of concerted action in the procurement of municipal water supplies that were both safe and ample, for—despite the continuation of political controversy—in the second half century of the country's existence real progress began to be made. Developments in the cities of New York, Philadelphia, and Boston will again be used to typify the drive that was to spread from these largest cities to others around the country. But notice must first be taken of two hydraulic engineers who were also writers and investigators who would provide a challenge for those who were to follow in gradually increasing numbers for the next century and more.

The first was the Liverpool-born James Renwick (1792-1863), a 1797 migrant and 1807(!) graduate of Columbia College. He served his alma mater from 1820 to 1853 as professor of natural philosophy and experimental chemistry, but was said to have been an authority on every branch of engineering. As an engineering consultant he investigated the feasibility of uniting the Delaware and Hudson Rivers, and thereafter designed and supervised the construction of the Morris Canal between them, which was opened to traffic in 1831. Its most noteworthy feature was the use, in addition to 23 normal locks, of an equal number of boat railways, which—though the idea was not wholly original—he had patented in 1827. These had an average rise of 63 feet on a 10% slope, the motive force being provided by a series of "Scotch mills" (an imported form of Barker's mill) having a total of some 700 horsepower. Renwick was also the author—from 1826 to 1833—of ten books on natural philosophy and applications of mechanics to practical purposes. Among these his 1832 *Elements of Mechanics* warrants special mention. As he stated in his Preface, "In the use of the term 'Mechanics,' it has been employed as including the whole science of Equilibrium and Motion, and therefore as comprising the departments of Hydrostaticks and Hydrodynamicks." Of the volume's 508 pages, 87 dealt with the equilibrium of fluids, including both gravitating liquids and elastic gases, and 122 with the motion of fluids, including chapters on orifices, tubes, pipes, open channels, rivers, canals, fluid resistance, waves, gases, chimneys, winds, and atmospheric vapors. The earlier parts were algebraically quantitative, reflecting the work of Mariotte, Pitot, Bossut, Du Buat, Coulomb, Prony, Venturi, and Venturoli; however, the approach necessarily became more highly qualitative as the topics progressed from the simple to the relatively complex. More immediately useful, of course, was his 1840 *Application of the Science of Mechanics to Practical Purposes,* and it now provides a good picture of the state of American technology at that time.

The second man was Charles Storer Storrow (1809-1904), a native of Montreal, whose early education was received in both American and French schools. During his last year at Harvard, Storrow studied civil engineering in the office of Loammi Baldwin Jr, and after graduation he went to England and France for further engineering training, particularly at the *Ecole Polytechnique* and the *Ecole Nationale des Ponts et Chaussées* in Paris. On his return to the States, Storrow at first practiced railroad engineering but eventually turned to hydraulics. In fact, he was the author of the first American book specifically on the subject: *A Treatise on Water Works for Conveying and Distributing Supplies of Water,* published at Boston in 1835. The volume was a small one (242 4x7-inch pages), and he said in the Preface "I can, of course, make few claims to originality . . ." beyond the conversion of the tables from metric to American units. But taken together with the sections on hydraulics in the more general books of Allen, Bigelow, and Renwick, it laid a firm foundation for the many works to come. As was the European custom, the Introduction reviewed much of what had gone before, in the course of which the author briefly mentioned the contributions of essentially all of the hydraulicians whose names have appeared in the foregoing chapters. As Storrow himself stated, he leaned most heavily on the writings of Prony, Eytelwein, and Belanger, for his primary emphasis was on the subjects of pipe and channel resistance and backwater calculations. His chapter titles were as follows:

I Theory of the Motion of Water in Open Channels
II Theory of the Motion of Water in Pipes
III General Remarks on the Means of Supplying Cities with Water
IV Means of Measuring the Flow of Water
V Conveyance of Water by Canals or Aqueducts
VI Conveyance of Water by Conduit Pipes
VII Of Pumps
VIII Reservoirs and Pipes for Distributing Water
IX Pipes of Different Diameters, and Jets d'Eau
X Artesian Wells

It is interesting to note that, except for introductory references to the work of Bernoulli and d'Alembert, practically no attention was given to phenomena of nonuniform flow. The calculus, on the other hand, was by no means scorned.

It might be remarked in passing that the *U.S. House Documents* for the 1st Session of the 23rd Congress contains a complete transcript of the 1833 Institution of Civil Engineers paper "Canal Navigation" interpreting the results of experiments on ship resistance made at the Adelaide Gallery, London, by the Englishman John MacNeill. Rather more pertinent is the fact that the experimental equipment used by MacNeill was constructed by the migrant American Joseph Saxton (1799-1873), a Pennsylvania-born clockmaker somewhat better known for the current meter that he had built and rated in 1832 in the same Adelaide Gallery flume. Saxton later returned to the States to take charge of the U.S. Office of Weights and Measures, forerunner of the present National Bureau of Standards.

Another early American author worthy of reference was Thomas Ewbank (1792-1870) of New York. He published in 1842 the first of at least four editions of *A Descriptive and Historical Account of Hydraulic and Other Machines for Raising Water, Ancient and Modern,* a five-part tome of 550-odd pages, copiously illustrated and as garrulous as its title would indicate. In fact, though the author protested that this was not to be the case, it seemed to describe every type of pump that had till then been invented, including a primitive centrifugal unit. In addition he discoursed on innumerable related matters like atmospheric pressure and the ability of flies to walk on ceilings. Ewbank later headed the U.S. Patent Office. While still on the topic of books, mention might logically also be made of the publication in 1848 by Walter Rogers Johnson of an American edition of the English translation, *Weisbach's Mechanics and Engineering,* and in 1852 of Joseph C. Bennett's translation of d'Aubuisson de Voisins' work under the title *A Treatise on Hydraulics, for the Use of Engineers.* The latter deserved rather less attention than it received and the former much more; in fact, although Weisbach's book was to have considerable influence upon American hydraulics texts, its effect might usefully have been still greater.

The year before Storrow's treatise appeared, his mentor Loammi Baldwin Jr submitted a report on the Boston water supply, recommending a gravity-flow aqueduct from a number of ponds some twenty-five miles west of the city. No pipes would be necessary till near the end, for Baldwin was a canal builder to whom the use of steam-driven pumps was still somewhat unnatural. For the usual reasons, his plan was not to be adopted for more than a decade. In the meantime New York, still plagued with high death tolls from cholera, slowly turned its attention from the previously recommended use of the Bronx River and Rye Ponds as sources of supply to the idea of running an aqueduct from the Croton River much farther to the north. This municipal undertaking was finally approved by popular vote in 1835; its urgent need was accentuated later that same year by the worst fire that the city had ever suffered, the water supplied by the Manhattan Company being wholly inadequate to control it. In 1836 John Bloomfield

Jervis (1795-1885) of New York (who had been a resident engineer on a portion of the Erie Canal, then chief engineer of the Delaware and Hudson Canal, and—after an interlude in railway construction—in charge of the enlargement of the Erie's eastern division) was appointed chief engineer of the Croton project. Under his able direction the main dam, 40 miles of masonry conduit on a uniform grade, 16 tunnels, many bridges (including the Harlem River High Bridge), and the Murray Hill distributing reservoir on the site of the present Public Library were constructed, and by 1842 the city had its first adequate supply of good water: 79,000,000 gallons per day for a population of 360,000.

Spurred on by the success of the Croton Aqueduct, Boston began in 1846 the construction of the project that had been recommended 12 years earlier by Loammi Baldwin Jr. Jervis was brought up from the Croton Project as consultant. Some 14 miles of brick conduit led from Long Pond—renamed Lake Cochituate—to a receiving reservoir at Brookline, whence two iron mains led to distributing reservoirs on Beacon Hill and Telegraph Hill. By 1848 a capacity flow of 16,000,000 gallons per day for a city of 128,000 had thus been provided; but soon another main to East Boston was required, and in 1851 the Water Board bought out the facilities of the old Jamacia Pond Aqueduct Corporation. In Philadelphia the earlier availability of relatively good water from the Schuylkill project, coupled with the city's relatively low incidence rate of cholera, had been used by New York and Boston as goals for their own projects. The latter, however, proved so far superior in water quality to that of Philadelphia that this city in turn had to undertake improvements. These took the then-novel form of keeping sources of contamination well removed from the canal by means of bordering parkland. Filtering had also been proposed there and elsewhere, but still without actually being adopted. In the meantime, water-supply projects were carried out at other large cities, such as Baltimore, Pittsburgh, New Orleans, and Chicago, with varying degrees of satisfaction.

The steam engine was evidently to play a vital part in powering the Industrial Revolution, not only through improving transportation by water and rail but by providing the motive force for machinery that was becoming ever larger and better. Nevertheless, the industrialization of New England resulted initially from water power rather than steam. Even before the turn of the century, water-driven spinning mills had been set up in various places, particularly in eastern Massachusetts. In 1792 a corporation named the Proprietors of the Locks and Canals on the Merrimack River (known simply as the Proprietors) had been formed for the purpose of improving navigation, and thirty years later a group of Boston capitalists comprising the Merrimack Manufacturing Company purchased 400 acres near the Pawtucket Falls, a site which soon developed into the town of Lowell. The Company constructed a

950-foot dam on the river, which produced a 35-foot head and 18 miles of backwater, the pondage feeding 11 independent mills. In 1826 the property was transferred to the Proprietors. Charles Storrow was retained by them in 1835 to measure the quantity of water used by each of the mills, so that costs might be justly shared. He later became chief engineer of a similar company formed to develop power 12 miles downstream at a point that is now Lawrence, where he designed and built another dam and several additional mills. The financial success of these mill cities gave rise to similar ventures in other parts of the country, where the power was used for many purposes beyond the spinning and weaving of southern cotton.

Storrow's commission to measure rates of flow to the various mills culminated in a number of reports on methodology submitted to the Proprietors in 1841 by James Fowle Baldwin (1782-1862), younger brother of Loammi Jr, George Washington Whistler (1800-1849), father of the artist, and Storrow. To provide an "absolute" basis of measurement, 7 paddle wheels 10 feet long and 16 feet in diameter were placed side by side across a channel having an 80x4½-foot flow section. Paddle clearances at piers and bed were no greater than ¼ inch, the bed was curved locally on the same radius as the wheels, and there were always two paddles of each wheel over the curved part, so that the rate of flow could readily be evaluated from the geometry of the wheel, the depth of water, and the rotational speed. In the approach channel, which was 150 feet long, 27 feet wide, and 8 feet deep, surface floats were timed over known distances, and through comparison with simultaneous paddle-wheel measurements it was possible to determine the ratio between mean and surface velocities and thence the coefficient of the float as a discharge indicator. The results were reported to be in accord with data obtained by Du Buat and by Prony.

James Bicheno Francis (1815-1892), a native of Oxfordshire, England, who had worked on canals with his father, migrated to the States in 1833 as assistant to Whistler on the New York-to-Boston railroad. When Whistler went to Lowell (as much for the building of locomotives as for the tending of canals), he took Francis with him; there his protégé first participated in the design of the locomotives and then succeeded Whistler as canal superintendent. In 1845 Francis became the Proprietors' chief engineer, remaining in this post for nearly 40 years. In his long and active life he served as consultant on many projects. Two of his responsibilities at Lowell are of particular interest to this story: continued measurement of the flows used by each of the manufacturing companies to permit fair assessment of costs; and improvement of their machinery for converting the flows into mechanical power. These are described at length in his tome *The Lowell Hydraulic Experiments,* the first edition of which was published in 1855, and the fifth still being in print a half century later. So far as measurement was concerned, Francis made numerous tests on sharp-crested weirs both with and without side contractions, using one of the idle locks as volumetric basin and thereby determining the numerical values in the so-called Francis weir formula, the form of which he acknowledged to have been suggested by his very able colleague Uriah Atherton Boyden (1804-1879), a native of Massachusetts, who was also the inventor of the hook gage first used in the tests. The velocity of approach was taken into account when necessary by the theoretical correction generally attributed to Weisbach (whose work was known to, but not respected by, Boyden owing to the many errors in the translated version). When limited to heads less than one-third the crest length (no mention being made of weir height) Francis claimed that his formula would yield accurate results for heads from 6 inches to 2 feet. Disagreement with the results of Poncelet and Lesbros he attributed to differences in scale. The second (1868) edition of his book included his studies of measurement with weighted floats extending nearly the full channel depth to obtain average velocities in the vertical, the corrected values for the whole cross section being compared with weir indications. Tests were also described on divergent tubes or diffusers, which he expected to play a significant role in hydraulic machinery. But before the power aspect of his work is examined further, the background of turbine development should be reviewed.

Though one of the earliest mills in the Colonies (1634, near York, Maine) utilized an undershot wheel driven by impounded tides, wheels used by American mills through the 18th century were traditionally of either the overshot or the breast type, on which literally hundreds of American patents were granted. Many "improvements," however, simply took the form of increases in size, and eventually wheels 20 to 30 feet in diameter were not uncommon; in fact, the 1851 Burden wheel at the Troy Iron Works in New York was 60 feet in diameter and 22 feet wide! At the beginning of the 19th century, machinery of a different sort commenced to appear: Barker's mills, of the jet-propulsion (i.e. reaction) type; flutter wheels, of the jet-deflection (i.e. impulse) type; and curved-bladed tub mills, forerunners of what were later ambiguously called reaction turbines. It is to be emphasized that these were at first not constructed of iron by mechanics but of wood by millwrights, worthy successors of Oliver Evans. Little theory was used, aside from attributing the action of the tub mills to centrifugal force, and each fabricator independently developed his own designs. The most successful of these were probably Austin and Zebulon Parker of Zanesville, Ohio, about whom little else seems to be known.

In France, on the other hand, Claude Burdin and his pupil Benoit Fourneyron had been experimenting since the early Twenties with vertical-axis turbines of iron, and in the Thirties Fourneyron was able to patent his outward-flow design and to manufacture and sell a number of operating units with efficiencies that were claimed to be as high as 80%. The *Journal* of the Franklin Institute carried articles on the French machines in 1839, 1840, and 1842. But the design spirit was already in the air, for in 1838 Samuel B. Howd of Geneva, New York, had patented an inward-flow wheel, and again in 1842 an outward-flow wheel which (because of its proper utilization of centrifugal force!) he considered to be superior. Howd apparently constructed no wheels himself but licensed millwrights to do so, and quite a number of inexpensive units were put into operation. In 1843 Ellwood Morris translated Arthur Morin's French work on waterwheels with vertical axis, and according to Francis he built two of them near Philadelphia. Uriah Boyden, who had had a rather varied engineering career, in 1844 designed for the Appleton Company of Lowell an improved Fourneyron outward-flow turbine of 75 horsepower with an efficiency (determined through use of an improvised Prony brake) of 78%. This was followed two years later by three units of 190 horsepower each and still higher efficiencies; a noteworthy addition of Boyden's was an outlet diffuser in the form of slightly flaring coaxial disks yielding a twofold increase in the circumferential exit section and a 3% increase in turbine efficiency.

In the late 1840's the Proprietors acquired the regional rights to the original Howd patent and to those of Boyden. Francis, by then chief engineer, built in 1847 a model "centre-vent" (i.e. inward-flow) wheel similar to Howd's. Though its efficiency was not high, two years later several inward-flow wheels of 230 horsepower apiece were constructed from his design for the Boott Cotton Mills, and tests indicated peak efficiencies of nearly 80%. He also had four outward-flow units fabricated in 1851 for the Suffolk and Tremont Mills according to Boyden's design but without diffuser. All of these units are described in Francis' book. Though he and Boyden belittled the mathematical approach, they did follow the Carnot principle of shock-free entrance to and minimum-velocity exit from the runner, carefully shaping the guide vanes and runner blades according to the plotted streamlines. To this extent the Francis wheels were an improvement over those of Howd, just as Boyden's were over those of Fourneyron. To only a negligible degree, however, did they resemble the so-called Francis turbines of today. At the outset they utilized purely radial-flow runners, and they possessed neither the familiar scroll case nor the draft tube of modern units. The spiral scroll case (invented by the Parker brothers in the late 1820's) finally came into use in the early 1850's, but the flaring draft tube (a uniform one had been used by Austin Parker in 1833 to make the unit more accessible) was not introduced till the 1860's and then for a time was forgotten. Although both Boyden and Francis eventually increased the outlet depth of their runners, the mixed-flow type of blade was really developed at North Chelmsford, Massachusetts, in 1857 by Asa Methajer Swain (1830-1908), previously a patternmaker in the Lowell Machine Shops, by the rather crude process of literally cut-and-try. A variant known as the American wheel was patented the following year, and with the further blade-shape contributions of John B. McCormick (1834-1924) around 1870 it became the popular forerunner of the modern mixed-flow unit. Why the name of Francis continues to be associated with it presumably stemmed initially from the widespread attention attracted by his book and then from the resulting adoption of this designation by the German and Swiss firms which led in its scientific development later in the century.

The centrifugal turbine's pumping counterpart (first proposed by Leonardo da Vinci) was introduced in the States in 1818 by an unknown inventor. Now called the Massachusetts pump, variants appear to have been used in New York City in 1830, 1838, and 1844, and a patent was obtained on a similar design by William Draper Andrews (1818-1896) of Massachusetts in 1846. However, centrifugal pumps were not produced commercially in this country much before the last quarter of the century. Positive-displacement devices, on the other hand, date from Alexandrian times, and it has already been noted that steam-driven units of this type were used in the water supply of Philadelphia early in the century. Apparently a major difficulty still lay in the matter of valving—for example, in the operation of boiler feed pumps on steamboats, which had to stop operating at canal locks and so lost their prime. The man who overcame this problem was Henry Rossiter Worthington (1817-1880) of New York, the son of a millwright, who became a skilled draftsman while working in his father's establishment. In 1840 he entered a competition for the design and construction of a steam-driven boat to be used on the Erie Canal, in the course of which he invented the first automatic direct-acting feed pump and patented it in 1844. The boat that he built with his father's financial support was a mechanical success, but the New York Legislature soon canceled his license to operate it because of complaints by boatmen that it was driving them out of work. However, Worthington adapted his steam pump to other uses and began their manufacture through a company bearing his name. An improved unit was fabricated for the *SS Washington* in 1850, and in 1854 he built and installed his initial waterworks pumping system for Savannah, Georgia, in which three compound direct-acting engines supplied a total of nearly one million gallons of water per day. The following year Worthington developed a duplex piston-type water meter, the first to come into general use, and this led in 1857 to his major invention: the duplex direct-acting pump. His chief claim to fame, however, came from his first duplex compound pumping engine of waterworks size, which by 1836 was supplying Charleston, Massachusetts, with 5,000,000 gallons per day. Worthington was to become in 1880 one of the founding members of the American Society of Mechanical Engineers.

Attention was called in the foregoing chapter to the stimulating influence of the steamboat on river navigation and of the resulting efforts that were made to improve river navigability by dredging, removing snags, and installing crude training structures. On the smaller streams this could proceed without great ado, but on the Ohio and the Mississippi Rivers the scale was vast and the difficulties innumerable. From almost the outset this was the province of the U.S. Army Engineers, and as early as 1822 General Simon Bernard (1779-1839) and Lieutenant Colonel Joseph Totten (1788-1864) submitted a descriptive report that dealt with both rivers but emphasized the falls and subsequent bars of the Ohio. This was but the first of a steadily growing series of reports on the general subject. In 1841 W. A. Brooks published in England a related treatise on the formation of bars and other obstructions. In the Proceedings of the American Association for the Advancement of Science for 1848 there appeared an article by Andrew Brown on measurements of both discharge and sediment at Natchez, Mississippi; and in the same journal for the following year Lieutenant Robert A. Marr of the U.S. Navy wrote of similar but more comprehensive measurements at Memphis, Tennessee. The same year Charles Ellet Jr (1810-1862) submitted to the Smithsonian Institution a memoir on the physical geography of the Mississippi Valley, with recommendation of a reservoir system to improve navigation on the Ohio. In 1850 a report was made by Professor Caleb Goldsmith Forshey (1812-1881) to the Louisiana Legislature on the use of levees. A year later Ellet prepared for the War Department a report on methods of preventing overflows in the Mississippi Delta. A second series of observations was made by Lieutenant Marr in 1850-51, including discharge, temperature, evaporation, rainfall, and sediment concentration over a twelve-month period. The *Journal* of the Franklin Institute for 1857 contains papers on the improvement of the Ohio by Ellwood Morris and by Milnor Roberts. A critical review of the general navigation problem was published by David Stevenson first as an article for the *Encyclopedia Britannica* in 1858 and then as a separate treatise, certain American observations being criticized therein.

The foregoing is preliminary to discussion of a tremendous tome (some 600 7x12-inch pages) which appeared in 1861: *Report upon the Physics and Hydraulics of the Mississippi River,* by Captain Andrew Atkinson Humphreys (1810-1883) and Lieutenant Henry Larcom Abbot (1831-1927) of the Army Corps of Topographical Engineers. Not only did the references just cited stem from this work, but the authors stated that a great number of unreferenced reports existed in the files of the War Department. In an early section of the volume they followed the customary European practice of reviewing the previous literature. Therein a very comprehensive coverage of names, titles, and dates was given, but the initial assessment of the content of each item was almost naive in its vagueness—a situation that would be of less import were it not for the fact that a supposedly original pamphlet on the history of hydraulics published some 80 years later borrowed much of the historical material, including the naiveté. To Humphreys and Abbot's credit it must be noted that a subsequent section reviewed in great detail the relevant part of the source material—namely, existing methods of measuring velocity and discharge and of predicting channel resistance. The larger part of the volume presented a wealth of historical, geographical, and morphological information on the various divisions of the Mississippi Basin from headwaters to delta, much of which stemmed from the authors' own observations. Their measurements, to be sure, hinged largely on application of the rather antiquated double-float method, though some use was made of the propeller type of current meter devised in 1832 by Joseph Saxton. Throughout the book the authors reflected the growing belief of the Corps in the efficacy of levees and the uselessness of reservoirs for the control of floods. They were particularly unsuccessful in their purely hydraulic contribution. In the effort to develop an accurate method of predicting the resistance of any stream whatever, they presented a system of formulas reflecting (except for the effect of roughness) not only their own measurements but all available data in the international literature. They claimed thereby to have furnished

> crowning proof of the exactness of the new formulae as applied to water moving in natural channels. Joined to the two preceding tests, it establishes beyond reasonable doubt, first, that the same laws govern the flow of water in the largest rivers and in the smallest streams; second, that the new formulae truly express those laws; and, third, that the formulae heretofore proposed do not express them even approximately.

Other hydraulicians (notably Ganguillet and Kutter of Switzerland, the land of mountain torrents) claimed to have far less success with the method. Two positive effects seem to have resulted, however: succeeding empiricists (including Ganguillet and Kutter) sought even more determinedly to encompass all streams with their formulations, and their methods of doing so became steadily simpler.

Following Humphreys and Abbot's presentation, attention continued to be given to the country's rivers. Though Humphreys became in due time general and Chief of Engineers, he grew to be a rather bigoted proponent of the Corps' infallibility, not to mention the utter correctness of his and Abbot's report. Abbot, like Humphreys, took a prominent part in the Civil War and thereafter continued to work and write on various aspects of rivers, harbors, and canals—though invariably guided by the principles of his chief. Together, for instance, they belittled the telegraphic-indicating cup-type current meter developed by Daniel Farrand Henry (1833-1907) in 1868 as a "pretty toy" in comparison with their own double floats for velocity measurement. Ellet, very broad in his engineering interests, had already been retained by the War Department for planning the improvement and protection of the Mississippi Delta; in the Civil War he participated in both naval design and operations. The German-born Henry Flad (1824-1898) likewise saw duty in the Civil War, then served under Eads and Kirkwood, whose names will soon again be mentioned, and later developed a number of measurement methods as a member of the Mississippi River Commission. Perhaps the most productive engineer engaged on Mississippi River projects was the Hoosier James Buchanan Eads (1820-1887), who had a fairly long, highly varied, and extremely remunerative career. A builder of bridges (including the one at St. Louis that still bears his name, erected in the face of Humphreys' strong tactical opposition), ironclad warships, underwater salvage gear, and jetties, his consulting work took him to many parts of the world. His brochures *Improvement of the Mouth of the Mississippi River* (1874), *Physics and Hydraulics of the Mississippi River* (1876), and *Mississippi Jetties* (1879) aptly recorded his work and times. The second of these (the title is actually that of the U.S. Levee Commission report that he discussed) protested against what he considered the dogmatism of the Corps of Engineers in recommending flood alleviation through the opening of new outlets in the delta region and simultaneously increasing the levee elevation. It was Eads' contention that closing some of the existing outlets and introducing jetties in the main pass would so deepen the channel that the existing levee system could even be lowered. His perceptive remarks on sediment movement resulted in large part from his examination of many sections of river bottom on foot in one of his diving bells. The following quotation from the first title is typical:

> The popular theory advanced in many standard works on hydraulics, to wit, that the erosion of the banks and bottom of streams like the Mississippi, is due to the *friction* or *impingement* of the current against them, has served to embarrass the solution of the very simple phenomena presented in the formation of the delta of the Mississippi, because it does not explain why it is that under certain conditions of the water, it may develop with a gentle current, an abrading power, which, under other conditions, a great velocity cannot exert at all. A certain velocity gives to the stream

> the ability of holding in suspense a proportionate quantity of solid matter; and when it is thus charged it can sustain no more, and hence will carry off no more, and therefore cannot then wear away its bottom or banks, no matter how directly the current may impinge against them.

Eads was finally permitted to build the jetty system that he recommended and was wholly successful in clearing the South Pass.

Other hydraulic engineers continued on the water-supply projects that have formed a considerable part of this presentation. James Pugh Kirkwood (1807-1877) was a migrant to the United States from his birthplace in Edinburgh. At first a structural engineer, he later also participated in water-supply endeavors for New York and Boston. Of special note were his investigations of lead poisoning from distribution pipes (he was probably the first in America to use tar-coated water mains, laid in Boston in 1858), and of the possible pollution of rivers used for water supply. In 1868 Kirkwood was sent to Europe by the City of St. Louis to study methods of water purification. His book on the subject the following year advocated the use of sand filters, but his recommendations were not adopted by the city; at Poughkeepsie, New York, however, he designed and actually built the first American filter, in 1872-73. One of Kirkwood's contemporaries was John Cresson Trautwine (1810-1883) of Philadelphia; his many international projects included the Delaware Breakwater, the Cartagena Canal in Colombia, Puerto Rican and Canadian harbors, and studies for interoceanic railroads in Panama and Honduras; in the latter regard it is interesting to note that he also sought an interoceanic canal route across Panama but reported such a scheme to be impossible; it was he, moreover, who first published the long-lived *Civil Engineer's Pocket-Book.* Another Philadelphian, William Milnor Roberts (1810-1881), had worked with Canvass White on various canals, with particular attention to the utilization of inclined tracks instead of locks. After numerous canal and railroad projects, he changed his mind about the use of the inclines; if Renwick can be said to have started the practice, it was Roberts who ended it. He also was involved in the improvement of the Ohio River (on which he wrote books in 1856 and 1857), the Mississippi Delta, and the Philadelphia Water Works.

William Jarvis McAlpine (1812-1890) of New York City learned railroad and canal engineering under John Jervis. He succeeded Jervis as chief engineer of the eastern division of the Erie Canal at the age of only 24. He later became involved in the water supply of Brooklyn and Albany, and in 1851 was employed by the water commissioners of Chicago for similar purposes, completing a pumping and distributing system from an intake crib in Lake Michigan by 1854. He thereafter consulted on the water-supply problems of Rochester, Buffalo, San

Francisco, Montreal, Norfolk, Philadelphia, New York, and Toronto. He was also engaged on various railroad, bridge, harbor, and river projects, including consultation on the Iron Gate region of the Danube River in the Balkans. Equally notable among the water suppliers was a native of Baltimore, Ellis Sylvester Chesbrough (1813-1886), sometimes called the father of American sanitary engineering. While he played no part in advancing the chemical treatment of water, he was well aware of the dangers of pollution. With almost negligible schooling, he learned the civil-engineering profession under various railroad engineers in the east, advanced to the post of chief engineer and then commissioner of the Boston Water Works, and thereafter (1855) moved to Chicago to become engineer of its Sewerage Commission. After a study tour of Europe the following year, he planned and supervised the tremendous task of raising Chicago's main streets and buildings so that newly installed sewers would drain toward Lake Michigan, and then constructed a 2-mile tunnel out into the lake to provide—for a time—a supply of uncontaminated water.

During the first half of the 19th century several attempts were made to form a society of civilian engineers. The first of these, in Atlanta in the 1830's, came to naught. The second, in Baltimore in early 1839, attracted 40 participants from 11 states, by whom Benjamin Latrobe was elected president. An organizing Committee of Seventeen met at Philadelphia later in the year, drafted a constitution, and proposed the name American Society of Civil Engineers; however, only seven of the original 40 approved the draft, and the movement soon died. Less than a decade later, however, the Boston Society of Civil Engineers was founded. Four years after that—in 1852—a meeting was called in the office of the Croton Aqueduct Department "for the organization, in the city of New York, of a Society of Civil Engineers and Architects." One of the sponsors was James Laurie (1811-1875), an engineer of Boston who had helped organize the BSCE, and he was chosen as the first president. After three years of activity, a twelve-year period of lethargy set in, and not till just after the Civil War was interest resumed. At that time James Kirkwood became the second president. Under his leadership a Committee on Publication was appointed; the name of the Society was changed to its present form; John Jervis (one of the previous Committee of Seventeen) was elected to honorary membership; and the first volume of Transactions was published (1872) and the Norman Medal established. Other hydraulic engineers already mentioned who later served as president were McAlpine (also an honorary member), Chesbrough, and Francis (also an honorary member of the ASCE as well as past president of the BSCE).

In the foregoing pages several references have been made to the Civil War. An event of that same period which must also be noted was the passage by Congress in 1862 of the Morrill Land Grant Act; this was to have a profound effect on American engineering education. The early influence of the French *Ecole Polytechnique* on the West Point curriculum has already been emphasized. Counterparts of the German *Technischen Hochschulen* were eventually to be found in such schools as the Rensselaer Polytechnic Institute (1824), and the English establishment of engineering faculties as integral parts of their universities was matched by Harvard (1847) and Yale (1852). American state universities, led by Michigan in 1852, followed suit, but it was the land-grant colleges of agriculture and mechanic arts that really made engineering education available to the masses; fully 70 of these colleges (Cornell University among them) were established during the decade immediately following passage of the Act before the country was even a century old. Perhaps the mean level of education was lowered thereby, but an immensely practical sort of engineering graduate who learned by doing in shop and field was produced—a worthy successor to the product of the Erie School.

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