HISTORY OF THE SCIENCE OF HYDRAULICS.

BY W. J. L. NICODEMUS, A. M., C. E.
Professor of Civil Engineering in the University of Wisconsin.

Although some of the fundamental principles of the science of hydraulics were discovered and applied by Archimedes, the progress of this science was almost imperceptible until about the fourteenth century. And this, notwithstanding we read that Rome in A. D. 98 was supplied with water by nine aqueducts, whose discharge was 27,000,000 cubic feet per day, and whose aggregate length was 250 miles. About the beginning of the fourteenth century, great damage was experienced by the overflowing of the mountain streams of Italy, which resulted in disastrous litigations, arising from the stringent laws enacted for the protection of property. This called the attention of practical and scientific men to the necessity of inventing some means of preventing these inundations and rendering the streams more navigable. This resulted in the invention of the canal lock, which was first applied to the canal between the Ticino and Milan, which is at the present day in a perfect state of preservation. From this date hydraulic engineering was ranked as a science, and has steadily progressed to the present time. The successive stages of this progress it is now proposed to follow.

Towards the last of the fifteenth, or the beginning of the sixteenth century, Leonardo da Vinci, one or the architects engaged upon the construction of the cathedral at Milan, first applied his invention of the mitre-sill gate to the lock above mentioned. Canals were now rapidly constructed throughout all parts of Italy. In 1628, Castelli first introduced the meth-
od of estimating the discharge of a river by the velocity of the water. In 1643, Torricelli discovered the general theory of hydraulics that neglecting resistances, the velocities of fluids in motion are in the sub-duplicate ratio of the pressures. He also argued that the acceleration of the currents of rivers was due to the slope of their surfaces, basing his conclusions upon the supposed analogy between spouting fluids and rivers. Pascal made valuable contributions to the science in his works published between 1646 and 1663. A dispute having arisen in 1665, among the inhabitants of the Chiana valley as to the disposition of the water of a certain stream, Rome and Florence assembled a scientific congress to report upon the best plan of accomplishing this task. Many theoretical essays upon river improvements were submitted, but these added very little to what was previously known upon the subject.

Near the close of the seventeenth century appeared the work of Mariotte and Guglielmini. These authors adopting the parabolic theory of rivers, of the celebrated Torricelli, perfected it. According to this theory the velocity of any particle of water in a river will be the same as that of a body falling from a state of rest through a distance equal to that of the particle below the plane of the surface of its source produced. As this theory is contrary to observation and was adopted by so many writers it shows how theoretical was the science at this period of its history. The principal writers upon it being philosophers whose lives were passed in inventing theories and deducing therefrom practical laws instead of making practical observations and building upon this foundation their theories.

Newton in his Principia, published in 1714, discusses the friction of fluids on solids and the discharge through orifices, and though some of his conclusions are erroneous his contributions to the science are valuable.

The Marquis Poleni first discovered that by adapting a small cylindrical tube to an orifice in a thin plate the discharge
could be increased. His work upon the discharge of fluids through orifices was published in 1718. Varignon in 1725 published his work on hydraulics in which he reduced the parabolic theory of rivers to algebraic formulae.

M. Pitot, between the years 1730 and 1738, made a series of experiments upon the velocities at different depths by means of the tube which bears his name. These experiments proved the fallacy of the parabolic theory of flowing water. In 1782, were published the results of the experiments by Couplet upon the discharge of water-pipes at Versailles. At the same time appeared the works of many Italian writers, such as Grandi, Manfredi, Zandrini, Frisi, Zanotti, Gennette. In 1798 was published the work of Daniel Bernouilli, who applied the principle of living force to the motion of fluids, which forms one of the schools of hydraulics.

Between the years 1742 and 1752 appeared the works of John Bernouilli and d’Alembert, upon the theoretical science of hydraulics. Valuable theoretical papers upon the motion of fluids by the celebrated engineer, Leechi, and by Euler, appeared between 1765 and 1771. Professor Michelotti of Turin, and the Abbé Bossuet of Paris, first established it as a fundamental principle, that formulae must be deduced from experiment and not from theory. The former conducted an extensive series of experiments under the patronage of the king of Sardinia, the results of which were published in 1774; the latter conducted a series of experiments under the patronage of the French government, the results of which were published from 1771 to 1778. Both of these furnish important data, particularly the latter, and have been of great value to succeeding writers in deducing constants and testing the accuracy of formulae. We consider that the origin of the modern school of hydraulics is due to the last two named authors. The works of the earlier writers are now of but little importance to the practical engineer.

In 1775, M. Chezy, an eminent French engineer, deduced
the first formula for mean velocity in terms of the slope and dimension of cross-section.

In 1782 was published a voluminous work of Belidor, Architecture Hydraulique, Paris. In 1874, M. l'Espinasse published in the Memoirs of the Academy of Science, at Toulouse, two papers on the expenditure of water through large orifices, and on the junction and separation of rivers.

In 1786 was published the celebrated work of M. Dubuat, which is still a standard authority in the science. He produced a formula which is applicable to most problems respecting the uniform motion of water. He fully illustrates its practical application and touches upon all the general questions of interest to the hydraulic engineer. Valuable works on hydraulics were published by Bernard in 1787, by Brünings in 1790, by Woltman between the years 1791 and 1799. Fatre published a work on torrents in 1797. Venturi published a memoir in 1798, giving the result of a series of experiments upon the contraction of the fluid vein, in which he discusses, among other things, the effect of eddies in rivers and shows that they retard the current.

In 1800 Coulomb published a paper in which he enunciated the principle that the resistance arising from the friction between fluids and solids may be represented by a function consisting only of two terms, being the first and second powers of the velocity. This is called Coulomb's law. In 1801, M. Eytelweine published a large work on hydraulics, following the methods of Dubuat, which has been translated by Nicholson, and has received a very flattering notice from Dr. Young in the Journal of the Royal Institute. In 1803, M. Girard first applied the law of Coulomb to flowing water in open channels, producing a much more simple and practical formula than that of Dubuat. Some of his other articles, particularly those on canals are of special importance. M. de Prony published his first work on hydraulics between 1790 and 1796, his second work in 1802, and his third in 1804. These works
have placed him in the foremost rank of writers on this subject. He shows in his third volume, by discussing experiments, that the resistances of fluids in uniform motion may be represented, as indicated by Coulomb, by an expression involving only two terms, one containing the first, and the other the second, power of the mean velocity; but that these terms should be affected by independent coefficients, and not by a common one, as advocated by Coulomb and Girard. He then deduces the value of these coefficients for pipes and canals by employing two methods given by La Place in his Mécanique Céleste, and by a general equalization of disturbing causes; he gives a new formula of his own for obtaining the mean velocity, etc., from that of the surface.

He published an additional paper in 1825, giving methods of simplifying the application of his formulæ. In 1804, Lecreulx published his Recherches sur la Formation et l’Existence des Ruisseaux, Rivières et Torrents.

In 1808–9 appeared the work of Fánk, a celebrated German scientist, upon hydraulic architecture. M. Krayenhoff published in 1835, his "Receuil des Observations Hydrauliques et Topographiques faites en Hollande," containing a full collection of tables of observations upon the hydrography and topography of Holland, a standard work of great value. He made detailed measurements of discharge, slope of surface, etc., determining the velocity by means of observing the time of transit past a base line of vertical poles reaching from the surface nearly to the bottom. In the Memoirs of the Academy of Berlin, 1814, 1815, appeared the celebrated articles of M. Eytelwein, giving new values to the constants in de Bouy’s formulæ, etc. In 1816, Girard read before the French Academy his valuable work upon the Nile; his graphic representation of the daily gauges kept for the years 1799, 1800 and 1801, is the first diagram of the kind on record. In 1820 appeared Fánk’s second work on hydraulics. Escherde la Linth, in 1821, read a paper before the Helvetic Society of
Natural Sciences in Basle, upon the upper Rhine. By modification of Eytelwein's formulæ from a few measurements of surface velocity, he deduced by a daily gauge-record the annual discharge from 1809 to 1821 at Basle. De Prony published 1822, his noted work on the Pontine Marshes. In this year was published the result of a reconnoissance of the Ohio and Mississippi rivers by General Bernard and Lieut. Colonel Totten, of the United States Engineers. This contains valuable information, especially upon the Ohio river.

In 1823 was published a valuable collection of Italian papers which made the collection complete from the fourteenth century. In 1824–26, M. Rancourt made his well-known experiments upon the Neva when frozen and when open. Mr. Poncelet published in 1828 his theory of permanent motion, that is, the permanent motion of water moving through a channel of variable area and slope. In the same year M. Belanger published his noted work on the same subject containing an original formula which gave more accurate results than any which had preceded it. In 1829, M. Genieys published a practical treatise upon water-works. In 1827 experiments were begun at Hetz upon a large scale to establish the principles of, and fix the constants in, the formulæ for water flowing through orifices. The results were published in 1842, by order of the French government and are known as the Poncelet and Lesbros experiments. In 1833 were published the results of observations upon the Rhine and its tributaries. This is the most important contribution to river improvement of modern times. The works used were both temporary and permanent. The temporary works were built for the purpose of inducing deposits of sediment, etc., which being of service but for a short period, were made of perishable materials. The permanent works consisted of levees and either solid revetments or breakwaters, to prevent the banks caving. These improvements were under of charge Defontaine. He advocates two general plans for improving the Rhine, first by closing all
chutes to confine the river to a single channel; and second, converting all straight lines to curved in the river's course. His reason for the latter plan is that in a bend the caving is limited to one bank, and can be more easily prevented than in a double line of defensive works on a straight line. The dimensions of the levees are far greater than those of the Mississippi. They are 10 feet thick at top, with a slope of one upon two towards the river and one upon one and a half toward the land. The height is calculated to be a foot and a half above the highest floods. Even the large levees are not considered sufficient. Strips of grass-land are left on both sides 6 1-2 feet wide on the exterior and 3 1-2 feet on the interior, measuring from the foot of the slope of the levee. On the outer edges of these strips are planted willows and poplars. To guard against filtration when the levees are more than 7 feet high a banquet is added. Here and there when the current of the river would be liable to act upon the levees, large and strong traverses at distances of 600 to 1000 feet apart are placed and protected, if need be, by fascines, to break the force of the current.

In 1834 appeared the first edition, and in 1840 the second edition of a general treatise on hydraulics by D'Aubuisson de Voisins. In 1835, M. Destrem published the result of a carefully conducted gauging of the Neva and its various branches, under his immediate supervision. In the same year appeared a historical sketch of the progress of hydraulics by Charles S. Storrow, Boston, giving the demonstrations and practical applications of various formulae proposed by different writers on hydraulics. In 1836, Tredgold published Smeaton's experimental papers on the power of water and wind to turn mills; Venturi's experiments on the motion of fluids (1798); and Dr. Young's summary of practical hydraulics, chiefly from the German of Eytelwein. In 1840, M. Dausse obtained a premium for a paper upon the best methods of improving the navigation of the principal rivers of France. Between 1843-
and 1853, the celebrated hydraulic engineer Lombardini, published a number of papers upon the hydraulic condition of the river Po, in which he demonstrates that levees have not elevated the bed of the river, although they have increased the height of floods by retaining between the banks the waters which before escaped through crevasses; and this height has been further increased by the more rapid flow caused by clearing the mountain sides of their forests. In 1841, M. Surell published a paper upon the torrents of the Alps, showing that forests exercise an important moderating effect, and advises their cultivation for that purpose. In 1843, M. de Buffon published his theoretical and practical treatise upon irrigation. He adopts de Prony’s formula for the mean velocity with Eytelwein’s co-efficients. He thinks the float, from its simplicity, is superior to all other instruments for measuring the velocity. M. Weisbach in his mechanics, published at Freiberg in 1846, treats very fully of hydraulics, for which task the special study of many years had peculiarly fitted him.

M. Surrell, in 1847, published an elaborate work upon the improvement of the river Rhone. In 1848 appeared Dupuit’s work on hydraulics, which is a valuable contribution to the science. This same year was published a memoir by M. Baumgarten upon a portion of the Garonne, giving the various works used in the improvement and discussing their effects. He reports some very interesting experiments, among others that of measurements upon the transverse section of the water-surface at a nearly straight portion of the river (width about 600 feet), both when the water was rising and falling. When rising, at the rate of about 5 feet in twenty-four hours, with a maximum velocity of about 7 feet per second, he found the water in the middle to be about 0.4 of a foot above that on the right bank, and 0.1 above that on the left. When falling at the rate of about 8 feet in twenty-four hours, with a maximum velocity of about 7.5 feet per second, the water-surface was sensibly a plane, being at the right
bank a little less than 0.1 of a foot above its level at the opposite side of the river. In the proceedings of the American Association for the Advancement of science for 1848 and 1849, are valuable papers, which contain the results of experiments made at Natchez and Memphis upon the Mississippi river. The daily discharge at Memphis was determined by making a cross-section of the river, and subdividing it into three partial areas. The surface velocity in each of these areas was measured by anchoring the boat and using a chip and line. During calm weather the relative velocity near the bottom was also measured by comparing the velocity of a surface float and a double float whose lower portion, composed of a tin vessel, was sunk nearly to the bottom. The discharge was equal to the sum of the products of the partial areas by the average velocities in them. The temperature of the water at the bottom was found to be the same as at the surface. The velocity near the bottom was to that at the surface in the ratio of 268 to 300. The average downfall was 0.11 inches, and the average evaporation from the surface of the water of considerable depth, was 0.13 inches daily.

Mr. Ellet, in a memoir to the Smithsonian Institution in 1849, advocated the reservoir system for the improvement of the Ohio and other rivers. M. Boileau made a very extended series of hydraulic experiments by order of the French government between the years 1844 and 1854, which were published in the last mentioned year. It is a work of great value to the science.

In 1851 Mr. Ellet submitted a report to the War Department upon a survey made by him under its direction to determine the best method of preventing the overflows of the delta of the Mississippi. In the same year appeared a work on hydraulics by M. de Saint Venant, which contains much original and valuable matter. In 1855, Herman Haupt published a pamphlet advocating the improvement of the Ohio river, by a low dam and chute plan. Lombardini, in 1858,
published a memoir upon the recent inundations in France and the means of remedying the evils thereof. During this same year Dupuit in France, David Stevenson in England and Ellet in this country, made valuable contributions to the science.

The annual reports to the Chief Engineer of the Army furnish valuable information upon the improvement of rivers and harbors. Time at present will not permit my tracing farther the progress of this science, and I will merely add that the governments of all civilized nations have fully awakened to its importance, and by authorized experiments are daily aiding in its advancement.