HISTORY OF WATER FLOW MEASUREMENT

Knowledge of the velocity and the ability to measure water flow was necessary for the fair distribution of water through the aqueducts of such early communities as the Sumerian cities of Ur, Kish, and Mari near the Tigris and Euphrates Rivers around 5,000 B.C… and in the Aqueducts of Ancient Roman Empire. Even today, the distribution of water among the rice patties of Bali is the sacred duty of authorities designated the "Water Priests."

Our understanding of the behavior of liquids and gases (including hydrodynamics, pneumatics, aerodynamics) is based on the works of the ancient Greek scientists Aristotle and Archimedes. In the Aristotelian view, motion involves a medium that rushes in behind a body to prevent a vacuum. In the sixth century A.D., John Philoponos suggested that a body in motion acquired a property called impetus, and that the body came to rest when its impetus died out.

The concept of a water meter is fairly straight forward—the idea being to measure the flow of water through a pipe—however the actual and accurate implementation is more complicated. Everything from temperature, to pressure, to the angles of the pipes and build-up can affect the exactness of a meter read.
However, in the early 1500s, none other than Leonardo DaVinci conceived a prototype of what might be the first water meter ever. For him, water in all its forms was a subject of fascination, intrigue, and learning; his interest in measuring water was, mainly, educational—a way of studying it more closely.

In 1687, the English mathematician Sir Isaac Newton discovered the law of universal gravitation. The operation of angular momentum-type mass flow meters is based directly on Newton's second law of angular motion. In 1742, the French mathematician Rond d'Alembert proved that Newton's third law of motion applies not only to stationary bodies, but also to objects in motion.
The time came to 1730. Pitot Tube, named after its father Henri Pitot, was used to determine the relation between the rise of water in the tube and the velocity of flow.
Another element that stalled the creation and refining of an accurate water meter was simply that there wasn't a pressing need. Most places in the world did not sell water by volume until the mid-1800s, so innovation was understandably slow until then.

So, it wasn't until more than 350 years later after DaVinci that the need to meter water usage for economic purposes would be met with the first, official water meter. As cities grew, so grew the need to secure urban infrastructure from theft of resources. Patented in 1855, a device created by Henry R. Worthington can claim to be America's first water meter—it was durable, accurate, and set the tone for the metering of the future.

Mechanical water flowmeters history and billing

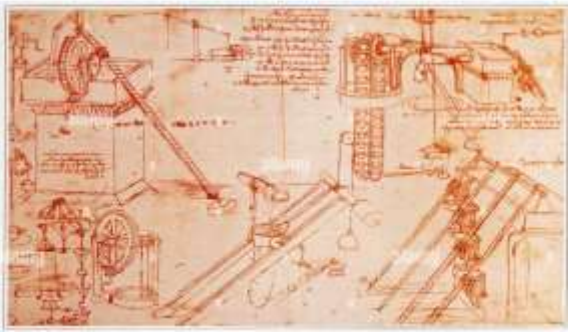
All positive displacement flow meters operate by isolating and counting known volumes of a fluid (gas or liquid) while feeding it through the meter. By counting the number of passed isolated volumes, a flow measurement is obtained. Each PD design uses a different means of isolating and counting these volumes. The frequency of the resulting pulse train is a measure of flow rate, while the total number of pulses gives the size of the batch.

Types include:

- Positive Displacement Types: Nutating Disc, Oscillating Piston, Oval gear Rotary Piston types.
- Paddlewheel,
- Turbine & Helix,
- Inferential,
- Multi-jet,
- Proportional.

Electronic Type:

- Vortex
- Pressure Differential
- Electromagnetic
- Capacitive
- Coriolis
- Ultrasonic



Chinese water transfer devices -BC

The Flow Principle Pioneers

A major milestone in the understanding of flow was reached in 1783 when the Swiss physicist Daniel Bernoulli published his Hydrodynamica. In it, he introduced the concept of the conservation of energy for fluid flows. Bernoulli determined that an increase in the velocity of a flowing fluid increases its kinetic energy while decreasing its static energy. It is for this reason that a flow restriction causes an increase in the flowing velocity and also causes a drop in the static pressure of the flowing fluid.

The permanent pressure loss through a flow meter is expressed either as a percentage of the total pressure drop or in units of velocity heads, calculated as V2/2g, where V is the flowing and g is the gravitational acceleration (32.2 feet/second2 or 9.8 meters/second2 at 60o latitude). For example, if the velocity of a flowing fluid is 10 ft/s, the velocity head is 100/64.4 = 1.55 ft. If the fluid is water, the velocity head corresponds to 1.55 ft of water (or 0.67 psi). If the fluid is air, then the velocity head corresponds to the weight of a 1.55-ft column of air.

The permanent pressure loss through various flow elements can be expressed as a percentage of the total pressure drop (Figure 1), or it can be expressed in terms of velocity heads. The permanent pressure loss through an orifice is four velocity heads; through a vortex shedding sensor, it is two; through positive displacement and turbine meters, about one; and, through flow venturis, less than 0.5 heads. Therefore, if an orifice plate (Figure 2) with a beta ratio of 0.3 (diameter of the orifice to that of the pipe) has an unrecovered pressure loss of 100 in H2O, a venturi flow tube could reduce that pressure loss to about 12 in H2O for the same measurement.

Figure 1: Pressure Loss-Venturi vs. Orifice

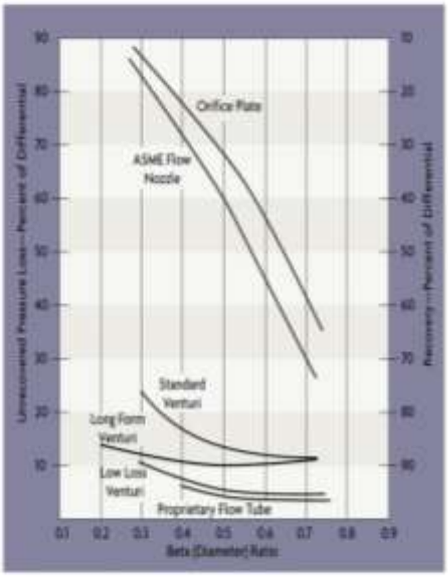
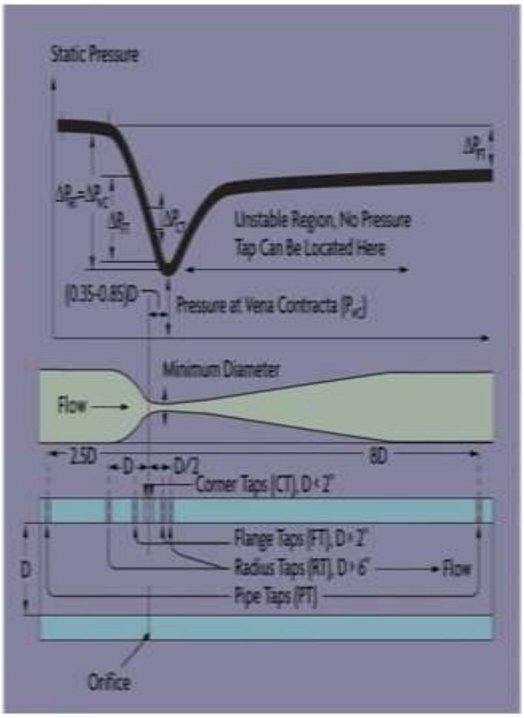


Fig2: Conversion of Static Pressure Into Kinetic Energy



In 1831, the English scientist Michael Faraday discovered the dynamo when he noted that, if a copper disk is rotated between the poles of a permanent magnet, electric current is generated. Faraday's law of electromagnetic induction is the basis for the operation of the magnetic flow meter. As shown in Figure 3, when a liquid conductor moves in a pipe having a diameter (D) and travels with an average velocity (V) through a magnetic field of B intensity, it will introduce a voltage (E) according to the relationship:

E = BVDC   Where C is the constant for units conversion.

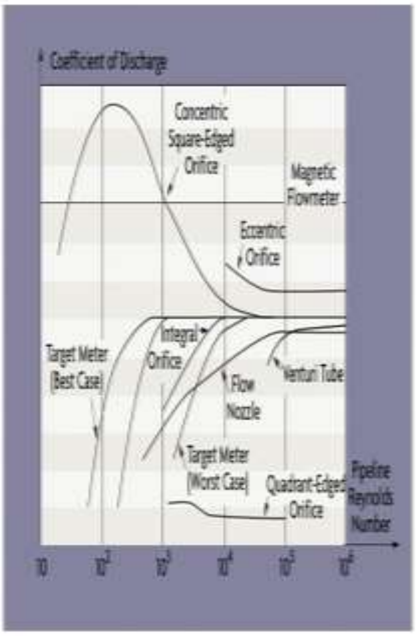


Fig3: Faraday's Law Is the Basis of the Magnetic Flow Meter

Over the past several years, the performance of Electromagnetic flow meters has improved significantly. Among the advances are probe and ceramic insert designs and the use of pulsed magnetic fields (Figure 4), but the basic operating principle of Faraday's law of electric induction has not changed.

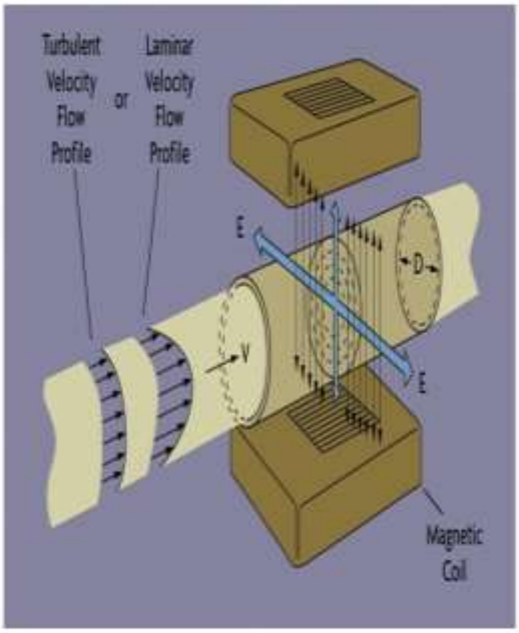


Figure 4: Magmeter Accuracy

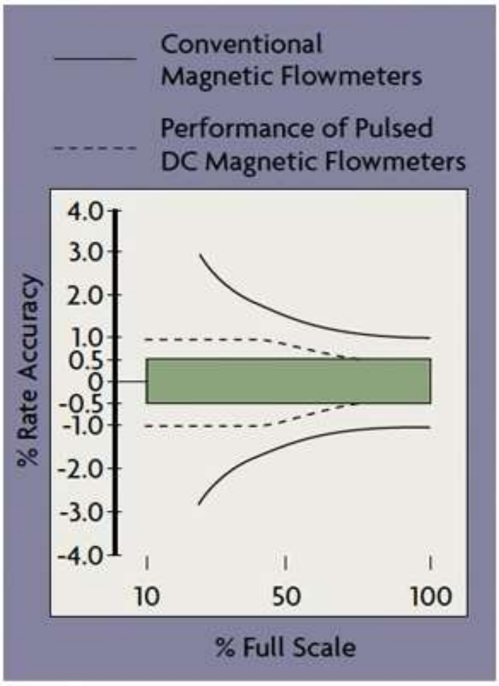
In 1883, the British mechanical engineer Osborne Reynolds proposed a single, dimensionless ratio to describe the velocity profile of flowing fluids:

$Re = DV\rho/\mu$

Where D is the pipe diameter, V is the fluid velocity, ρ is the fluid density, and μ is the fluid viscosity.

He noted that, at low Reynolds numbers (below 2,000) (Figure 5), flow is dominated by viscous forces and the velocity profile is (elongated) parabolic. At high Reynolds numbers (above 20,000), the flow is dominated by internal forces, resulting in a more uniform axial velocity across the flowing stream and a flat velocity profile.

Fig.5: Effect of Reynolds Numbers on Various Flow Meters

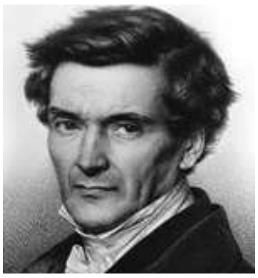


Until 1970 or so, it was believed that the transition between laminar and turbulent flows is gradual, but increased understanding of turbulence through supercomputer modelling has shown that the onset of turbulence is abrupt.

When flow is turbulent, the pressure drop through a restriction is proportional to the square of the flowrate. Therefore, flow can be measured by takin the square root o a differential pressure cell output. When the flow is laminar, a linear relationship exists between flow and pressure drop. Laminar flow meters are used at very low flowrates (capillary flow meters) or when the viscosity of the process fluid is high.

In the case of some flow meters technologies, more than a century elapsed between the discovery of a scientific principle and its use in building a flow meter. This is the case with both the Doppler ultrasonic and the Coriolis meter.

In 1842, the Austrian physicist Christian Doppler discovered that, if a sound source is approaching a receiver (such as a train moving toward a stationary listener), the frequency of the sound will appear higher. If the source and the recipient are moving away from each other, the pitch will drop (the wavelength of the sound will appear to decrease). Yet it was more than a century later that the first ultrasonic Doppler flow meter came on the market. It projected a 0.5-MHz beam into a flowing stream containing reflectors such as bubbles or particles. The shift in the reflected frequency was a function of the average traveling velocity of the reflectors. This speed, in turn, could be used to calculate a flowrate.



The history of the Coriolis flow meter is similar. The French civil engineer Gaspard Coriolis discovered in 1843 that the wind, the ocean currents, and even airborne artillery shells will all drift sideways because of the earth's rotation. In the northern hemisphere, the deflection is to the right of the motion; in the southern hemisphere, it is to the left. Similarly, a body traveling toward either pole will veer eastward, because it retains the greater eastward rotational speed of the lower altitudes as it passes over the more slowly rotating earth surface near the poles. Again, it was the slow evolution of sensors and electronics that delayed creation of the first commercial Coriolis mass flow meter until the 1970's.

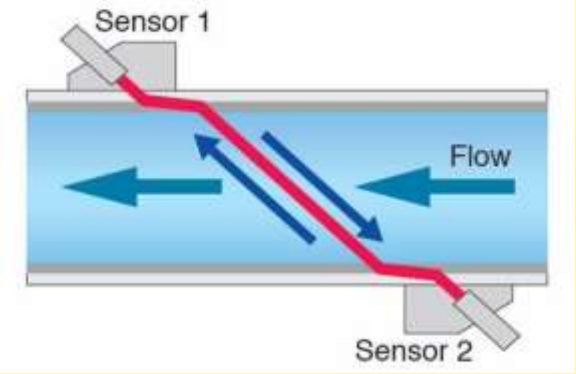
It was the Hungarian-American aeronautical engineer Theodore von Karman who, as a child growing up in Romania, noticed that stationary rocks caused vortices in flowing water, and that the distances between these traveling vortices are constant, no matter how fast or slow the water runs. Later in life, he also observed that, when a flag flutters in the wind, the wavelength of the flutter is independent of the wind velocity and depends solely on the diameter of the flagpole. This is the theory behind the vortex flow meter, which determines flow velocity by counting the number of vortices passing a sensor.

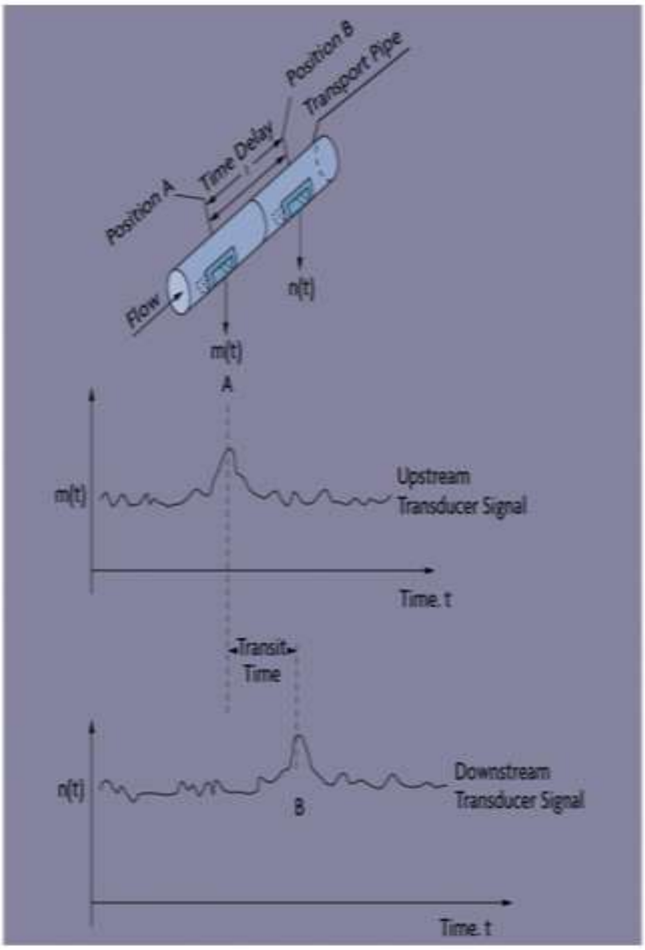
Von Karman published his finding in 1954, and because by that time the sensors and electronics required to count vortices were already in existence, the first edition of the Instrument Engineers' Handbook in 1968 was able to report the availability of the first swirl meter.

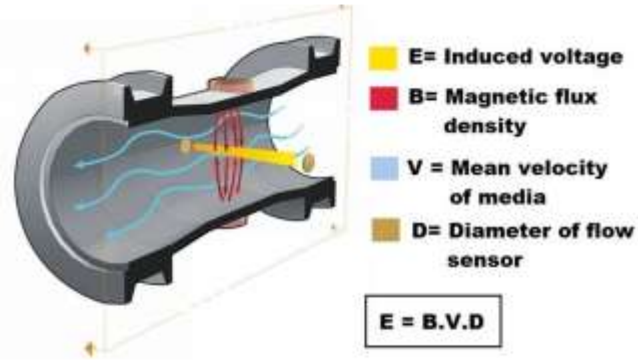
The computer has opened new frontiers in all fields of engineering, and flow measurement is no exception. It was only as long ago as 1954 that another Hungarian-American mathematician, John Von Neumann, built Uniac – and even more recently that yet another Hungarian-American, Andy Grove of Intel, developed the integrated circuit. Yet these events are already changing the field of flow metering. Intelligent differential pressure cells, for example, can automatically switch their range between two calibrated spans (one for 1-10%, the other for 10-100% of D/P), extending orifice accuracy to within 1% over a 10:1 flow range. Furthermore, it is possible to include in this accuracy statement not only hysteresis, rangeability, and linearity effects, but also drift, temperature, humidity, vibration, over-range, and power supply variations effects.

Figure 6: The Ultrasonic Transit-Time Flow Meter

With the development of superchips, the design of the universal flow meter also has become feasible. It is now possible to replace dye-tagging or chemical-tracing meters (which measured flow velocity by dividing the distance between two points by the transit time of the trace), with traceless cross-correlation flow meters (Figure 6). This is an elegant flow meter because it requires no physical change in the process – not even penetration of the pipe. The measurement is based on memorizing the noise pattern in any externally detectable process variable, and, as the fluid travels from point A to point B, noting its transit time.







Let’s return to the history of creation of water meters.

The first water meter in history was born in Britain in 1825. It marked the beginning of a long journey that has spanned nearly 200 years, evolving into the intelligent water meters we have today—a crucial part of smart cities.
The idea of such a device was patented in 1851 by the German engineer and industrialist Carl Wilhelm Siemens, by demand of London’s water companies. The first official US patent for a water meter was obtained by William Sewell of Williamsburg in 1850.
However, in the United States, the claim to producing the first water meter was made by Henry Worthington in 1857. These early designs were of the reciprocating piston type, inspired by steam engine principles.
America’s first successful meter—a Worthington duplex piston meter is from the 1890s. The meter, with serial number 55,542, is a testament to the ingenuity of its time.

Most modern water-meters act on the principle of counting the number of turns made by a small reaction turbine moved by the water as it flows through it. This is the basis of Sir William Siemens' invention, who patented his water meter (‘fluid meter’) in April 1852 . Until that time, water metering was not possible; several attempts had been made to devise a suitable device, but all had failed. W. Siemens also invented meters for other applications (bathometer for the depth of the sea, electric pyrometer, etc.).

Public water supplies remain a critical factor in improving the health and well-being of urban populations and are instrumental to reducing illness and mortality rates. Every civilization has had public water supplies, which encompass a wide range of activities including individual consumers gathering water from a nearby lake, river, spring or well, deliveries of water to consumers by a public or private entity, and distribution of water through artificial channels such as aqueducts, canals, or pipelines.
In the USSR the production of water meters began in 1935. However, very soon soviet state decided to abandon their use and introduced general water consumption standards.

Water meters have come a long way since those early days, and today they play a crucial role in measuring water use for residential and commercial buildings supplied by public water systems. From oscillating piston and nutating disc meters to modern electromagnetic and ultrasonic meters, these devices help us manage our water consumption efficiently

NEPTUNE FLOWMETERS USA -Nutating disc, positive displacement principle has been time-proven for accuracy and dependability since 1892, ensuring maximum utility revenue. The T-10 water meter consists of three major assemblies: a register, a lead free, high-copper alloy maincase, and a nutating disc measuring chamber.
Nowadays, water meters, instead of mechanical transmission of movements and signals (as in old clock gearing), send magnetic, electric, or digital pulses which can be stored (remote dial counter or display, data-logger, etc.)

Automatic Meter Reading - Brief History

In 1972, Theodore George “Ted” Paraskevakos, while working with Boeing in Huntsville, Alabama, developed a sensor monitoring system which used digital transmission for security, fire and medical alarm systems as well as meter reading capabilities for all utilities. This technology was a spin off of the automatic telephone line identification system, now known as Caller ID.

In 1974, Mr. Paraskevakos was awarded a U.S. patent for this technology. In 1977, he launched Metretek, Inc., which developed and produced the first fully automated, commercially available remote meter reading and load management system. Since this system was developed pre-Internet, Metretek utilized the IBM series 1 mini-computer. For this approach, Mr. Paraskevakos and Metretek were awarded multiple patents.

The primary driver for the automation of meter reading is not to reduce labor costs, but to obtain data that is difficult to obtain. As an example, many water meters are installed in locations that require the utility to schedule an appointment with the homeowner in order to obtain access to the meter. In many areas, consumers have demanded that their monthly water bill be based on an actual reading, instead of (for example) an estimated monthly usage based on just one actual meter reading made every 12 months. Early AMR systems often consisted of walk-by and drive-by AMR for residential customers, and telephone-based AMR for commercial or industrial customers. What was once a need for

monthly data became a need for daily and even hourly readings of the meters. Consequently, the sales of drive-by and telephone AMR has declined in the US, while sales of fixed networks has increased.
The trend now is to consider the use of advanced meters as part of an Advanced Metering Infrastructure.

PIONEERING RESIDENTIAL WATER USAGE STUDIES in Australia.

Alexander Manu from ManuFlo was a pioneer introducing in 1991 a high resolution non-powered pulse output, retaining the mechanical water meter totalizer for billing purposes. The water flow meter is for connection to dataloggers to allow government agencies to accurately monitor residential water usage demand habits.
https://manuflo.com/water-residential-end-use-studies/

A brief history of hydrometry 29/4/24

1. The Antiquity

Figure 1. Surface velocity measurement by Leonardo da Vinci. [Source: reconstruction by Arthur H. Frazier]The **first** river **flow measurements** were made by **Greek mathematicians and mechanics** Ctesibios and then Heron of Alexandria (3rd century BC and 1st century AD respectively). This was a work of no consequence, because in the West, the principles and practice of hydrometry were then **forgotten** until the Renaissance.

In China, the first systematic water level surveys were reported to have begun in 251 BC on an irrigation complex. In 1078, Fan Ziyuan presented the principles of measuring a river flow in order to compare the water resources available on several rivers. The first surface speed measurements are taken on the Yellow River, using **a horse running on the bank at the same speed as the surface current**, which was followed by floats drifting along the river.

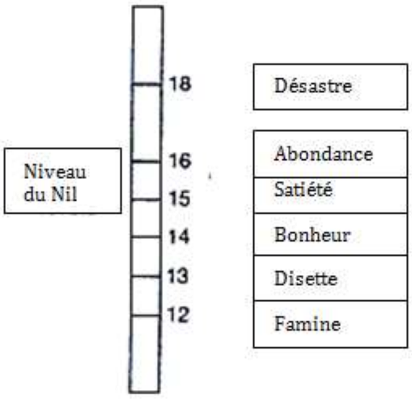


Figure 2. Nilometric cubit graduations (0.525 m) – unit used from the Pharaonic period to the adoption of the metric system in Egypt. [Source : reconstruction of the principle diagram, according to Hansen, 2004]Nile level measurements have been documented since **3000 BC**; they announced, from the upstream of the first cataract (towards Aswan), the rise and importance of the Nile flood as indicators of the expected harvest. The Umayyads resumed observations around 725 and an almost continuous series of annual minima and maxima of the river could be formed up to the contemporary era. But there was no **notion of quantifying the** associated **flow**. We were only trying to anticipate possible food crises, due to a lack of water for crops or destruction by large floods.

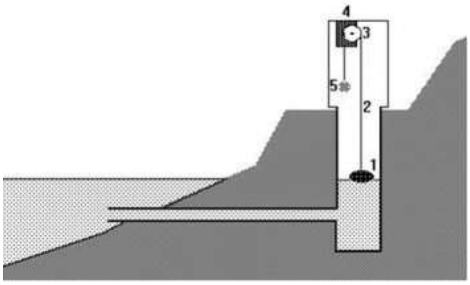
2. The Middle Ages and the Enlightenment

The Arab-Muslim civilization, however, had practically completed the theoretical reflection on the water cycle and & the origin of rivers around the 10-12th centuries (which Antiquity had not realized) and expressed the flow of a river as the **number of mills** that it could supply.

In the West, **Leonardo da Vinci** is studying the distribution of velocities in rivers and will conduct the first serious attempt to **determine the velocity of the current** by floats (Figure 1).

The 17th century saw the reflection continue, motivated by the analysis of the water cycle in nature. **Pierre Perrault** (1674) & **Edmée Mariotte** (1686) carried out the first precipitation/flow calculations on the Seine basin & carried out the first gauges (surface speed measurements with weighted sticks). **Edmond Halley** (1686) assesses the flows of the main rivers of the Mediterranean, compared to Thames Kingston Bridge. **D.Guglielmini** holds the first chair of hydrometry, created in Bologna 1694.

The 18th century saw the **first systematic surveys of scales**, in order to note and date at different points the level of **flood rise**: Seine in Paris (1719), Elbe in Magdeburg (1727), Rhine in Emmerich (1770)… The formalization of the laws of hydraulics (Antoine Chézy, Daniel Bernoulli, etc.) accompanied metrology; the devices for measuring river speed were improved: taking up the work of the English **Robert Hooke** and **Henry de Saumarez** on devices for **measuring ship speed, Estavao Cabral** (1786) and **Reinhardt Woltman** (1790) developed the first **hydrometric reel.** A little earlier (1732) the French **Henri Pitot** invented the Pitot tube, “a machine to measure the speed of running water and the wake of ships”. It is with this device in particular that gauging will be carried out on the Seine in Paris during the great flood of 1910; & that the speed of aircraft is still routinely measured today.



3. The modern era

Figure 3. Principle of river level measurement developed by Palmer. A float in a well follows the level variations of the watercourse. The system became widespread in the 1950s, and was gradually replaced in the 1990s by more modern sensors, easier to automate and teletransmit.

In 1831, **Henry Palmer** designed the first **continuous** water **level recorder** (with recording on a paper graph); his invention was installed in 1832 on the Thames at Sheerness.

The **complete sequence** measures heights + gauges + calibration curve + continuous flow calculation is being implemented on a few rare sites: Rhine in Basel (1808), Memel in Schmalleninken (1812).

During this 19th century, as the socio-economic system became more complex and modern, it also became more vulnerable. The **great floods of the 1840s and 1870s** triggered major discussions in Western Europe. In 1854, **Eugène Belgrand** set up a **monitoring system with the ambition of predicting the floods of the Seine in Paris** three days in advance.

Figure 4. Flooding of the Loire in Orléans. Spring 1856 was accompanied by catastrophic floods, particularly on the Rhône and Loire rivers. It is under the administration of Napoleon III (represented on the right in this image of Epinal) that the systematic observation of watercourses in France was really structured. “Before seeking the remedy to a problem, it is necessary to study the cause well” he wrote to the Minister of Public Works on July 19, 1856 (letter called “de Plombières”); he thus illustrates the Saint-Simonian principle of carrying out studies in order to determine the actions to be undertaken.

But the real densification of measurement networks, with the production of daily flow sequences, will only take place at the turn of the century, for the knowledge of **hydroelectric** potential: Norway (1890), Iceland (1894), Sweden (1907), France (1903). In 1906, 290 hydrometric stations were operating in Switzerland.Proposed by the French **Théophile Schloesing** in 1863, dilution gauging – well adapted to mountain torrents – only became truly controlled in the early 1950s. The first tracers used called for very significant quantities to be spilled: for a river flow of about 2.5 m3/s, two gauges on the Guil on 17 February and 11 March 1944 called for the injection of **1480** and **2190 kg of** denatured salt respectively. For this reason, other tracers were sought, stable, highly soluble and not present in water in its natural state. Sodium dichromate was introduced in France in the early 1950s and was massively replaced in 1990 by fluorescent **rhodamine** tracers.

Figure 5. Gauging by exploring the speed field on the Durance at Embrun (Hautes Alpes) in 1910; on the right, Woltman principle reel of the “Richard” brand used from the boat.

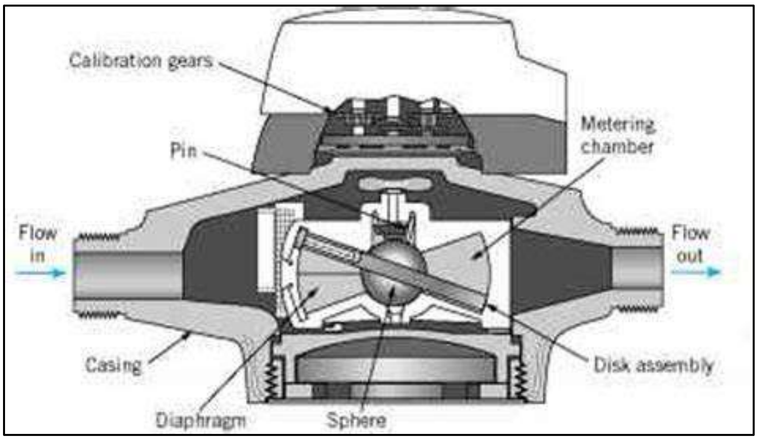
Maurice Pardé (1893-1973) is the author of a monumental thesis on the Rhône (1925), an analysis that is still authoritative. He is considered to be the founder of **potamology**, the study of rivers and their regimes. Maintaining a network of correspondents from all over the world, it **promotes hydrometric information** in brilliant syntheses on the main rivers, particularly in the field of flooding.

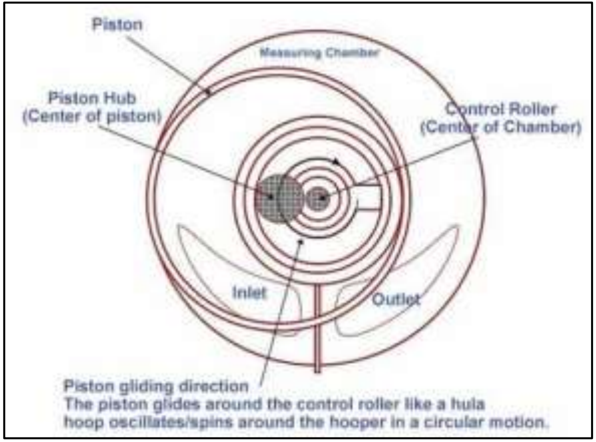
From the 1960s onwards, other problems emerged (agricultural, drinking water, leisure, regulatory), measurement networks were no longer concentrated on landforms and *“went down to the plains*“: the stations were **better distributed** geographically.

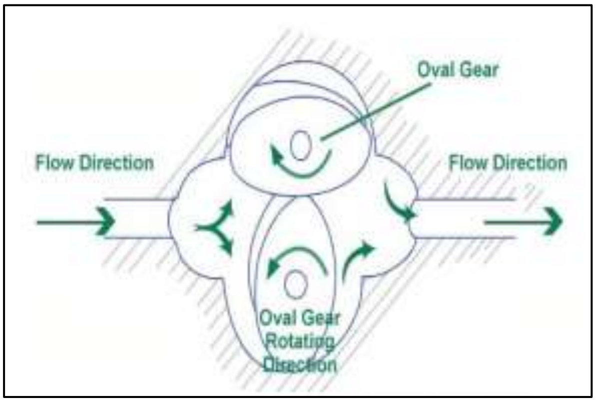
Remote transmission of height data became widespread in the 1980s. In France, data from the Ministry of the Environment’s networks were made available to the general public by computer servers in the mid-1990s.

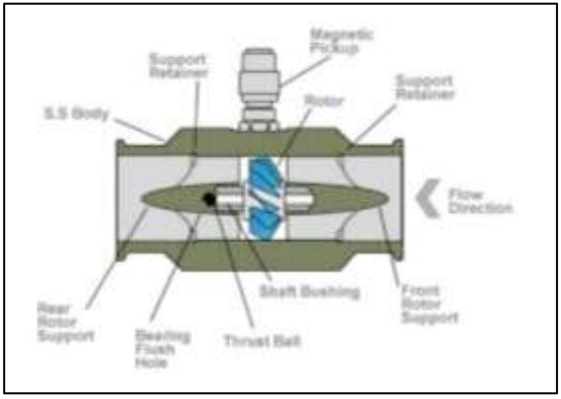
Between 1980 and 2010, the emergence of **new techniques (**ultra-sound velocity measurement, ADCP, LSPIV) finally made it possible to better understand the compartments poorly covered by hydrometry: flatland rivers at slow flow velocity, tidal reaches, torrents subject to flash flooding – with strong movement of associated sediments..

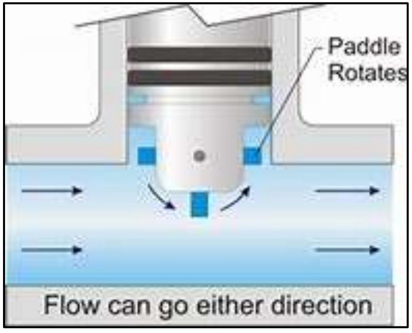
Principles of operation for conventional mechanical water flowmeters;

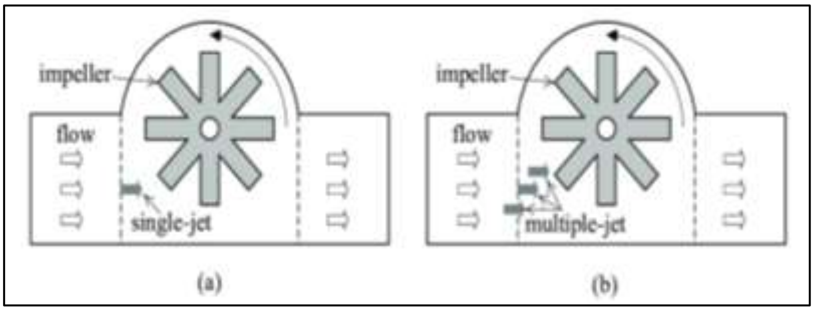












The nutating disc meter, which uses the same geometry and concept as the Dakeynes' original engine, is probably the most widely used flowmeter in the world, and it is claimed that more than half the water meters installed in domestic premises in the US and Europe are of this type. Used for 150 years, it is essentially a Dakeyne Disc Engine and was most probably developed by Farey and Donkin who mentioned a "fluid measurement meter" in their 1850 disc engine patent granted in 1850. By 1859 they were being manufactured by the Buffalo Meter Company of Buffalo, New York.

The Dethridge wheel was invented by John Dethridge in Australia in 1910. Dethridge was then commissioner of the Victorian State Rivers and Water Supply Commission. The wheel consists of a drum around an axle with four spokes originating from each end of the axle. Eight v-shaped vanes are fixed to the outside of the drum which then spins. Wheels generally last for 15 to 20 years, and the axle is replaced every five years. The revolving wheel measures the flow of water from the irrigation. Dethridge wheels became extremely popular because they were relatively cheap, robust, simple to use and reasonably accurate. Around the end of the 20th century, tens of thousands were still in use in Australia and other countries including the USA, Israel and parts of Africa. In recent years, however, there has been a trend towards using more accurate electronic meters to measure water flow in irrigation systems.

108 Water Meters Display Exhibit (USA)

The National Museum of American history boasts what may be the world's largest and finest collection of historic water meters -- 108 in all, each one made in the United States. Most of these meters came to the Smithsonian in 1965, a gift from A.A. Hirsch of Shreveport, Louisiana. An odd collection, perhaps, and yet an important one, reminding us of such key aspects of the American experience as the development of public water works and the related concern with water conservation. As there have been many hundred water meter patents, the collection calls attention to American ingenuity. And the history of water meter manufacturers and water meter scandals indicate the large sums of money to be made from urban infrastructure.

Except for a few early prototypes -- namely that discussed by Frontinus in ancient Rome, and that designed by Leonardo da Vinci in the early sixteenth-century -- the water meter story began in the early nineteenth century and expanded along with the growth of urbanization and industrialization. Water meters are conceptually simple but difficult to execute. Thus, a well-informed commentator observed in 1870: "Measurement of water flowing through pipes, under any and all circumstances of position, pressure, and velocity, has, perhaps, more difficulties than any other with which the modern mechanic can grapple." Another observed in 1885: "Notwithstanding the demand the effort made by inventors to meet these desiderata, such marked success has not been attained as to make it a universal custom to sell water by the volume." That situation, however, was soon to change as inventors devised meters that were accurate, reliable, durable and relatively inexpensive, and that would measure low flows as well as gushers.

The museum's oldest meter is a Worthington duplex piston, serial number 55,542, that was probably made in the 1890s, and is a late example of America's first successful meter. The form was designed, patented (in 1855), and produced by Henry R. Worthington (1817-1880), a New York manufacturer of pumps and other hydraulic machinery. The museum's most recent meter, a 1971 gift from the Rockwell Manufacturing Company in Pittsburgh, features a sealed register magnetic drive that, according to the donor, kept the register clean, dry and free from fog. It was also the twenty-one millionth meter made by that firm. The meters in between represent all the major American makers and most of the major forms.

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