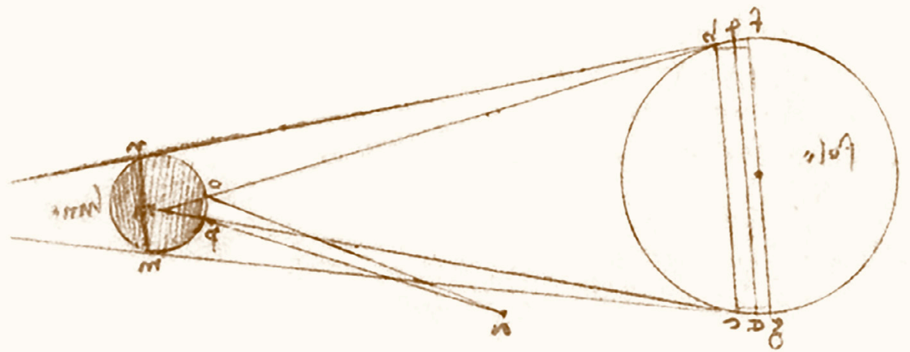
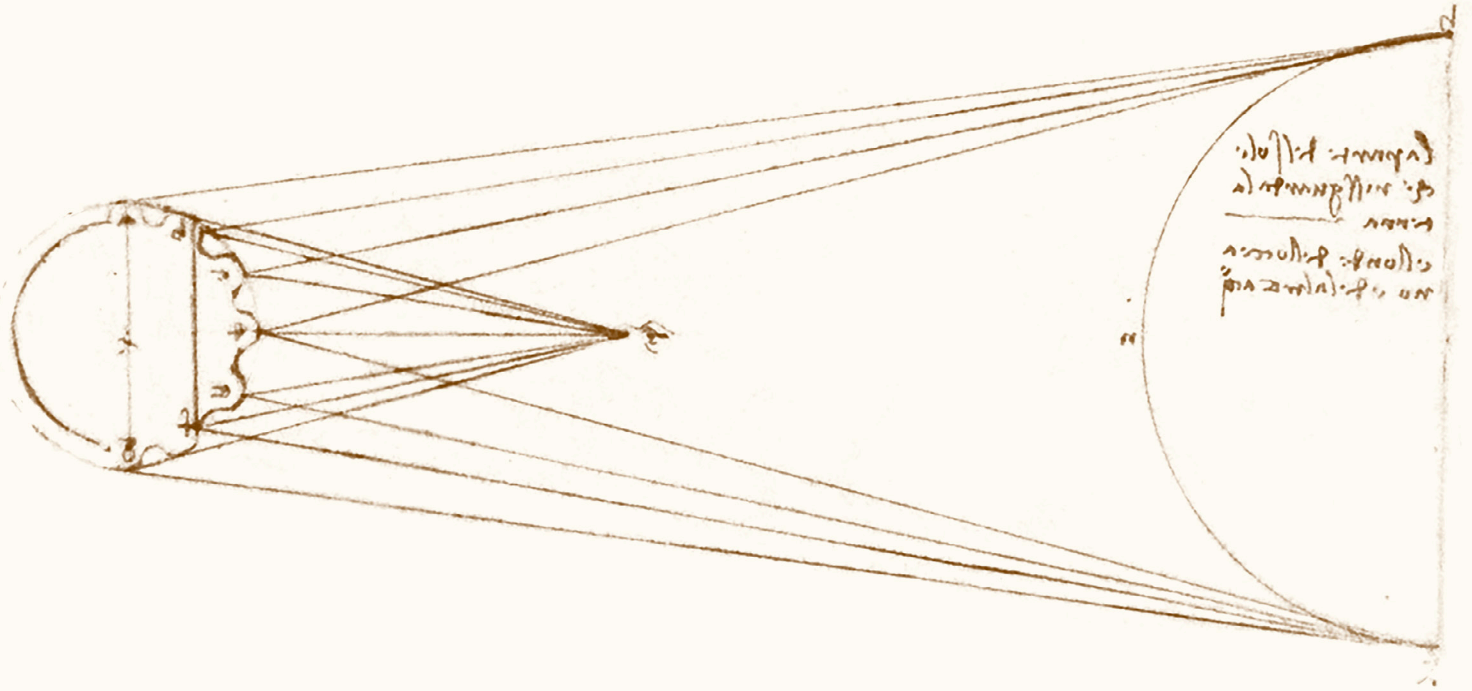
SHEET 1A: FOLIOS 36v & 1r

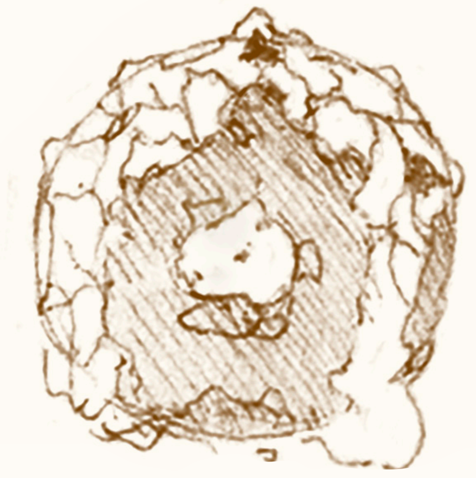
What can moonlight tell us about the moon? Leonardo diagrams the path of sunlight as it hits the moon and reflects to Earth. If the moon had a smooth surface (left), the rays would veer off and miss the Earth. Leonardo surmises that the moon's surface is covered with wavey water, and as a result, light bounces off in multiple directions (right) and some reaches us on Earth.

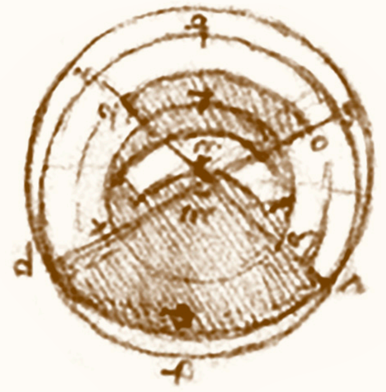




SHEET 1B: FOLIOS 1v & 36r

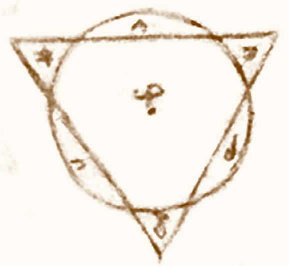
Leonardo deploys a different kind of diagram—the cross-section—to illustrate his theory about the Earth's core. He speculates that large, water-filled caverns lie below the surface; when they cave in, they change the Earth's center of gravity, pushing other land masses up to form mountains.



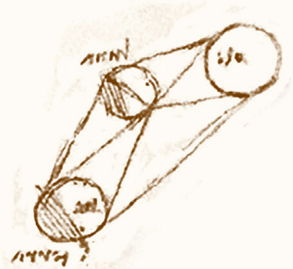


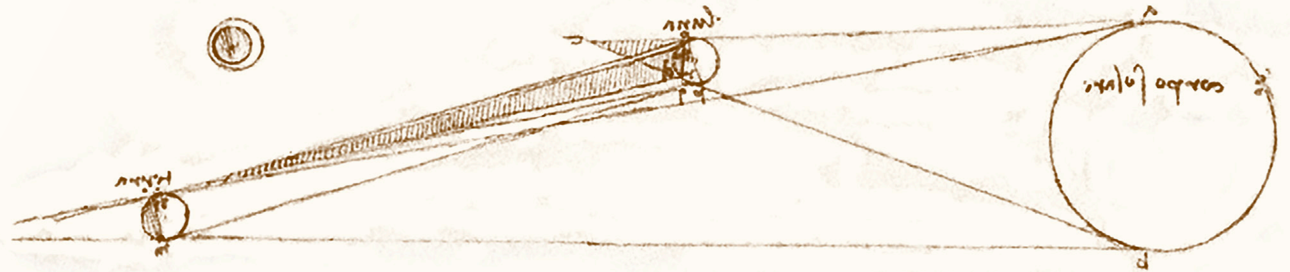
SHEET 2A: FOLIOS 35v & 2r

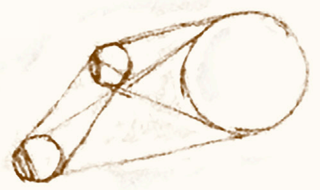
This enigmatic diagram of a triangle inside a circle is Leonardo's way of depicting balance or harmony among the planet's geological formations. Later, he compares the natural process of land rising and falling on the Earth's surface to the geometric transformation of one shape into another of equal volume (5a folio 32v).



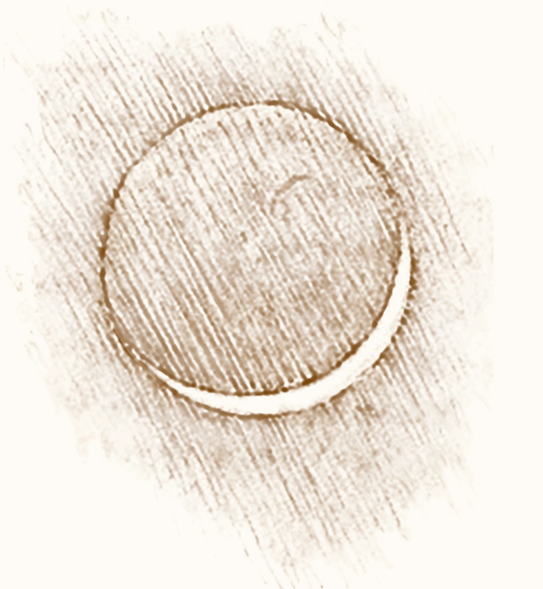
Leonardo figures that because the Earth and the moon behave similarly in orbit that they must have the same elements—earth, air, water—as well as gravity holding them in place. He draws the moon, Earth, and sun at various points in their orbit to show this.







He also sketches the moon illuminated both by the sun (the bright crescent) and by sunlight reflected from Earth (the darker area), what astronomers call Earthshine. He knows enough about optics and perception to realize that the dark part is in fact illuminated, it just appears darker by contrast with the bright part.



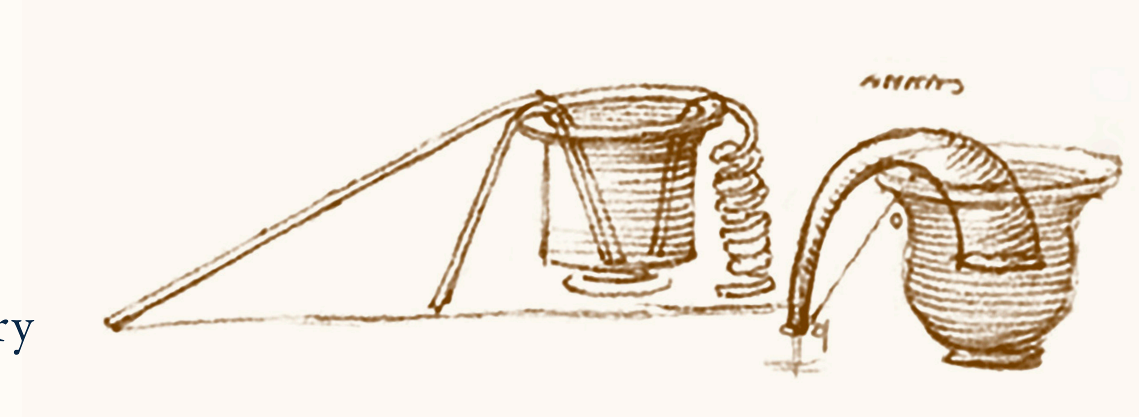
SHEET 2B: FOLIOS 2v & 35r

Leonardo investigates an incredible variety of subjects with the same style of inquiry. On the left page, he illustrates the ability of water to move objects and the ability of objects to move water. He also speculates about gravity holding water on the moon and the momentum of a stone skipped across moving versus still water.

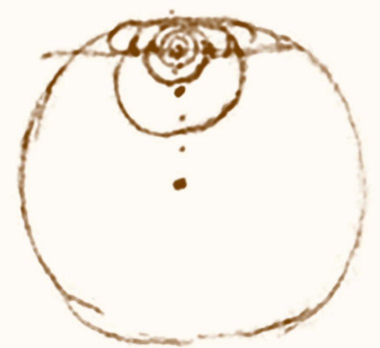
On the opposite page, he takes up tides, the interplay of water moving at different speeds, and the origin of stratified rocks. He always begins with banal observations, quickly tests hypotheses, then investigates further, each conclusion raising new questions. His inquiry expands, rather than narrows, constantly ranging from the particular to the universal and back again.

SHEET 3A: FOLIOS 34v & 3r

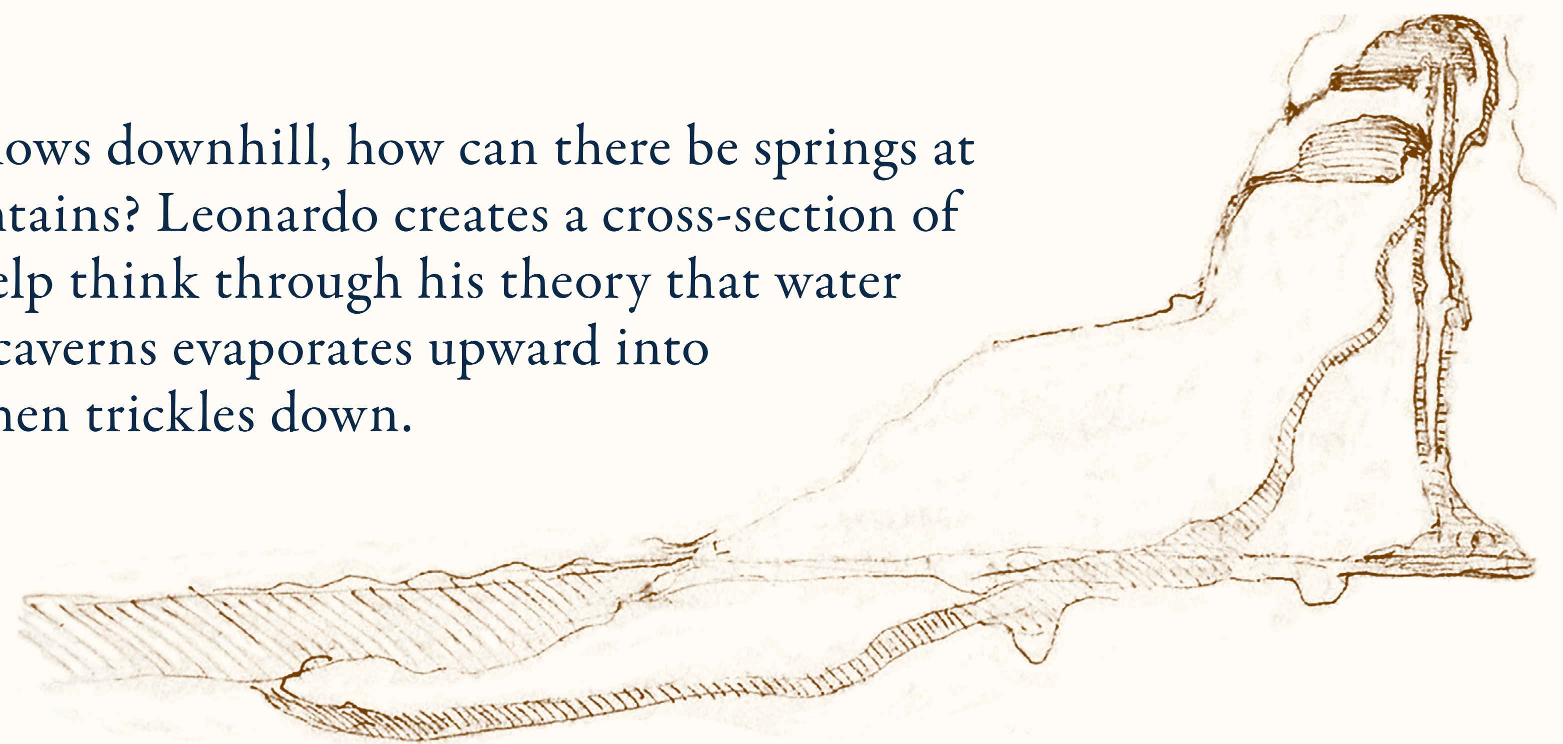
Based on his drawings in the Leicester Codex, Leonardo was clearly familiar with the scientific instruments and glassware kept in the workshops and laboratories of his day. He likely had access to this equipment himself. In many cases, however, drawings like these do not depict actual experiments, but serve as illustrations of the physical properties of water to advance Leonardo's arguments. In other words, Leonardo didn't always do the experiments necessary to prove or refine his ideas; it was sometimes enough for him to imagine them.



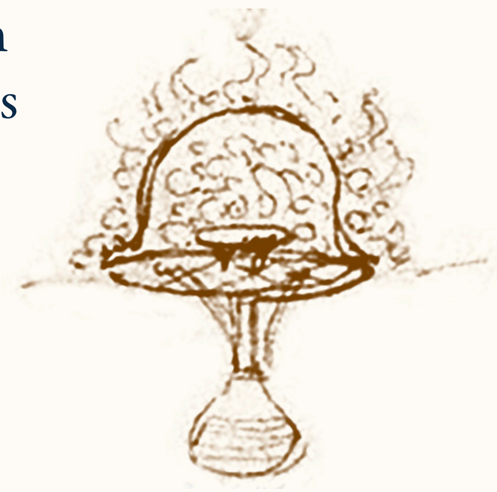
Leonardo saw nature as math and vice versa, certain that mathematical laws governed the world. This illustration argues that a dewdrop behaves like the top of a sphere cut by a flat plane: as the sphere expands, the plane cuts off more and more of the curved surface and the exposed part appears flatter. As dewdrops grow in size, they appear flatter, too.



If water always flows downhill, how can there be springs at the tops of mountains? Leonardo creates a cross-section of a mountain to help think through his theory that water in subterranean caverns evaporates upward into mountaintops, then trickles down.



He uses a still, in which heated liquid evaporates and then condenses on a bell-shaped canopy above, as an analogy for the earth. He later rejects this theory.



On the left page, Leonardo draws parallels between the living bodies of animals and the geological "body" of the earth, "interwoven with a network of veins which are all joined together and are formed for the nutritious vivification of the earth and its creatures."

On the right, he speculates that the sky is blue because of water vapor scattering light: "I say that the blue which is seen in the atmosphere is not its own color but is caused by the heated moisture having evaporated into the most minute, imperceptible particles which the beams of the solar rays attract and cause to seem luminous against the deep intense darkness" of outer space. He was remarkably close—air, not water, scatters light to create the color of the sky.

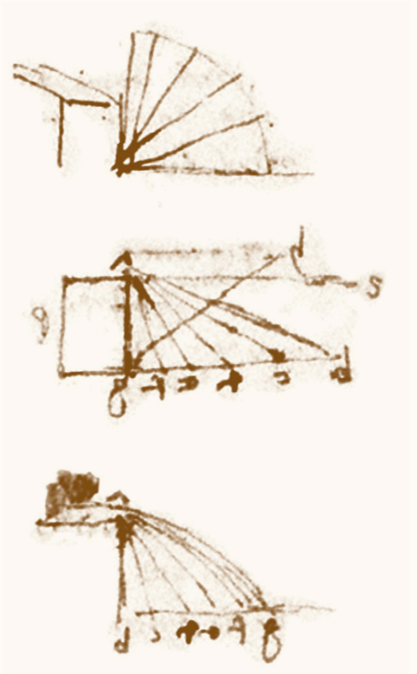
Leonardo documents the motion of waves to understand the forces that propel them.

In order to study water in nature, Leonardo first wants to understand the properties of water when it's in its purest form and in a controlled environment. Following mathematical principles, Leonardo argues that it splatters evenly when it hits a perfectly flat and level surface.

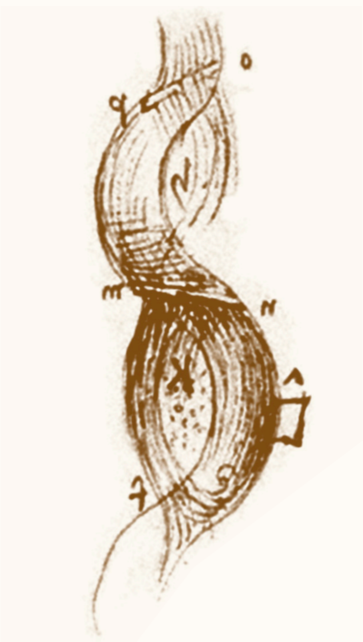
Why do some rivers bend while others flow straight? Leonardo presents a side by side comparison of both types, using heavy lines to show where water flows faster and with greater force. Applying what he knows about waves, he shows that a meandering river becomes even more twisted as water pushes against its banks, while a straight river remains straight. Knowing this, he figures water can be manipulated to advantage.

SHEET 5B: FOLIOS 5v & 32r

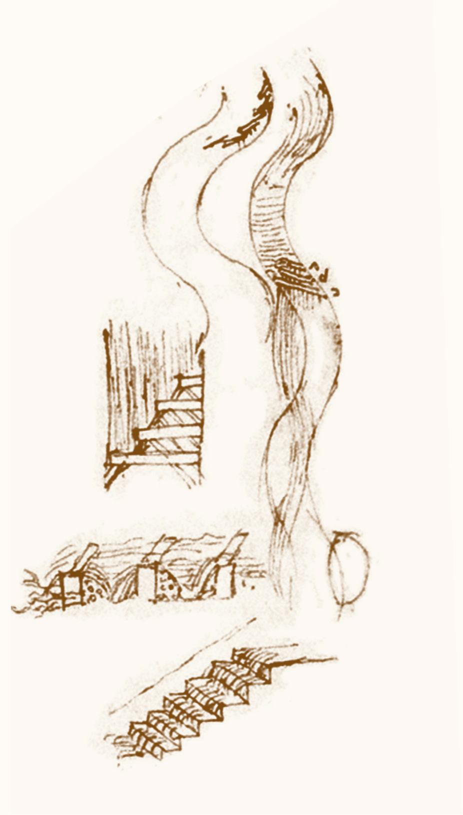
Leonardo uses drawing to work through his thoughts in various ways. Here, geometrical diagrams clarify abstract concepts, like the physics behind water carving a riverbank.



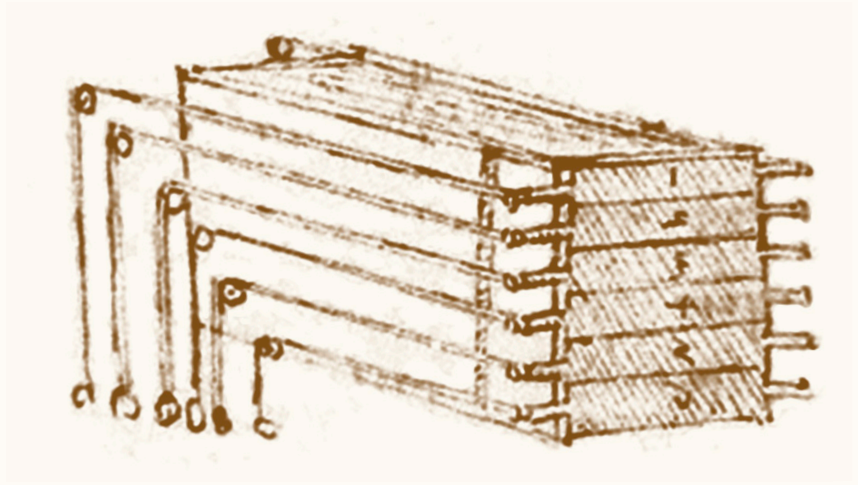
Here, Leonardo applies what he learns to a practical, if hypothetical, problem: He imagines a house beside a river and how he could redirect the flow so that it adds silt to the riverbank below the house, building it up rather than washing it away.



Finally, he sketches one of his ideas that came to fruition: the cascading steps of a fountain he designed for his patron’s country estate near Milan.



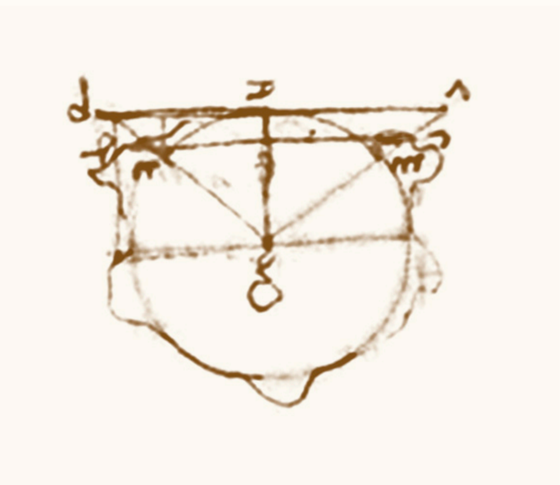
Leonardo was more than a dreamer with a pen. His illustrations often puzzled out practical ideas, like this experimental device for gauging water pressure. He would fill the tank with water—increasing the height of the sides, if necessary, to add more water—and watch it squeeze through holes at various levels. Based on the force of the exiting water, he concluded there was more pressure at the bottom of the tank than at the top.



SHEET 6B: FOLIOS 6v & 31r

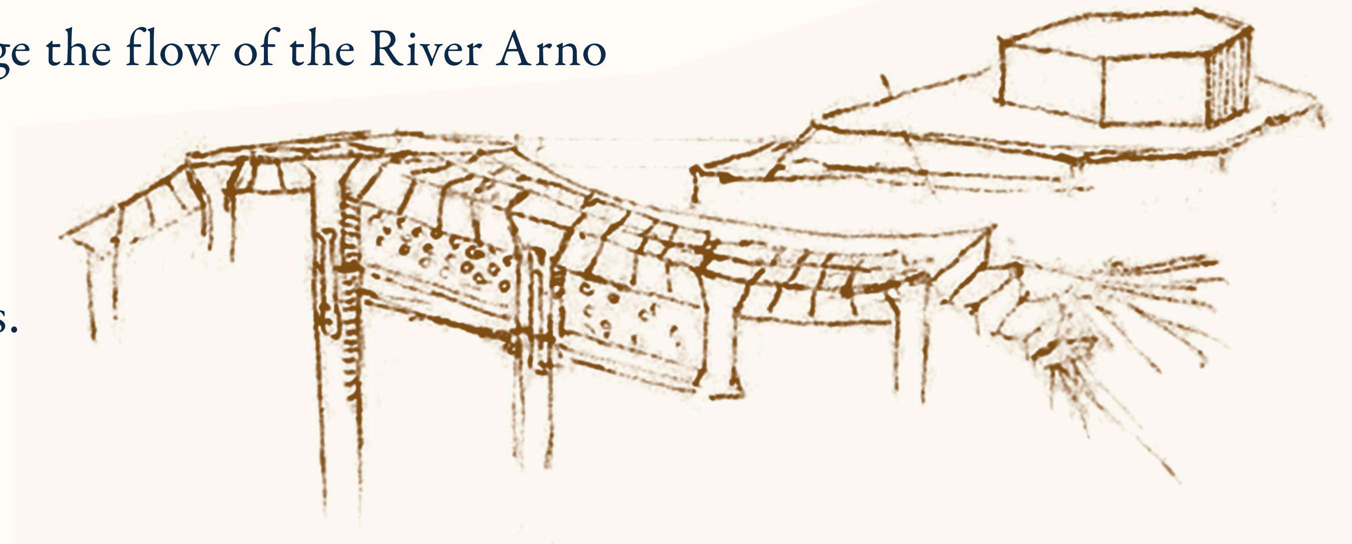
Thanks to gravity, water always seeks the lowest level. Leonardo is curious, then, why there are springs on mountaintops. His poetic explanation is that the earth itself is a living body, shown at left in his anatomical style of drawing with its crust peeled back to reveal veins.

On the right, he draws a horizontal line between two mountains separated by a body of water, showing that the curve of the earth can create the illusion that the sea is actually higher than mountains in the distance—something that people used to believe was true.

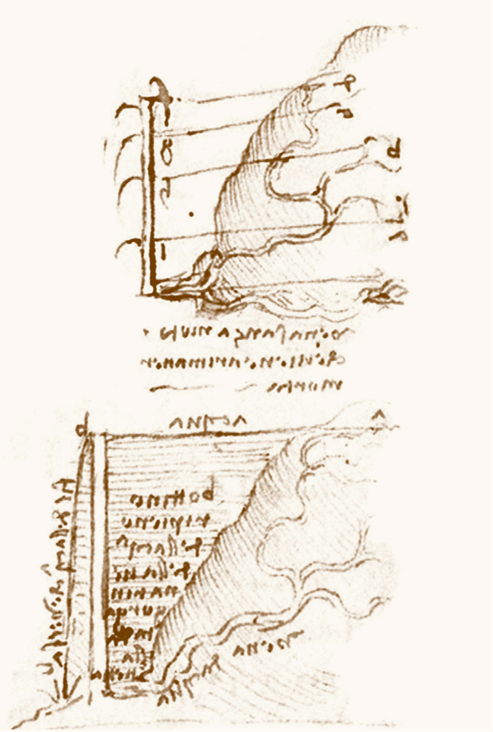


Leonardo imagines two air currents colliding in a kind of tornado. He makes visible the invisible vortices, the circular flow of wind, he observed in nature: "I once saw such winds, raging around together, produce a hollow in the sand of the seashore as deep as the height of a man, removing from it stones of a considerable size, and carrying sand and seaweed through the air for the space of a mile and dropping them in the water...."

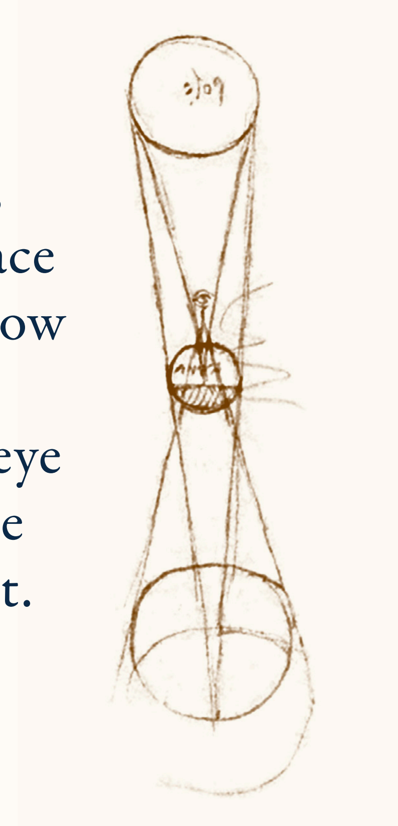
Among Leonardo's courtly duties was dealing with water, designing and improving structures that would move it to where it was wanted and block it from where it was not. He studied the systems designed to manage the flow of the River Arno through Florence. In the lower drawing, he shows a cross-section view of the proper construction of a barrier, with pylons, rubble fill, and interlocking stones.



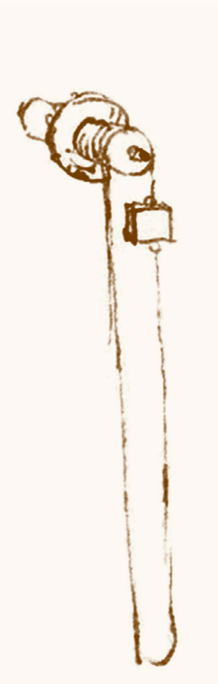
Leonardo proposed ways to dam water flowing from the foot of a mountain, showing "veins" of water and what would happen if the flow were blocked by a dam.



To show how light travels and is reflected, Leonardo returns to the illuminated surface of the moon, theorizing that its diffuse glow results from light reflected off waves. It is hard to make out, but he places a human eye between the sun and the earth to illustrate how rays of light converge at a single point.



Leonardo was perhaps the ultimate Renaissance Man, delving into multiple disciplines in a feverish quest to understand and improve the world. Nowhere is this better illustrated, literally, than in the Codex, which ranges from outer space to this simple mechanism for measuring the speed of a boat.



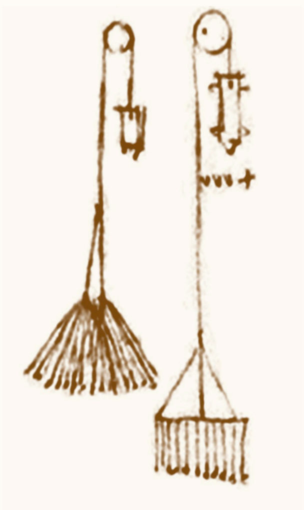
How does a bullet cut through the air? Leonardo does some ballistics research with his pen, diagramming invisible forces. The round bullet compresses the air in front of it and leaves a vacuum behind. But does the air rushing in to fill the vacuum actually propel the bullet? His answer: no.

What goes up must come down—somewhere. Leonardo was a big believer in equilibrium, opposing forces balancing out. Underground caverns collapsed, mountains rose up. Here, he demonstrates the point with a whimsical sketch of people riding a teeter-totter.

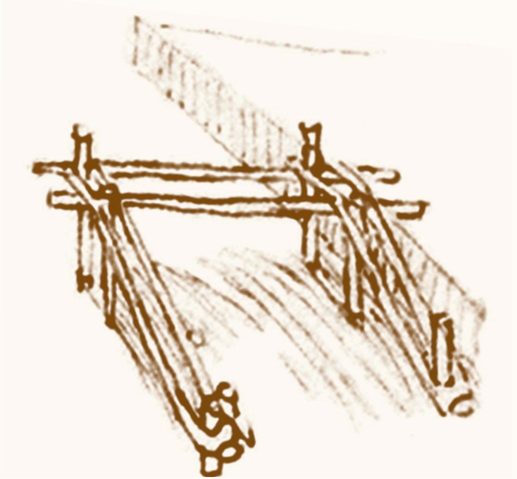
SHEET 8B: FOLIOS 8v & 29r

Leonardo consistently applies observation and logic as he reconsiders the conventional wisdom of his day. On the left-hand page, he goes to great lengths to counter the notion that the biblical Deluge (40 days and nights of rain flooding the Earth) is responsible for seashells found in the high mountains of Italy. Observing that fossils appear in stone that has layers, he theorizes on the formation of sedimentary rock, suggesting its successive layers are made of sand and sediment deposited by water over time.

On the right-hand page, Leonardo outlines the physics of movement in a straight line, and the angles and degrees of movement between two objects as they strike each other. He compares his observations on the reflection of light to moving water as it bounces off a stationary object.



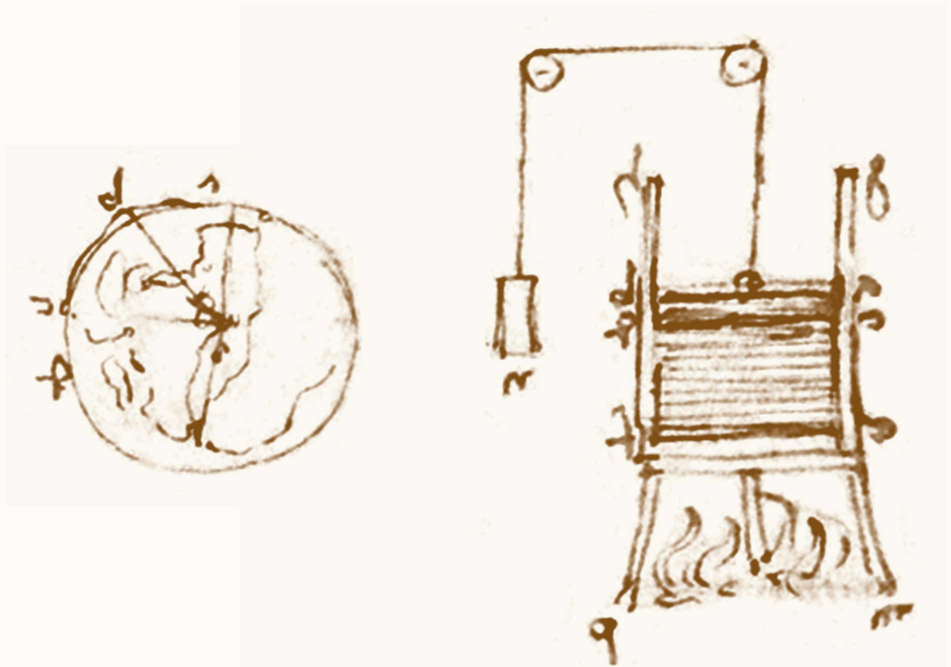
Leonardo was usually hired as a problem solver; his art helped him devise practical solutions. Here, he illustrates the movement of water and the force it exerts on structures to help define problems and understand their causes. He sketches pile drivers that could be used to strengthen riverbanks and dams noting that his design is more efficient because it uses a human counterweight to increase the ramming force. The opposite page tackles an entirely different concern: the types of shells found at various geological sites, particularly at high altitudes, and what they suggest about the movement of water and land.



Leonardo put his observations to the test, as illustrated by this drawing of a glass-walled wave tank which he designed and built so he could recreate what he saw in nature in the controlled environment of his laboratory. He concluded that waves on the surface do not affect objects at the bottom.

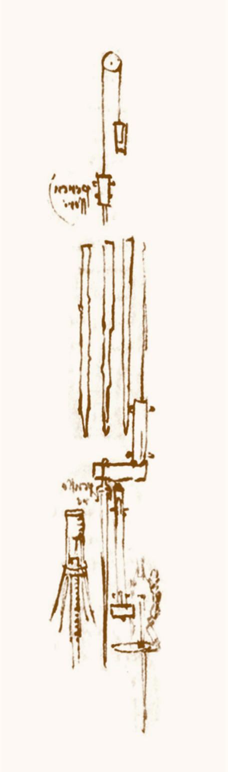
SHEET 10A: FOLIOS 27v & 10r

Leonardo changed his theories when a better idea came to him. Here, having posited that mountains rose as caverns collapsed, he suggests another possibility: the earth's inner heat turns the water in caverns into steam and the resulting pressure pushes up mountains. To illustrate his point, he presents this apparatus, which heats water and measures the increased volume as it changes to steam.

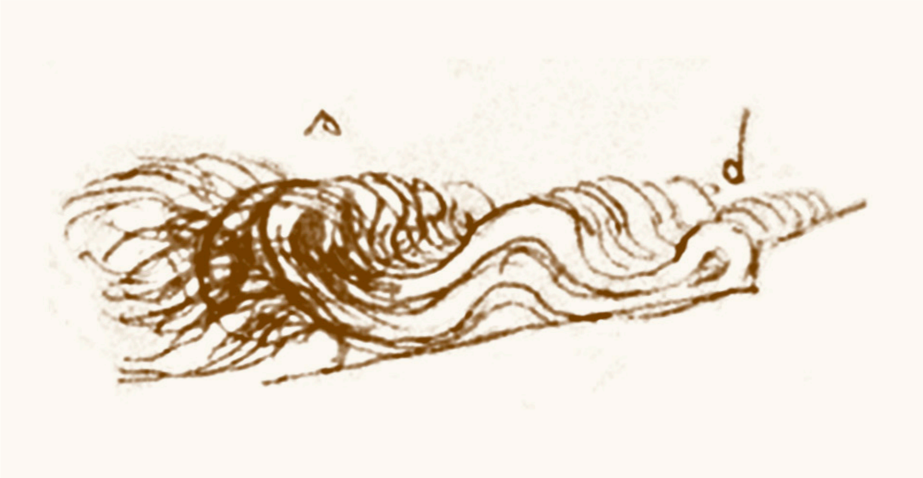


SHEET 10B: FOLIOS 10v & 27r

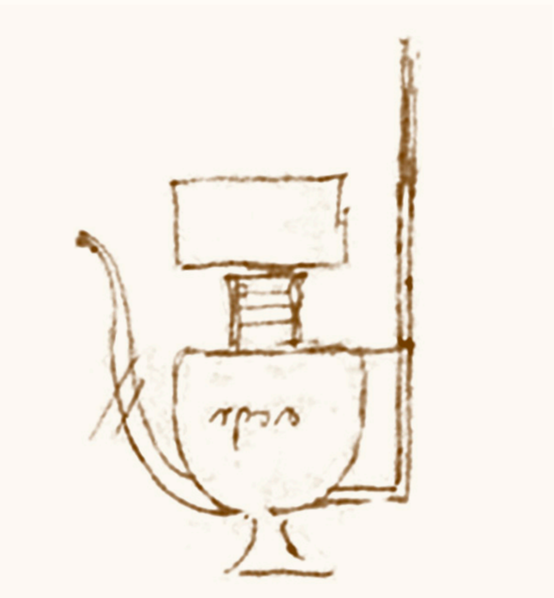
To Leonardo and his patrons, controlling the flow of water was more than an intellectual exercise. In Renaissance Italy, it affected everything from public health to city planning to warfare—Leonardo was a pacifist and once declared that he could force the surrender of a city by cutting off its water supply. Here, he considers the force necessary for a pile driver to push a pole into a riverbank as part of a structure for channeling water, offering practical advice on how the shape of the pole affects the transfer of force as it is pounded into a riverbank.

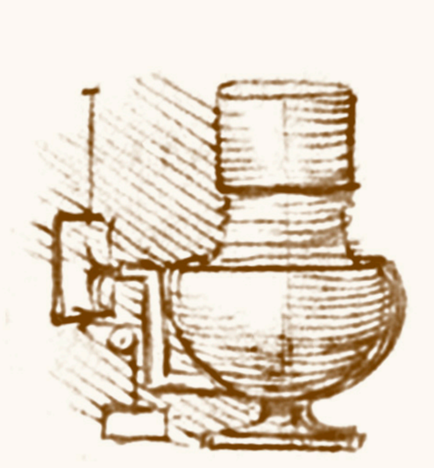


SHEET 11A: FOLIOS 26v & 11r



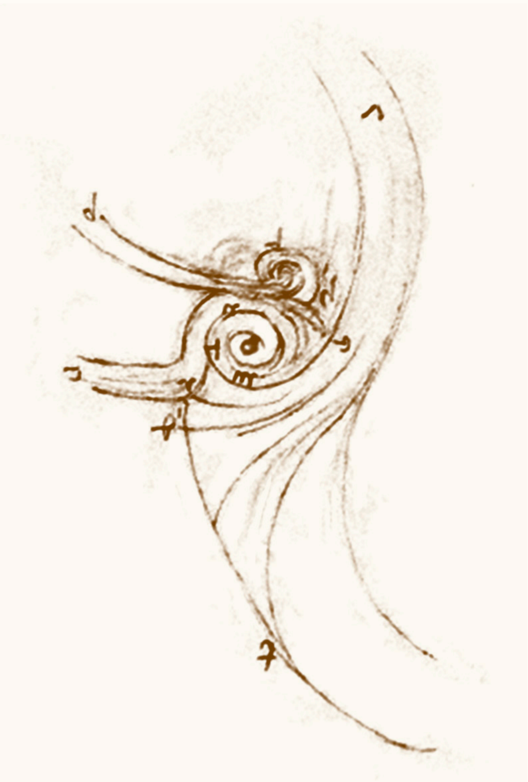
Waves essentially move in circles. But Leonardo shows on these pages that the motion is fairly complex, and he's labeled various points—a, b—to make sense of the direction. Related to this are the concepts of "continuous quantity"—add water to wine, for instance, and it divides the wine into an infinite number of parts—and water pressure, which Leonardo explores by forcing water through the spout of what looks like a coffee pot.



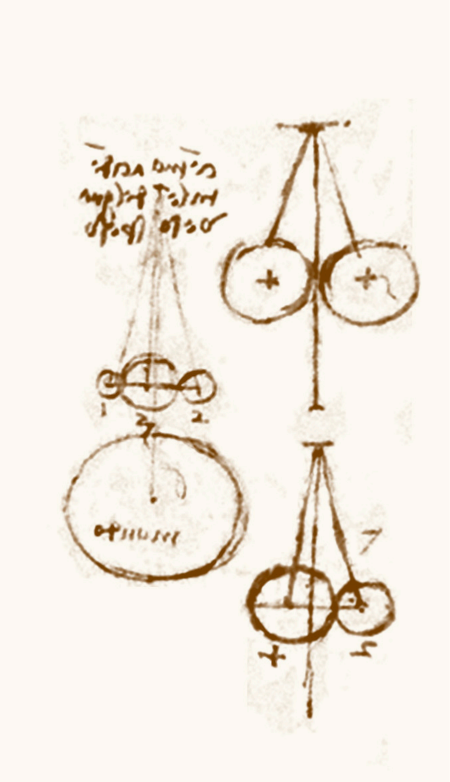


How do you drain a swamp? With a siphon, per this simple diagram by Leonardo, a method he arrived at after much discussion of water pressure. Why did Leonardo care? His patrons needed to look after their subjects, and draining swamps created farmland, eliminated breeding areas for malaria-carrying mosquitos, and was thought to help with flood control (we now understand that wetlands themselves help prevent flooding).

One of Leonardo's greatest puzzles was what happens when currents of water flowing from different directions meet. Here, he diagrams the swirls and eddies created in such an encounter, possibly in a laboratory setting, showing how he sought to understand the underlying principles of the phenomena he observed in nature.



Here, Leonardo proposes a clever way to determine the relative masses of two dissimilar objects. When hung from the same point in space on equal lengths of string, the heavier object displaces the lighter one, such that the amounts on either side of an imaginary vertical line drawn through the center have the same weight.



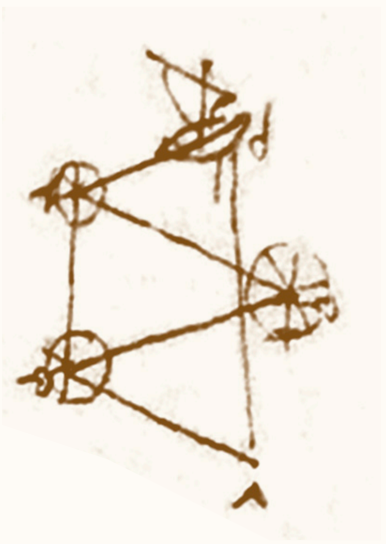
SHEET 12B: FOLIOS 12v & 25r

Ripples of water in a bowl, the movement of smoke, wind smacking the side of a mountain—Leonardo diagrams these actions to show the similarities between three of the four elements (air, wind, and fire, with earth being the fourth). He explored what we now call "fluid dynamics" more than anyone else in his day.

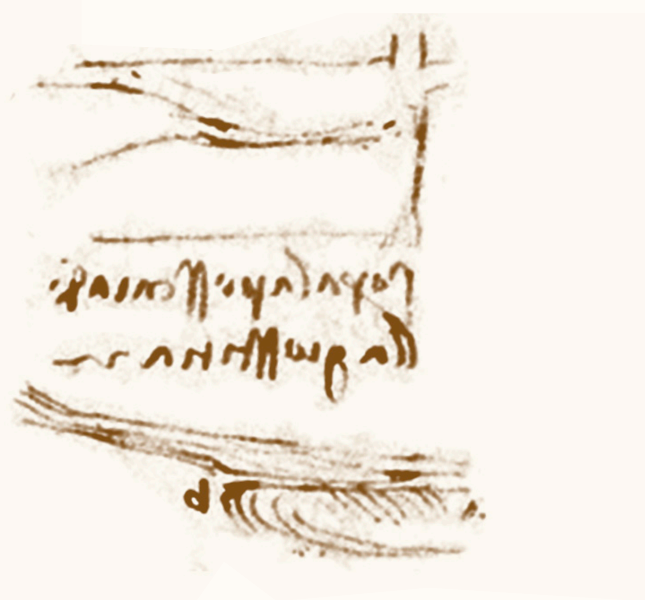
Leonardo is once again contemplating the circulation of water in the earth and how it reaches the tops of mountains, observing that water is attracted to itself. It's a quality called "cohesion" and helps water draw itself upward. To show what he means, he draws a soap bubble. When the straw used to inflate it is removed, the water immediately comes together to seal the hole.

SHEET 13A: FOLIOS 24v & 13r

Leonardo's many studies of water flow benefited the boatmen who made their living on Italy's rivers and canals. On these pages, he sketches some practical applications, like a way to use geometry to measure the speed of a boat.



Here Leonardo shows how hidden rocks create currents underwater, and how boatmen can read the water's surface to avoid beaching their vessels on sandbars—or worse.

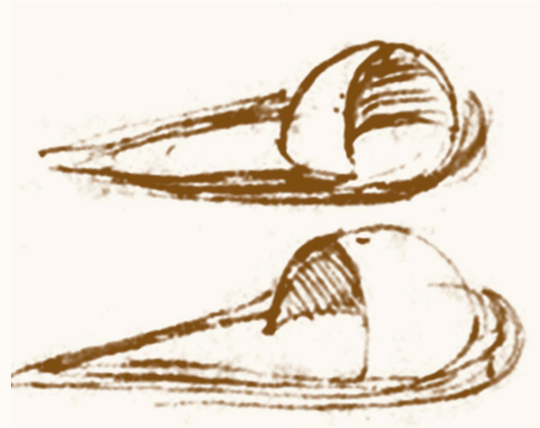


Leonardo offers a simple way to observe the motion of currents at the bottom of a river: drop a weight attached to a float at the surface. The float's movement will reflect the current below.

How does water flow around various obstacles? Leonardo devises experiments, draws, and eventually applies what he observes to his plans for canals, dams, and rivers. He continues to develop this line of thinking, using visual explanations, on Sheet 14A, folio 14r.

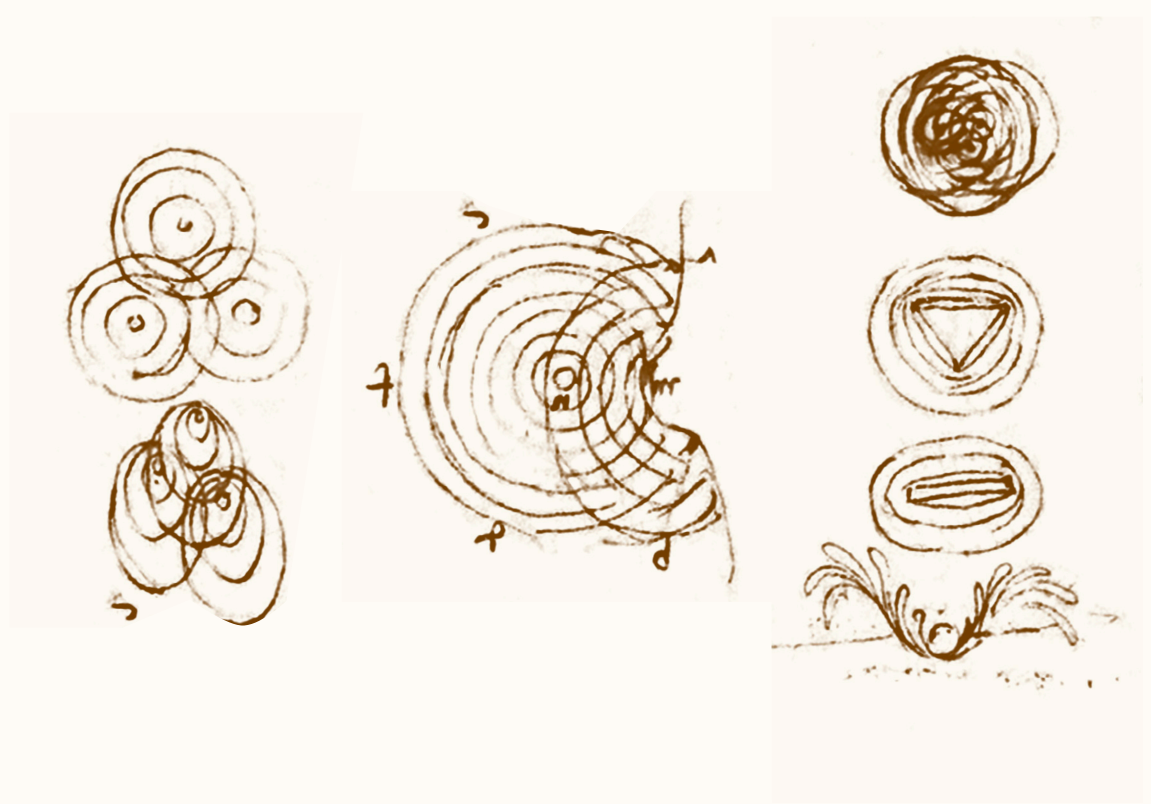
SHEET 14A: FOLIOS 23v & 14r

What Leonardo sees with his naked eye is profound. Watching water fall from pipes, he notices how it breaks apart and then coalesces into droplets due to its property of "cohesion." These drawings show how skillfully he documents the intricacies of what he sees, melding art and science on paper. In the drawing, Leonardo continues to develop his thinking on the behavior of flowing water as it confronts obstacles—a discussion he initiated on Sheet 13B, folio 24r—and the practical applications of his conclusion.



SHEET 14B: FOLIOS 14v & 23r

Who hasn't thrown a stone into water and watched the resulting waves ripple out in circles? Leonardo diagrams sets of circular waves as they intersect, and what happens when one set hits a bank and rebounds into itself. Each set of waves, he shows, passes through the other unchanged. He also notes that all objects, of any shape, create circular rings when dropped in water. A final drawing (bottom right), of the moment a stone hits the water, is loose, almost humorous, perhaps reflecting the simple joy of heaving stones into ponds.



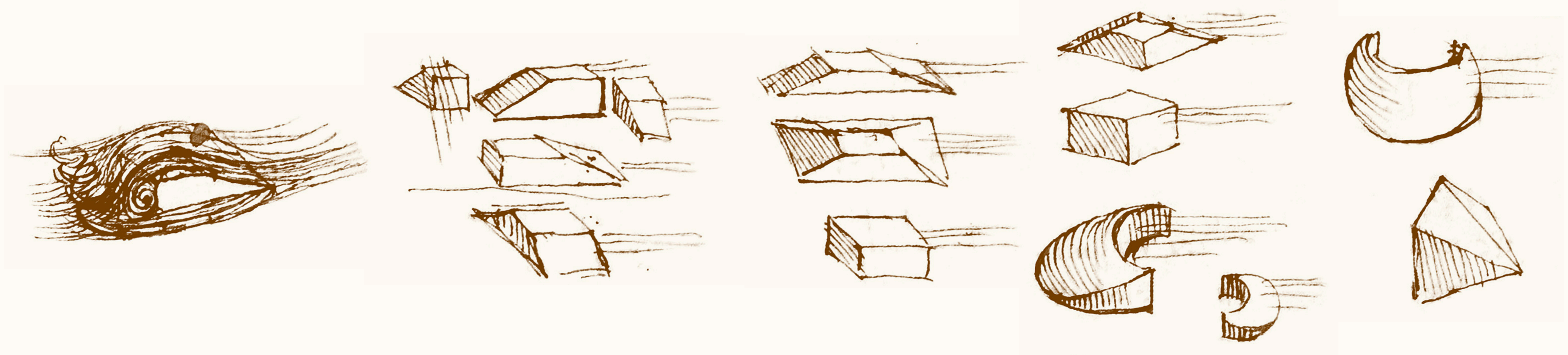
SHEET 15A: FOLIOS 22v & 15r

Leonardo has practical advice for those who would venture into water: how swimmers can escape whirlpools, how snorkels can be used in underwater warfare. He also diagrams how underwater gates that help control water levels, called sluices, could be designed to clear themselves of silt.

Having studied the points where the Rifredi, Mugnone, and Umbrone rivers flow into the Arno, Leonardo replicates his observations and further explores the principles that underlie them through controlled experiments with sand and water.

SHEET 15B: FOLIOS 15v & 22r

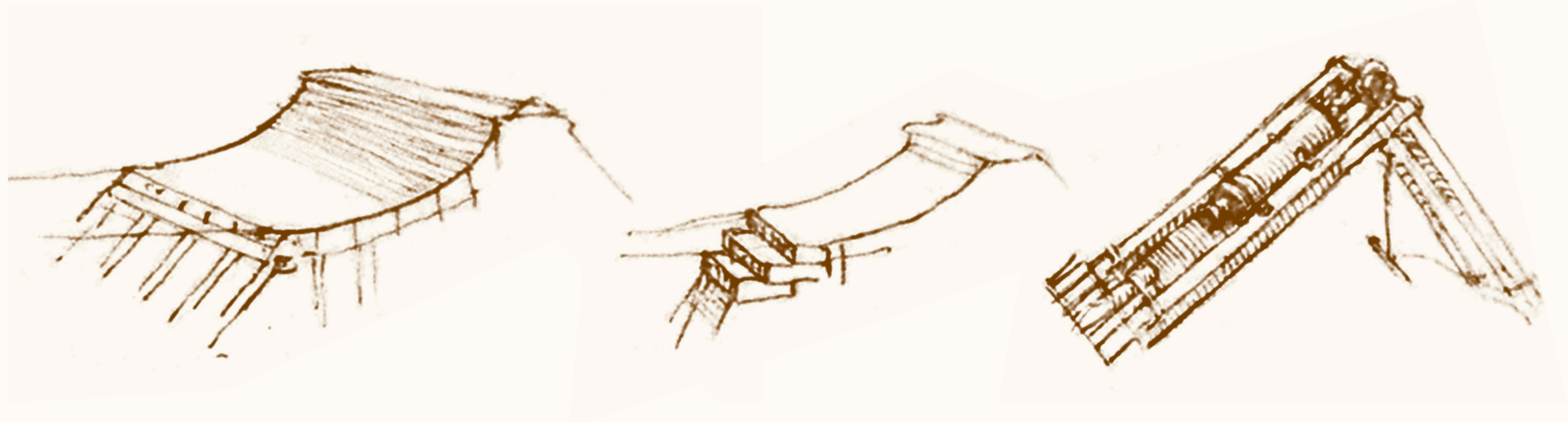
Leonardo's studies of water flowing around objects leads him to propose a new science about it: "The science of these objects is of great usefulness, for it teaches how to bend rivers and avoid the ruins of places percussed by them." He draws several forms that could be placed in rivers to direct their flow.



"Water by itself does not move unless it descends," Leonardo writes. True enough. More philosophically, Leonardo compares the flow of blood from the heart to the brain to the flow of water from the sea to the height of mountains. On the right-hand page, he presents "23 Propositions" about currents in rivers. More neatly composed than most of his other writings, it's probably a polished combination of earlier documents that no longer exist.

How to prevent dams and bridges from collapsing? Leonardo recommends building stepped falls and weirs (low dams) made of trees to slow the destructive rush of water. He also sketches a design for a pile-driver that can be adjusted for the ideal angle, something that could come in handy in his many canal-building projects.

In two lines at the top of the left page, Leonardo notes the work of an ancient Greek scientist-philosopher, Theophrastus, indicating that he studied his predecessors.



SHEET 17A: FOLIOS 20v & 17r

Leonardo rarely makes sketches within the text, preferring to illustrate his major points in the margins. This sheet is a rare example of flipping between writing and drawing as he fleshes out his ideas.

Leonardo moves easily between philosophy and practical application. On the left page, he considers the effects of obstructions on the river bed or in the form of weirs (low dams); the drawings illustrate the potential water flows in response to breaks or deflection. On the right page, Leonardo explains how to drain a swamp.

SHEET 17B: FOLIOS 17v & 20r

Leonardo planned to write a "book on waters," summarized on these pages as exploring how wind moves waves, why fish bones and shells are found at mountaintops, and how water relates to earth, air, and fire. Are tides "generated by the moon or sun, or [are] they…made by the breathing of this earthly machine"? Regarding the timeless question of why the sky is blue, he writes of light scattered by water particles and speculates that "…the blue that appears in it is caused by the darkness which is hidden behind the atmosphere."

Having established that water in its purest form behaves according to mathematically derived truths, Leonardo puzzles through the effects of density, impurities, and friction on the flow of water. Here, he depicts a spout of water rising from a hole or hose. It's highest in the center, he argues, because the water in contact with the sides is slowed by friction.

Leonardo studies what happens when a smaller river joins a larger one. The result varies depending on the relative speeds of the two rivers: a faster river carries more material, which settles to the bottom if the river meets one that moves slower.

Leonardo's theories on how rivers flow together, and can be redirected using low dams, were put to the test in 1508. The French King Louis XII, then the ruler of Milan, was a generous patron of Leonardo and gave him a stretch of the Naviglio Grande Canal for his hydraulic experiments. He drew these straight channels of water with branches as he began a major canalization project, a reminder of his responsibilities—and the resources at his disposal.