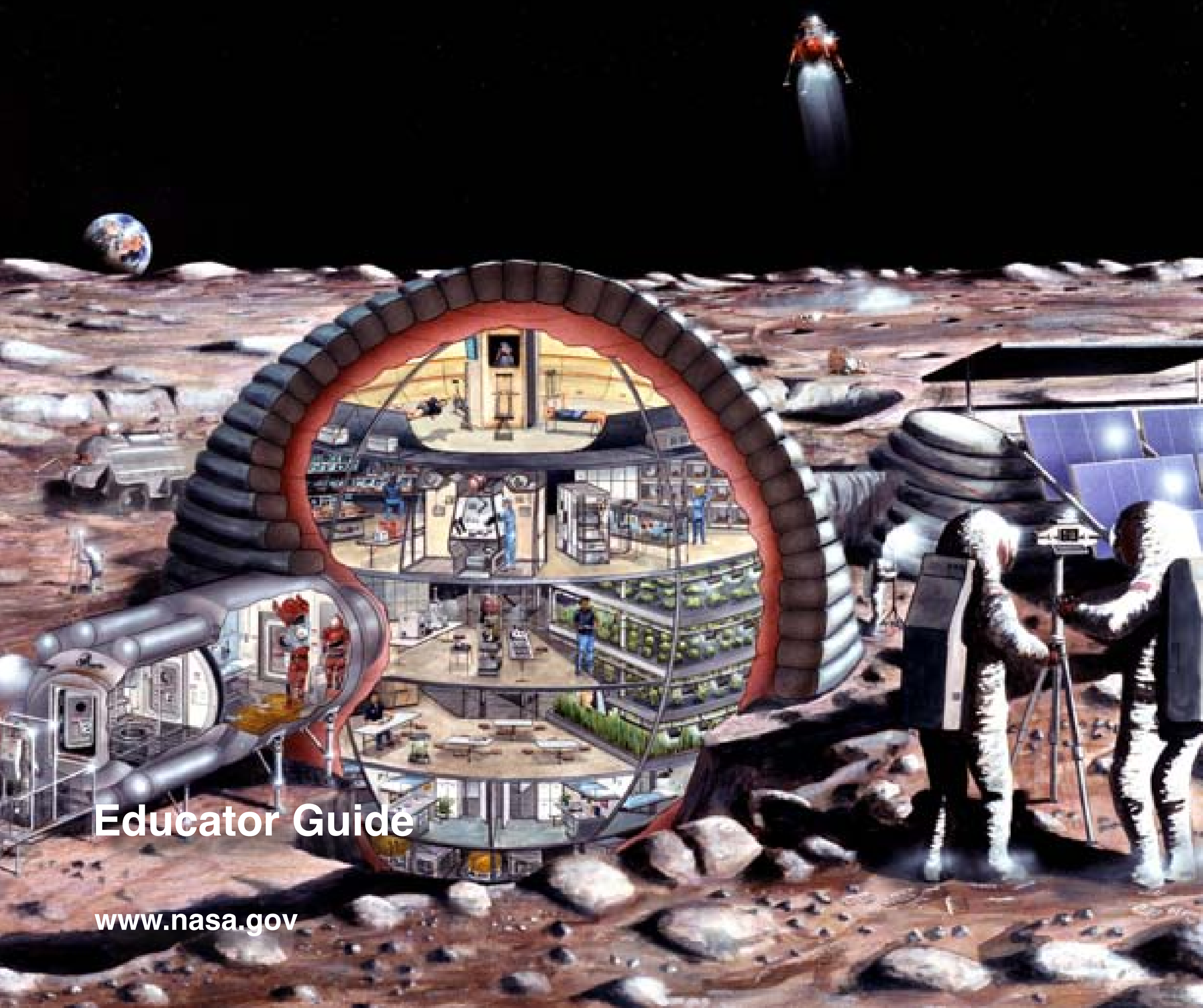
National Aeronautics and Space Administration

Waste Limitation Management and Recycling Design Challenge



Educator Guide

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Cover Illustration

This is one of many artist renditions of a future Moon base. It was created in 1989 and is a part of the continually-evolving lunar base concept. This particular concept shows a cutaway of the interior of a 16 m-diameter habitation dome. The "sandbags" covering it are filled with lunar dust and provide some radiation protection. Inside are living quarters, exercise facilities, laboratories, and a hydroponic garden for growing food, replenishing oxygen, and recycling water.

Refer to the reference section of this guide on how to locate and download this lunar base image and many more, including concepts for Mars bases.

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Educator's Guide with Activities in Science, Technology, Engineering, and Mathematics

Grades 5-8

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Dear Educators,

The National Aeronautics and Space Administration is continuing its exploration of the solar system and looks forward to establishing its first remote outpost on Earth's nearest neighbor, the Moon. A lunar base is our next logical step in preparing for human missions to the planet Mars. The technologies needed for setting up a "home away from home," are many and these technologies must be proven and reliable if we are ever to establish an outpost on Mars. The Moon provides the ideal testbed to try and perfect them. In travel time, the Moon is only three days from Earth, whereas Mars (using current rocket technology) is at least a six-month trip and could be much longer depending upon the relative positions of Earth and Mars in their orbits around the Sun.

One of the major issues in maintaining a base on the Moon or anywhere else is the need for resources. Resources, such as air, water, and food can be transported from Earth, but the cost to do so is great. On Mars, the cost would be prohibitive. Recycling and reusing resources is the obvious solution. The question is how.

This educator guide is a starting point for middle school students to begin researching and answering the challenging questions of how to maintain human habitations on the Moon and other planets in our solar system. The guide focuses specifically on the need for water recycling. For direct consumption, humans need about 3 to 4.5 liters of water a day. Add in other uses of water (e.g., food preparation, personal hygiene, toilet flushing, clothes washing) and a human actually uses about 20 liters of water every day; on a 6-month, 4-person mission, that amounts to 14,600 liters of water! Discarding the water after use is unacceptable. Because water is recyclable, it can be used again, saving valuable transport space for other things needed from Earth.

Find the WLMR Design Challenge starting on page 42 of this guide. Information about the WLMR DC contest will be found at: http://wlmr.nasa.gov/

The guide begins with a background section that provides information on a wide range of topics relating to the Moon, Earth's water cycle, and water recycling, followed by several basic classroom activities on water recycling. Both the background material and activities prepare the students for the Waste Limitation Management and Recycling Design Challenge (WLMR DC). In the WLMR DC, small teams of students are challenged to design and test a prototype system for recycling water on the Moon.

To begin the challenge, a simulated wastewater stream will be created from basic household materials. Using technologies they design or adapt, the teams will:

- clean the water of impurities
- test the water using designated tests
- evaluate their success
- prepare and give a scientific/business presentation to explain and promote their system

The WLMR DC is a dynamic, standards-based classroom project that provides your students opportunity to investigate, create, test, and evaluate a solution for a real world problem that will not only apply to our future in space, but to water problems in many places on Earth as well.

Table of Contents

A 1986 NASA lunar base concept "under construction." A spacecraft from Earth is about to land, while bull dozers pile up lunar regolith (a layer of pulverized rock covering the Moon's surface) to shield the latest habitat module from space radiation.

New World

On Earth, we take an amazing number of things for granted. When future lunar astronauts arrive on the Moon, they won't be able to set up house like they would here on Earth, when moving from one city to another. The Moon is different. It's a new world that will require new ways of doing things.

Earth is a rocky planet featuring a large metal core with internal motions that create a powerful magnetic field. Its surface is covered with a thin veneer of soil and water and surrounding the surface is a thick atmosphere with a 21% oxygen content. Earth's distance from the Sun allows for moderate temperatures and its axial tilt creates the seasons. Cycles of gas, water, minerals, and energy continually refresh the surface and life abounds. Millions of species interact with each other and the environment that supports them.

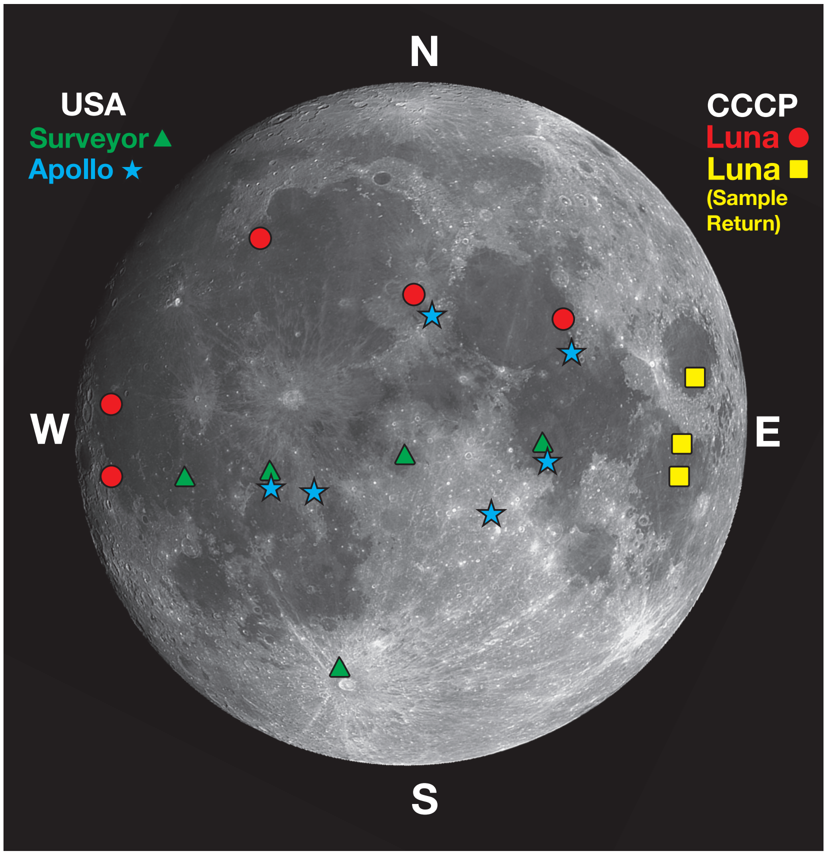
The Moon has little in common with Earth, even though it is a close neighbor and travels with Earth as it orbits the Sun. Like Earth, the Moon is a rocky world, but its core is virtually dead. It has no appreciable magnetic field. It does have occasional moon quakes, but their strength are only equal to the weak background vibrations continually crossing Earth's active interior.

Sunlight reflected off the Moon's surface enables us to see our closest neighbor in space. This is the only side of the Moon we see from Earth.

Apollo 15 astronaut David Scott is documenting a sample collection site near the Hadley Rille. Note the powdery regolith covering the surface and sticking to the legs of his space suit.

The Moon's surface is covered with a coating of pulverized rock called regolith, which resembles a grey-black soil, but without the organic content that enriches soil on Earth. The Moon is virtually free of water and atmosphere. It does not have any seasons. The primary cycle is the heating and cooling of its surface during day and night, each lasting approximately 14 Earth days. Even the magnitude of the Moon's gravity is different, only one-sixth that of Earth gravity.

For more than 50 years, scientists and engineers from many nations have been sending automated spacecraft to the Moon. Their instruments have photographed the Moon's surface up close, mapped the far side that is never seen from Earth, and impacted or soft landed to test the firmness and composition of its surface. From 1969 to 1972, six American astronaut crews landed on the Moon's near side and brought back 382 kilograms of rocks and regolith for detailed study. In the 1970s, eight Soviet robotic



Sites for U.S. and CCCP (Soviet) soft-landing robotic missions and manned missions on the Moon.

spacecraft landed on the Moon. Three of the spacecraft had small on-board rockets that automatically returned to Earth with samples of the Moon's surface, bringing back a total of 326 grams of regolith. The collected moon rocks and regolith represent the geology of approximately 4-5% of the Moon's total surface.

There have been over 60 successful robotic spacecraft missions to the Moon (more than half fly-by or orbiter missions), including three Apollo fly-around missions. In addition, more than 100 meteorites found on Earth appear to have been blasted off the Moon during impacts. The originating locations of these rocks on the Moon are unknown.

Robotic and human missions, added to millennia of visual observations using human eyes, geometric measurement tools, and astronomical telescopes, has taught us much about the Moon. Still, the next generation of lunar astronauts will encounter many surprises. This is part of the reason for going there.

What do we know about the moon? Certainly enough to realize that it cannot provide the basic elements (air, water, food) needed to sustain life. Therefore, long-term human missions to the Moon will have to include systems to provide these life support elements. What things do we know about the Moon that will help us design these life support systems?

Moon Primer

The Moon is Earth's natural satellite. It is a spherical body 3,476 kilometers in diameter (about one-quarter the diameter of Earth). Its total mass, 7.349×10^{22} kg, is about one-hundredth that of Earth's. The Moon's low mass is due to its smaller size (Earth's volume is about 50 times greater) and a mean density that is only six-tenths that of Earth's.

Because of its smaller mass and diameter, the surface gravity of the Moon is about one-sixth that of Earth. Earth's gravity causes falling objects to accelerate at a rate of 9.8 meters per second squared. On the Moon, the rate of acceleration due to gravity is 1.6 meters per second squared. A person who has a body weight of 100 kilograms on Earth, as measured on a spring scale, would discover a body weight of only 16 kilograms on the Moon. Do not confuse weight with mass - both can be measured in kilograms. Weight depends upon gravity, while mass is a measure of total amount of matter in a person.

The Moon's low gravity has an interesting implication for erecting structures on its surface too. Structures on the Moon can be built much taller, or of equivalent height using fewer materials of lesser strength.

The Moon orbits Earth at a variable distance ranging from 363,300 to 405,500 kilometers. The orbit is slightly tilted, causing slight seasonal variations in the altitude the Moon appears above Earth's horizon. The

WLMR Question: What effect would lunar gravity have on a vertical gravity-driven water filtration system? [On Earth, wastewater enters the top, passes through filter media, and comes out the bottom.]

Moon makes one orbit, using the stars as a reference point, every 27.32 Earth-days.

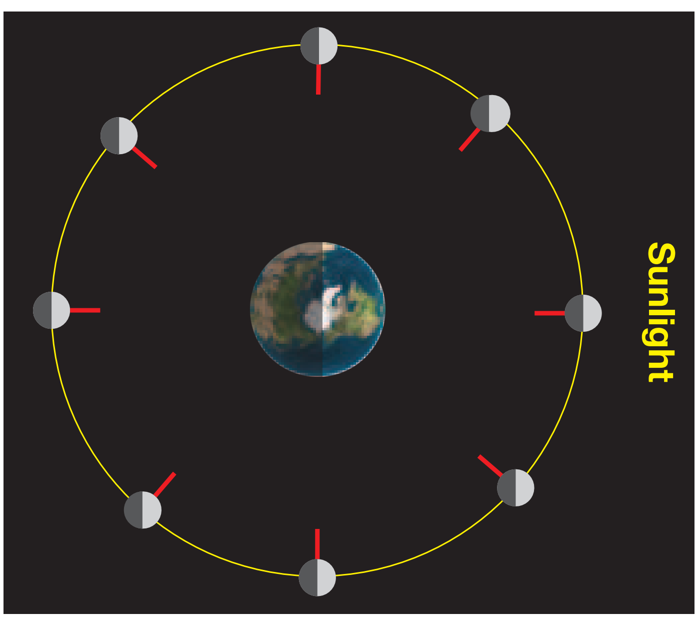
At the same time the Moon is orbiting Earth, the Moon is also rotating. Its rotational period (one-day) is also 27.32 Earth-days long. The Moon's rotation and revolution work together to keep one side of the Moon continuously facing Earth.

The synchronized rotation and revolution of the Moon is a result of tidal forces created by the combined gravitational attractions of Earth and the Moon on each other. On Earth, tides are most easily seen in the rise and fall of oceans, but tides of lesser height also occur in the solid Earth. Tides occur in the solid Moon as well and over billions of years, the lunar tide has produced a drag effect that gradually slowed the Moon's rotation. This has resulted in a near side of the Moon which we see from Earth, and a far side that is never seen from Earth.

As a result of the Moon's position in orbit around Earth, we see cyclical changes in the amount of light and dark areas across the Moon's near side. Exactly one half of the moon is always illuminated by the Sun (the Moon produces no light on its own). How much we see of the lighted and dark areas at any one time depend upon the relative positions of the Earth, Moon, and the Sun. These changing shadows and light are the phases of the Moon and they repeat in a period lasting 29.53 Earth days - two days longer than the Moon's rotation period. This difference is due to Earth's orbital motion. During one lunar day (one complete lunar orbit), Earth advances approximately one-twelfth the distance in its own path around the Sun. This places Earth in a different direction from the Sun than the month before. In order to complete a lunar month of phases, the Moon has to travel two additional days around Earth to compensate for Earth's orbital movement.

One of the benefits of lunar phases is that the changing angle of sunlight on the Moon's surface produces shadows that help define surface features. From Earth, during a full moon, the Moon presents a somewhat bland combination of light to dark gray shades. During partially-lighted phases, the picture

Lunar surface topography is clearly outlined by shadows near the terminator line that separates the lighted and dark areas.



Gravitational coupling
In this illustration, a pole on the Moon points at Earth. While the stick continues to point at Earth, its true direction in space continually changes. After one orbit, the Moon, as shown by the pole, has rotated exactly one time.

WLMR Question: If abundant solar energy falling on the Moon's surface is used to power a water purification system, how will the system work during approximately 14 continuous days of darkness every lunar orbit?

changes dramatically - shadows nearest the line separating the lunar night and day accentuate the details of a myriad of basins, highlands, and craters.

The Moon's near side is a stark, but amazing place. Large areas, once thought to be lunar seas, are actually huge basins that were blasted out of the surface by asteroid impacts more than three billion years ago. These impacts were followed by upwellings of molten basalt rock that flooded and leveled basin floors. Upon cooling, the basin surfaces turned dark. Surrounding the basins are rugged highlands consisting of light-colored anorthosite rock rich in feldspar minerals. Also found on the Moon is a type of rock called breccia, which is composed of fragments of pre-existing rock from the Moon's surface. Breccias are formed when the Moon's surface is impacted and the rock is partially melted and fused back together.

Punctuating the entire lunar surface are millions of large and small craters carved out by the collisions of meteorites, comets, and asteroids. The most recent craters have sharp edges, while the rims of more ancient craters are worn-down due to the continuous rain of space rock and the overlapping impacts on their surface.

All these lunar near side features are visible from Earth with binoculars or telescopes. Thanks to orbital and fly-by spacecraft, we

Lunar crater #308 (Daedalus) taken by the crew of Apollo 11 when they were orbiting on the far side of the Moon.

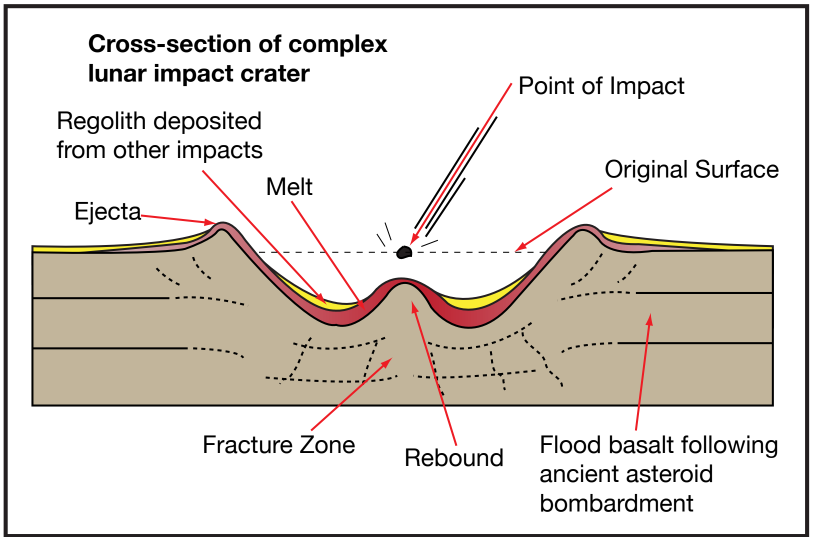
Anorthosite rock (primarily plagioclase feldspar and anorthite) collected by the Apollo 15 crew from the Hadley Rille region of the Moon.

know that the Moon's far side lacks the large basaltic lava flows characteristic of its near side, but is heavily marked with craters and craters within craters.

For billions of years, the Moon has been pounded by space rocks. Each impact has pulverized and melted the surface and spread debris, called ejecta, in circular splatter patterns and long ray-like streaks.

Prior to the Apollo manned landings, scientists worried that the Moon might be covered in deep fields of dust that would swallow any spacecraft touching down. U.S. and Soviet robot spacecraft landed on the Moon successfully and remained on the surface. There was lots of "dust," but the surface of the Moon was firm and easily capable of supporting spacecraft.

The "dust" covering the surface of the Moon is actually lunar regolith, a powdery sand-like material consisting of a thick layer of loose dust, sand, and crushed rock. It is dominated by three igneous minerals - olivene, pyroxene, and plagioclase feldspar; lesser minerals include spinels, armalcolite (an iron titanium oxide mineral named after the Apollo 11 crew - Armstrong, Aldrin, Collins), silica, iron, and ilmenite. In addition to the crushed rock and minerals, regolith also contains another material called agglutinate. Agglutinates are glassy, jagged-edged particles "welded" together by the melting and freezing that occurrs during impacts. Virtually the entire lunar surface is covered with regolith, ranging in depth from 2 to as many as 30 meters. Actual lunar bedrock is only seen in steep-sided crater walls.



There has been some speculation in recent years that another material might exist on the lunar surface - water ice. This water ice is thought to have been delivered to the lunar surface during impacts by comets and meteorites containing water ice. Most of the ice would vaporize from the heat of impact, create a temporary atmosphere, and escape to space; however, some of the water might condenses and freeze on the floors of permanently shadowed craters. It is thought that both the Moon's north and south poles could have craters deep enough that sunlight would never cross their lowest reaches, protecting the ice. Recent data from three spacecraft have confirmed the presence of small quantities of water and hydroxyl molecules (one atom each of hydrogen and oxygen) in the upper millimeters of the surface in the Moon's polar regions. Initial estimates indicate that perhaps as much as one liter of water could be harvested from a ton from the regolith. As of this writing, no ice has been found on the Moon. Further investigations are underway.

Weather over most of the Moon is either searingly hot or shatteringly cold. The temperature ranges from -156°C (-248.8° F) during the long lunar night to 121°C (249.8° F) during the long lunar day. Practically speaking, there isn't any in between. This is due to an essentially non-existent atmosphere. On Earth, the atmosphere balances world temperatures but this doesn't happen on the Moon. Estimates of the lunar atmosphere vary but the total mass of gases surrounding the Moon amounts to not much more than a few thousand kilograms. In one estimate, the total amount of gas might equal the amount of air contained in a large movie theater on Earth. The main components of the lunar atmosphere are helium, neon, and hydrogen (primarily delivered to the Moon by the Sun), and argon produced by outgassing from the radioactive decay of krypton in the Moon's interior.

There are two locations on the Moon where the extreme temperatures are not so severe - the north and south poles. Because the Moon is not tilted as much as the Earth, variations in temperature in the polar regions is small. Crater floors may be continuously shaded, resulting in consistently cold conditions while high elevation areas can be almost constantly sunny.

While Earth's powerful magnetic field shields all but the most powerful space radiation particles, the Moon, on the other hand, is a shooting gallery of solar particles and galactic cosmic rays. Because the Moon does not have an appreciable magnetic field, the surface is not protected from radiation. Apollo astronauts traveled to the Moon during relatively quiet periods of space radiation and were little affected by radiation during their short stays. Future lunar missions will last far longer and will have to provide radiation protection to maintain astronaut health.

WLMR Question: Does the Moon have any resources that might be used to create a water recycling system?

Future lunar base concept

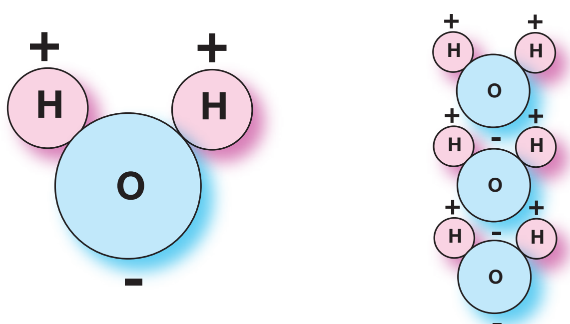
The Blue Marble

From outer space, the view of Earth is amazing. Approximately three-quarters of its surface is covered with water. At the right distance from the Sun, Earth boasts temperatures that permit water to exist in three states simultaneously - solid, liquid, and gas.

Image of Earth without clouds during the month of December. (Source: Visualization Analysis Lab, NASA Goddard Space Flight Center)

Water - The Miracle Molecule

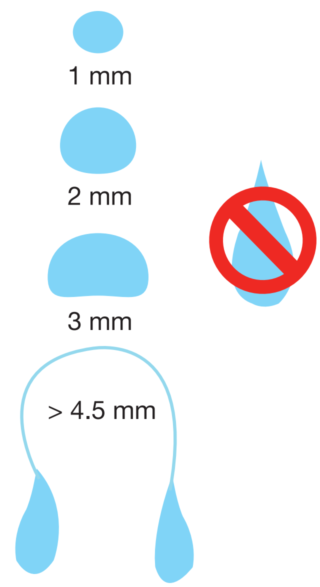
Almost everybody knows that two hydrogen atoms bond together with one oxygen atom to form a molecule of water. This combination is expressed by the famous H_2O formula. The two hydrogen atoms, which have a positive electrical charge, are arranged on one side of the oxygen atom, which has a negative electrical charge. In diagram form, a water molecule resembles the shape of Mickey Mouse's head. It is a wonderful arrangement that has enormous implications.



The arrangement of hydrogen and oxygen atoms creates a bi-polar molecule, meaning the water molecule has a positive and negative side, each capable of attracting the oppositely charged side of another water molecule.

Each water molecule acts like a little magnet. One side of the molecule is positively charged and the other negatively charged. As a result, the positive side on one molecule attracts the negative side of another. This brings them together, making water "sticky." When trillions of water molecules are attracted together, a water drop is formed. The drop has a rounded shape because the charges of all the molecules tend to pull them toward the center of the drop.

Because of gravity, big water drops resting on a flat surface tend to be squashed, although their edges are still rounded and the middles slightly mounded. When falling, water drops (raindrops) larger than 2 mm in diameter are distorted by the air flow. The stickiness of the water molecules keeps the drops together, but as the drop increases in diameter, the pressure on the lower edge of the drop causes it to distort and separate into two drops. The classic "teardrop shape" is really more like a hamburger bun.

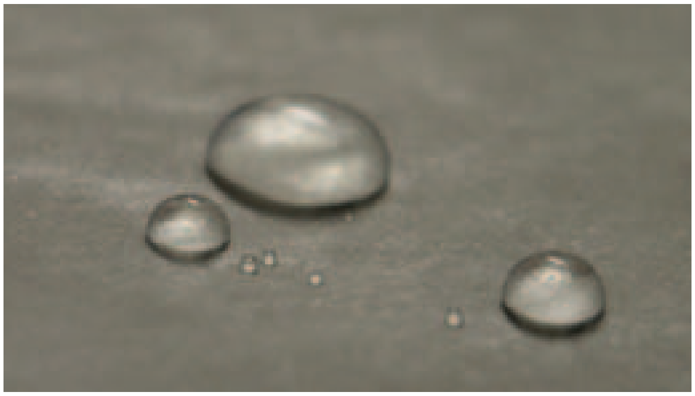


Source: US Geological Survey

True raindrop shapes.

The rounding effect caused by surface tension can easily be seen by placing water drops of different sizes on a piece of wax paper. The smallest drops tend to be very rounded, while the larger drops are somewhat flattened.

In environments with different gravity forces, water drops may become more flattened or rounded. A centrifuge, a device that spins samples to create an "artificial gravity" greater than Earth's gravity, flattens water drops. On the other hand, the free-fall environment on the International Space Station, an internationally-developed research laboratory in low Earth



Water drops on waxed paper. Notice the nearly spherical shapes of the smallest drops.

orbit, enables water drops, even very large ones, to form nearly perfect shimmering spheres.

> WLMR Question: What do you think will happen to the shape of water drops in a future Moon base (an environment with one-sixth the gravity of Earth)?

Water Primer

At first glance, water seems boring. In its pure form, it is a colorless liquid with no taste or odor. It is very abundant on Earth. In fact, it is estimated that 1,386,000,000 cubic kilometers of water is distributed across Earth as oceans, ice, lakes, rivers, soil moisture and ground water, atmospheric water, and water in living things. About 97 % of all Earth's water is salt water (primarily contained within the oceans found on Earth), only about one percent is potable (fit for consumption) by humans and animals.

Water is sometimes called the "universal solvent." It has the ability to dissolve more substances than any other known liquid. Flowing over Earth's surface, through the soil, or through our bodies, water picks up chemicals, minerals, and nutrients. These change the chemical content of water and reduces its potability. It is the chemicals dissolved in water that give it a taste or flavor. All popular drinks, such as milk, soda, coffee, and tea, get their flavors from the chemicals dissolved or suspended in water.

The attraction of water molecules for each other creates a surface effect called surface tension. Surface tension is easily seen by sprinkling fine ground pepper on the surface

Earth's atmosphere holds approximately 12,900 cubic kilometers of water in vapor (gas), liquid (raindrops), and solid (ice crystals). The visible water in clouds consists of liquid and solid water held aloft by air currents.

Large spherical water drop clinging to a leaf in a plant experiment on the International Space Station. Because buoyancy does not take place in microgravity, the bubble remains in the center of the drop.

of water in a glass. The pepper floats because it doesn't have enough mass to penetrate the tension on the water's surface. A more dramatic surface tension demonstration can be made by gently placing a sewing needle on the surface of the water. It too will float, although close examination shows that the mass of the needle actually depresses the surface of the water. It is almost as though the water surface is an elastic membrane.

Water is an exceptional liquid for cleaning. We use water to wash ourselves, clothes, dishes, and cars. And although water is a great cleaning agent in itself, a drop of liquid soap or detergent greatly enhances water's cleaning ability. Soap molecules get between the water molecules and interferes with their attraction for each other, reducing surface tension. This enables water to penetrate fabrics in a washing machine more easily and extract the dirt and stains. Place a drop of liquid soap in the middle of the glass of water sprinkled with the pepper, and the pepper immediately moves to the sides and begins sinking. The needle will also sink, because the surface tension that was keeping it afloat has been interrupted .

Another way of reducing surface tension is to raise the temperature of water. We use this method in cooking. Cooking in water alters ingredients and distributes them throughout the food. The effect of heat can be shown by adding several teaspoons of sugar to a glass of room temperature water and a glass of warm water. It is easier to dissolve the sugar in the warmer water.

Although not necessarily a function of dissolving, water has a powerful effect on the solid Earth. Over time, running water can wear away mountains, breaking down solid rock into tiny particles and carrying them away as suspended silt. The muddy appearance of rivers, especially far downstream, is due to these silt particles, which remain suspended due to the turbulence of the water flow.

Two important gravity-driven processes

Water Properties

Property	Data	Note
Density	1 gram per cubic centimeter (or 1 gram per 1 milliliter) at 4 °C	Density diminishes to 0.95865 grams per cubic centimeter at 100 °C. When frozen, the density of water is 0.9167 grams per cubic centimeter.
Weight	1 kilogram per liter (on Earth)	Do not confuse with mass, which is also 1 kilogram. Weight changes in different gravitational environments. A liter of water on the Moon will weigh 166 grams.
Freezing Point	0 °C	Water can change directly from a solid to a gas (sublimate).
Boiling Point	100 °C	Boiling point depresses with increasing altitude. At 4,270 meters (14,009 feet) above sea level, the boiling point drops to 86 °C.
Ph	7	Water can become acidic or basic with impurities. Rainwater, for example, is slightly acidic because of carbon dioxide (CO_2) picked up from the atmosphere.
Description	Liquid, solid, or gas - tasteless, odorless, and colorless	When water has color, taste, or odor, the source of these properties is a combination of one or more impurities or organic compounds contained in the water. Water has a great heat storage capacity.

WLMR Question: How many kilograms, would one liter of water weigh on the Moon? (Be careful. We are talking weight, not mass. Its mass would still be one kilogram!)

in water are sedimentation and buoyancy. Any material that has a lower overall density than water will float on its surface. We call this buoyancy. Sedimentation is the opposite of buoyancy. Materials that have a greater density than water sink or settle to the bottom.

One-cubic-meter of white pine wood weighs 350 kilograms (density = 0.35 grams per cubic centimeter). It is easily supported (bouyant) in water that has a weight of 1,000 kilograms for the same volume (density = 1 gram per cubic centimeter). On the other hand, the element lead has a density of 11.3 grams per cubic centimeter. A 1-cubic meter block of lead would weigh 11,300 kilograms and quickly sink (sedimentation) in water.

In bodies of water, the accumulation of materials that settle to the bottom are called sediment. This is an easy concept to demonstrate. Obtain a sample of muddy water and place it in a jar. Set it to the side for a few days and observe what happens. The suspended particles, made of very tiny pieces of rock, settle to the bottom. Layers may form if the suspended material are made of different size or densities. The denser or larger particles will settle first and the lighter materials after. This very same process has led to most of the exposed land surface of Earth being covered with sedimentary rock.

WLMR Question: How will the Moon's gravity affect water properties such as surface tension and affect the processes of buoyancy and sedimentation.

"Living Waters"

Although small compared to the total water of Earth, biological water is of the greatest importance to living things. All living things contain water. Humans, for example, are composed of approximately 70 % water, much of which is found within cell walls. We use water to transport nutrients and oxygen throughout the body (blood is approximately 83 percent water) and remove waste products through urine, perspiration, respiration, and water in fecal matter. Water helps to digest our food and control body temperature.

Every day the average human must replace about 2.4 liters of water through drinking and eating. To remain healthy, the water being consumed must be uncontaminated. Water expelled from the human body, however, contains many elements and compounds that must be cleansed from the water before it can be used by humans again.

On Earth, water cleansing is a natural process that has been functioning since long before humans first appeared. Because of the tendency of large numbers of humans to cluster together in cities and because of intense agricultural and industrial activities, artificial methods of water cleansing (recycling) have become necessary.

The Water (Hydrologic) Cycle

The water cycle is one of planet Earth's miracles - the original water recycling system. Like many other life-giving cycles, it begins with energy delivered to Earth by the Sun. The Sun moderates Earth's temperature, keeping most of its surface liquid water.

On the daylight side of Earth, the Sun's heat warms the surface and the air above it, creating rising air currents. The night side is cool and dark, creating falling air currents. Because of Earth's rotation, all parts of Earth receive changing amounts of light and heat in regular cycles which triggers the movements of water around the planet.

The water or hydrologic cycle, as it is sometimes called, is a continuum. Except for the Sun's heat, there is really no beginning or end. Water continually cycles from oceans to the atmosphere to land and back.

As mentioned earlier, the oceans store almost 97% of Earth's water. Although many organisms live in the oceans, the water is not fit for consumption by humans and most land organisms.

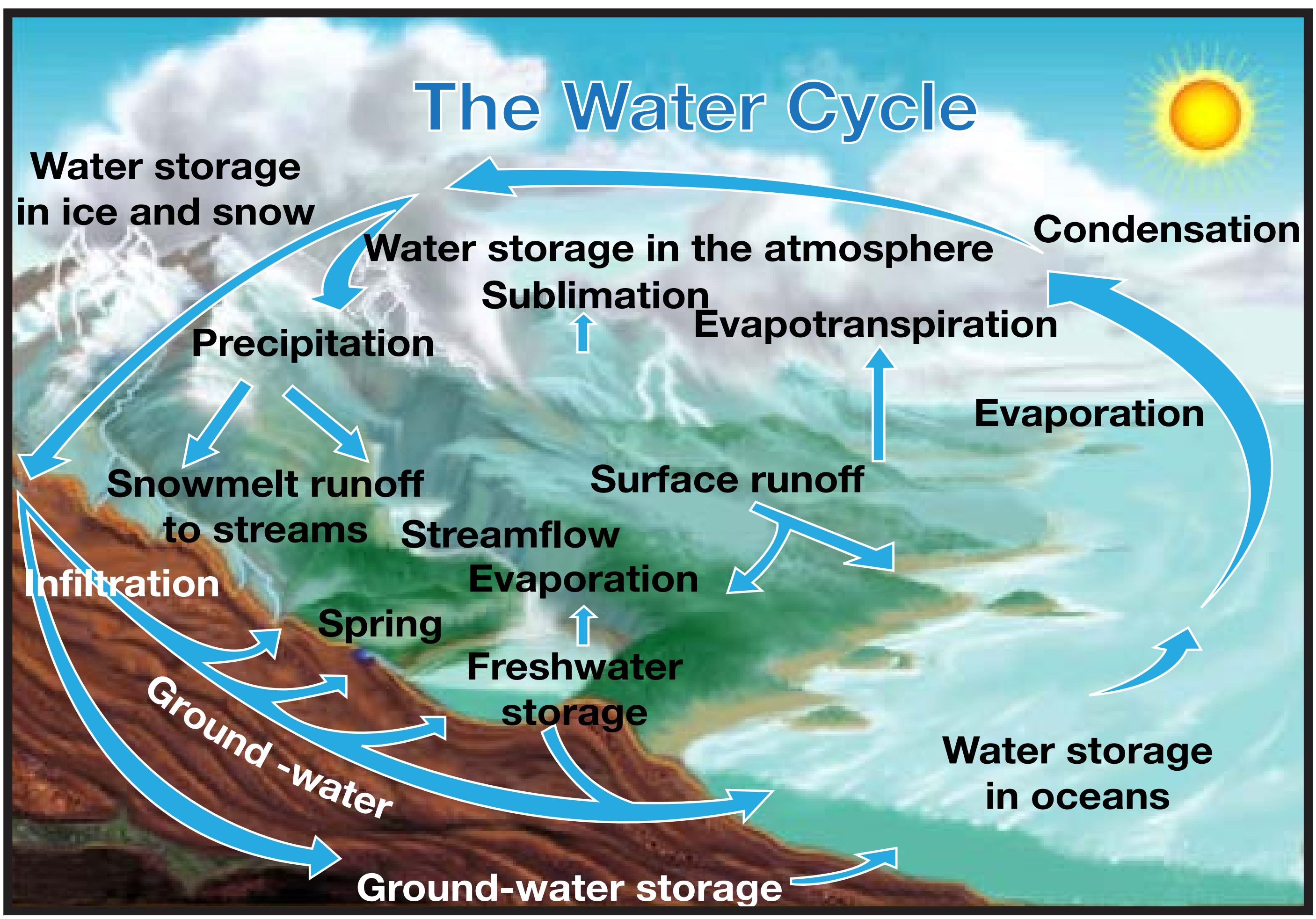
Heat from the Sun warms the ocean surface and accelerates the process of water evaporation. Individual molecules of water escape into the atmosphere. Heat currents carry the molecules skyward where they begin to cool and condense onto microscopic dust particles found naturally in the air. Tiny droplets form and accumulate into great whitish clouds that spread over the planet. Air currents carry the clouds over the land and when the droplets have grown into a mass that is too heavy for air currents to support, the water droplets fall as rain (or snow if the temperature is low enough).

When raindrops land on Earth's solid surface, they splash. Some of their water is absorbed into the soil and join a great water storage system: some is absorbed into the roots of plants; the rest flows in streams and rivers or joins lakes, where it is temporarily stored. Snow accumulates on the solid surface of the Earth, and if the quantity is great enough, compresses into glaciers, another temporary water storage.

Gradually, over days, years, or even thousands of years, the water works its way back to the oceans, and the cycle continues.

Recycling Water

Earth's water cycle is a wonderful example of how water can be renewed. Water easily picks up a wide range of chemical, biological, and mineralogical contaminants during the water cycle and naturally rids itself of most of these contaminants just as easily. Evaporation, for instance, converts water into a gas and contaminants, such as salts, are left behind. Later, that evaporated water condenses and falls back to Earth as rain or snow. Water, seeping into the ground, is filtered of impurities as it slowly passes through porous rock, or is absorbed by land plants, which transpire pure water back into the atmosphere. Aquatic plants too absorb impurities, leaving behind cleaner water.



Source: United States Geological Survey

The water cycle can be described as "regenerative," meaning created anew. No water is lost by the cycle, although water can remain in a form that is unusable by humans for a very long time.

Unfortunately, human activity on Earth has created major challenges for regenerating water. Large numbers of people, living in relatively small areas, strain the ability of Earth to regenerate water. Agriculture, energy production, industrial processes, transportation, and daily living create further stress on the environment by introducing concentrated amounts of wastes, including a wide range of artificial chemicals.

Because only about one percent of all the Earth's accessible water is potable, humans must resort to massive water treatment systems to maintain an adequate water supply. Typically, there are two types of water treatment systems - those that process sewage and those that purify wastewater into drinking water. Human wastewater is cleaned as much as possible with sewage treatment facilities. Solid components of these wastewater streams are collected, processed, and eventually incorporated into landfill or other products. After using one or more treatment technologies, the water from these waste streams is discharged (e.g., into into large lakes or oceans, rivers or even the ground) as effluent.

In the second type of water treatment system, water withdrawn from the environment (influent) is purified by one or more technologies to make it potable. It is advantageous to use the purest influent water available to minimize the amount of treatment required. Consequently, sewage treatment plant discharges and the inlets for potable water treatment plants are kept as far from each other as possible.

Space travel creates unique requirements for water treatment. The International Space Station and the future lunar base are very tiny worlds compared to Earth. Their resources are extremely limited and very expensive. In these environments, wastewater is not really waste. It is rather a valuable resource. The effluent from the International Space Station or lunar base wastewater treatment system becomes potable water influent that sustains the crew and environmental systems.

WLMR Question: What would a water treatment/recycling system on the Moon consist of and how would it work?

In designing a water recycling system (effluent and influent), it is useful to investigate different potential technologies for removal of contaminants from water.

Specific methods for water treatment are driven by local conditions. How you make water fit to drink, for example, depends on the condition of the source of non-potable water. For example, if the water source is high in salts (ocean water), some sort of distillation system is usually employed. Distillation is a physical process that accelerates the evaporation of water into a gas. In this process the salt-rich water is heated and the salt is left behind as the water is changed to gas. The water vapor is then directed to a condensor that cools the vapor and changes it back to liquid. The vastly improved liquid water is collected. However, water isn't the only liquid that can be distilled with heat; some potential contaminants like ammonia may pass through the distillation process as well. Thereefore, further processing, involving chemical or biological treatment, may be required.

One of the interesting parts of distillation is the effect that pressure can have on the temperature needed to distill the water. Water will boil at lower temperatures if the surrounding pressure is reduced. For instance, at sea level, water boils at 100 °C. On top of Mount Everest, the boiling point depresses to about 69 °C. This phenomenon can be taken advantage of to accelerate the distillation process by using a sealed chamber in which the pressure has been lowered.

Hikers, on backpacking expeditions, may carry small hand pump-operated water filters. These filters have very small pores and are designed to remove harmful microorganisms from mountain streams.

Communities drawing their water from wells or rivers use multi-filtration beds, each addressing different contaminants, and chemical and biological treatment to make the water potable.

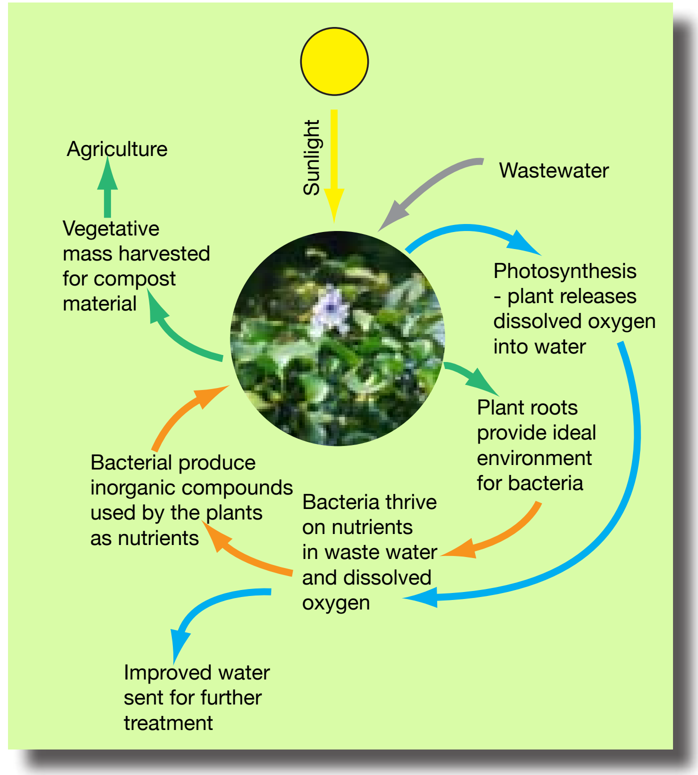
Human wastewater, on the other hand, is treated using a variety of different systems and methods. Home septic systems consist of a large tank that collects waste, while permitting water to percolate into the ground across a large filtration bed. Gradually, the water reaches the ground water table, but in a much cleaner state than when it started out. Periodically, septic tanks have to be pumped to remove accumulated solids.

Urban sewage treatment facilities have to handle large volumes of wast. These systems are very complicated, but in general treat wastes in three stages. Prior to entering the first stage of treatment, screens are used to block and remove large solids, such as gravel, plastic, cans, and other debris from the wastewater stream. In the primary or first stage various kinds of solids and liquids are separated from the sewage stream using settling tanks, where grease and oil float to the top and heavier organic solids settle to the bottom. The settled and floating materials are removed and the remaining liquid is subjected to secondary treatment.

In secondary treatment, the wastewater streams are treated using aerobic biological processes, in which bacteria and protozoa (occurring naturally in the wastewater) breakdown various organic compounds into carbon dioxide and water, in the presence of oxygen.

In tertiary treatment, the water that has undergone primary and secondary treatment is disinfected by the addition of chlorine, or other chemicals, and sent through various filters to kill bacteria and other microorganisms and make it as clean as possible before discharge back into the environment.

In addition to biological treatment of wastewater with bacteria and protozoa, aquatic plants are also used in some systems. Plants such as water hyacinths and water lettuce are sometimes grown in secondary treatments tanks. Through photosynthesis, these plants release additional dissolved oxygen to the water and their roots provide an ideal environment for bacteria to thrive. This creates



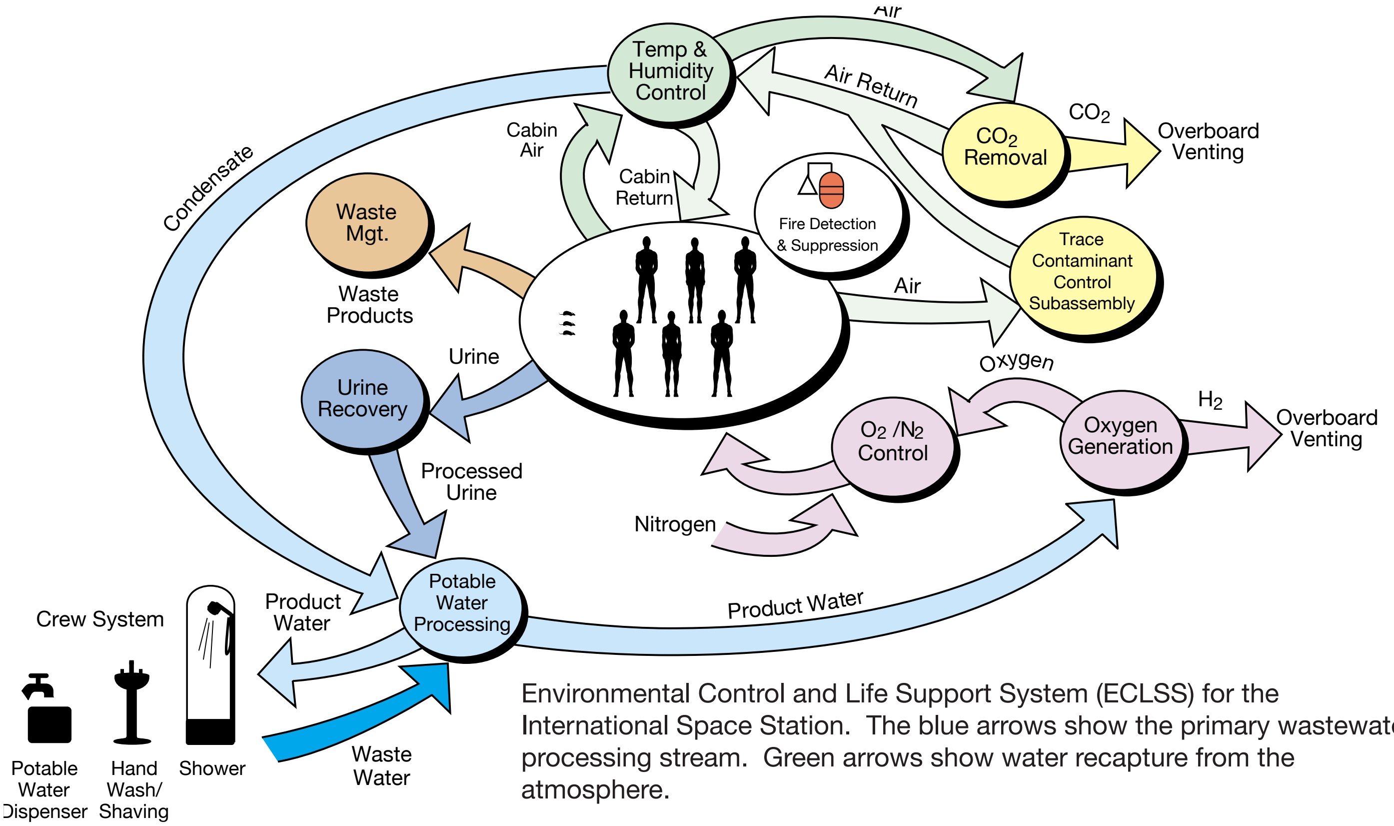
Secondary treatment incorporating aquatic plants

a symbiotic system; the bacteria process chemical contaminants in the water and make compounds that serve as nutrients for plant growth. Every few days, a portion of the plants are harvested and dried for compost.

These are just a few of the wastewater treatment strategies employed to remove contaminants from wastewater streams. Often, the local conditions determine what technologies are put to use. (Much information on water treatment is available on the Internet. Refer to the resources section at the end of this guide). One of the most highly specialized water treatment systems is used on the International Space Station.

Water on the International Space Station

Unlike the early explorers of Earth, astronauts exploring outer space cannot count on finding water along the way to sustain them. Water for Mercury and Gemini missions was carried in storage tanks inside the capsule. Apollo missions to the Moon incorporated fuel cells that combined oxygen and hydrogen in a reactor to produce electricity for powering the spacecraft; potable water was a by-product of the process. A similar system is used on the Space Shuttle.



Environmental Control and Life Support System (ECLSS) for the International Space Station. The blue arrows show the primary wastewater processing stream. Green arrows show water recapture from the atmosphere.

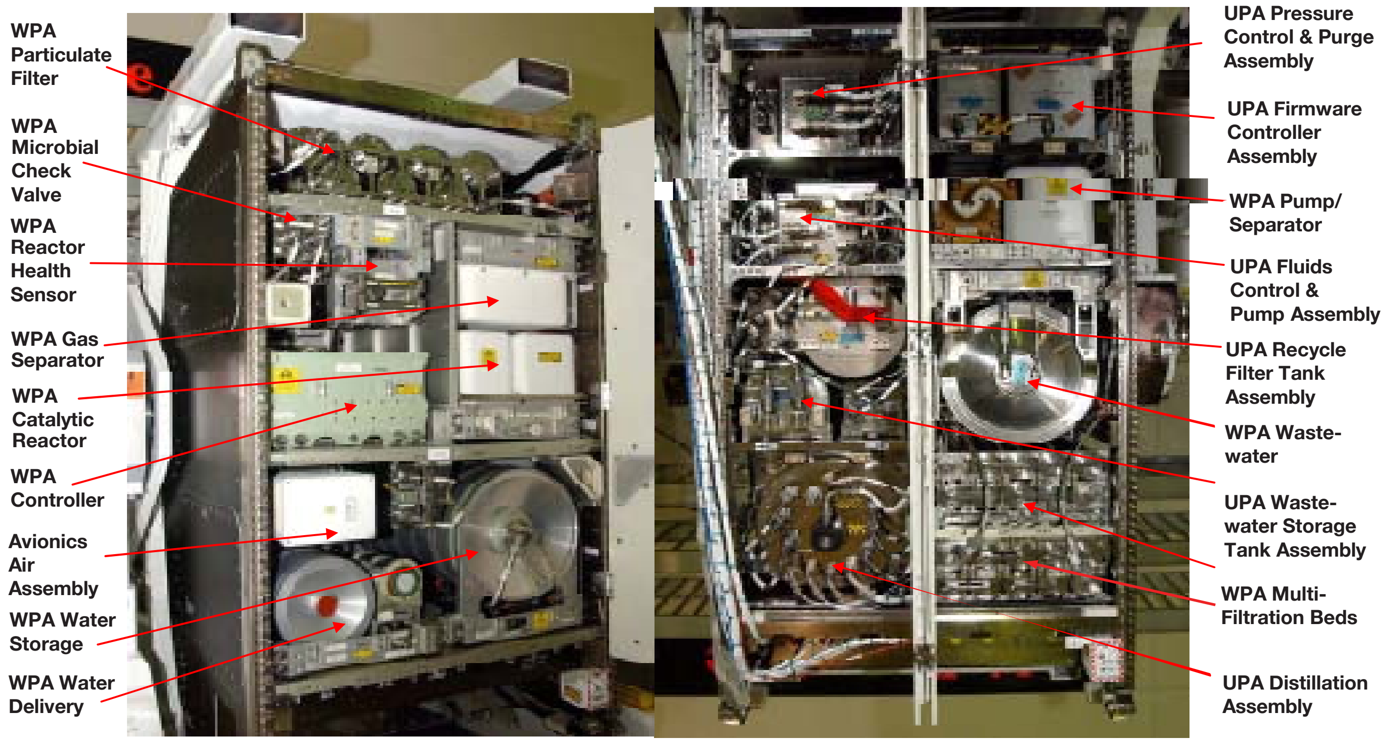
Like any other spacecraft, the International Space Station (ISS) depends on water supplies to support the crew and sustain the necessary environmental conditions for life on the space station. Water is needed for drinking, food preparation, washing, and hygiene. Because the ISS is a permanent station, its need for water is continuous. Water, in large collapsible bags, is brought to orbit by the Space Shuttle and the Russian Progress spacecraft; doing so is extremely expensive though. The launch cost for a simple 1 liter bottle of water that we take for granted here on Earth, would be approximately $22,000. Supporting a crew of six astronauts on the ISS requires about 6,800 liters of water to be launched per year at a cost of almost $150 million! The obvious, but not so easy, solution is to recycle the water already there, so that it can be reused.

On the International Space Station, there are many waste streams of used water on the ISS that can be collected and recycled. The main wastewater streams are:

- urine;
- Wash (hygiene and food cleanup);
- Crew respiration water;
- Perspiration;
- Research animals; and
- transpiration and “spent” nutrient solutions from plant processes

To process the ISS wastewater stream, a complex multi-function system called the Environmental Control and Life Support System (ECLSS) is employed. About the size of three refrigerators, the ECLSS performs a variety of environmental management functions including:

- providing oxygen for metabolic consumption;
- providing potable water for consumption, food preparation, and hygiene uses;
- removing carbon dioxide from the cabin air;
- filtering particulates and microorganisms from the cabin air;
- removing volatile organic trace gases from the cabin air;
- monitoring and controling cabin air partial pressures of nitrogen, oxygen, carbon dioxide, methane, hydrogen, and water vapor;
- maintaining total cabin pressure;



ECLSS racks for the International Space Station house components of the Water Recovery System's urine processing assembly (UPA) and water processor assembly (WPA).

- maintaining cabin temperature and humidity levels; and
- distributing cabin air between connected modules.

The Water Recovery System of ECLSS consists of a urine processor assembly and a water processor assembly. Urine collected from crewmembers and laboratory animals, if present, is subjected to a low pressure (vacuum) distillation process that speeds the evaporation of water from the urine. (The urine production from a full complement of 72 rats equals the output of one human in terms of water recycling.) The vacuum speeds the evaporation of water from the urine. The evaporated water is collected for more processing, leaving behind chemical and particle contaminants.

The urine processor assembly incorporates a rotating cell that centrifuges the urine as it evaporates. This facilitates the separation of gas bubbles, hair, and lint from the urine. On Earth, a similar system would employ gravity and strain the urine through a filter and remove large solids while gas bubbles simply rose to the top. The microgravity environment of the ISS, however, requires a different strategy. The rotating distillation cell produces an artificial gravity through centrifugal acceleration. Urine is accelerated to the outside while gas bubbles move toward the middle of the cell. This effect of the rotating cell is quite similar to what happens in your washing machine during the spin cycle -water escapes through perforations in the spinning drum walls, while the clothes remain behind.

WLMR Question: Considering the low gravity on the Moon, would some sort of centrifuge be a useful part of a water recycling system?

Product water from the urine processor assembly is added to the wastewater stream generated by other ISS functions. The other wastewater sources also contain various solid materials and gas bubbles that need to be separated from the water before further processing, so the entire wastewater stream is filtered using the same rotating cell process.

The entire wastewater stream is then directed into the water processor assembly through a series of filtration beds that further purify the wastewater stream. After passing through a particulate filter (essentially a fine

International Space Station crewmembers (L-R) Koichi Wakata, Cennady Padalka, Mike Barratt toast the team that created the ECLSS with a drink of recycled water from the Water Recovery System.

mesh screen) the stream passes through five successive filtration beds. The first is activated charcoal (AC), which removes the larger organic compounds from the wastewater stream. The remaining four beds are different ionic exchange resins (IRN) that remove inorganic ions (electrically charged atoms) and small organic molecules.

The next stage of wastewater processing, volatile removal assembly (VRA), removes any remaining organic compounds. The assembly is a packed bed of spheres coated with a platinum catalyst. Under high temperature and in the presence of oxygen, the organics are oxidized to CO_2. Additional ionic exchange resins adjust the pH of the water back to a neutral state (about 7 pH). Last, the water flows through a microbial check valve (MCV) that contains ionic resins coated with iodine that dissolves in the water to serve as a biocide to limit any microbial growth in the water storage tanks.

The last step in the water processing is to check the water for purity using electrical conductivity sensors. If the purity is not acceptable, the water is re-directed through the system for further processing. Water that passes the purity test is sent to a storage tank for use by the crew.

The Water Recovery System on the ISS is capable of recovering an average of 93 percent of the water contained in the waste stream. Approximately 15% of the urine water component is retained by the system as a high salt “brine” liquid that must be disposed of. The urine water loss is balanced by a nearly 100% recovery of atmospheric condensate and other non-urine wastewater. The water recovery significantly reduces the quantity of water that must be launched to space to support crew operations. That saved launch mass can be used to support other ISS operations.

WLMR Question: In addition to the routine contaminants that would collect in the wastewater stream of a lunar base, what contaminants might get into the stream that are unique to the Moon? What effect might these contaminants have on purifying water?

Waste Limitation Management and Recycling Considerations for the Moon

Regardless of whether or not water is eventually discovered on the Moon, a future lunar base will require a water recycling system. Except for the introduction of the initial water and occasional water replenishment, a lunar wastewater recycling system should be closed-loop to the extent possible. The system will have to be capable of returning three main sources of used water to a potable state:

1. Urine - Urine secreted by the kidneys of humans or animals contains numerous waste compounds from the life processes of the body’s cells, including urea, a nitrogen-rich compound, dissolved salts, and organic

compounds. Approximately 95 percent of urine is water.

2. Atmospheric condensate - Water evaporated into the lunar base atmosphere from sweat and from moisture released directly into the air by breathing.

3. Hygiene water - Personal hygiene (showers, washing hands, brushing teeth, etc. clothes and dish washing), and food preparation.

There is a potential fourth used water source as well - flush water passed through toilets to remove fecal materials. Because of the extra difficulties this source presents for water treatment, alternatives are being sought. Some sort of waterless toilet, similar to that being used on the ISS, is likely. On the ISS, urine and fecal matter are collected in separate containers. The urine is sent to the water recovery system and the fecal matter is stored in porous bags and vacuum dried between toilet uses. Periodically, the fecal bags are removed and placed, along with other ISS wastes, on a robotic supply spacecraft docked to the station. When the supply spacecraft is returned to Earth, the fecal waste disintegrates on atmospheric re-entry.

Disposal of fecal matter on the Moon will be more challenging than on the ISS. Disposal by atmospheric reentry is not possible. An alternative approach would involve stabilization of the fecal waste through a drying process. In this scenario, the dried solids would be stored and the extracted water would become an input stream to the water recovery system.

The three main human waste streams provide water recycling system designers with significant purification challenges. Combined, the three streams contribute the following contaminants to the wastewater:

<u>Salts (sodium and chloride ions)</u>

Salts are a major component of urine wastewater. Humans excrete excess salts in their urine in order to osmoregulate (a process that maintains an organism's water content). Salt and its effect on osmoregulation is the reason you can't drink salt water or urine.

Salts cannot be broken down, or altered or transformed by biological systems. Unlike the other substances contributed by these waste streams, salts cannot be removed by biological treatment. Distillation or filtration (using high pressure to force the fluid through the filters with very small pores) will separate salts from a wastewater stream but both techniques require external energy (as in the Sun, which drives evaporation on Earth).

> *WLMR Question: What energy sources are available on the Moon? Does your location on the Moon affect the potential sources of energy?*

<u>Organic Matter</u>

Organic matter affects the aesthetics of the water (i.e., taste, color, and smell). Some organic compounds taste bad, but others taste good (e.g., sugar). In general, the organic matter content in the water needs to be low or bacteria will grow in the potable water storage tanks, leading to possible spread of disease and unpleasant taste and odors. Organic matter can be treated by breaking it down with microorganisms in a bioreactor. During this treatment method, the organic compounds are converted to carbon dioxide (using the same process –respiration – we use when we burn organic matter for fuel and breathe out $CO_{2)}$.

Other methods for dealing with organic matter include chemical conversion using ultraviolet radiation and a titanium dioxide catalyst, and absorbing organic particles with a material like activated charcoal.

Organic matter is found in the three main water sources, but in varying composition and concentration. Atmospheric condensate contains low levels of volatile organic compounds. Urine contains relatively small amounts of organic matter other than urea (see "Ammonia" below), but may contain trace amounts of "bioactive" compounds, such as hormones and residual drugs. Hygiene water contains organic matter rinsed from the human body and to a greater degree, surfactants (i.e., soaps) used for cleansing.

Microorganisms

Microorganisms are another aesthetic issue affecting the taste, color, and smell but more importantly, can be a source of a disease. Some protozoa can lead to rather unpleasant gastrointestinal reactions.

Urine is normally free of microorganisms when it is released from the body, unless the person has a urinary tract infection, and hgiene water contains relatively low levels of microorganisms, although it may include traces of the variety of microorganisms found on and inside people. Atmospheric condensate contains relatively low levels of microorganisms, but may be "contaminated" with the normal microflora present within the spacecraft.

Ammonia

Ammonia is a relatively unique compound commonly found in wastewater. Animals excrete excess nitrogen as ammonia, and humans excrete ammonia in their urine in the form called urea (i.e., basically two ammonia molecules that are linked together, but are rapidly separated after the urine is released from the body). Ammonia is unique because it is volatile, and is biologically active. Because ammonia is volatile, it can be passed along through the distillation process and certain bacteria used in the later treatment stages, are able to oxidize ammonia to nitrate, gaining energy from the process. Some bacteria are able to convert ammonia to nitrate, gaining energy from the process. These bacteria may be used as a treatment to remove ammonia form the wastewater.

WLMR Question: In designing a water recycling system for the Moon, do you mix all three water streams together or use different processes for different streams?

Classroom Activities

1995 NASA concept for a simulated Mars mission on the Moon. Lunar astronauts evaluate a future Mars spacecraft in the harsh lunar environment. Testing Mars systems, while only three days from Earth, will provide the opportunity to solve potential problems before the Mars mission is attempted. In the distance is the lunar base.

Establishing a base on the Moon will provide many challenges for future astronauts, not the least of which have to do with resources. Making effective use of resources requires a recycling strategy that will work in the Moon's unique environment. The Waste Limitation and Management of Resources Design Challenge offers students the opportunity for creative application of science, technology, engineering, and mathematics.

The challenge consists of recycling a simulated wastewater stream to recover as much water as possible and make it potable for astronauts and other applications on a lunar base.

Instructions for creating a simulated water waste stream and testing procedures for evaluating the success of student-designed recycling systems are found at the end of this activity section.

In order to be successful, student teams will experiment with various recycling strategies. As in any scientific experiment, controlling variables is essential.

The activities that follow offer suggestions to help students understand the processes of water recycling, but do not include all possible technologies that could be employed. The activities should be considered starting points in the creative efforts to design a water recycling system for the Moon.

Included are activities related to distillation, sedimentation, filtering, centrifuging, biological filtration, and chemical treatment. By investigating each of these strategies separately, students will enhance their background knowledge and be able to construct a complete prototype system and predict how it will function in the design challenge.

National Science[1] and Mathematics Standards[2] Activities Matrix

	Filters	Distillation	Separation by Force	Sedimentation	Biological Filters	WLMR DC
SCIENCE						
Unifying Concepts and Processes						
Change, constancy, and measurement	X			X	X	X
Form and function	X	X	X	X	X	X
Science as Inquiry						
Abilities necessary to do scientific inquiry	X	X	X	X	X	X
Understandings about scientific inquiry	X	X	X	X	X	X
Physical Science						
Properties and changes of properties in matter	X	X	X	X	X	X
Motions and forces			X	X	X	X
Transfer of energy		X	X			X
Earth and Space Science						
Structure of the earth system	X			X	X	X
Earth in the solar system						X
Science and Technology						
Abilities of technological design	X	X	X	X	X	X
Science in Personal and Social Perspectives						
Personal health	X			X	X	X
Populations, resources, and environments	X	X		X	X	X
Risks and hazards	X			X	X	X
MATHEMATICS						
Number and operations	X			X	X	X
Geometry			X	X		X
Measurement	X			X	X	X
Connections	X		X	X	X	X
Communication	X		X	X	X	X

1. National Research Council. 1996. National Science Education Standards. National Academy Press: Washington, DC.
2. National Council of Teachers of Mathematics. 2000. Principles and Standards for School Mathematics, 3rd edition. National Council of Teachers of Mathematics: Reston, VA.

Filtration

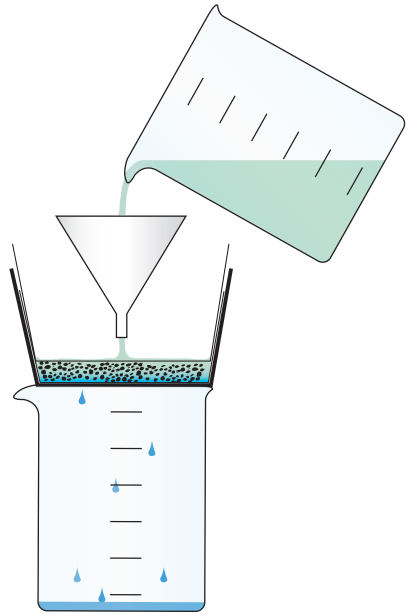
Objective:
Students will use water quality tests to measure the effectiveness of various filter media in improving the quality of simulated wastewater.

Description:
Student teams will collect candidate materials for filter media and test the media's ability to purify a measured quantity of wastewater using standardized tests.

Materials:
(per team of students)
Coffee filter basket
10 paper coffee filters to fit the basket
Two 500 ml beakers
Small funnel
Simulated wastewater (see pages 42-43)
Empty and washed plastic milk bottle to hold simulated wastewater
Water testing kit (see pages 43-45)
Various candidate filter media to test
Beam balance or electronic scale

Background:
Most water recycling strategies involve some sort of filtering system, consisting of one or more filters to remove particles, algae, microorganisms, and some chemicals dissolved in the wastewater. Filters can be as simple as a fine screen that captures particles larger than the screen's pore size or a porous ceramic material with pores about 1/1000th of a milimeter in diameter that can block protozoans such as *Giardia lamblia* (often found in untreated water in wilderness regions of the U.S.).

Some filters work because the material they are made out of has an affinity for certain chemicals. Still others work because they have very large surface areas that "latch" onto organic matter and other compounds. Activated carbon is an excellent example of a filter with a large surface area - a single gram of powdered activated carbon is estimated to have a cumulative surface area of about 500 square meters.



Other filters work because they are made out of materials, such as zeolites, that block molecules of one size, while letting others pass through. Zeolites are crystals made from of the elements silicon, aluminum, and oxygen. The crystals consist of alternating arrays of silica (beach sand, SiO_2) and alumina (aluminum oxide, Al_2O_3) and can take on many geometric forms, such as cubes and tetrahedra. Internally, zeolites are rigid sponge-like structures with uniform, but very small openings (e.g., 0.1 to 1.2 nanometers (a unit of length equal to one billionenth of a meter). Because of this property, these inorganic crystals are sometimes called "molecular sieves." and work like an atomic-sized "spaghetti strainer."

Because filtering materials can be specific to a particular contaminant, multiple filtration beds are often used for water treatment. Water to be recycled passes the various filters one at a time and each filter does its specific job.

TIP Encourage students to do their own research on potential filter media. Each team should identify one or two filter media for testing. The staff of aquarium and swimming pool stores and municipal water treatment plant staff can provide advice on materials used as filter media. Commercial materials available from these businesses include activated carbon, zeolites, porous gravel, and diatomaceous earth. Lawn and garden businesses can provide sand and gravel of various grain size, and volcanic rock chips. Volcanic rock can be pulverized into sand by placing it in a cloth bag and mashing it with a hammer.

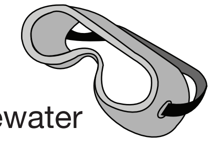
Procedure: Material Assembly

1. Prepare the simulated wastewater according to the instructions found on page 43 of this guide. Prepare 1 L of simulated wastewater per team of students.
2. Review with your students the quality testing procedures found on page 45.
3. Provide student teams with a coffee filter basket and ten coffee filters to fit.

Procedure: Conducting the Tests

1. Place two paper coffee filters into the coffee filter basket. Run 250 ml of tap water through the basket to soak the filters. Discard the water.

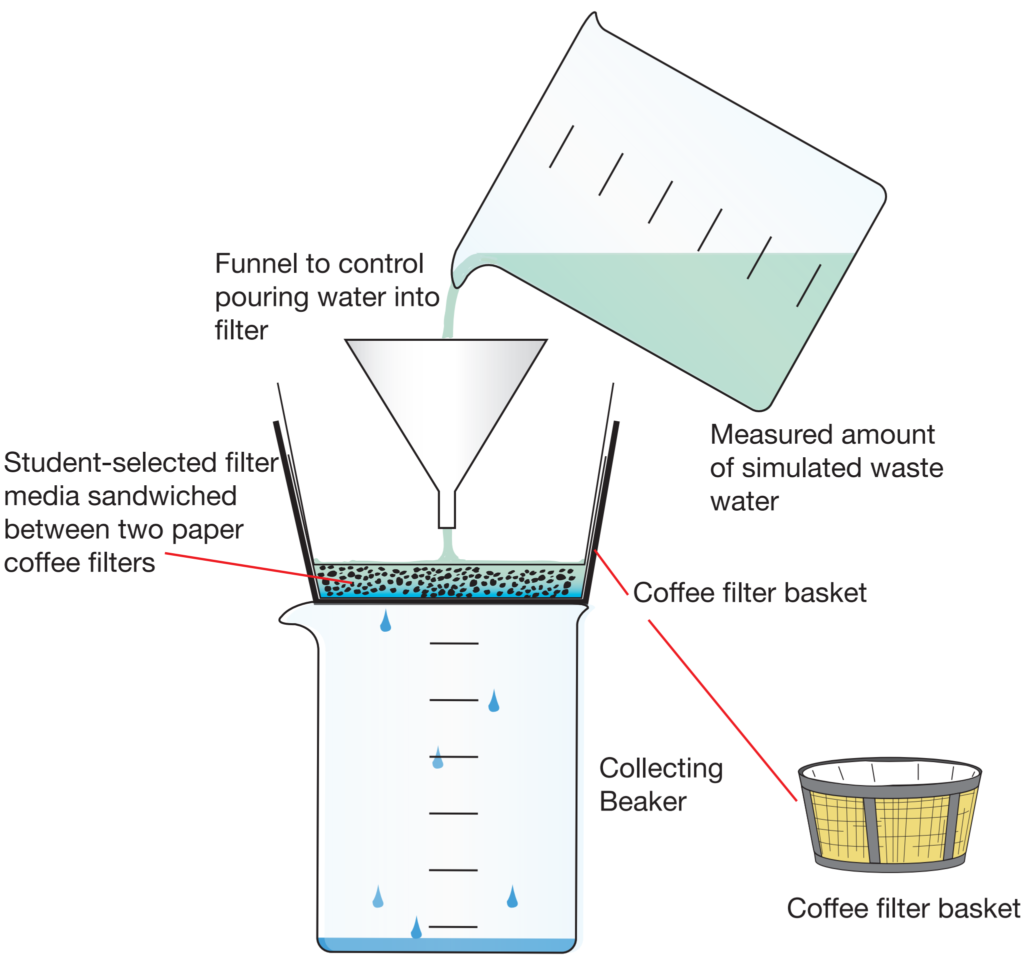
Safety Procedures



Although the simulated wastewater is safe to handle, good laboratory safety procedures should be followed at all times.

- Wear eye protection.
- Wash hands after handling the wastewater.
- Dispose of filters and media properly
- Do not drink the filtered water (we are not using disinfectant chemicals in these activities).

2. Test 1: Slowly pour 250 ml of simulated wastewater through the funnel. Following the testing procedure on page 45, collect for testing. Record the results.
3. Test 2: Place a new paper filter into the coffee filter basket and add a 1-cm-deep layer of filter medium to be tested. Smooth the layer to a consistent depth of 1-cm. Cover the



medium with a second paper filter. Carefully remove both the paper and filter medium and measure the total mass. Record the results. Carefully place the filters back in the basket, smoothing the filter media to a consistent depth of 1 cm. Slowly pour 250 ml of tap water through the basket and discard the water collected in the beaker below. Pour 250 ml of simulated wastewater through the filter as done in Test 1 and test the water. Record the results. Carefully remove and measure the mass of the paper and media to determine how much water was retained. Record the results.

TIP You can recycle used filter medium later by sprinkling it in a garden.

4. Test 3: Repeat the steps for Test 2 with different filter media. Record the testing results.

Procedure: Analyzing The Results

1. Construct charts displaying the results achieved for each test.
2. Hold a class discussion to share the results. Tabulate and average the data for teams that tested the same filter media.

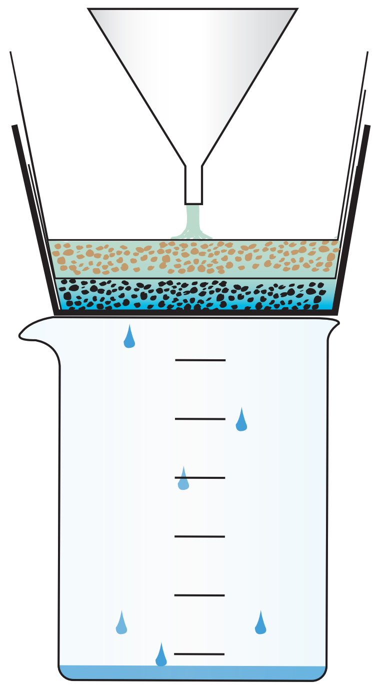
Procedure: The Next Step

1. Based on the posted results, teams should design and test a multi-filtration system. (Set up the filters as before, but stack one or more additional filters on top following this sequence: paper filter, medium, paper filter, medium, paper filter, etc.) Discuss the results.

Discussion Questions:

Why are two sheets of filter paper used and the water poured slowly through a funnel?

Coffee filter baskets have screen holes on the sides and bottom. Pouring the water slowly through the funnel keeps the water from moving to the sides of the basket and bypassing the filter media. The top filter paper prevents the force of the pouring water from producing holes in the filter media, permitting the water to pass directly through without being filtered.



Why were the paper filter tested by themselves?

This is a precaution, in case the filter paper had an effect on the simulated wastewater. Testing the paper by itself provides a baseline for data comparison.

What potential filter media might be found on the Moon?

The surface of the Moon is covered with a thick layer of pulverized rock fragments, referred to as regolith, that has formed as the result of asteroid and meteorite impacts over billions of years (see page 8). The layer is referred to as regolith and its primary source is the volcanic rock that is found over much of the lunar surface. Eons-worth of meteorite impacts have pulverized the rock and deposited the regolith. Lunar regolith samples brought back by Apollo astronauts revealed that the regolith is a mixture of dark gray powder and very angular, tiny rock fragments. The material is very porous and small quantities have large cumulative surface areas.

Which of the tested filter media do you think will work best on the Moon?

(Individual answers.) Students should not only think in terms of the effectiveness of the filter media in purifying one or more aspects of the wastewater stream, but should also think about the mass of the media. If the filter media cannot be found on the Moon, it will have to be transported there; in that case, lower mass materials are preferred due to their lower transportation cost.

Assessment:

Student team charts displaying their test data.

Extensions:

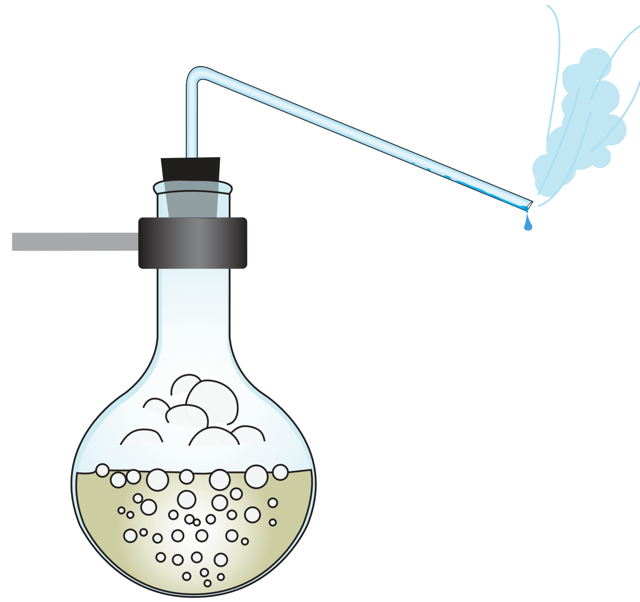
- Each filter media test involved a 1-cm layer of medium. Would a thicker layer be better? Ask students to prepare a research plan to determine the optimum thickness of each filter media.
- Obtain several liters of pond water for testing. Use care when handling pond water. Wear eye protection and wash hands after handling. Pond water is likely to have a noticeable odor. Do the various filter media have an effect on the odor? Compare untreated vs. treated pond water.
- If you have stereo microscopes available, have students examine and describe the surface texture and porosity of filter media particles. Compare the physical observations of the media to their effectiveness in water purification.

WLMR Design Challenge Notes:

- It is tempting to conclude that a particular filter medium is the most effective based only on the analysis of the filtered water. For a system intended to operate on Earth, that would probably be correct but a filtration system on the Moon might work better if a different filtering medium was used. An essential question for a lunar system is how many times the filter media can be used before it has to be replaced. If a high-performance filter has to be replaced after just one use, there is a problem. Besides the time consuming task of continually replacing the filter, there is also the transportation/cost issue of continually resupplying filters from Earth.

If a team chooses to pursue some form of filtration for their WLMR Design Challenge, they should carefully consider the potential life cycle of the material to be used. This would require repeated testing of the material to determine its long-term effectiveness. Methods for regenerating the material (e.g., heating to remove attached contaminants) should also be considered in an effort to reduce the costs of water treatment.

Distillation



Objective:
Students will investigate distillation as a method for recycling used water.

Description:
In this activity, two methods for distillation are investigated - heat distillation and vacuum distillation.

Materials:
Glass boiling flask (Florence flask)
Solid rubber stopper
One-hole rubber stopper
Ring stand and clamp
Glass tubing to fit stopper
Glycerine or liquid soap
Dish cloth or gloves
Water
Food coloring
Table salt
Tablespoon
Heat source (Bunsen burner or propane torch)
Dish pan
Safety glasses

Background:
Distillation is a physical proces for separating mixtures. If you have two or more liquids mixed together in some sort of chamber or a mixture of liquids and solids, distillation can be used to separate them. Normally, the distillation process is initiated by applying heat to the bottom of the chamber. Different liquids have different volatilities; and will therefore boil at different temperatures. The liquid with the lowest volatility (or boiling point) will boil, or convert to a vapor, first. For example, under ordinary circumstances, water boils at 100°C (212°F). Isopropyl alcohol, used for cleaning, has a boiling point of 82.3°C (180.1°F). If you had a batch of water contaminated with isopropyl alcohol, you could use distillation to separate them. Heating the mixture to between 82.3°C and 100°C would vaporize the isopropyl alcohol, leaving the pure water behind. In distillation, the vapor collects in the air space above the mixture and is passed through a condensor. A condensor is usually a tube, sometimes coiled, that is kept at a lower temperature. The vapor cools when passing through the condensor and condenses back into its original state; in this case, into pure isopropyl alcohol.

Saltwater is a mixture of water and salt, or sodium chloride (NaCl). When mixed, salt breaks down into sodium and chloride ions (electrified atoms). If the salt water is boiled, pure water is produced from the condensate and the sodium and chloride ions are left to bond together again into salt crystals. Distilling salt water is usually referred to as desalinization.

The requirement for an outside energy source for heating the salt water can be greatly reduced by a process called flash distillation. Desalinization plants, often located in coastal regions, use a combination of low heat and low pressures to quickly (flash) boil salt water to form a vapor. Lowering the atmospheric pressure also lowers the boiling point of water. A flash distillation plant is essentially a large vacuum chamber in which water is heated to a temperature considerably lower than the standard 100°C (212°F). The water boils at the lower temperature and the vapor produced is condensed and collected for drinking water.

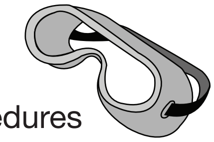
Another way of increasing the rate of distillation is to reduce the humidity of the surrounding air. If vapor in the surrounding air is immediately drawn off and condenced back into a liquid, the air has a greater capacity to receive additional water vapor. Consequently, the distillation rate increases.

Distillation has many applications. It is used to separate gasoline and other by-products from crude oil. It is used in the production of certain beverages, perfumes, and oils. Large ships and submarines employ desalinization plants to supply water needs, taking advantage of the excess heat produced by nuclear reactors to process the seawater.

Procedure: Heat Distillation

1. Demonstrate the heat distillation process by preparing a boiling flask as shown in the diagram below. Begin by gently inserting the glass tube into the one-hole stopper. Use a bit of glycerine or liquid soap to lubricate the tubing. It is best to wear gloves or surround the tubing with cloth to protect your hands in case the tube breaks. While wearing safety glasses, heat the tube with a torch or Bunsen burner. Rotate the tubing until it becomes soft and bends as shown. Let the tube cool before handling.
2. Add tap water to the flask until it is half full. Add several drops of food coloring and a tablespoon of table salt. Swirl the flask to mix the "contaminants."
3. Grasp the neck of the flask with a clamp and mount it on a ring stand. Place the stopper with the bent tube into the neck of the flask and place a cup under the tube to capture the water condensate.
4. Heat the flask to boil the water.
5. Record observations of the process. Describe the appearance of the water in the flask and what happens when boiling starts.
6. Describe the properties of the condensate water collected in the cup when it is cool.

Safety Procedures



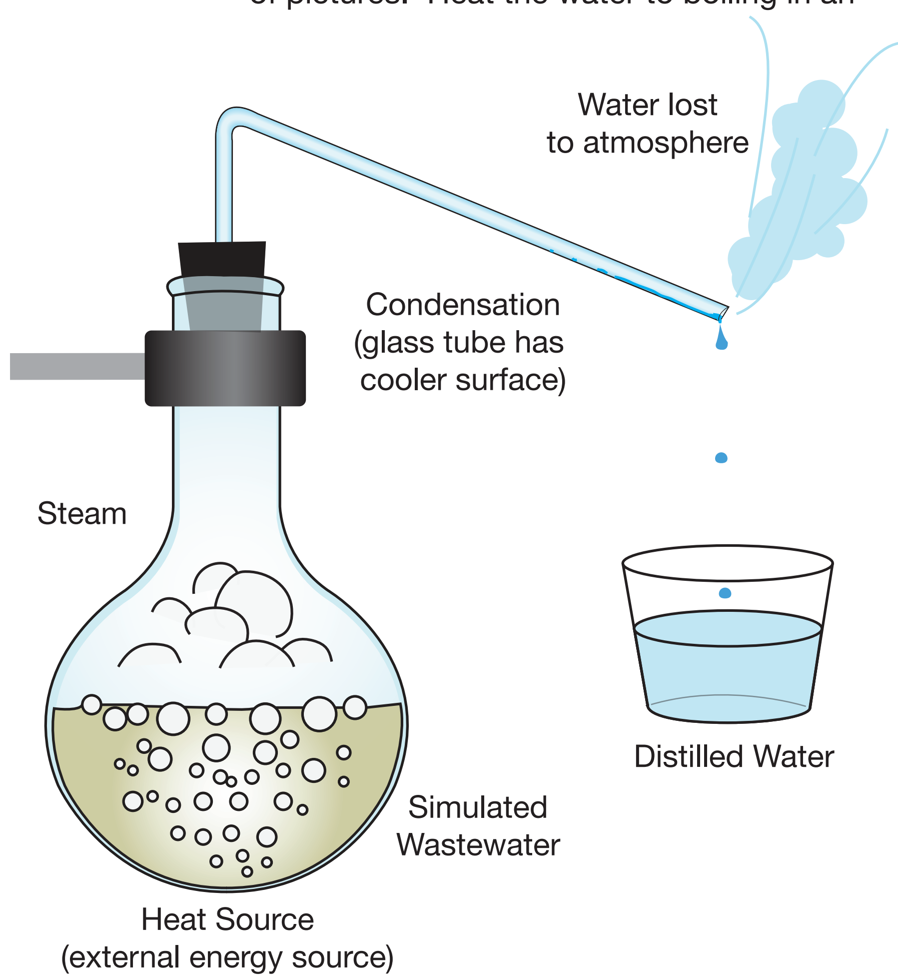
Good laboratory safety procedures should be followed at all times:

- Wear eye protection.
- Use hand protection when handling and forming the glass tubing.
- Do not drink the distilled water (the water will likely be potable, but there is the potential for contamination due to handling in the classroom).

TIP The rate of condensation can be increased by laying a piece of paper towel soaked in very cold water over the glass tube. Keep the towel cold.

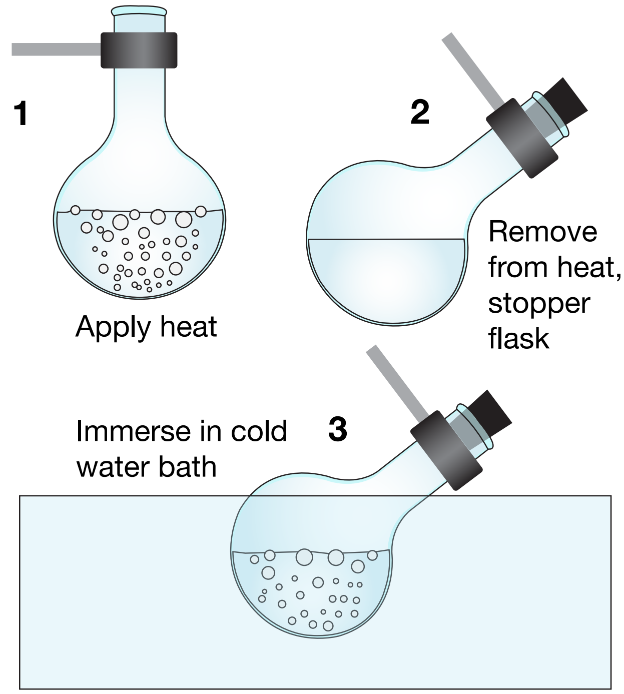
Procedure: Vacuum Distillation Demonstration

1. Set up the flask as shown in the next series of pictures. Heat the water to boiling in an



open flask. Observe what happens to the water.

2. When the water begins a brisk boil, remove the flask from the heat. Wait a few moments until the boiling stops and immediately seal the flask with a stopper.
3. Quickly immerse the flask into a pan of very cold water. Observe what happens to the water in the flask.
4. Ask students for their ideas about the potential for a vacuum distillation system on the Moon and how it might be employed.



Discussion Questions:

Why did the water in the sealed flask begin boiling again when it was immersed in cold water?

During boiling, the air above the water in the flask became heated. The air was still hot when the flask was sealed. Immersing the flask in the cold water chilled the air pocket inside the flask. The air contracted as it cooled and this produced a partial vacuum. The lower air pressure inside the flask initiated boiling again.

What are some other applications for distillation?

Distillation is an important physical process. Petroleum products like gasoline and kerosene are separated from crude oil by distillation. Many alcoholic beverages are distillation products and perfume and various chemicals are processed by distillation.

How can you improve the efficiency of a condenser?

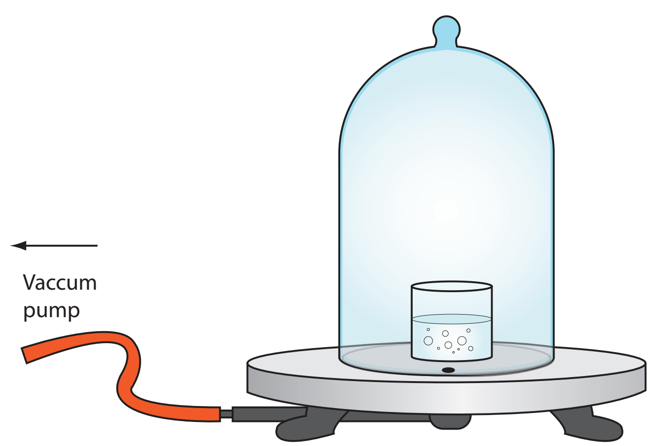
To be effective, condensers need to have a lot of interior surface for the vapor to condense on and the surfaces need to be kept cool. Longer condenser tubes, tubes with a greater inside diameter, and a cool water bath surrounding the condenser tubes improves condenser efficiency.

Assessment:

Have students create journals of the observations they made during the demonstrations. Have them write questions for future research and their preliminary ideas for a water recycling system that could be used on the Moon.

Extensions:

- If you have access to a vacuum pump and chamber, vacuum distillation can easily be demonstrated. Simply place a cup of water inside the chamber and draw a vacuum. When the pressure drops sufficiently, the water will boil. Immediately remove the boiling water from the chamber and have a student test the water with a finger to verify

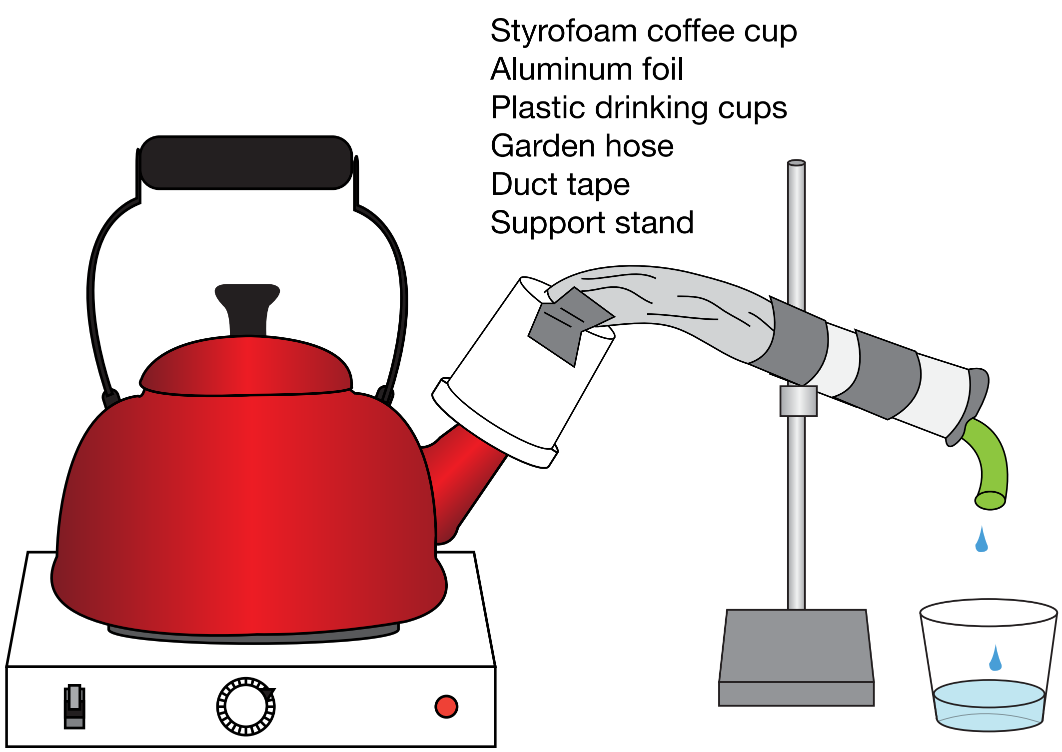


that the water is actually room temperature. Discuss how the vapor produced in the vacuum chamber might be collected for use.

- Challenge students to make an efficient teakettle distillery. Obtain an old teakettle without a spout cap (or remove the cap). Have students design a condenser system that can be attached to the spout. The condensor should not be physically attached to the teapot. Aluminum foil, plastic cups with bottoms removed, plastic milk bottles, hoses, and other scrap materials can be fashioned into some sort of tube for a condenser. Use a hotplate for heating the water. Different designs can be tested using the same teapot. The vapor produced by boiling the water in the kettle will rise upward from the spout because of its buoyancy (hot air rises). The object is to make an efficient condensor that quickly captures water from the vapor. Compare the speed of each condensor design in condensing 10 milliliters of water from the vapor.

WLMR Design Challenge Notes:

- Student teams should examine potential heat sources on the Moon. Solar energy is the obvious choice, but other heat sources may be possible. Solar energy is intense during the lunar day but what will happen during the lunar night? If solar energy is the principle source, where should a lunar base be located to maximize its utility? If another (perhaps lower temperature) heat source is to be used, could it be combined with a low pressure system to accelerate boiling?



Example of a tea kettle distillery

Separation by Force

Objective:
Students will investigate methods for using force to separate impurities in a wastewater stream.

Description:
In this activity, students construct a pressure-driven water filter and examine centrifugal acceleration as a potential way of separating solids and gases from a liquid.

Materials:
Two funnels
Filter paper for the funnels
Filter media of student's choice (activated charcoal, zeolite, sand, etc.)
Large glass storage bottle or 2-l soft drink bottle
Two hole stopper to fit bottle
One 500 ml or larger beaker
Glass or plastic laboratory tubing to fit stopper
Aquarium airline hose or laboratory hose to fit tubing
Aquarium air pump or small hand pump, such as a balloon pump
Simulated wastewater (see pages 42 and 43)
Shampoo in clear plastic bottle
Wire (bailing or solid core copper)
Short piece of clothesline or heavy cord
BBs or small pebbles

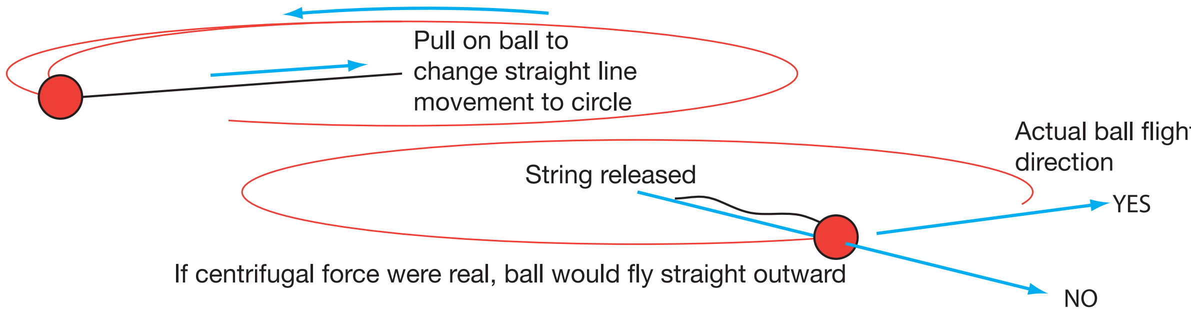
Background:
On Earth, gravity exerts a force capable of moving wastewater through filters. Wastewater spread across a filter will travel downward, due to gravity, to a collector below. In a lunar base, water would also flow downward through a filter, but its movement would be considerably slower due to the Moon's lower gravity (one-sixth that of Earth). Given enough time, water would move to the next stage but not perhaps quickly enough to meet the needs of the lunar crew.

One strategy for speeding up the process involves a pressure system. The idea is to force the wastewater through the filters. The filters are enclosed in a cell and the pressure is increased slightly, causing the water to be driven through the filters at a greater rate than by gravity alone.

Another potential strategy for forcing wastewater through filters is to create a tower-like system. Water towers for municipal water systems create pressure in the water distribution lines by raising the water storage tank many meters above the ground. Water pressure increases about 10 kPa (kilopascal) per meter of a water column. One kPa is about equal to 0.15 pounds per square inch. Wastewater at the bottom of a column would be under pressure due to the weight of the entire column above. In other words, gravity creates pressure in columns of water due the water's accumulative weight.

A third potential strategy for recycling wastewater using force is already employed in the Environmental Control and Life Support System (ECLSS) onboard the International Space Station (see page 17). A centrifuge is used to separate gas and particles from the waste stream. Wastewater entering the system is spun, causing heavy particles to accelerate to the outside of the centrifuge, while gas bubbles move to the center.

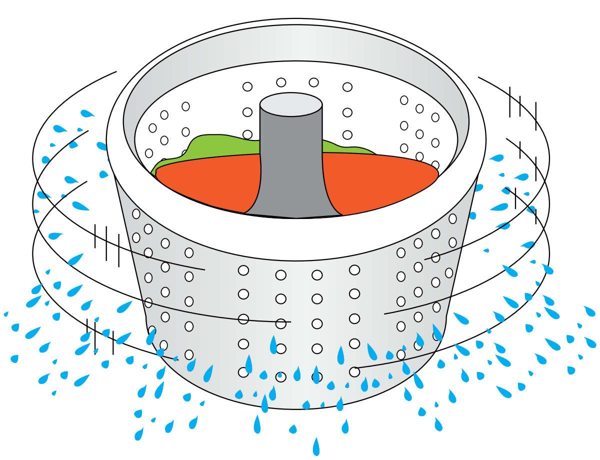
A centrifuge works on the principle of centrifugal acceleration. Old science books sometimes incorrectly refer to this as "centrifugal force." Centrifugal force is what people think they feel when traveling in a car



that makes a sharp turn. Their bodies feel pressed in the opposite direction, as though they are trying to fly straight out the car door. The best way to understand what is actually going on with centrifugal acceleration is to tie an object, such as a ball to the end of a string and twirl it in the air. The person twirling the ball perceives an outward force; however, the force doesn't exist. If there were an outward force, releasing the string would cause the ball to shoot straight outward from the person. The ball doesn't do that. Instead, it travels in a straight line in the direction it was moving at the moment of release. The ball travels away in a tangent to the circle.

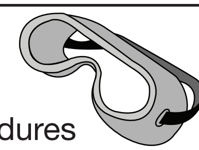
Then, what is the person actually feeling when twirling the ball? All the time the ball is moving, it is trying to travel in a straight line. It is obeying Isaac Newton's first law of motion. Part of that law states that objects in motion will travel in a straight line unless acted upon by an unbalanced force. The string prevents the ball from traveling in a straight line. The direction of the ball continually changes because the person doing the twirling is continually pulling on it, creating an unbalanced force. The resistance of the ball to that pull (the ball's inertia) is what the person perceives as centrifugal force.

If instead of a ball, the twirling object were a spinning water-filled tub, the water would move from the middle of the tub to the outside due to the acceleration produced by the spinning. This is exactly what happens in a washing machine. The spin tub accelerates water to the tub walls where the water slips through small holes and down the drain.



Washing machine centrifuge (spin tub)

Safety Procedures



Good laboratory safety procedures should be followed at all times:

- Wear eye protection.
- Use hand protection when handling glass tubing.
- Wash hands after handling the waste-water.
- Dispose of filters and media properly.
- Do not drink the filtered water (we are not using disinfectant chemicals in these activities).

Procedures: Pressure Filter

1. Prepare a funnel with a paper filter. Typically, paper funnel filters are circles. Fold the filter in half and in half again to make a wedge shape. Moisten the filter with tap water and insert it into the filter cone. Spread open one of the folds to span the cone.
2. Fill the filter paper with filter medium of choice. From this point, keep the funnel upright at all times.
3. Invert and attach a second funnel to the first with plastic tape. Carefully seal the two rims together so that there are no air leaks. The

filter is ready to process wastewater.

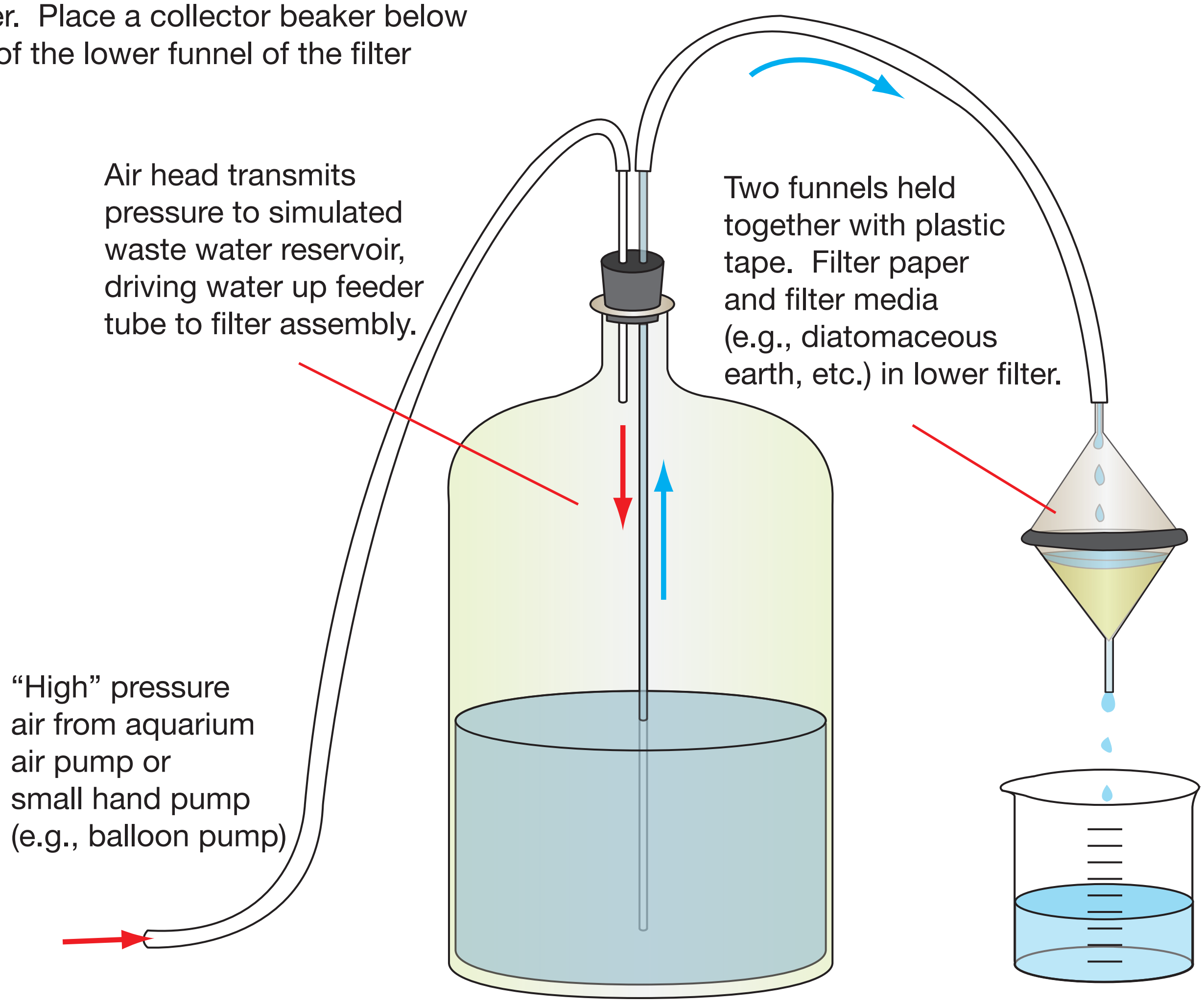
4. Using a glass jug or 2-L plastic soft drink bottle, set up a pre-treatment wastewater chamber as shown in the diagram below. Be sure to use a lubricant such as liquid soap or glycerine, to help the tubes slip through the stopper. Protect your hands with a cloth or cloth gloves while inserting the tubes.
5. Connect a hose to the outlet tube from the chamber to the stem of the upper funnel. You may need to tape the hose to the filter depending upon the diameter. Secure the hose tightly.

TIP Hardware stores carry a variety of connectors that permit tubes of different diameters to be firmly joined without leaks.

6. Connect another hose to the short tube. This is the pressure line. Join the other end of this hose to either an aquarium air pump or small hand pump.
7. Partially fill the chamber with simulated wastewater. Place a collector beaker below the outlet of the lower funnel of the filter assembly.
8. Turn on the air pump or pump air manually into the chamber. Observe what effect the pressurized air from the pump has on the wastewater in the chamber. Air pressure will force wastewater to rise up the long tube and travel to the filter. If the funnels are well sealed, the space above the filter media will be pressurized as water is pumped into it. The pressure will help gravity force the water through the filter media.

Procedure: Centrifuge Demonstration

1. Place a dozen or so BBs or small pebbles into a clear bottle of shampoo. Seal the bottle cap.
2. Wrap the bottle neck with some wire and form a loop that goes over the cap. Attach a string to the loop.
3. Gently agitate the bottle so that the air bubbles and the BBs or small pebbles are distributed through the shampoo.



4. Set the bottle on a table top and observe what happens to the pebbles and bubbles in a gravity environment. Record your observations.
5. Discuss what would happen in a microgravity environment such, as found on the International Space Station. What would happen in the one-sixth gravity environment of the Moon? What would happen if the bottle were twirled in the air at the end of the string?
6. Agitate the contents of the bottle again and twirl the bottle a couple of times while holding on to the string. Stop the bottle and quickly examine it again. What happened?

Discussion Questions:

Why did the wastewater travel up the long tube when pressure was added to the bottle?

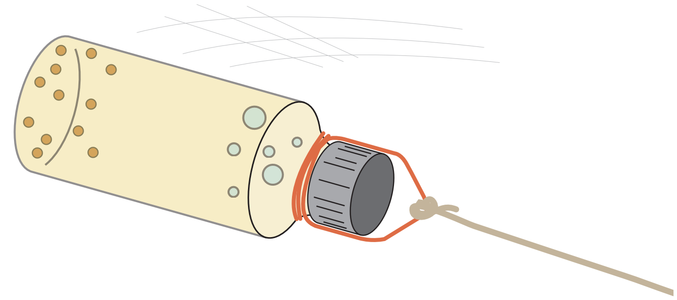
Air added to the chamber exerts pressure in all directions. It presses on the surface of the simulated wastewater creating a downward force, but the wastewater is constrained by the bottle. The long tube inserted into the water provides an outlet for the wastewater, so the wastewater travels up the tube toward the filter.

What are some other applications for centrifuges?

Centrifuges are used in many industries for separating materials of different densities. In laboratories, centrifuges are used for separating blood samples and concentrating cell samples. NASA uses centrifuges to simulate the high-gravity accelerations encountered by astronauts during space launches, and many cooks use a spinner, which utilizes centrifugal acceleration to remove water from washed greens.

Assessment:

Write out the steps for your own filtration system. Be sure to include the correct scientific vocabulary and concepts. Make sure that the materials you include are available or of a logical design. Include a diagram of your plan.



Extensions:

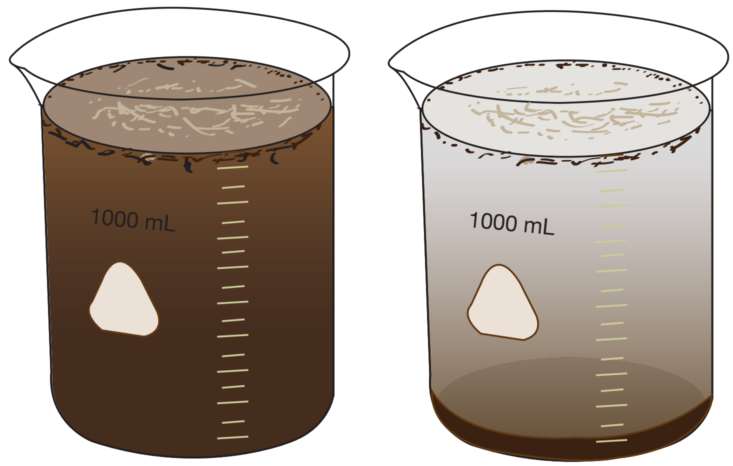
Set another funnel filter assembly (without the pressure chamber). Pour water into a vertical feed line and compare the processing rate for the gravity only system to that of a pressure and gravity system. Be sure the vertical column of water is the same height for both systems for accurate comparison.

WLMR Design Challenge Notes:

- A gravity-driven wastewater filter on the Moon would have to be taller than one on Earth to achieve similar results.
- What source of energy could be used to generate forces needed for separation/filtration? Electrical energy is commonly used on Earth to power pumps, but what if electrical energy was limited on a lunar base? Think of alternative approaches that could be used to power filtration/separation systems to take advantage of the unique environment on a Moon base. Remember, a lunar base is surrounded by the vacuum of space.

NASA Ames Research Center 20 g human centrifuge (notice the person to the left)

Sedimentation



Objective:
Students will investigate sedimentation as a primary water treatment technology.

Description:
In this activity, students create batches of muddy water, observe the effects of sedimentation over time, and experiment with the use of alum to accelerate sedimentation.

Materials:
(per team of students)
150 ml of garden soil
2 l of tap water
Two glass 1 l beakers or clear glass jars (that will hold at least 1 l)
20 g of alum (available in the spice section of supermarket)
Two stirring rods
Metric ruler
Plastic "secchi" probe (See instructions for making a secchi probe on page 38.)
Timer or clock with a minute hand
Safety goggles
Cleanup supplies
Light source

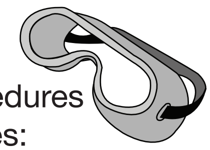
Background:
More than 90% of the rocks at the surface of planet Earth are sedimentary. Water is a powerful force in restructuring the Earth's surface. Weathering and erosion of rock results in the breakdown and transport of pebbles, sand, and very fine particles by river water to lakes and oceans. As the velocity of water decreases, so does its ability to suspend particles. Sedimentation begins. Large pebbles fall first and are followed by sand-size particles and silt and clay-size particles in turn. The settling rate of individual particles has to do with their mass to surface area ratio. Bigger diameter particles have a greater mass to surface ratios than smaller particles and settle more quickly.

The different settling rates of particles leads to a layering effect when the particles pile up on the lake or ocean bottom. Over eons, the sediment is consolidated and cemented into rock layers such as conglomerates, sandstone, and shale.

When recycling water, sedimentation is a very useful process. Allowing the particles to settle makes very dirty, nearly opaque water into water that is optically clear (although not necessarily safe to drink, because it is likely to contain dissolved impurities and bacteria). Pebbles, grains, silts, and clay settle in layers at the bottom, while any buoyant materials, such as twigs, leaves, plastics, etc., rise to the top. The sediments and floating debris can be removed so that the remaining water can be easily treated.

Sedimentation is a slow process. It can be many days before the finest particles settle out. Water treatment plants are able to accelerate the process by adding alum to the water and agitating the water to dissolve the chemical. Alum is hydrated aluminum potassium sulfate ($KAl(SO_4)_2 \bullet 12H_2O$). When dissolved in dirty water, alum catches the very fine suspended particles in a gel-like precipitate of aluminum hydroxide. The aggregated particles, called flocculent, sink to the bottom. In municipal water filtration processes, the addition of alum greatly speeds up the sedimentation process, permitting a greater volume of water to be processed in the same amount of time.

Safety Procedures



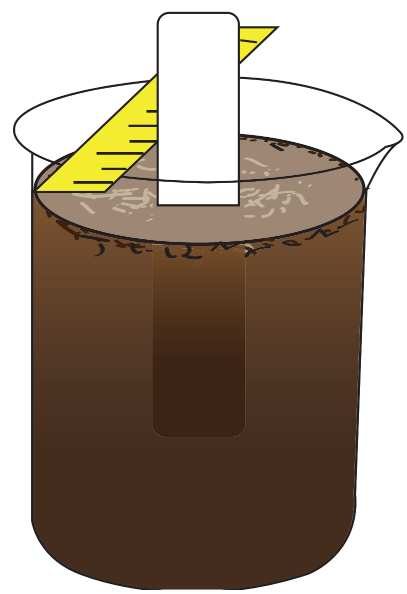
Good laboratory safety procedures should be followed at all times:

- Wear eye protection.
- Wash hands after handling the beakers.
- Dispose of dirt and test water properly.

Procedures: Sedimentation

1. Create two tables (similar to the one shown at right) for recording the results of the sedimentation test with and without alum. The center column is for recording the secchi probe data and the right column provides space to write your descriptive observations at set time intervals.
2. Place 75 ml of garden dirt into each of two 1-l glass beakers or large clear jars and add 1 l of tap water to each jar. Stir both jars an equal amount to break up soil clods and distribute sediment in the water.
3. Add 20 g of alum to one of the two beakers. Mark the beaker to remember which one has the alum.
4. Stir both beakers gently for 5 minutes. Be careful not to disturb the beakers after the stirring is completed.
5. Observe the condition of the water immediately after stirring has been completed. Be sure to observe the two beakers with back lighting; window light is ideal, but a lamp or flashlight can also be used for observations.
6. Using a separate table for each beaker, record your observations for each beaker in tables created in step 1. The center column is for recording the secchi probe data. The right column provides spaces to write descriptive observations.
7. Using a secchi probe, measure the initial (0 minutes) transparency (also called turbidity) of the water in each beaker. Very gently slip the probe strip (patterned circle at the bottom facing towards you) into the water at the front side of the beaker, lowering it halfway. Very slowly move the strip toward the other side of the beaker and stop when the pattern at the bottom of the strip is no longer recognizable. Using a ruler, measure in centimeters how far from the beaker wall the strip had to be moved before the pattern disappeared. Record the measurement in the center column of each table and write descriptive observations in the right column.
8. At five-minute intervals, observe the condition of the water in each beaker Estimate changes in the color and clarity of the water and record measurements in the tables.

Time	Transparency (cm)	Observations
0 minutes		
5 minutes		
10 minutes		
15 minutes		
20 minutes		
25 minutes		
30 minutes		
24 hours		

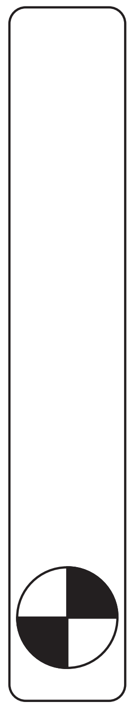


Secchi probe at the point where the pattern is no longer recognizable.

9. Leave the beakers undisturbed over night and record observations the next day.
10. Have students plot graphs of their data and write a paragraph summarizing their observations. Have them include ideas for ways to scale up the process to handle larger volumes of water.

How to Make a Secchi Probe

Oceanographers and limnologists (scientists who study inland waters) often use a device called a secchi disk to measure the transparency of water. The disk, a circle with alternating black and white quadrants, is lowered into a water body and the depth is measured when the disk pattern is no longer visible. For this activity, a modified secchi disk will be used. Cut a strip of white plastic 2.5-cm wide and 15-cm long from a detergent bottle. Using a permanent black marker, draw a circle with an alternating black and white pattern (as shown at right) at the lower end of the strip.



Secchi Probe

TIP When cleaning up, have a bucket available for emptying beakers. Discard all wastewater and sediment in a garden.

Discussion Questions:

In which beaker did the particulates settle more quickly?

The beaker with the alum became dramatically clearer in a short amount of time, which indicates that the settling rate was significantly faster. The alum formed a sticky gel-like material upon which fine particles became trapped. The mass of the trapped particles increased and this accelerated their falling to the bottom.

How could the clear center water (between the floating debris and the accumulated sediment at the bottom) be transferred to the next treatment stage in a water treatments system?

(Individual student answers.) Siphoning might work. A screen dipper could also be used clear off the floating debris and then the water gently poured from the beaker; however, the bottom sediment is very easily disturbed.

Assessment:

- Review the observations, conclusions, and ideas of the teams for scaling up the process to handle larger volumes of water.

Extensions:

- Challenge students to use a digital camera for data collection. How would they set up lighting to create an accurate picture of the water color and turbidity? Have them take pictures every 30 seconds for the 30 minute total observation period. Load the pictures into a slide or movie program on a computer to create a time lapse movie of the sedimentation rate.
- Have students use the Internet to research other chemicals that can be used in place of alum to accelerate the sedimentation in water treatment systems.

WLMR Design Challenge Notes:

- Sedimentation systems on the Moon will be somewhat hampered by the lower lunar gravity; however, sedimentation rates could be improved with chemical additives, such as alum. If planning to use a flocculant chemical, like alum, is there an efficient way to recycle the chemical for repeated use? Does the Moon have elements and compounds that could be used to promote sedimentation?
- This lab activity demonstrates the effectiveness of alum flocculation for the removal of fine particulate matter from water, but contaminants in the WLMR wastewater are dissolved materials. Will alum flocculation remove these materials? Will the actual wastewater generated on a lunar base contain fine particulate matter?
- Rather than use a flocculant chemical, the International Space Station ECLSS uses a centrifuge to accelerate the separation of particles and gas from the waste stream. Would such a system work on the Moon? How would it be powered?

Biological Treatment

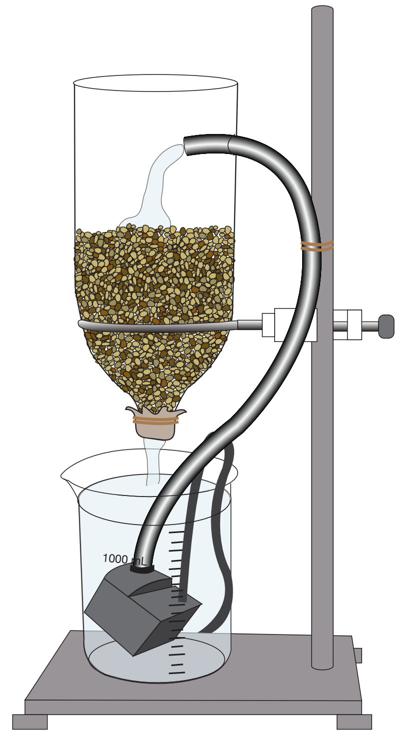
Objective:
The students will investigate the process of using biological filters for water purification.

Description:
This two-part activity focuses on the use of plant transpiration for water purification and on bacterial activity for removing contaminants in water.

Materials:
Part A - Bioreactor
- Small fountain pump
- Large beaker or jar to hold the pump
- Plastic tubing to fit the pump
- 2-l plastic soda bottle
- Ring stand
- Aquarium gravel
- Netting to cover opening on the soda bottle
- Rubber bands
- Simulated wastewater (see pages 42 and 43)
- Nitrifying bacteria (available at aquarium stores as biological aquarium cleaner)
- Ammonia test kit (e.g., from an aquarium store)

Part B
- Two sealed plastic containers with sealed lids approximately 3 to 4-l (food storage boxes)
- Two small plastic or glass containers
- Plastic wrap
- Two plants
- Potting mix
- Thread or string
- Treated water from Part A
- Tap water

Background:
The combined actions of plants and microorganisms play a significant role in water purification on Earth and may serve as biological filters for water recycling in space, as well. Several important biological processes need to be considered. The first process to consider is plant transpiration. Plants release water from tiny holes (i.e., stomata) in their leaves to the air as a cooling mechanism.



Students and adults are surprised to learn the amount of water transpired by plants. From June to October, a mature oak tree may transpire about 125 tons of water from its leaves, and a single corn plant transpires approximately 200 liters in a season. So, how do we adapt this process for water recycling? If plants are grown in a closed container (such as a spacecraft or lunar base), then the transpired water can be condensed back out of the air. This atmospheric condensate is not directly potable, but can be easily treated to potable standards.

Even water that is not transpired can be partially purified, or biologically filtered, as it passes over the roots of the plants. Plants can

Scientists at the Kennedy Space Center conduct food plant growing studies in a chamber as part of a ground-based simulation of hydroponic gardening in space.

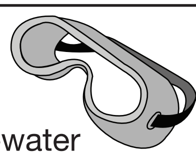
remove certain “contaminants” from the water, because they are nutrients that help sustain plant growth. In addition, the high number of microorganisms typically associated with plant roots can decompose organic contaminants in the water. Plant roots, therefore, act as an excellent “free” bioreactor.

A major issue with using plants for purification of waste streams with high salt content, like urine, is that many plants typically grown for food do not tolerate salt very well. You can grow salt tolerant plants, but then you don’t have the dual-use benefit of food production and water recycling.

Another worry is the transfer of harmful microbes from the wastewater to the food. Wastewater should not be used for plants grown for food, unless the the edible portions do not come into contact with the wastewater and will be well cooked prior to consumption.

An alternative approach to biological filtration is the use of microorganisms alone. Microorganisms can use certain contaminants (e.g., organic compounds, ammonia, etc.) as food and thereby, purify the water. One example of this approach is the use of nitrifying bacteria, which convert ammonia to nitrate.

Safety Procedures



Although the simulated wastewater is safe to handle, good laboratory safety procedures should be followed at all times.

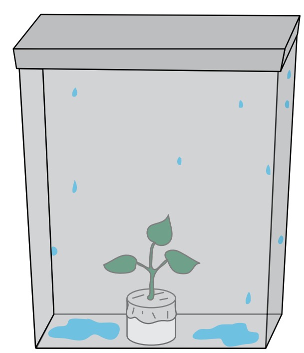
- Wear eye protection.
- Wash hands after handling the wastewater.
- Dispose of gravel properly.
- Do not drink the biologically-filtered water (we are not using disinfectant chemicals in these activities).

Procedures: Part A - Bioreactor

1. Prepare the simulated wastewater according to the instructions on pages 42 and 43 of this guide.
2. To set up your filtration system cut the bottom off a 2-l soda bottle. Using netting or hosiery, cover the pour spout of the bottle and secure the netting with a rubber band. Cut a hole about 3 cm from the cut rim, just large enough for the hose to be pushed through the plastic bottle wall.
3. Set the beaker on the stand and place the fountain pump, with hose attached, inside the beaker. Invert the soda bottle and place it in the ring. Adjust the ring position so that it is about 5 cm above the beaker rim.
4. Measure and cut the tubing and slip the open end through the hole in the bottle. Make sure to have about 5 cm of tubing extending inside the bottle. Secure the tube to the stand.
5. Rinse the gravel and then place it into the soda bottle.
6. Test the ammonia level of the simulated wastewater using the ammonia test kit and record your results.
7. Start the pump and run for three days. Test the ammonia again and record your results.
8. Add two drops of the nitrifying bacteria to the solution. Test the ammonia levels daily for the next few days and record your results.

TIP Reduce evaporation by wrapping the beaker and bottle with cellophane.

Procedures: Part B - Transpiration



1. Take two plants and pot each in a small container (with no drainage holes)using the potting mix.
2. Test the tap water for ammonia. Record the results.
3. Water each plant - one with tap water and one with the treated wastewater from the bioreactor activity (Part A).
4. Wrap plastic wrap around the pots to cover the soil and seal container. Be careful not to damage the plant.
5. Place the prepared plants, one each, in the large plastic containers and close the lid tightly to seal in the atmosphere. Label each container “tap water” or “treated wastewater.”
6. Once transpiration has occurred and water

has collected on the bottom, open the containers and pour out some of the water, each into a separate clean test tube. Test again for ammonia and record your results.

7. Graph the ammonia data collected and compare the changes in ammonia levels, starting with the initial wastewater stream.

Discussion Questions:

What will happen to the plant if it is left in the sealed container too long?

Unlike regular terrariums where transpired water falls back into the soil and is absorbed back into the plant through the roots, the sealed plants do not receive any water back. Instead, the water collects at the bottom of the container. If the plant is left in the sealed container too long, the soil moisture will be gradually depleted and the plant will die.

What purpose does the gravel play in the bioreactor experiment?

The bacteria grow on the surfaces of the gravel and remove ammonia, as the water circulates through. The gravel also creates air spaces, so oxygen can diffuse into the water. Oxygen is important, because the nitrifying bacteria are aerobic (i.e., oxygen-requiring)

What happens to other wastewater contaminants, such as salt, as the water flows through the bioreactor and plant system?

Bacteria cannot decompose sodium or chloride, so they pass through the bioreactor. Some salt may be taken up by the plants, which may cause problems with plant growth, depending on the type of plant and concentration of salt.

Assessment:

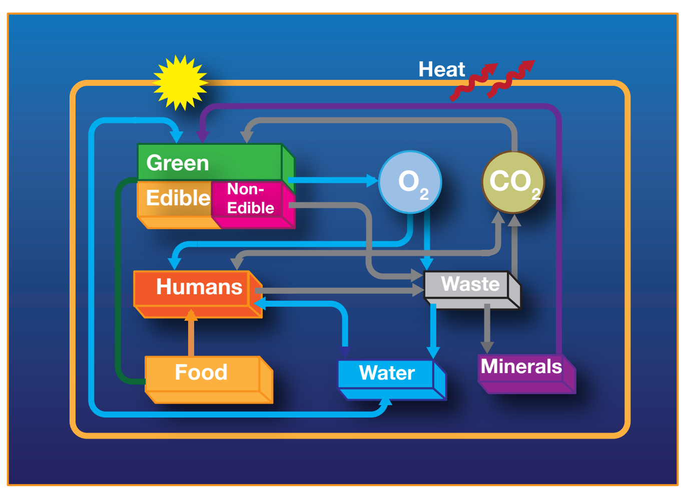
Have students record and graph the ammonia data they collect and write their observations of the two experiments. Have them summarize their ideas about the potential use of these two processes in a lunar water recycling system. They should justify their answers with experiment data.

Extensions:

Learn about hydroponic systems and their ability to maintain nutrient-rich water for plants to grow. Keep in mind that as plant roots decay, organic matter and nutrients are released.

WLMR Design Challenge Notes:

- Like on Earth, growing food on the Moon requires large amounts of water. Transpiration is a vital part of a water recycling system. On Earth, transpired water enters Earth's hydrologic cycle and moves to another part of the planet. On the Moon, every water drop counts and must be directly recovered.
- Plants may have multiple benefits for life support (food production, CO_2 removal, oxygen production, and water recycling), but one must carefully consider the overall costs of the system. Will natural sources of sunlight be used or will electricity be needed to generate artificial light? Who will take care of the plants and how much time will this require?
- Biological processes are inherently more regenerative than physical or chemical processes. Adsorbents or catalysts with limited life spans are replaced by living cells, which produce their own catalysts (i.e., enzymes). Microorganisms do not require energy to decompose the contaminants, but actually live off the energy within these molecules. Biological processing requires less energy and consumables, but the rate of conversion tends to be slower than physical processing. Slower rates typically mean you have to have a larger system to process the same amount of material, so biological systems will tend to be larger.



The relationship between humans and resources offers many opportunities for recycling strategies on the Moon.

WLMR Design Challenge

The Waste Limitation Management and Recycling Design Challenge is the culmination of the knowledge and achievements students have gained in the preceeding activities. The design challenge is the opportunity to “put it together” in creating a practical and vital system that could do much to make future self-sustaining bases on the Moon feasible.

Objective:
Student teams will design and test a complete water recycling system for future use in an outpost on the Moon.

Description:
Working in four phases, small teams of students create a simulated wastewater stream consisting of common chemicals that together simulate the wastewater generated in a lunar outpost. The teams immediately analyze the properties of the simulated wastewater using basic tests and then create a prototype system that can recycle that waste stream. The teams test the purified water stream using the same tests and compare the results to the initial tests to determine the effectiveness of their recycling system. Finally, the teams present their results.

Water recycling on the Moon will be initiated with water delivered from Earth. The WLMR system should be easy to maintain and involve as few non-reusable materials as possible. Water may someday be found frozen in deep craters shielded from sunlight. Even if large supplies are found, water recycling will still be necessary to avoid disposal problems that would impact the lunar environment.

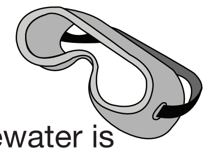
PHASE ONE: Creating the Simulated Wastewater

Materials:
- Clean 1-l graduated cylinder or volumetric flask
- Stirring rod
- Small 50-100 ml graduated cylinder
- Beam balance or electronic scale
- Filter paper
- Eye protection
- Household ammonia cleaner (without scents and coloring agents)
- White distilled vinegar
- Baking soda
- Table salt
- Baby shampoo

Background:
The wastewater stream in a lunar outpost will consist of water derived from several sources. The most obvious source will be crewmember urine. The crew will also generate water from perspiration and breathing and this water will be condensed out of the air (i.e., so-called humidity condensate). In addition, wastewater will come from food preparation, washing of dishes and utensils, clothes washing, and personal hygiene water from bathing, washing hands, and brushing teeth.

The wastewater stream will include various particles such as lint and surfactants (soap and detergent), and a range of chemicals, such as ammonia, sodium chloride, and bicarbonate. The wastewater stream will also include bacteria and other microorganisms, which are washed off crew members or grown in water collection systems.

The chemicals in the wastewater recipe for this activity simulate particular components of an actual lunar base wastewater stream. For example, the ammonia cleaner simulates the ammonia (i.e., urea) found in urine. White vinegar simulates the volatile organics (i.e., acetic acid) found in atmospheric condensate and hygiene water. Table salt and baking soda simulates the salt and bicarbonate in urine. baby shampoo simulates the organic material in cleaning products (i.e., surfactants).



Safety Procedures

Although the simulated wastewater is safe to handle, good laboratory safety procedures should be followed at all times.

- Wear eye protection.
- Wear gloves when handling the chemicals.
- Wash hands after handling the wastewater.
- Do not drink the wastewater.
- Follow all water text kit safety instructions.

Procedures: Creating Simulated Wastewater

1. Put 600 m l of tap water into the cylinder or flask.
2. Add the ingredients to the cylinder or flask of water.

Household ammonia cleaner - 30 ml
Baking soda - 2 g
Table salt - 1 g
White vinegar - 2 ml
Baby shampoo - 6 ml

TIP When measuring dry chemicals, place a piece of filter paper on the balance pan. Re-zero the balance to compensate for the mass of the paper and measure the chemical. Pick up the paper and curl it slightly to facilitate pouring the chemical into the cylinder or flask.

3. Gently mix the contents of the cylinder or flask. Vigorous stirring or shaking will cause the surfactant to foam. If a foam is created, let the solution rest until the foam subsides.
4. Gently add additional tap water to increase the volume of wastewater to 1 l.

TIP If several teams are doing the activity, multiply the recipe by the numbers of liters of simulated wastewater needed. The water can be transferred to a larger container, such as an empty plastic carboy or washed plastic soft drink or milk bottle. <u>Remember,</u> perform transfers gently to avoid foaming and allow any foam that may form to settle before analysis.

PHASE TWO: Testing the Analog Wastewater

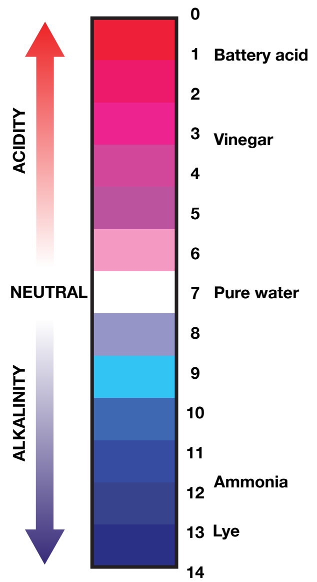
Materials:
(per team of students)
pH test kit
Ammonia test kit
Conductivity meter
Dissolved oxygen meter or test kit

TIP The pH and ammonia test kits can be obtained from aquarium stores or school science supply catalogs. Some kits contain supplies for multiple tests; check the package details for the kit that best suits your needs. Conductivity and dissolved oxygen meters can be significantly more expensive, although some meters along with the pH and ammonia test kits obtained from school science supply catalogs can be somewhat inexpensive. Like the kits, these too can be shared by the teams. You can also purchase conductivity and dissolved oxygen probes that interface with existing data loggers and probeware in your science lab. A no-cost approach to obtaining meters is to contact local water monitoring laboratories. Your municipal water supplier will have meters, natural resource agencies, or environmental science programs at high schools and colleges will have the equipment, and along with the equipment will come expert assistance.

Background:
Many things affect the potability and quality of drinking water. The first test students will be conducting to assess water quality is a pH test.

pH is a test that measures the acidity or alkalinity of common liquids. A pH test strip is immersed in liquid and the color of the strip is compared to a color chart. Pure water is neutral and does not affect the strip color. If the liquid is acidic, the color changes to shades of red. If the water is alkaline, it changes to shades of blue. The optimal pH range for drinking water is 6.5—8.5. A pH lower than 6.5 can cause a bitter, metallic taste, while a pH over 8.5 results in a slippery feel like soapy water and bitter taste. The the analog wastewater pH range will be approximately 9.5.

pH Color Chart for Litmus Test



pH color charts generally look like this one. <u>Be sure to compare the color of your test strips to the chart that comes with the test kit.</u>

Ammonia is a major dissolved ion in wastewater. Ammonia can be measured directly, with a simple colorimetric test (using test strips or additive liquids that yield color changes).

Aquarium test kits are designed to measure ammonia levels in the 1—10 mg/L range, given the sensitivity of fish to low levels of ammonia. The expected ammonia levels in the simulated wastewater analog is 300—400 mg /L. To be able to use aquarium ammonia tests, you will have to dilute the wastewater to be in the proper range of the detection system. Instructions for doing this are included in the procedures that follow.

NASA's spacecraft water exposure guideline (SWEG) for ammonia is 1 mg/L. This level is based not on the toxicity of ingested ammonia to humans, but rather the odor threshold of 1.5 mg/L. NASA set the so that potable water remains free of any factors that might discourage water consumption by the crew. The threshold for taste is approximately 35 mg/l, so ammonia levels higher that 1.5 mg/l may be tolerated for short periods, especially if the taste and odor could be masked by adding something to the water, such as dry beverage mixes (e.g., the NASA-made-famous Tang® may help.)

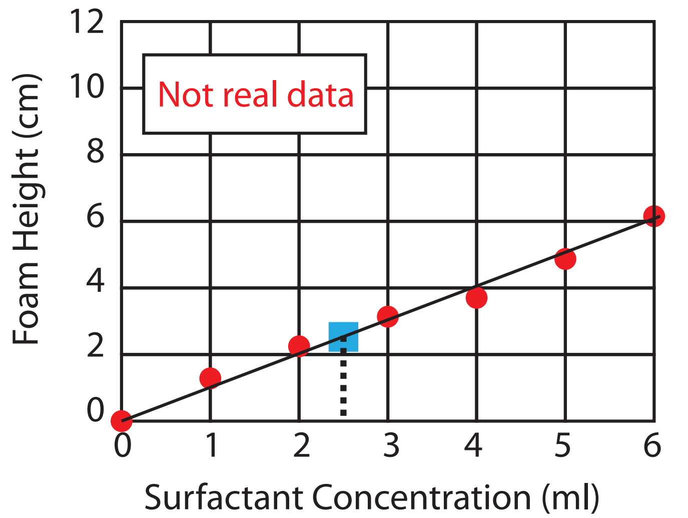
Electrical conductivity is a useful measure of the amount of impurities, such as salts and nutrients, in the water. To test conductivity of a liquid, a current is applied across electrodes immersed in the liquid and the potential (voltage) is measured. Greater concentrations of ions, such as sodium and chloride ions from salt, produce a greater potential. In other words, salt water is a better conductor of electricity than fresh water. The more salt, the greater the conductivity.

Measuring electrical conductivity is relatively simple with a commercial conductivity meter. These meters display the conductivity as siemens. Siemens is the SI unit of electrical conductance equal to one ampere per volt. The conductivity of the simulated wastewater should be approximately 5000 μS/cm (or one millionth of a siemens per centimeter), in large part due to the high levels of sodium (approximately 1 g/l). Drinking water should have sodium levels below 200—300 mg/L, indicating that the conductivity of your treated water needs to be reduced by 3-4-fold (i.e., to <2000 μS/cm.)

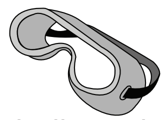
Organic compounds can make water taste bad and can be a significant health hazard if toxic or if they promote the growth of microorganisms.

The major organic contaminant in the simulated wastewater is baby shampoo. It is a surfactant (surface acting agent) that has both hydrophobic ("water-hating") and hydrophilic ("water-loving") components. Surfactants dissolve oils and grease. Water containing surfactants tend to form bubbles or foam when agitated. This happens because surfactant molecules trap air, creating two layers – dense liquid below and foam head above. In microgravity, the bubbles disperse throughout the liquid. Foaming can be a problem when handling or processing wastewater, causing system clogging (see cautions above).

Trying to measure the concentrations of all the different organic compounds in wastewater is a complex and expensive endeavor. Typical methods to measure even a single class of compounds, such as surfactants, requires advanced equipment and training. A simpler approach will be used here. Wastewater will be tested for its foaming properties (i.e., the less foaming, the less organic matter present).



Sample graph showing how surfactant concentration might affect foam height. The square represents the final treated wastewater test. Graph indicates a surfactant reduction.



Procedures: Wastewater Testing

Continue following safety procedures indicated at the beginning of the design challenge.

The procedures for testing the simulated wastewater will depend upon test kits and meters you obtained. Be sure to follow the instructions that came with your kits and meters.

1. Construct a data table for your results from each of the tests. Provide spaces in the table for notes and observations.
2. For pH of the wastewater, follow the instructions on the test kit package as given.
3. For ammonia testing, dilution is necessary to bring the wastewater into the range of the ammonia test kit of the test kit. Extract 10 ml of simulated wastewater and place it in a 1,000-ml beaker. Add 490 ml of tap water to the beaker. This will dilute the wastewater, so that the ammonia content falls within the testing limits of the ammonia test kit. Test the ammonia level of the wastewater, following the instructions for the test kit. Multiply the results of the test by 50 to arrive at the ammonia content of the simulated wastewater stream.
4. Test the conductivity of the wastewater, following the instructions accompanying the meter.
5. Measure the organic matter content of the wastewater with a "foam test." Because the dominant organic compounds in the simulated wastewater are surfactants in the shampoo, foam will form when the wastewater is agitated. Foaming indicates the amount of surfactant remaining in the treated water. Have students design a test to measure foaming in their treated wastewater versus foaming in untreated wastewater. Less foaming in the treated wastewater indicates the treatment system was effective in removing some or all of the organic matter. Students should consider the following in designing their foam test:
   a. Use empty ½ liter water bottles for the foam test. Measure 100 ml of water to be tested and pour it into the bottle. A long-neck funnel is useful for the transfer. Cap the bottle.
   b. Shake the test bottles the same way and number of times for each test. Give the shaken samples a timed rest period before measuring the foam height to allow larger bubbles to settle.
   c. Conduct baseline tests of wastewater batches with different amounts of soap to compare with the treated wastewater samples later.
   d. Repeat tests several times and average results.
   e. Construct a line graph to show the effect of different amounts of soap in wastewater batches. Use the graph to compare the foam test for treated wastewater with the test for the known samples. Refer to the above graph to see how it can be used to interpret data.
   f. Investigate other chemicals in the simulated wastewater for their foaming properties as an extra activity.

PHASE THREE: Creating a Prototype Lunar Outpost Water Recycling System

Background:
NASA explores space in a team effort. Dozens, hundreds, or even thousands of scientists, engineers, technicians, doctors, managers, and astronauts combine their effort to solve the many challenges that the space's environment presents. Flights to the Moon, space shuttle missions, and the International Space Station are all examples of the NASA team at work.

The challenges of establishing a lunar outpost will be met through a systems approach. Astronauts on the Moon will need an atmosphere, radiation protection, food, space suits, water, and so on. Individual teams at NASA (government employees, contractors, and research universities) will tackle specific challenges. The Waste Limitation Management and Recycling team is looking at creating or stretching supplies of water, air, and other resources for long-term lunar habitation.

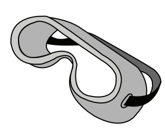
Generally, a team consists of a team leader (or project manager) and a group of specialists that are experts in meeting the expected and unexpected challenges that will arise. The team's first step is to identify the problem and its components, and then collect ideas on how to meet the problem. Next, the team builds and tests a prototype and evaluates its performance. If the prototype is successful, the system is presented to higher levels of NASA management and it is evaluated for how well it will fit into the plan for meeting the overall objective (i.e., a lunar outpost).

The challenge of this activity is to design, construct, test, and evaluate a prototype water recycling system for a lunar outpost. As a prototype, the system does not have to fit into a small cabinet like the Environmental Control and Life Support System (ECLSS) on the International Space Station. The prototype can cover one or more table tops. The idea is to create an effective series of steps to purify the simulated wastewater made in the first phase of this activity.

When student teams begin this challenge, the first step is to identify the roles of team members. They will then identify the problem, brainstorm ideas for what to do, organize their strategy (e.g., what water purification technology to use first, second, etc.), collect materials, construct the stages, and begin the test. At the conclusion of water purification, teams will then conduct the same tests on the purified water and prepare their reports (Phase Four).

Materials:
Simulated wastewater (created in Phase One)
Other materials, as selected by the design teams

Procedure:



Continue following the safety procedures indicated at the beginning of the design challenge.

1. Create design teams of up to six students. Teams may recruit an outside mentor from a local college, health department, government natural or environmental resource department, etc. for assistance and guidance.
2. Create a water recycling prototype system for an outpost on the Moon. The system must be able to take simulated wastewater (created in Phase One of this activity) and recycle it to make it fit for human consumption. **Important Note:** <u>Because teams will be working with prototype systems, potentially hazardous disinfectant chemicals will not be used. Do not drink the purified water.</u> Instead, they will test water samples using the same procedures in Phase Two of this activity.
3. Begin the design process by having teams hold meetings to discuss the challenge and propose technologies they might use in creating their systems. The first step

in the meeting is to identify roles for team members. The following are suggested team roles:

Project Manager
Conduct meetings
Design and maintain project schedule
Supervise and ensure team safety

Chief Scientist
Research purification processes
Identify energy requirements and sources
Collect and record data

Chief Engineer
Supervise system creation
Manage construction process
Evaluate system components for potential improvements

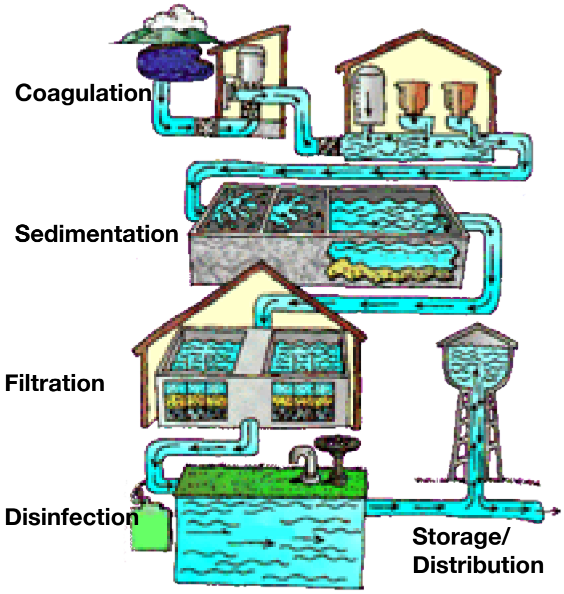
Material Resource Director
Obtain materials
Obtain tools
Become familiar with and inform the team of safety cautions for the various materials

Chief Financial Officer
Create budget
Track materials costs
Project costs of actual system on Moon

Communication Officer
Work with CS to prepare data charts
Design presentation on team's system
Contact point for media inquiries

Encourage team members to work together on all phases of the project.

Water Treatment Process



http://www.epa.gov/safewater/kids/watertreatmentplant/index.html

This is an example of a stage diagram of an urban water treatment process provided by the U.S. Environmental Protection Agency It shows and identifies the steps for purifying water to make it fit for human consumption. Notice that the task is relatively easy, because the source water is shown as rainfall and a clean lake. On the Moon, the source of water will include the outpost wastewater stream.

4. Complete the following:
- Design the system;
- Assemble components;
- Pretest the simulated wastewater;
- Recycle the simulated wastewater;
- Test the recycled simulated wastewater
- Prepare a summary report on their system; and
- Create a visual report to present in class.

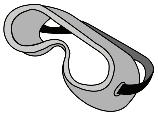
PHASE FOUR: Evaluation and Reporting

Background:
The design technology process is far more than building a system. The process involves testing, evaluation, redesign, retesting, and evaluation, and so on until the desired results are achieved. The design technology process at NASA also involves frequent meetings and briefings where teams report their progress and answer questions from the other teams especially regarding how different systems interact with each other.

Materials:
Recycled Wastewater (from Phase Three of this activity)
Testing supplies (See Phase Two)

Poster board and markers or
Presentation software and LCD projector

Procedures:



Continue following the safety procedures indicated at the beginning of the design challenge.

1. Following the wastewater recycling process, test the samples using the same testing supplies and procedures employed in the Phase Two of this activity. All data should be carefully recorded.
2. Teams should also record their observations of the recycling process. How long did it take the water to pass through each stage? Was water lost in any of the stages (e.g., water absorbed by the filter media, evaporation, etc.)?
3. Have teams create a poster or an electronic presentation that describes their system and its performance.
4. Hold a classroom briefing in which all the teams present their results. Invite any outside mentors to attend the presentations. Permit teams to question each other.

Assessment:
Review the team posters or electronic presentations. Compare the results of the teams and rank them by the quality of the purified water and the efficiency of the system.

Extensions:
- Enter the team with the best results in NASA's 2009 Waste Limitation Management and Recycling Design Challenge. This is a national contest to design a water recycling system for the Moon. The winning team will be brought to the NASA Kennedy Space Center for VIP tours and other experiences. Information about the contest can be found at the following site: http://wlmr.nasa.gov/ If future contests will be held, information about the contests will be found on the same site.

Waste Limitation Management and Recycling Design Challenge

Team Names: ____________________
____
____
____
____
____

Simulated Waste Water Stream Tests

Volume of water: ____________ ml

pH: _______

Ammonia: ___________ mg/l

Conductivity: __________ µS/cm

BOD: _____________g/m;

Observations/Notes:

Recycled Wastewater Tests

Volume of water: ____________ ml
(remaining)

pH: _______

Ammonia: ___________ mg/l

Conductivity: __________ µS/cm

BOD: _____________g/ml

Observations/Notes:

(Sample Data Sheet)

- Hold WLMR Design Challenge team briefings for other classes.
- If your school hosts a science fair, have teams set up their systems and conduct demonstrations for fair visitors.

WLMR Rubrics and Pre and Post Test Evaluation:
The next several pages contain a set of rubrics and pre and a post activity tests to assist in the evaluation of individual and team performance in the WLMR design challenge.

Analytic Holistic Rubric for WLMR Design Challenge

Water Quality Testing Results

Proficient - 3 Points	The team's project has a hypothesis, a procedure, collected data, and analyzed results. The project is thorough and the findings are in agreement with the data collected. There may be minor inaccuracies that do not affect the quality of the project.
Adequate - 2 Points	The team's project may have a hypothesis, a procedures, collected data, and analyzed results. The project is not as thorough as it could be. There are some overlooked areas and a few inaccuracies that affect the quality of the project.
Limited - 1 Point	The team's project may have a hypothesis, a procedures, collected data, and analyzed results; however, the project has many inaccuracies and overlooked areas that affect the quality.

Sustainability of the Design

Proficient - 3 Points	The team has estimated the cost of their system (i.e., energy, resupply requirements, manpower, etc.) and considered long-term operational issues that are consistent with current knowledge of the lunar environment.
Adequate - 2 Points	The team has estimated the cost of their system (i.e., energy, resupply requirements, manpower, etc.) and considered long-term operational issues that are consistent with current knowledge of the lunar environment. There are a some overlooked areas and inaccuracies that affect the quality of the project.
Limited - 1 Point	The team has estimated some of the costs of their system (i.e., energy, resupply requirements, manpower, etc.) and considered long-term operational issues that are consistent with current knowledge of the lunar environment. However, there are many overlooked areas and inaccuracies that affect the quality of the project.

Creativity

Proficient - 3 Points	The team's project design is innovative and includes evidence of multiple testing and adjustments based on the results.
Adequate - 2 Points	The team's project design is innovative and includes some evidence of testing and adjustments based on the results.
Limited - 1 Point	The team's project design includes some minimal evidence of testing and adjustments based on results.

Teamwork

Proficient - 3 Points	All team members were actively involved and contributed to the project's design, construction, testing, reporting, and success.
Adequate - 2 Points	Most team members were actively involved and contributed to the project's design, construction, testing, reporting, and success.
Limited - 1 Point	Some team members were actively involved and contributed to the project's design, construction, testing, reporting, and success.

Waste Limitation Recycling and Management Pre-Test

Name: ______________________________

1. The process by which plants release water into the air is called

(A) *photosynthesis*
(B) *transpiration*
(C) *distillation*
(D) *hydration*

2. In Earth time, approximately how long is sunrise to sunset on the Moon?

(A) *24 hours*
(B) *48 hours*
(C) *7 days*
(D) *14 days*

3. A water molecule is made up of what elements?

(A) *helium and oxygen*
(B) *sodium and chlorine*
(C) *oxygen and hydrogen*
(D) *carbon and oxygen*

4. What ways will water be used for a future lunar base?

(A) *washing*
(B) *drinking*
(C) *cooking*
(D) *all*

5. Why is it important to recycle water on the Moon?

(A) *The Moon's water is not fit to drink.*
(B) *It costs too much to bring water from Earth.*
(C) *There is no place on the moon to dispose of wastewater.*
(D) *Wastewater has to be returned to Earth.*

6. Approximately how much does it cost to launch one liter of water to the space station?

(A) *$220*
(B) *$2,200*
(C) *$22,000*
(D) *$220,000*

7. Distillation is the process by which water is

(A) *condensed*
(B) *frozen*
(C) *changed to vapor*
(D) *transpired*

8. The Moon's gravity is one-sixth that of Earth's. How much will a 120-pound person weigh on the Moon?

(A) *180 pounds*
(B) *60 pounds*
(C) *90 pounds*
(D) *20 pounds*

9. Which of the following energy sources is available on the Moon?

(A) *nuclear*
(B) *solar*
(C) *fossil fuel*
(D) *chemical*

10. What are the benefits of growing plants on a lunar base?

(A) *food source*
(B) *changes carbon dioxide into oxygen*
(C) *absorbs pollutants from wastewater*
(D) *all*

11. What compound is least likely to be removed from wastewater by distillation?

A *salt*
B *organic compounds (containing carbon)*
C *ammonia*
D *detergents*

12. The large bowl-shaped craters on the Moon were created by

A *meteorite impacts*
B *volcanic eruptions*
C *lakes that are now dried up*
D *erosion*

13. Which of the following materials is not expected to be in the wastewater in a lunar base?

A *oil*
B *ammonia*
C *salt*
D *detergent*

14. Which of the following conditions do not speed up the process of distillation?

A *low pressure*
B *heat*
C *bright light*
D *low humidity*

15. What does condensation do?

A *turns water into vapor*
B *returns water from plants back into the atmosphere*
C *turns water vapor back into liquid water*
D *filters water to make it clean*

16. What does ISS stand for?

A *Institute for Space Science*
B *International Space Station*
C *Inertial Space Survey*
D *International Space Shuttle*

17. Which of the following materials would make a good filter for removing sediment from wastewater?

A *sand*
B *salt*
C *detergent*
D *all*

18. What term is missing from the following hydrologic cycle sequence? evaporation - condensation - _____ - runoff - evaporation

A *distillation*
B *transpiration*
C *absorption*
D *precipitation*

19. The Moon's lack of an atmosphere would aid which water recycling method?

A *sedimentation*
B *evaporation*
C *distillation*
D *both B and C*

20. In a water purification process, what does disinfecting do?

A *filters out particles*
B *removes urine*
C *kills bacteria*
D *removes soaps and detergents*

Waste Limitation Recycling and Management Post-Tes

Name: ______________________________

1. The Moon's gravity is one-sixth that of Earth's. How much will a 120-pound person weigh on the Moon?

Ⓐ *20 pounds*
Ⓑ *75 pounds*
Ⓒ *150 pounds*
Ⓓ *60 pounds*

2. The process by which plants release water into the air is called

Ⓐ *photosynthesis*
Ⓑ *distillation*
Ⓒ *dehydration*
Ⓓ *transpiration*

3. Which of the following land forms is not found on the Moon?

Ⓐ *ancient river channels*
Ⓑ *craters*
Ⓒ *lava-covered basins*
Ⓓ *mountains*

4. The Moon's surface is covered with

Ⓐ *ice*
Ⓑ *dust*
Ⓒ *smooth rock*
Ⓓ *gravel*

5. Which of the following energy sources is available on the Moon?

Ⓐ *nuclear*
Ⓑ *chemical*
Ⓒ *solar*
Ⓓ *wind*

6. Approximately how much does it cost to launch ten liters of water to the space station?

Ⓐ *$2,2000*
Ⓑ *$22,000*
Ⓒ *$220,000*
Ⓓ *$2,200,000*

7. Distillation is the process by which water is

Ⓐ *precipitated*
Ⓑ *changed to a vapor*
Ⓒ *solidified*
Ⓓ *frozen*

8. Which of the following is a benefit of growing plants on a lunar base?

Ⓐ *food source*
Ⓑ *creates new water*
Ⓒ *protects the crew from radiation*
Ⓓ *none*

9. In Earth time, how long is a lunar month (one orbit around Earth with respect to the Sun)?

Ⓐ *1 day*
Ⓑ *15 days*
Ⓒ *29 days*
Ⓓ *32 days*

10. In a water purification process, what does disinfecting do?

Ⓐ *removes sediment*
Ⓑ *removes ammonia*
Ⓒ *makes water taste good*
Ⓓ *kills bacteria*

11. What compound is least likely to be removed from wastewater by distillation?

Ⓐ *detergents*
Ⓑ *organic compounds (containing carbon)*
Ⓒ *ammonia*
Ⓓ *salt*

12. The large bowl-shaped craters on the Moon were created by

Ⓐ *meteorite impacts*
Ⓑ *volcanic eruptions*
Ⓒ *lakes that are now dried up*
Ⓓ *erosion*

13. If no water is lost in a water recycling process, how many times can water be recycled?

Ⓐ *two times*
Ⓑ *five times*
Ⓒ *ten times*
Ⓓ *no limit*

14. Which of the following conditions can speed up the process of distillation?

Ⓐ *low humidity*
Ⓑ *heat*
Ⓒ *low pressure*
Ⓓ *all*

15. Scientists are searching for water on the Moon. Where do you think they might find it?

Ⓐ *in deep polar craters*
Ⓑ *burried lake beds*
Ⓒ *underground rivers*
Ⓓ *frozen ponds*

16. Which wastewater will be recycled for drinking?

Ⓐ *urine*
Ⓑ *wash water*
Ⓒ *cooking water*
Ⓓ *all*

17. Adding chemicals, like alum, to dirty water speeds the rate of

Ⓐ *disinfectioin*
Ⓑ *sedimentation*
Ⓒ *buoyancy*
Ⓓ *all*

18. What term is missing from the following hydrologic cycle sequence? evaporation - _____ - precipitation - runoff - evaporation

Ⓐ *distillation*
Ⓑ *transpiration*
Ⓒ *condensation*
Ⓓ *precipitation*

19. The Moon's lack of an atmosphere would aid which water recycling method?

Ⓐ *distillation*
Ⓑ *condensation*
Ⓒ *precipitation*
Ⓓ *disinfection*

20. Which compound is least likely to be removed from wastewater by using microorganisms?

Ⓐ *salt*
Ⓑ *organic (carbon) compounds*
Ⓒ *ammonia*
Ⓓ *detergents*

Waste Limitation Recycling and Management Pre and Post Test Answer Keys

Pre Test Key

1. B
2. D
3. C
4. D
5. B
6. C
7. C
8. D
9. B
10. D
11. C
12. A
13. A
14. C
15. C
16. B
17. A
18. D
19. C
20. C

Post Test Key

1. A
2. D
3. A
4. B
5. C
6. C
7.B
8. A
9. C
10. D
11. C
12. A
13. D
14. D
15. A
16. D
17. B
18. C
19. A
20. A

NASA and WLMR Resources

The above picture is just one of many hundreds of concept pictures NASA planners have created to help them visualize what our future in space might look like. This 1995 concept shows an advanced lunar base with mining facilities for extracting oxygen from lunar rock. This picture and many more are available for download from NASA and may be helpful in inspiring student teams in creating their own lunar concept. (Source: http://spaceflight.nasa.gov/gallery/images/exploration/index.html)

The following list provides a wide range of WLMR-related resources from NASA and other U.S. agencies and educational institutions:

National Aeronautics and Space Administration

NASA Portal

http://www.nasa.gov/

http://www.nasa.gov/audience/foreducators/index.html

NASA WLMR Design Challenge

http://wlmr.nasa.gov/

Moon Information
http://nssdc.gsfc.nasa.gov/planetary/planets/moonpage.html

Exploring the Moon Educator Guide
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Exploring.the.Moon.html

Field Trip to the Moon Educator Guide
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Field_Trip_to_the_Moon_Educator_Guide.html

International Space Station Water System, Exploration, etc.

http://science.nasa.gov/headlines/y2000/ast02nov_1.htm

http://science.nasa.gov/headlines/y2001/ast03apr_2.htm

http://www.nasa.gov/mission_pages/station/behindscenes/waterrecycler.html

www.nasa.gov/centers/marshall/pdf/104840main_eclss.pdf

http://www.nasa.gov/vision/earth/everydaylife/jamestown-needs-fs.html

Environmental Control and Life Support Systems Water Filtration Challenge Educator Guide
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Water_Filtration_Challenge.html

Water: Production, Reclamation, Disinfection (on-line resource guide for a student space settlement design competition)
http://www.nas.nasa.gov/About/Education/SpaceSettlement/teacher/course/water.html

Closing the Loop: Recycling Water and Air in Space (video guide)
www.nasa.gov/pdf/146558main_RecyclingEDA(final) 4_10_06.pdf

United States Geological Survey

Water Resources of the United States
http://water.usgs.gov/

United States Environmental Protection Agency

EPA Student Center

http://www.epa.gov/region5/students/waste.htm

http://www.epa.gov/region5/students/water.htm

Ground Water & Drinking Water

http://www.epa.gov/safewater/topics.html

Guidance Manual on Turbidity Provisions - Chapter 10. Turbidity Through The Treatment Process
http://www.epa.gov/safewater/mdbp/pdf/turbidity/chap_10.pdf

Activities for Students and Teachers
http://www.epa.gov/safewater/kids/index.html

National Oceanic and Atmospheric Administration

Hydrology Page

http://www.erh.noaa.gov/er/ctp/hydro/cycle/mainpage.htm

The Global Water Sampling Project: An Investigation of Water Quality

http://www.k12science.org/curriculum/waterproj/index.shtml

The Globe Program

http://www.globe.gov/

Lunar and Planetary Institute

http://www.lpi.usra.edu/

World Health Organization

Water Sanitation and Health

http://www.who.int/water_sanitation_health/dwq/wsh0207/en/index6.html

Suppliers of Water Treatment Materials

Water testing supplies, instruments, and filter media are available from many sources.

School science supply catalogs
Aquarium stores
Pool supply stores
Camping stores
Supermarkets
Hardware stores

Waste Limitation Management and Recycling Design Challenge
Educator's Guide with Activities in Science, Technology, Engineering, and Mathematics

EDUCATOR REPLY CARD

The goal of this educator guide is to be a valuable resource for teachers and students in science, mathematics, and technology. NASA continually seeks to involve the educational community in the development and improvement of its educational products and programs. Your opinions and suggestions are both vital and appreciated.

Please take a few minutes to share your thoughts and ideas with us. When complete, please send this form to the address on the other side.
Thank you for your assistance and support.

Please tell us a little about youself.

What is your position? (Check all that apply)

- ☐ Teacher
- ☐ Resource Teacher
- ☐ Curriculum Specialist
- ☐ Administrator
- ☐ Museum/Science Center Educator
- ☐ Homeschool Teacher
- ☐ Other (please describe) ____________________

In what subject(s) and grade levels(s) did you use this guide?

Subject(s):____________ Grade Level(s):__________

Where do you live?____________________

Please share your opinions about this educator guide.

Overall, how would you rate this guide for your use?

Valuable Resource	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	Not Useful

Please Fold Along Line and Tape Closed

Would you recommend this guide to a colleague?

☐ Yes ☐ Maybe ☐ No

Why?____________________

What parts of this guide were most effective for you?

Please share your thoughts on how this guide can be improved.

Additional Comments:

Again, thank you for your assistance and support.

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Where to next?

1985 concept of a Mars outpost in a dry canyon near one of Mars's large volcanoes.

Mars offers far greater challenges for human outposts than the Moon. Even at the closest point between Earth's and Mars' orbits, Mars is 150 times further from Earth than the Moon. Waste Limitation Management and Recycling will be critical as humans cross the solar system.

John F. Kennedy Space Center
Kennedy Space Center, FL 32899

www.nasa.gov

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