SANFORD UNDERGROUND RESEARCH FACILITY

Water Filtration Challenge (grades 5-10)

Materials Needed

<u>For Facilitator*</u>

- Chart paper and markers for each team of students
- *WWTP Overview*- Slides
- *WWTP process map (optional)*
- *Biochemical Pathways (optional)*

<u>For each team of 2-3 students</u>

"Dirty" Water

- A container for mixing (something that will hold at least a quart)
- Water
- Substances to foul the water such as:
  - Litter (i.e. bits of plastic, small objects like paperclips, etc.)
  - Food scraps (i.e. coffee grounds, orange peels, egg shells, etc.)
  - Other organic matter (i.e. soil, bits of leaves, grass, twigs, etc.)
  - Food coloring
  - Cooking oil
  - Salt or dried spices
  - Any other substances you may have (be creative)

Filter

- Plastic bottle with narrow neck (clear bottles work best)
  - If you do not have a plastic bottle find a large funnel or a disposable cup with a hole in the bottom. Then place over a clear container to collect the filtered water.
- Scissors or craft blade

Filter Materials

- Natural materials (i.e. leaves, grass, pine needles, mulch, sand, gravel, rocks, etc)
- Manufactured materials (i.e cotton balls, fabric, paper) (Again, be creative)

For Investigation

- Paper for science notebook
- A small, clear cup (only needs to hold a few ounces)
- Paper towels, rags or sponges on hand in-case of spills

*Chemistry students may benefit from discussing the biochemical pathways document

Note:
Begin collecting empty plastic bottles weeks or months in advance of this activity to save the cost of purchasing bottles. (16-20 ounce bottles work well)

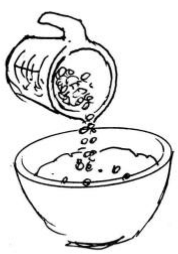
Prepare "Dirty" Water Sample

You must prepare the "dirty" water before doing the investigation.
Set time aside 1-2 days prior to launching the challenge.

(Ideally students would create their own dirty water sample. However, the teacher may choose to prepare a large batch for all groups to use.)

For each team you'll need:
1. A container for mixing (something that will hold at least a quart)
2. Water
3. Substances to foul the water such as:
   - Litter (i.e. bits of plastic, small objects like paperclips, etc.)
   - Food scraps (i.e. coffee grounds, orange peels, egg shells, etc.)
   - Other organic matter (i.e. soil, bits of leaves, grass, twigs, etc.)
   - Food coloring
   - Cooking oil
   - Salt or dried spices
   - Any other substances you may have (be creative)

Record your "dirty" water recipe below. (Remember to include measurements)
1. Add 1 inch of water to the container.
2. Mix in any of the substances above to create "dirty" water for the investigation.
3. Stir well, then add more water to fill the container.



My Dirty Water Recipe

Prepare Filter Components

You must prepare the filter components <u>before</u> doing the investigation.

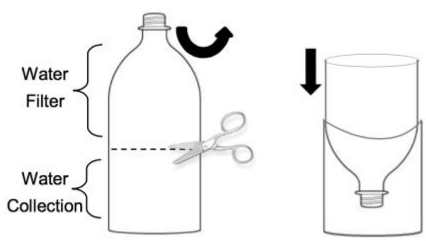
Set time aside 1-2 days prior to launching the challenge.

(Ideally students would create their own. However, the teacher may choose to prepare the plastic bottles for all groups to use.)

For each team you'll need:

- Plastic bottle with narrow neck (clear bottles work best)
    - If you do not have a plastic bottle find a large funnel or a disposable cup with a hole in the bottom. Then place over a clear container to collect the filtered water.
- Scissors or craft blade
- Natural materials (i.e. leaves, grass, pine needles, mulch, sand, gravel, rocks, etc)
- Manufactured materials (i.e cotton balls, fabric, paper) (Again, be creative)

1. Cut the plastic bottle into two sections.



2. Place the top half of the plastic bottle upside-down (like a funnel) inside the bottom half. (Make sure the cap is off). The top half will hold the filter materials and the bottom half will collect the water as it is filtered.
3. Keep both pieces together and set aside for investigation.

Water Filtration

<table>
<tr><th></th><th>Water Filtration Challenge</th></tr>
<tr><td>Overview</td><td>Overview
During this challenge, you will work as a team to design and construct a basic water filter using everyday materials. You will then test the effectiveness of your filter and consider the feasibility of using this design with larger quantities of water. Your challenge is to design a filtration system to eliminate as many impurities as possible from your water sample.

You will also learn about the water treatment process at SURF.
(Filtration is just one step)

• Construct a filter and observe the process of filtration
• Perform an investigation to determine the effectiveness of water filtration
• Consider design constraints</td></tr>
<tr><td>Background Information</td><td>The Universal Solvent
Water is amazingly good at dissolving things and can mix easily with natural (organic) or manufactured (human-made) substances. Due to its incredible properties, water is often considered the universal solvent; of course it cannot dissolve everything.

Water often has additions that make it less than “clean”. It may contain suspended dirt and other substances that can be easily identified and filtered. It may also include dissolved components (like salt), or bacteria and other microscopic organisms that cannot be easily seen and will require more than filtration to remove.
*This investigation is only concerned with filtration, which removes most but not all of the impurities from the water.

What is Water Filtration?
Water filtration is the process of removing or reducing the concentration of particulate matter, including suspended particles, macroinvertebrates, algae, and other impurities from water.

Types of Filtration
The three main types of filtration are mechanical, biological, and chemical filtration. *This investigation focuses on a mechanical filtration which physically traps impurities.

The most basic form of mechanical filtration uses gravity to filter a mixture. The mixture is poured from above onto filter material and gravity pulls the liquid down. The solids are left in the filter, while the liquid flows below it.

How Water Filters Work
Water is made up of very small particles called molecules. When water is first poured into the filter, some of the water molecules stick to the filter materials and get them wet. Once the filter is wet, the rest of the water molecules slip through the spaces in between the materials. Some of the other particles are bigger than the water molecules, so they can't get through. They get stuck in the filter.

It’s important to keep in mind that filtration is typically an imperfect process and is frequently paired with other processes to more thoroughly “clean” water.</td></tr>
</table>

Water Filtration

<table>
<tr><td>Questions</td><td>Questions to Ponder
• How will you determine the success of your design?
• What aspect of your design do you think worked best? Why?
• What aspect of your design would you like to revise? Why?
• If you could use another material(s) what would you like to try? How do you think this material might help with the challenge?
• How do you think your filter would be able to withstand water running through it for an hour (or more)? Why?
• As an engineer, what are some limits (constraints) you might need to consider when designing an industrial water filter?
• Would your design be practical in a setting like SURF? Why or Why not?</td></tr>
<tr><td colspan="2">Launch (40 minutes)</td></tr>
<tr><td>Engagement and Communication</td><td>Let’s think for a moment about a glass of water. Hold up glass of water.
• Where did that water come from?
• What do you think happened to that water before it filled the glass?

Ask students to quietly write their responses in their science notebooks. (2-3 minutes)

Randomly call on several students to share their ideas.

Students might have considered the water’s immediate source (e.g., the faucet, the water fountain, a bottle)—they might have even considered the fact that the water originally came from a body of water such as a lake, river, or reservoir. The source could be nearby or hundreds of miles away. Either way, the water in that glass has a story to tell.

Now think for a moment about the bigger picture.

Station to Station
Teams of 2-3 students make their way to a chart (station) where a question is posed. Each team discusses the question and writes comments. After several minutes, each team rotates to the next station. They can add new ideas, questions, or comments. Before students return to their seats, make sure that they get a chance to see what other groups have written.
• What are all the places around you where you can find water?
• Would you consider the water in those locations “clean”? Why? Why not?
• What else could be in the water besides water?
• What are some ways that water can get contaminated?
• How could you clean up dirty water?

“Dirty” water cannot be cleaned with soap! You need a filter, a device that removes impurities, like dirt, from water.</td></tr>
</table>

Water Filtration

Explore (45-60 minutes)

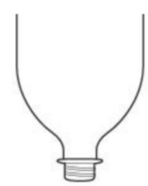
Procedure

Ask students to come up with some everyday examples of filtration?

- ✓ Making coffee or tea, keeping an aquarium….
- ✓ Heating, ventilation, and air conditioning (HVAC) systems use filters to remove particles and sometimes odors from air.
- ✓ Vehicles rely on filters for the fuel, oil, air, transmission fluid, etc. to keep running smoothly.

Your challenge is to work as a team to design a filtration system to eliminate as many impurities as possible from your water sample. If your system works, the water will be more clear than it was when it started. If it works very well, you will be left with water that looks completely clear. If your system doesn't work as well as you hoped, you can always redesign and try again!

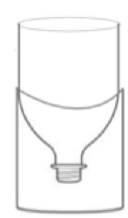
Design Your Own Filtration System



1. Look closely at each of the filter materials available to determine which you think will work best to clean up the "dirty" water. Discuss with your team members.
2. As a team, decide which of the materials you will be using. (You will need to use at least three materials in your design)
3. In your science notebook, sketch your design and clearly label each layer.
4. Predict which impurities you think will be caught in each layer?
5. Explain why you placed a particular material as the top layer/middle layer/bottom layer?
6. Explain how you think the end result (how well the water was filtered) would change if the order of the materials were switched?

Note: It might be helpful to know that filters with lots of material to flow through (a deep filter) tend to be more effective than those with very little material in the filter (a shallow filter).

Construct Your Filtration System



7. Carefully layer the filter materials in the top portion of your filter apparatus. Use the sketch in your science notebook as a guide.

If the material you planned for your first layer is at risk of falling through the mouth of the bottle, you may wish to place something across the opening to help keep it in place. Make sure it will allow the filtered water to pass through.

8. Once your filter is complete pour some clean water through to rinse and wet the filter materials. (Do not save this water)

	Test Your Filtration System 9. Gently stir the "dirty" water. 10. Pour a small amount into a separate cup as your control. (This will allow you to compare the water before and after filtration) 11. Set this off to the side for later. 12. Very slowly pour “dirty” water into the filter. 13. Observe what happens during filtration. (You may wish to keep notes in your science notebook) **Important:** this demonstrates water filtration only and will not purify water for drinking purposes. **Evaluate Your Filtration System** 14. Place your control sample next to the water collected from your filter. 15. Describe the differences between samples- “filtered” vs “dirty” water. • How would you rate your team’s success in creating a filtration system that improved the “dirty” water? 16. Carefully take apart the filter (one layer at a time) 17. Look closely at each of the different layers. Record your answers in your science notebook. • What did each material filter from the water? • What worked well? • What could work better? **Try it Again** (optional) -Save a sample of water from filter #1. -Redesign your filter to see if you can improve the output! You might try layering materials in a different order or try using different amounts of each material.
Summarize (10 minutes)	
Communicate	**Think Big. Class Discussion** • What aspect of your design do you think worked best? Why? • What aspect of your design would you like to revise? Why? • If you could use another material(s) what would you like to try? How do you think this material might help with the challenge? • How do you think your filter would perform with lots of water running through it for many hours every day? Why? • How do you think the filter materials would perform if they needed to filter hundreds or thousands of gallons of water each day? Why? *These considerations are called design requirements and design constraints. They are conditions that need to be taken into consideration when designing and building.*

- As an engineer, what are some conditions (constraints) you might need to consider when designing an industrial water filter?

Students might consider the size of the filter necessary to accommodate the amount of water to be filtered, or decided that multiple filters are needed. What about the cost of the materials or the maintenance required to keep the filter running efficiently? And don't forget to think about its durability and expected life span.

Engineering Connection
Environmental engineers design wastewater treatment plants to clean water before discharging into rivers, streams, lakes, and seas. They use a variety of stages and processes to remove solids and contaminants from wastewater, including biological and mechanical processes. Filters and settling are common mechanical processes used to remove large particles. The removal of plastic from a water source is a new challenge for engineers, given the fact that plastic is not soluble or magnetic and varies in its size and decomposition state.

Compare
While your filter might have been created from an assortment of filter materials, the wastewater treatment plant at SURF uses only natural filter materials.

There are multiple filters, each with four layers: (starting at the top) anthracite coal, fine garnet sand, coarse garnet sand and, finally, small gravel. As water filters through to the bottom of each filter more and more impurities are removed. To keep this system running efficiently the filter materials (media) require only an occasional quick rinse to keep from getting clogged. This makes them very low maintenance and long lasting.

Waste Water Treatment at SURF-- *WWTP Overview Slides*
As part of normal operations at Sanford Underground Research Facility (SURF), water is pumped from deep underground and treated before it is released back into the environment. The water that comes from underground isn't toxic, but it does contain dirt and some suspended solids, like iron, which gives the water a rusty color.

The treatment cycle combines mechanical procedures (screening and filtration), chemical procedures (coagulation, flocculation), and biological procedures (Rotating Biological Contactors-RBC's).

A basic overview of the water treatment process. Learn more here

- As water is pumped from the source (deep within the lab) it is **screened** to remove large debris.
- That water is transported to the water treatment plant through a series of pipes.
- The water is pumped to a series of sand **filters** to remove impurities and then transferred to an iron sludge conditioning tank.
- **Coagulation/flocculation** is used in the tank to make very small iron particulates attach to each other creating larger ones. The iron floc is then sent to geo-tubes for containment. The water in the geo-tubes drains out over time leaving behind the iron particulates.

Water Filtration

	• Then water runs through a series of **Rotating Biological Contactors** (RBCs) to treat ammonia. • Water is then pumped through another series of sand **filters** (polishing filters) to remove residual impurities. • The water is then released over a hillside (**aeration)** into the environment.
Terminology and Concepts to Solidify	**Macroinvertebrates-** are organisms without backbones, which are visible to the eye without the aid of a microscope **Water filtration**- a process used to filter particulate matter from water (including suspended particles, parasites, algae, and other undesirable substances)

Optional (but encouraged) Virtual WWTP tour (~15 minutes)

This can be paired with the WWTP process map

Extensions

Have students rinse the filter until the water runs clear. Repeat procedure using prepared Kool-Aid. Students may question if filtration removed sugar from the Kool-Aid solution.

> ***No tasting of the discharge from this filter is allowed.** However, evaporation of the solution is a valid test.

Write about the type of filtration systems campers might need to employ if they ran out of water and needed to consider drinking water from a stream of unknown water purity.

Math connections

- Rate -- have students measure how much water they add and how long it takes for the water to travel through the filter (liters/minute)
- Ratios/fractions -- how much of the water added was collected in the end?
- One way to present the data for the entire class would be to make a graph of the clarity versus time of percolation.

Business

Assign prices to materials used to build filters. Have students determine cost vs efficiency, or cost to maintain.

Social Studies

Students will read a story (such as- Saving Salila's Turtle) and learn about the impact pollution has on the Ganges River in India (or other community).

Water Filtration

Additional Background Information

Sand and gravel may seem unlikely choices for materials to use to construct a water filter. Yet water has been filtering through these substances underground for millions of years. The result is spring water, some of the cleanest water on Earth. Spring water is pure precisely because it has filtered through porous layers of sediment. These natural filters are much deeper and more complex than a bit of sand and gravel in a plastic bottle.

Pure spring water results from filtration through hundreds of feet of sediment, sand, and gravel — a thorough and extremely slow process. Experts estimate that water moves through most natural sediment filters at a rate of less than 0.1 gallon (0.4 liter) per minute for every square foot of area. As it moves through these layers, solids suspended in the water are trapped in the sediments. Disease-causing microorganisms, such as bacteria, are also trapped, and either die naturally or become food for microorganisms that live in the sediment. In the end, the water that bubbles out of artesian springs or is pumped from aquifers several hundred feet below the surface is on average more than 99.9 percent free of impurities.

Of course, pure spring water is not always easy to find. Surface water is much more readily available, but it often contains contaminants, including disease-causing organisms and toxic chemicals. In many places, groundwater is similarly contaminated. To make water from these sources safe, most treatment facilities use processes and materials similar to those that remove contaminants in natural sediment filters. Modern facilities use substances called coagulants to chemically trap particles and organisms, which are then easily skimmed off. Afterward, additional fine-grained filtration completes the process.

The primary goal of wastewater treatment is to remove suspended solids so that the treated water can be released into the environment safely. If these solids remain in the water, as they break down, they use up the oxygen in the water that supports the plants and animals living in the water. Primary treatment removes 40-50 percent of the solids. Secondary treatment removes approximately 90 percent of the pollutants. Tertiary treatment (polishing filters) completes the process.

Why do we need such a complex process to remove particles from water? Some particles would settle out of the water on their own, given enough time. But other particles would resist settling for days or months due to small particle size and to electrical charges between the particles.

Particles in Water

There are three types of objects that can be found in water. In order from smallest to largest, these objects are chemicals in solution, colloidal solids, and suspended solids. Coagulation/flocculation will remove colloidal and suspended solids from water.

Chemicals in solution have been completely dissolved in the water. They are electrically charged and can interact with the water, so they are completely stable and will never settle out of the water. Chemicals in solution are not visible, either using the naked eye or using a microscope, and are less than 1 Mu in size. (A Mu, or millimicron, is equal to 0.000000039 inches.) An example of a chemical in solution is sugar in water.

Colloidal solids, also known as non-settleable solids, do not dissolve in water although they are electrically charged. Still, the particles are so small that they will not settle out of the water even after several years and they cannot be removed by filtration alone. Colloidal solids range between 1 and 500 Mu in size and can be seen only with a high-powered microscope. Examples include bacteria, fine clays, and silts. Colloidal solids often cause colored water, such as the "tea color" of swamp water.

Water Filtration

Finally, suspended, or settleable, solids will settle out of water over time, though this may be so slow that it is impractical to merely allow the particles to settle out in a water treatment plant. The particles are more than 1,000 Mu in size and can be seen with a microscope or, sometimes, with the naked eye. Examples of suspended solids include sand and heavy silts.

Filtration

The purpose of filtration is to remove suspended particles from water by passing the water through a medium such as sand. As the water passes through the filter impurities get stuck in the sand and the clean water goes through.

How are particles removed from water using filtration? Four mechanisms have been found to be part of the filtration process - straining, adsorption, biological action, and absorption. Each mechanism will be explained below.

Straining

Straining is the passing of water through a filter in which the pores are smaller than the particles to be removed. This is the most intuitive mechanism of filtration, and one that you probably use in your daily life. Straining occurs when you remove spaghetti from water by pouring the water and spaghetti into a strainer.

In the past, straining has been assumed to be very important in the filtration process. However, in many cases, the pores between sand particles in the filter are much larger than the particles captured by the filter. It has been suggested that small particles become wedged between sand grains as filtration occurs, making the pore spaces smaller and allowing the filter to strain out yet smaller particles. However, a clean filter will produce clean water before any of this pore size-reduction has occurred. Therefore, it is now believed that straining is not an important part of most filtration processes.

Adsorption

The second, and in many cases the most important mechanism of filtration, is adsorption. Adsorption is the gathering of gas, liquid, or dissolved solids onto the surface of another material. Coagulation takes advantage of the mechanism of adsorption when Van der Waal's forces pull small floc particles together. In filtration, adsorption involves particles becoming attracted to and "sticking" to the sand particles. Adsorption can remove even very small particles from water.

Biological Action

The third mechanism of filtration is biological action, which involves any sort of breakdown of the particles in water by biological processes. This may involve decomposition of organic particles by algae, plankton, diatoms, and bacteria or it may involve microorganisms eating each other. Although biological action is an important part of filtration in slow sand filters, in most other filters the water passes through the filter too quickly for much biological action to occur.

The WWTP at Sanford Lab uses a biologic process to remove ammonia from the water. Rotating Biological Contactors (RBCs) come in contact with the water separate from the filtration process.

Water Filtration

Absorption
The final mechanism of filtration is absorption, the soaking up of one substance into the body of another substance. Absorption should be a very familiar concept - sponges absorb water, as do towels.

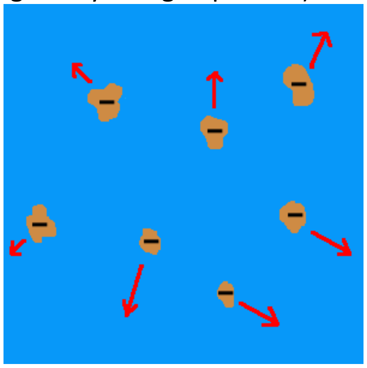
In a filter, absorption involves liquids being soaked up into the sand grains. After the initial wetting of the sand, absorption is not very important in the filtration process.

Polymer Aids
Although filtration does not require the addition of any chemicals, polymer aids may sometimes be added to the influent water. These chemicals improve the quality of the effluent water by helping the floc get caught in the filter.

Polymer aids come in two main types. Moderate molecular weight cationic polymers (DADMA) are added ahead of flocculation to strengthen the floc while relatively high molecular weight nonionic polymers (polyacrylamides) are added just before filtration to aid in floc removal.

Polymer aids can be troublesome in some respects. The powdered form of the polymer is very slippery, so spills should be cleaned up quickly. In addition, extended use of polymer aids may gum up the filters. As a result, polymer aids are often used like coagulant aids - in extreme situations to improve the water quality for a short time.

Electrical Charges
The chemistry of coagulation and flocculation is primarily based on electricity. Electricity is the behavior of negative and positively charged particles due to their attraction and repulsion. Like charges (two negatively charged particles or two positively charged particles) repel each other while opposite charges (a positively charged particle and a negatively charged particle) attract.



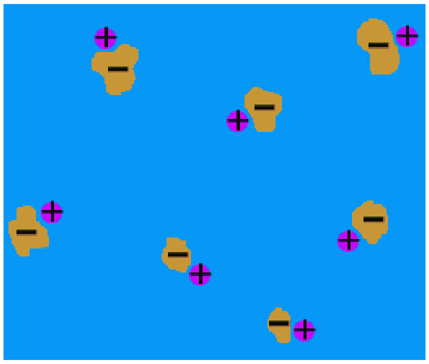
Negatively charged particles repel each other due to electricity.

Most particles dissolved in water have a negative charge, so they tend to repel each other. As a result, they stay dispersed and dissolved or colloidal in the water, as shown above.

The purpose of most coagulant chemicals is to neutralize the negative charges on the turbidity particles to prevent those particles from repelling each other. The amount of coagulant that should be added to the water will depend on the zeta potential, a measurement of the magnitude of electrical charge surrounding the colloidal particles. You can think of the zeta potential as the amount of repulsive force that keeps the particles in the water. If the zeta potential is large, then more coagulants will be needed.

Water Filtration

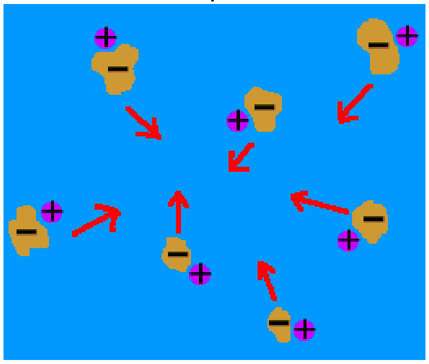
Coagulants tend to be positively charged. Due to their positive charge, they are attracted to the negative particles in the water, as shown below.



Positively charged coagulants attract to negatively charged particles due to electricity.

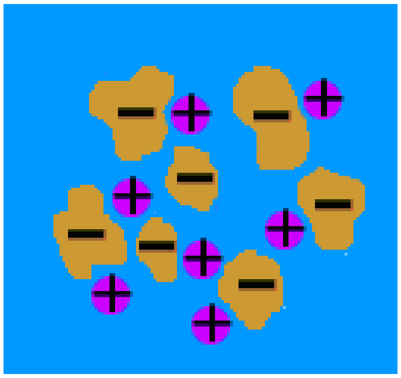
The combination of positive and negative charge results in a neutral charge. As a result, the particles no longer repel each other.

The next force that will affect the particles is known as van der Waal's forces. Van der Waal's forces refer to the tendency of particles in nature to weakly attract to each other even if they have no charge.



Neutrally charged particles attract due to van der Waal's forces.

Once the particles in water are not repelling each other, van der Waal's forces make the particles drift toward each other and join together into a group. When enough particles have joined together, they become floc and will settle out of the water.



Particles and coagulants join together into floc.

Water Filtration