Student Manual
University of Illinois at Urbana-Champaign
College of Engineering
Women in Engineering Program
Department of Civil and Environmental Engineering
# 2015 Environmental Engineering and Sustainability
## G.A.M.E.S. Learning Camp Schedule

<table>
<thead>
<tr>
<th>When?</th>
<th>What?</th>
<th>Where?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sunday, June 21st</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:00-1:00 pm</td>
<td>Lunch for Coordinators</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>3:00-5:00 pm</td>
<td>Camper registration</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>5:00-6:15 pm</td>
<td>Opening remarks and dinner</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>6:30-6:50 pm</td>
<td>Camp introduction</td>
<td>Illini Union</td>
</tr>
<tr>
<td>6:50-8:00 pm</td>
<td>Environmental engineering scavenger hunt</td>
<td>Illini Union</td>
</tr>
<tr>
<td><strong>Monday, June 22nd</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:45-9:10 am</td>
<td>What do civil and environmental engineers do?</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>9:15-10:45 am</td>
<td>Sustainability</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>10:50–11:30 am</td>
<td>Introduction to Air Quality</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>11:45 am - 12:45 pm</td>
<td>Lunch</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>1:00-2:30 pm</td>
<td>Air pollution from cook stoves</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>2:35-3:05 pm</td>
<td>Dispersion of air pollutants</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:05-3:15 pm</td>
<td>Snack break</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:15 -3:45 pm</td>
<td>Dispersion of air pollutants</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:50-4:45 pm</td>
<td>Climate change</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td><strong>Tuesday, June 23rd</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:45-10:00 am</td>
<td>The nitrogen cycle</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>10:05-11:15 am</td>
<td>Measuring ammonia in air</td>
<td>Newmark 1233 and 1225</td>
</tr>
<tr>
<td>11:30 am -12:45 pm</td>
<td>Lunch</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>1:00-3:00 pm</td>
<td>Water footprints</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:00-3:15 pm</td>
<td>Snack break</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:15-4:45 pm</td>
<td>Measuring evapotranspiration</td>
<td>Newmark 1233 and outside</td>
</tr>
<tr>
<td>When?</td>
<td>What?</td>
<td>Where?</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td><strong>Wednesday, June 24th</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:45-10:00 am</td>
<td>Water quality</td>
<td>Newmark 1233 and outside</td>
</tr>
<tr>
<td>10:00-11:30 am</td>
<td>Water quality lab</td>
<td>Boneyard creek</td>
</tr>
<tr>
<td>11:45 am -12:45 pm</td>
<td>Lunch</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>1:00-3:15 pm</td>
<td>Nanotechnology</td>
<td>Newmark 1233 and outside</td>
</tr>
<tr>
<td>3:00-3:15 pm</td>
<td>Snack break</td>
<td>Newmark 1233 and outside</td>
</tr>
<tr>
<td>3:15-4:45 pm</td>
<td>Nanotechnology lab</td>
<td>Outside</td>
</tr>
<tr>
<td><strong>Thursday, June 25th</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:45-11:30 am</td>
<td>Visualization of environmental data</td>
<td>Engineering Hall 406B</td>
</tr>
<tr>
<td>11:45 am -12:45 pm</td>
<td>Lunch</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>1:00-2:45 pm</td>
<td>Biofuels</td>
<td>DCL 3110, 3116, 3211</td>
</tr>
<tr>
<td>2:45-3:00 pm</td>
<td>Snack break</td>
<td>DCL 3110, 3116, 3211</td>
</tr>
<tr>
<td>3:00-4:45</td>
<td>Biofuels</td>
<td>DCL 3110, 3116, 3211</td>
</tr>
<tr>
<td><strong>Friday, June 26th</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:45-9:45 am</td>
<td>Guest talk: Professor John Abelson</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>9:50-11:30 am</td>
<td>Solar power</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>11:45 am -12:45 pm</td>
<td>Lunch</td>
<td>Hendrick House</td>
</tr>
<tr>
<td>1:00-2:45 pm</td>
<td>Wind power</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>2:45-3:00 pm</td>
<td>Snack break</td>
<td>Newmark 1233</td>
</tr>
<tr>
<td>3:00-4:45 pm</td>
<td>Tidal power</td>
<td>Hydrosystems Lab 1518</td>
</tr>
<tr>
<td><strong>Saturday, June 27th</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00 am -12:30 pm</td>
<td>Closing ceremony</td>
<td>Yeh Student Center, 2nd floor (205 N. Mathews, Urbana)</td>
</tr>
</tbody>
</table>
# Table of Contents

The people involved iii
Laboratory safety basics iv

**Environmental Engineering-Scavenger Hunt (SH)**
- SH-Worksheet (1) [SH]
  - Drinking water treatment SH-5
  - Wastewater treatment SH-7
  - Hazardous waste remediation SH-9
  - Air quality control SH-11
  - Waste to energy technology SH-13

**Sustainability (SUS)**
- SUS-Worksheet (1) – Sustainable house SUS-5

**Air Quality (AQ)**
- AQ-Worksheet (1) – Air quality I.Q. AQ-5
- AQ-Worksheet (2) – The basics AQ-7
- AQ-Lab (1) – Air pollution from cook stoves AQ-12
- AQ-Worksheet (3) – Air pollutant dispersion AQ-21
- AQ-Worksheet (4) – The nitrogen cycle AQ-32
- AQ-Lab (2) – Food production and ammonia in the atmosphere AQ-40

**Climate Change (CC)**
- CC-Worksheet (1) CC-3

**Water Footprints**
- WF-Worksheet (1) – Personal water footprints WF-5
- WF-Worksheet (2) – National water footprints WF-8
- WF-Worksheet (3) – Global water footprints WF-10
- WF-Worksheet (4) – Connections to water resources WF-12
- WF-Worksheet (5) – Measuring evapotranspiration WF-16
- WF-Worksheet (6) – Introduction to Leaf Area Index WF-18
- WF-Worksheet (7) – Measuring LAI and transpiration for tomato plants WF-20
- WF-Worksheet (8) – Measuring LAI for trees WF-27
- WF-Worksheet (9) – Estimating Evapotranspiration Using the
<table>
<thead>
<tr>
<th>Topic</th>
<th>Code</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penmen-Monteith Equation</td>
<td>WF-30</td>
<td></td>
</tr>
<tr>
<td>WF Worksheet (10): Global LAI and Evapotranspiration</td>
<td>WF-38</td>
<td></td>
</tr>
<tr>
<td><strong>Water Quality (WQ)</strong></td>
<td>WQ</td>
<td></td>
</tr>
<tr>
<td>WQ-Worksheet (1) – Water use and challenges we face</td>
<td>WQ-4</td>
<td></td>
</tr>
<tr>
<td>WQ-Lab (1) – Measuring water quality parameters</td>
<td>WQ-11</td>
<td></td>
</tr>
<tr>
<td><strong>Environmental Nanotechnology (ENT)</strong></td>
<td>ENT</td>
<td></td>
</tr>
<tr>
<td>ENT-Worksheet (1) – Environmental nanotechnology introduction</td>
<td>ENT-3</td>
<td></td>
</tr>
<tr>
<td>ENT-Worksheet (2) – Calibration curve</td>
<td>ENT-10</td>
<td></td>
</tr>
<tr>
<td><strong>Visualization of Environmental Data (VED)</strong></td>
<td>VED</td>
<td></td>
</tr>
<tr>
<td>VED-Worksheet (1) – Reading a map</td>
<td>VED-4</td>
<td></td>
</tr>
<tr>
<td>VED Worksheet (2) - Developing a map</td>
<td>VED-6</td>
<td></td>
</tr>
<tr>
<td>VED Worksheet (3) – Geographical information systems</td>
<td>VED-8</td>
<td></td>
</tr>
<tr>
<td>VED Worksheet (4) – Mapping ambient NH3 concentrations in ArcGIS</td>
<td>VED-14</td>
<td></td>
</tr>
<tr>
<td>VED-Worksheet (5) – Spatial analysis</td>
<td>VED-16</td>
<td></td>
</tr>
<tr>
<td><strong>Renewable Energy (RE)</strong></td>
<td>RE</td>
<td></td>
</tr>
<tr>
<td>RE-Worksheet (1) – Introduction to biofuels and biofuel combustion chemistry</td>
<td>RE-4</td>
<td></td>
</tr>
<tr>
<td>RE-Worksheet (2) – Biofuel combustion chemistry</td>
<td>RE-5</td>
<td></td>
</tr>
<tr>
<td>RE-Lab (1) - Biofuel calorimeter experiment</td>
<td>RE-10</td>
<td></td>
</tr>
<tr>
<td>RE-Lab(2) - Algae composition and Hydrothermal Liquefaction (HTL)</td>
<td>RE-18</td>
<td></td>
</tr>
<tr>
<td>RE-Lab (3) – Solar power</td>
<td>RE-26</td>
<td></td>
</tr>
<tr>
<td>RE-Lab (4) – Wind power</td>
<td>RE-38</td>
<td></td>
</tr>
<tr>
<td>RE-Lab (5) – Tidal current power</td>
<td>RE-48</td>
<td></td>
</tr>
</tbody>
</table>
The people involved...

Session leaders:
Abelson, John (*Sustainability*)
Balasubramanian, Srinidhi (*Air Quality, Sustainability, Scavenger Hunt, Visualization of Environmental Data*)
Boyd, Tory (*Climate Change, Nanotechnology, Renewable Energy-Wind and Solar, Scavenger Hunt*)
Jackson, Nicole (*Water Footprints, Scavenger Hunt*)
Koloutsou-Vakakis, Sotiria (*Air Quality, Sustainability*)
Konar, Megan (*Water Footprints*)
Leow, Shijie (Moses) (*Renewable Energy-Biofuels*)
Li, Yalin (*Renewable Energy-Biofuels*)
Shah, Rishabh (*Air Quality*)
Strathmann, Timothy (*Water Quality, Renewable Energy-Biofuels*)
Tenorio, Raul (*Water Quality*)
Wallace, Jeff (*Renewable Energy-Tidal energy*)

Camp Coordinators:
Balasubramanian, Srinidhi
Jackson, Nicole

Session Assistants:
Fu, Kan
Sheehan, Lexi
Sun, Tianye

Guest Faculty Speaker:
Abelson, John

Organizing Faculty:
Koloutsou-Vakakis, Sotiria
Konar, Megan
Strathmann, Timothy

Contributing Faculty:
Bond, Tami
Espinosa-Marzal, Rosa
Rood, Mark J.
Rutherford, Cassandra
Laboratory Safety Basics

A science or chemistry laboratory can and should be a safe place to perform experiments. Accidents can be prevented if you think about what you are doing at all times, use good judgment, observe safety rules, and follow directions. Each experiment will include comments to alert you to probable hazards, including how to protect yourself and others against injury.

- Eye protection (goggles or safety glasses) must be worn when working on experiments. Make a habit of putting them on before the experiment begins and keeping them on until all clean-up is finished.
- Do not eat or drink while in the laboratory.
- Do not taste any chemical.
- Long-sleeved shirts and leather-topped shoes must be worn at all times.
- Long hair must be tied back, so it will not fall into chemicals or flames.
- Do not work alone.
- Never perform any unauthorized experiment.
- All glassware must be washed and cleaned. Wipe all counter surfaces and hands with soap and water.
- All experiments that produce or use chemicals that release poisonous, harmful, or objectionable fumes or vapors must be done in a well-ventilated area.
- Never point the open end of a test tube at yourself or another person.
- If you want to smell a substance, do not hold it directly to your nose. Instead, hold the container a few centimeters away and use your hand to fan vapors toward you.
- When diluting acids, always add the acid to the water; never water to acid. Add the acid slowly.
- Flush with large quantities of water when disposing of liquid chemicals or solutions in the sink.
- If you spill any acid or base material on you, wash the exposed area with large amounts of cold water. If skin becomes irritated, see a physician.
Scavenger Hunt

Sunday, June 21, 2015
Lesson Developers
Balasubramanian, Srinidhi (UIUC/CEE)
Boyd, Tory (UIUC/CEE)
Jackson, Nicole (UIUC/CEE)

2015 Lesson Instructors
Balasubramanian, Srinidhi (UIUC/CEE)
Boyd, Tory (UIUC/CEE)
Jackson, Nicole (UIUC/CEE)
Introduction

Welcome to the Environmental Engineering and Sustainability G.A.M.E.S. Camp! We hope you will have a great time this week while learning about what environmental engineers do. To get things started, we will focus on a few engineering projects that highlight the importance of environmental engineers. These projects include water and air quality, renewable energy, and hazardous waste. You will split into groups and go on a scavenger hunt to find clues and information about an engineering project.

Drinking water treatment

Wastewater treatment

Hazardous waste remediation

Air quality control

Waste to energy technology
**SH-Scavenger Hunt-Worksheet (1)**

**Let’s get started!**

Split into groups of three or four and choose one of the following topics:

1. Drinking water treatment
2. Wastewater treatment
3. Hazardous waste remediation
4. Air quality control
5. Waste to energy technology

You will be given your first clue to get the scavenger hunt started. There are four other cards that you will need to find. They are hidden throughout the Illini Union. Once you have found the fifth and final clue return to the Courtyard Cafe and continue with rest of the worksheet.

**GOOD LUCK!**

**The next step:**

Continue with the worksheet that corresponds to your project

**Finally:**

You will give a short presentation (three to five minutes) to the rest of the group about your project. Some information you may want to include in your presentation:

1. The importance of your topic
2. Some details about your project
3. Any conclusions you draw from your worksheet
Drinking water treatment

1. Why is drinking water treatment important?

2. What are some details of your project?

3. The average American uses 100 gallons of water per day (EPA, 2013). This includes water used in showers, sinks, toilets, dishwashers, washing machines, and yard maintenance. There are many ways to conserve water. Calculate how much water a **family of four** would save **each day** if they chose **two** of the following conservation options. *You will need to make assumptions!*
   a. Low flush toilets save 1.5 gallons of water per flush
   b. Low flow shower heads save about 5 gallons of water per day per shower
   c. High efficiency washers save 20 gallons of water per load of laundry
   d. High efficiency dishwashers save about 5 gallons of water per load
3. More space for problem three calculations:

4. How much water would be saved in one year?

5. What do you do at home to conserve water?
Wastewater treatment

1. Why is wastewater treatment important?

2. What are some details of your project?

3. The average American uses 100 gallons of water per day (EPA, 2013). This includes water used in showers, sinks, toilets, dishwashers, washing machines, yard maintenance. If the cities of Champaign and Urbana have a population of 124,098, what is the daily and yearly water consumption of the city?

How many swimming pools is the amount of water you estimated above, if an Olympic size swimming pool holds about 660,000 gallons?
4. It costs about $0.006 per gallon to treat wastewater. How much does it cost to treat water for Champaign Urbana for one year?

5. Choose one of the following water conservation options and calculate how much water Champaign Urbana would save in one day if every person incorporated that option into their home. You will need to make a few assumptions!
   a. Low flush toilets save 1.5 gallons of water per flush
   b. Low flow shower heads save about 5 gallons of water per day per shower
   c. High efficiency washers save 20 gallons of water per load of laundry
   d. High efficiency dishwashers save about 5 gallons of water per load
Hazardous waste remediation

1. Why is hazardous waste remediation important?

2. What are some details of your project?

3. Environmental engineers estimate the **risks** that contaminants pose to humans in order to determine if a site needs to be remediated. We use **risk factors** that have been determined through toxicology studies in order to do this. Benzene is a common carcinogen found in areas which have been polluted with fuel. The EPA has set the acceptable risk level for carcinogens at one in a million. This means **less than one in a million** people can develop cancer from the site. Use the following information and equation to determine if the site is safe.

The site of a former gas station has a leaking tank of fuel which is emitting benzene into the atmosphere. Wind is blowing the benzene to a nearby neighborhood. The concentration of benzene in the air was measured to be **0.001 mg/m³** in the neighborhood. **Is the neighborhood safe?**

\[
Risk = Intake \times \text{slope factor}
\]

Let’s calculate the inhalation intake of benzene for an average adult. The intake is the amount of benzene taken in per kg of body weight per day.
The slope factor is the risk factor we use for carcinogens.

The slope factor for benzene is: 0.029 $\frac{kg \ day}{mg}$

Is the neighborhood safe?
Air quality control

1. Why is air quality control important?

2. What are some details of your project?

3. Let’s use the following information to identify a few additional features of the power plant:
   a. Natural gas is used to produce electricity during summer (assume May to August). Coal is used as the fuel of choice for the remaining months. Number of months coal is burnt at Abbot power plant = 

   b. Electricity generated across the year = 

   c. Let’s assume that every month, electricity generated is the same. Hence, electricity generated from coal = (b) x (a)/12 =

   d. Emission factors are used to estimate quantity of pollutants emitted from coal combustion. Fill in the table using the given formula.

   \[ \text{Emissions} = \text{Emission factor} \times \text{electricity generated from coal} \]
4. Air quality engineers develop and install devices to minimize emissions of pollutants to the atmosphere. Abbot power plant has several devices installed since early 1980’s including electrostatic precipitators, wet scrubbers and low nitrogen oxide burners. Let’s assume that the wet scrubbers remove 95% of the sulfur oxides. How much is emitted to the atmosphere after the pollutant control devices were installed?

a. Total sulfur dioxide emitted before = ______________ (from table)
   Total efficiency of electrostatic precipitator (ESP) = ___________
   Emissions after installation of device = \((1 - \frac{95}{100}) \times \text{total sulfur dioxide}\)
   = _______________ kg
Waste to energy technology

1. Why is waste to energy technology important?

2. What are some details of your project?

3. Let’s use the following information to identify a few additional features about municipal solid waste management.
   a. Average per capita solid waste generated in United States in 2011 was 2 kg/day. Can you estimate the waste generated by a single person in that year?

   b. Total population of Unites States in 2011 was 318,298,000. What was the total waste generated across the country that year?
c. 34% of the waste generated in households were sent to recycling facilities and 54% of the waste was sent to sanitary landfills. Remaining waste was disposed elsewhere or incinerated. Can you estimate the quantity of waste sent to recycling facilities and sanitary landfills in 2011?

d. Of the waste sent to landfills, 11.7% of the waste was sent to facilities that recover energy from waste. Can you estimate the quantity of waste that was processed in these facilities?

e. If every person in United States reduced waste generation to 1.5 kg/day, can you estimate how much waste is sent to landfills and then to waste to energy facilities. Assume all other parameters remain constant.
References:


U.S. Environmental Protection Agency (EPA), 2013. Water trivia facts, water.epa.gov.
Sustainability
Monday, June 22, 2015

G.A.M.E.S.
CAMP
Front page picture:

OS House, Racine, WI
Johnsen Schmaling Architects
This LEED platinum-rated house shows how a small building can go green even without a massive budget. Taking advantage of the breeze from nearby Lake Michigan and the site's solar exposure, outdoor rooms reduce the house's depth, which allows for better cross-ventilation. A compact structured plumbing system with low-flow fixtures and an on-demand hot-water circulator pump reduces water consumption.

http://content.time.com/time/photogallery/0,29307,2065341_2265689,00.html
Lesson Developers
Balasubramanian, Srinidhi (UIUC/CEE)
Boyd, Tory (UIUC/CEE)
Koloutsou-Vakakis, Sotiria (UIUC/CEE)

2015 Lesson Updates
Koloutsou-Vakakis, Sotiria (UIUC/CEE)
Shah, Rishabh (UIUC/CEE)

2015 Lesson Instructors
Balasubramanian, Srinidhi (UIUC/CEE)
Jackson, Nicole (UIUC/CEE)
Shah, Rishabh (UIUC/CEE)
Sustainability

What does “sustainability” mean?

The US Environmental Protection Agency describes sustainability as: “Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to making sure that we have and will continue to have, the water, materials, and resources to protect human health and our environment.”

The most recent United Nations Conference on Sustainable Development, or Rio +20 took place on June 20-22, 2012, in Rio De Janeiro, Brazil. Seven priority areas were recognized: decent jobs, energy, sustainable cities, food security and sustainable agriculture, water, oceans and disaster readiness.

Promoting sustainability is not just the job of domestic and international decision makers. Sustainability is framed by the choices and actions of each individual. Each one of us needs to be an active participant, to motivate and inspire behaviors, decisions and actions that will ensure that next generations of humans and the other living creatures on the Earth will continue having favorable living conditions on the planet.

In this module, we consider the implementation of sustainability principles for the case of a family house and we focus on energy efficiency of the house.

A few points of reference:

- In the US, we live at the receiving end of a “fire hose” of products that derive from the Earth’s resources. Fill your car with gas and drive to the mall to see them.
- Worldwide, the exponential growth of modern (technological) societies implies that in the next 25 years, we will mine and consume as many resources as were previously mined during all of history.
- One billion people live in abject poverty and lack adequate drinking water, food, sanitation, medical care, education, ...
- One billion people, mostly in Asia, will rise into the middle class during the next 30 years, vastly increasing their well-being and their material consumption.
SUSTAINABLE HOUSE
SUS-Worksheet (1)

Sustainability Goals
1. What is Sustainable Development?

2. List the three Pillars of Sustainability (triple bottom line):

3. List some basic principles of sustainability that you believe a sustainable house should fulfill:
Choose some design features of a comfortable house for a 5 member family

A. List the private (bedrooms/bathrooms) and public spaces (e.g. kitchen, dining room, media room), you want to have in the house for a family of 5.

<table>
<thead>
<tr>
<th>Type of room</th>
<th>Number of rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Let’s focus on energy needs of the household: For what purposes is energy needed in a household?
C. Where does energy used for a house come from?

D. Some energy sources are available everywhere in the USA. Are all possible energy sources available everywhere? How about having a look at the renewable energy posters and make notes on:

Wind energy

Solar energy

Geothermal energy

Hydropower
E. Thinking about indoor air quality:

Is it important? Why?

What can affect the quality of air inside the house?

What can help improve or keep good indoor air quality?

F. What other factors can affect energy demands in a house? (Think about outside conditions as well as the needs of the occupants)
G. Let us estimate the energy needs of the house

Estimating the energy needs of any building involves many parameters and one has to:
1) Consider where energy is needed
2) Examine how alternative solutions affect the energy requirements
3) Compare the energy savings among solutions
4) Examine what types of energy sources are available in different locations, around the country (see posters/focus on the Chicago, IL area).
5) Make a final decision based on cost and benefit tradeoffs.

In our camp, we will focus on the environmental impacts of a house, specific to its energy use.
G.1. Energy consumption for indoor comfort and good indoor air quality

In order to obtain approximate energy requirements estimates, we will use the MIT Design Advisor (http://designadvisor.mit.edu/design/), an online building energy calculator. The calculator enables the user to try different building designs and operating parameters (such as how much outdoor air is brought into the building per minute and what temperature and humidity are preferred but also needed for good indoor air quality).

Go to the website http://designadvisor.mit.edu/design/
In the left side ribbon click Introduction to read what the software is about.
Then click Setup
A window will appear with entry fields for your chosen input data.
Click Getting Started, on top, for general instructions

Let us run a basic scenario and then modify it so that we can compare results.

Here is some information to help you with the first scenario

Main building characteristics:
Let us assume a 2-level house, with and area of 100 m² for each level. The building has an assumed N-S/E-W orientation, with dimensions 10 m x 10 m.

Geography:
We assume that the house is located in the Chicago, IL area. Geographical location is important in estimating energy needs and energy supply solutions for two reasons:

1) 

2)
Here is a screenshot of base scenario inputs

Setup: Describe the Building You Wish to Simulate

Getting Started

Building Properties
1. Climate
Region: USA
City: IL - Chicago

2. Occupancy and Equipment
Occupancy Schedule
5:00 PM begins
0:00 AM ends

3. Ventilation System
Mechanical Cooling & Heating
Indoor Air Temperature
Max: 26 °C
Min: 20 °C
Max Relative Humidity
60%

4. Thermal Mass
High Mass: exposed concrete slab floor
Low Mass: lightweight or obstructed floor
Zero Mass

5. Building Geometry
Entire Floor (4 facades + core) well mixed air between zones

6. Roof Description
Modified Bitumen Roof
Roof Insulation: Residential (Medium Insulation)
Roof Insulation Location: Insulation on bottom of roof slab
R-Value: 2 (m2°C)W
Floors: 2

Typical Room Properties
7. Room Dimensions
Width: 4 m
Depth: 4 m
Height: 3.5 m

8. Window Description
Window Area: 50 % of exterior wall area
Select a Window Type:
- single glazed
- double glazed
- triple glazed
- single glazed
- double glazed
- triple glazed
- inside vent.
- outside vent.

Overhang
Distance: 0.1 m

9. Wall Description
Wall Insulation: Residential (Medium Insulation)
Wall R-Value: 2 (m2°C)W

Show/Hide debugging options
Run Scenario 1 (base)
This scenario corresponds to a conventional house, with moderate measures to save energy.

Max T=26 °C (79 °F)
Min T=20 °C (68 °F)
RH = 60%
Ventilation Rate= 15 L/s/person
Bitumen roof
Lighting for fine work
Double glazed windows with blinds
Medium insulation
N-S/E-W orientation

Once you input the data click on Scenario 1 at the bottom of the webpage and wait a few minutes (3-5), until the results are produced. When the scenario box appearance changes, you may check the results by clicking the tabs in the results menu on the left. Report will give you an output with detailed results on energy consumption by month. You need to save the file.

More scenarios:

Make a hypothesis: What parameters do you think, you need to modify in order to keep comfortable living conditions and good indoor air quality, while keeping energy requirements low, at the same time?

Build your own scenario now and run it.

Run Your Scenario - Scenario 2

Max T=
Min T=
RH =
Ventilation Rate=
Choose roof type
Lighting for (choose)
Choose window types and treatments
Choose insulation
N-S/E-W orientation
You may now compare results for your scenarios by clicking the results tabs on the left ribbon.

Which scenario resulted in higher energy efficiency?

**G.2. Energy source for your house**

What will be the energy cost for keeping your house running per year?

A. Choose the scenario that resulted in the lowest energy requirements.

B. Check the distributed cards that include cost information for different types of renewable energy sources. Keep in mind that not all of these sources are available in the location of your house. Which energy sources do you think are realistic for the location of your house? **If you are not sure about a renewable energy source, check again the renewable energy posters around the room or ask one of the assistants.**

1. Calculate how much energy per year your house will need. Read the total energy per square meter from your chosen scenario output.

   \[
   \text{Total energy} = [\text{energy per m}^2] \times [\text{total floor area of your house in m}^2]
   \]

2. Which energy sources are realistic for Chicago?
3. We are not able to cover 100% of our energy needs from renewable energy sources (such as wind, geothermal etc.), yet. In the table below, choose up to two renewable energy sources to supplement conventional sources. Just make an assumption about what percentage of the energy needs you plan to cover with each renewable source.

Table 2. Energy cost for sources chosen.

(Use the cards distributed in class)

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of energy needs covered by source (0 - 100%)</th>
<th>Amount of energy from source (kWh)</th>
<th>Cost ($/kWh)</th>
<th>Cost of energy from energy source ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>1</td>
<td>Total energy that you estimated above in kWh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Example: Wind (you choose) e.g. 20%</td>
<td>Multiply (C_1 \times B_2 / 100)</td>
<td>(from cards) e.g. 0.131</td>
<td>Multiply (D_2 \times C_2)</td>
</tr>
<tr>
<td>3</td>
<td>Conventional sources (electricity, natural gas)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL

4. The average cost of residential electricity in Chicago was approximately 17.2¢/kWh, in Feb 2015 [http://www.bls.gov/regions/midwest/news-release/averageenergyprices_chicago.htm](http://www.bls.gov/regions/midwest/news-release/averageenergyprices_chicago.htm). How does this compare to your energy plan, using different energy sources?
5. **Global warming implications**: What are the carbon dioxide (CO₂) emissions associated with your energy plan? (Use the information on the cards, the same choices as in Table 2 and use Table 3 to answer this question.)

**Table 3.** Emissions from chosen sources

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Amount of energy from source (kWh)</th>
<th>CO₂ (kg/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example: Wind</td>
<td>Transfer in this column the numbers from column C of Table 2</td>
<td>Use the information on the cards.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Review all your results and explain why you believe your energy decisions are reasonable or why you would consider revising them and how?
Air Quality

Monday, June 22, 2015
Tuesday, June 23, 2015
Lesson Developers

Balasubramanian Srinidhi (UIUC/CEE, Air Quality, Dispersion of Air pollutants, Nitrogen Cycle, Atmospheric Deposition)
Koloutsou-Vakakis Sotiria (UIUC/CEE, Air Quality, Dispersion of Air pollutants, Nitrogen Cycle, Ammonia Measurement, Atmospheric Deposition)
Lehmann Christopher (ISWS/NADP) (Ammonia Measurement)
Thompson Ryan (UIUC/CEE) (Cookstoves)

2015 Lesson Instructors

Balasubramanian Srinidhi (UIUC/CEE)
Koloutsou-Vakakis Sotiria (UIUC/CEE)
Shah Rishabh (UIUC/CEE)
Sun Tianye (UIUC/CEE)
Air Quality

Depending on the level of activity (ranging from sitting to running) a child, on average, breathes in 7-32 liters of air per minute, an adult female 8-51 liters of air per minute and an adult male 9-58 liters of air per minute. If you think that a day has 1440 minutes, a year has 525,600 minutes and so on, this is a whole lot of air going through our respiratory systems during our lifetimes! It is not surprising then that the ingredients of the air we breathe can have serious effects on our health. Poor Air Quality causes increased incidence of asthma and other illnesses of the respiratory system.

Air pollution does not only affect human health but all species and components on the planet! It is the cause of acid rain and smog, it promotes eutrophication (nutrient overload) in aquatic and pristine land ecosystems, causes material damage and visibility reduction and has effects on climate and on the protective ozone layer, up in the stratosphere. For all these reasons, the government has developed laws to regulate the amounts of pollutants that are emitted in the atmosphere.

What do Environmental Engineers do to improve Air Quality?

Control: Environmental engineers design equipment to clean the air that comes out of air pollution sources, such as power plants and cars.

But not all sources can be controlled in the same way and not all sources are always known.

Monitoring: Environmental Engineers also design and use instruments to identify air pollutants and measure the amounts of different air pollutants in the atmosphere. This helps us know if the levels of air pollution are safe for human health, and if the control measures we take at the sources have the expected effect on improving Air Quality. Numerous national, state and local monitoring networks have been established for this purpose.

But we cannot measure air pollution everywhere.

Modeling: Environmental Engineers develop and use computational tools (models) that help predict how air pollutants travel and how much pollution different sources contribute to the air we breathe.

Policy Making: Environmental Engineers by monitoring Air Quality, investigating and understanding the relationship between source emissions and ambient concentrations of air pollutants, provide the scientific basis for governments and multi-national environmental conventions to make decisions on actions that will help improve Air Quality locally and globally.
Can Environmental Engineers improve Air Quality alone?

Measuring and controlling at some sources are not enough to provide sustainable air quality solutions. Each one of us contributes to Air Pollution because we all use fossil fuels to heat our houses and drive our cars, fertilize our lawns and consume fertilized crops and numerous industrially produced consumer products. A holistic look at all of these, along with citizen education and active citizen involvement are essential for improving Air Quality.

In the News:

25 March 2014 | Geneva - In new estimates released today, WHO (World Health Organization) reports that in 2012 around 7 million people died - one in eight of total global deaths – as a result of air pollution exposure. This finding more than doubles previous estimates and confirms that air pollution is now the world’s largest single environmental health risk. Reducing air pollution could save millions of lives.

References


WHAT DO YOU KNOW ABOUT AIR QUALITY? AQ-IQ
AQ - Worksheet (1)
Read carefully and circle true or false in each of the following questions.

1. Air pollution is harmful only in cities.   True   False
2. Ozone in the stratosphere is protecting us from UV radiation True   False
3. Air pollution affects only the respiratory system. True   False
4. When the plume from a smokestack is white, no pollution is coming out. True   False
5. Air pollution is expensive to control. True   False
6. At any time our air may contain contaminants (air pollution) emitted by natural sources such as forest fires, volcanic eruptions, and decaying vegetation. True   False
7. Ozone is a pollutant in the lower atmosphere, but an essential for life component of the upper atmosphere. True   False
8. Most air pollution caused by human activity originates from fossil fuel combustion. True   False
9. Destruction of material and crops by air pollution represents a significant economic loss for nations. True   False
10. Clean, unpolluted air is a pure substance. True   False
11. Air pollution is a health concern only outdoors. True   False
12. Exhaust from the school bus tail pipe affects only outdoor air. True   False
13. High humidity in the house is good for indoor air quality. True   False
14. Ozone in the troposphere is emitted by cars  True  False

15. Fine particles are most dangerous for your health.  True  False

16. Environmental Engineers design equipment to clean the air that comes out of smoke stacks and car tailpipes.  True  False

17. Environmental Engineers design instruments to measure concentrations of Air Pollutants.  True  False

18. Environmental Engineers build computer models to help develop Air Quality Management strategies.  True  False

Give to each correct question one point.

Total points:

If you scored at least 16 points you are a team of AQ experts!
If you scored less, do not despair! You will know so much more by the end of the camp!
AIR QUALITY - THE BASICS
AQ-Worksheet (2)

1) The layer of the atmosphere where humans live is called

2) What is Air Pollution?

3) Let us name some important Air Pollutants – Know their sources and their effects. In the following Table, circle the correct answers and cross out the wrong ones.
### Air Quality

<table>
<thead>
<tr>
<th>Air Pollutant</th>
<th>Main Sources</th>
<th>Health effects to Humans</th>
<th>Other Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur dioxide, SO2</td>
<td>1. Burning sulfur-containing fossil fuels such as coal, and oil. 2. Ore smelters, oil refineries. 3. Biological activity of marine plankton, bacteria, plants. 4. Volcanic eruptions.</td>
<td>1. Severe respiratory problems and increased asthma symptoms</td>
<td>1. Sulfur dioxide is an acid precursor (i.e., contributes to the formation) which is a source of acid rain. 2. Sulfur dioxide is a precursor for particulate matter formation.</td>
</tr>
</tbody>
</table>
4) List some actions that can help improve outdoor air quality

5) List some actions that can help improve indoor air quality

6) Let us revisit the AQ – IQ sheet. Go ahead and revise answers if needed.
**Air Pollution from Cookstoves**

**Introduction**

Approximately half the people in the world (3 billion people) cook their food with biomass and other solid fuels, including wood, agricultural crop waste, charcoal, and coal. There are many problems associated with biomass cookstoves, but the people that use them have no other choice, because they cannot afford cleaner-burning types of stoves and fuels. The problems caused by cookstoves include human health effects, deforestation, and climate change.

“Cleaning up the air we breathe prevents noncommunicable diseases as well as reduces disease risks among women and vulnerable groups, including children and the elderly,” says Dr Flavia Bustreo, WHO Assistant Director-General Family, Women and Children’s Health. “Poor women and children pay a heavy price from indoor air pollution since they spend more time at home breathing in smoke and soot from leaky coal and wood cook stoves.”

Biomass cookstoves are often used inside homes, which causes indoor air pollution of smoke and other pollutants such as carbon monoxide. Some people cook outside when the weather is good, and some use a chimney to vent the pollution outside, but this does not eliminate their exposure to the pollutants. Biomass cookstoves are known as the “Killer in the Kitchen”. The World Health Organization estimates that over 4 million people die per year from cookstove indoor air pollution, mostly women and children.

Cooking fuel is gathered from surrounding areas, causing deforestation and ecosystem degradation in many parts of the world, where fuel demand is high. In some places, fuel wood is scarce, and women spend many hours walking long distances to find fuel.

Biomass stoves have a significant effect on the Earth’s climate. Emissions of carbon dioxide, other greenhouse gases, and black carbon, absorb solar radiation and contribute to global warming. However, biomass stoves also emit organic carbon that scatters solar radiation and which can result in global cooling. Therefore, there is a climate effect but it is not certain if warming or cooling dominates, when it comes to particulate emissions from cookstoves.

What are solutions to the cookstove problem? As people earn more money, they can switch to cleaner-burning cooking fuels such as liquefied petroleum gas (LPG) and...
electricity. This change can improve indoor air pollution. However, since we still use fossil fuels when we burn LPG or use electricity, the climate effects still remain. Efforts are also made to develop clean-burning biomass cookstoves. Combustion technology in the world is fairly advanced considering amazing jet engines, automobile engines, and coal and natural gas power plants. Yet, half of the people in the world are using the same cooking technology that their ancestors did thousands of years ago (the open fire), because new technology is not available to poor people in developing countries. Now is the time to change that and Environmental Engineers are busy working on this serious problem.

To be able to assess how good new technological solutions are, Environmental Engineers need to know how much pollution is emitted by old stoves and how much pollution is emitted by new technology stoves. Air pollution measurements are a critical part of the solution in order to understand how much air pollution is emitted, why it is emitted, and how much it is reduced when we use new technology.

References:


1. Who cooks at your home? List all the people in order from who cooks the most to who cooks the least.

2. What cooking appliances/stoves are used at your home? List them in order of most used to least used and include the type fuel/energy source for each appliance.

3. Why do you think your household has chosen to use the particular cooking appliances and fuels listed above in Question 2?

4. What are two health effects from cookstoves?

5. What are two products of wood combustion?

6. Why do environmental engineers measure cookstove emissions?
How do we measure PM concentrations?

**Particulate Matter (PM) Filter Sampling**

PM emitted by cookstoves are very tiny. The diameters of the particles are no bigger than 1/1000 of a human hair diameter. It is not possible to see them with our eyes. How can we then measure them?

The easiest and most common way is to collect lots of them on a filter and measure how much the weight of the filter changed because of the PM it collected.

Today, we are going to build a pump and filter sampler to collect a PM sample from a cookstove.

**PM Mass Concentration**

The PM mass concentration is the mass of PM suspended in a given volume of air:

\[
PM \text{ mass concentration} \left[ \mu g/m^3 \right] = \frac{\text{mass}_{PM} \left[ \mu g \right]}{\text{volume of air} \left[ m^3 \right]}
\]

1 µg is equal to \((1/1,000,000)\) gram.

The mass of PM emitted is small. However, it is still very damaging because these tiny particles can travel deep into the lungs.

To measure the PM mass concentration, we pull air with suspended PM through a filter. The air passes through the filter but the PM does not, so the PM collects on the filter.

To find the mass of the PM collected, we subtract the weight of the clean filter from the weight of the filter after it has collected PM. We need a very accurate and sensitive balance (called a microbalance) for that, as the mass of the collected particles is very small.

To find the volume of air that passed through the filter, we measure the flow rate of
air across the filter (Q) (how much volume of air per unit time) and we also measure with a timer the sampling time (t). We calculate the total volume (V) of air collected.

\[ V[m^3] = Q \left[ \frac{\text{liter}}{\text{min}} \right] \times t[\text{min}] \times \frac{1}{1000} \left[ \frac{m^3}{\text{liter}} \right] \]

The formula includes unit conversions because usually we measure flow rate in liters per min but we express PM concentration in \( \mu g/m^3 \), by convention.

**Part 1. How can we built a sampling apparatus to measure PM concentration?**

- Time to put on your goggles and lab coats.

**Pump and Filter PM Sampler**

Use the tools and parts we provide you to assemble a PM sampling system:

**Caution:**

- Remember that the filter you will use is very fragile. Use the tweezers in your supply box to carefully remove the filter from the petri dish and place it in the filter holder.

**Preparation Steps:**

1. **Load Filter:** Refer to the following illustrations. The filter is extremely delicate. Only touch the edge of the filter with the tweezers, so the filter is not damaged.
(i) Parts required to setup a filter. Always use nitrile/latex gloves and tweezers.

Top screw  Filter plate  Black o-ring  Orange o-ring  Tweezers  Collecting Filter  Top port  Base port

(ii) start with the base port.

(iii) place the orange o-ring on it.

(iv) place the collecting filter on the orange o-ring

(v) observe - the filter plate is grooved on one side, flat on the other.

Grooves  Flat side
Caution:
- The pump pulls air, keep this in mind so that your system is built according to the direction of the airflow, as shown in the schematic.

2. Assemble the sampling system (start assembling from left to right as in image below): Connect the parts together with hoses to build the system pictured in the schematic. Make sure the longest hose is connecting the filter holder to the sampling probe. Things to keep in mind:
   
a. The needle valve has a flow direction inscribed on it. Make sure it is connected such that the flow is in the correct direction.
   b. Flow direction inside the rotameter is ALWAYS bottom-to-top. Make sure it is connected such that the flow is in the correct direction.
   c. The collecting filter and backup filter do not have a particular direction of
flow.

3. **Set the Flow:** Turn the pump on and adjust the needle valve until the flow reading on the bubble meter is about 3 lpm. The rotameter should ALWAYS be held in upright position. Record the flow rate on the worksheet below. Once flow is set, hold the needle valve by its brass body (golden color) and not the black knob.

4. Once the flow rate is set, turn off the pump. Your sampling device is now ready to sample PM.

**Part 2. Let us now use our sampling apparatus to measure concentration of PM emitted from a cookstove, while we prepare popcorn!**

- Keep your goggles and lab coats on. Our cook stove will likely produce less smoke than a campfire. Still if you wish, we have dust masks available to put on. The students who will hold the probes are advised to wear welder’s gloves just in case the stainless steel probes feels too hot.

**Measurement Steps:**

1. In the Tables, identify the Table for your team color and **record the start time** when you turn the pump on.
2. **Hold the probe about 1 m above the stove.**

3. **Take notes**
   - What do you see being emitted from the stove?
   - Can you see any smoke and what color is it?
   - What else do you think is being emitted that you can’t see?

4. After sampling for about 10 min, turn off the pump. In the Table, **record the stop time** when the pump is turned off.

5. Enjoy some popcorn!

6. Back into the classroom, carefully remove the sampling filters from their holders and place them into the petri dishes provided.

7. Your instructor will take these to the lab to weigh them, while we will think about what happens to PM after they are emitted from a source.

**After the Test (once the filters are weighed)**

8. In your team Table, **record the mass of your team’s filter.**

9. **Calculate the PM mass concentration.**

   \[ t[\text{min}] = \text{stop time} - \text{start time} \]

   \[ V[\text{m}^3] = Q\left[\frac{\text{liter}}{\text{min}}\right] \times t[\text{min}] \times \frac{1}{1000} \left[\frac{\text{m}^3}{\text{liter}}\right] \]

   \[
   \text{mass}_{PM}[^{\mu}g] = \text{final filter mass} - \text{initial filter mass}
   \]

   \[
   \text{PM mass concentration}\left[\frac{^{\mu}g}{\text{m}^3}\right] = \frac{\text{mass}_{PM}[^{\mu}g]}{\text{volume of air} \left[\text{m}^3\right]}
   \]

10. **In the Table, record value.**
Data recording Tables

Filter 1 (team RED)

<table>
<thead>
<tr>
<th>Start time</th>
<th>Initial filter mass [ug]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop time</td>
<td>Final filter mass [ug]</td>
</tr>
<tr>
<td>Sample time, t [minutes]</td>
<td>PM mass on filter [ug]</td>
</tr>
<tr>
<td>Flow rate, Q [liter/min]</td>
<td>PM mass concentration [ug/m^3]</td>
</tr>
<tr>
<td>Volume of air sampled, V [m^3]</td>
<td></td>
</tr>
</tbody>
</table>

Filter 2 (team BLUE)

<table>
<thead>
<tr>
<th>Start time</th>
<th>Initial filter mass [ug]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop time</td>
<td>Final filter mass [ug]</td>
</tr>
<tr>
<td>Sample time, t [minutes]</td>
<td>PM mass on filter [ug]</td>
</tr>
<tr>
<td>Flow rate, Q [liter/min]</td>
<td>PM mass concentration [ug/m^3]</td>
</tr>
<tr>
<td>Volume of air sampled, V [m^3]</td>
<td></td>
</tr>
</tbody>
</table>

Filter 3 (team GREEN)

<table>
<thead>
<tr>
<th>Start time</th>
<th>Initial filter mass [ug]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop time</td>
<td>Final filter mass [ug]</td>
</tr>
<tr>
<td>Sample time, t [minutes]</td>
<td>PM mass on filter [ug]</td>
</tr>
<tr>
<td>Flow rate, Q [liter/min]</td>
<td>PM mass concentration [ug/m^3]</td>
</tr>
<tr>
<td>Volume of air sampled, V [m^3]</td>
<td></td>
</tr>
</tbody>
</table>

Estimate the mean PM concentration:

\[
\text{mean } C_{PM} = \frac{C_{PM \text{ (filter1)}} + C_{PM \text{ (filter2)}} + C_{PM \text{ (filter3)}}}{3}
\]

Answer: ................................................................. [μg/m^3]
Why the concentrations from the 3 filters are not identical?

Do you think this stove type is safe to use in your home? (Explain)

**Extension and connection with background material:**

Can you compare what you measured with existing standards? (Circle the answer that is correct after discussion in class, so that you remember it later).

YES (Explain)

NO (Explain)
AIR POLLUTANT DISPERSION
AQ-Worksheet (3)

How do Air Pollutants travel? - A Physical Model
1. Name three parameters that control the dispersion of the plume

2. Movement of air parcel in the atmosphere
   a. How does the pressure and temperature change with height in the atmosphere?

   b. What is the inherent assumption for heat transfer by an air parcel?

   c. Does the air parcel expand as it rises in the atmosphere?

   d. Does the temperature increase or decrease when the air parcel expands?

   e. What happens when the temperature of the air parcel equals the temperature of the atmosphere?
How do Air Pollutants travel? - A Mathematical Model

In the previous activity, we used a physical model to visualize and understand how air pollutants travel in the atmosphere. However, we cannot replicate all possible situations and landscape combinations with physical models.

Scientists and engineers more often use mathematical models to predict how air pollutants will disperse in the atmosphere, how they will transform and finally how they will be removed. In other words, scientists use mathematical equations to describe the motions of the atmosphere and the chemical reactions that happen in the atmosphere and then, given the locations and emission strengths of the air pollution sources, they solve these equations to estimate what concentrations of air pollutants these emissions will produce at different locations away from the sources.

In this activity, we will use such a mathematical model, which is called HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory), to make predictions about where your cookout emissions will end up, after one or more days. The model was developed by the scientists at the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA/ARL).

Go to the website http://ready.arl.noaa.gov/HYSPLIT.php
**HYSPLIT TRAJECTORY MODEL**

Click on *Run HYSPLIT Trajectory Model*

Click on *Compute forecast trajectories*

In Number of Trajectories: choose 1

Type of Trajectory: choose Normal

Click Next

For Meteorology, choose: GFS 0.5 Degree

Decimal Degrees   Latitude: 40.1152 N
                   Longitude: 88.2258 W

Click Next, we will accept the default choice in the new screen.

Click Next

**Model Parameters**

Trajectory Direction choose: Forward (this means away from the source)

Vertical Motion, choose: Model vertical velocity

Start time: provide the approximate time of your cook-out (but it has to be in Universal Coordinated Time (UTC), which at this time of the year is 5 hrs ahead of our daylight savings time in central US)

Total run time: 24 hrs

Leave the rest of the parameters at the values they show (notice that latitude and longitude are your starting location)

**Display Options**

GIS output of contours?  None  Google Earth (kmz)  GIS Shapefile

Choose: Google Earth

Click Request trajectory at the bottom of the page.

Wait for a few seconds.
QUESTIONS:

Which direction do the air pollutants travel?

Where have they reached 24 hrs after they were released based on today’s forecasted meteorology?

Allow the assistants to download the maps to their flash drives for printing copies for your files.

You can now rerun the model.
Click Return to main menu (keep user inputs)

Where are the pollutants 72 hrs after their release?
Does this type of the model provide us with useful information? Why?

What other information would you want to have about air pollutants at their destinations?
**HYSPLIT DISPERSION MODEL**

The trajectory model does not inform us how much pollution is contributed to the locations trajectories arrive at. In order to get such information, we need to run the HYSPLIT dispersion model.

On the top line you see on your screen click on **HYSPLIT**.

This will bring you to the initial page. Click on **HYSPLIT Dispersion Model**.

Click Compute archive dispersion (3rd main bullet, where no registration is required).

### Release Type, Meteorology & Starting Location

<table>
<thead>
<tr>
<th>Release Type:</th>
<th>Unknown Material (Generic Mass, &lt; 24 hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorology:</td>
<td>GDAS (1 degree, global 2006 – present)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source Location (enter using one of the following methods):</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Decimal Degrees" /> Latitude: 40.115  Longitude: 88.225</td>
</tr>
<tr>
<td><img src="image" alt="Get Lat/Long from Google Maps" /></td>
</tr>
<tr>
<td><img src="image" alt="DDD/MM/SS Latitude" /></td>
</tr>
</tbody>
</table>

Click Next
Meteorology File

<table>
<thead>
<tr>
<th>Event Type:</th>
<th>Exercise - Cookstoves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release:</td>
<td>Unknown</td>
</tr>
<tr>
<td>Pollutant:</td>
<td>Unknown</td>
</tr>
<tr>
<td>Meteorology:</td>
<td>Archived GDAS1</td>
</tr>
<tr>
<td>Source Location:</td>
<td>Lat: 40.115200 Lon: -88.225800</td>
</tr>
</tbody>
</table>

Choose an archived meteorological file: Current 7 days

Deposition: YES

Advanced Options: NO

Click Next

Model Run Details

<table>
<thead>
<tr>
<th>Event Type:</th>
<th>Exercise – Cook stoves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release:</td>
<td>Unknown Mass</td>
</tr>
<tr>
<td>Source Location:</td>
<td>Lat: 40.115200 Lon: -88.225800</td>
</tr>
<tr>
<td>Source Term:</td>
<td>This will be provided by the instructor later</td>
</tr>
<tr>
<td>Meteorology:</td>
<td>Archived GDAS1</td>
</tr>
<tr>
<td>Output:</td>
<td>Concentration/deposition</td>
</tr>
</tbody>
</table>

Model Run Details

The archived data file (GDAS1) has data beginning at 06/22/15 xxxx UTC.

Source Term Parameters

Dispersion direction:  

- Forward
- Backward (Change the default start time!)

Release starting time (UTC): year month day hour minute

Current time: xx:xx

Source latitude: 40.1152 degrees
### Source location:
-88.225 degrees (West is negative)

### Release properties:
- **Release top:** 500 meters AGL
- **Release bottom:** 0 meters AGL
- **Release quantity:** 2400 mg (choose from drop-down menu)
- **Release duration:** 24 hours (choose 1 minute)

### Runtime Parameters
- **Total duration:** 24 hours
- **Averaging period/Output interval:** 0.5 hour
- **Top of averaged layer:** 100 meters AGL (must be >= 100m)

### Deposition Parameters
- **Pollutant characteristic:** Gas
- **Dry deposition velocity (meters/second):** 0.001
- **Henry’s Constant for wet deposition of a gas:** 0.0
- **Wet deposition of particle: In-cloud (L/L) and below-cloud (1/s):** 0.002
- **Sum deposition over total run time?** Yes

### Output Parameters
- **GIS output of contours:** Google Earth/Maps (kmz), GIS Shapefiles
- **Plot resolution (dpi):** 96
- **Zoom factor:** 70
- **Distance circle overlay:** None, Auto, 4 circles km apart
- **U.S. county borders?** Yes
- **Postscript file?** Yes
- **Create PDF file of graphics?** Yes

Click **Request Dispersion Run**
Wait 1-5 min.

When the results are ready you can see maps of how the particles spread in 30 min intervals.

**QUESTIONS:**

How is the output of the dispersion model different from the output of the trajectory model?

Try to run the dispersion model without deposition. Can you see differences in the results?

**Dispersion of volcanic ash in the news**

This aerial photo shows the Eyjafjallajokull volcano billowing smoke and ash in April, 2010. (HALLDOR KOLBEINS/AFP/Getty Images)

Depiction of the estimated ash cloud at 18:00 UTC on 16 April 2010. Clouds of volcanic ash blanketed parts of rural Iceland, as a vast, invisible plume of grit drifted over Europe, disrupting air traffic.
The Nitrogen Cycle and Air Quality

Introduction - Biogeochemical Cycles

What are they?

Biogeochemical cycles describe the complex processes that move, transform and store chemicals in the geosphere (soils for the discussion here), hydrosphere (water), biosphere (organisms) and atmosphere (air). In a biogeochemical cycle, one identifies sources and fates of chemical elements, as they cycle through the system. Such elements include oxygen, nitrogen, carbon, sulfur and phosphorous.

How do Biogeochemical Cycles relate with Air Quality?

The composition of the atmosphere is ultimately controlled by the exchange of elements between the different reservoirs of the Earth that is the geosphere, the hydrosphere, the biosphere and the atmosphere.

When we discuss sources and sinks of Air Pollution, it is important to consider both the ones associated with human activities and the ones that are happening because of the natural functions of the Earth system.

The Nitrogen Cycle

Nitrogen (N₂) is the major gas in the atmosphere and occupies 78.3% by volume of the Earth’s atmosphere. Most of the nitrogen resides in the biotic environment as an essential part of living organisms in the form of amino acids, proteins and DNA. By itself, it is unusable by organisms; however it transforms to chemical compounds that living organisms can use. But N₂ is chemically un-reactive at ambient temperatures and pressures, so how does transformation to other molecules occur?

N₂ molecules become usable by living organisms when they break apart during lightning strikes, combustion of fossil fuels and by the activity of certain types of bacteria that reside in the soil, some associated with legume plants such as soybeans or in water (oceans, lakes, rivers).

The Nitrogen cycle relates closely to Air Quality because nitrogen compounds emitted during combustion of fossil fuels are air pollutants or lead to the formation of secondary air pollutants such as particulate matter and ozone (main ingredient of smog). Nitrogen acid compounds washed down by rain can cause damage to vegetation. Nitrogen compounds deposited from the atmosphere can also worsen eutrophication. Certain nitrogen compounds are greenhouse gases and warm up the planet and others travel up in the stratosphere and through complex chemical reactions damage the ozone layer.
But let us see how these processes happen. We will take you first through an introduction and then you will assume the form of a nitrogen atom and travel through the four spheres.

References:

THE NITROGEN CYCLE
AQ - Worksheet (4)

The Nitrogen Cycle Game

You have assumed a role of a nitrogen atom in this game and travelled through different environmental media (or spheres). This exercise is designed to support your understanding about nitrogen cycling through the different spheres and its implications on the environment. Ensure that you fill in your nitrogen passport first before you answer these questions.

a. Where did you start? Where did you end?

b. How many stops did you make? How many stops could have been made?

c. Did you visit the same station more than once?

d. How many biotic media did you visit? Abiotic?
e. Draw a diagram of your trip:
Biogeochemical Cycles

a. State three examples of biogeochemical cycles that are found in the environment

b. Define a biogeochemical cycle

c. Let’s complete a schematic of the nitrogen cycle
The Nitrogen Cascade

The nitrogen cascade denotes the effects that a single atom of N can have in various reservoirs, after it has been converted from a nonreactive to a reactive form.

a. Name two anthropogenic sources that add reactive nitrogen in the atmosphere

b. Fill in the schematic for the nitrogen cascade
c. How has the addition of excess nitrogen benefitted humans?

d. Name any two implications of the nitrogen cycle on air quality.

e. How does the nitrogen cycle impact water quality?

f. Name two ways in which Environmental Engineers can manage the nitrogen cycle.
Food Production and Ammonia in the Atmosphere

What is ammonia?

_A colorless gas, under standard atmospheric pressure, with characteristic odor._ It is composed of one atom of nitrogen and three atoms of hydrogen, NH₃. Its molar mass (MM) is 17 g / mole (atomic mass of N = 14 g / mole, atomic mass of H = 1 g/mole).

NH₃ is very reactive. It is corrosive, highly soluble in water and it reacts with acids to form ammonium (NH₄⁺) salts. NH₃ is the basic compound for the production of numerous other chemical products such as house cleaners and explosives. NH₃ is also the major ingredient of _chemical fertilizers_ that farmers use to increase their crop yields.

An example you likely know if you have fish pets: NH₃ in aquariums

When dissolved oxygen is available, in water, bacteria quickly oxidize ammonia to nitrate through nitrification. Increased amounts of NH₃ are found in waters where there is not much dissolved oxygen. Therefore, NH₃ is an indicator for water quality. High pH and warmer temperatures increase the toxicity of a given ammonia concentration for aquatic life.

What are the sources of ammonia in the atmosphere?

NH₃ is emitted naturally from decaying organic matter and from the excreta of humans and animals. NH₃ has also anthropogenic sources such as use of fertilizers, waste disposal, industrial processes and fossil fuel combustion.

The _biggest sources of NH₃ are concentrated animal feeding operations and crop fertilization._

What are the main benefits of NH₃ use for humans?

Use of chemical fertilizers has made it possible to produce enough food to sustain a continuously increasing human population.
What are the adverse effects of ammonia in the environment?

- Unpleasant odor.
- Harm to human and animal health (NH₃ is toxic at high concentrations for humans. Also, think about your pet fish aquariums, where even small amounts of NH₃ can harm the fish).
- Harm to vegetation.
- Over-fertilization can reduce crop yields.
- Forms particulate matter in the atmosphere (harm to human and animal health)
- Deposits to land and water bodies and contributes to soil acidification and eutrophication.

What do Environmental Engineers do to reduce the adverse effects of NH₃?

- Measure and estimate NH₃ emissions from different sources.
- Use these emissions as inputs to Air Quality Models to be able to predict impacts of NH₃ on Air Quality.
- Measure NH₃ concentrations in the atmosphere.
- Measure deposition of NH₃ and ammonium species from the atmosphere.
- Work on technical solutions to minimize emissions of NH₃ and other reactive nitrogen compounds from human and animal waste treatment to air and water.
- Cooperate with other scientists (plant biologists, crop scientists, microbiologists) to identify solutions for crop fertilization that minimize use of fertilizers with no decline on crop yields.
- Work on solutions to treat run off from crop fields so that no excessive reactive nitrogen reaches ground and surface waters.
- Provide the scientific basis for the need to improve food production practices, so that we can produce food sustainably.
Useful information

What is a mole?

A mole is the quantity of anything that has the same number of particles found in 12 grams of Carbon-12.

That number of particles is Avogadro's number, which is roughly $6.02 \times 10^{23}$ particles per mole. A mole of carbon atoms is $6.02 \times 10^{23}$ carbon atoms. A mole of chemistry teachers is $6.02 \times 10^{23}$ chemistry teachers.

What is molar mass?

It is the mass of one mole of a substance.
FOOD PRODUCTION AND AMMONIA IN THE ATMOSPHERE

AQ - Lab (2)

How do we measure NH₃ concentrations in the atmosphere?

NH₃ concentrations can be monitored in real time by instruments that have been built for this specific purpose. Such instruments are expensive to buy, so we usually measure NH₃ concentrations with indirect methods that allow us to use laboratory resources that we have available for many other purposes. The latter measurements are typically not real time measurements as NH₃ is collected by samplers over several hours or days.

Direct, real time or indirect measurement of NH₃ concentrations should be made with extra care because NH₃ is very reactive. Thus, it can easily be “lost” due to chemical reaction. If we are not careful enough with our measurement procedure, we can end up measuring smaller or larger NH₃ concentrations than these in the atmosphere.

How much do we trust measurements, in general?

![Accuracy and Precision Diagram]

What is measurement accuracy?

Accuracy is how close a measured value is to the actual value.

What is measurement precision?

Precision is how close the measured values are to each other, in a series of repeated measurements.
What is measurement bias?

**Bias** is a systematic error, which makes all measurements wrong by a certain amount.

Examples:

- You measure your height wearing shoes
- The scale you use reads "1 kg" when no weight is on it

What do we do to improve the quality of our measurements?

We develop and apply protocols for quality control (QC) and quality assurance (QA).

**Quality Control** (QC) consists of the steps you will take to determine the validity of specific sampling and analytical procedures. QC is typically performed during measurements to ensure your instruments are providing accurate data. One example of this is the use of measurement standards (something for which you know the concentration or weight) and control charts (plots of the same measurement material over time to look for changes).

**Quality Assurance** (QA) generally refers to a broad plan for maintaining quality in all aspects of a program. QA is typically performed after measurements, to ensure they meet the project requirements. (For example, if your experiment specifies that you should make 4 measurements, does your data table have 4 entries?)

What are blanks?

Blanks are additional samples that are used along with the samples we collect for a particular purpose. Their primary purpose is to estimate contamination that may occur in our samples due to conditions in the surrounding environment, possible wrong handling of the sampling material, possible malfunction of instruments or possible deficiencies of the methods we use. Using blanks is a QC step.

There are different types of blanks: field blank, trip blank, method blank, instrument blank.
Experiment Description

As explained earlier, one of the important sources of NH$_3$ in the atmosphere is chemical fertilization. The following experiment was inspired by a real measurement campaign organized by your instructors at the University of Illinois and collaborators from the National Oceanic and Atmospheric Administration$^1$. It has been modified for classroom use and it is very similar to a real research project in that we do not know the results, until we perform the measurements.

About one month ago, we sowed corn seeds in the numbered pots you see in class. About two days ago, we added nitrogen fertilizer to some pots as described on the stickers. We then covered the pots with plastic to reduce effects from the environment and attached two passive diffusive NH$_3$ samplers, on each plant. Each passive sampler was given an identification number, so that we know on which potted plant, it was attached.

Two more diffusive samplers were hang in the room for two days (48 hrs) before we moved the plants in (we analyze these and the results will be shown in Table 1, as blanks).

Today, you will measure NH$_3$ concentrations around the plants based on how much NH$_3$ the diffusive samplers collected over the past 2 days (48 hrs). You will use a method called colorimetry for this purpose.

---

$^1$ This material is part of broader impact work supported by the National Science Foundation, under Grant Number 1236814. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
How do the diffusive samplers work?

In this experiment, we use Radiello™ NH₃ diffusive samplers (Fondazione Salvatore Maugeri IRCCS, Italy). This type of sampler is used in the ammonia monitoring network (AMoN), of the National Atmospheric Deposition Program (NADP). In the AMoN, NH₃ concentrations are measured at many sites across the U.S..

The Radiello samplers are made of a cartridge and a diffusive body that encloses the cartridge. The cylindrical sampling cartridge is made of microporous polyethylene and it is impregnated with phosphorous acid, so that it can capture NH₃ molecules from the surrounding air (acid – base reaction). Flow of air toward the cartridge is controlled by diffusion through the pores of the enclosing body. The manufacturer provides a theoretical flow rate through the diffusive body of 235 mL of air per min.

The Radiello samplers do not provide a direct reading. How then can we know how much NH₃ they collected?

We will use a colorimetric method, which is the same method used by NADP.

➢ Time to put on your lab coats, safety goggles and gloves.

➢ Remember our sweat and breath contain NH₃ or ammonium (NH₄+) salts that can cause contamination of our samples. To minimize these effects, we should not touch the cartridge with bare hands and we should do the separation of the cartridge from the body fast. Avoid breathing on the cartridges.

What is colorimetry?

A technique used to determine the concentration of colored compounds in solution. It is based on the principle that the amount of light a substance absorbs (‘absorbance’) is directly proportional to the concentration of the substance.
How does a colorimeter work?

To use colorimetry, you need to have:
1. a solution that absorbs light,
2. a light source that sheds light through a cuvette that holds the solution sample,
3. a filter to allow through the wavelength mostly absorbed by the solution,
4. a detector that measures how much light is transmitted through the cuvette that contains the solution.

Estimation of concentration is based on Beer – Lambert law that relates light intensity to concentration of the substance in solution:

\[ \frac{I_E}{I_o} = e^{-kC_\ell} \]

where,
- \( I_E \) = intensity of emerging light
- \( I_o \) = intensity of incident light
- \( e \) = base of neutral logarithm
- \( k \) = a constant
- \( C \) = concentration
- \( \ell \) = thickness of the solution (that will depend on the dimensions of the cuvette that holds the solution)
STEP 1. Organize your team

This laboratory activity is designed for teams of four. Please designate:

1. Field engineer 1 (retrieves from the plant and extracts diffusive sampler 1).
2. Field engineer 2 (retrieves from the plant and extracts diffusive sampler 2).
3. Lab engineer (performs the measurements with the hand-held colorimeter, with the help of the field engineers, as needed).
4. Quality assurance engineer (makes sure the steps below are followed, records the result of the measurements and calculations, and reports final result to the instructor, who will insert it in the comparison table).

STEP 2. Extraction

1. Transfer 10 mL of DI water from the wash bottle into the graduated cylinder.
2. Carefully transfer the core from the body of the Radiello sampler to the empty clean Radiello testing tube.
3. Pour the DI water from the graduated cylinder into the testing tube.
4. Cap the testing tube and place it into the tube holder.
5. Repeat 1-4 for the second Radiello.
6. Place the holder with the testing tubes into the Ultrasonik bath filled with DI water and sonicate for 20 minutes.
7. Samples are ready to be analyzed.
8. All samples should be capped until the analysis begins.

Note: DI water, we use is ammonia free.

STEP 3. Chemical Analysis

<table>
<thead>
<tr>
<th>Range</th>
<th>0.00 to 3.00 ppm NH₃-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>0.01 ppm</td>
</tr>
<tr>
<td>Measurement Method</td>
<td>Colorimetric</td>
</tr>
<tr>
<td>Accuracy (@25°C/77°F)</td>
<td>±0.05ppm ± 5% of reading</td>
</tr>
<tr>
<td>Light Source</td>
<td>Photodiode @470 nm</td>
</tr>
<tr>
<td>Light detector</td>
<td>Silicon photocell</td>
</tr>
</tbody>
</table>
1. Turn the meter on by pressing the button. All segments will be displayed. When the display shows “Add”, “C.1” with “Press” blinking, the meter is ready.

2. Fill the cuvette with 10 mL of the unreacted extracted sample 1 and replace the cap. Place the cuvette into the meter and close the meter’s cap.

3. Press the button. When the display shows “Add”, “C.2” with “Press” blinking the meter is zeroed.

4. Remove the cuvette from the meter and unscrew the cap. Add 4 drops of HI 700A-0 reagent A. Replace the cap and swirl the solution.

5. Unscrew the cap and add 4 drops of HI 700B-0 reagent B. Replace the cap and swirl the solution. Place the cuvette back into the meter.

6. Press and hold the button until the timer is displayed on the LCD (the display will show the countdown prior to the measurement) or, alternatively, wait for 3 minutes and 30 seconds and press the button.

7. The instrument displays the results in mg/L (ppm) of ammonia nitrogen (NH₃-N), which means it is built to report the result in terms of N and not of NH₃ (we will take care of that later). Write the displayed result in cell (B3) of Table 1.

8. REPEAT steps 1-8 for the extracted sample 2. Write the displayed result in cell (B4) of Table 1.

9. Discard the contents of the cuvettes by pouring into the waste container and rinse cuvettes once, by using the wash bottle (this will prevent permanent coloring of the cuvettes). Pour rinse water into the waste container and cover waste container.

10. Calculate the mean of the two measurements as shown in Table 1. Write the result in cell B5.
11. Copy the values for the blanks that the instructor will provide in cells B8 and B9 of Table 1. Calculate the mean blank value as shown in Table 1. Write the result in cell B10.

### Table 1. Measurement of NH$_3$ concentration in water.

#### A. NH$_3$ concentration from diffusive samplers

<table>
<thead>
<tr>
<th></th>
<th>(A)</th>
<th>(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Reading from NH$_3$ checker NH$_3$-N in water (mg/L)</td>
</tr>
<tr>
<td>3</td>
<td>Your plant - Diffusive Sampler 1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Your plant - Diffusive Sampler 2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Mean (B4+B5)/2</td>
<td></td>
</tr>
</tbody>
</table>

#### B. NH$_3$ concentration from blanks

<table>
<thead>
<tr>
<th></th>
<th>(A)</th>
<th>(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Reading from NH$_3$ checker NH$_3$-N in water (mg/L)</td>
</tr>
<tr>
<td>8</td>
<td>Blank 1 <em>(instructor will provide values)</em></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Blank 2 <em>(instructor will provide values)</em></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Mean (B7+B8)/2</td>
<td></td>
</tr>
</tbody>
</table>

12. Subtract (B5) - (B10) to correct for possible sample contamination.

Result.......................... mg/ L of NH$_3$-N in water

13. To convert to mg/L of ammonia (NH$_3$), multiply above result by 1.214. (molecular mass of NH$_3$ = 17 g/cm$^3$, molecular mass of N =14 g/cm$^3$, then to convert mass of
N to mass of NH₃ that contained that amount of N, you need to multiply by 17/14 = 1.214).

\[ \text{Result} \quad \text{mg/L of NH}_3 \text{ in water} \]

**STEP 4. Calculation of NH₃ concentration in the air**

Congratulations! You have measured the concentration of NH₃ in the air that was captured by the Radiello cartridge! However, the result is in mg NH₃/L in water.

Can we find what the concentration of NH₃ in air was? (that’s what we are interested in).

Concentration is calculated as

\[ C_{\text{NH}_3\text{-air}} = \frac{\text{mass of gaseous NH}_3}{\text{volume of air sampled}} \]

and it is typically expressed in μg/m³.

Note: 1 μg = 1/1,000 mg = 1/1,000,000 g = 1/1,000,000,000 kg.

1 m³ = 1,000 L

Start by thinking that:

Mass of NH₃ captured from air = Mass of NH₃ measured in water.

Copy the NH₃ concentration (mg/L) that you calculated above, into cell A4 of Table 2.

Then perform the following easy calculations:

a. Mass of NH₃ measured in water = Concentration of NH₃ measured in water (mg/L) x volume of water (L)

Multiply cell A4 by 0.01 L (because the volume of water you analyzed was 10 (ml) that is 0.01 L)
Write the result in cell B4 of Table 2.

b. The Radiello samplers were exposed to air over the plants for 2 days x 24 hrs per day x 60 min per hr = 2,880 min.

Write 2,880 in cell C4 of Table 2.

c. The flow rate of air through the Radiello diffusive body is 235 mL of air per min at 25°C and 1.0 atm, which is 0.235 (L/min).

(For simplicity, we assume that our room temperature is 25°C and pressure in the room is 1.0 atm. This means, we do not need to correct the air flow rate, for these calculations)

Write 0.235 in cell D4 of Table 2.

d. Now calculate the total volume of air that the Radiellos were exposed to:
0.235 (L/min) x 2,880 (min) = ......................... (L)

Write the result in cell E4 of Table 2.

e. Calculate the NH₃ concentration in air by dividing the number in cell B4 over the number in cell E4. The result has units mg/L.

Write the result in cell F4 of Table 2.

f. Make the unit conversion from (mg/L) to (μg/m³).

\[
\text{quantity in } \left( \frac{mg}{L} \right) \left( \frac{1000 \mu g}{mg} \right) \left( \frac{1000L}{m^3} \right) = \text{quantity in } \left( \frac{\mu g}{m^3} \right)
\]

Multiply number in cell F4 by 1,000,000.
Write the result in cell G4 of Table 2.

DONE!
### Table 2. Calculation of NH₃ concentration in the air.

<table>
<thead>
<tr>
<th>(1)</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
<th>(D)</th>
<th>(E)</th>
<th>(F)</th>
<th>(G)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NH₃ conc. in water (mg/L)</td>
<td>NH₃ mass in water (mg)</td>
<td>Time Radiellos were exposed (min)</td>
<td>Air flow rate through Radiello diffusive body (L/min)</td>
<td>Total volume of air through Radiello (L)</td>
<td>NH₃ conc. in air (mg/L)</td>
<td>NH₃ conc. in air (μg/m³)</td>
</tr>
<tr>
<td>(2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td></td>
<td>Multiply (A4) by 0.01 (L)</td>
<td></td>
<td>Multiply (C4)x(D4)</td>
<td>Divide (B4)/(E4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td></td>
<td>2,880</td>
<td>0.235</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Results from all teams.

<table>
<thead>
<tr>
<th>Plant ID</th>
<th>Amount of fertilizer applied (gr)</th>
<th>Mean gaseous NH₃ concentration (μg/m³) over each plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What do you observe from compilation of the results from all teams?
Critical Thinking:

Facts: the air we exhale contains NH₃, plants may emit or use NH₃, NH₃ is very reactive in the environment.

Based on this information, write one or two sentences about what sources could have contributed to the NH₃ concentrations you measured today.

Is there evidence to support that the highest NH₃ source was the fertilizer in the pot soil? Explain.

How could you improve the measurement procedure in a more controlled environment such as a laboratory?

Could we have used additional blanks?
Summary

In this lesson, we reviewed information about NH$_3$, a gaseous trace pollutant. The main sources of NH$_3$ are concentrated animal feeding operations and crop fertilization. We discussed the environmental impacts of increased NH$_3$ emissions in the atmosphere.

We used a simple fertilization experiment to cause NH$_3$ emissions around baby sweet corn plants. We placed diffusive samplers over each plant to help us measure concentrations of NH$_3$ collected on the samplers over the course of a week. The purpose of the experiment was to investigate if varying amounts of fertilizer would result in varying amounts of NH$_3$ concentration in the air immediately around the plants.

We used a hand-held colorimeter to measure NH$_3$ concentration in the sampler cartridge extract in DI water. We then converted the measured concentration in water to NH$_3$ concentration in air.

We discussed about measurement accuracy and precision and about quality assurance, quality control and the role of blanks. We identified weaknesses in our procedure that can result in measurement errors and discussed how we could have minimized errors, if the procedure was performed in a controlled laboratory environment.

References


You may check the methods used in the AMoN monitoring network, at the Illinois State Water Survey webpage: http://nadp.isws.illinois.edu/amon/sites/data/
Lesson developer and 2015 instructor: Tory Boyd (UIUC/CEE)
CLIMATE CHANGE

Introduction
The Earth’s average temperature has risen by over a degree in the past century, and it is predicted to rise another 2 to 11.5°F in the next. This increase in temperature is called global warming, and is mainly caused by rising levels of greenhouse gases in the atmosphere. Greenhouse gases act like a blanket, trapping energy in the atmosphere and heating the Earth. This heating effect is called the greenhouse effect, and is necessary to keep the planet at a livable temperature. However, the continued buildup of greenhouse gases in the atmosphere as a result of human activities can change the Earth’s climate and have dangerous consequences on humans and the environment.

The BBC Climate Challenge Game
List a few options for addressing climate change from each of the game categories

National:

Trade:

Industry:

Local:

Household:
The Climate System:

What is the difference between climate and weather?

The three ways to change the radiation balance on Earth:

1. Incoming solar radiation
2. Fraction of solar/shortwave radiation reflected (albedo)
3. Longwave/infrared radiation from Earth back to space

What is albedo?

How can humans impact the radiation balance? Give three examples.
Greenhouse Gases and the Greenhouse Effect:

Greenhouse gases (GHGs):
*Gases in the atmosphere that capture solar and infrared radiation and re-emit energy in all directions to heat the Earth*

Greenhouse effect:

What are the major GHGs?

What GHG is the largest contributor to the greenhouse effect?

Why are GHGs important?
Calculate your carbon footprint:

Measure your impact on the climate by calculating the amount of CO₂ and other GHGs that are emitted by you daily activities. There are many carbon footprint calculators available online, we will use one provided by The Nature Conservancy.

My carbon footprint: ______ tons CO₂ equivalent/year

What were the biggest contributors to your carbon footprint?

1.

2.

Which of your choices had the largest impact on your carbon footprint?

1.

2.

3.

US average: ______ tons CO₂ equivalent/year

World average: ______ tons CO₂ equivalent/year
Climate Change:

Major changes in temperature, rainfall, snow, or wind patterns *lasting for decades or longer*

The EPA has divided climate change indicator into five categories. With your groups, list two indicators that fall into each category.

1. Weather and climate
2. Greenhouse gases
3. Oceans
4. Snow and ice
5. Society and ecosystems
Climate Change Management:
List four ways we can manage climate change:

1. 

2. 

3. 

4. 

Some fun sites to check out:
http://www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge/
http://www.planitgreenlive.com/
http://www.nature.org/greenliving/carboncalculator/index.htm
http://www.epa.gov/climatechange/science/future.html
http://2050-calculator-tool.decc.gov.uk/pathways/1111111111111111111111111111111111111
References:

Lesson Developers
Konar, Megan (UIUC/CEE)
Jackson, Nicole (UIUC/CEE)

2015 Lesson Instructors
Konar, Megan (UIUC/CEE)
Jackson, Nicole (UIUC/CEE)
What is a “Water Footprint”? 

A “water footprint” is the amount of water used to produce a product throughout the entire production process of that product. It can be measured for a single product, such as the tomato and hamburger illustrated above. When summed across all products consumed by a group of people, we can also obtain the water footprint of a country, or for the entire world.

We primarily think of the “direct” water that we use for drinking, washing, and flushing our toilets, when we think of water resources use. However, much more “indirect” water is used to grow our food and to produce many of the products that we use, such as cars or computers. If we include the water requirements to produce the goods and service that we use, then we have a better understanding of our personal water footprint, or how much water is required to maintain our current lifestyle.

There are three types of water footprints:

**Green water footprint:** measures the water that is evapotranspired by plants. This is especially important for agriculture.

**Blue water footprint:** measures the water that is consumed from a surface reservoir or groundwater aquifer.

**Grey water footprint:** measures the water required to dilute pollution from both point and non-point sources.

In this module, we will explore the key concepts related to water footprints. You will calculate your personal water footprint and understand its major determinants. We will discuss water footprints of nations and the global water footprint of humanity. Concepts related to the water footprint of agriculture will be explored followed by plant evapotranspiration measurements. Finally, we will identify the critical need for tomorrow’s engineer to integrate engineering design with economic understanding.
1. Which of these products do you think has the highest water footprint?

Sugar  Tomato  Chocolate  Hamburger

2. Which of these products do you think has the lowest water footprint?

Sugar  Tomato  Chocolate  Hamburger
WF Worksheet (1): Personal Water Footprints

This exercise is designed to support your understanding about water footprints at different scales: personal, national, and global, and for different sectors of the economy: industrial, municipal, and agriculture, as well as its implication on the environment.

**Personal water footprint calculator:**

Fill in the personal water footprint calculator available at: [http://waterfootprint.org/en/resources/interactive-tools/personal-water-footprint-calculator/] to determine your water footprint by answering the following questions:

Country of residence:

Gender:

Dietary habit:  ____ Vegetarian

____ Average meat consumer

____ High meat consumer

Gross yearly income: ____________ $ per year (only that part of the family income consumed by yourself)

3. **What is your personal water footprint?** ____________

4. **How does this compare to the person sitting next to you?**

   Higher             Lower

   _______             _______
5. Why are there differences between your footprints?

6. What happens if you change your dietary habits? Does your water footprint increase, decrease, or stay the same?

7. Why do you think it changes?

8. What happens if you change your gross yearly income? Does your water footprint increase, decrease, or stay the same?
9. Are you surprised by the questions used to calculate your personal water footprint?

   Yes   No

10. What questions surprised you the most and why?
WF Worksheet (2): National Water Footprints

National Water Footprint Explorer:

Now that you have calculated your personal water footprint, we can also think about footprints on the national level. A national water footprint can be seen as an aggregate of all product and industrial footprints for a given country. In particular, we often distinguish between the national footprints for production and consumption as well as the amount of virtual water that is exported and imported. We combine all of these factors to create the water footprint of the nation as shown in Figure 1.

Figure 1. Worldwide water usage - "water footprints" of the nations.

11. Which regions of the world have some of the highest annual per capita water usage?

12. Which regions of the world have some of the lowest annual per capita water usage?
For the next questions, we are going to do some comparative analysis of external and internal water footprints. The external water footprint is the footprint associated with imported products or ingredients. Conversely, the internal water footprint is the footprint that is derived from within the country itself.

First, type the following URL into your browser:

Note: You can click and drag the map to move around the world.

We are going to compare the footprints of two countries.

13. What is the name of the first country you have selected? ____________

14. What is the external fraction of Country 1’s water footprint? _________

We are going to repeat the process by selecting another country.

15. What is the name of the second country you have selected? __________

16. What is the external fraction of Country 2’s water footprint? _________

17. What do you think accounts for these differences?

18. From a sustainability perspective, do you think it is better for a country to have a large internal or external footprint?
WF Worksheet (3): Global Water Footprints

Global Water Footprint Statistics:

Now we have considered both personal and national water footprints. The last realm to consider is the global scale.

The global water footprint of humanity is 9,087 km³/year.

Agriculture accounts for 92% of the global water footprint of humanity.

19. What is the global water footprint of agriculture? ________

20. What do you think is the largest water footprint of agriculture?

        Green        Blue        Grey

21. How would you rank each from largest to smallest?

        Green        Blue        Grey

22. Does this ranking surprise you?
Water Footprint Wrap-up:

As you have learned so far, water footprints can be calculated for lots of different products besides agricultural goods. Let’s examine some everyday items that you might be familiar with.

23. What do you think has the largest water footprint? (Check one)
   
   _______ T-shirt    _______ Jeans    _______ 2L of Soda    _______ Car

24. How would you rank each from smallest to largest?
   
   _______ T-shirt    _______ Jeans    _______ 2L of Soda    _______ Car

25. Does this ranking surprise you?
WF Worksheet (4): Connections to Water Resources

You now know how water footprints are calculated on the personal, national, and global levels. One thing you might ask yourself is: where does all of the water come from? As discussed earlier, these footprints are comprised from green, blue, and gray waters. Let’s spend some time discussing blue water. Recall that blue water is the water that is consumed from a surface reservoir or groundwater aquifer.

In Figure 2, we have three major aquifers in the United States (see hatched areas).

Figure 2. Virtual groundwater transfers for key US aquifers.

26. What are some states that are drawing the most amount of water from the Central Valley aquifer?

27. What are some states that are drawing the most amount of water from the High Plains aquifer?
28. What are some states that are drawing the most amount of water from the Mississippi Embayment aquifer?

29. What do you think causes some states to be more dependent on a given aquifer than others?

This is a Circos plot that shows how water flows from an aquifer to another country. The size of the ribbon is scaled by the volume of the virtual water flow. The color of each ribbon corresponds to the aquifer it is receiving resources from.

Figure 3. Per gallon water consumption of virtual groundwater flows.
Working with a partner, answer the following questions based on Figure 3.

30. Which aquifer shows the most virtual groundwater transfers?

   _______ Central Valley _______ Mississippi Embayment _______ High Plains

31. What country or region is the recipient of the most virtual groundwater from the Central Valley aquifer?

32. What country or region is the recipient of the most virtual groundwater from the Mississippi Embayment aquifer?

33. What country or region is the recipient of the most virtual groundwater from the High Plains aquifer?

34. Are you surprised by these results?
For the second part of this module, we are going to discuss how water footprints can be calculated at the product level for agricultural goods. A critical component of these calculations is to determine the amount of evapotranspiration that is occurring for a given crop. Evapotranspiration refers to the lumped return of liquid water to the atmosphere. The term is lumped for all water that evaporates and transpires from plants.

Figure 4. Overview of processes involved in evapotranspiration.

Globally, it is estimated that 60-70% of all water on the land surface is evapotranspired, so it is a key part of the hydrologic cycle. Additionally, evapotranspiration links the water and energy cycles.

As the climate changes and the atmosphere warms, scientists are increasingly interested and concerned with changes in evapotranspiration. They seek to understand questions such as:

- How will a warmer climate impact global patterns of evapotranspiration?
- Will more water evaporate before plants can use it?
- Will plants use water more efficiently under a higher CO2 atmospheric concentration?

For all of these questions, it is important to measure evaporation and transpiration individually.
WF Worksheet (5): Measuring Evapotranspiration with pans and towers

Measuring evapotranspiration is very challenging!

There are three common methods for estimating evapotranspiration: evaporation pans, eddy flux towers, and leaf area index.

**Evaporation Pans:**

The evaporation can be estimated using a pan and keeping track of the amount of water in it. In fact, we can calculate the evapotranspiration as follows:

\[
ET = K_{pan} \times E_{pan}
\]

where \( K_{pan} \) is the pan coefficient, and \( E_{pan} \) is the pan evaporation.

We have placed a small pan outside whose coefficient is 0.75. The water depth in the pan on day 1 is 150 mm. 24 hours later, we return to the pan. The measured water depth on day 2 is 143 mm.

**Working with a partner,** let’s estimate how much evaporation has occurred.

35. **What is the pan evaporation \((E_{pan})?\)**

36. **How much evapotranspiration has occurred overnight, \(ET?\)**
Eddy Flux Towers:

Eddy flux towers are used as an alternative estimation method. These towers carry instruments that have three major components: data/signal processor, gas analyzer, and 3D sonic anemometer. The gas analyzer is responsible for making gas (such as CO₂ and H₂O vapor) concentration measurements. The 3D sonic anemometer collects vertical and horizontal wind speed and temperature measurements. Finally, the data/signal processor obtains the results from the analyzer and anemometer and sends them back to the researcher’s laptop for further calculations and interpretation. Often, these towers are powered by solar cells.

The reason they are called eddy towers is because measurements are taken, as the air flows horizontally forming turbulent vortices (circular rotations), called “eddies”. These eddies move air molecules upwards or downwards, as they simultaneously travel horizontally. Together with air, heat and molecules of water vapor and trace gases also travel, moving upwards and downwards, creating a vertical flow of these molecules, over space and time, called “flux”.

The flux tower instruments help us measure the vertical flux of water vapor from measurements of water vapor concentration and vertical wind speed, at a given time and place. We can then input these measurements into complex mathematical models to estimate, how much evapotranspiration is occurring in the measurement location (e.g. an agricultural field).

https://upload.wikimedia.org/wikipedia/commons/6/65/Py%C3%B6rrekovarianssi-tekniikan_kaaviokuva.jpg
WF Worksheet (6): Introduction to Leaf Area Index (LAI)

The last method we will consider for measuring evapotranspiration is the leaf area index (LAI). This index helps us understand how much resistance of vapor flow through the transpiring crop or plant and evaporating soil surface exists. Before we can estimate evapotranspiration this way, we’ll need to understand what the LAI is. We can consider this index for all types of vegetation including crops and trees.

Let’s take a moment and think about how plants work. Remember that photosynthesis is the process by which the plants convert light into food. But, plants need water to help perform photosynthesis and transport food. Plants obtain water from the ground. The excess water travels to the leaves and released as water vapor during photosynthesis through the stomata, which are small openings in the leaves.

Another critical part of photosynthesis is light. The light is converted to energy (heat) by the leaves. Leaf area is a factor that affects the amount of light captured.

Let’s consider Plant A and Plant B shown in Figure 5.

Figure 5. Hypothetical plants for comparing area and coverage.
37. Which plant has more leaves?

_________ Plant A  _________ Plant B

38. Which plant do you expect to have a higher leaf index area?

_________ Plant A  _________ Plant B

39. Can you write a relationship between the area covered by the leaves and the area of the ground the leaves cover?

You have now written an equation to determine the leaf area index! The index is a unitless number, because it is a ratio of areas (the units cancel out).
WF Worksheet (7): Measuring LAI and Transpiration with Tomato Plants

You are now going to calculate LAI on your own!

Before you arrived, we started growing some tomato plants.

**Working in your team**, select one of the plants to examine.

You will notice that we have bagged some leaves on each plant.

40. **How many leaves were bagged for your plant** ($l_{bag}$)? ______________

41. **What is the bag capturing?**

Carefully remove the bag from the plant. Be careful with the contents inside of the bag, as we going to measure those contents in another step. But first, let’s determine the LAI of the tomato plant.

Using the grid on the next page, we can estimate the leaf area. First, begin by tracing your leaf on to the grid. You can be as colorful and artistic as you want to be, as long as you have a good outline of your leaf.
42. How many squares does your leaf occupy? __________________

43. What is the area occupied by your leaf?

We now have a representative sample of leaf area for your plant. We can extend this information to estimate the leaf area of the plant.

44. How many leaves does your tomato plant contain ($l_{Total}$)? __________

45. What is the relationship between the number of leaves, individual leaf area, and total leaf area?

46. Calculate the total leaf area for your tomato plant;
Estimate: What is the ground area covered by your plant?

Now that you know the total leaf area and ground area, you can determine the leaf area index of your plant.

What is the leaf area index of your tomato plant?

We are now going to determine how much water the bag has captured. The amount of water captured will help us understand how much water has transpired through the leaves over time. Using the scale, we can determine the weight of the water.

The mass of my bag before we bagged the leaves is ($m_{bag}$)? __________

What is the total mass of your bag plus the water ($m_{total}$)?

___________

What is the mass of your bag water ($m_{water}$)?  ___________
52. What is the relationship between volume and mass for a material?

53. Using this relationship, what is the volume of water captured in your bag ($v_{water}$)?
   Note: the density of water at room temperature is 1000 mg/mL.

54. How many days has your bag been collecting water ($t$)? __________

55. What is the transpiration rate for your bagged leaves ($T_{r,bag}$)?
   Note: Your rate should have the units of volume/time.
Now that you know how much your bagged leaves have transpired and how many leaves your plant has, we can also extend this to understand how much your entire plant has transpired during this time period.

56. **What is a possible relationship between the number of bagged leaves** \((l_{bag})\), **total number of leaves on your plant** \((l_{total})\), **your bagged leave transpiration rate** \((T_{R,bag})\), and **the plant’s total transpiration rate** \((T_{R,plant})\)?

Hint: Think about proportionality to help relate all of your variables.

57. **If a typical tomato has a growing season of 70 days, what is the total amount of water that it will have transpired by the end of the growing season?**

You have now estimated leaf area index and the amount of transpiration for a crop during its growing season!
WF Worksheet (8): Measuring LAI for Trees

As you have just seen in the previous worksheet, measuring the leaf area index can be a straightforward calculation for a single crop. However, if there is dense foliage, we must use indirect methods to estimate LAI. This is often the case when wanting to know the LAI for a tree.

**Within your teams**, we are going to estimate the tree’s height \(H\) and diameter \(D\).

![Diagram of tree with dimensions](image)

Figure 6. Schematic of crown (D) and height (H) dimensions on a tree.

Once, we know this information, we can calculate the total leaf area for the tree by using the following formula:

\[
\log[\text{leaf area}] = 0.6031 + 0.2375H + 0.6906D - 0.0123 \left[ \frac{D(H + D)}{2} \right]
\]

Note: the formula is for \(H\) and \(D\) in units of meters!
Let’s go outside and gather some tree data! **Working in teams**, select a tree to measure and answer the following questions. Be careful to note the units you are using.

Here are some helpful conversions for you as you obtain your measurements:

1 mm = 0.003937 inch
1 foot = 0.3048 m
1 inch = 0.0254 m

58. What is the crown height of your tree \((H)\)? ________________.

59. What is the crown diameter of your tree \((D)\)? ________________.

In order to use the leaf area formula, let’s do the math in parts.

60. What is \(0.2375 \times H\)? ________________.

61. What is \(0.6906 \times D\)? ________________.

62. What is \(\frac{D(H+D)}{2}\)? ________________.
63. Putting your results from above together, what is the log of your total leaf area?

\[
\log(\text{leaf area}) = \quad \text{log[leaf area]} =
\]

64. Now that you know the log of the total leaf area, what is your leaf area?

65. Using your crown diameter \((D)\), what is the ground area covered by your tree?

\[
A = \frac{\pi d^2}{4} = \quad A =
\]

Recall from earlier in this lesson, we related total area and ground area to develop the leaf area index.

66. What is the leaf area index for your tree?

You have just obtained the LAI of your tree! Now that we know the LAI, we will need a relationship to relate it to evapotranspiration. We have now seen how we can calculate the LAI for both crops and trees. However, as we will see in the next section, connecting LAI to evapotranspiration is a complex calculation.
WF Worksheet (9): Estimating Evapotranspiration Using the Penmen-Monteith Equation

The most common way of relating LAI to evapotranspiration is through the Penmen-Monteith equation.

\[
ET_0 = \frac{\Delta(R_n - G) + \rho_a C_p \left(\frac{e_s - e_a}{r_a}\right)}{\left(\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)\right) \lambda}
\]

where
- \( ET_0 \) = reference evapotranspiration rate
- \( R_n \) = net radiation,
- \( G \) = soil heat flux,
- \( e_s - e_a \) = vapour pressure deficit of the air
- \( \rho_a \) = mean air density at constant pressure
- \( C_p \) = specific heat of air
- \( \Delta \) = slope of the saturation vapour pressure temperature relationship
- \( \gamma \) = psychometric constant
- \( r_s \) = (bulk) surface resistance
- \( r_a \) = aerodynamic resistance
- \( \lambda \) = latent heat of vaporization

This equation allows us to determine the reference evapotranspiration for our location. It is commonly based on either short or tall vegetation. Grass is often used as a proxy for short vegetation.

Both the soil heat flux and surface resistance are functions of leaf area index! However, since this equation provides us with reference evapotranspiration, we will be using the LAI for grass.

The Penmen-Monteith equation has a lot of parameters to measure, and there are many other equations that go into calculating those parameters. To simplify the process of using the Penmen-Monteith equation, we have created a spreadsheet. There are a few critical inputs that we need to know that are location specific.

**Working in teams**, you will be able to estimate the reference evapotranspiration rate for a location of your team’s choosing.

We have already constructed the spreadsheet that you can use for your calculations:
Please enter the following URL into your browser:
As a team, select the city for which you are going to calculate evapotranspiration.

67. **What city did your team choose?**

- Belleville
- Carbondale
- Freeport
- Monmouth
- St. Charles

In your team, click on the tab that corresponds to the city you chose.

Now that you have chosen a city, please enter the critical parameters for your community on your team worksheet from **Table 1**.
Table 1. Critical parameters for Penmen-Monteith equation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Belleville</th>
<th>Carbondale</th>
<th>Freeport</th>
<th>Monmouth</th>
<th>St. Charles</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>32.2</td>
<td>32.778</td>
<td>17.222</td>
<td>26.667</td>
<td>20</td>
</tr>
<tr>
<td>T&lt;sub&gt;min&lt;/sub&gt;</td>
<td>23.3</td>
<td>23.889</td>
<td>14.444</td>
<td>18.889</td>
<td>14.444</td>
</tr>
<tr>
<td>RH&lt;sub&gt;max&lt;/sub&gt;</td>
<td>96</td>
<td>82</td>
<td>100</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>RH&lt;sub&gt;min&lt;/sub&gt;</td>
<td>50</td>
<td>50</td>
<td>86</td>
<td>70</td>
<td>83</td>
</tr>
<tr>
<td>R&lt;sub&gt;s&lt;/sub&gt;</td>
<td>285</td>
<td>273</td>
<td>56</td>
<td>142</td>
<td>59</td>
</tr>
<tr>
<td>U&lt;sub&gt;z&lt;/sub&gt;</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Z</td>
<td>133</td>
<td>137</td>
<td>265</td>
<td>229</td>
<td>226</td>
</tr>
<tr>
<td>LAT</td>
<td>38.5183</td>
<td>37.6997</td>
<td>42.2800</td>
<td>40.9333</td>
<td>41.9044</td>
</tr>
</tbody>
</table>

You should only adjust the columns in orange under the ‘Inputs’ header with the appropriate information.

Once you have entered the critical parameters into the ‘Inputs’ area, the spreadsheet will automatically calculate the reference evapotranspiration for your community.
68. What is the reference evapotranspiration rate for your community?

69. How does your evapotranspiration compare to other communities?

<table>
<thead>
<tr>
<th>Community</th>
<th>Reference Evapotranspiration Rate (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belleville</td>
<td></td>
</tr>
<tr>
<td>Carbondale</td>
<td></td>
</tr>
<tr>
<td>Freeport</td>
<td></td>
</tr>
<tr>
<td>Monmouth</td>
<td></td>
</tr>
<tr>
<td>St. Charles</td>
<td></td>
</tr>
</tbody>
</table>

Workspace for additional thoughts on these values.

70. What do you think accounts for the differences among communities?
Evapotranspiration for Crops

The Penman-Monteith equation can also be applied to crops. Now that we know the reference evapotranspiration for our community, $ET_0$, we can combine it with the crop coefficient, $K_c$, to determine the crop evapotranspiration, $ET_c$ by using the following equation:

$$ET_c = K_c ET_0$$

71. Based on what you have learned thus far, do you think the crop coefficient, $K_c$, is the same throughout the growing season?

Yes  No

72. Why did you choose that option?
Working with a partner, let’s compare evapotranspiration for some crops. In Table 2, we have different crop coefficients for several crops.

Table 2. Crop coefficients for select vegetation.

<table>
<thead>
<tr>
<th>Crop</th>
<th>$K_{c,ini}$</th>
<th>$K_{c,mid}$</th>
<th>$K_{c,end}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>0.4</td>
<td>1.2</td>
<td>1.15</td>
</tr>
<tr>
<td>Blueberries</td>
<td>0.4</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>Corn</td>
<td>0.3</td>
<td>1.15</td>
<td>0.25</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0.7</td>
<td>1</td>
<td>0.95</td>
</tr>
<tr>
<td>Potato</td>
<td>0.5</td>
<td>1.15</td>
<td>0.75</td>
</tr>
<tr>
<td>Raspberries</td>
<td>0.4</td>
<td>1.2</td>
<td>0.75</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>0.7</td>
<td>1.05</td>
<td>0.8</td>
</tr>
</tbody>
</table>

What is the evapotranspiration for your crops throughout the growing season?

You can answer this question by completing the table below. There is space on the next page to complete your calculations. Don’t forget to use the appropriate crop coefficient value for each column.

<table>
<thead>
<tr>
<th>Crop</th>
<th>$ET_{c, ini}$ (mm/day)</th>
<th>$ET_{c, mid}$ (mm/day)</th>
<th>$ET_{c, end}$ (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Workspace to complete calculations

74. How do your evapotranspiration values compare to your partner’s values?

75. If you had a field with 1000 plants on 1 acre, how much evapotranspiration would be occurring on your farm for a single day?
76. Now imagine that there are 1 million acres of crops growing that are similar to yours. How much transpiration is occurring on those farms in a single day?

77. Do crop coefficients have any correlation to irrigation?
WF Worksheet (10): Global LAI and Evapotranspiration

It is important to understand if local scale measurements can be aggregated to arrive at large scale estimates, such as the national estimates we have discussed earlier, in the afternoon. We can also extend our leaf area index concept globally.

Figure 7 presents a map of global leaf area index values. Darker areas represent regions with higher leaf area indices.

Figure 7. Global leaf area index values in m²/m²

78. What types of vegetation do you think grow in the brown parts of the global map?

79. What types of vegetation do you think grow in the green areas?
Now we can also see evapotranspiration on a global scale as shown in Figure 8. As with the leaf area index in Figure 7, darker regions represent areas that have higher evapotranspiration rates.

80. Do you notice any similarities between the color patterns on this global leaf area index and evapotranspiration maps?

81. For global evapotranspiration, what types of landscapes do areas in white correspond to?

82. Which areas demonstrate the highest levels of evapotranspiration and why?
References

   http://extension.uidaho.edu/kimberly/files/2014/06/Penman_Monteith_Encyclopedia_Soils_00399.pdf

   http://edis.ifas.ufl.edu/ae459

   http://www.sws.uiuc.edu/warm/

   http://www.fao.org/docrep/x0490e/x0490e0b.htm#tabulated%20kc%20values

5. Koirala, S. University of Tokyo.  
   http://hydro.iis.u-tokyo.ac.jp/~sujan/research/gswp3/test-simulations/land-cover-classification.html

6. Crosson, W. et al. The water cycle from space: Use of satellite data in land surface hydrology and water resource management. NASA.  
   http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100040565.pdf
Additional Notes
Additional Notes
Lesson Developers
Kwon Choe Jong (UIUC/CEE alumni)
Strathmann, Timothy (CSM/CEE)
Tenorio Raul (UIUC/CEE)

2015 Lesson instructor
Tenorio Raul (UIUC/CEE)
Water Quality

We use water every day. For most of us it is readily available from our water taps, showers, and drinking fountains. We water our plants and yards, go swimming at the pool, and wash our cars. But where does our water come from and how is it treated to make it safe to use and drink? It may be hard to think of water as a scarce resource since it covers over 70% of the Earth; however, only 3% of Earth’s water is freshwater. And over two thirds of that is trapped in glaciers!

The availability and quality of water depends on the location. In most of the United States we can access clean and plentiful water from lakes, rivers or even underground sources. However some parts of the U.S., like the southwest, are facing water shortages and droughts. Several health and sanitation issues especially in developing countries in Africa, South America and Asia can be resolved by the provision of clean, drinking water.

Water must be treated before it is safe for human consumption. An important concern of environmental engineers is the treatment of drinking water. In the U.S., drinking water treatment plants use multiple processes such as coagulation, sedimentation, filtration, and disinfection to remove harmful bacteria, viruses, particles, and chemicals. This module will provide the students with an overview of different water sources, the contaminants of concern to human health and how they are regulated and the engineering solutions that can help people across the world access clean, drinking water.
WQ-Worksheet (1)
Water Use and Challenges We Face

The objective of this lecture is to learn basics of water in our environment and think how our life is impacted by the uses of water resources. Answer the following questions as the lecture proceeds.

I. Water in Nature and Its Cycle
1. What is water? List at least three different forms water exists in nature.

2. Let’s learn about water cycle. Open web browser and type in following URL to address bar (http://www.epa.gov/ogwdw/kids/flash/flash_watercycle.html) and press enter. In your own words, briefly describe the water cycle.

3. What percentage of water on Earth is fresh-water? _____

4. What percentage of freshwater is available as groundwater or surface water? _____
II. Water use in human activities
1. List at least three different ways water is used by human activities.

2. Discuss with your group members and then guess how much water is used for different human activities, matching the choices at the right with each category on the left.

   __ Taking a shower  
   __ Watering the lawn  
   __ Washing the dishes  
   __ Washing clothes  
   __ Flushing the toilet  
   __ Brushing teeth  
   __ Drinking  
   __ Needed to process one can of fruit or vegetable  
   __ Needed to produce one ton of a steel  
   __ Needed to manufacture a new car and its four tires

   A.) 1 gallon  
   B.) 30 gallons  
   C.) 15-30 gallons  
   D.) 1/2 gallon  
   E.) 180 gallons  
   F.) 4-7 gallons  
   G.) 9-20 gallons  
   H.) 39,090 gallons  
   I.) 62,600 gallons  
   J.) 9.3 gallons

1 Gallon of Water =

About 7.5 regular bottles water
3. Are you surprised by the amount of water used for any particular activities? If so, please list them below.

4. For the activities below, rank the order (i.e., 1 to 4 where 1 is greatest and 4 is lowest) of estimated use of water in the United States

___ Domestic use
___ Thermoelectric power
___ Irrigation
___ Public supply
III. Global water crisis

1. Based on 2008 UNICEF report, how many people in the world do not have access to a clean water supply?

2. Assuming there are 6.7 billion people in the world, what percentage of total population do not have access to a clean water supply?
3. Let’s create time schedule for one day. On left bar, write down your typical time schedule. Now on right bar, write down how your typical time schedule needs to be adjusted if you have to spend 4 hours each day to collect water.

<table>
<thead>
<tr>
<th>Time</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 -1 AM</td>
<td>12 -1 AM</td>
</tr>
<tr>
<td>1-2 AM</td>
<td>1-2 AM</td>
</tr>
<tr>
<td>2-3 AM</td>
<td>2-3 AM</td>
</tr>
<tr>
<td>3-4 AM</td>
<td>3-4 AM</td>
</tr>
<tr>
<td>4-5 AM</td>
<td>4-5 AM</td>
</tr>
<tr>
<td>5-6 AM</td>
<td>5-6 AM</td>
</tr>
<tr>
<td>6-7 AM</td>
<td>6-7 AM</td>
</tr>
<tr>
<td>7-8 AM</td>
<td>7-8 AM</td>
</tr>
<tr>
<td>8-9 AM</td>
<td>8-9 AM</td>
</tr>
<tr>
<td>9-10 AM</td>
<td>9-10 AM</td>
</tr>
<tr>
<td>10-11 AM</td>
<td>10-11 AM</td>
</tr>
<tr>
<td>11-12 AM</td>
<td>11-12 AM</td>
</tr>
<tr>
<td>12-1 PM</td>
<td>12-1 PM</td>
</tr>
<tr>
<td>1-2 PM</td>
<td>1-2 PM</td>
</tr>
<tr>
<td>2-3 PM</td>
<td>2-3 PM</td>
</tr>
<tr>
<td>3-4 PM</td>
<td>3-4 PM</td>
</tr>
<tr>
<td>4-5 PM</td>
<td>4-5 PM</td>
</tr>
<tr>
<td>5-6 PM</td>
<td>5-6 PM</td>
</tr>
<tr>
<td>6-7 PM</td>
<td>6-7 PM</td>
</tr>
<tr>
<td>7-8 PM</td>
<td>7-8 PM</td>
</tr>
<tr>
<td>8-9 PM</td>
<td>8-9 PM</td>
</tr>
<tr>
<td>9-10 PM</td>
<td>9-10 PM</td>
</tr>
<tr>
<td>10-11 PM</td>
<td>10-11 PM</td>
</tr>
<tr>
<td>11-12 PM</td>
<td>11-12 PM</td>
</tr>
</tbody>
</table>

Based on your two timesheets, what activities (e.g., leisure time, schoolwork) were affected the most by adding time to collect water?
4. List at least two water related diseases.

5. How can we contribute to decreasing the amount of water use? Please list at least four things you can do at home to save water. Also please list at two things industry can do to save water.

IV. Water quality and pollution
1. What are sources of water pollution? List at least four sources.

2. What are current strategies to prevent water pollution caused by human activities?
(Optional) Water Knowledge Quiz
Open web browser in the computer and type in following URL to address bar (http://www.epa.gov/safewater/kids/flash/flash_qagame.html) and press enter.

References:
http://ga.water.usgs.gov/edu/waterrycleprint.html
http://scienceblogs.com/aardvarchaeology/2008/03/tap_water_is_not_a_naturally_o.php
http://www.pinnycoren.com/2007/02/19/marketing-wisdom/bottled-water-packaging-comparison/
http://www.water.ca.gov/recycling/
http://schools.cbe.ab.ca/b344/Trees%20Forests%20and%20Wetlands/wetland_functions.html
Measuring Water Quality Parameters: Getting Our Feet Wet.

**DO NOT DRINK WATER USED IN THIS LAB!!**

**Background**

I. Water Quality

Water quality refers to the physical, chemical, and biological characteristics of water. It is often measured to determine whether the water is suitable for human uses or other purposes such as health of ecosystems. Regulatory agencies like the U.S. Environmental Protection Agency (USEPA) enforce laws to monitor and treat different constituents in water to ensure that water is safe for different purposes (e.g., drinking, industrial use, release to rivers and lakes).

Following is a list of indicators that are often measured for drinking water:

- pH
- Color of water
- Water hardness
- Taste and odor
- Dissolved salts
- Dissolved metals
- Heavy metals
- Other contaminants that pose risk to human health

In this lab experiment, we will characterize the quality of water samples collected from different sources and decide whether or not they would be safe to drink (**DO NOT DRINK ANY OF THE SAMPLES USED IN THIS LAB!!**).

II. Test Strips and Color Charts

Water quality indicators are often expressed in numerical values. For example, concentration is expressed in mg/L (milligrams per liter). A simple way to measure water quality indicators is to use specially designed test strips. When a test strip is in
contact with a specific chemical, the strip changes color. Color intensity corresponds to
the chemical concentration in the solution. A *calibration* color chart can be made by
preparing a set of standard samples with known concentrations. Each concentration will
yield a specific color intensity. The concentration of chemicals in unknown samples can
then be measured by (1) observing the color intensity of test strip that is contacted with
the unknown sample and then (2) matching the unknown sample color intensity with
the color intensity of the color chart. Below, is an example of the color chart for pH.

III. Electronic probes

For more accurate and precise measurements of water quality, electronic meters
equipped with special measuring probes can be used. The probes measure the electrical
potential between a target solution (a water sample) and an internal reference solution
inside of the probe (usually potassium chloride, KCl). The probe converts the measured
electrical potential between the two solutions into a numerical water quality parameter
value (e.g. pH units). Similar to test strips, these electronic meters need to be calibrated
before use to precisely convert from electrical potentials to chemical concentrations in
the solution.

**Procedures**

I. Getting Started

1. Students will be divided into 5 teams of 4 students.
2. Walk to Boneyard Creek. Each team will walk to a sampling station along the
creek.
3. Decide the roles of each group member. Each group will need 1 Field Sampler, 2
   Analyzers, and 1 Recorder.
4. Each group will be given a sampling kit which includes the following:
   a. 4 beakers containing samples #2 - #5
      i. *Note: Boneyard Creek measurements will be done directly in the
creek.*
   b. 1 pH meter
   c. 5 turbidity sample cells, 1 for each sample
   d. 5 Total hardness test strips, 1 for each sample
   e. 5 Nitrate/Nitrite test strips, 1 for each sample
   f. 5 Free chlorine test strips, 1 for each sample
   g. 5 Iron test strips, 1 for each sample
h. Squirt bottle
i. Kimwipes and paper towels
j. Water proof boots

II. Water Quality Measurement: Getting Our Feet Wet

*Note: Please read the entirety of section II before beginning. Organize your teams by assigning roles to each team member.*

*Sharing Equipment: Each group has their own test strips and pH meter. However, we only have 2 Turbidity Meters and 3 TDS electrodes. So, if your group needs either of these probes, let the instructor know so that they can retrieve one from another group.*

5. Students will measure the pH, Total Dissolved Solids (TDS), turbidity, total hardness, nitrate/nitrite, free chlorine, and iron concentrations of 5 samples using test strips and probes. *(See Useful Information Section for instructions)*
   - Boneyard Creek measurements will be made by placing probes or test strips directly into the creek.
   - Measurements for all other samples will be made by placing probes or test strips inside of beakers.
   - Each group will have 1 Field Sampler, 2 Analyzers, and 1 Recorder.

6. **Field Samplers:**
   a. The Field Sampler will wear waterproof boots and walk out into Boneyard Creek to measure water quality parameters using the test strips.
   b. After the test is complete, the used strip should be returned to the Analyzers for assessment.
   c. The 2 Analyzers will retrieve the results from the Field Sampler, and give the Field Sampler a new test strip to measure as she needs them. The Analyzers can then determine the concentrations of the used strip.
   d. The Field Sampler will also need the assistance of 2 Analyzers to measure the pH, Total Dissolved Solids (TDS), and turbidity of Boneyard Creek using the electronic meters.
   e. **Please note:** Only probes get into the water. The electronic meters should stay out of the water at all times! Analyzers should hold meters on land while Field Samplers submerge probe in Creek water.

7. **Analyzers:** For each sample, Analyzers will measure different water quality parameters using test strips and probes for samples #2 - #5. Field Samplers will use test strips and probes on the Boneyard Creek Sample (#1).
**Using test strips**

a. Dip a test strip into the sample for a certain contact time with or without gentle back-and-forth motion (Contact time varies for different test strips, read the Useful Information section).
b. Remove and shake strip to remove excess sample.
c. Wait the designated amount of time (see Useful Information section)
d. Match with the best color to determine concentration of each test and record in the data log sheet.

**Using probes**

a. For measurement using probe meters, dip a probe into the sample for a certain contact time (no back-and-forth motion), and read the value shown on the meter’s front screen once it stabilizes and remains constant.

8. **Recorders:** The Recorder is the quality assurance person. After the Analyzers have agreed on the results, the Recorder will make a final judgment and record the results in the **Data Log Sheet** (in the last few pages). It is also the Recorder’s job to lead the team and oversee that instructions are followed precisely. If the other team members are unsure about what to do next, the Recorder should read the instructions aloud and keep up the pace of the experiment.

**III. Useful Information:**

1. **Test Strip Instructions**

a. **Total Hardness:** Dip one strip into a sample for **3 seconds**, without motion. Remove and immediately match to the color chart. Complete color matching within 1 minute. Units are in mg/L.
b. **Nitrate and Nitrite:** Dip one test strip (both pads submerged) into a water sample for **2 seconds**, remove, wait **1 minute**, and match Nitrate/Nitrite colors. Complete color matching within 1 minute.

Nitrate in mg/L as N (end pad)

![Nitrate color chart]

Nitrite in mg/L as N (pad nearest handle)

![Nitrite color chart]
c. *Free Chlorine Test*: METHOD A: Dip one test strip into a **20 mL** sample for **10 seconds** with a constant, gentle, back and forth motion. Remove the strip and match METHOD A colors. Units are in mg/L
d. *Iron Test:* Dip one strip into sample (be sure pad is in contact with liquid) for 30 seconds with constant, gentle back and forth motion. Remove strip, wait 2 minutes, then match with closest color on color chart. Units are in mg/L.

2. **Electronic Meters**
   
   a. Water Quality Meter, left. Probe connections, right.
b. **Probe attachments:** pH electrode, right. TDS electrode, left. Connect only ONE at a time.

   i. **pH measurement:** Connect pH electrode ONLY by pressing it on and twisting to lock. Press Power. Submerge the pH electrode glass bulb into a sample (no motion required). Once the value stabilizes, you may record. If it fluctuates closely between two values, select one to record. No units (“pH units”).

   ii. **TDS measurement:** Connect TDS electrode by unlocking the black switch, pressing the connector in, and re-locking the black switch. Press power. Press the “C” button once. Submerge the broad end of the TDS electrode into a sample (no motion required). Once the value stabilizes, you may record. If it fluctuates closely between two values, select one to record. No units (“pH units”)
c. *Turbidity Meter:*
   i. Compartment closed, left. Compartment open, right.

d. *Turbidity sample cell, left. Sample cell in compartment, right.*
i. *Turbidity Measurements:* Fill sample cell at least above the 10 mL mark. Open the sample compartment and place the sample cell into the compartment aligning both the white markers. Close the compartment and press TEST/CAL. “test” will flash across the screen before it displays the reading in Nephelometric Turbidity Units (NTU). Record the value.
Cool Facts! (from EPA.gov)

a. pH: drinking water is typically in the pH range of 6 – 8.5

b. TDS
   ii. Palatability – excellent to good < 600 mg/L TDS
   iii. Freshwater < 1,000 mg/L TDS
   iv. Brackish water 1,000 – 10,000 mg/L TDS
   v. Saline water 10,000 – 30,000 mg/L TDS
   vi. Brine >30,000 mg/L TDS

c. Turbidity
   vii. Drinking water < 1 NTU
   viii. Low turbidity streams < 20 NTU

d. MCL = Maximum Contaminant Limit; a legal threshold limit on the amount of a substance that is allowed in public water systems under the Safe Drinking Water Act.
   ix. Iron MCL = 0.3 mg/L
   x. Nitrate MCL = 10 mg/L as N
   xi. Nitrite MCL = 1 mg/L as N

e. Total Hardness
   xii. “Soft” water is between 0 – 120 mg/L Total Hardness
   xiii. “Hard” water is between 180 – 1000 mg/L Total Hardness
   xiv. Hard water is not harmful to one’s health

f. Chlorine
   xv. The Maximum Residual Disinfectant Level (MRDL) is the level of chlorine in drinking water that does not cause adverse health effects to humans. This level is 4 mg/L.
DO NOT DRINK WATER USED IN THIS LAB!!

Team Name:

I. Experimental results

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value (test strip)</th>
<th>Value (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please list any other characteristics (e.g., color, smell) of this water sample below:

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value (test strip)</th>
<th>Value (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please list any other characteristics (e.g., color, smell) of this water sample below:
#3 Groundwater:

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value (test strip)</th>
<th>Value (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please list any other characteristics (e.g., color, smell) of this water sample:

#4 Mystery Sample:

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value (test strip)</th>
<th>Value (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please list any other characteristics (e.g., color, smell) of this water sample:
#5 Mystery Sample:

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value (test strip)</th>
<th>Value (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please list any characteristics (e.g., color, smell) of this water sample:

II. Discussion

Do any of the samples have particularly high values for total hardness, free chlorine, etc.? Why do you think that is?

#1 Boneyard Creek:

#2 Tap Water:

#3 Groundwater:
Based on the parameters you have measured, can you guess the source of the mystery samples? What information helped you reach this conclusion? Good luck!

#4 Mystery Sample:

#5 Mystery Sample:

Based on the parameters you have measured, which samples do you think are safe to drink? Not Safe to drink? What other “things” could there be in the water samples (parameters we HAVEN’T measured) that would make them unsafe to drink?

#1 Boneyard Creek:

#2 Tap Water:

#3 Groundwater:

#4 Mystery Sample:

#5 Mystery Sample:
Environmental nanotechnology is one part of a larger field called nanotechnology. Nanotechnology is the science of understanding and controlling matter at the nanoscale, which means the size of the objects are between 1 - 100 nanometers. When materials are considered at such a tiny size, they sometimes display different physical, chemical and biological properties. The field of environmental nanotechnology seeks to understand these different properties as they relate to environmental applications and manipulate nano-sized objects to develop new materials for use in the environment.

One common environmental nanotechnology material is a catalyst. Catalysts are materials that make reactions occur faster and, in some cases, occur at all. Catalysts can be used for many purposes and in this lesson, we will discuss their use for contaminant remediation. When it comes to remediation, catalysts have the benefit of chemically changing the contaminant to non-harmful byproducts. This mechanism is distinctly different than the sorption mechanism we will see using activated carbon (AC). Activated carbon is not a nanotechnology, but it does display some nano-properties and is commonly used in remediation. Sorption is different than catalysis because sorption does not chemically change the contaminant; it merely removes it from the water and retains it within the activated carbon. During the experiment conducted during this section, you will use a catalyst and activated carbon to remediate a contaminant and we will discuss the pros and cons of their use.
**ENT- Worksheet (1)**

**Environmental Nanotechnology Introduction**

I. What is Nanotechnology?

1. What is nanotechnology? List at least three ideas about what nanotechnology involves.

2. Scientifically, what is nanotechnology?

3. Discuss with your group members and then try to match the nano-sizes of the following items:

   __ Sheet of paper          A) 45,500,000 nm
   __ One atom of gold (Au)   B) 2.5 nm
   __ One inch               C) 80,000 nm
   __ Diameter of DNA        D) 100,000 nm
   __ Strand of hair         E) 1/3 nm

4. Go to [http://htwins.net/scale2/](http://htwins.net/scale2/) and scroll up and down to see how the different items relate to each other in size. List two things that are around nanometer size.
5. Let’s think about nanotechnology and the environment.

   a. How could nanotechnology be beneficial to the environment?

   b. How could nanotechnology be harmful to the environment?

II. Environmental Nanotechnology

1. List two main applications of environmental nanotechnology for water treatment:

   A. ________________________________

   B. ________________________________

2. How do catalysts help chemical reactions? Draw the activation energy chart below:

   ![Activation Energy Chart]

3. What is an example of a catalytic process that is used in the car you drive?
III. Photocatalysts

1. What is the key component required to make photocatalysts work?

2. Why are photocatalysts so appealing to environmental engineers?

3. Write the chemical formula for titanium dioxide. _________

4. What are some of the common uses for titanium dioxide?
   a. 
   b. 
   c. 

6. Why is surface area such an important property of materials for remediation?


8. Why is surface area important for TiO₂? What does the increased surface area allow?
IV. Dyes

1. What is your favorite color? List 3 things you own in that color.

2. Discuss with your group and list 5 ways dyes are used in everyday life.

3. List some negative impacts dyes have on the environment and human health.

4. What is methyl orange primary used for?

5. What does UV-Vis Spectrophotometer do?
V. Photocatalytic and AC Experiment

The purpose of this experiment is to use nanotechnology for an environmental application and test the effectiveness of activated carbon (AC) and titania in degrading methyl orange. Each team will conduct two experiments and take samples during both experiments. The samples will be analyzed using the UV-Vis and the results will be plotted. Convert absorbance to concentration using the calibration curve provided. Each team will plot their results on the next page and a class-wide plot of results will be made on the large posters.

**Team Name:**

*(You’ll need this later when we plot the results.)*

Volume of water: _________  Speed of stir plate: _________

Mass of catalyst: _________

Calculate concentration of catalyst:

Mass/Volume of dye: _________

Calculate concentration of dye:

**Steps:**
1. Plug in stir plate
2. Add stir bar to bottle
3. Add catalyst to bottle
4. Add water to bottle
5. Add methyl orange to bottle
6. Turn on stir plate and start timer
7. Take samples
   1. Record sample number, sample time and observations of the bottle/system
8. Analyze samples
**TiO₂ Experiment:** Record your team’s sample results on the chart below.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Time</th>
<th>Color Observation</th>
<th>Absorbance Reading</th>
<th>Convert to Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What observations can you make about the rate of degradation of methyl orange?
AC Experiment: Record your team’s sample results on the chart below.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Time</th>
<th>Color Observation</th>
<th>Absorbance Reading</th>
<th>Convert to Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What observations can you make about the rate of sorption of methyl orange?
The following data were obtained using calibration standards and the UV-Vis spectrophotometer.

<table>
<thead>
<tr>
<th>Absorbance</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.048</td>
<td>1.0</td>
</tr>
<tr>
<td>0.712</td>
<td>10.0</td>
</tr>
<tr>
<td>2.6518</td>
<td>50.0</td>
</tr>
</tbody>
</table>

From this data, the chart below was constructed. Using this chart and the linear trend line shown,
convert your UV-Vis absorbance readings into a concentration value.

Plot the concentrations in your workbook and on the large plot in the classroom.
1. Discuss some observations about the experiment with your group. What do you notice about your experiment?

2. Was the methyl orange degraded as quickly as you expected? Why or Why not?

3. Was it adsorbed in the activated carbon as quickly as you expected? Why or Why not?

4. How do you think stirring impacted the experiment? What about shaking?
5. What are some ways you think the performance could be increased? List 3.

A. _______________________________

B. _______________________________

C. _______________________________

6. We discussed current research that is attempting to increase the effectiveness of TiO$_2$ by combining it with carbon. What findings did the researchers discuss regarding the combination of TiO$_2$ and activated carbon?

Was the hybrid material better or worse than the standard P25 you used for the experiment today?
Visualization of Environmental Data

Thursday, June 25, 2015
Lesson Developers
Balasubramanian Srinidhi (UIUC/CEE)

2015 Lesson Instructors
Balasubramanian Srinidhi (UIUC/CEE)
Tianye Sun (UIUC/CEE)
Why visualize environmental data?

Environmental scientists and managers employ visualization tools to study different environmental phenomena; develop forecasts for the future and communicate their results. We are exposed to visualization of environmental data on a daily basis—think about the local weather reports on the radio and in the newspapers, internet predictions of rainfall across the world, status of pollen for the benefit of asthma patients and national trends of the air quality index. The list of examples is endless! Environmental data for all these purposes is usually collected in the field at different point locations. Visualization tools are invaluable in condensing these vast quantities of complex spatial information in meaningful forms for stakeholders like scientists, government and the public.

This module focuses on the role of cartography as a medium for visual communication of environmental data. Students will learn to interpret and develop maps using basic concepts of cartography and principles of Geographical Information Systems (GIS). They will develop a GIS data layers and maps using data obtained from the Ammonia Monitoring Network (AMoN)\(^1\), a national network of air quality stations across USA. Different features of spatial representation of data will be explained followed by the exploration of spatial patterns of ambient ammonia concentrations in USA. The module is designed using the commercial software package ArcGIS 10.2.2\(^2\).


\(^2\) Maps throughout this module will be created using ArcGIS® software by Esri.
**VED-Worksheet (1) – Reading a Map**

Let’s learn about the basic concepts of developing and reading maps. A map has been provided to you here. Please, answer the following questions.

- a. The study and practice of developing maps is called ____________________

- b. Let’s make a few interpretations from the given map?
  
  - i. *The map depicts the region of ____________________________*
ii. __________________ parameter is represented on the map

iii. *The maximum recorded rainfall is ________________

iv. *The data for the map has been obtained from ________________

v. *The black dots on the map represent ________________

c. Maps are used for a wide variety of applications in environmental engineering. Suggest one example for each application mentioned below.

   i. Identify locations

   ii. Mapping quantities

   iii. Forecasting

   iv. Mapping change
VED-Worksheet (2) - Developing a Map
The following table indicates total depth of precipitation (cm) in USA in 2012. Data represent the average precipitation across an entire state. Based on this information, create a precipitation map with your group.

<table>
<thead>
<tr>
<th>State</th>
<th>Precipitation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK</td>
<td>57</td>
</tr>
<tr>
<td>AL</td>
<td>148</td>
</tr>
<tr>
<td>AR</td>
<td>128</td>
</tr>
<tr>
<td>AZ</td>
<td>35</td>
</tr>
<tr>
<td>CA</td>
<td>56</td>
</tr>
<tr>
<td>CO</td>
<td>40</td>
</tr>
<tr>
<td>CT</td>
<td>128</td>
</tr>
<tr>
<td>DE</td>
<td>116</td>
</tr>
<tr>
<td>FL</td>
<td>138</td>
</tr>
<tr>
<td>GA</td>
<td>129</td>
</tr>
<tr>
<td>IA</td>
<td>86</td>
</tr>
<tr>
<td>ID</td>
<td>48</td>
</tr>
<tr>
<td>IL</td>
<td>99</td>
</tr>
<tr>
<td>IN</td>
<td>106</td>
</tr>
<tr>
<td>KS</td>
<td>73</td>
</tr>
<tr>
<td>KY</td>
<td>124</td>
</tr>
<tr>
<td>MA</td>
<td>121</td>
</tr>
<tr>
<td>MD</td>
<td>113</td>
</tr>
<tr>
<td>ME</td>
<td>107</td>
</tr>
<tr>
<td>MI</td>
<td>83</td>
</tr>
<tr>
<td>MN</td>
<td>69</td>
</tr>
<tr>
<td>MS</td>
<td>150</td>
</tr>
<tr>
<td>MT</td>
<td>39</td>
</tr>
<tr>
<td>ND</td>
<td>45</td>
</tr>
<tr>
<td>NE</td>
<td>60</td>
</tr>
<tr>
<td>NH</td>
<td>110</td>
</tr>
<tr>
<td>NJ</td>
<td>119</td>
</tr>
<tr>
<td>NM</td>
<td>37</td>
</tr>
<tr>
<td>NV</td>
<td>24</td>
</tr>
<tr>
<td>NY</td>
<td>106</td>
</tr>
<tr>
<td>OH</td>
<td>99</td>
</tr>
<tr>
<td>OK</td>
<td>93</td>
</tr>
<tr>
<td>OR</td>
<td>69</td>
</tr>
<tr>
<td>PA</td>
<td>109</td>
</tr>
<tr>
<td>PR</td>
<td>n/a</td>
</tr>
<tr>
<td>SC</td>
<td>126</td>
</tr>
<tr>
<td>SD</td>
<td>51</td>
</tr>
<tr>
<td>TN</td>
<td>137</td>
</tr>
<tr>
<td>TX</td>
<td>73</td>
</tr>
<tr>
<td>UT</td>
<td>31</td>
</tr>
<tr>
<td>VA</td>
<td>112</td>
</tr>
<tr>
<td>VT</td>
<td>109</td>
</tr>
<tr>
<td>WA</td>
<td>98</td>
</tr>
<tr>
<td>WI</td>
<td>83</td>
</tr>
<tr>
<td>WV</td>
<td>115</td>
</tr>
<tr>
<td>WY</td>
<td>33</td>
</tr>
</tbody>
</table>

a. What symbology (legend you use) did you choose to represent this map?

b. How does your map differ from the other maps?

If there is no data for a state mark that as ‘not defined’. Remember data is not always available when you work with real life data.
VED-Worksheet (3) –Geographical Information Systems

a. What does GIS stand for? Can you name the five cornerstones of GIS based approach?

Now let’s learn how to interpret a GIS database! For this exercise, we use data obtained from Ammonia Monitoring Network (AMoN) measurements. AMoN is the only network in United States to provide a long term record of concentrations of ammonia (NH₃) gas in the atmosphere.

- To develop a GIS database, we will be using the software ArcGIS 10.2.2. Please ensure that your computer is turned on. If you are not logged in, use the details below or call an assistant for the same.
- **Login details:** Username = engr-register-user
  Password: R3gister!!!)))
- The instructions may appear to be long, but don’t despair! These instructions are detailed to assist you in carrying out a meaningful analysis. Once you are familiar with the display screen, it becomes simpler to follow the instructions.
b. Let’s analyze the ArcGIS database. Follow the instructions and answer the questions

**Step 1: Open the ArcGIS Map document**

- Double-click the ESRI ArcMap Document ‘2015_GAMES_AMoN’ file.

  Note: A database has been prepared for you. There should be two files in the left pane of the ArcMap window. Let us know if this does not appear on your screen.

  This step can take a few minutes.

**Step 2: Reading spatial information from data layers**

*Identifying data and its format is important for a meaningful GIS analysis.*

- Right click on the layer ‘AMoN_sites’ >> **Open Attribute Table**.
- Can you identify the column containing unique information about AMoN measurement sites? Fill in the worksheet in column 2 and 3 in question c-(i).
- Repeat the same procedure with the layer entitled ‘US_Mainland’. Can you identify the column containing unique information about this layer? Fill in the worksheet in column 2 and 3 in question b-(i).

---

i. *Let’s discuss the different spatial layers available in the GIS database.*

<table>
<thead>
<tr>
<th>Name of the Spatial Layer</th>
<th>Column name that identifies the unique attribute in this layer</th>
<th>Type of map data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Step 3: Adding spatial information from Excel worksheets

- Click on **Add Data** function ( ) >> Navigate to ‘AMoN_data.xls’ >> Click Add >> Choose ‘Concentration Data$’ >> Add.
- Click **Add Data** function ( ) >> navigate to ‘AMoN_site_data.xls’ >> Select ‘Site_Data’ >> Add.
- Answer question c-(ii). You can view the added Excel worksheets by right clicking on them and then choosing **Open**.
- Click on **Save** function ( ). It is important to save your information frequently to save time and resources that is required in duplicating these efforts.
- Close the tables that are open before you proceed to Step 4.

ii. What information do the two Excel sheets contain?

<table>
<thead>
<tr>
<th>Excel document</th>
<th>Information contained in Excel document</th>
<th>Information needed for GIS analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 4: Combining spatial information from different data layers

Combining spatial information allows users to derive new and meaningful interpretations. Here we combine four independent layers to interpret the database. The Join and Relates function only works on layers and not Excel worksheets.
Right click on the layer ‘AMoN_sites.’ >> Joins and Relates >> Join. In this step we “join” the spatial information of the AMoN measurement stations with the actual data measured at these sites.

Select the following information for each related question:

- What do you want to join in this layer?: “Join attributes from a table”
- Choose the field in this layer that the join will be based on: “Name”
- Choose the table to join to this layer, or load the table from disk: “Concentration_Data$”.
- Join Options: “Keep only matching records”. This is chosen because only a few measurement sites have valid data. Click OK.

Verify if new data has been added – Open attribute table for AMoN_sites’.

Can you spot the new additions? If yes, move the table to the second screen so that you can work more efficiently. If not, call one of the assistants.

Repeat the process with the ‘Site_Data’ excel sheet. Right click on the layer ‘AMoN_sites.’ >> Joins and Relates >> Join. Choose the following options:

- What do you want to join in this layer?: “Join attributes from a table”
- Choose the field in this layer that the join will be based on: “Name”
- Choose the table to join to this layer, or load the table from disk: “Site_Data$”.
- Join Options: “Keep only matching records”. This is chosen because only a few measurement sites have valid data.

You have now completed the step required to combine multiple spatial layers. Move to Step 5 where you will interpret data.

**Step 5: Interpreting the attribute table**

In this step, we will use several option within ArcGIS 10.2.2. Each option will allow you to make a unique interpretation from the existing GID database that you have developed.

Follow each instruction below and answer the corresponding question.

- Right click on the worksheet ‘Site_Data$’ >> Open.
• **To identify the total number of AMoN sites** -
  Check the Records value at the base of the table. Look out for (0 out of <number> selected). Close the table.

  The total number of AMoN measurement sites is ___________________

• Right click on the layer ‘AMoN_sites’>> **Open Attribute Table**. Repeat the same procedure to identify record of total number of AMoN sites with valid measurement data in 2013. The answer will be different from the one before because not all sites were active in 2013 nor did all active sites collect valid data.

  The total number of active AMoN measurement sites is ___________________

• **To identify the number of stations in the State of Illinois** -
  Right click on the column ‘SITEID’ >> Choose ascending. Count the number of rows that have the letters ILxx mentioned. (eg IL37).

  Total number of AMoN sites in the State of Illinois is ________________.

• **To identify the lowest and highest recorded NH₃ concentrations** -
  In the attribute table, locate the parameter ‘Avg_conc’ and right-click the top of the column. Select ‘Sort Ascending’ or “Sort Descending’ depending on whether the maximum or the minimum value is required. The station ID will correspond to the value under ‘SITEID’ and name will be listed under ‘name’. Close the attribute table after you note the values.

  Highest recorded ambient NH₃ concentration (µg/m³) in 2013 is ______________ and is recorded at the station _____________________.

  Lowest recorded ambient NH₃ concentration (µg/m³) in 2013 is ______________ and is recorded at the station _____________________.

To identify features of any point from the map -

Click on Identify function (i) and then on the point of interest. A pop up table will contain information about the data point. For the data point you chose, answer the following questions.

Name of Station is _________________. SITE ID is ______________.

It is located at an elevation of ________ m.

The site started on ____________ date and stopped collecting data on ____________ date.
VED-Worksheet (4): Mapping Ambient NH$_3$
Concentrations in ArcGIS

Follow the given instructions and generate a map of ambient NH$_3$ concentrations for year 2013. This is a fun exercise – play around before you finalize a symbology! Remember to print the final map.

Instructions

We are working in Data view. This setting permits up to pan the map to the scale we are comfortable with and conduct spatial analysis. To create a map we have to switch to Layout view. Look for this function at the base of the window pane.

- Denotes the Data view

- Denotes the Layout view

**Step 1: Switch to layout view**

- We are working in the Data view. Click to change to the Layout view. You will notice that the map is now surrounded by two borders.

**Step 2: Adjust the map to fit the printing area**

- Use the Pan tool to adjust the position of the map within the boundary.

- Use these tools as needed. Ensure that the map stays within the inner boundary.

*Note: The map may disappear for a few seconds when you adjust the size and position. It usually comes back up. In case it does not do so, call the assistant.*

**Step 3: Manage the map properties that you wish to display.**

- Right click the layer ‘AMoN_sites’ >> Properties >> Symbology tab.

- On the left side choose Quantities >> Graduated symbols. We use graduated symbols as the NH$_3$ concentrations lies within a given range of values.

- In Value field, choose ‘Avg_conc’. Set Normalization to None.
In the Classification tab, choose Classify. Select the Method and Classes as you think is appropriate. Once you make your choices, click on OK.

To make the symbols bolder, click on Symbol >> Properties for all Symbols >> Set Size 10.00 or larger >> OK >> again on OK.

The data exists in the form of point measurements. Hence a color change will be observed at these data points and not across the entire map. We will learn more about the latter in the next section.

Click on the toolbar to save the map.

Please try different options before you decide on your final map. You could change legend (e.g., 4 versus 6 classes), color scheme, symbol size or type of symbology! Try using graduated symbols, proportional symbols or charts option if you like.

**Step 4: Add in the different map elements**

a. For the Title: Choose the function Insert from title bar >> Title. Type in a suitable title for the map. Reposition the title to a suitable position.

b. For a Legend: Insert >> Legend. Select the layers that you wish to highlight and click on Next. Add a legend title and click on Next. Keep clicking on Next till the legend appears on the screen. Reposition the legend to a suitable position.

c. For a Scale: Insert >> Scale Bar. Choose the scale template and reposition.

d. For the Orientation: Insert >> North Arrow. Choose the symbol of your choice and click OK. Reposition the arrow to a suitable position.

**Step 5: Saving the map**


b. In the File name, save the map with a unique name. In Save as type choose JPEG. Click on Save. Call the assistants to print the map.

*Congratulations on making your first map using ArcGIS!! Remember there are multiple ways to represent a map. Each of you has created a unique map to represent the given spatial information.*
**VED-Worksheet (5): Spatial Analysis**

a. What is spatial analysis?

b. Why is spatial smoothing of point data required?

c. Can you estimate the attribute value at location \( z \) using the Inverse Distance Function?

\[
\hat{z} = \frac{Z_1}{d_1^2} + \frac{Z_2}{d_2^2} + \frac{Z_3}{d_3^2}
\]

\[
\hat{z} = \left( \frac{Z_1}{d_1^2} + \frac{Z_2}{d_2^2} + \frac{Z_3}{d_3^2} \right)
\]

1. \( d_1 = 15 \text{ m} \)
2. \( Z_1 = 50 \)
3. \( Z_2 = 70 \)
4. \( d_2 = 25 \text{ m} \)
5. \( d_3 = 10 \text{ m} \)
6. \( Z_3 = 100 \)
d. Follow the instructions and develop a map using the inverse distance function.

**Step 1: Selecting IDW function from the ArcToolbox**

- Switch back to the Data view by clicking on  at the base of the window.
- Select Customize >> Extensions >> Click Spatial Analyst >> Close.
- Click  to activate the ArcToolbox >>Spatial Analyst >>Interpolation >> IDW function. A window should open up.

**Step 2: Setting the parameters for Inverse Distance Function**

- Environments >> General Settings >> Output Coordinate System>> Select the Same as Display option.
- Scroll down to Cartography >> Cartographic Coordinate System>> Same as Display. Click OK.
- Set the following parameters: -
  - Input point features: AMoN_sites
  - Z value field: Concentration_Data$.Avg_conc
  - Output raster: Navigate to your folder (Desktop >> 2015_Data) and give the file a unique name (eg_IDW1).
  - Output cell size: 25000 (output data is stored in grids of size 25 km x 25 km)
  - Power: 2 (The power function represents the formula for IDW function)
  - Search radius: Fixed
  - Distance: 1000000 (Every iteration will run data in a radius of 1000 km)
- A new layer will appear covering a rectangular domain around USA mainland.
- In Worksheet 5, answer questions i-iii.

**Step 3: Saving the map**


d. In the File name, save the map with a unique name. In Save as type choose JPEG. Click on Save. Call the assistants to print the map.
i. Provide two general comments on the trends observed in the map. Think of where the highest and lowest concentrations of NH$_3$ occur and the occurrence of hotspots (clustering of maximum values).

ii. How is this map different from the first map you created?

iii. Name one limitation of using the inverse distance function to develop trend surface maps.

You are now a GIS specialist! Remember spatial analysis can be used in multiple ways to extend understanding of environmental phenomena.
Renewable Energy

Thursday, June 25, 2015
Friday, June 26, 2015

Student Manual
Lesson Developers
Boyd, Tory (UIUC/CEE, Solar Power, Wind Power)
Leow, Moses (UIUC/CEE, Biofuels)
Li, Yalin (UIUC/CEE, Biofuels)
Rutherford, Cassandra (UIUC/CEE, Tidal)
Strathmann, Timothy (CSM/CEE)
Vardon, Derek (UIUC/CEE, Biofuels)

2015 Lesson Instructors
Boyd, Tory (UIUC/CEE, Solar Power, Wind Power)
Leow, Moses (UIUC/CEE, Biofuels)
Li, Yalin (UIUC/CEE, Biofuels)
Strathmann, Timothy (CSM/CEE)
Wallace, Jeff (UIUC/CEE, Tidal)
Introduction:

Over 85% of energy in the United States is provided by non-renewable fossil fuels. Regardless of presently available amounts of fuel reserves and when they are likely to run out, there is an urgent need for biofuels with numerous advantages to serve as replacement for conventional fossil fuels. Environmental engineers, with their keen interest in preserving the quality of the environment through research and engineering applications, are in a unique and important position to ensure the continued development of biofuels that are produced green and burn clean. In this lesson, you’ll be introduced to the biomass to biofuels model and how it aims to provide a meaningful alternative to fossil fuels. You’ll also learn about the different types of biomass that is being used to produce a wide variety of biofuels.
RE-Worksheet (1) Introduction to biofuels and biofuel combustion chemistry

1. The two main problems with petroleum fuels are that they are:
   a) ___________
   and
   b) ___________

2. Biofuels can potentially serve as replacements to petroleum fuels. By nature and design, biofuels must be “green”. If not, there is no point in encouraging their use. What four elements of the biomass-to-biofuels model ensure that biofuels remain so?
   1) ________________________________
   2) ________________________________
   3) ________________________________
   4) ________________________________

3. Different biomass and their corresponding conversion technologies produce biofuels with vastly different qualities. Some of them contain more energy than others. Even so, can you think of a couple of reasons why there is still demand for various types of biofuels?
Biofuels such as ethanol and biodiesel are increasingly meeting a greater percentage of our nation’s energy needs. Both kinds of fuel provide energy in the same way – the breakdown of higher-energy molecules (such as ethanol or octane) into lower-energy molecules (mainly carbon dioxide and water) allows energy to be produced from each reaction. The “rearrangement reactions” that release energy are known as combustion. In this exercise, we will explore and calculate the theoretical amount of energy different types of biofuels produce in a combustion reaction. Practically, this allows us to predict how much energy we can recover from each type of biofuel.

1. Modeling the chemical structure of biofuels

Using your molecular model kits, construct a model of ethanol (an alcohol), octane (an alkane), and methyl octanoate (an ester). When you’re finished, have an instructor check your model.

Ethanol

Octane

Methyl octanoate

Q: Based on their chemical structure, how do you think these fuels differ? Think about what the different type of bonds may mean e.g. C-H, C-O, C=O etc.
2. Energy of Combustion

In the following exercise, we will be comparing how much energy is released during the combustion of various fuels.

Q: From a transportation perspective, why would this matter?

2a. Ethanol Combustion

Ethanol (C\textsubscript{2}H\textsubscript{5}OH) has 3,240\,kJ of stored energy per mole (a chemical unit, one mole of ethanol contains 6.022×10\textsuperscript{23} molecules) in its chemical bonds. O\textsubscript{2} has 495\,kJ of stored energy per mole in its chemical bonds. After combustion, CO\textsubscript{2} contains 1607\,kJ of stored energy per mole and H\textsubscript{2}O contains 929\,kJ of stored energy per mole in its chemical bonds. Using the balanced reaction and given bond energies complete the following table, and then find the energy released:

1. Balanced reaction? *Don’t forget to account for number of moles!*

\[ \text{C}_2\text{H}_5\text{OH} + \_ \text{O}_2 \rightarrow \_ \text{CO}_2 + \_ \text{H}_2\text{O} \]

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Bond-Energy (kJ/mol)</th>
<th>Products</th>
<th>Bond-Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td></td>
<td>CO\textsubscript{2}</td>
<td></td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
<td></td>
<td>H\textsubscript{2}O</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

2. Energy Released = SUM of Product Bond Energy – SUM of Reactant Bond Energy

\[ = \_ \text{kJ} \text{ (\_ kJ per moles of carbon atoms)} \]
2b. Octane Combustion

Octane (C₈H₁₈) has \textbf{9,887 kJ} of stored energy per mole in its chemical bonds.

As before, O₂: \textbf{495 kJ} \quad \text{CO}_2: \textbf{1607 kJ} \quad \text{H}_2\text{O}: \textbf{929 kJ}

Using the balanced reaction and given bond energies complete the following table:

1. Balanced reaction? \textit{Don’t forget to account for number of moles!}

\[ \underline{\_ \text{C}_8\text{H}_{18} + \_ \text{O}_2} \rightarrow \underline{\_ \text{CO}_2 + \_ \text{H}_2\text{O}} \]

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Bond-Energy (kJ/mol)</th>
<th>Products</th>
<th>Bond-Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane</td>
<td></td>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td></td>
<td>H₂O</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

2. Energy Released = SUM of Product Bond Energy – SUM of Reactant Bond Energy = _______ kJ (_______ kJ per mole of carbon atoms)
2c. Methyl Octanoate Combustion

Methyl octanoate (C₉H₁₈O₂) has 11,385 kJ of stored energy per mole in its chemical bonds.

As before, O₂: 495 kJ  CO₂: 1607 kJ  H₂O: 929 kJ

Using the balanced reaction and given bond energies complete the following table:

1. Balanced reaction? Don’t forget to account for number of moles!

    \[ _{\text{C}_9\text{H}_{18}\text{O}_2} + _{\text{O}_2} \rightarrow _{\text{CO}_2} + _{\text{H}_2\text{O}} \]

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Bond-Energy (kJ/mol)</th>
<th>Products</th>
<th>Bond-Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl Octanoate</td>
<td></td>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td></td>
<td>H₂O</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>TOTAL</td>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

2. Energy Released = SUM of Product Bond Energy – SUM of Reactant Bond Energy

    Energy = _______ kJ (_______ kJ per mole of carbon atoms)
**Bonus question:** Methyl octanoate is an *ester* derived from octatonic acid (structure below). What is the energy released from octatonic acid during combustion? How does it compare to methyl octanoate?

![Octanoic Acid Structure]

Bond energy of octanoic acid: **10,251 kJ** of stored energy per mole

As before, O₂: **495 kJ** CO₂: **1607 kJ** H₂O: **929 kJ**

\[
\_ \text{C}_8\text{H}_{16}\text{O}_2 + \_ \text{O}_2 \rightarrow \_ \text{CO}_2 + \_ \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Bond-Energy (kJ/mol)</th>
<th>Products</th>
<th>Bond-Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octanoic acid</td>
<td></td>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td></td>
<td>H₂O</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

Energy Released = SUM of Product Bond Energy – SUM of Reactant Bond Energy

= _____ kJ (______ kJ per mole of carbon atoms)

Other than energy differences, can you think of reasons why we prefer the ester derivative instead of simply using the acid?
RE-Lab (1) Biofuel Calorimeter Experiment

Fuels that we use have a wide variety of Heating Values. The heating value defines how much heat is generated in the exothermic combustion reaction when the fuel is burned. The heating value can be presented in terms of energy released per number of moles, or mass or volume of fuel (we will calculate all three ways shortly). Petroleum fuels have very high heating values, and this makes them a very desirable fuel. Biofuels generally have a lower heating value. Thus, you often need to use larger volumes of biofuels than a petroleum fuel to provide the same amount of energy.

1. How can we measure the heating value of a fuel?

A calorimeter is a tool used to measure the heating value of a fuel. The name comes from the standard use of “calories” as a measure of heat energy. A calorie is the amount of heat required to increase the temperature of one gram of water by one degree Celsius. Heat energy is also often measured in Joules (J) and British Thermal Units (Btu). In a calorimeter, the fuel is burned creating a source of heat, which is used to heat water surrounding the container where the fuel is burned. The increase in water temperature is directly proportional to the heat input to the water.

<table>
<thead>
<tr>
<th>Experimental Concept</th>
<th>What happens</th>
<th>What we measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water is heated</td>
<td>The temperature of a measured mass of water in the flask increases</td>
<td>Mass (or volume) of water</td>
</tr>
<tr>
<td>Fuel is Combusted</td>
<td>Mass of fuel decreases as it is combusted</td>
<td>Initial temperature of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final temperature of the water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Initial mass of fuel and can</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final mass of fuel and can</td>
</tr>
</tbody>
</table>
Safety Aspects

- Instructors: Familiarize yourself with the lab setting, especially locations of exits, fire alarms, fire extinguishers, and first aid kits.
- The combustion of fuels is inherently dangerous. The experiment requires open flames. Safety goggles must be worn and no loose hair or clothing allowed.
- The fuel and water vessels get very hot; tongs of insulated gloves are required for disassembly and the final weighing of the fuel.
- Some fuels create a lot of smoke when combusted. A fume hood or room with great air ventilation should be used.

Instructions

1. Put your safety goggles on and tie back any long hair.
2. **Record your fuel type** in the Data Table.
3. The calorimeters have been preassembled by your instructors, and sufficient fuel has been added into them. Weigh the calorimeters with fuel and record the **initial weight in the data table**.
4. Assemble the experimental setup according to the diagram on the next page. Pour 100 mL (approximately 100g) of water into the flask (using the graduated cylinder for accurate measurements).
5. Measure the initial temperature of the water in your can and **record the value below**.
6. Place the soda can fuel container below the flask of water. Place your aluminum foil shield around the bottom of the flask like a skirt.
7. Carefully light the wick using a lighter and let the fuel burn for about ten minutes, or until you get about 30-40°C increase in the temperature of water in the flask. Use a thermometer in the flask to slowly stir the water.
8. **Record the final temperature** of the water as you prepare to extinguish the wick. Extinguish the wick by covering with ceramic crucible.
9. Allow the setup to cool for a while, and then record the final mass of the soda can (with remaining fuel and wick).

Calorimeter Setup (Pre-assembled)

Experiment Setup (Assemble with your partner)

Calorimeter with wick and fuel below beaker to be filled with water. Before lighting the wick, wrap the foil shielding to prevent flame from being extinguished, and to minimize heat losses.

Available fuel types*

1. Biodiesel B100 – Produced from waste cooking oil; a mix of esters
2. Green diesel – Produced from waste cooking oil; a mix of alkane hydrocarbons
3. Algae derived jet fuel – Produced from B. Braunii; kerosene like compounds
4. Plastic oil – Derived from waste plastic bags; a mix of alkane hydrocarbons
5. Corn/sugarcane ethanol – Fermented corn/sugarcane (depending on which is available seasonally); 80-90% ethanol

*Availability may change based on current research work at ISTC
2. Experimental Records

Before combustion

Fuel type =

Mass of soda can + wick + fuel = g

Mass of water in beaker (m) (density of water is 1 g/mL) = g

Initial temperature of water = °C

After combustion

Final temperature of water = °C

Mass of soda can + wick + fuel after experiment = g

Mass of fuel combusted during experiment = g

Temperature raised during experiment (ΔT) = °C
3. Calculations

Concepts of Calorimetry

The heat that is used to raise the temperature of the water can be calculated based on the specific heat of water:

\[ Q = m \cdot c \cdot \Delta T \]

Where:

- \( Q \) is the heat flow (calories)
- \( m \) is the mass of the water (grams)
- \( c \) is the specific heat of water (\( c = 1 \text{ calorie/gram } ^\circ \text{C} \))
- \( \Delta T \) is the temperature change (\( ^\circ \text{C} \))

It is assumed that the heat energy used to raise the water temperature equals the heat released by the exothermic combustion reaction. The quality of the measurements depends on the efficiency of the system in directing all heat from the flame to the water. Any losses to the ambient air and water/fuel containers will reduce the calculated heat value of the fuel.

1. Calculate the heat flow in calories released by combusting your fuel, use the following formula and check your units:

\[ Q = m \cdot c \cdot \Delta T \]
2. The metric unit of energy is the joule (J). Calculate the number of joules released during your fuel combustion. (1 calorie = 4.186 joules)

3. Divide the number of joules released by the mass of oil combusted. What is the heating value of your fuel (MJ/kg)?

4. Gather your results. What is the average calculated heating value? What is the standard deviation value? What do they represent?

An average (arithmetic mean) is the measurement of central tendency, and should be the expect value.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i = \frac{1}{n}(x_1 + \cdots + x_n)$$

Standard deviation is a measure that is used to quantify the amount of variation of a set of data values. A small standard (meaning much smaller than the average value) indicates that the data points tend to be very close to the average value of the set, while a large standard deviation indicates that the data points are spread out over a wider range of values. (note that \( n = N \) and \( \mu = \bar{x} \))

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2}, \quad \text{where} \quad \mu = \frac{1}{N} \sum_{i=1}^{N} x_i.$$
4. Discussion Questions:

How do your results compare to the reported heating values of diesel (46 MJ/Kg), biodiesel (33–40 MJ/Kg), or canola oil (37 MJ/Kg)?

How does the experiment we performed differ from an ideal, controlled experiment? Where do you think the biggest errors came from?
The 2011 Bugatti Veyron ($2.25 million, 0-60 MPH in 2.4 seconds) can cover 15 miles with 1 gallon of gasoline (47 MJ/kg). The density of gasoline is 6 pounds per gallon. How much more of your fuel would the car need to carry in order to travel the same distance, assuming similar densities?

(Asked another way, how much shorter a distance can the Veyron cover with 1 gallon of your fuel?)
BF-Lab (2) Algae composition and Hydrothermal Liquefaction (HTL)

Hydrothermal liquefaction (HTL) is a chemical process used to convert wet biomass (algae, wood, manure..., etc.) into crude-like oil. This process happens under “extreme” conditions with:

- High temperature
  250-350°C
  (Temperature for tasty ribeye!)

- High pressure
  10-20MPa
  (1000m undersea!)

1. Biocrude Oil from Hydrothermal Liquefaction

During hydrothermal liquefaction, high moisture biomass breaks down and reforms the chemical building blocks into biocrude oil.

The conversion mimics the natural geological processes which produced our current fossil fuel reserves and allows for the conversion of a wide range of feedstocks.
Tested feedstocks include algae, swine manure, sawdust, and even garbage!
**2. Inside Algae: Carbohydrate, Lipid, and Protein**

Algae provide many potential routes for the conversion into biofuels, including hydrothermal liquefaction.

Major components in algae include carbohydrate (starch, cellulose, lignin..., etc.), protein, and lipid. During HTL process, these macromolecules will break down into small units, and eventually become valuable products like fatty acids (crucial to convert biocrude oil into biodiesel!)

Content of these macromolecule will greatly affect the final product yield. So it is very important to determine the concentration of these macromolecules in algae. Today we will learn to use “biuret test” for protein content comparison.
3. Biuret Test

Biuret test is a chemical test used for detecting the presence of peptide bonds (all protein molecules have peptide bonds). In the presence of peptide bonds, a copper (II) ion forms purple compounds in an alkaline solution. Shade of color indicates the protein concentration.

Samples we are going to analysis today are 2 algae (Spirulina and Dunaliella), and soybean powder.

Safety Aspects

- Please tie up long hair.
- Biuret reagents are corrosive to your eyes/skin, so keep in mind that you need to wear goggles, gloves, and lab coat all the time.
- Syringe needles are very sharp, pay attention not get cut.

Instructions

- Check if you have all needed reagents and samples
  - Reagents: Biuret reagent A (1% KOH), to destroy algae cell wall; reagent B, 0.2% CuCl₂, to show color
  - Samples: 3 in total
- Put a 8 mL vial (larger one, without cap) inside the scale, tare it, then use the spatula to carefully put in samples
  - Weigh **0.08 (±0.001)** gram for each sample, and record the mass
  - Use different spatulas for each sample
  - Remember to label the vials
- Use a **5 mL** syringe to add **4 mL** of biuret reagent A into each vial, cap the vials, then vortex each vial for 30 seconds
  - Vials must be capped and held tightly, or the liquid may splash out
  - Do not forget the blank sample (only add biuret reagent A)
- Use a **10 mL** syringe to uptake all of the mixed solution
Syringe needles are pretty sharp, be careful not to hurt yourself!
Use different syringes for each sample, remember to label the syringes.
- Change syringe needles to syringe filter, then filter the solution into a new clear vial.
  - Use different filters for each sample.
  - Remember to label filters and vials.
- Use a 1 mL syringe to add 0.4 mL of filtered sample into a small GC vial.
  - Use different syringes for each sample.
  - Remember to label syringes and vials.
- Use another 1 mL syringe to add 0.2 mL of biuret reagent B into each GC vial, then cap it.
- Carefully shake each vial to mix solutions.
  - Pay attention not to splash.
- Let all vials sit for 10 min.
  - Calculate the protein content in soybean powder (discussion part) while waiting.
- Compare and record the color for each sample, determine what sample 1 to 3 are based on the relative protein concentration.
  - Put a white tissue behind samples for better observation.
Experimental Records

<table>
<thead>
<tr>
<th>Sample</th>
<th>Added mass (g)</th>
<th>Final color</th>
<th>Sample type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Sample 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion

Nutrition table of soybean powder is shown here, can you calculate the protein content in percent? Typical protein content for *Spirulina* and *Dunaliella* are 50% and <1%, can you determine what sample 1 to 3 are based on the protein content and experiment results?

Soybean Powder: Protein content:
Introduction:

Solar power takes the sun’s energy and turns it into thermal or electrical energy. Generally we think of solar power as electricity which is generated by solar panels. Solar panels are used to produce electricity directly from the sun’s energy. Electricity can also be generated by concentrating the sun’s energy to heat a fluid, which then generates steam, turns a turbine, and powers a generator. This process is similar to fossil fuel power plants, except the sun is used instead of burning fuel to generate heat. Solar power plants are mostly located in the South, South West, and East Coast in the United States. In 2012, solar power generated 11.5 billion kilowatt hours, or about 2.3% of the renewable energy generated (EIA, 2013). Although this is a small contribution to the renewable energy generation, solar power is predicted to account for almost 30% of total renewable energy by 2040 (EIA, 2013).
RE-Lab (3) Solar Power

Part 1: What are the parts of a photovoltaic cell?

The solar panel is made of photovoltaic cells, or PV cells. These cells are thin wafers made of crystalline silicon, which convert sunlight directly into electricity.

- Cover glass:

- n-type silicon:

- p-type silicon:

- Junction:

- Front and back contacts:

- Wires or leads:

Source: Brooks, 2011
Part 2: How is a photovoltaic cell made?

Most photovoltaic cells are made up of the element silicon (Si). Silicon is a semiconductor and is the second most abundant element in the Earth’s crust.

**A: What is Silicon?**

1. Find silicon on the periodic table below:

2. What is the atomic number of Si?

3. How many protons, neutrons, and electrons does Si have?

4. Si has four valence electrons. What does this mean?
B: Build a Molecular Model of Crystalline Silicon

A type of solar cell is called crystalline silicon cells, or c-Si. These PV cells are made up of silicon in its crystalline form. In this form, all four valence electrons are bonded to other atoms.

1. Create a Si atom with the black molecules and grey bonds. Use one molecule to represent the nucleus of the Si atom and four empty bonds to represent the valence electrons. The valence electrons all must be at equal angles to each other. Your atom should look like the figure to the right.

2. Connect the atom to other Si atoms together to form the crystalline model. (*Hint: The atoms will form a hexagon pattern.*)

3. Make sure you have **at least two Si atoms bonded to four other Si atoms**! This will be important for the next part of the lab.

You have just created a pure silicon crystal lattice. However, crystalline silicon is not an ideal conductor of electricity. **Why do you think this is the case?**

To solve this problem, photovoltaic cells are made of n-type and p-type silicon, not pure silicon.

C: Doping the Crystalline Silicon

A process called “doping” is used to create the specially treated n- and p-type silicon. This process **intentionally** introduces small amounts of impurities to the silicon in order to change its electrical properties. Let’s look at the impurities **phosphorous** and **boron**.
Phosphorous

1. Find phosphorous (P) on the periodic table.

2. How many valence electrons does phosphorous have? (Use the figure to the right.) What does this mean?

3. Create a phosphorous atom using a blue molecule for the nucleus and five empty grey bonds to represent the valence electrons. Your atom should look like the figure to the right.

As a result of the doping process, phosphorous atoms replace some of the silicon atoms in the crystalline model. Phosphorous bonds with four silicon atoms; the fifth valence electron is not bonded. This is a free electron.

4. Replace one of the Si atoms with a P atom. You have just created the n-type silicon! What did this do to the model?

Note: The n-type silicon is not charged because there is an equal number of protons and electrons. But, some of the electrons are not held tightly to the phosphorous atoms and are free to move within the crystalline structure.

5. Doping silicon with phosphorous increases the amount of electricity that can be produced. Why? (Hint: Remember electricity is the flow of electrons.)
Boron

1. Find boron (B) on the periodic table.

2. How many valence electrons does boron have (use the figure to the right)? What does this mean?

3. Create a boron atom using a blue molecule for the nucleus and three empty grey bonds to represent the valence electrons.

Doping silicon with boron results in some silicon atoms being replaced with boron atoms. Boron can bond with three of the surrounding silicon atoms because it only has three valence electrons. This creates a “hole”, or area of positive charge, in the crystal structure which will attract electrons.

4. Replace one of the Si atoms with a B atom. You have just created a p-type silicon!

What did this do to the model?

D: How It All Works
1. When the p-type and n-type silicon are connected, free electrons flow from the n-side into the p-side for a split second, and then create a barrier for any other electrons to move between the two sides. The contact point between the two sides is called the p-n junction.

   At this point there is a negative charge in the p-side (gained electrons) and a positive charge in the n-side (lost electrons). This charge imbalance creates an electric field between the two sides.

2. When the PV cell is placed in sunlight packets of particles called photons strike the p-n junction.

3. The electrons in the junction become energized and are knocked free of their atoms. These electrons are attracted to the positive charge in the n-layer and repelled by the negative charge in the p-layer.

4. When an external path is available (a complete circuit, like wires to a light bulb) the electrons can move along that path; this flow of electrons is electricity.
Part 3: Test a Solar Panel

We will now test the power output of a small solar panel under different conditions. The solar panels that we will use can produce up to 5 W of power, or they are rated at 5 W. What does this mean?

A: Measure the power output of the solar panel

In order to measure the power output of the panel we need to understand a few things about power.

**Power:** The rate at which electric energy is supplied to a circuit or consumed by a load (e.g. a light bulb). We will use the units of **watts** (W) to measure power.

**Voltage:** The electric potential difference between two points. Think of this as the force or pressure pushing the electrons through the circuit. We will use the units of **volts** (V).

**Current:** A measure of the amount of electrons in motion along the circuit. We will use the units of **amperes or amps** (A).

We will use a **multimeter** to measure the voltage and current of the panel, and then use those measurements to calculate power.

\[
Power \ (watts) = Current \ (amps) \times \ Volatge \ (volts) \\
W = A \times V
\]

1. Connect the positive (red) wires on the solar panel to the positive lead on the multimeter. Do the same for the negative (black).

   *Voltage is measured across the circuit.*

2. Turn on the multimeter to the direct current setting for voltage (V ===)

3. Write down the voltage (V) reading from the multimeter in the table below.
4. Detach the multimeter and attach one of the wires on the LED to the positive solar panel wire. Next attach the positive multimeter lead to the other LED wire, then the negative multimeter lead to the negative solar panel wire.

   *Current is measured inside the circuit.*

5. Turn the multimeter to the direct current setting for current (A\(\rightarrow\)).

6. Write down the current (A) reading from the multimeter.

7. Calculate the power output by multiplying the two readings together. *Be careful with units!*

8. What is the power output of your panel? How does this compare to the rated power output of the panel (5 W)? Why do you think the output you calculated is different?

**B: Measure the Power Output of the Solar Panel Under Different Conditions**

1. Cover different fractions of the solar panel with paper. Measure the voltage and amperage, record the numbers in the table, and calculate the power output.

   How does the power output change?

   When would this happen in real life?

   Can solar panels be used to completely replace other sources? Why or why not?
2. Take the solar panel to a sunny part of the classroom and measure the voltage and current. How does this compare to your other measurements?

3. Take the solar panel outside. Measure the voltage and amperage in the sun and in the shade, record the numbers in the table, and calculate the power output.

   How does the power output compare to your indoor calculations? Why?

   How do your measurements in the shade compare with your indoor measurements? What does this mean?

4. Connect multiple LED lights in series. How many lights can your solar panel power?

5. How does solar power relate to environmental engineering?
## References:

- **Cover image:**
  


---

<table>
<thead>
<tr>
<th>Condition</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraction covered:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraction covered:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraction covered:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside: Sunlight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside: Sunlight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside: Shade</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Introduction:

Renewable energy accounted for about 13% of the total energy production in the United States in 2013. Wind power was the second largest source of renewable energy, accounting for 32% of renewables (or just over 4% of total energy production). Wind power is the fastest growing renewable energy source, with over 47 billion kilowatt hours of electricity added between 2010 and 2012 (EIA, 2013).
RE-Lab (4) Wind Power

What is wind power?

Wind power involves capturing wind and converting it into electricity.

1. Wind blows over the blades
2. The blades turn a shaft connected to a generator
3. The generator turns and creates electricity

How does a generator work?

By moving a wire through a magnetic field which creates a flow of electrons

- Electrons are pushed along the wire using a magnet (Similar to how a pump pushes water along a pipe)
- The number of electrons in motion is the current
- The force pushing the electrons is the voltage

Wind power in Illinois:

The Twin Groves Wind Farm in McLean County, IL is located about 50 miles northwest of Champaign Urbana. It contains 240 wind turbines which are spread out over 22,000 acres. Twin Groves can generate about 396 MW of power.

If the wind farm operates on average 10 hours per day and 300 days per year what is the annual electricity generation in kWh? Be careful with your time units!

\[ \text{Electricity} = \text{Power} \times \text{Time} \]

\[ 1 \text{ MW} = 1,000 \text{ kW} \]
The average Illinois household uses about 38,000 kWhr per year (EIA, 2009). Champaign Urbana contains about 124,000 households. What is the annual electricity consumption for Champaign Urbana in kWhr?

Can Twin Groves power all of Champaign Urbana? If not how many households can it power?
## Advantages and disadvantages of wind power

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>2.</td>
<td>2.</td>
</tr>
<tr>
<td>3.</td>
<td>3.</td>
</tr>
<tr>
<td>4.</td>
<td>4.</td>
</tr>
<tr>
<td>5.</td>
<td>5.</td>
</tr>
</tbody>
</table>
Wind turbine design
You will be designing the blades for a small wind turbine. Your turbine will be tested for both power output and efficiency. Don’t worry if your first design doesn’t work out well. You will have a chance to redesign your turbine to optimize its performance. Redesign is an important part of engineering!

Turbine blade design:
You will have 10 minutes to design your turbine blades.

Design variables:
1. Number of blades

![Blade designs]

2. Shape of blades

![Blade shapes]

3. Size of blades

Design constraints:
1. The maximum number of blades is 12
2. Your blades must be less than 9” long
**Graph paper for turbine blade design**

(Each box is 0.5 x 0.5 inches)
Turbine construction:
You have **20 minutes** to construct your turbine.

This includes:
1. Cutting out your turbine blades
   You will need **two cutouts per blade**
2. Hot gluing your blades onto dowels
   Sandwich the wooden dowel between two blade cutouts. **Make sure to keep 1-2 inches of the dowel out of the blade** so it can be attached to the hub.
   You will need to work fairly quickly but **BE CAREFUL!**
3. Attaching the dowels to the turbine hub
   You will need to tilt the blades in order for the blades to catch the wind.

Turbine testing:
You will have **10 minutes** to test your turbine.

1. Attach your hub with blades to the turbine tower
2. Measure the wind speed of the fan with an anemometer
   *(Record the speed on the table on page 10)*
3. Measure the current and voltage of your turbine
   *(Record your measurements on the table on page 10)*
4. Calculate the power output of your turbine
   
   \[
   \text{Power (watts)} = \text{Volatage (volts)} \times \text{Current (amps)}
   \]

   *(Record your calculation on the table on page 10)*
Calculate the efficiency of your turbine:
In order to determine the efficiency of your turbine you need to calculate the maximum potential power in the wind. Pay close attention to units!

\[ P = \frac{1}{2} \rho A v^3 = \frac{1}{2} \rho \pi r^2 v^3 \]

Where:
- \( P \) is the potential power in \( \text{kg m}^2 \text{s}^{-3} \) or \text{watts} \n- \( \rho \) is the density of air (\( \rho = 1.1839 \text{ kg/m}^3 \))
- \( A \) is the swept area \( \text{m}^2 \)
- \( v \) is the wind speed \( \text{m/s} \)
- \( r \) is the radius of \( A \) \( \text{m} \)

**Potential power calculation**

\[ Efficiency = \frac{\text{Measured power output}}{\text{Potential power}} \times 100 \]

**Efficiency calculation**
Redesign:
You will have **25 minutes** to redesign and test your turbine. Change the number, shape, and/or size of your turbine blades to increase the power output. The teams with the greatest power output and most efficient turbines will win a prize!

Table of results:

<table>
<thead>
<tr>
<th>Design</th>
<th>Wind speed (m/s)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Measured P (W)</th>
<th>Potential P (W)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wind power and environmental engineering:
References:


- Kid Wind Project. Renewable energy education. 2014.
Friday, June 26, 2015
RE-Lab (5) Tidal Current Turbines

Introduction

Tidal power, also called tidal energy, is a form of hydropower that converts the energy of tides into electricity. A tidal stream generator, often referred to as a tidal energy converter (TEC) is a machine that extracts energy from moving masses of water, in particular tides, although the term is often used in reference to machines designed to extract energy from run of river or tidal estuarine sites. Certain types of these machines function very much like underwater wind turbines, and are thus often referred to as tidal current turbines.
Tides vs currents

A tide is a regular rise and fall of the surface of the ocean due to the gravitational force of the sun and moon on the earth. The centrifugal force is produced by the rotation of the Earth and moon about each other. Tidal phenomenon is periodic and varies according to the lunar and solar gravitational effects, respective movements of the moon and sun, and other geographical features.

Horizontal movement of water is called current. Tidal current is the periodic horizontal flow of water accompanying the rise and fall of the tide.

Tidal currents occur in coastal areas and in places where the seabed forces the water through relatively narrow boundaries. Thus, both high tidal ranges and narrow channels are generally required to cause significant tidal stream currents.

Tidal currents can flow in two directions; the current moving in the direction of the coast is known as flood current and the current receding from the coast is known as ebb current. The current speed varies from zero to a maximum.

Which moon cycle would you expect to have the largest tidal range? Why?
Advantages/limitations of tidal current turbines

Discuss the following issues for tidal currents:

1. Advantages over other renewable energy sources

2. Environmental impacts

3. Obstacles to further development
Design considerations for determining where to build a tidal current turbine

*Fill in the blanks.*

1. How much possible ______________ can be generated?

2. How far from ______________?

3. What is the water ______________?

4. What is the water ______________?

5. What are the ______________ in the water?
1. **Calculating possible energy generation**

The kinetic power, \( W \), is given by the equation

\[
P = \frac{1}{2} \rho Av^3
\]

where \( \rho \) is the density of material, \( A \) is the area of the sweep of the turbine blades and \( V \) is the magnitude of the depth averaged maximum velocity.

Let’s compare a tidal current turbine to a wind turbine with the same area. *How much energy \((W)\) can you generate from the following two turbines:*  

1 tidal current turbine with 2 rotors and 16 m diameter blades (total Area = 402 m\(^2\)), water velocity is 4 m/s, \( \rho_{\text{water}} \) is 1025 kg/m\(^3\)

1 wind turbine with 22.6 m diameter blade span (Area = 402m\(^2\)), air velocity is 4 m/s, \( \rho_{\text{air}} \) is 1 kg/m\(^3\)

*Why are they different?*
2. Location of cities

Map of population in the US

US map of tidal velocities
(dark blue =2 m/s, purple =3-4 m/s, light blue>4 m/s)

*Determine locations with both a large population and a high tidal velocity?*
3. Velocity of water

The amount of possible power depends on the velocity of the water.

*How much power density ($P/A$) can be generated for the following locations:*

$$P/A = \frac{1}{2} \rho v^3$$

<table>
<thead>
<tr>
<th>Location</th>
<th>Velocity (m/s)</th>
<th>Power Density (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cook Inlet Alaska</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Nantucket Sound Massachusetts</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Rosario Strait Washington</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

$\rho$ is 1025 kg/m³

*Do your calculations below:*
4. Depth of water

For example, look at the sea floor depths (bathymetry) around Nantucket Sound. What are the factors you should take into account?
5. Obstacles in the water
What is Turbulence?

Turbulent flow is the irregular movement of water around objects. For example, water moving around rocks in a river creates rapids. Underwater obstacles can also cause turbulence and vortexes around and behind the object.

The distance of the effects of the turbulence can be generalized as shown in the figure below, where B is the diameter of the cylinder.

What are the effects of turbulence on a turbine?
Where should you construct a tidal current turbine:

Imagine you are a member of an engineering team responsible for determining the location of a tidal current turbine farm. Your team has two possible sites (Site A and B) that have obstacles upstream from where you would like to place your turbines. Your team’s goal is to generate the most power possible by your turbine.

To help you with making a decision, your team has decided to run model scale tests in a flume with velocity, \( v = 0.25 \text{ m/s} \). The diameter of the obstacles in model scale, \( B = 0.038 \text{m} \). The area of the model turbine blades, \( A = 0.013 \text{ m}^2 \). The density of the water \( \rho = 1000 \text{ kg/m}^3 \).

In the site maps below, determine the best location for your turbine downstream from the obstacles.

1) List the factors that will affect the placement of your turbine in the flume.

2) Calculate the maximum power (W) you expect to generate without any obstacles for the model turbine. \( P = \frac{1}{2} \rho A v^3 \) where \( \rho \) is the density of material, \( A \) is the area of the sweep of the turbine blades and \( v \) is the velocity.

| Maximum power (W) |   |
3) Calculate the effects of turbulence created by the obstacles for site A and B (Use the turbulence around an obstacle equation). Draw the effects around the obstacles. Remember that $B = 0.038m$

**SITE A**

<table>
<thead>
<tr>
<th>Position</th>
<th>Equation to use</th>
<th>Turbulence</th>
</tr>
</thead>
<tbody>
<tr>
<td>To the side of each obstacle</td>
<td>2.5B</td>
<td></td>
</tr>
<tr>
<td>Behind each obstacle</td>
<td>4B</td>
<td></td>
</tr>
</tbody>
</table>

**SITE B**

<table>
<thead>
<tr>
<th>Position</th>
<th>Equation to use</th>
<th>Turbulence</th>
</tr>
</thead>
<tbody>
<tr>
<td>To the side of each obstacle</td>
<td>2.5B</td>
<td></td>
</tr>
<tr>
<td>Behind each obstacle</td>
<td>4B</td>
<td></td>
</tr>
</tbody>
</table>
4) Mark **TWO locations** on the maps that your team wants to place the turbine behind the starting line.

5) Measure the distance from behind the starting line on each site to the location of your turbine. Count the number of blocks from the starting line to your turbine location. Each block = 0.01 m

6) Once you have finished the first site, let the instructor know.

7) We will experimentally measure the power output of the turbines in a flume in the Ven Te Chow Hydrosystems Laboratory.

**Total Score**

The total score is a function of the distance in meters from behind the starting point and the power output in watts.

\[ \text{Score} = (1/\text{Distance}) \times \text{Power output} \]
Draw the effects of turbulence on the map and mark 2 locations that you want to place your turbine behind the starting line. Each block = 0.01 m
Draw the effects of turbulence on the map and mark 2 locations that you want to place your turbine behind the starting line. Each block = 0.01 m
Data collection at the flume:

Record one reading every ten seconds.

**SITE A – Location 1**

<table>
<thead>
<tr>
<th>Reading</th>
<th>Time (seconds)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum (add power from rows 1 through 6)

Average = Sum/6

\[
Power \ (\text{watts}) = \text{Current (Amps)} \times \text{Voltage (Volts)}
\]

\[
W = A \times V
\]

1 W = 1000 mW
**Data collection:**

Record one reading every ten seconds.

**SITE A – Location 2**

<table>
<thead>
<tr>
<th>Reading</th>
<th>Time (seconds)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum (add power from rows 1 through 6)

Average $= \frac{\text{Sum}}{6}$

$Power \ (\text{watts}) = \text{Current (Amps)} \times \text{Voltage (Volts)}$

$W = A \times V$

$1 \ W = 1000 \ mW$
Data collection:

Record one reading every ten seconds.

**SITE B – Location 1**

<table>
<thead>
<tr>
<th>Reading</th>
<th>Time (seconds)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum (add power from rows 1 through 6)

Average = Sum/6

*Power (watts) = Current (Amps) x Voltage (Volts)*

\[ W = A \times V \]

1 W = 1000 mW
Data collection:

Record one reading every ten seconds.

**SITE B – Location 2**

<table>
<thead>
<tr>
<th>Reading</th>
<th>Time (seconds)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum (add power from rows 1 through 6)

Average = Sum/6

\[ \text{Power (watts)} = \text{Current (Amps)} \times \text{Voltage (Volts)} \]

\[ W = A \times V \]

1 W = 1000 mW
Measuring the power output of your turbine:

We will use a **multimeter** to measure the voltage and current of the turbine, and then use those measurements to calculate power.

\[
Power \ (watts) = Current \ (Amps) \times Voltage \ (Volts) \\
W = A \times V
\]

1. Connect the wires to the negative and to the positive lead on the multimeter. Plug the red lead into the position that is labeled with a V. Connect the black wire to the COM location.

2. Turn on the multimeter to the alternating voltage setting for voltage (V) and the range to mV.

3. Write down the voltage in millivolts (mV) from the multimeter in the table below every 10 seconds.

4. Move the red lead to the mA connection.

5. Turn the multimeter to the alternating current setting for current (A).

6. Write down the current in milliamps (mA) reading from the multimeter.

7. Calculate the power output by multiplying the two readings together. *Be careful with units!"
Data analysis:

1. Average your six readings for each site and location by adding the power column and dividing by six.
2. Report your average power for each site and location to the instructor.
3. Which site and location did you have the highest average power?

Discussion:

_How could your team have improved the power output readings? What would you have changed?_
References:


- Kid Wind Project. Renewable energy education. 2014.

- Cover images:
  - Renewable energy: stuffpoint.com, 2013
  - Biofuels: European Community, 2006
  - Solar power: Mainframe Group, 2013