What Factors Affect Stream Temperature?

A Laboratory Exercise for Undergraduate Ecology Courses

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Sponsored by
The Ecological Research as Education Network and the National Science Foundation's Research Collaborative Networks – Undergraduate Biology Education Program (#0955344)

Student Instructions

Recommended citation
Simmons, J.A. 2012. Investigating factors that affect stream temperature: A laboratory exercise for undergraduate ecology courses. http://erenweb.org/project/stream-temperature-project/. Accessed xx/xx/20xx.

Learning Objectives

1. Students will be able to describe and apply the concepts of the heat budget of a stream

2. Students will be able to employ a computer simulation model to develop and answer questions

Background

The temperature of water in aquatic ecosystems has myriad effects on the ecological structure and function. In lakes for example, temperature differences are the cause of summer stratification that has wide-ranging effects on water chemistry, organisms distribution and ecosystem processes like productivity. All organisms have a **range of tolerance** for temperature and those populations living at the southern edge of their distribution can be regularly exposed to temperatures near their upper tolerance limit. Thus, any increase in stream temperature due to human activity could mean extirpation of those populations. Finally, all biochemical processes that occur in aquatic organisms – from photosynthesis to cellular respiration – are influenced by temperature through the effects of diffusion and activation energies.

Stream warming can result from several human activities such as logging, damming, climate change, and discharge of heated water (Gomi et al. 2006; Kaushal et al. 2010). Therefore, it is important to understand how a stream's physical environment is affected by these activities and, in turn, how the biota are affected.

At first glance measuring stream temperature seems very simple and straightforward; however, what we really need to measure is the **temperature regime** of a stream which includes the water temperatures at all <u>times</u> (including **diurnal**, seasonal and annual fluctuations) and at all <u>locations</u> within the stream (bank to bank, surface to bottom and all along the length). In Ecology we would say that the temperature regime encompasses the entire range of temporal and spatial **scales**. So, to thoroughly examine the temperature regime of even a small stream, you would need to deploy hundreds of continuously recording temperature data loggers. This is not feasible, so most research projects focus on a narrower sub-range of temporal and spatial scales.

The scale is important because it determines the type of impact temperature can have on biota. For example, fine-scale fluctuations (e.g., diurnal) have immediate effects on cellular processes like photosynthesis. (How do you think photosynthesis will respond to temperature?) Moderate scale temperature variability as measured by daily mean temperatures can dictate what species are present in the stream or can cause chronic stress. Seasonal and annual temperature variations can be represented by mean annual temperature or growing season length and will affect ecosystem-scale processes like net primary productivity (NPP). Thus, the scale of the temperature measurements will dictate what ecological processes can be examined.

Computer simulation models can aid researchers by describing the stream temperature regime based on relatively less information. Some models use the fact that stream water temperatures are often strongly correlated to air temperatures at the scale of weeks to months. Other models, called mechanistic models, estimate stream temperatures using equations from physics and meteorology that comprise the **heat budget** of the stream.

The **temperature** of a stream is an instantaneous measure of the concentration of heat energy contained in the water. The amount of heat contained in the water is constantly changing as heat is added to or lost from the stream (Poole and Berman 2008). A heat budget is an accounting of all of these inputs and outputs of heat energy. Thus each input and output has the potential to influence the stream temperature regime. These fluxes include: incident solar radiation, conduction, and evaporation. among others (Figure 1). There are several computer models available that simulate the energy budget of a stream (e.g., Bartholow 2000).

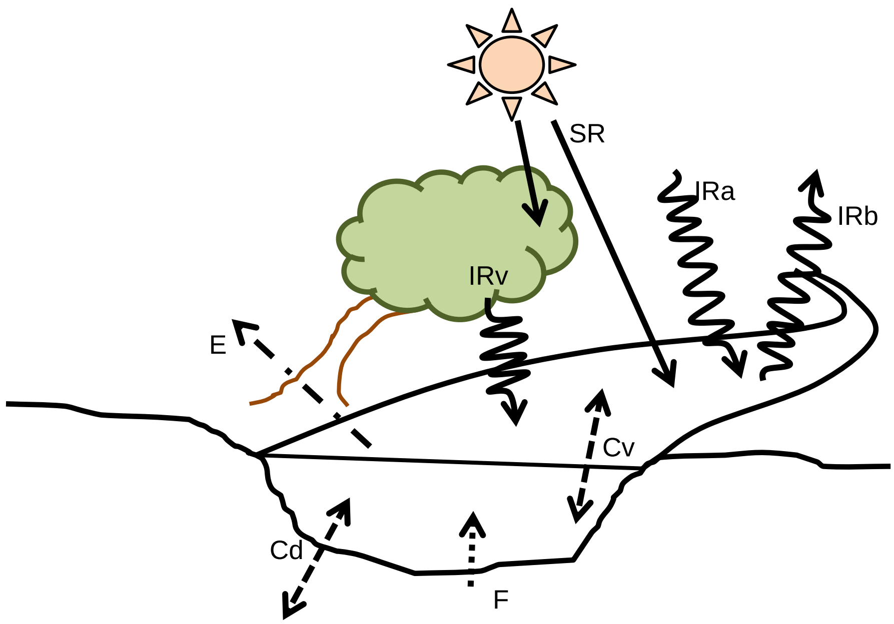


Figure 1. Diagram of the heat budget of a stream. Fluxes and abbreviations are defined in Table 1.

The heat budget consists of an equation like the one below:

$$\text{Net Heat Flux } (j/m^2/s) = \sum\text{Inputs} - \sum\text{Outputs}$$

where "Inputs" represents all of the pathways by which energy enters the water in a stream and "Outputs" represents all of the pathways by which energy is lost from the water (both are in units of joules m^{-2} s^{-1}). The Inputs and Outputs are listed in Table 1 and illustrated in Figure 1.

Many of these fluxes are affected by physical factors and climate including: the relative width and depth of the channel, the amount of riparian vegetation, wind speed, sun angle, and discharge. In addition, inputs of water (from tributaries or groundwater) may have a big impact on stream temperature. *(Can you guess which heat fluxes in Table 1 are affected by discharge, sun angle, or wind speed?)*

This lab exercise is derived from the RBAST research project (Riparian Buffers Affect Stream Temperature) . The data you will be working with was taken from one of the study sites from that project, St. Mary's Run, a small, first-order stream located on the campus of Mount St. Mary's University in Emmitsburg, MD. A segment of St. Mary's Run flows first through a small forest stand and then flows through an open, grassy field. This makes an ideal experimental comparison of a forested **riparian zone** (the land adjacent to the stream) and a non-forested (grassy) riparian zone. The **microclimate** within a forest is much different than the microclimate in an open field and this is likely to affect the heat budget of the stream.

Table 1. Definitions of the major energy fluxes into (I) and out of (O) a stream. These fluxes occur at the water/air interface and at the water/sediment interface. Note that some fluxes can go either direction.

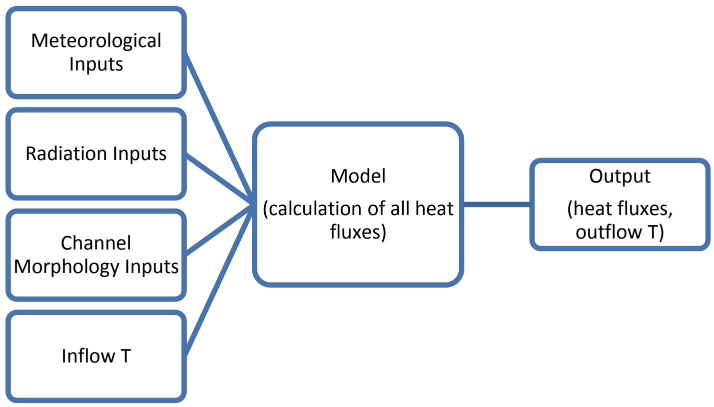
Convection (Cv)	I,O	Heat brought to the stream surface or carried away from the surface by wind
Conduction (Cd)	I,O	Diffusion of heat from air to water (or vice versa) and from the streambed to water (or vice versa)
Evaporation (E)	O	Evaporation of water at the surface consumes energy, so it is a loss of heat
Back Radiation (IRb)	O	Warm water emits infra-red (IR) radiation into the atmosphere
Atmosphere Radiation (IRa)	I	The atmosphere (especially clouds) emits IR radiation, some of which will hit the water surface
Friction (F)	I	Friction of moving water against the substrate generates heat
Direct Solar Radiation (SR)	I	Sunlight is absorbed by the water and converted to heat; this can be partially blocked by vegetation
Vegetation Radiation (IRv)	I	Overhanging vegetation emits IR radiation, some of which will strike the water surface

In this section of the lab we are going to try to answer the following question: *How does the presence/absence of a forested riparian zone affect the stream temperature regime?* Go to question 1 in the Analysis section and make a prediction about how a forested riparian zone will affect the daily mean, the daily maximum and the daily minimum temperatures.

You will make use of a computer model called SSTEMP that is freeware provided by the U.S. Geological Survey. Computer models are commonly used in watershed studies to make predictions about how a proposed activity or action will affect water quality and aquatic habitat. In Part 1 you will familiarize yourself with the model by using it to compare the heat budget of a forested and non-forested stream. In Part 2 you will create your own hypothesis regarding the heat budget of a stream and test it using the model.

About SSTEMP

SSTEMP is a mechanistic model, meaning that it its predictions (i.e., output) are derived from mathematical equations of real physical processes (the mechanisms). This is in contrast to empirical models that make predictions of one variable based on correlations to another variable (for example, predicting surface soil temperature from air temperatures). The model requires several input variables in order to make its predictions. These can be categorized as meteorological (wind speed, relative humidity, etc.), radiation (latitude, date, possible sun, etc.), and channel morphology (segment inflow, width, elevation, etc.).



The model simulates the heat budget of a stream segment (the length of which is defined by the input variable *Segment Length*) for one day. The daily mean temperature at the upstream end of the segment is needed as in input. The main output of the model is the daily mean temperature at the downstream end of the segment. The inputs and outputs are all scaled to days (daily mean temperature, daily maximum temperature, daily average wind speed, etc.); hourly temperature outputs are not possible. The stream segment is assumed to be uniform in its physical characteristics (e.g., the model assumes that discharge is uniform along the length of the segment; no tributaries or groundwater inputs). The water in the segment is also assumed to be well-mixed so that water temperature, for example, does not vary with depth.

The model runs in the Microsoft Windows™ operating system only. A Mac version is not available.

Reference: Bartholow, J.M. 2002. SSTEMP for Windows: The Stream Segment Temperature Model (Version 2.0). US Geological Survey computer model and documentation. Available on the Internet at http://www.fort.usgs.gov/

PROCEDURES

Part 1. Compare Forested vs. Non-forested Riparian Zone

A. Download the Software

1. *Important Note: SSTEMP runs only in the Windows™ operating-system, so if you have a Mac you will need to share a computer with someone who has a PC.*

2. Go to this web address: http://www.fort.usgs.gov/Products/Software/SNTEMP/

3. Scroll to the bottom of the page and download the last program at the bottom of the page (ssunzip.exe) and save it to a folder on your C: drive or in My Documents.

4. Navigate to the folder containing the new file and double-click on it to unzip it. Extract the files to the same folder that contains the zipped file.

5. Navigate to the Set Up program (Setup.exe) and double-click on it to install the SSTEMP model (2.0.8). Follow the instructions on the screen.

6. To start the model, go to the Start Menu/Programs and look for the folder "SSTEMP". Inside you will find the SSTEMP program; click once on it to start it.

B. Enter Input Parameters into the Model

1. Examine the layout of the SSTEMP program window (Figure 2). The white variable boxes are filled with default **input values** that come from the Poudre River in Colorado. The three boxes on the right side (*Intermediate Values, Mean Heat Fluxes at Inflow, and Model Results – Outflow Temperature*) are the **output values** from the model. Note that the *Mean Heat Fluxes at Inflow* box shows the magnitude of all the components of the heat budget. The first three values in bold in the box in the lower right (*Model Results – Outflow Temperature*) are predicted daily mean, daily maximum and daily minimum temperatures for that day at the outflow (downstream end of the reach).

2. A few notes about using the model:

   a. When the program first opens it shows all of the values in red in American units (Fahrenheit, cubic feet per second, etc.). We will be using metric units, so click on the fourth button at the top of the page (a "page" with a red and a blue arrow) to switch to metric units.

   b. To save a "picture" of your output, go to File/Save As… in the drop-down menu and save your results with a unique file name. To retrieve, go to File/Open…

   c. You can label your output by going to the very bottom of the window where it says "Double-click to add title."

   d. A gray box means that input value is optional.

   e. As you enter each new input variable, the model instantly recalculates the outputs.

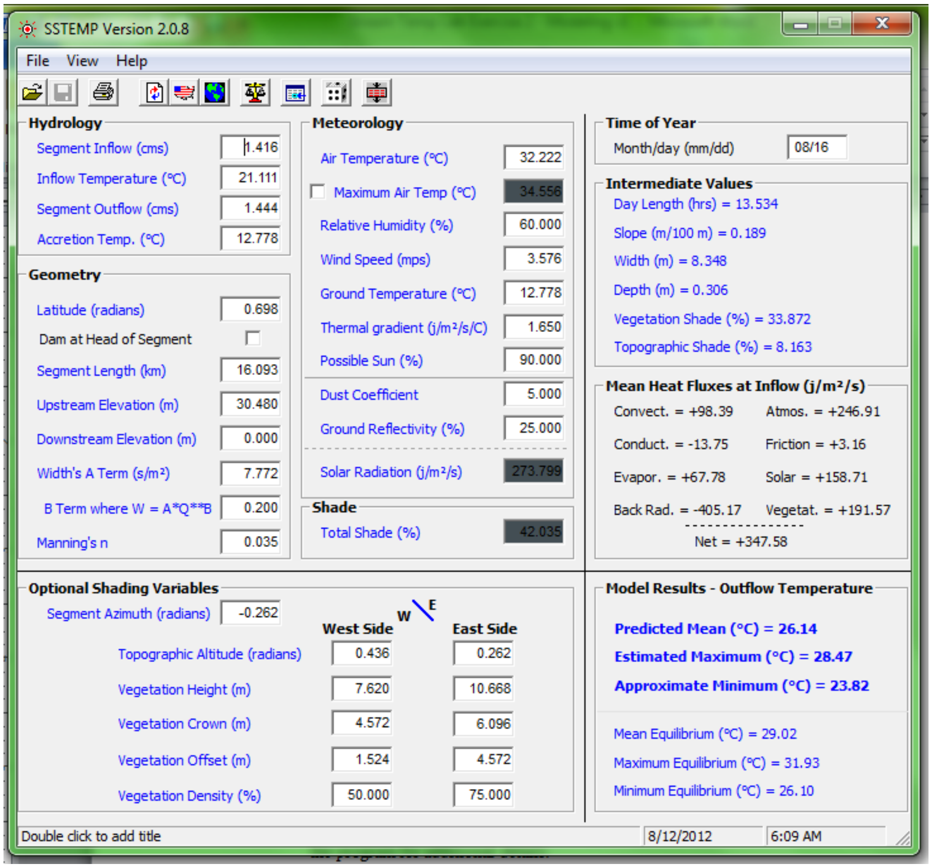


Figure 2. Screenshot of the SSTEMP program window.

f. Refer to the software instructions (sstemp.doc.pdf) that were included in the *ssunzip.exe* file for additional details.

3. For this exercise you will gain familiarity with the program by entering new values for a number of the input parameters that represent the conditions in St. Mary's Run. You'll start with the forested reach of St. Mary's Run. Enter all of the input variables listed in Table 2 under "Forested Segment" into the SSTEMP model. Be sure to hit [ENTER] or [TAB] after each input.

4. Record the <u>output</u> values from the Forested simulation in Table 3.

5. Next enter the input values from the "Non-Forested Segment" column in Table 2 that represents the open section of stream (no riparian trees).

6. Record the output results in Table 3.

7. Answer questions under part 1.B in the Analysis Worksheet (located at the end of this handout).

Table 2. List of input variables to use in Part 1. The "Forested Segment" values pertain to the section of St. Mary's Run that has forested riparian zones. The "Non-forested Segment" values pertain to the section that has non-forested (grassy) riparian zones. Asterisks mean that the model's default value should be used. All data were measured on 11 September 2011.

Model Input Variables	**Forested Segment**	**Non-forested Segment**
Segment Inflow (cms)	0.18	0.18
Inflow Temperature (ºC)	18.73	18.73
Segment Outflow (cms)	0.18	0.18
Accretion Temp (ºC)	16.3	16.3
Latitude (radians)	0.693	0.693
Dam at Head of Segment	Unchecked	Unchecked
Segment Length (km)	0.20	0.20
Upstream Elevation (m)	506	502
Downstream Elevation (m)	502	500
Width's A Term (s/m^2)	4.66	3.66
B Term	0.90	0.90
Manning's n	0.035*	0.035*
Air Temperature (ºC)	15.94	17.85
Max Air Temperature (ºC)	Unchecked	Unchecked
Relative Humidity (%)	84.3	54.1
Wind Speed (mps)	0.67	1.27
Ground Temperature (ºC)	16.3	16.3
Thermal Gradient (j/m2/s/ºC)	1.65*	1.65*
Possible Sun (%)	86	86
Dust Coefficient	5*	5*
Ground Reflectivity (%)	25*	25*
Solar Radiation (j/m2/s)	*	*
Total Shade (%)	97	8
Month/day (mm/dd)	09/11	09/11

Table 3. Data table for recording model output.

	Baseline Forest *(j/m2/s)*	**Baseline Open** *(j/m2/s)*	**Notes**
Convection			
Conductance			
Evaporation			
Back Radiation			
Atmosphere Radiation			
Friction			
Direct Solar Radiation			
Vegetation Radiation			
Net Heat Flux			
Predicted Mean			
Estimated Maximum T			
Estimated Minimum T			
(Predicted Outflow mean T – Inflow T)			
Daily Range (Max T – Min T)			

Part II. Create and Test Your Own Hypotheses

Now it's time to use some of your creativity to develop a hypothesis about stream temperatures or the heat budget that can be tested using the model. Many ecologists and river or watershed managers find computer models very useful in their work. Computer models allow researchers to conduct "experiments" on a water body that might not be possible or desirable. For example, introducing an invasive predatory fish to a river to see what happens to the food web would not be prudent (nor popular with local anglers!). Long-term experiments that might take decades to collect results can be simulated in seconds. Finally, running a model is usually faster, less expensive and requires fewer resources than conducting a field experiment.

Computer models also have some potential drawbacks. Can you think of some?

Your Instructor will tell you if you should work individually or in groups. The main steps for this exercise are to a) ask a question, b) develop a testable hypothesis, c) use the model to test the hypothesis, and d) summarize and interpret your results.

A. Ask a Question

1. What questions do you have about what influences a stream's temperature? In the Analysis section for question 2.A., write out the basic question that you want to try to answer. It should be a question for which you really don't know the answer. As an example, in Part 1 we asked, "*How does the presence/absence of a forested riparian zone affect the stream temperature regime?*"

2. Here are some prompts that might help you come up with a question:

    i. Stream managers are interested in controlling (usually reducing) stream temperatures.

    ii. Every aquatic species has a range of tolerance for temperature and different conditions may push them out of their tolerance range.

    iii. Streams of different sizes, shapes, locations may vary in their heat budgets or in their response to forested riparian zones.

3. Finally, here is an example question: *How does cloudiness affect the warming that occurs in a non-forested stream reach?*

B. Develop Testable Hypotheses

1. Next, from your main question develop a **hypothesis set** (a null and a working hypothesis) that can be tested using the SSTEMP model. Your hypotheses will be more specific than your overall question and will usually refer to one specific output variable (like mean outflow temperature, net heat flux, evaporation flux, etc.)

2. Limit yourself to one hypothesis set even if your main question could be answered with multiple hypotheses (unless your Instructor allows you to do more).

3. In the Analysis section under part 2.B., write out your null and working hypotheses making sure that the two hypotheses are logical opposites of each other.

4. Here is an example hypothesis set to go with our example question from 2.A.3. Note that the question asks about cloudiness. One input variable that would be affected by clouds is *Possible Sun.* This variable ranges from 5– 100% depending on the average degree of cloudiness during the day.

   Null: There is no relationship between the amount of solar radiation received per day and the daily maximum temperature in a non-forested stream.

   Working: There is a relationship between the amount of solar radiation received per day and the daily maximum temperature in a non-forested stream.

5. What statistical test will you use to determine if you can accept or reject the null hypothesis? Correlation? t-test? ANOVA? chi-square? If you cannot figure out which test to use, that often indicates that your hypotheses may need to be rewritten or reworded.

C. Test the Null Hypothesis

1. Before you wildly start plugging in numbers, do some planning. Record your answers to the following questions in the Analysis worksheet under part 2.C.

   i. What will be your treatment input variable?

   ii. What values for the treatment variable will you use? Justify these values. How do you know these values are realistic? You may need to do a literature search to find appropriate values. Enter your answer on the Analysis Worksheet.

   Example: Under heavy cloud cover, direct solar radiation may get as low as 5% of full sunlight, so we will use the following values for Possible Sun: 5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 100 % .

   iii. What will you use for your "baseline" or "reference" condition? If you are using the "Forested Segment" or "Non-Forested Segment from Table 2 above, you can simply reference that table. Otherwise, list the values for ALL of the input variables that you will use along with some justification for each in the Analysis Worksheet

   iv. Ideally, you will alter just one of the model's input variables (the **treatment variable**) and keep all of the others the same so that any observed differences in output can be attributed to the treatment variable. Write a statement that either 1) affirms that this is indeed the case or 2) describes additional changes that were made with a justification for each one.

Example: We will be varying the Possible Sun *variable to mimic changes in day-to-day cloudiness. We used the input variables from the "Non-Forested Segment" column in Table 2.*

2. Create a data table to record the relevant output data.

3. Run the model! Start with the "baseline" or "reference" inputs and record the relevant outputs. Then change the value of your treatment variable and record the new output. Repeat as necessary.

D. Summarize and Interpret

1. Run your statistical test on the output from the model. Ask your Instructor for assistance if needed. Record the statistical results in the Analysis Worksheet under part 2.D. Write a sentence or two stating whether or not you rejected the null hypothesis and explain why.

2. Determine the best way to present or summarize your output results. Can you make a figure or would a table be more appropriate? Using a graphing program like Excel or Word, create either a graph or table of your statistical results and/or modeling results. Follow the formatting guidelines given to you by your Instructor.

   Example: A correlation analysis was conducted to determine if there was a significant relationship between Possible Sun and Daily Maximum T. A scatterplot of Possible Sun *versus* Daily Maximum T *with a trend line would be appropriate.*

3. In the Analysis Worksheet under part 2.D write a 1 paragraph conclusion in which you restate your original question and then answer the question based on your results.

 Name: ___________________________________

Analysis Worksheet

Part 1.B.

1. (4 pts.) Make a prediction about how daily mean stream temperature in a forested site will differ from daily mean temperature in a non-forested (grassy) site. Explain the reasons for your prediction.

2. (2 pts.) By how much did the daily mean temperature change between the inflow and outflow in the forested site? Is this a substantial amount?

3. (2 pts.) Of all the Heat Fluxes, which ones were the largest in terms of absolute value?

4. (4 pts.) Compare and contrast the daily mean and daily maximum outflow temperatures from the forested and open sites.

5. (2 pts.) Calculate the Daily Range for the forested site and open site. Daily Range is the difference between the daily maximum and minimum temperatures. How do they differ between the sites? Speculate as to why they differ between the sites.

6. (6 pts.) Now examine the Heat Fluxes for the Forested and Open sites. Use these fluxes to explain the observed differences (or lack thereof) in mean daily T, daily maximum T and the daily range. Relate these flux differences to the differences in the riparian zones.

Part 2.A. Ask a Question

7. (2 pts.) Write out the basic question that you want to try to answer.

Part 2.B. Develop Testable Hypotheses

8. (4 pts.) Write out your null and working hypotheses making sure that the two hypotheses are logical opposites of each other.

9. (2 pts.) What statistical test will you use to determine if you can accept or reject the null hypothesis? Why?

2.C. Testing Hypotheses

10. (2 pts.) What will be your treatment input variable?

11. (2 pts.) What values for the treatment variable will you use? Justify these values. How do you know these values are realistic? You may need to do a literature search to find appropriate values.

12. (2 pts.) What will you use for your "baseline" or "reference" condition?

13. (2 pts.) Write a statement that either 1) affirms only one input variable was changed or 2) describes additional changes that were made along with a justification for each one.

2.D. Summarize and Interpret

14. (6 pts.) Record the statistical results here. Write a sentence or two stating whether or not you rejected the null hypothesis and explain why.

15. (8 pts.) Write a one paragraph conclusion in which you restate your original question and then answer the question (if possible) based on your results.

16. (6 pts.) Don't forget to attach a paper copy of your graph from Part 2 or email it to your Instructor.