An Investigation of the Effects of a Thermal Plume Generated by the Brunner Island Power Plant on the Bacterial, Phytoplankton, and Zooplankton Populations of the Susquehanna River

Senior Thesis Proposal

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INTRODUCTION

Aquatic life may be severely affected by hot water discharged from power plants (Gibbons and Sharits, 1974; Esch and McFarlane, 1976; Mason, 1991; Wellborne and Robinson, 1996). Brunner Island is a local coal-fired power plant located in York County, Pennsylvania that is known for its generation of thermal effluents into the Susquehanna River. Brunner Island is comprised of three units which all started to operate in the 1960’s. These three separate units have an electricity generating capacity of 1,458 megawatts (“PPL Brunner Island” 2005). Thermal plumes are generated because of the particular power plant’s use of river water as a cooling agent. In this process, river water is up taken and transferred to the cooling system. Here, the water is exposed to high temperatures so it may act as a cooling mechanism (Choi et al. 2002). At Brunner’s Island, the water at a temperature of 90 °F is then released into a discharge channel. The channel then leads back into the river creating areas of high temperature (Klimanis 2005). In the Susquehanna River, the thermal plume is seen on the west bank, adjacent to the power plant (Figure).

It is in these areas of elevated temperature or so-called thermal plumes where the structure of aquatic life may be changed. Phytoplankton, zooplankton, and bacteria are some of the smallest organisms found in freshwater ecosystems, and are likely to be the most severely affected by a dramatic change in temperature. These three organisms play vital roles in aquatic systems, being necessary members of the food chain. Phytoplankton are eaten by zooplankton which in turn become food for other microorganisms and eventually fish. Bacteria serve as mainly decomposers, but can also be a source of food for smaller zooplankton species, which then become food for larger zooplankton
Therefore, if thermal effluents are adversely affecting these organisms, the food sources of nearly all aquatic organisms will be depleted resulting in a failing river ecosystem. This research is also important and extremely interesting because the thermal effluents have the potential of affecting every biological aspect of the river from dissolved oxygen content, ammonia, and nitrate, to denaturing the proteins of microorganisms. Thermal effluents even have the potential to contain chemicals such as chlorine which can be extremely lethal to organisms.

This future study will investigate the role of the Brunner Island power plant in the ecology of the Susquehanna River, in particular phytoplankton, zooplankton, and bacteria. Since only one side of the river is predicted to be influenced by the thermal effluents due to both the curve and the flow rate of the river, data from both sides will be collected. This comparison will serve as a mechanism to determine if the thermal effluent discharged from the power plant is indeed correlated to any ecological effects observed. By completing this research, we will be able to determine if the thermal plumes are having a positive, negative, or neutral effect on the bacterial, zooplankton, and phytoplankton populations of the Susquehanna River.

REVIEW OF LITERATURE

The investigation of the effects of power plants on surrounding bodies of water has long been a topic researched by scientists. The areas of elevated temperature as a result of generated thermal effluents gained interest from many researchers because of temperature’s significant biological role in nearly all aquatic organisms (Martinez-Arroyo et al. 2000). Elevated temperature can be significant due to its ability to affect a variety
of aspects and functions of the organism such as metabolism. Temperatures can even be elevated to such an extent to cause lethality to the organism (Langford 1990; Rajadurai et al. 2005). Since phytoplankton and zooplankton are the beginning of a large scale food chain, it is essential to determine how communities are affected by thermal pollutants (Martinez-Arroyo et al. 2000). Bacteria also carry out important functions in aquatic systems such as decomposition of organic matter and the release of nutrients. Some zooplankton species even feed on bacteria, thereby becoming another link in the food chain. Therefore, it is necessary to determine if bacteria can also be affected by thermal plumes.

Although thermal effluents have been studied for over thirty years, there are still many gaps in knowledge. Since every thermal effluent is different in size, width, temperature, and other factors, studies often obtain different results. Therefore, any solid conclusion as to the overall impact of thermal effluents has yet to be made. Up until the 1970’s, a huge increase in the number of power plants built along bodies of water was seen (Martinez et al. 2000). In an experiment conducted by Schubel and Marcy (1978), it was concluded that for every megawatt of electricity generated $3 \text{m}^3$ of cooling water was needed every minute (Poornima et al. 2005). In another experiment, Morgan and Carpenter (year?) proposed that not only did power plants generate effluents of elevated temperature, but also the discharge water could contain chemicals such as chlorine which could also negatively affect organisms (Poornima et al. 2005). In fact, studies conducted in the 1970’s and to the present have concluded that chlorine may actually impact the organism more negatively than higher temperatures alone (Eppley et al., 1976; Hamilton et al., 1970; Jolley et al., 1978; Geider and Osborne, 1992; and Martinez et al., 2000).
Langford (1990) conducted a similar study in which bacteria were studied. Langford found that the bacteria were not significantly affected when exposed to elevated temperature for a short period of time. However, Langford concluded that the overall effect on the bacteria depended on how much chlorine was present. Whether or not Brunner Island releases chlorine is unknown, however it is likely since most power plants add chlorine to the up taken water to prevent the growth of organisms in the cooling system (Choi et al. 2002).

Another interesting aspect of past research has to do with how different classes or species of phytoplankton react to elevated temperature. In a study conducted by Rajadurai et al. (2005), the rate of growth of two different species of diatoms exposed to elevated water temperature was studied. When the two diatoms were exposed to a temperature increase from 28 °C to 40 °C, *Amphora coffeaeformis*, maintained a consistent growth rate, while *Chaetoceros wighami*, exhibited a decreased rate of growth. Since *A. coffeaeformis* maintained a steady growth rate despite the elevated temperature, and was primarily located around the outfall site of the condenser, Rajadurai and his collaborators predicted that the continuous exposure of this species to high temperatures had actually helped them to become acclimated to it. Thus, the species was able to withstand the sudden heat shock. Since *C. wighami* was the dominant species at the intake site, Rajadurai predicted that this species was not able to acclimate to the high temperature. Therefore, *C. wighami* was readily affected by the thermal plume (Rajadurai et al. 2005). Despite the difference in growth seen between the two species, a study completed by Poornima et al. (2005) at the same power station in India, indicated
that the thermal discharge did not have a significant effect on the phytoplankton population.

Another study completed by Poornima et al. (2005) also indicated that thermal discharge does not have a significant effect on the phytoplankton population. This study was also conducted at the Madras Atomic Power Station located in India. Instead of looking at diatoms specifically, Poornima simply quantified the number of phytoplankton per mL and also measured dissolve oxygen, nitrate, ammonia, nitrite, and chlorophyll a concentration (2005). At the outfall point where water was discharged, Poornima observed a 35-70% reduction in the number of cells in the phytoplankton as well as the chlorophyll a concentration. However, in the coastal waters, the dissolved oxygen, nitrate, nitrite, and ammonia levels as well as the phytoplankton populations were not affected by the thermal effluent. The thermal effluent did not affect the coastal waters because it was most likely thoroughly diluted by the ocean. However, the results could have been quite different if the study had been conducted in a small body of water.

Poornima also came to a very interesting conclusion when the role of chlorine in thermal effluents was looked at. A smaller decrease in phytoplankton was observed when exposed to elevated temperature and chlorine rather than just chlorine alone. Therefore, high water temperature may help in dissipating the chlorine and thus reducing the amount of phytoplankton subjected which was also the case in another study done by Choi et al. in 2002 (Poornima 2005). In Choi’s study, bacteria also displayed the same characteristics with high temperature combined with chlorine actually increasing the abundance of the bacteria (2002).
However, a study conducted by Martinez et al. in the Gulf of Mexico showed negative results. In objection to Poornima’s study, Martinez found a lower oxygen concentration at the point at which the hot water was being discharged. Although, Martinez also did not see a major change in the overall plankton population, it was observed that at one of the stations, near where the hot water was discharged, that the number of cells seen were extremely low compared to other stations (200). Also in Martinez’s study, algae were negatively affected by the plume. Samples taken from the point of discharge showed high temperature, lower oxygen, and decreased production (200).

Another common aspect of power plants and thermal plumes that has been long studied is how seasons influence the thermal effluent effects on organism such as plankton and bacteria. According to many past studies in the 70’s and 80’s, aquatic life is more apt to experience adverse effects of the effluents in the summer months when already warm water temperature is further elevated by the effluent (Durrett and Pearson, 1975; Gallup et al., 1975; Lenat, 1978; Parkin and Stanl, 1981; Wellborn and Robinson, 1996). Therefore, in the winter months when production by organisms is already down due to the colder water, thermal effluents may act as a mechanism to elevate temperature, increase production, thereby increasing the population of the organism (Dahlberg and Conyers, 1974; Wellborn and Robinson, 1996). In a more recent study in 1996, Wellborn and Robinson also took this avenue of research and studied the effects of at herm effluent from a power plant, in summer and winter, on marcoinvertebrates in a pond located in Texas. The data collected d suggested that during the summer the pond was extremely warm as a result the lowest abundance of organisms was seen (Wellborn and Robinson
On the other hand, during winter, Wellborn’s and Robinson’s data suggested different results than previous studies. The data suggested that lower abundance of aquatic organism were still seen in the pond during the winter despite the cooler water. Therefore, it appeared that the thermal plume was so strong that abundance was always negatively affected despite the season (Wellborn and Robinson 1996).

Although thermal effluents have been extensively studied for over 30 years, few scientists have examined the effects of elevated temperature on freshwater aquatic organisms. One of the very few studies that researched this particular topic was a study done by Michael Mallin, Karen Stone, and M. Pamperl in 1994. This study investigated the effects of thermal effluents on the phytoplankton communities of several U.S. reservoirs and lakes. One lake in particular, Lake Julian, showed interesting results. Although the overall abundance of phytoplankton did not seem to be affected by the thermal effluents, there was intriguing seasonal variation. In contrast to the results of Wellborn and Robinson’s study, phytoplankton populations seemed to be highest in the summer, while decreasing in the spring and winter months (Mallin et al. 1994). This particular lake also has allowed an exotic fish species, the blue tilapia, to reside there since the 60’s, due to the presence of thermal effluents. However, fish can often be negatively affected by the thermal plumes. For Example, in the Lee Cooling Pond, elevated water temperatures in the summer due to thermal plumes lead to a bloom of blue-green algae which was ultimately responsible for killing many fish (Mallin et al. 1994).

Therefore, although research on the effects of thermal plumes has been studied for decades, each study seems to contradict the next. Whether or not phytoplankton,
zooplankton, and bacteria will be affected can be dependent on any number of factors including season, water temperature, species, etc. Furthermore, very rare are studies conducted in freshwater systems. In fact, a study investigating the effects of thermal plumes from a power plant in a river has never been completed. Therefore, it is the goal of this study to determine the effects of a thermal effluent generated by the Brunner Island coal-fired power plant on the phytoplankton, zooplankton, and bacterial populations of the Susquehanna River. The side of the river containing the effluent will be compared to the other side of the river to determine if differences in the populations exist. The study will be conducted in the summer and winter months to determine if seasonal variations will influence the impact of the thermal effluent. This research will address the null hypothesis that there is no difference in population size of phytoplankton, zooplankton, and bacteria between the tow sides of the river. An additional null hypothesis is that there is no difference in season in the effects of the effluent on the populations of organism. By addressing these hypotheses, hopefully gaps in knowledge can be filled and the role of thermal effluents in the lives of aquatic organism can be more fully understood.

**DESIGN AND METHODS**

This study will be conducted in the vicinity of the Brunner Island power plant along the Susquehanna River in York County, Pennsylvania. The plant is located on the west side of the river, and is located 15 miles from Harrisburg, Pennsylvania (“PPL Brunner Island” 2005).
Pilot Study

A pilot study will be conducted in order to assess the basic characteristics of the river to further our understanding of its ecology and how certain parts of the actual experiment will take place. The first important piece of information is determining the temperature of the thermal plume in comparison to the river and how far it ravels down the river, which will ultimately determine how many samples will need to be taken. The length of the plume will be determined by assembling thermometer probes along side of the river. Also, the flow rate of the river will be measured to determine how long of a period of time the organisms will be exposed to the elevated temperature. The flow rate will be measure by means of a flow-meter. Also, by means of a thermometer, we will be able to determine the depth of the effluent in the water, although the warm water should remain at the surface.

Another piece of information that will need to be determined is how wide the thermal effluent is. Due to the structure of the river, the effluent should tightly remain on the west side. However, depending on the length of the pipes from which the effluent is being discharged, the width may be different than expected. Since we will be using a zooplankton net to collect the zooplankton in the actual study, we will need to determine the length of time the net needs to remain in the water to collect a sufficient quantity of the organisms. One last aspect of the pilot study will be to look for any algae that may be growing in the vicinity of the thermal plume, since the effects on the algae may be an important piece of data in the future study.

Actual Study
In the study, samples will be taken from both sides of the river at the exact same location. A GPS system will ensure proper location during the various sampling periods. Depending on the length of the thermal plume, 5-10 samples will be taken, with the same number of samples being collected on the opposite side of the river. To assess for seasonal variation, samples will be collected in the summer months of June, July, and August, and also in the winter months of December, January, and February.

Before any collection of organisms from the river, the river will be characterized on both sides. Using a dissolved oxygen meter, the dissolved oxygen levels will be measured, and also the levels of nitrate, ammonia, and phosphate will be determined by means of a “Hach Kit.”

Samples of bacteria will then be collected from both sides of the river and stained with DAPI (49, 6-diamidino-2-phenylindole) according to Porter and Feig (1980). This stain will actually stain the DNA of the bacteria. The samples will then be filtered onto a 0.2 micrometer filter. Using an epifluorescent microscope, the bacteria will be quantified. This particular microscope has a light which will cause the DAPI stain of the bacterial DNA to flow. Next, 1L water samples of phytoplankton will be collected. Using 2% Formalin, the phytoplankton will be observed and then quantified under the microscope per mL using a Sedgewick-Rafter slide. Zooplankton will be quantified the same way as the phytoplankton, but will be collected by using a zooplankton net. Once the phytoplankton and zooplankton have been quantified, they will be organized in tables according to class.

If algae are present in the vicinity of the thermal plume, a tile will be placed in the water for a month to see how much algae would grow on it to determine if the warm
water would affect the growth rate of the algae. Lastly, as a means to gain a full knowledge of the thermal effluent’s effects on aquatic life, a qualitative analysis of the fish in the river will be completed. By talking to local fisherman, we will be able to gain a sense of the particular fish in the river and their population size.

LITERATURE CITED


Table 1. Most abundant and least abundant classes of phytoplankton and zooplankton most likely to be found in the Susquehanna River.

<table>
<thead>
<tr>
<th>Aquatic Organisms</th>
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<tbody>
<tr>
<td><strong>Phytoplankton</strong></td>
<td></td>
<td><strong>Zooplankton</strong></td>
</tr>
<tr>
<td>Most Abundant Class</td>
<td>Diatoms, Chlorophytes</td>
<td>Copepods</td>
</tr>
<tr>
<td>Least Abundant Class</td>
<td>Dinoflagellates</td>
<td>Cladocerans, Ostracods</td>
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Figure 1. Map of Brunner Island as well as the Susquehanna River.
Figure 2. Aerial image of the Brunner Island Power Plant and the Susquehanna River. Pink color shows the thermal plume discharged from the plant and how far it extends down the river.
Figure 3. A diagram of the Brunner Island Power Plant system as located on the west bank of the Susquehanna River. The diagram depicts how water is up taken from the river, transferred to the cooling system, and ultimately discharged back into the river to create a thermal plume.
Figure 4

Phytoplankton → Zooplankton → Fish

Bacteria → Small Zooplankton

Figure 4. A depiction of the food chain as seen in aquatic systems. When zooplankton and phytoplankton die, bacteria decompose the remains. The bacteria may then become food for small zooplankton known as heterotrophic nanoflagellates, which then become food for larger zooplankton species.
Figure 5. Linear regression of relationship between distance from power plant where samples collected and temperature of water at collection sites on the west side of the river adjacent to the power plant and the east side of the river opposite to the plant. Both sets of data are represented by separate regression equations as well as correlation coefficients as indicated by "r."
Figure 6. Relationship between distance from power plant where samples collected and relative abundance of bacteria, phytoplankton, and zooplankton populations in the summer and winter seasons as collected from the west side of the river adjacent to the power plant.
Figure 7. Temperature of water samples collected in summer and winter at the intake, mixing point, and outfall site of the power plant. Asterisk indicates a significant difference in water temperature in summer and winter at the intake site as indicated by an unpaired t-test (p<0.0001). Second asterisk represents a significant difference in water temperature collected at the mixing point in summer and winter as indicated by the Mann-Whitney test (p=0.0079). Third asterisk also indicates a significant difference in water temperature in summer and winter at the outfall site as indicated by an unpaired t-test (p<0.0001).