California State University Northridge

UNITING TECHNOLOGY & THE ENVIRONMENT

A Student Design Project

California State University
Northridge

Phase II: Satellite Chiller Plant And Subtropical Rain Forest: Design, Build, Construct Project

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1. Introduction

The 1 MW fuel cell plant, located on the California State University (CSUN) campus, is the world's largest fuel cell plant at a university site. A fuel cell is an electrochemical energy conversion device. It produces electricity from fuel (on the anode side) and oxidant (on the cathode side), which react together in the presence of an electrolyte. The reactants flow in and the products flow out while the electrolyte remains in the cell. Fuel cells can virtually operate forever, as long as the necessary flows are maintained. CSUN's fuel cell plant runs on natural gas and produces electric power with a theoretical potential 83% combined (heat & power) efficiency as compared to a 33% utility power grid rate throughout the US with conventional systems. This means more power, less waste.

Phase I of the project, was completed in January 2007 following the University's Physical Plant Management (PPM) successful purchase and self-installed high-efficiency 1 MW Direct FuelCell® (DFC®) fuel cell plant, located south of the University Student Union complex. Phase II of the fuel cell project installs a highly efficient 2000 ton campus satellite chiller plant (powered by the fuel cell plant) to efficiently serve the immediate and growing air conditioning and heating needs of the Institution. The charge to the Student Design Team was to analyze all of the Phase I and Phase II normal waste byproducts, particularly the CO2 emissions of the fuel cell plant, and to design and implement processes that would make this already unique power / chiller plant the most sustainable plant possible with a minimal carbon footprint. The work enclosed will demonstrate the analysis and design methodology to utilize the various waste byproducts, including the waste from the fuel cell plant and the latent exhaust heat recovery, the heat rejected from the chiller plant (absorbed from our campus classrooms) in the form of warm humid air, and carbon dioxide rich exhaust gas from the fuel cell plant. Ultimately these waste byproducts were determined to optimally support a fast growing sub-tropical rainforest environment which was then designed to deliver the CO2 fuel cell exhaust to, enriching the surrounding plant environment, and promoting maximum CO2 sequestration.

California State University, Northridge (CSUN) is a major university enrolling 32,000 students in the San Fernando Valley, Los Angeles County. The Physical Plant Management is the University's largest department with approximately 250 employees and 50 students. Physical Plant Management is a service oriented department designed to meet the day to day operations and life cycle needs of CSUN. The PPM employees range from highly skilled craftsmen to student assistants.

The second phase of this fuel cell project, Phase II, was undertaken in order to fully utilize the potential of the waste byproducts generated by fuel cell site and chiller plant. The fuel cell site generates a side stream of the CO_2 exhaust gas, water from the reverse osmosis/electro-deionization system (RO/EDI), and more water condensed in the latent heat exchanger recovery process. The chiller plant is designed to absorb heat from the campus (classrooms & other spaces) via chilled process water and exhaust that heat to the atmosphere via a cooling tower. The cooling tower rejects the heat through forced evaporation and the heat of vaporization, sending great volumes of warm very humid air into the environment. This condenser water process also generates large volumes of high dissolved solids blowdown water. Conventional power and chiller plants are not designed to utilize the mentioned above byproducts. The PPM executive director, Tom Brown, provided the impetus to initiate and implement Phase II. The main goal of the project is to design and build the ultimate sustainable system where all byproducts are used. Carbon dioxide, a greenhouse gas, is transferred to a subtropical rainforest to reduce its concentration by ability of plants to sequester CO_2. The man-made rainforest will be located on a strip of land adjacent to the fuel cell and chiller plant. Biochar will be applied to the rainforest soil in order to increase CO_2 storage in the soil as well as help with plant productivity. Heat exchanger latent heat recovery condensate, RO/EDI water, and cooling tower's blowdown water were evaluated for rainforest irrigation needs. Evaporated cooling tower water is the warm moist air that will create a unique moist microclimate inside the subtropical rainforest. The fuel cell and chiller satellite plant will be a unique, sustainable, and an environmentally friendly plant that represents the union of technology and nature.

The enriched CO_2, along with waste stream water, will sustain the plant life in the rainforest. This report discusses the various aspects of the Phase II project and includes: CO_2 delivery, irrigation system design, subtropical forest species selection, and project presentation.

Carbon dioxide and water are the main by-products of the fuel cell and chiller plants operation. The first part of this discussion covers the design, assumptions, and milestones of the carbon dioxide enrichment system. Current global models predict that carbon dioxide levels will double the pre-industrial levels by the year 2050. The fuel cell site constantly emits 3260 ft^3/min (@STP) of carbon dioxide. Physical Plant Management decided that instead of dumping CO_2 gas directly into the atmosphere, it is much wiser to deliver and diffuse the carbon dioxide to a man-made subtropical rainforest. It is well known that plants take in CO_2 during photosynthesis and emit oxygen as a byproduct. There is sufficient empirical evidence that by increasing the concentration of CO_2 in the plant's growth area, the plants will yield more and grow up to 30% faster (8). The main goal of this part of the project is to lower the carbon foot-print of the fuel cell.

In addition, the fuel cell waste water can be used in the rainforest irrigation system to dramatically reduce irrigation costs. However, waste water has a high concentration of certain acids. This report includes a discussion of the detailed water analysis and research to ensure healthy plant growth. The irrigation system was designed to include cost considerations and efficiency parameters.

Plant selection is another important aspect of the Phase II project. Plants will be irrigated by the fuel cell's waste water which has high concentration of potassium chloride, sulfate, and total dissolved solids. The subtropical rain forest will also be exposed to a CO_2 concentration that is higher than the ambient environment. The plant team worked on the plant species selection that would be sustained in the given environment. This section of the report covers methods and techniques used to make a knowledgeable species selection.

The last part of the report summarizes the project with a multimedia report. Throughout the project, the media team made many video clips, photos, and obtained information regarding the various aspects of Phase II. The media section covers the steps and techniques used to produce the final presentation.

2. Carbon Dioxide Enrichment

2.1 FACE Approach

Overview: The completed construction of California State University, Northridge's (CSUN) one megawatt fuel cell in January 2007 marked a beginning to the second phase of the project, a 2000 Ton chiller plant and subtropical rainforest. The main objective of the rainforest is sustainability where the exhaust from the one megawatt fuel cell is used to create a rich and warm carbon dioxide (CO_2) environment. Initially, the basis for the design of the enriched CO_2 subtropical rainforest came from the FACE model, which stands for Free Air CO_2 Enrichment as shown in Figure 2.2. The FACE model makes it possible to provide a means by which the environment around growing plants may be modified to realistically simulate future concentrations of atmospheric CO_2 (1). Unlike growth chambers and greenhouses, no containment is required with the FACE designs. FACE research technology creates a platform for multidisciplinary, ecosystem-scale research on the effects of elevated atmospheric CO_2 concentrations over extended periods of time. In doing so, a large amount of high-CO_2-grown plant material can be produced, enough to support the research of many cooperating scientists (1). The CSUN subtropical rainforest is intended to be a non-research facility that only emphasizes sustainability by using the fuel cell CO_2 discharge. In addition, by analyzing various possible delivery techniques and performing efficiency calculations, it has been shown that the FACE model is inappropriate for the given application.

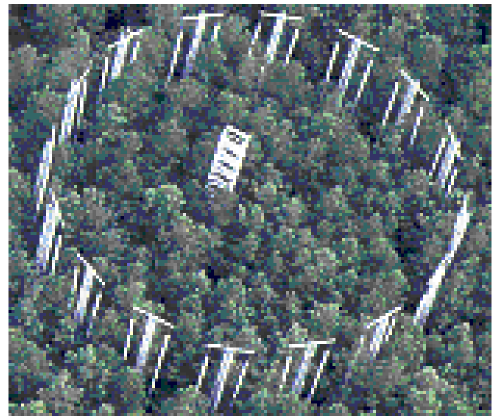

Figure 2.1: CSUN Rainforest Area **Figure 2.2:** Typical FACE Model

Knowns: Area, topography specifications, and exhaust specifications.

Unknowns: Wind speed/direction and best CO_2 distribution.

Assumptions: Steady state, constant temperature, equal distribution, and friction loss of 0.03 in. of water column.

Analysis: A vector analysis was performed for a preliminary border delivery system which is similar to the FACE model. The preliminary design included adjusting ball type diffusers around the perimeter spaced two feet apart. Using AutoCAD, as depicted in Figure 2.3 to visualize the above concept, it was evident that the average throw would have to be approximately 23 feet from each diffuser. This throw requirement is more than what a typical adjustable ball diffuser is capable of achieving. The average throw results were obtained by drawing and measuring the distances between centerline and diffuser's locations since it would depict a uniform CO_2 distribution. The model objective was to simulate the diffuser requirements and to determine how uniformly the system could distribute the CO_2. Calculations predicting the pressure drop showed that the ball diffusers had a 3.0" of pressure loss, which exceeded the 0.03" allowable limit. The calculations were made with an Excel spreadsheet and are shown in Appendix A.

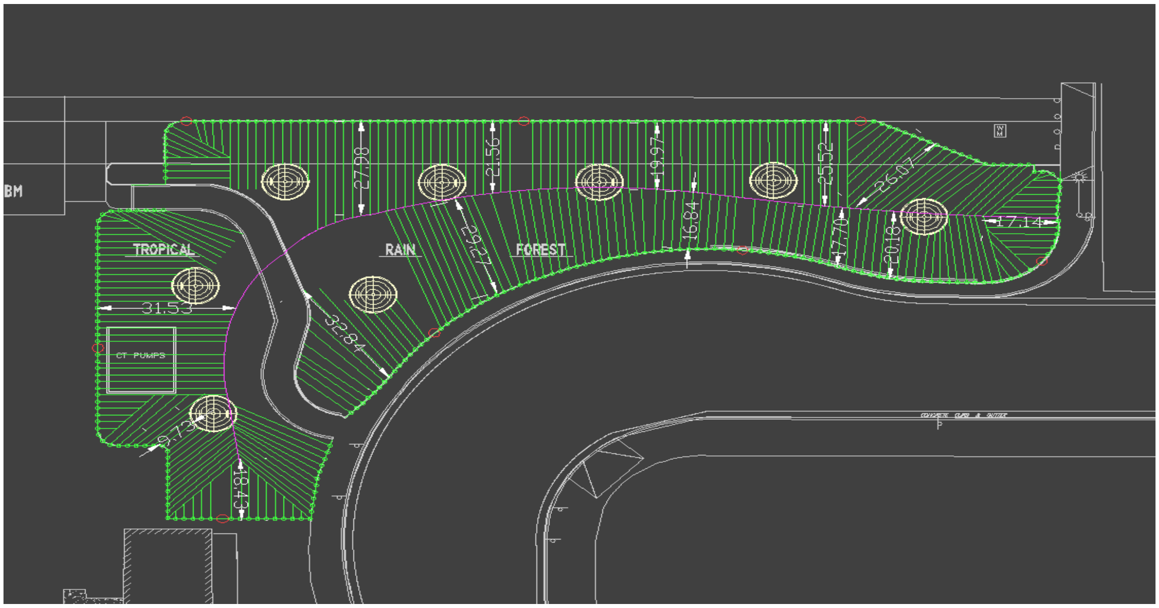

Figure 2.3: AutoCad Vector Analysis

Conclusion: The FACE model was used as a starting point in designing a CO_2 distribution system for the rainforest. Nevertheless, application of the FACE model was not particularly suitable since it is based on a circular shape which requires a simpler control and distribution system than that of the irregular shaped (figure 2.2). Rainforest configuration can be seen in figure 2.1. The diffusers that can achieve the desired throw and allowable pressure drop requirements are not realistic for a perimeter delivery system. Therefore, more conventional heating, ventilating, and air conditioning (HVAC) methods would be the best. HVAC method includes variable volume and independent pressure controls which are more practical and widely available in industry.

2.2 CO_2 Delivery System

Overview: The preliminary CO_2 delivery system design included a basin and perimeter mode. The basin mode delivers CO_2 to the base of each cooling tower when the cooling tower is running in a reverse downward draft, creating an outward delivery of CO_2. The perimeter mode delivers CO_2 from the outer edges of the rainforest when the cooling towers run in the normal up draft mode. The perimeter mode draws CO_2 from the edges of the rainforest into the basin of the cooling tower to achieve a uniform distribution of CO_2. The main objective of both delivery systems is an efficient and uniform distribution of CO_2. The basin mode delivery uses practical heating, ventilating, and air conditioning (HVAC) practices with steady and equally balanced flow. Figure 2.4 shows a preliminary AutoCAD concept for the basin mode. The perimeter delivery system involves the placement of large capacity diffusers around the circumference of the rainforest as shown in Figure 2.5. Perimeter delivery creates a disbursement of CO_2 into the rainforest area opposed to the basin of the cooling towers.

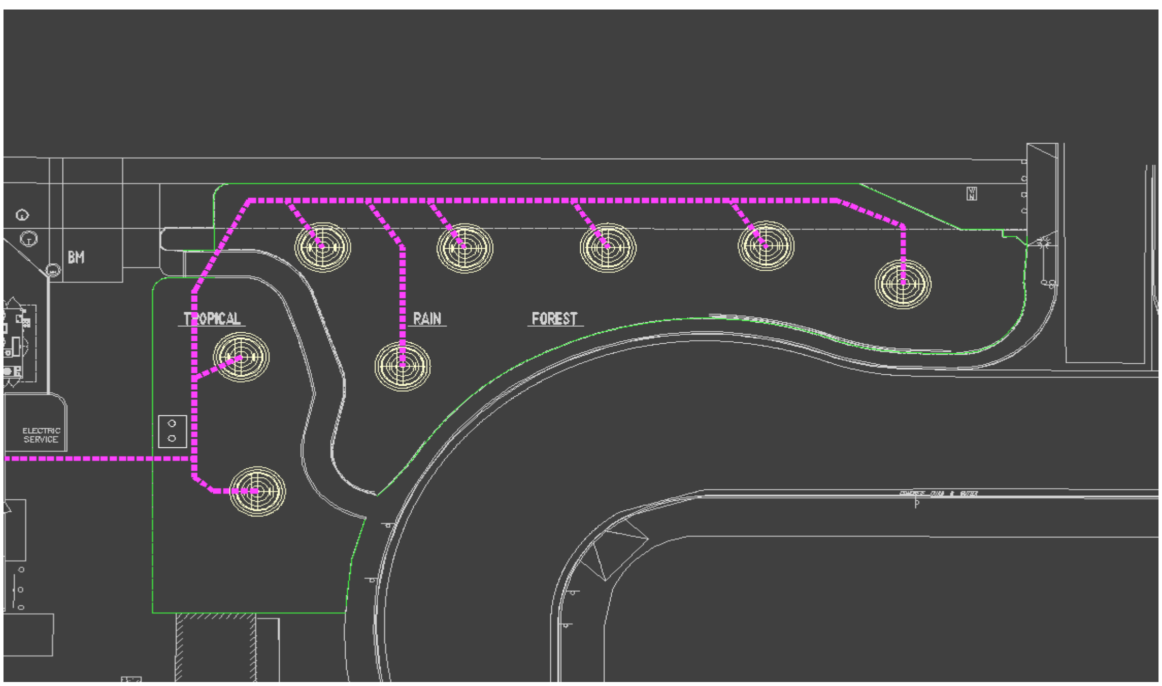

Figure 2.4: Basin Mode Delivery System

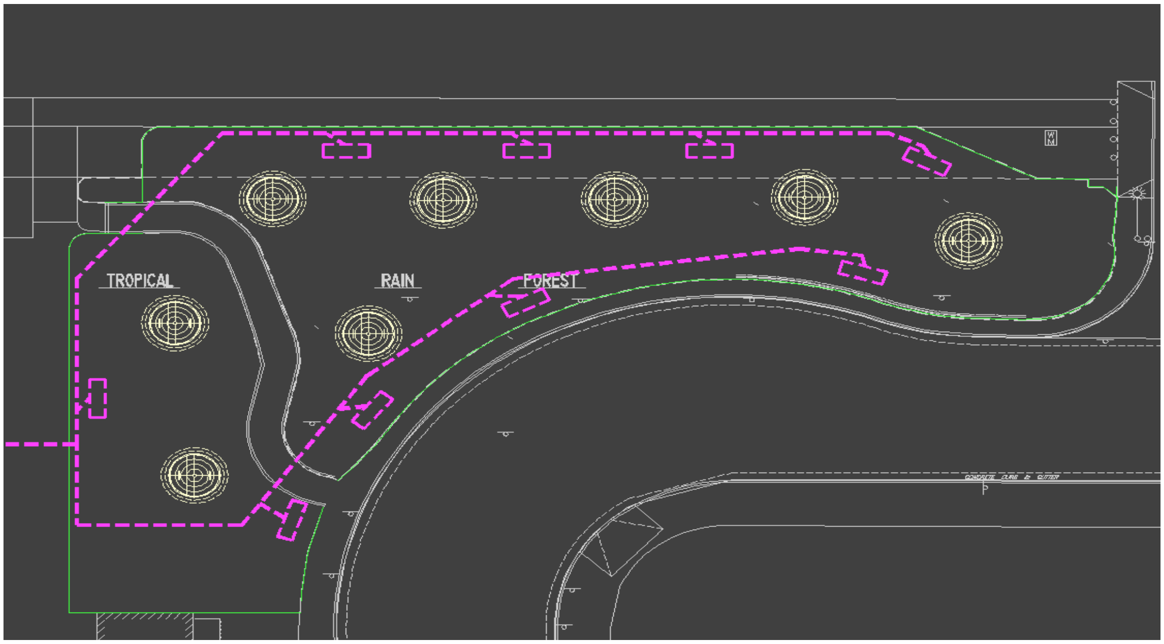

Figure 2.5: Perimeter Mode Delivery System

Problem: The perimeter delivery system is based on the cooling towers (Figure 2.6) capability to draw CO_2 inwards from the edges of the rainforest. The cooling towers when running in the normal mode blow warm air from the top and act as a vacuum at the bottom and, therefore, are a major component of the perimeter delivery system. Efficiency and cost are the primary factors considered for CO_2 delivery design. The velocity vectors of the perimeter CO_2 delivery system where calculated using the exposed screen area, cooling tower air volume flow rate, increasing radiuses by 7 feet from the cooling tower, and assuming an increase in surface screen area as radius increased. The magnitude of each vector was represented in an AutoCAD drawing to show the distribution of CO_2 (Figure 2.7). From the velocity vector representation, it was evident that there is a need to add perimeter diffusers in some locations to create a uniform distribution. Cost of additional diffusers increased a concern about building cost versus effectiveness in the design since only one diffuser per cooling tower was expected to be used. Also, running the cooling towers in normal upward draft mode is used when there is a demand for the chillers full cooling capacity. The fact that most of the time the cooling towers will not run in upward draft mode raised the question whether constructing the perimeter delivery is feasible or not.

Figure 2.6: Cooling Tower

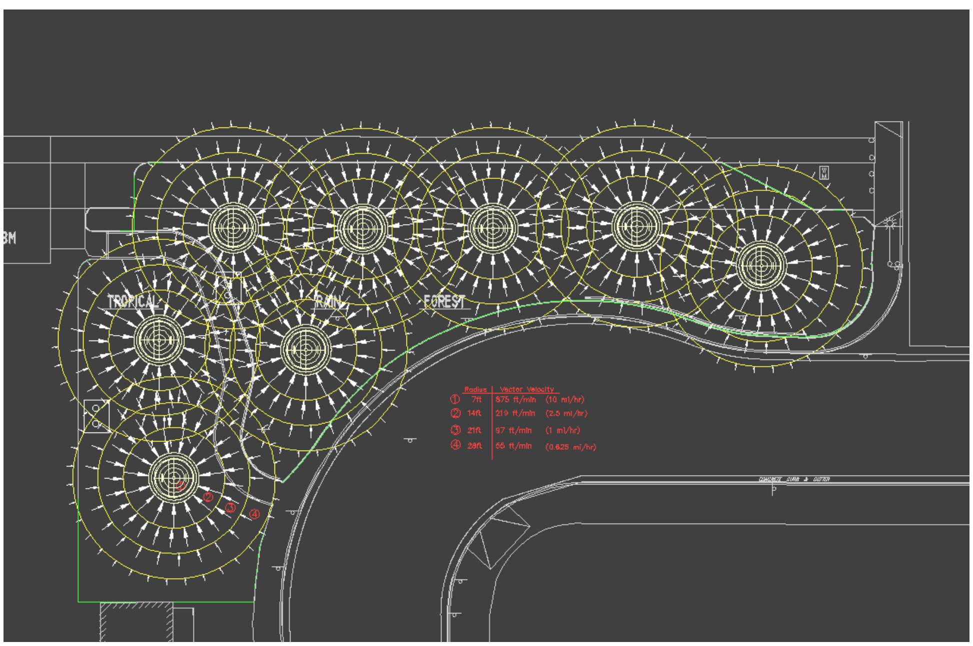

Figure 2.7: Perimeter Mode Velocity Vectors

Analysis: Demand for the chillers full cooling capacity requires running the cooling towers in the normal upward draft mode. Referencing to 2005 Digital Energy's report on CSUN's Central Heating & Cooling Plant Evaluation, the 2000 ton chiller's cooling capacity will be reached at year 2024. The above statement shows that the need to run the cooling towers in upward draft will not be necessary anytime soon. Also, when the outdoor temperature is at a peak, the chillers are considered to be at full load (9). This peak, based on York International's article on Chiller Plant Energy Performance, occurs on average six hours per year (9). Therefore, the normal mode will rarely be used and constructing a perimeter CO_2 delivery system that depends on this would not be feasible. Also, the article states that a chiller only runs about 0.01% of its potential operating hours at full load. All of the above facts prove that the perimeter CO_2 delivery system is not the proper design choice because of low usage and construction costs.

Underground Design: The basin mode combined with practical HVAC techniques was the final CO_2 delivery system choice. The distribution system would disperse CO_2 uniformly around the cooling tower by an underground supply rising and wrapping around it. The first step in designing this was to acquire the cooling tower piping diagrams to coordinate the CO_2 delivery system appropriately. Figure 2.8 shows the CAD drawings for the supply and return lines for the cooling towers. As you see in the figure it is evident that underground space for additional piping for irrigation and CO_2 is scarce. Next, a quick sketch with the labeled lengths and proposed layout for the underground piping was done (Figure 2.9). This enabled us to be able to find the total equivalent length of all fittings and the longest run the CO_2 would travel. These lengths were important for sizing the piping. Using the equal friction method, an approach that wishes to have equal pressure drop per length, we where able to determine the size of a pipe from start to finish. Figure 2.10 shows the finished layout of the underground CO_2 delivery. Refer to appendix A for technical calculations and details of underground pipe sizing.

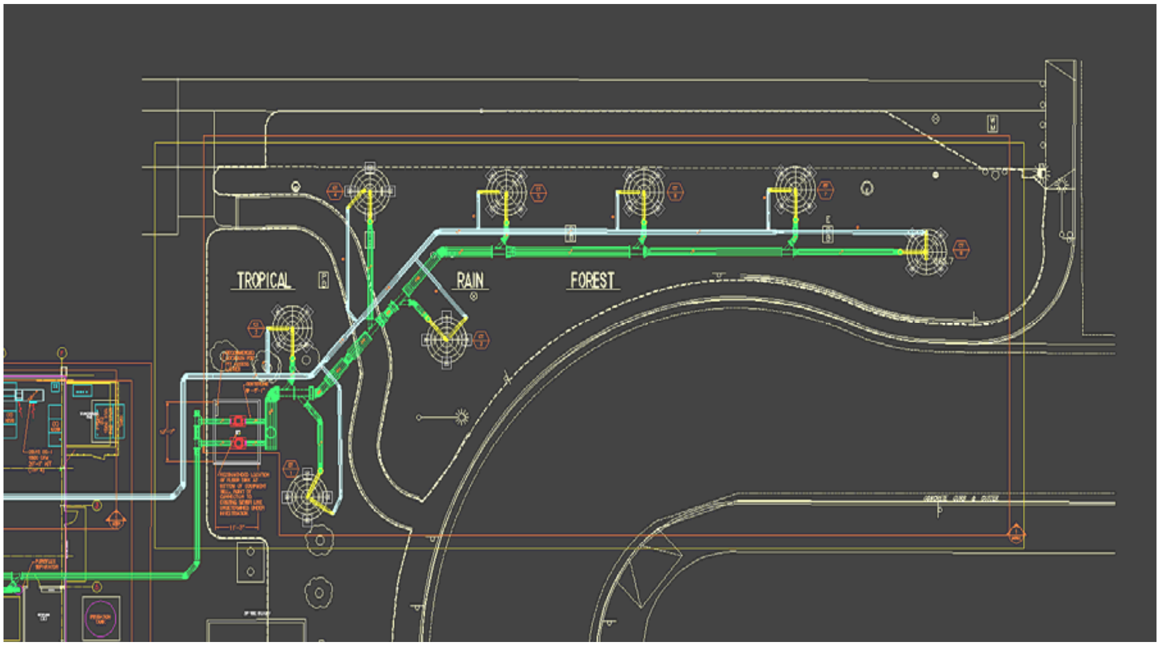

Figure 2.8: Cooling Tower Supply and Return Lines

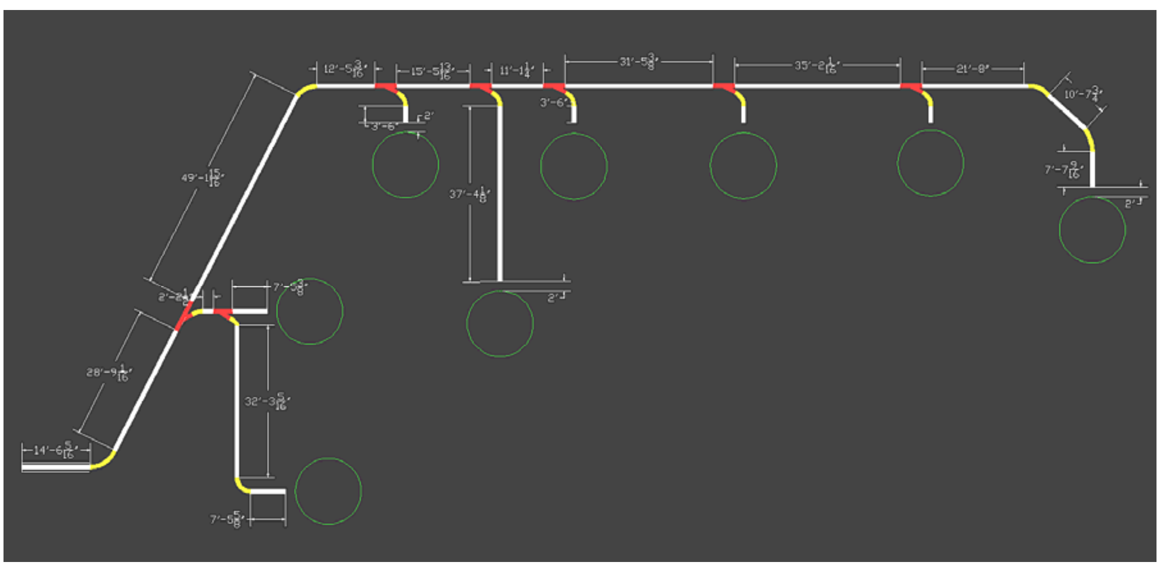

Figure 2.9: Proposed Underground Layout and Lengths.

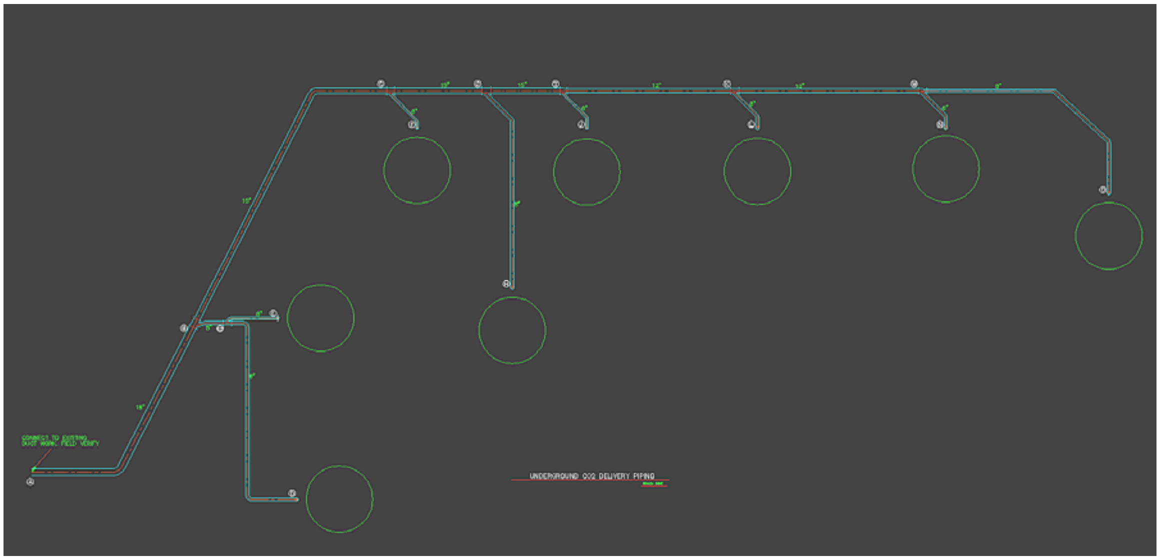

Figure 2.10: Final CO_2 Underground Delivery System

<u>Aboveground Design:</u> The underground CO_2 delivery system ended just right before the perimeter of the cooling tower. Since we wish to use the outward draft coming from the basin of the cooling tower to equally distribute the $CO_{2,}$ a flexible pipe wrapped around the cooling tower will diffuse the CO_2. Figure 2.11 shows an overhead schematic of the above ground CO_2 distribution. This design has been given the name of "ring diffuser."

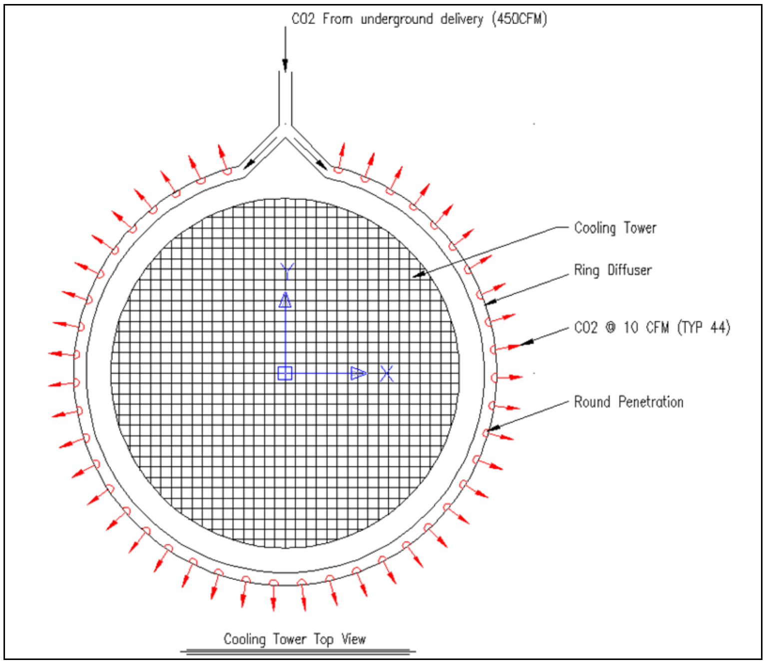

Figure 2.11 : Overhead Schematic of Aboveground CO_2 Distribution

Using the Mechanical Engineering Reference Manual to get the equation for volumetric flow rate through an orifice meter it was possible to size our ring diffuser penetrations (46). Orifice sizes ranged from 1-1/4" at the initial entrance, up to 1-5/8" at the end of the run. Also, when analyzing this fluid flow only half of the ring was considered since the other half is simply its mirror image. From this analysis it was found that 21 diffusers had a flow rate of 10 CFM (each) and the last diffuser had a flow of 15 CFM. Refer to Appendix I for details and calculations of the ring diffuser design.

2.3 Cooling Tower Short Cycling

Problem: During the design, there was a concern that there would be stratification/ short cycling of heat reject air at the cooling tower basin which decreases its performance. Short cycling is the process where waste air flow from the heat rejection process of a cooling tower is not sufficiently directed away from the process and returns back into the top of the cooling tower causing a drop in efficiency.

Known: (refer to the figure below)

V_1= 77,000cfm / entrance area = 1581 ft/min = 8.0315 m/s

V_2= 10mi/hr = 875 ft/min = 4.445 m/s (Obtained from ring vector analysis)

Δh = 69-7/8 in. = 1.77 m

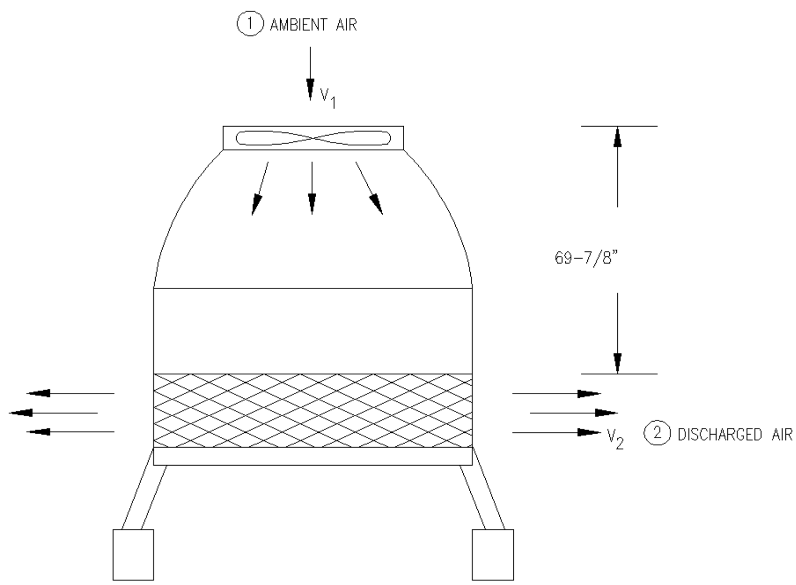

Figure 2.12: Cooling Tower Reverse Mode Air Flow Schematic

Assumptions: Knowing the ΔP between points 1 and 2 will make it evident how much pressure the dynamic pressure at point 2 will have to overcome to go from point 2 to 1 (bottom to top).

Analysis: Compare pressure at two points with the pressure drop (ΔP) from 1 to 2.

ρ = air density @ 95°F

$Q = ½ * \rho * V^2$ = dynamic pressure = $½ * (1.145\ kg/m^3) * (4.445\ m/s)^2$ = 11.311 $kg/m*s^2$ = 11.311 N/m^2 = 0.0016405 psi = **0.045 in. w.g**

<u>Using the Bernoulli equation to find ΔP</u>

$$P_1 + ½* \rho V_1^2 + \gamma z_1 = P_2 + ½* \rho V_2^2 + \gamma z_2$$

Rearranging

$P_1 - P_2 = ½*\rho*(V_2^2 - V_1^2) + \gamma (z_2 - z_1) =$

$= ½* (1.145kg/m^3)*[(4.445m/s)^2 – (8.03m/s)^2] + 11.23N/m^3 * (-1.77m) =$

$= -5.74\ N/m^2 =$ **-0.023 in w.g**

ΔP is negative since air travels from the highest to lowest point

Conclusion: Since the pressure drop from 1 to 2 was lower than the dynamic pressure, it was evident that short cycling could result. However, at the exit, the air would have a high velocity resulting in a large throw. This would make it difficult for the exiting air to travel backwards and back into the cooling tower.

2.4 Wind Direction

Overview: Since the subtropical rain forest is located outdoors, it was desired to obtain accurate local wind speed and direction, important factors that are essential for calculating the CO_2 escape rate into the atmosphere.

Knowns: CSUN Weather Report 1998-1999

Unknowns: Wind speed and direction

Analysis: All the data was entered using an Excel spreadsheet to calculate the average wind speed and direction throughout a given year. In order to do so, WRPLOT View software provided by Lakes Environmental Company was utilized. Lakes Environmental supplies robust and easy-to-use air dispersion modeling software to consulting companies, industry, governmental agencies and academia. The WRPLOT View software was used to plot the CSUN wind rose. A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions. The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. A wind rose plot may contain additional information, in that each spoke is broken down into color-coded bands that show wind speed ranges. A simple example of a windrose is shown on figure 2.13 below:

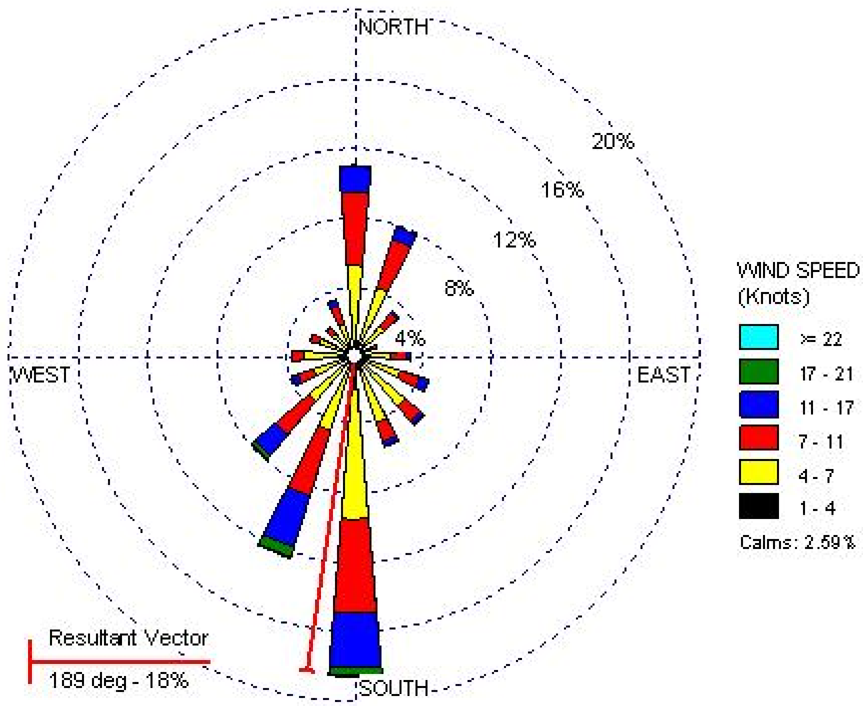

Figure 2.13: Example of windrose.

Wind roses typically use 16 cardinal directions, such as north (N), NNE, NE, etc., although they may be subdivided into as many as 32 directions (2). All the data and graphs are attached in Appendix B.

Conclusion: It was found that in 1998, the average wind speed on the CSUN campus was 1.13 m/s blowing from a predominantly easterly direction. In 1999, the average wind speed was 1.14 m/s blowing from an easterly direction as well. It was also found that the measured wind direction changes through out the year. The wind blows from the north during winter months and from an easterly direction during summer months. All the data was used to estimate the CO_2 escape rate and to locate CO_2 diffusers in order to achieve the best possible uniform distribution.

2.5 Plant CO_2 Sequestration

Overview: The purpose of the subtropical rainforest is to utilize the CO_2 which is provided by the fuel cell. The CO_2 enrichment team searched the literature and online resources to find the amount of CO_2 that various plants sequester.

Known: Plants Sequester CO_2.

Unknown: What are some average amounts of CO_2 that various plants sequester? How is the process of sequestration accomplished?

Assumptions: There is an average rate of CO_2 sequestration.

Conclusion: According to the U.S. Agriculture and Forestry Greenhouse Gas Inventory, 447 Teragrams of CO_2 are sequestered by trees for every 1000 Hectare of trees during every 5 year period (3). This is equivalent to 1,831 lbs/ft^2 per year. The literature search also showed that sequestration strongly depends on the sample size, where the sample was taken, and what plants are being used for sequestration. The two sampling locations were used to conduct experiment: “forested area” and “urban area” which are different in the species that grow in each area. The type of plants used, for example, includes Norway maples, sorghum grain, and soybean. According to the U.S. Department of Energy, in 1995, Norway maples have an annual sequestration rate of 2.7 lbs per tree (4). There is a difference in CO_2 values, with the U.S. Agriculture and Forestry Greenhouse Gas Inventory claiming 1,831 lb/ft^2, while the U.S. Department of Energy of 2.7 lb/tree. The difference between variables can be accounted by how they were estimated. The U.S. Agriculture and Forestry Greenhouse Gas Inventory used the FORCARB2 simulation model, and each ecosystem including trees was separately calculated. The U.S. Department of Energy article of "Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings" estimated sequestration with two criteria: the type of tree (separated only by two types: hardwood and conifer) and growth rate (separated by three types: slow, moderate, and fast). Therefore, we decided to calculate the CO_2 sequestration rate using the U.S. Department of Energy's method rather than that of the U.S. Department of Agriculture and Forestry Greenhouse Gas Inventory i.e. the amount of CO_2 each plant sequesters is calculated by identifying the tree type and growth rate.

Careful consideration was given to how most plants take in the CO2. The carbon dioxide enters through openings called stomata or stomate (singular: stoma) which are usually open during the day. Figure 2.12 shows that stomata are usually found on the bottom side of a leaf, making it advantageous to have CO2 coming from the ground upwards.

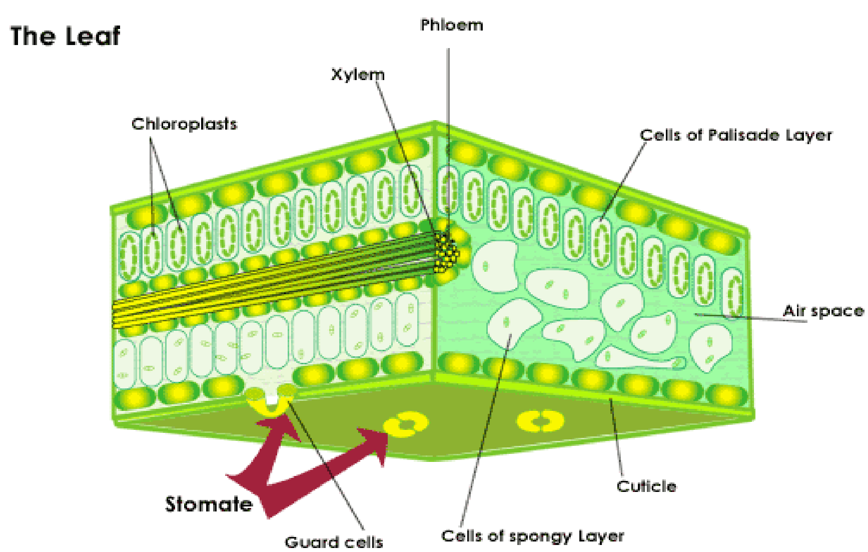

Figure 2.14: Cross Section of a Leaf

3. Irrigation system

3.1 Introduction to irrigation system

There are two different sources of water that come out of the fuel cell which can be used for plant irrigation. The main source is the reverse osmosis / electro-deionization system (RO/EDI), and the other is the latent heat exchanger condensed water which is collected in the "white" interior tank. In addition, the blow down of the condenser water loop system, which is used we the final heat rejection medium, is also consider for use for irrigation. The system is looped through eight cooling towers. These cooling towers have open meshes which allow some cooling water to escape and irrigate the plants around them. Figure 3.1 shows the basic irrigation system. The complete preliminary and finalized water systems of the fuel cell and subtropical rain forest are shown in Appendix C to help visualize the whole concept.

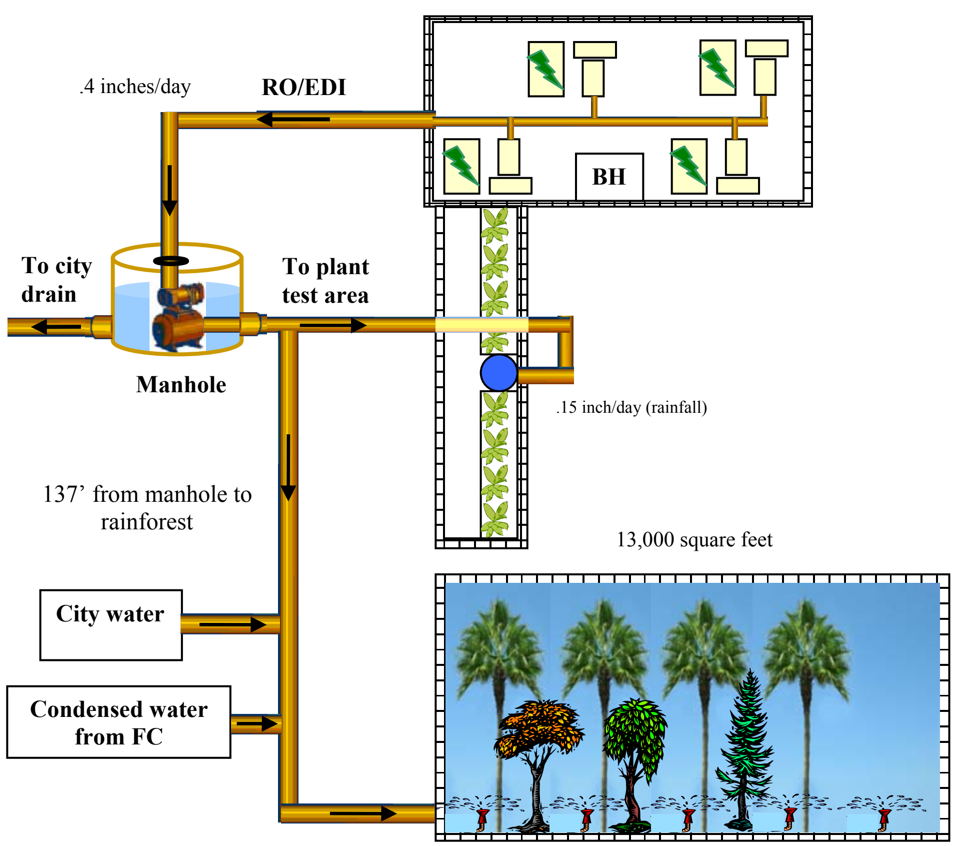

Figure 3.1: Preliminary Basic Irrigation System Schematic

The DFC300MA fuel cell power plant water treatment system (WTS) treats and stores water for injection into the fuel humidifier. Humidified fuel is needed for the fuel reforming reactions (hydrogen generation) within the fuel preparation system and the fuel cell stack. The WTS includes the treatment system and a water storage tank. The treatment system consists of pretreatment filters (particulate, carbon, and cartridge), a duplex regenerative softener, a reverse osmosis (RO) unit, and an electro-deionization (EDI) polishing system.

When the water tank is being filled, the WTS typically draws up to approximately 3.6 gallons per minute (0.8 m^3/hr) of supply water. The supply water is pretreated in pass-through filters and the softeners. The softeners exchange salt for the hardness in the water and prevent hardness fouling of the RO and EDI membranes. The pretreated water is de-ionized in the RO / EDI system, which generates about 1.1 gpm (0.3 m^3/hr) of reject water with a composition of essentially softened and concentrated (2-3X) feed water. The tank filling period is approximately 16 hours per day, depending upon fuel cell demand.

In addition to the RO/EDI discharge from tank filling, the WTS also undergoes periodic softener regeneration. During regeneration cycles, one softener provides water to service as well as to the regeneration brine solution tank. Typically, each regeneration cycle discharges up to 1 gpm (0.23 m^3/hr) of used regenerant solution for 7 minutes approximately every 3 hours, or less, based on feed water quality. The regeneration discharge is composed of a feed water/brine solution with hardness removed from the pretreated water. Additionally, the RO membranes automatically flush themselves out with a small amount of de-ionized water at the end of each tank filling cycle. The long-term average wastewater discharge from the WTS will include the contaminants contained in the feed water to the power plant, concentrated by a factor that depends on the quality of the incoming water, plus brine used for softener regeneration. The exception is that contaminants that are either adsorbed onto the activated carbon filter (chlorine, organics) or removed in the cartridge filters (sediment, particulates, suspended solids) are essentially removed from the wastewater stream. During full power operation of the fuel cell, overall water demand is up to approximately 57,600 gallons/day (217.6 m3/day), and wastewater discharge is up to approximately 9000 gallons/day (33.6 m3/day).

3.2 Gravity Irrigation System

As we mentioned earlier, fuel cell waste water and the heat exchange condensed water are collected in the common tank. The gravity irrigation system was chosen because of its efficiency, simplicity, and cost efficiency. A gravity irrigation system is the system in which the water flows and is distributed by gravity without the need of being pumped. Right away, the idea of the pop-up sprinklers was rejected since there was not enough water pressure. The water pressure in PSI can be determined by multiplying the height (feet) of the tank above the ground by 0.429. The pop-up sprinklers work at 30-40 PSI. In order to achieve such a pressure in irrigation system, the height of the tank must be 70-93 feet. The onsite water collection tank is only 18 ft tall and system would require a small pump. The pump would use energy that was unnecessary and wasteful. This led to selecting a gravity soaker system.

The gravity soaker system consists of the 4 inch main PVC pipe that goes from the water collection tank to the rainforest. It is connected to the 10 circuits of the smaller pipes. The total length of the main pipe is 100 ft and total length of the irrigation circuits is 200 ft. It was calculated and shown in Appendix C that each circuit consists of PVC pipe which is drilled every 9 inches. The hole is drilled at a 10 degree angle which allows the water throw to be about 3.5 ft on each side of the pipe. The total irrigation coverage of the pipe is then 7 ft. The irrigation time although calculated (appendix C) will be balanced and finalized toward the end of the project. The water flow can be adjusted depending on the irrigation needs. The water flow preliminary and finalized water distribution schematics are shown in appendix C, as well as the related irrigation calculations.

3.3 Waste Water Chemical Composition

Overview: Precise chemical composition of the waste fuel cell water is essential since it is used for irrigation purposes.

Knowns: Sample of the fuel cell waste water.

Unknowns: Chemical composition of the fuel cell waste water.

Analysis: In order to determine the precise chemical composition of waste water, the irrigation team collected a water sample from the fuel cell water discharge output. The sample was sealed and taken to EMS Laboratories Inc. to perform a secondary drinking analysis. This test included color, order, pH and chemicals such as: aluminum, chloride, copper, fluoride, iron, manganese, silver, sulfate, zinc, and amount of total dissolved solids.

Conclusion: National quality water standards and the chemical composition of waste water test results are in appendix D. It was found that waste water has higher concentrations of the following elements: sulfate, potassium, and potassium chloride. The higher concentrations were expected because of the water softener used in the fuel cell. It was important to find the precise chemical composition of waste water that will be used for irrigation, in order for the plant selection team to make the correct choice of suitable plants.

3.4 Plant Testing Results

Knowns: Fuel cell waste water is used to irrigate the subtropical rainforest. The exact composition of the water was determined by EMS Laboratories.

Unknowns: Waste water has higher concentrations of sulfate, potassium, and potassium chloride than the onsite tap water. It was desired to see if higher concentration of these elements in water would negatively affect plant growth and soil composition.

Analysis: Twelve plants were used to test the RO/EDI discharge liquid and were separated into four groups of three. One group was watered with the full concentration of the discharge (FC). The second group was watered with a carbon filtered discharge water (FFC). The plants in the third group were watered with the mixture of the city's water and the discharge from the RO/EDI system (MW). The last group was watered using the city's water (TW). The plants in each group were numbered to correspond to how much liquid was given to each plant. It was decided to water each group with three different amounts of water in order to determine the best irrigation scheme. The number 1 corresponds to watering the plants everyday with 0.17 liters, the number 2 corresponds to watering the plants everyday with double the amount of water (0.34 liters), and the number 3 corresponds to watering the plants every other day with triple the amount of water (0.51 liters). The base amount of water, 0.17 liters, was obtained by calculating the amount of annual rain fall in a subtropical rainforest (0.15 inches/day) and then converting that number to the size of the surface area of the potted plant.

Conclusion: As a result of the three month testing and observation, it was found that higher concentration of the sulfate, potassium, and potassium chloride in water does not negatively affect plant growth and soil composition. During the test period, a plant watered by 0.17 litter/day of fuel cell water showed the best results. The plant was able to recover from the sun damage and remained healthy throughout the rest of the test afterwards. In addition, the plant had new growths and grew outward better than all of the others. The main conclusion of the test is that RO/EDI discharge does not hurt the plants. The discharge seems to help the plants grow better than regular tap water. All of the pictures and comments are included in Appendix E.

While testing the plants, it was discovered that tested plants, “mother ferns”, are very sensitive to sunlight. The test side was exposed to open sunlight and the plants became sun damaged. To resolve the problem, a shade was placed over the test side. The good thing about the plants becoming sun damaged was that it was established that the plants could recover after being watered by all four types of water.

4. Plants

4.1 Plant sulfate regulation

Overview: Water, in addition to CO_2, is essential for plants to sustain life. After considering the use of tap water, the LADWP website was examined to obtain possible contaminants data. The LADWP Water Quality Report for 2006, points out that it is necessary to consider the effect of plants coming into contact with an overabundance of certain contaminants such as sulfates.

Known: LADWP Water Quality Report for 2006 sulfate values

Unknown: How sulfate is regulated within plants

Assumptions: One general assumption is that plants must be able to function within a certain range of sulfates. The goal after making this assumption is to establish what these ranges are and to search for signs of over and under abundance of certain contaminants.

Conclusion: How sulfates are assimilated into plants is currently being studied and is still unknown. Two different studies propose different concepts on how sulfate is assimilated. An experiment titled "Regulation of Sulfate Assimilation in Plants" considered a particular case in which the regulation of sulfate assimilation in higher plants (plants whose sulfur metabolism is initiated by the uptake of the sulfate by roots from the environment) was due to an enzyme ATP-sulfurylase. In the specific plant, Lemna minor, the enzyme stopped using the sulfate and returned an amount of H2S (6).

Another experimental paper considered is "Regulation of sulfur assimilation in higher plants". This study stated that sulfate intake was heavily influenced by the presence of a sulfate transporter gene. It also suggested that whatever the amount of sulfate activity currently in the system, the appearance or disappearance of the sulfate transporter can regulate how much sulfate is being taken up in the roots of the plant (7). The lower the amount of the sulfate the plant gets, the lower the probability that the sulfate transporter is present in the roots of the plant (created by the *Arabidopsis thaliana* gene “AST68”). In both cases, the experiments suggested that sulfate was regulated within the parameters of the LADWP’s sulfate water quality values.

4.2 Soil Composition and the Addition of Biochar

Overview: The composition of the soil must be analyzed before amending the existing soil to make it suitable for subtropical plants. We began this process by sending eight soil samples taken from the subtropical rainforest site to Wallace Labs in El Segundo, California. After testing, Garn A. Wallace, Ph.D recommended additions to the soil to make it suitable for subtropical plants by providing ranges for different parameters including pH levels and certain chemicals (K, Mg, Cl, etc). After receiving this information, we discovered Terra Preta – a type of soil found in the Amazon which has several beneficial qualities, including: increasing carbon storage, enhancing the moisture retention in the soils, increasing the habitat for beneficial microorganisms in the soil, and good retention of minerals and nitrogen compounds. With the focus being on maximum carbon sequestration, we searched for a way to acquire Terra Preta soil. After researching, we learned that there are different labels for soils that are basically the same; Terra Preta, literally translates to “black earth” can only be found in the Amazon. However, experiments have been carried out with another product which is an identical soil, dubbed “biochar” or “agrichar” obtained through a process called pyrolysis. Pyrolysis is the development of biochar where the biomass is heated in the absence of oxygen. Due to the fact that biochar studies are still in their infant stages, searching for biochar manfactures led to only two possible producers: Eprida and Dynamotive Energies. Our contact at Dynamotive Energies, Tom Bouchard, agreed to ship biochar from their main base in Vancouver, Canada. But then the question arose as to: what mass ratio of current soil to biochar would be ideal for the rainforest?

Unknowns: Terra Preta / Biochar / Agrichar data, current soil composition and analysis.

Known: Wallace Lab soil composition report, various recent studies on biochar as a product of pyrolysis, research data regarding Terra Preta, and biochar.

Assumptions: The current soil composition can be modified to sustain subtropical plant species. With biochar being a relatively new product, the mass ratio of biochar to existing soil has to be assumed.

Conclusion: Johannes Lehmann, a leading soil specialist on Biochar / Terra Preta from Cornell University, suggested a ratio between 1-5 tons per hectare for a minimum, and a 50-100 ton per hectare as a maximum. It has been decided to go with a 6,000 lbs / 13,000 ft^2 (24.8 ton/hectare) and have a volume of 9,750 ft^3 (approximately 13,000 sq ft^2, a depth of 9 inches). After taking this into consideration, we also analyzed what the projected cost to value ratio would be using so much biochar. Looking at the Chicago Climate Exchange (CCX) we realized that at the current price of carbon credits, it would not be fiscally reasonable to go with even 5% total volume of biochar. Due to this, we decided to go with 3% total volume biochar, which came out to be approximately 4,565 lbs. On top of this, we decided to contact American Soil Amendment Products for the remaining amendments suggested by Dr. Wallace, including agricultural gypsum, triple superphosphate, potassium sulfate, and ammonium sulfate. After discussing price and mixing, we went through with the purchase. Our total soil composition then included biochar which is 3% the total volume of the subtropical rainforest area (292.5 ft^3 of total volume 9750 ft^3) and the amendments recommended by Dr. Garn Wallace. Total volume of amendments and biochar was calculated to be 1480.5 ft^3.

4.3 Avoided CO2 emission by biochar production

Overview: Many of the current technologies that are designed to reduce CO2 emissions have initial cost such as carbon emissions and energy. Production of the biochar is not an exception. The pyrolysis process produces CO2 emissions that are initial cost of the biochar. The pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam (14). This initial carbon cost will be recouped over time as it offsets the carbon dioxide (and possibly methane) emissions that would have occurred if the biomass was not pyrolysed. It is desired to find the rate of the greenhouse gas payback (15).

Knowns:

$$CO_2\left(saved)\right) = \left(\int_0^t CO_2 \text{ @ } Decomposition.dt\right) - CO_2 \text{ @ } Pyrolysis \qquad \text{(Eq. 4.1)}$$

CO_2 @ Decomposition- the rate at which CO2 would have been produced if the biomass were allowed to decompose.

CO_2 @ Pyrolysis- the amount of CO2 released by pyrolysis (15).

Assumptions:

- Decay of biomass follows an exponential decay curve.
- During pyrolysis, 50% of the carbon in the biomass is released as CO2.
- Weight of the biomass is 20000 lbs.

- Biomass decay half-life is 10 years.

Using Excel spreadsheet, we plotted Figure 4.1 that shows CO_2 emission rate during the natural decomposition and the pyrolysis process of 20000 lbs of biomass with decay half-life of 10 years. In addition, Figure 4.2 shows the avoided CO_2 emissions over 50 years time period by using equation 4.1.

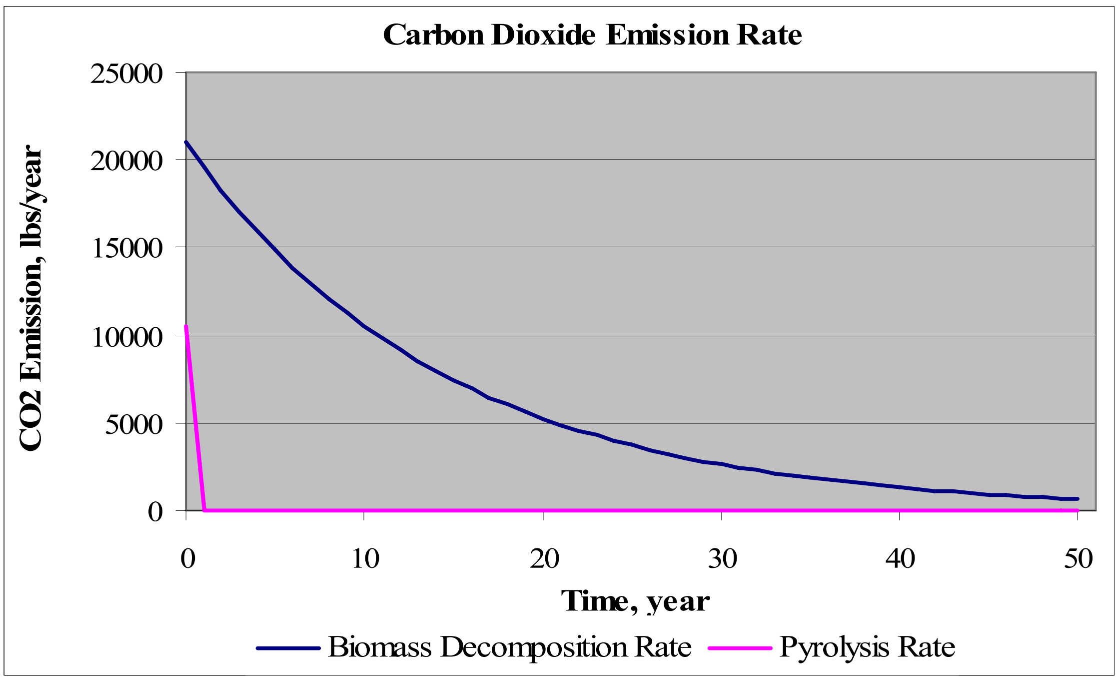

Figure 4.1: CO_2 emission during the natural decomposition and the pyrolysis

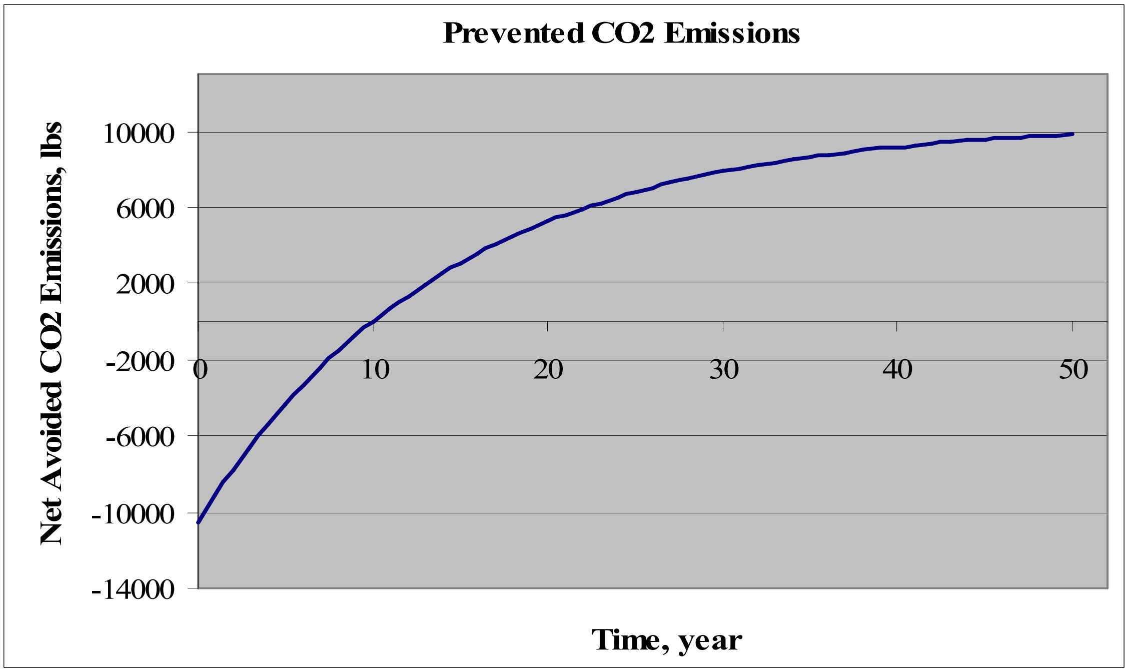

Figure 4.2: Avoided CO_2 emission by biochar production

4.4 Plants Selection

Overview: The selection of plants for the subtropical rainforest was critical in the final step of the project. The condition of the plants would become the visual representation of the successful work. If plants can flourish, then assumptions, design, and implementation were done correctly to recycle the CO_2 and water from the fuel cell to the plants. Although plants were initially selected to fit within parameters we set as a subtropical rainforest, due to availability and financial concerns, we decided to include plants outside of these parameters as well.

Unknowns: Soil composition, water composition, various wind data, average climate including rain and sunshine.

Knowns: Wallace Labs soil analysis, CSUN fuel cell and tap water analysis, wind data research, Sunset Western Garden Book climate zones.

Assumptions: Although, there are many subtropical species, we will narrow most of our selection to plants that will survive according to our climate and wind data.

Conclusion: Research was carried out on water intake, sunlight, and humidity.

Role of water with plants	Impact of water shortage
Primary component of photosynthesis and transpiration	• Reduced growth and vigor
Turgor pressure (pressure to inflate cells and hold plant erect)	• Wilting
Solvent to move minerals from the soil up to the plant: NO3-, NH4+, H2PO4-, HPO4-2, K+, Ca+2, Mg+2, SO4-2, H2BO3-, Cl-, Co+2, Cu+2, Fe+2, Fe+3, Mn+2, MoO4-2, and Zn+2	• Reduced growth and plant vigor • Nutrient deficiencies
Solvent to move products of photosynthesis throughout the plant, including down to the root system	• Reduced health of roots which leads (over time) to reduced health of plant
Regulation of stomatal opening and closure, thus regulating transpiration and photosynthesis	• Reduced plant growth and vigor • Reduced cooling effect = warmer micro-climate temperatures
Source of pressure to move roots through the soil	• Reduced root growth = reduced plant growth and vigor
Medium for biochemical reactions	• Reduced plant growth and vigor

Light Quality:

Light quality refers to the color or wavelength reaching the plant's surface. A prism (or raindrops) can divide sunlight into respective colors of red, orange, yellow, green, blue, indigo and violet. Red and blue have the greatest impact on plant growth. Green light is least effective (the reflection of green light gives the green color to plants). Blue light is primarily responsible for vegetative leaf growth. Red light, when combined with blue light, encourages flowering.

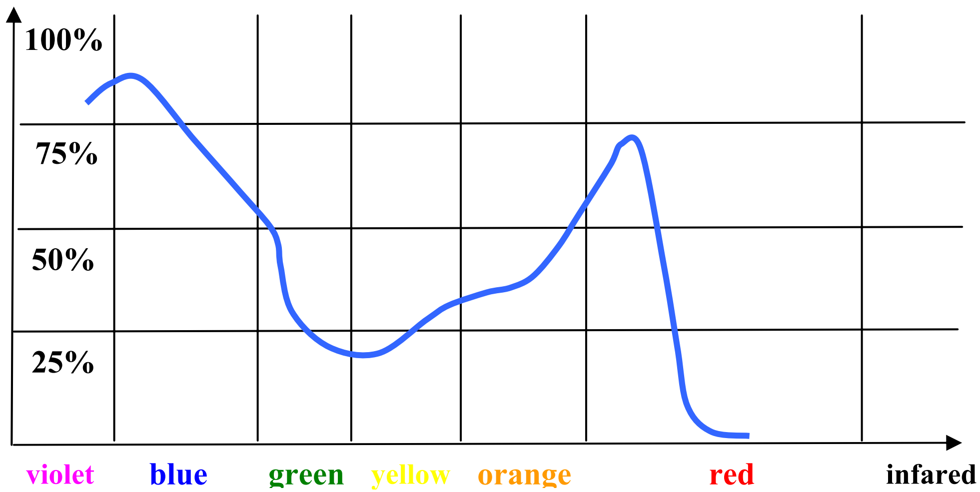

Figure 4.1: Relative Efficiency of Various Light Colors in Photosynthesis

Plants vary in their adaptation to light intensity. There is a need to understand the differences between these degrees of sun/shade:

Full sun – direct sun for at least 8 hours a day, including from 9 a.m. to 4 p.m.

Full sun with reflected heat – Whenever plants receive reflected heat from a building or other structure, temperatures can be extremely high. This situation significantly limits the choice of plants for the site.

Morning shade with afternoon sun –Southwest and west reflected heat can be extremely high and limiting to plant growth.

Morning sun with afternoon shade – This is an ideal site for many plants. The afternoon shade protects plants from extreme heat.

Filtered shade – Dappled shade filtered through trees can be bright shade to dark shade depending on the tree's canopy. The constantly moving shade pattern protects under-story plants from heat. In darker dappled shade, only the more shade tolerant plants will thrive.

Open shade – Plants may be in the situation where they have open sky above, but direct sunlight is blocked during the day by buildings, fences and other structures. Here only more shade tolerant plants will thrive.

Closed shade – The situation where plants are under a canopy blocking sunlight is most limiting. Only the most shade tolerant plants will survive this situation, like under a deck or covered patio.

<u>Relative Humidity:</u>

Water moves from areas of high relative humidity to areas of lower relative humidity. Inside a leaf, the relative humidity between cells approaches 100%. When the stomata open, water vapors inside the leaf rush out forming a bubble of higher humidity around the stomata on the outside of the leaf.

The difference in relative humidity around the stomata and adjacent air regulates transpiration rates and pulls water up through the xylem tissues. Transpiration peaks under hot dry and/or windy conditions. When the supply of water from the roots is inadequate, the stomata close, photosynthesis shuts down, and plants can wilt.

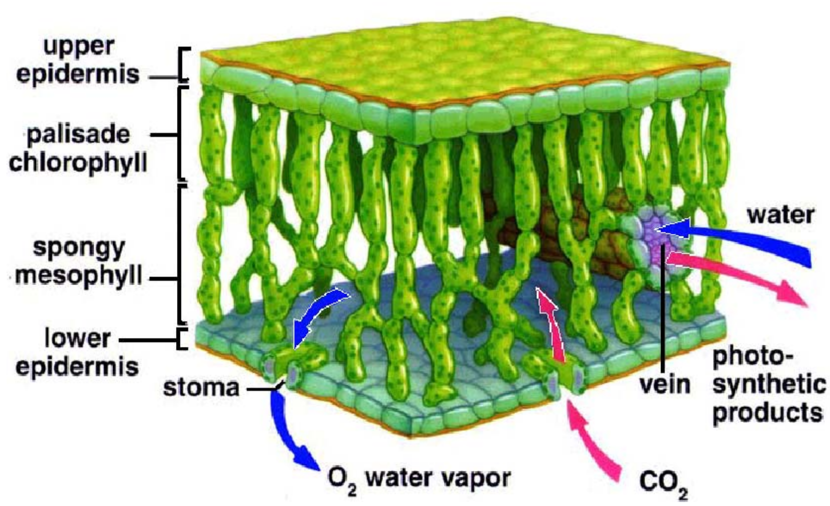

Figure 4.2: Leaf Cross Section

Temperature considerations:

Temperature factors that figure into plant growth potentials include the following:

- Maximum daily temperature
- Minimum daily temperature
- Difference between day and night temperatures
- Average daytime temperature
- Average nighttime temperature

After consulting Subtropical Rainforest index books, we finally chose these species:

Artocarpus altilis

Phoenix reclinata

Bambusa oldhamii

Inga edulis

Bambusa malingensis

Bambusa textilis

Otatea acuminate aztecorum

Kola

Durian

Tabebuia impetiginosa

Brahea armata

Livistona chinensis

Callistemon viminalis

Chamaerops humilis

Bambusa multiplex 'Rivereorum'

Bambusa multiplex 'Fernleaf'

Tibouchina urvilleana

Megaskepasma erythroch

Thevetia peruviana

Brugmansia

Acalypha wilkesiana

Hamelia patens

Alyogyne huegelli

Ruscus aculeatus

Cordyline fruiticosa

Sanchezia speciosa

Mimulus Guttatus

Crinum amabile

Strobilanthes dyerianus

Hibiscus schizopetalus

Dianella tasmanica Nephrolepsis cordifolia

Caladium bicolor Spathiphyllum 'Mauna Loa'

4.5 Guidelines for Planting in the Subtropical Rainforest

1) *Prevention of the short cycling*. Short cycling is an inherent risk of the cooling towers. The main concern is that effluent moist saturated air coming out of the bottom half of the cooling towers recycles upwards (due to barriers such as a tree) climbing back up and into the inlet at the top of the cooling tower (Fig. 4.3). This would decrease the efficiency of the cooling towers due to recycling the air. After measuring, we decided that it would be ideal to have trees that had a bottom canopy height of 10 feet to be planted next to the cooling towers. This setup would prevent short cycling (Fig. 4.4).

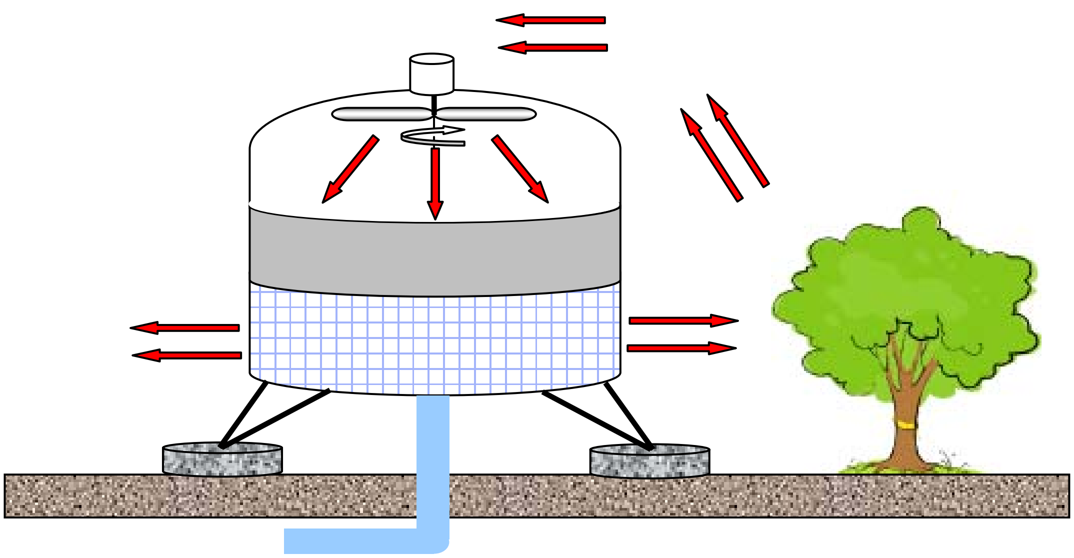

Figure 4.3: Short Cycling

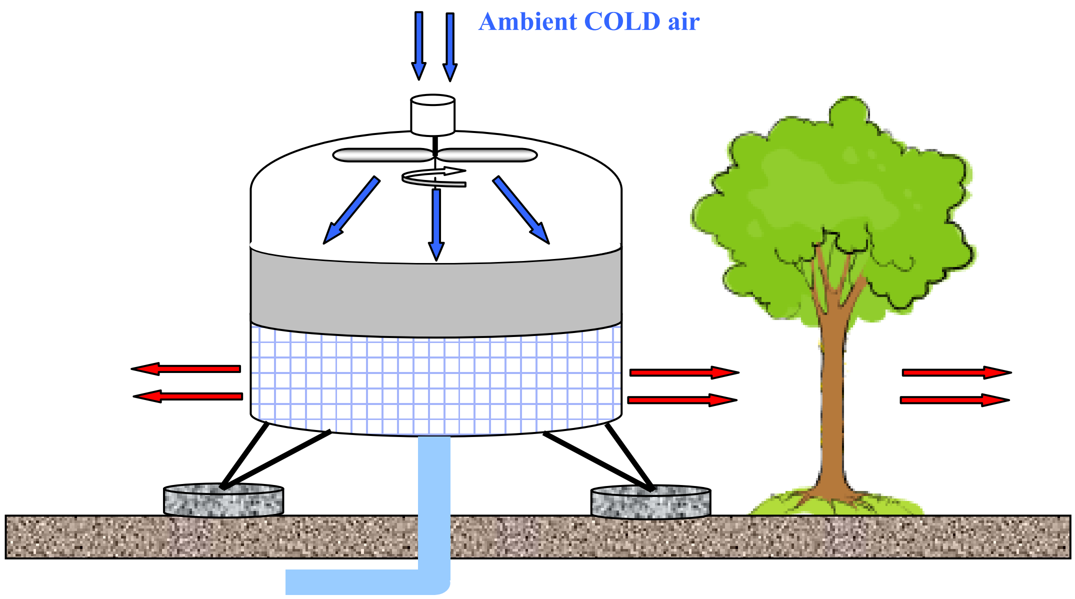

Figure 4.4: Short Cycling is prevented

2) *Main Line Avoidance.* The subtropical rainforest will have a main infrastructure lines running through the middle of the rainforest, and we will not be planting any trees with deep roots or any plants that easily spread as to protect these main utility lines. We will also plant accordingly as to not have heavy growth within these utility and service access areas

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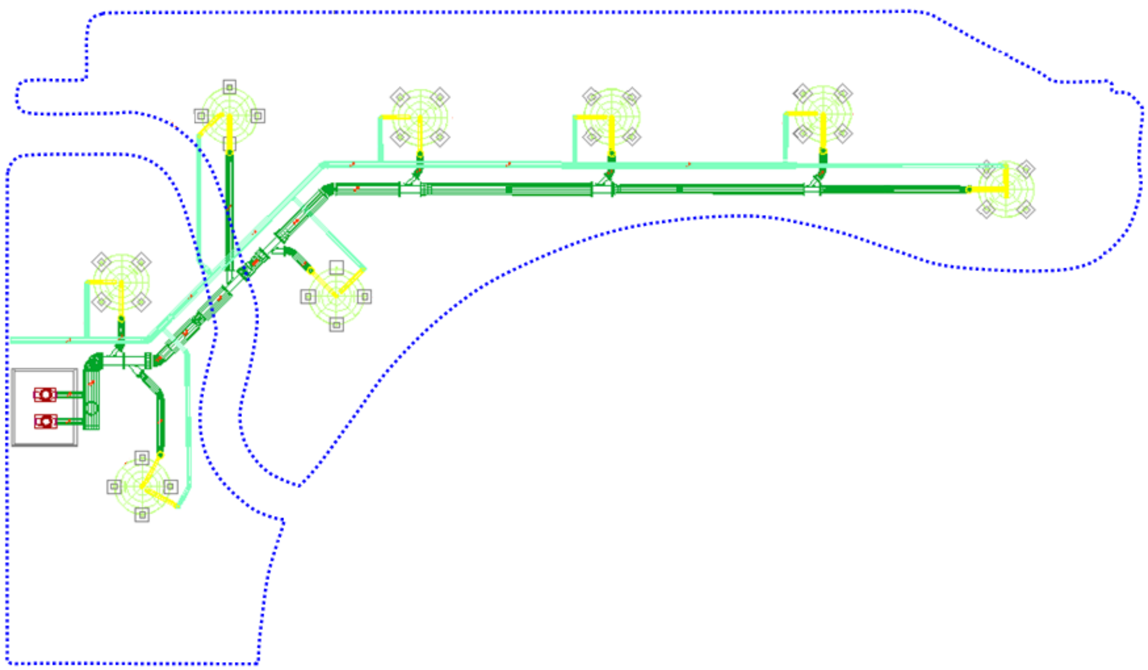


Figure 4.5: Main Piping

3) *Maximum Wind Velocities.* The cooling tower effluent wind velocities have been measured, and within a 7 foot radius of the tower there is an estimated 875 ft/min, or 9.943 mi/h. Due to this extreme wind velocity, we will be planting outside of this 7 foot radius of each of the cooling towers.

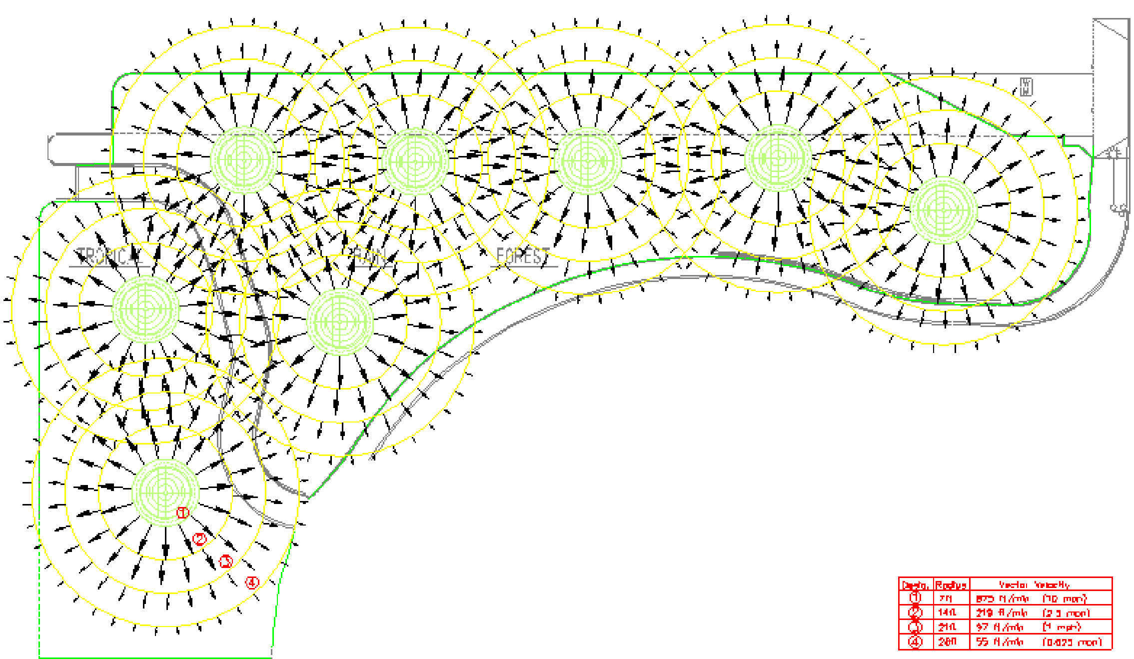


Figure 4.6: Maximum Wind Velocities

4) *Service Pathways.* We will also not be building any trees that hinder servicing the cooling towers. Doing so would cause harm to any plants or trees planted due to the necessity of maintenance on the cooling towers.

5) *Poisonous Plants.* We will also not plant any poisonous plants or trees in risk of harming those who may touch any flora coming from the rainforest.

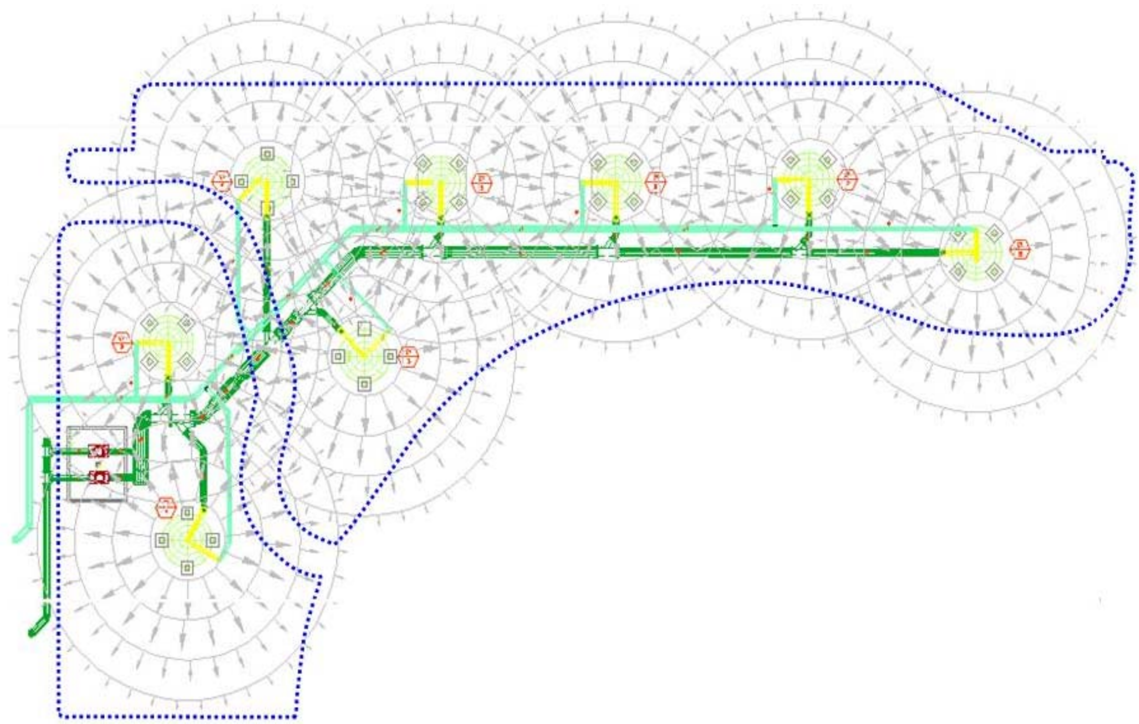
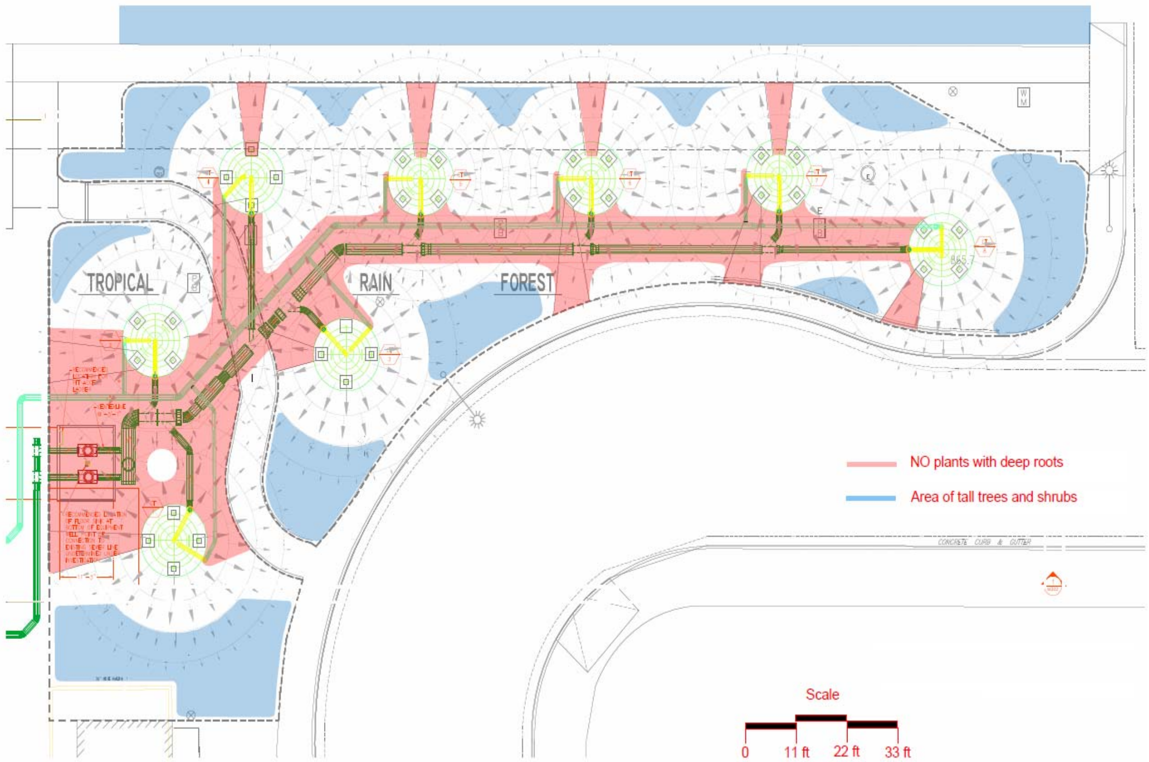


Figure 4.7: Maximum Wind Velocities and Main Pipe Lines


TROPICAL
RAIN
FOREST
NO plants with deep roots
Area of tall trees and shrubs
Scale
0
11 ft
22 ft
33 ft

5. Cooling Tower Cover Design

5.1 Material selection

Overview: The set of eight cooling towers used for the heat exchange in the Fuel Cell Project are located near the fuel cell plant and occupy approximately 12,000 square feet of space. Because of the ideal conditions created by the fuel cell wastes, vegetation sustainable in a sub-tropical rain forest environment is being planted around the cooling towers.

Problem: The heat exchange in the cooling towers occurs when air passes through the wet mesh within the tower, thus lowering the temperature. The air gap between the base of the tower and the mesh is instrumental for this process.

The falling of leaves or any debris of substantial size into the cooling tower is undesirable as this may block parts of the mesh which enables the heat exchange, thus reducing its efficiency and capacity. The metal mesh at the top of each tower, which also acts as a stand for the motor, has a large mesh size that would not serve as a good filter.

Thus, there is a need for a lid-like structure over each of the towers which will serve as a protection from debris that can affect the process and also add aesthetic value to the rainforest project.

Knowns: The following attributes must be considered during the design of the tower lid because of the nature of the operation of the cooling towers (both in updraft and down draft modes):

1. The lid frame should be lightweight and also provide easy access to the motor.
2. The mesh used for the cover should be lightweight and durable. Longevity and flexibility are also desired attributes.

3. The mesh size should be such that the flow of air in both upward and downward directions receives little resistance from it.
4. Most importantly, the mesh size should be such that it prevents most of the debris that would affect the cooling process, from falling into the towers.

Unknowns:

1. The first unknown in the design of the tower lid is the material to be selected for the cover. (This report in part, discusses how this material was selected by eliminating other possibilities and considering material characteristics)
2. The second unknown is the size of the mesh. Factors, such as air friction loss, size of the debris etc. will be considered.
3. Finally, the shape of the mesh lid is still unknown since it should facilitate easy access to the motor located on the top of the tower.

Analysis: The above unknowns led to the study of materials available for meshes / netting that are commonly made from commercially available meshes in plastics or metals. Considering the requirements of the design, plastic was selected over metal because it is less corrosive, more flexible, and easier to install.

This report provides a further detailed analysis of the chemical and physical properties of the various plastics commercially available in mesh forms. The following is a list of plastics shortlisted on the basis of availability and desired characteristics over the entire range available in the industry:

- ABS
- Nylons: Nylon MD and MDS, Nylon 6, Nylon NSM, Nylon GSM
- Polyethylene: HDPE , UHMW

- Acetal
- PVC
- PTFE/Teflon
- PEEK
- Polycarbonate
- Polysulfone
- Polypropylene

Conclusion: Out of all the materials listed above and their physical properties (Appendix F), nylons or polyetheretherketone (PEEK) are believed to be the ideal choices for this design. Further tests with samples of the above materials based on their availability and cost effectiveness would help in determining which of these materials will be the best.

5.2 Mesh-hole size selection

Overview: The material with the suitable physical properties was chosen first before proceeding with the mesh-hole size design for the cooling tower covers. After analysis, it was found that high density polyethylene (HDPE) best fits the constraints of the material design. The wet mesh inside the tower is the primary component in the heat exchange and keeping its surface clean of any debris is vital. Since the towers will be surrounded by a rainforest, falling leaves, twigs etc. are a concern for the normal operation of the towers.

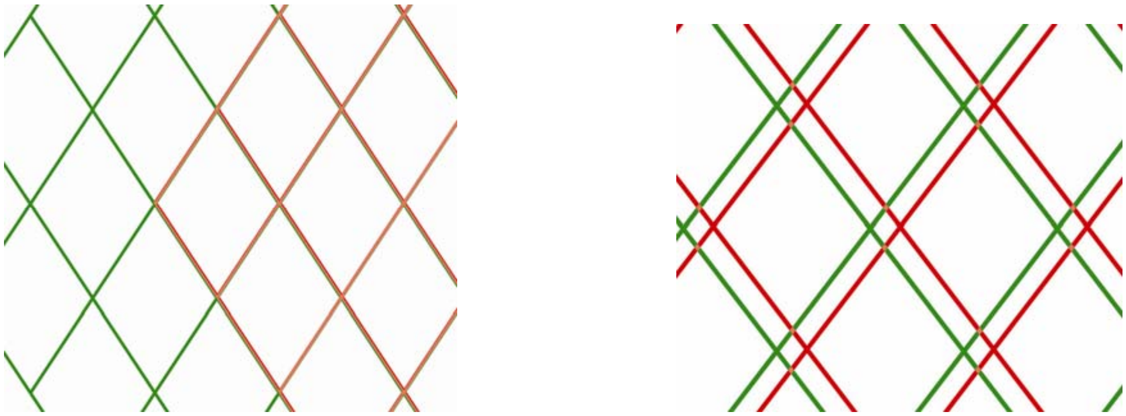
Design Constraints/Knowns: The hole size of the mesh inside the tower is known. It has irregular oval shaped holes with an approximate diameter of 0.5 inches. A design is needed to allow for air flow in both directions, namely upwards, out of the tower and downwards, coming into the tower.

Unknowns: The size of the debris that could block the mesh inside the tower and the surface area of the mesh cover above the tower are unknowns. To measure the size of the debris that could possibly block the mesh inside the cooling tower, the kind of vegetation that would be planted around the towers was studied and the average size of the falling leaves was estimated. Also, small pebbles that could ricochet off nearby moving vehicles and fall into the tower were considered. As the vegetation grows around the towers, the density of debris, other than vegetation, will decrease considerably since the vegetation cover serves as a filter. For the test at the site, samples of dry leaves and other debris were picked up from around the site and dropped onto the sample meshes acquired from one of the suppliers.

<u>Part 1</u>: Mesh Size Selection for the Cooling Tower Cover

Any debris smaller than the hole size of the mesh inside the tower will fall through the mesh onto the base of the tower. Thus, such debris will not affect the efficiency of the mesh. A simulation of the fill inside the cooling tower was created using Adobe Photoshop, taking the actual scale to minimize the error. The dimensions of the fill holes are 1 inch (width) by 1.5 inches (height). The shape of the fill holes is elliptical rather then circular. For the convenience of the design, the shape of the fill holes has been approximated by a diamond-like form. In addition, the fill layers inside the towers do not perfectly overlap. The holes from the first layer of the fill are not exactly matched with the bottom layers, thus creating an obstruction for any debris to fall through to the base.

To simulate the described effect, layers of the fill were overlaid to simulate different positions of overlap as shown in the figures below. The two overlapping fills are distinguished by the two colors.



a) b)

Figure 5.1: a) Perfectly Overlapping b) Out of Alignment

The described approach provided different hole dimensions to estimate the size of the debris that would fall through the fill down to the base of the cooling tower. A precise estimate of the debris size is essential since the debris has a direct impact on the efficiency of the cooling towers.

The following figure shows the worst case scenario of the overlap (and thus debris size tolerance level) which is used to estimate the mesh hole size of the cooling tower cover.

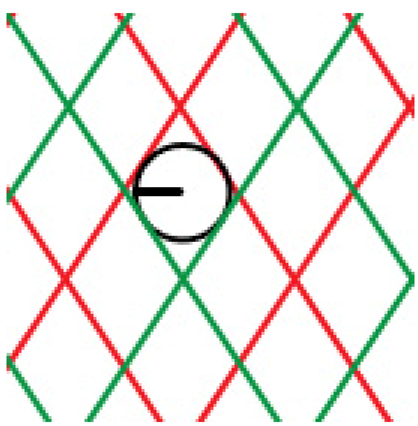


Figure 5.2: Worst case scenario, showing maximum tolerable debris radius

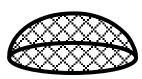
The circle inside the overlapping fills shows the maximum size of the debris that can pass through the cooling tower fill. The diameter of the circle is approximately ½ inches.

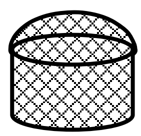
Conclusion: From the above approach, it is safe to assume that the cooling tower cover mesh size has to be at least ½" to avoid any debris problems. The other factors that would contribute in finalizing the mesh size are the friction loss across the cover surface and the shape of the cover. With the mesh opening size determined, and the maximum friction loss known, the minimum surface area was calculated and appropriate cover designs determined.

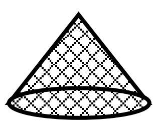
<u>Part 2</u>: Surface Area of the Cooling Tower Cover

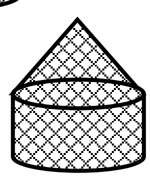
The frame of the cooling tower cover has to be designed to make the entire structure lightweight, easy to maintain, and provide access to the cooling tower motor.

Four shapes were considered:

1. Hemisphere 

2. Semi sphere over cylinder 

Conical 

3. Cone over cylinder 

The table providing surface area with suitable assumptions of the design is presented in Appendix H.

6. Aesthetics Requirements for a Learning Centered Project

Every project on the CSUN campus has opportunities to contribute to the campus' model of a learning centered environment. Beginning with the layout for the four fuel cells, the aesthetic goals for the project have been to show the project components and provide for a learning opportunity regarding fuel cell technology and the campus strategy on energy conservation. The aesthetic challenge for the project was to display the symbiotic relationship between the fuel cell / satellite chiller plant technologies and the environmentally sustainable aspect of the project, the sub-tropical rainforest. In this challenge, the main focus of the aesthetics was to unite technology and nature. It was desired for the rain forest to be highly diverse and consume as much CO_2 as possible, and at the same time be aesthetically pleasing and thematically relevant to a learning centered environment. The following chapter discusses some of the aesthetics key elements that were taken into consideration to create the satellite chiller plant/ rainforest layout.

6.1 Fuel Cell Design Elements

Several layouts for the four fuel cell units were considered to create maximum efficiencies for pipe runs and conserve space with a compact footprint which incorporated access overlaps. A perimeter fence design was selected to maximize views into the fuel cells and the BaTT (Barometric Thermal Trap). An information kiosk was included along the main pedestrian walkway with innovative touch screen technology and mapping software to inform visitors.

6.2 Cooling Tower Design Elements

Purpose: The design goal for the cooling towers is to tie them together visually, and while clearly retaining their mechanical process function and form, to integrate them into the surrounding rain forest landscape.

Unknowns: Aesthetic design on existing structure of each cooling tower.

Knowns: The cooling towers selected for the project are segmented cylinder shapes 16 feet in diameter and 12 feet in height. There is a fan motor at the top of each unit, and the cooling towers are evenly distributed over the available area. Each of the eight towers is mounted at the same elevation to facilitate balanced supply and return condenser water flow. The cooling towers come in a standard light gray color. Each cooling tower's perimeter is divided into eight segments that are separated by the structural segment seams. In addition, the bottom of the cooling tower is surrounded with the plastic mesh.

Conclusion: The design team recommended placing high definition vinyl poster pictures of different animal species over each side segment of the cooling towers. The total amount of sixty four panels will be used for all eight towers. Each tower having a specific species theme and ultimately named by one of the following names: Monkey tower, Snake tower, Lizard tower, Turtle tower, Cayman tower, Bird tower, and Insect tower. Themed towers will make identification of the cooling towers a lot easier for the future operation and maintenance personnel, as well as visiting community members and other campus faculty and student environment enthusiast. In addition, having different pictures on each panel will create more diversity among the forest. Panels will also improve the overall project site look and visually unify the technology and nature. To connect the towers visually there is a powerful colored LED light fixture with three horizontal beams of light mounted at the top of each tower. Since the towers are all at the same elevation these beams of light form a lighted grid or canopy above the cooling tower yard space.

Tower Pictures**:**

The species that we decided on are: turtles, lizards and caimans, large cats, insects, monkeys, birds, frogs, and snakes. We found an animal photographer, named Mark Kostich at www.kostich.com, and chose 300 dpi, (dots per inch), pictures of the species we wanted. Some species he did not have enough interesting pictures and so we decided on a couple of different species of the rainforest that could add to a different theme. Some of the pictures are also situated as being portrait orientation, a larger height than the width, when we needed them to have a landscape orientation, a width larger than the height. We decided to create a background on the portrait orientated pictures to extend the picture to a landscape orientation. This work was performed by the student team directly, as was taking additional photos of needed species to complete the cooling tower template.

The Turtle Tower:

There are only two backgrounds to extend.

The Snake Tower:

There were many species of snakes to choose from and we choose ones that were from a rainforest. There are two backgrounds to extend.



The Caiman and Lizard Tower:

We decided early on that one tower should have caimans and lizards together, because the two species are closely related. A minor problem that occurred is that Mark Kostich








only had a couple of caimans pictures that he felt were up to par, and so we decided to allow a more broader base specie and all types of alligators and crocodiles were added. There is one background to extend.

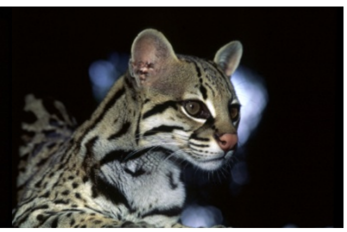
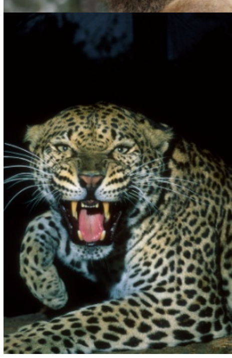
The Large Cat Tower:

The cats were plentiful and diversified. There are three backgrounds to extend and one photo will be cropped.







The Bird Tower:

The birds are all from a rainforest terrain and are diverse in subject matter. There is one background to extend.

The Frog Tower:

There are many kinds of frogs and many interesting pictures. There are five backgrounds to extend, cropping will also occur on some photos.

The Insect Tower (Spiders and Butterflies):

As the above title suggests, Mark did not have many different insects in his portfolio, but he had many interesting shots of spiders and was able to get different types of butterflies. The shots chosen displays the uniqueness of each arachnid and also displays the unique coloring of each butterfly. The juxtaposition of the two species will show how both species are beautiful, even though they are opposites in people's minds. There are no backgrounds to extend.

The Monkey Tower (Prehensile Tails Tower):

The conceived monkey tower had problems because Mark Kostich found out that his slides of rainforest monkeys was not up to par with the rest of the given photographs. We decided to change the criteria and include rainforest animals that have prehensile tails. There are only two photos of orangutans, which do not have tails, but the photos are excellent and it does not detract from the theme, being an ape. The coati is an interesting animal and it does add to making a diverse number of species and so we are using this animal instead of one species of monkey. There are four backgrounds to extend.

6.3 Site Lighting

Known: Light is required for pedestrians, as well as aesthetically for the site

Unknown: Aesthetic design and use of existing or new lighting methods

Conclusion: The first requirement to address is to light the pedestrian foot paths to allow for circulation. This is accomplished with campus standard overhead light fixtures. Architectural accent lighting is provided by LED fixtures at the top of each cooling tower and fence mounted LED color fixtures to accent the cooling towers and future tree canopy. These lights can change color and add a pleasant effect to pedestrians passing by. It will also create an umbrella effect that will separate the rainforest from other areas on campus, which will emphasize the uniqueness, creativeness, and special qualities that the project has. Another function the lights can serve is to show which area is being watered by changing the colors in each area.

<u>LED Light:</u>

Beta-Calco specification:

Body and trim: Die-cast aluminum

Finish: Silver powder coated

Front Fascia: Injection molded plastic, UV stabilized, painted

Casketing: Heat resistant silicone

Transformer: Integrated electronic, 120V

Mechanical: Mounts directly over a standard electrical junction box

Approval: UL, CSA for wet location

Color: cool white, blue, green, red, yellow

6.4 Fence Elements

Overview: To keep a barrier that will prohibit too much traveling among the rainforest.

Known: Two possible fencing options, Trellis and chain-link fencing. We have used Trellis fencing around the fuel cell.

Unknown: Aesthetic design and use of fence

Analysis: Trellis fencing has the ability to promote growth through a wired structure, as well as having an organic look to help make the technology and nature aesthetically tied. Chain-link fencing can also be utilized cheaply, although it will look cheap as well as making the rainforest look as if it is foreboding, malicious, and in disrepair.

Conclusion: The project is not for recreational use. Rainforest project is designed and layed out to sequester as much carbon dioxide that the fuel cell emits as possible and to use all byproducts that the plant generates. We do not want pedestrians to traverse through the subtropical rainforest. As a result, the student design team decided to put up fencing to keep people out along the south side of the subtropical rainforest, and to direct them to the pedestrian walks that do traverse through the site. Fence will protect pedestrians from accidental injuries as well as subtropical plants from being broken. The fence is going to be identical to the one placed around fuel cell site to clearly connect the entire project and make the whole project look aesthetically pleasing.

6.5 Entry Way Informational Booth

Overview: The information booth on the sides will allow people to learn about different aspects of the rainforest.

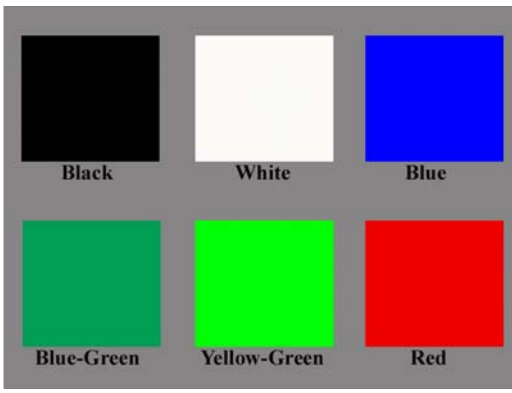
Knowns: Possible use of the current touch-screen in front of the fuel cell

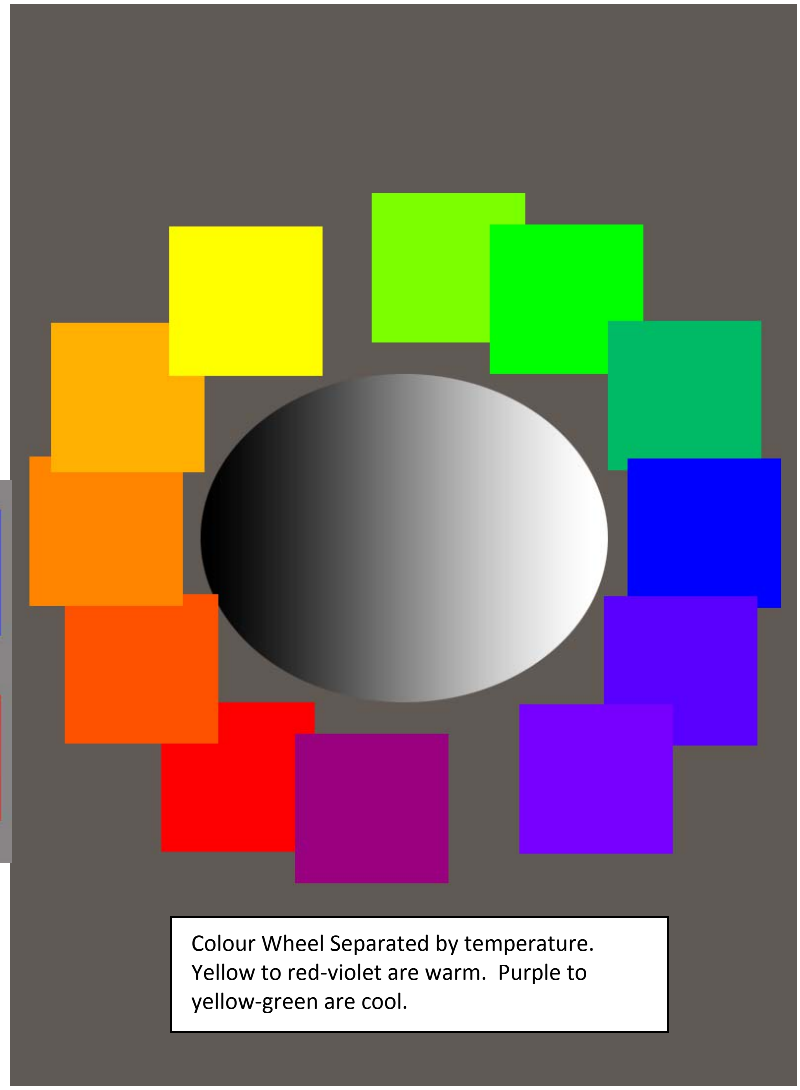
Unknowns: Possible placement of new booths

Conclusion: Using the touch-screen to inform the populace about the subtropical rainforest will work well with what we want. The traffic will be held at a minimum because of the current design of the place. Adding the information will be easy to do and it won't cost anything extra, because all the required material is already there. Having an info area at the walkways that are closest to the parking areas will be detrimental because it could cause an obstacle to other pedestrians. It is also detrimental because people will not have time to look at the information. Many of the pedestrians walking towards the campus are students on their way to class who do not have time to stop and read about the subject. While on the other hand the information area at the fuel cell leans towards more of the leaving students to visit and learn about the subtropical rainforest.

6.6 Educational Elements of the Cooling Tower and Satellite Plant

Overview: Early analysis of aesthetic design intent included color treatment of the tower components, and the influence and impressions left on the visitors within the environment.





Known: Bezold Theory and color interaction theories

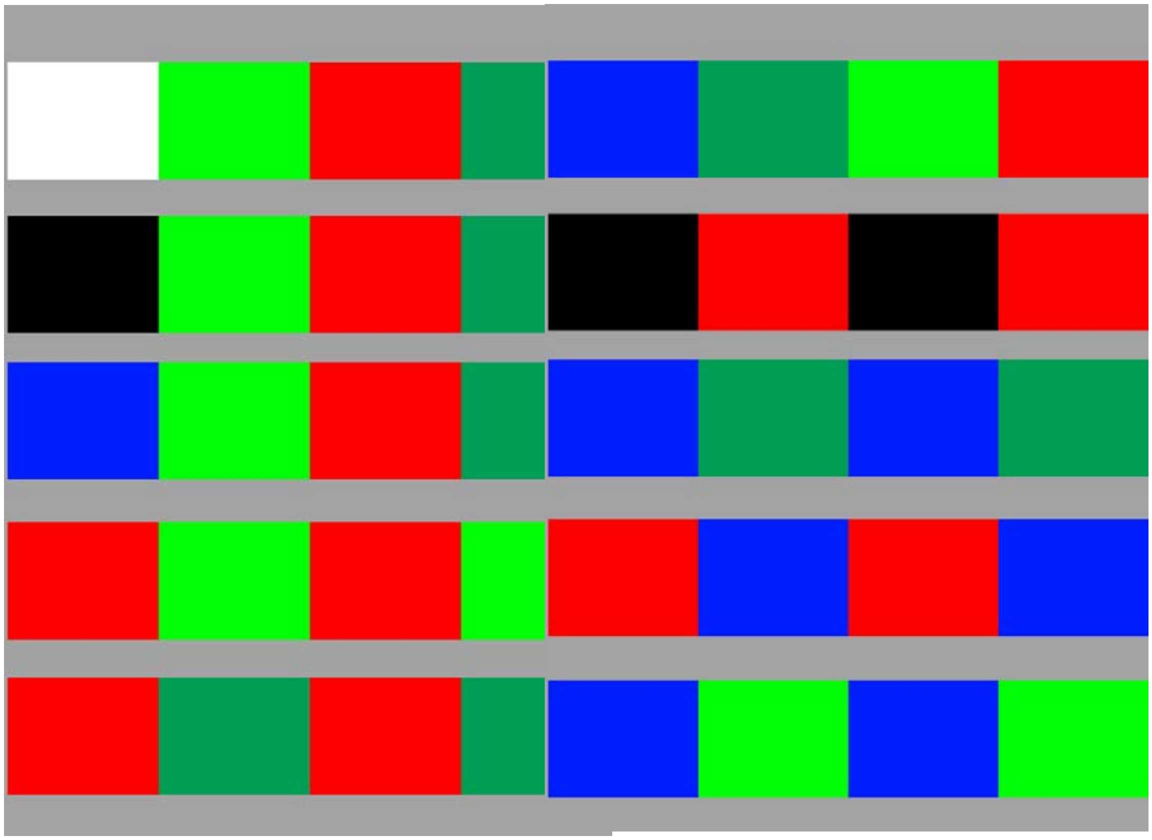
Conclusion:

<u>The Color for the Screens</u>

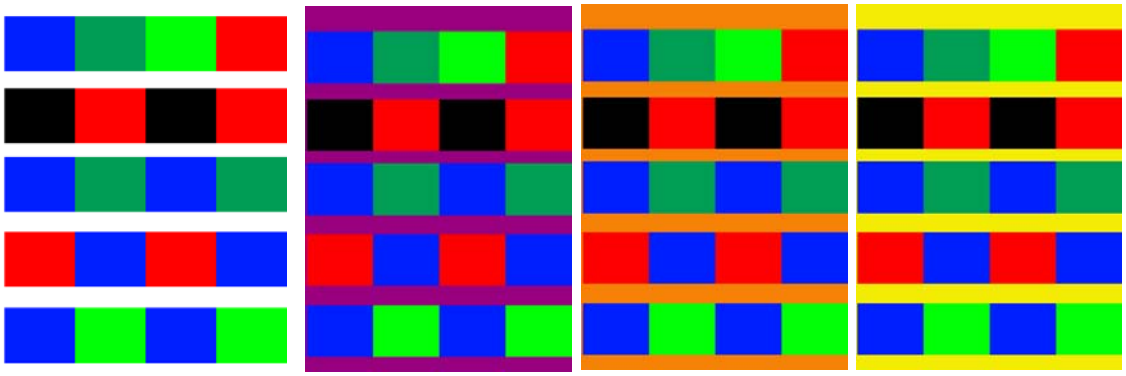
We have a limited number of colors to choose from for the color of the screens. These colors are red, black, an off-white, blue, yellow-green, and a blue-green.

The cooling towers' screens should use multiple colors to add to the appeal of the overall product. The cooling towers' screens can help bring viewers attention towards the rainforest and can cause an appealing appearance to the project. Artist uses color to help show off the artist's work and to help emphasize the overall effect on the viewer. A color interaction happens from the different colors used on a project. One color theorist, Wilhelm Bezold, realized how the changing of one color can substantially alter the perception of the viewer toward an art piece. The Bezold effect demonstrates the influence of color interaction. Color interaction becomes dramatic when complementary colors are used. This interaction of contemporary colors is expressed in the opponent theory. The opponent theory states that the cones in the eye can only register one color in the complementary pair at a time. The constant shifting between the opposing colors creates a visual overload at the edges which results in a glowing effect in the shapes and colors.

The temperature of the color is important in color interaction as well. The temperature of the color refers to how the heat plays off the colors physically and psychologically. Color temperature also helps create the illusion of space. The warm colors, yellow to violet, advance while the cool colors, yellow-green to blue-violet, recede. The intensity of the color relates to the purity of the primary and secondary colors. High intensity colors are often used to bring a more dramatic impact to the work.



The temperature of the colors will help create a perception of depth on the cooling towers. If we should place warm colors next to cool colors the visual effect of steps would be created, which would help bring a viewers attention to the site. These color effects will also help make the cooling towers more energetic and vibrant by using the colors' intensity, temperature, and complementary color scheme. With the cooling towers as they are now, they are dull and depressing. The color of the cooling towers is all gray and the singularity of the color makes it drab. The good thing about the cooling towers being grey is that when you add color with the grey it changes the perception of the object as being more vibrant. The colors above would not look as exciting as they do now if I had chosen a different color for the background. The color arrangement will also create a step effect because of the concept of warm colors advance and cool colors recede, and there is also an effect where light colors advance and dark colors recede. If we use a dark color, like blue or black, next to the lighter color, yellow-green, then the illusions of steps would appear. The colors that will have a positive effect on the showcasing of the cooling towers are blue, blue-green, yellow-green, and red. Another



choice of colors is: black, blue-green, yellow-green, and red. A third choice which uses the school colors are: red and black. The screens have a limited number of colors to choose from and they are: red, blue, black, grey, white, blue-green, and yellow-green. The first or second group of colors shows the best range of illusion and has a more vibrant look than others.

7. Presentation and animation

Overview: A presentation and animation was created to visually express the project to those inquiring of its features.

Conclusion: The media team gathered many video clips, photos, and information on the various aspects of Phase II. Some of the videos will be spliced together to form a final video clip that demonstrates step-by-step all of the work that was done. One video clip is already completed and covers fuel cell discharge research. The media team also has time lapse shots that show the growth of the plants that were used with the fuel cell discharge. The team is also planning to do an animation that shows the process of the cooling towers being erected, and then having plants growing around the placed cooling towers. The video clips and photos that the team created will show: the work that took place to complete Phase II, information about the work done, information about certain devices that are being used for Phase II, and elements that brought Phase II to completion. The team hopes that the entire video clip collection will be an excellent source of pride, education, as well as entertainment.

8. Conclusion

The main objective of Phase II of the fuel cell / satellite chiller plant was to marriage technology with nature and thus obtain optimally sustainable performance. The design of implementing the neighboring rainforest was to interact with the mechanical systems and increase the efficiency of the site from an environmental perspective by utilizing the waste products of the fuel cell and chiller plant. These waste products, including the CO2 exhaust gas, water from the reverse osmosis/electro-deionization system, and water condensed in the latent heat exchanger recovery process, and the waste heat from the campus via the chiller plant would be wasted if they were not designed to be used as inputs for the rainforest.

We have looked at previous experiments in which CO2 exhaust gas was sequestered from artificial generators, and realized what type of exhaust system we would use to feed CO2 to the rainforest. We have looked at possible detriments to the plan we have provided, as well as external factors that may influence the use of that design scheme. We have looked at how we could irrigate the water from the RO/EDI and latent heat exchanger condenser systems, and what plants would be suitable for this environment to, ultimately, sequester CO2. All of this was considered, while in reference to its location, made it aesthetically coherent with the CSUN campus.

The design of the rainforest is primarily an example of lowering the carbon footprint of the campus. Rather than having the CO2 dissipate into the atmosphere, having nearby plants to sequester the CO2 is much more advantageous both for the plant and the environment. With this in mind, we also used biochar, a soil amendment which underwent pyrolysis to lower even more CO2 content in the atmosphere while at the same time increasing plant productivity. Projections vary among sources of how much CO_2 is sequestered by plants, but the main idea is to sequester CO_2 optimally rather than have it negatively affect the environment.

The fuel cell and chiller satellite plant will be a unique, sustainable, and an environmentally friendly plant that represents the union of technology and nature. Phase II of the fuel cell and satellite chiller plant has been successful in design and will be the first of its kind. Pioneering this example of not only lowering waste products but also forming a union between technology and nature will provide inspiration for others and future projects within the campus as well as at other universities and businesses.

APPENDIX A

Part 1: Calculations to find the pressure drop across the ball type diffusers began with assumptions of the outlet diameter and velocity. Assumed parameters were based on the largest commercially available diffusers. Next, properties of the used effluent were tabulated at an assumed outlet temperature. Then, the Reynolds number was calculated to determine whether the gas flow is turbulent or laminar. Finally, the appropriate friction factor was used to calculate the pressure drop across the diffuser.

Assumptions		
Pipe Diameter	3	in
	0.0762	m
Velocity	1	m/s

Properties of CO2 @ Tavg = 89.5 C		
Ti	90	C
Te	89	C
Pr	0.7475	
μ	1.7929	kg/m*s
ρ	1.4838	kg/m^3
Cp	904.67	J/kg*k
k	0.02173	W/m*k
Ts	75	°C

Reynolds Number			
Re=(ρ*Vavg*Dh)/ μ			
ρ (kg/m^3)	Vavg (m/s)	Dh (m)	μ
1.4838	1	0.0762	1.7929
Re	**0.06**	**Laminar if Re<10,000**	

Pressure Drop		
ΔP= *f (L/D) * (ρ*V^2)/2**		
f = friction factor = 64/Re (fully developed laminar flow)		
f	1014.859	
L	0.0762	m

D	0.0762	m
ρ	1.4838	kg/m^3
V^2	1	m^2/s^2
ΔP	**752.9**	**Pa**
	3.023	**inch of water @ 4°C**
allowable	**0.03**	**inch**

Part 2: Underground CO_2 Ducting Calculations

Knowns:

$P_{available}$ = 1.8 in w.g (Based on best possible efficiency from fan performance curve)

$P_{balancing}$ = 0.3 in w.g (Subtracted from available to allow for balancing and loss through diffuser)

P_{design} = 1.5 in w.g (pressure that will be used at the start of the duct system and for longest run)

L_{eq} AO = 288 ft. (longest run accounting for loss through tee wye fittings and straight branch fittings)

Section AB (refer to the Fig.1a in appendix A)

L_{eq} = 48 ft.

ΔP = 1.5 in. w.g

ΔP' = ΔP / L_eq = 1.5 in. w.g/ 288 ft. = 0.0052 in. w.g / ft. = 0.5 in w.g / 100 ft.

Cfm = 3600

ΔP' =0.5 in w.g / 100 ft.

} Criteria to size Section AB using a ductulator

AB = 18" diameter

ΔP_{AB} = 1.5 in. w.g - [48ft * (0.5 in. w.g/ 100ft)] = **1.26 in. w.g**

Available Pressure at AB *Pressure drop through section AB = 0.24 in.*

Pressure available after Section AB

Section BE2

L_{eq} = 42.21 ft.

ΔP_{BE2} = 1.26 in. w.g

$\Delta P'$ = ΔP / L_eq = 1.26 in. w.g/ 42.21 ft. = 0.02985 in. w.g / ft. = 2.98 in w.g / 100 ft.

Cfm = 900

$\Delta P'$ =2.98 in w.g / 100 ft.

BE2 = 8" diameter

ΔP_{AB} = 1.26 in. w.g - [42.21ft * (0.5 in. w.g/ 100ft)] = **1.048 in. w.g** (pressure available for sections E2E and E2D)

Section E2E

L_{eq} = 12.45 ft.

ΔP_{BE2} = 1.048 in. w.g

$\Delta P'$ = ΔP / L_eq = 1.048 in. w.g/ 12.45 ft. = 0.08417 in. w.g / ft. = 8.4 in w.g / 100 ft.

Cfm = 450

$\Delta P'$ =8.4 in w.g / 100 ft.

E2E = 6" diameter

Section E2D

L_{eq} = 84.74 ft.

ΔP_{E2D} = 1.048 in. w.g

$\Delta P'$ = ΔP / L_eq = 1.048 in. w.g/ 84.74 ft. = 0.01236 in. w.g / ft. = 1.23 in w.g / 100 ft.

Cfm = 450

$\Delta P'$ = 1.23 in w.g / 100 ft.

E2D = 8" diameter

Section BC

L_{eq} = 71.63 ft.

ΔP' = 0.5 in. w.g/ 100 ft.

Since Section BC is a part of the longest run of the duct system, it will use the same design ΔP' as Section AB

Cfm = 2700

ΔP' =0.5 in. w.g/ 100 ft.

BC = 15" diameter

ΔP_{Bc} = 1.26 in. w.g - [71.63ft * (0.5 in. w.g/ 100ft)] = **0.90185** in. w.g (pressure available at Point C to use for Section CF)

<u>Section CF</u>

L_{eq} = 43.50 ft.

ΔP_{CF} = 0.90185 in. w.g

ΔP' = ΔP / L_eq = 0.9018 in. w.g/ 43.5 ft. = 0.02073 in. w.g / ft. = 2.07 in w.g / 100 ft.

Cfm = 450

ΔP' =2.07 in. w.g/ 100 ft.

CF = 6" diameter

<u>Section CG</u>

L_{eq} = 20.48 ft.

ΔP' = 0.5 in. w.g/ 100 ft.

Since Section CG is part of the longest run of the duct system, it will use the same design ΔP' as Section AB

Cfm = 2250

ΔP' =0.5 in. w.g/ 100 ft.

CG= 15” diameter

Sized for 14”, since using clay sewer pipe with 14” not available, will go to next size: 15”

ΔP_{CG} = 0.90185 in. w.g - [20.48ft * (0.5 in. w.g/ 100ft)] = **0.79945** in. w.g (pressure available after Section GH)

<u>Section GH</u>

L_{eq} = 77.34 ft.

ΔP_{GH} = 0.799 in. w.g

ΔP’ = ΔP / L_eq = 0.799 in. w.g/ 77.34 ft. = 0.01033 in. w.g / ft. = 1.033 in w.g / 100 ft.

Cfm = 450

ΔP’ =1.033 in. w.g/ 100 ft.

GH = 8” diameter

<u>Section GI</u>

L_{eq} = 16 ft.

ΔP’ = 0.5 in. w.g/ 100 ft.

Since Section GI is part of the longest run of the duct system, it will use the same design ΔP’ as Section AB.

Cfm = 1800

ΔP’ =0.5 in. w.g/ 100 ft.

GI= 15” diameter

Sized for 14”, since using clay sewer pipe with 14” not available, will go to next size: 15”

ΔP_{GI} = 0.799 in. w.g - [16ft * (0.5 in. w.g/ 100ft)] = **0.719** in. w.g (pressure available at Point I to use for Section IJ)

<u>Section IJ</u>

L_{eq} = 43.5 ft.

ΔP_{GH} = 0.719 in. w.g

ΔP' = ΔP / L_eq = 0.719 in. w.g/ 43.5 ft. = 0.016528 in. w.g / ft. = 1.65 in w.g / 100 ft.

Cfm = 450

ΔP' =1.65 in. w.g/ 100 ft.

IJ = 6" diameter

<u>Section IK</u>

L_{eq} = 36.45 ft.

ΔP' = 0.5 in. w.g/ 100 ft.

Since Section IK is part of the longest run of the duct system, it will use the same design ΔP' as section AB.

Cfm = 1350

ΔP' =0.5 in. w.g/ 100 ft.

IK = 12" diameter

ΔP_{IK} = 0.719 in. w.g - [36.45ft * (0.5 in. w.g/ 100ft)] = **0.53675** in. w.g (pressure available at Point K to use for Section KL)

<u>Section KL</u>

L_{eq} = 43.5 ft.

ΔP_{KL} = 0.53675 in. w.g

ΔP' = ΔP / L_eq = 0.53675 in. w.g/ 43.5 ft. = 1.233 in w.g / 100 ft.

Cfm = 450

ΔP' =1.233 in. w.g/ 100 ft.

KL = 8" diameter

<u>Section KM</u>

L_{eq} = 40.16 ft.

ΔP' = 0.5 in. w.g/ 100 ft.

Since Section KM is part of the longest run of the duct system, it will use the same design ΔP' as section KM.

Cfm = 900

ΔP' =0.5 in. w.g/ 100 ft.

KM = 10" diameter

ΔP_{KM} = 0.53675 in. w.g - [40.16ft * (0.5 in. w.g/ 100ft)] = **0.33595** in. w.g (pressure available at Point M to use for Section MN)

<u>Section MN</u>

L_{eq} = 43.5 ft.

ΔP_{MN} = 0.33595 in. w.g

ΔP' = ΔP / L_eq = 0.33595 in. w.g/ 43.5 ft. = 0.77 in w.g / 100 ft.

Cfm = 450

ΔP' =0.77 in. w.g/ 100 ft.

MN = 8" diameter

<u>Section MO</u>

L_{eq} = 40.16 ft.

ΔP' = 0.5 in. w.g/ 100 ft.

Since section MO is the part of the longest run of the duct system, it will use the same design ΔP' as section AB.

Cfm = 450

$\Delta P'$ =0.5 in. w.g/ 100 ft.

MO = 8” diameter

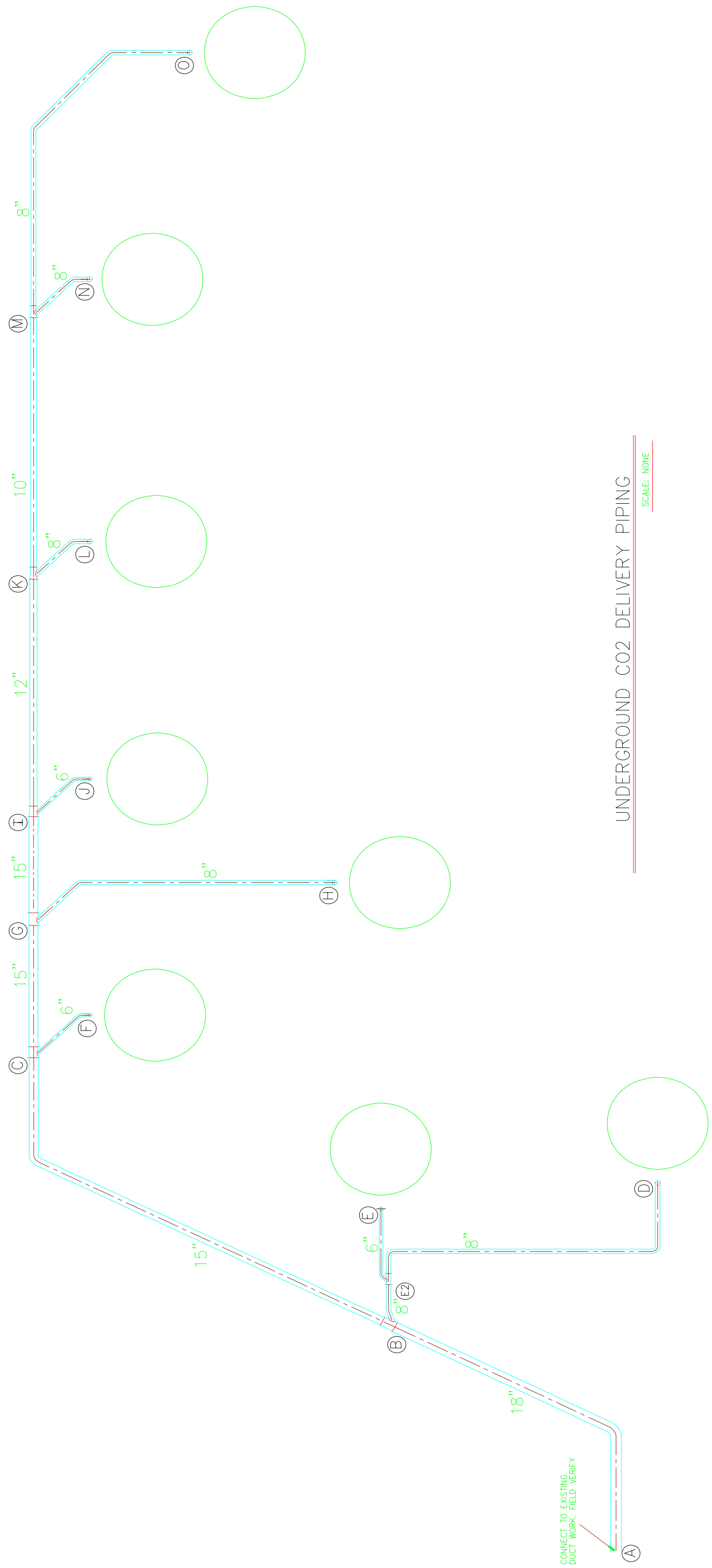
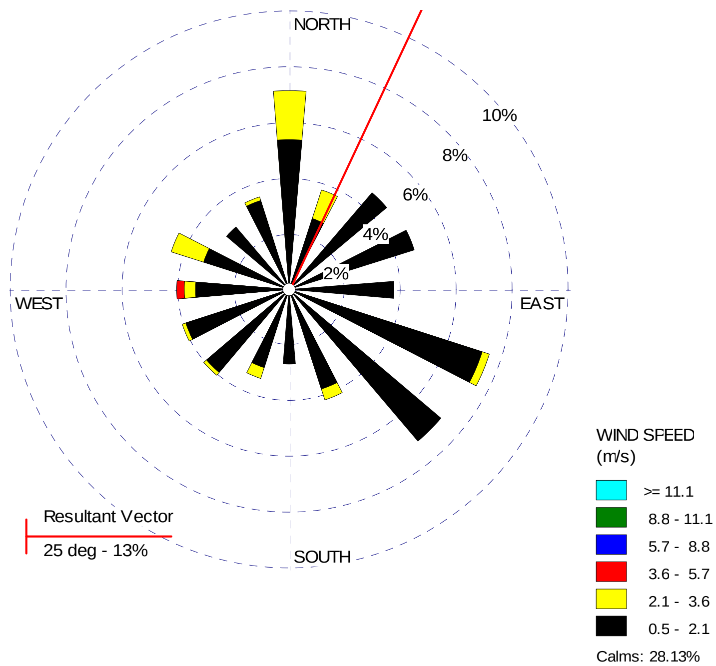


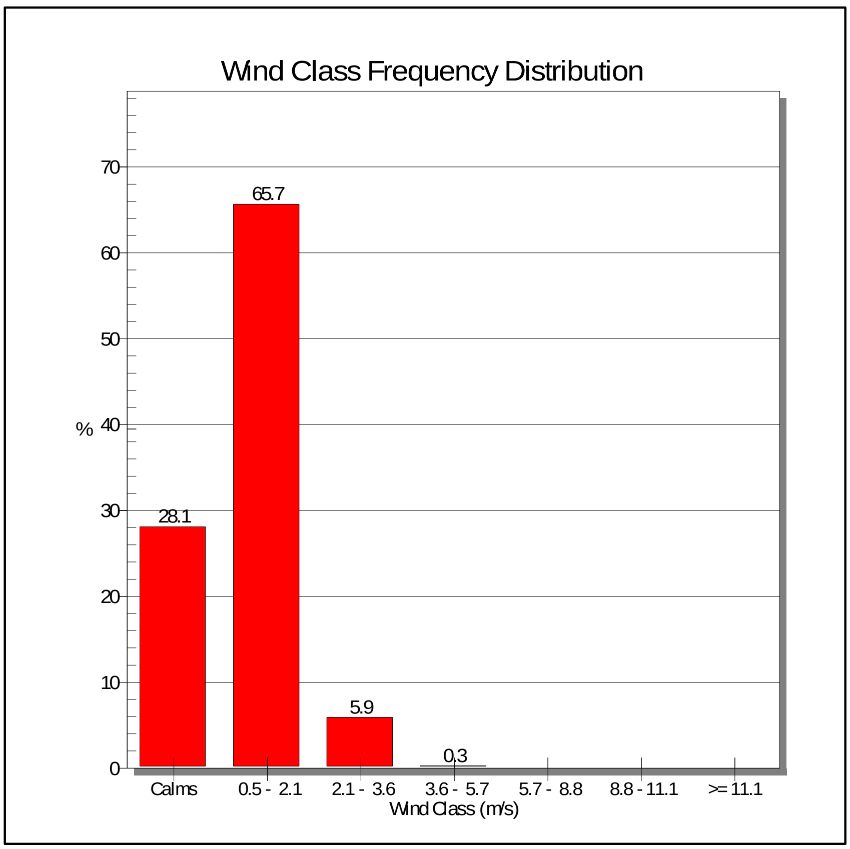
Figure 1a: Underground CO_2 Distribution

APPENDIX B

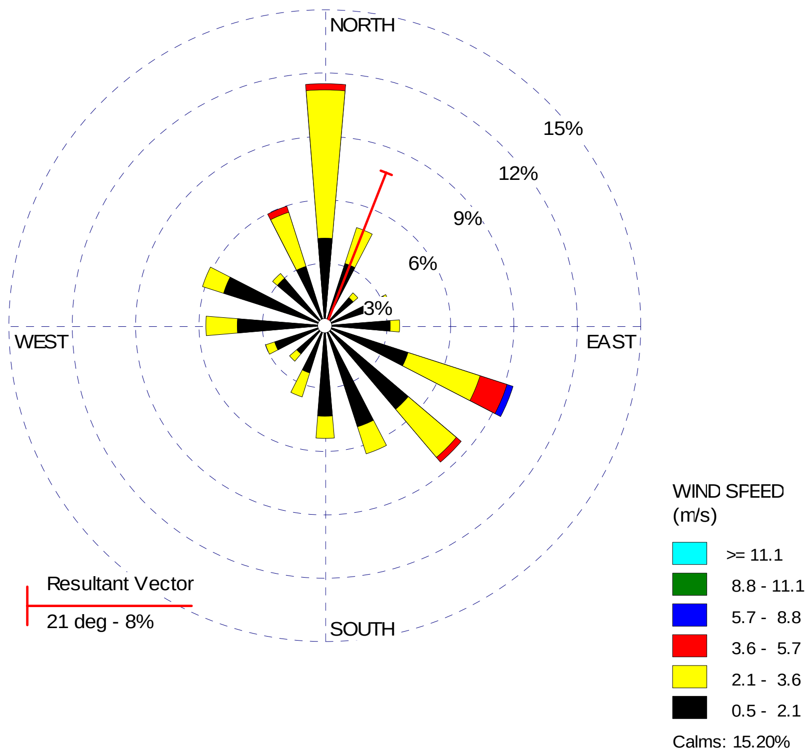
The data from the CSUN Weather Report 1998-1999 were analyzed by WRPLOT View software to obtain accurate local wind speed, average speed, and direction in rainforest area. All the data is represented in wind rose format. A wind rose is a graphic tool that gives an exact view of how wind speed and direction are typically distributed at a particular location. Each month of the year is presented on two graphs: wind rose and wind class distribution frequency. In conclusion, each year is presented separately to see the annual changes.

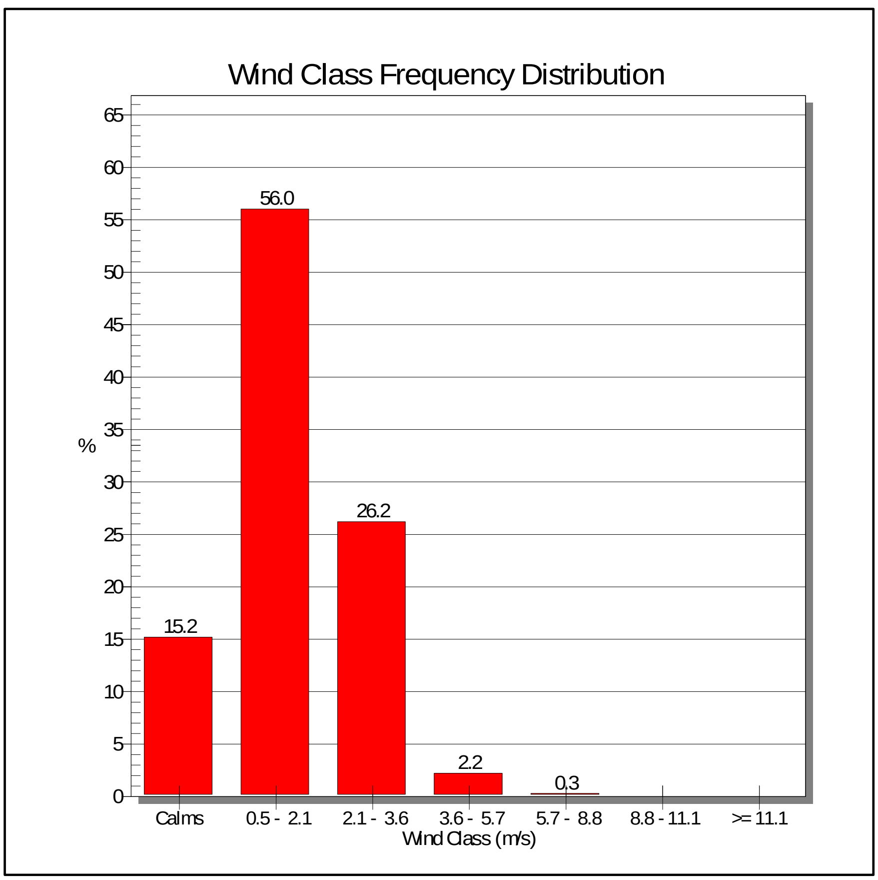
<u>January 1998:</u> Direction (blowing from) **Average Speed = 0.85 m/s**



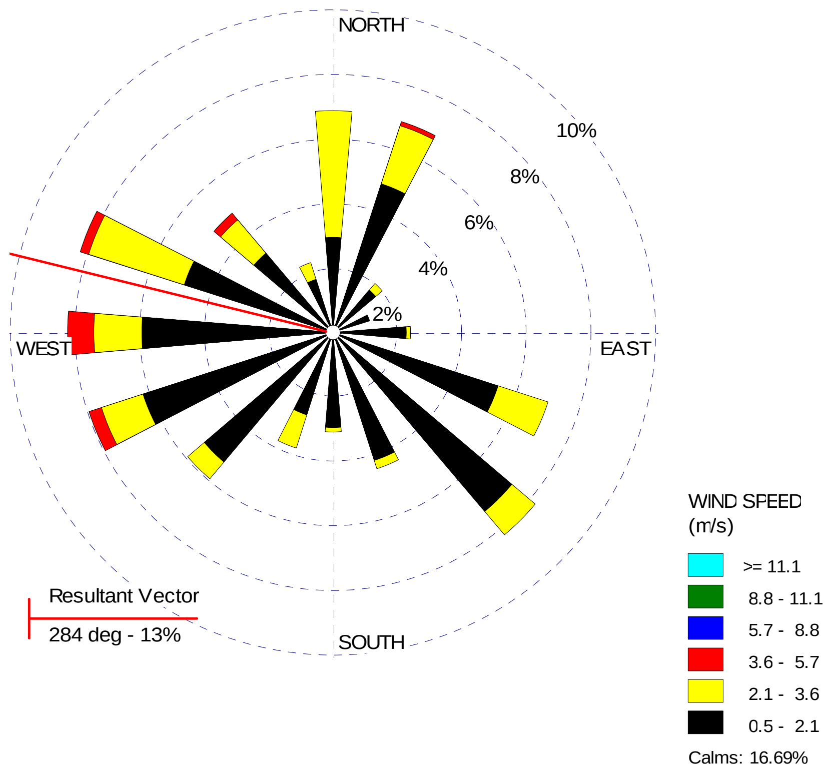


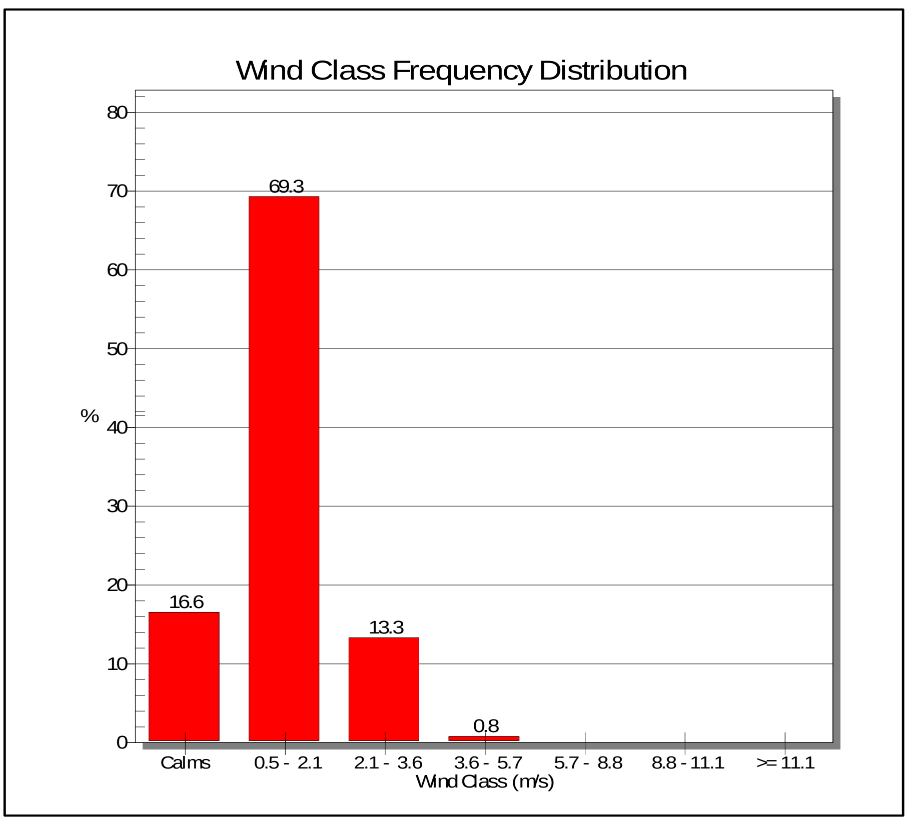
February 1998: Direction (blowing from) Average Speed = 1.52 m/s



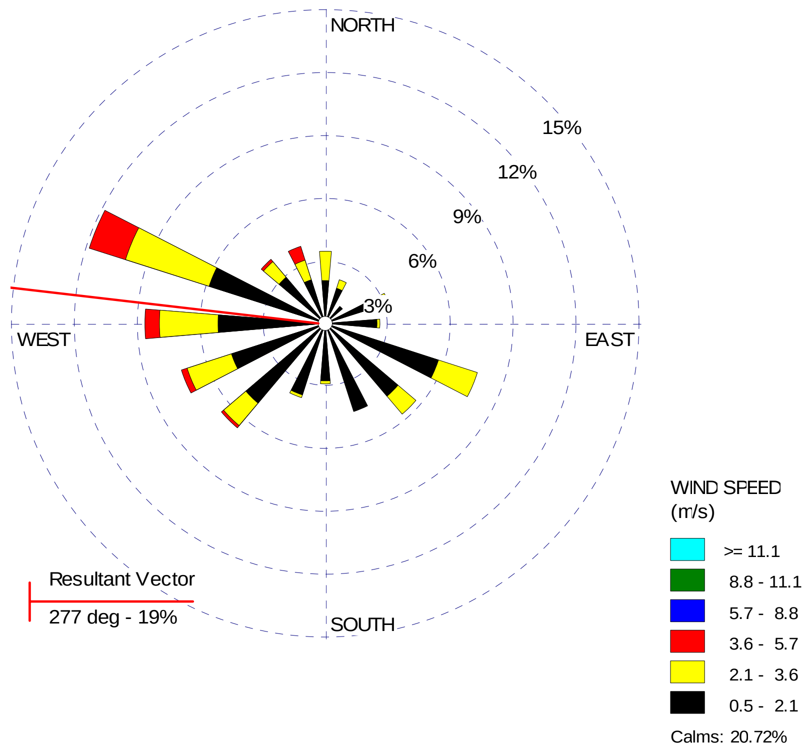


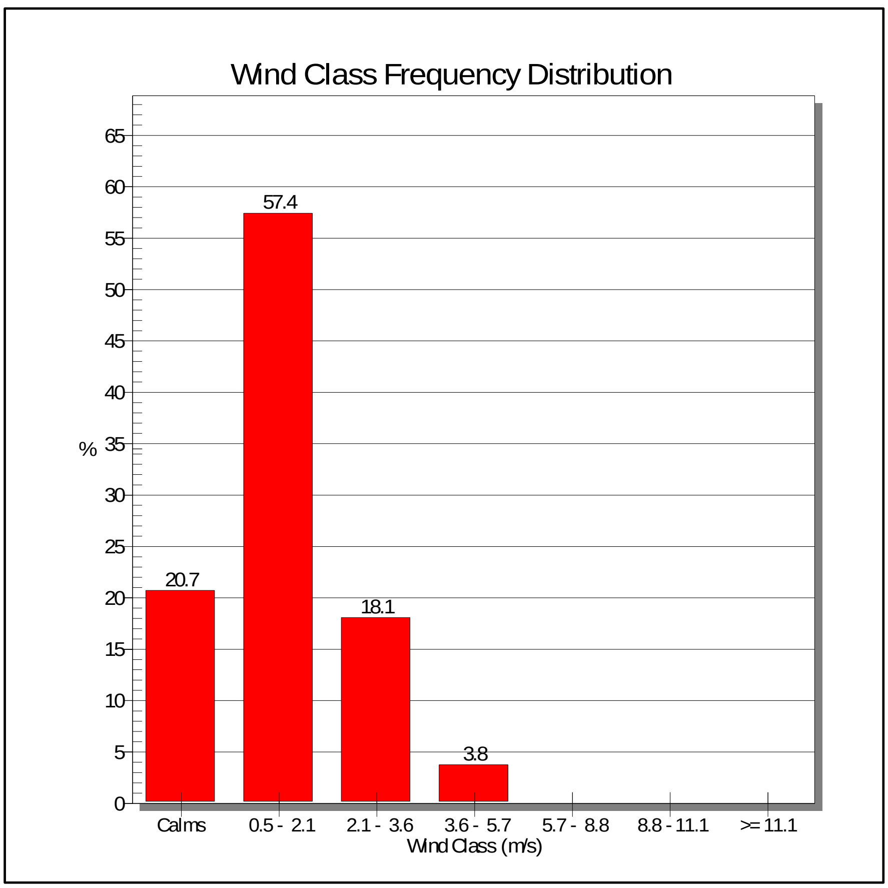
<u>March 1998:</u> Direction (blowing from) **Average Speed = 1.34 m/s**



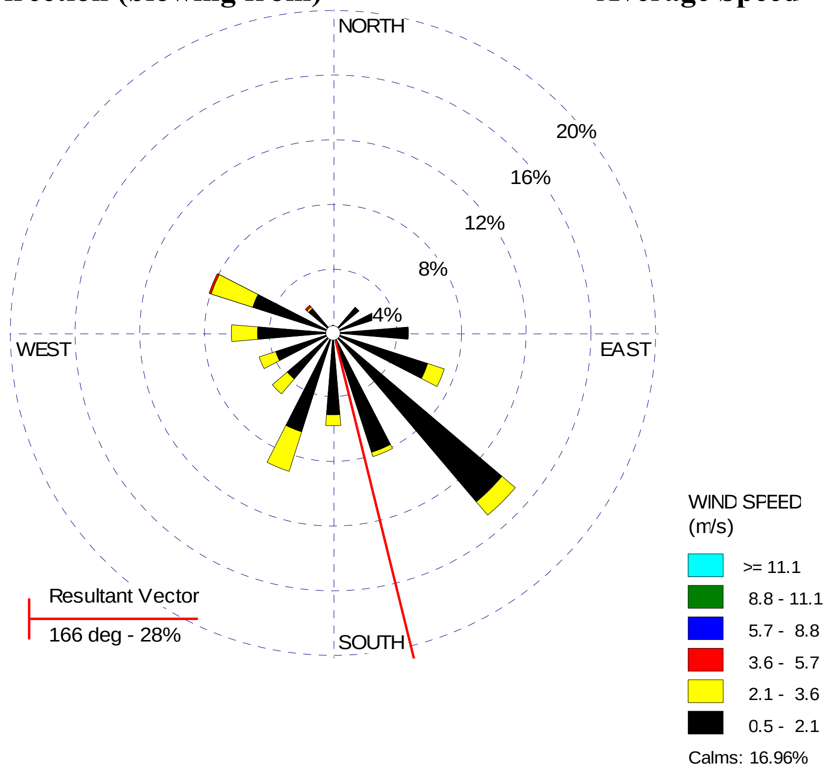


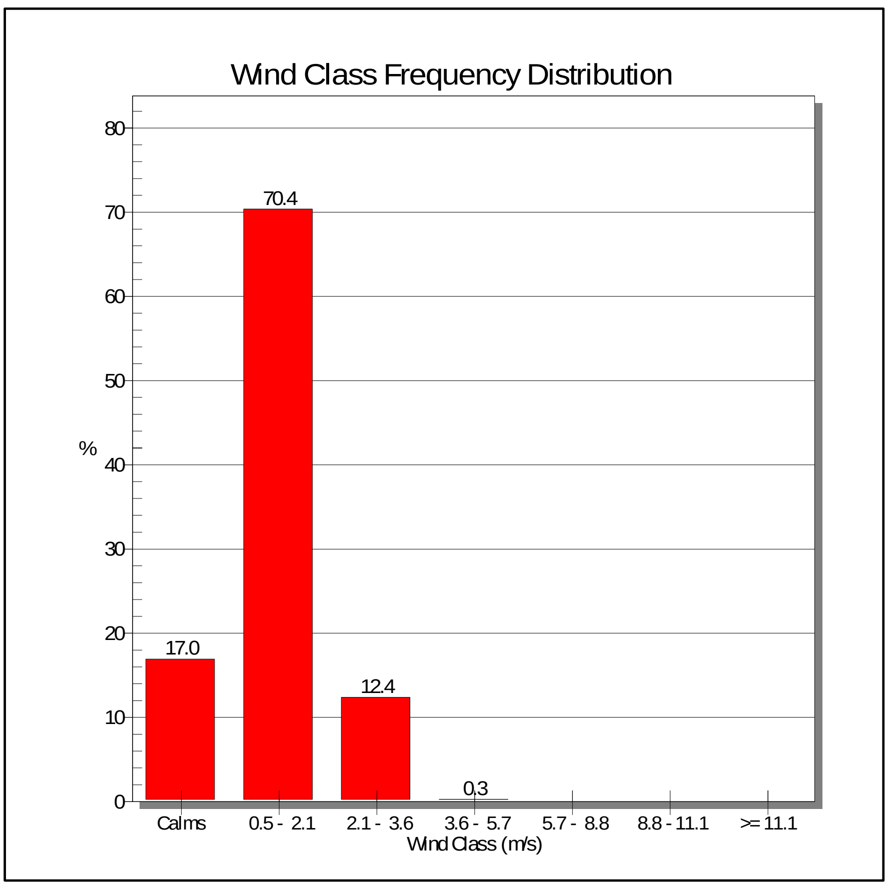
<u>April 1998:</u> Direction (blowing from) **Average Speed = 1.33 m/s**



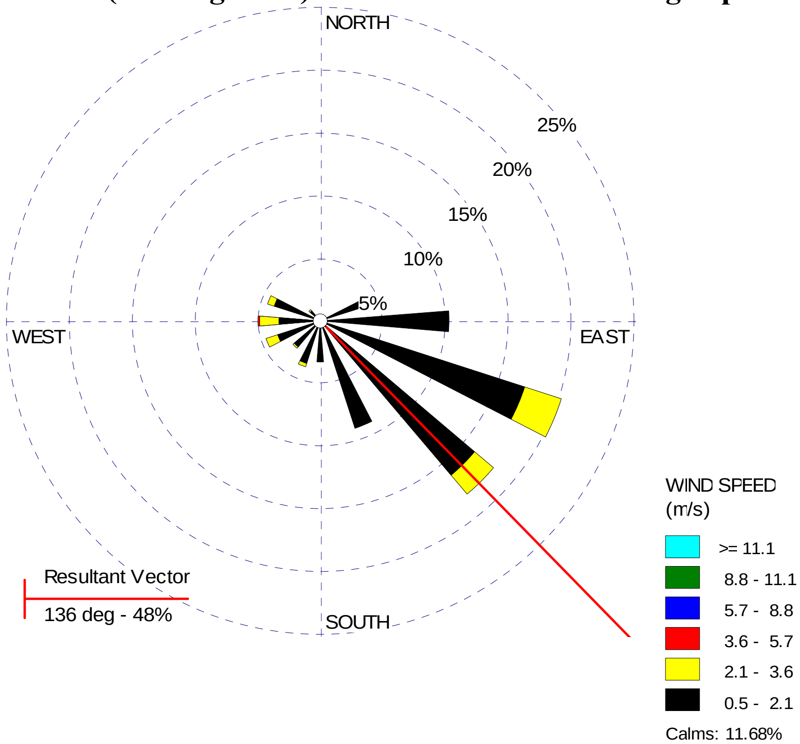


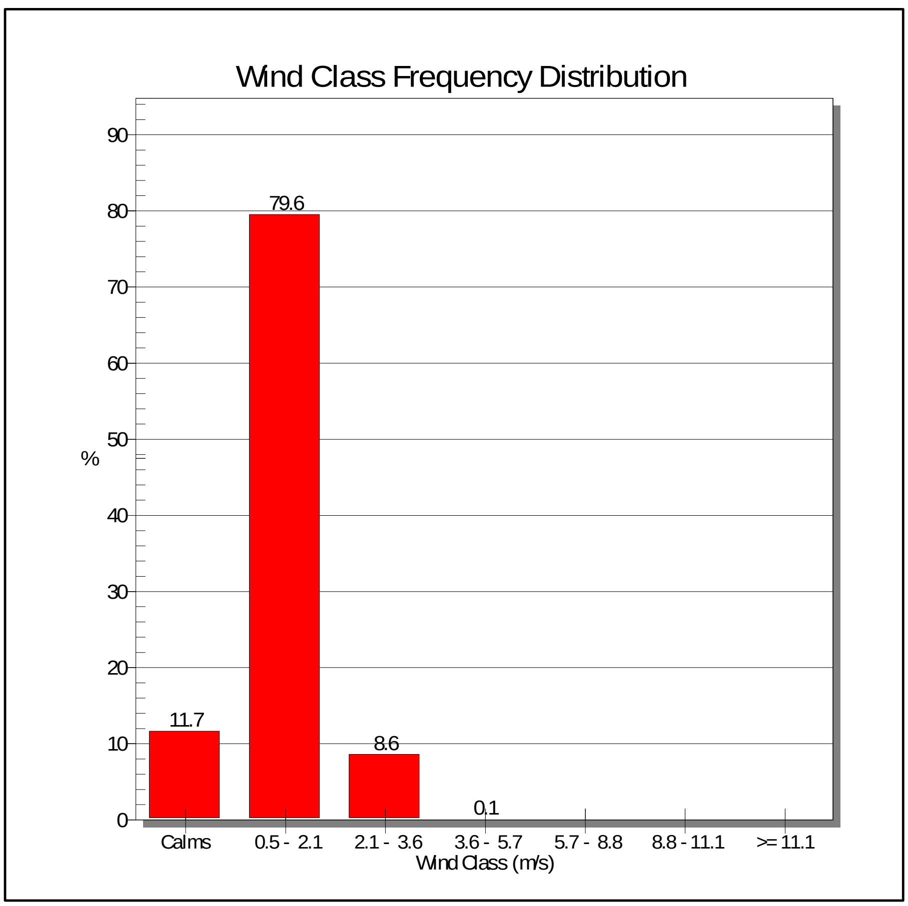
<u>May 1998:</u> Direction (blowing from) **Average Speed = 1.19 m/s**



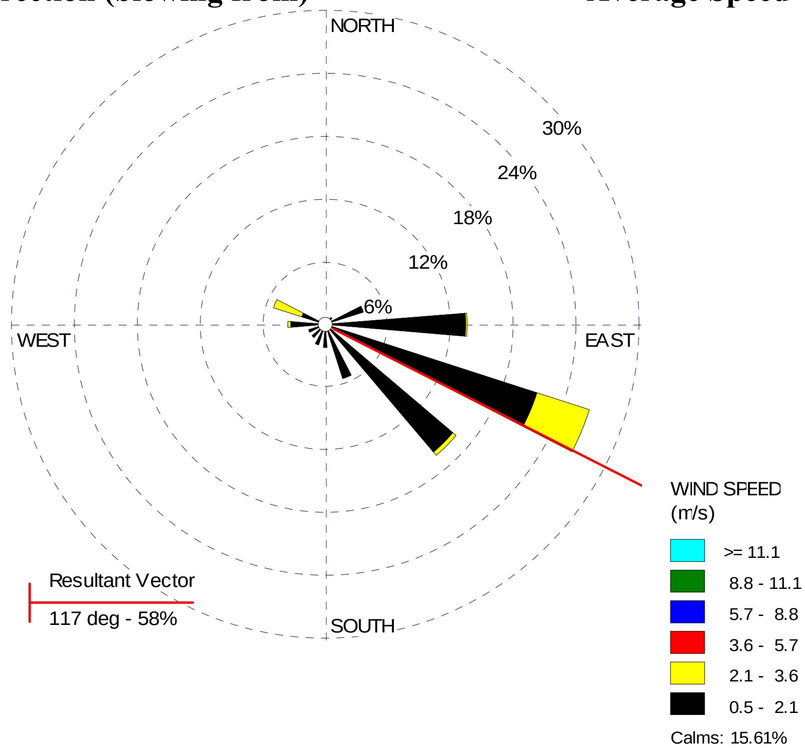


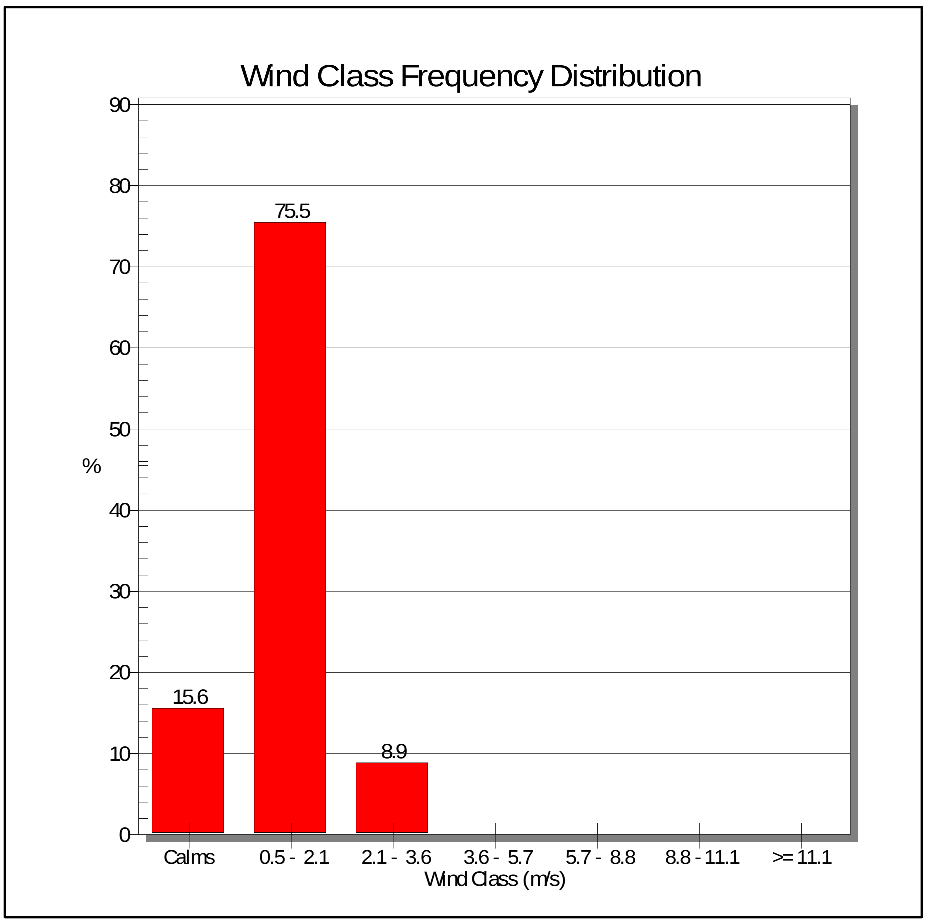
<u>June 1998:</u> Direction (blowing from) **Average Speed = 1.16 m/s**



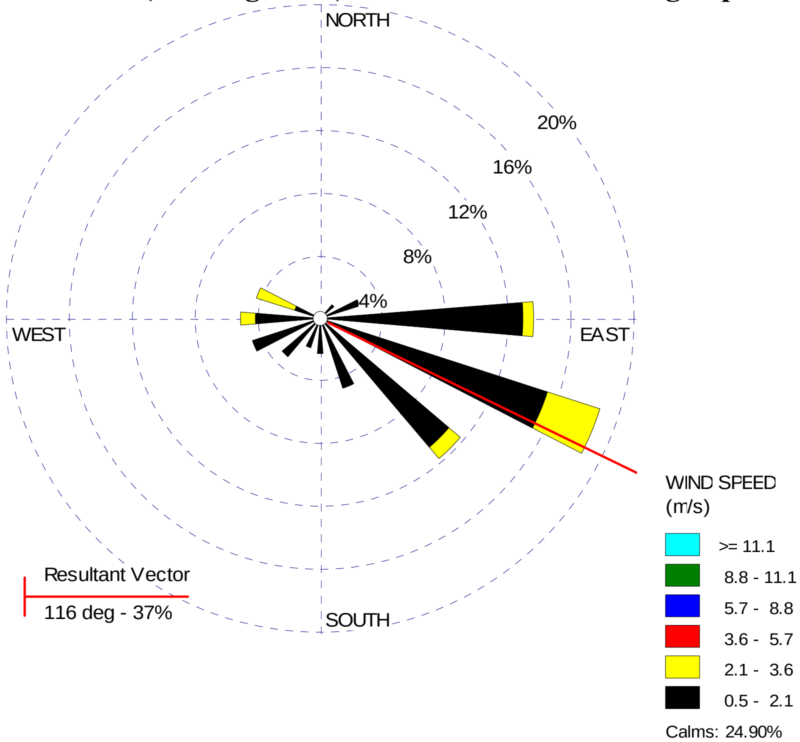


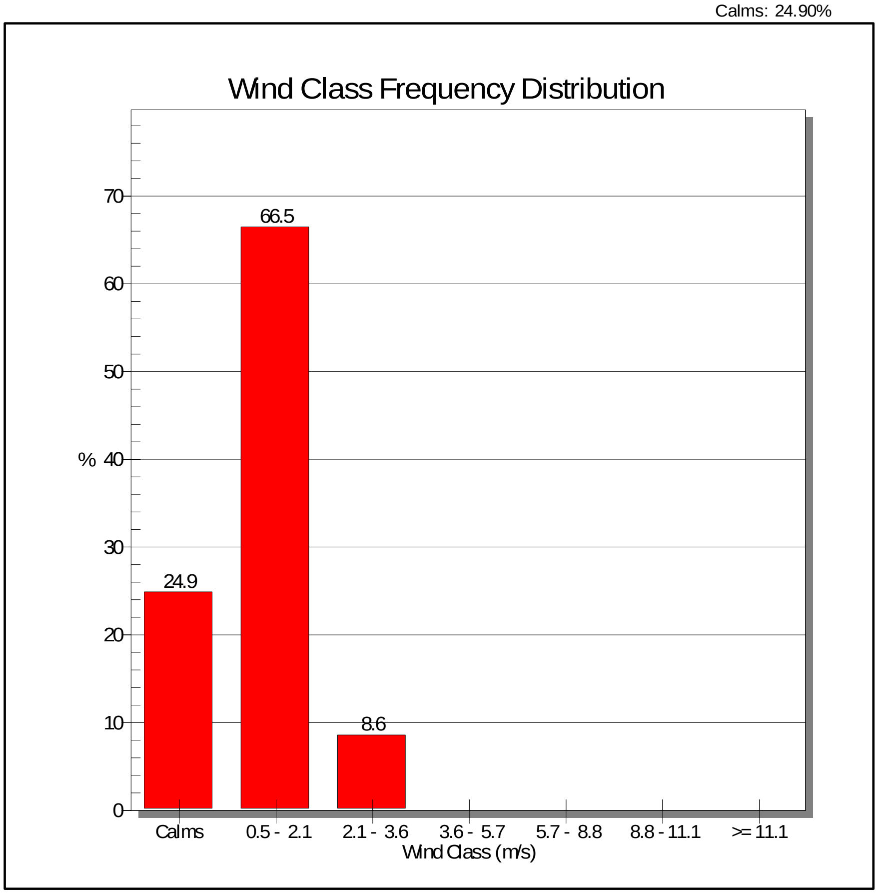
<u>July 1998:</u> Direction (blowing from) **Average Speed = 1.1 m/s**



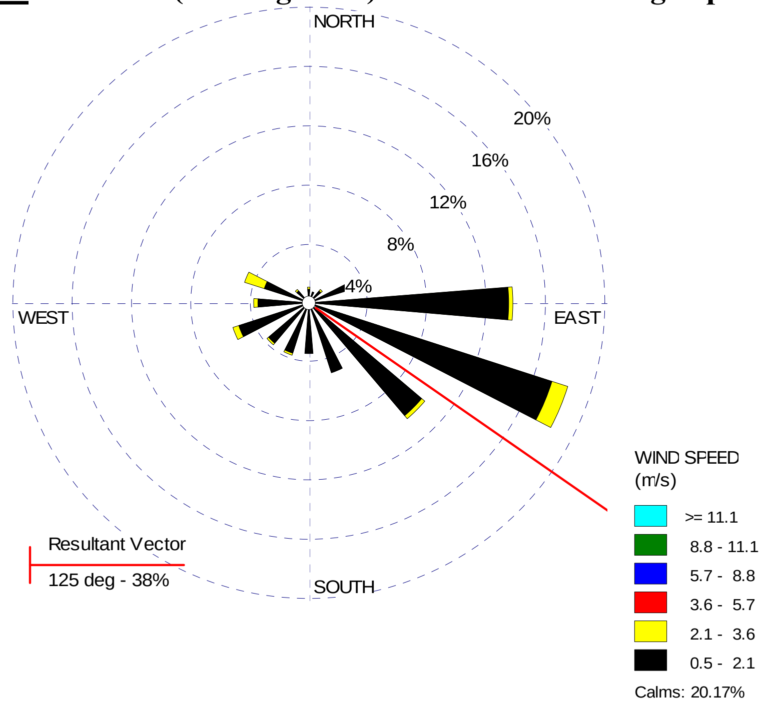


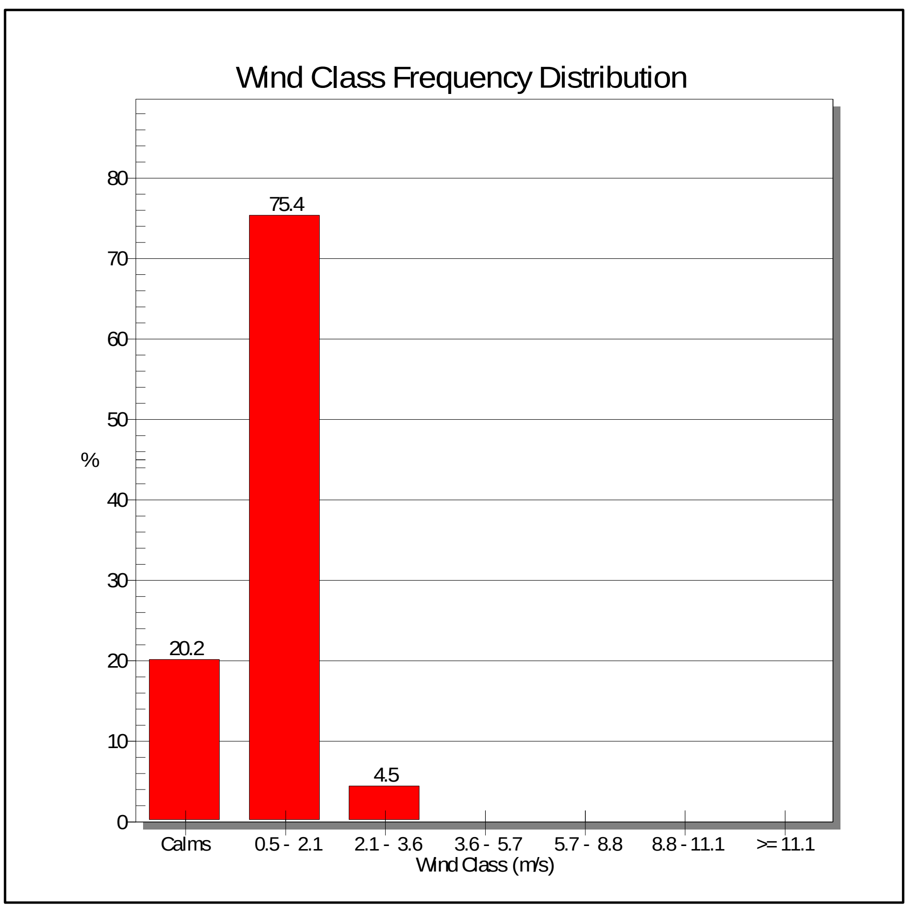
August 1998: **Direction (blowing from)** **Average Speed = 0.96 m/s**



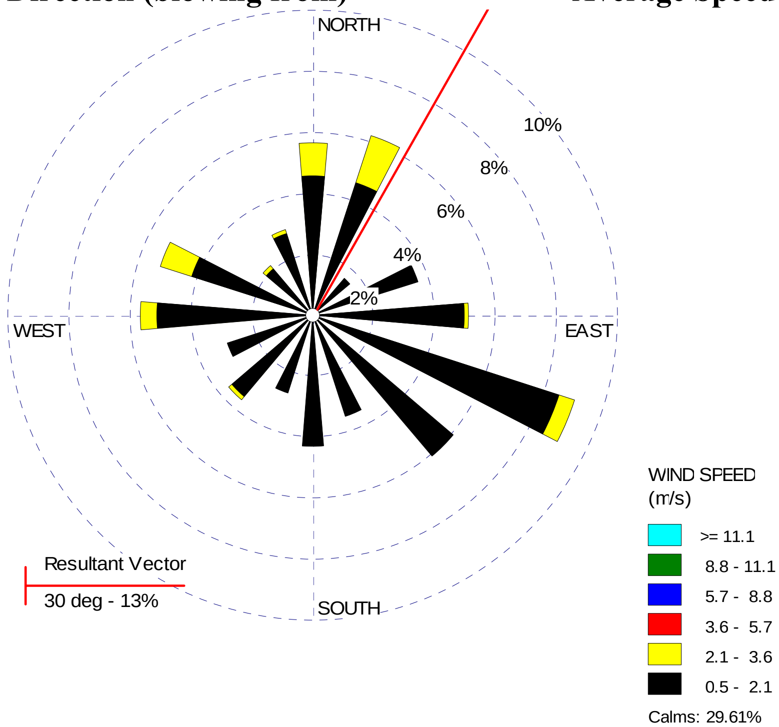


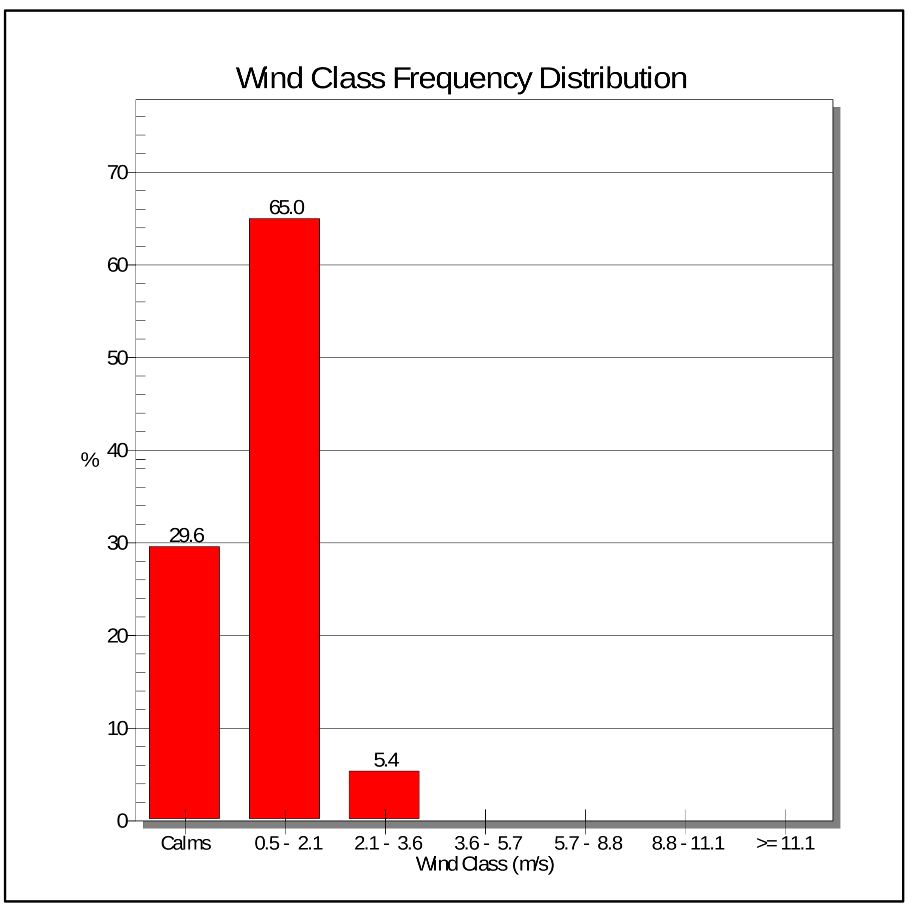
<u>September 1998:</u> Direction (blowing from) **Average Speed = 0.96 m/s**



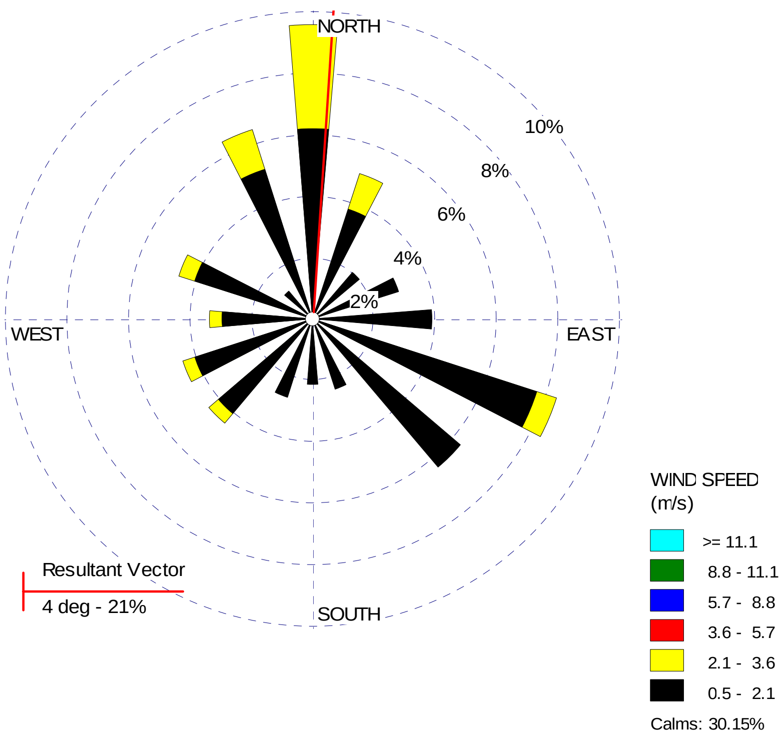


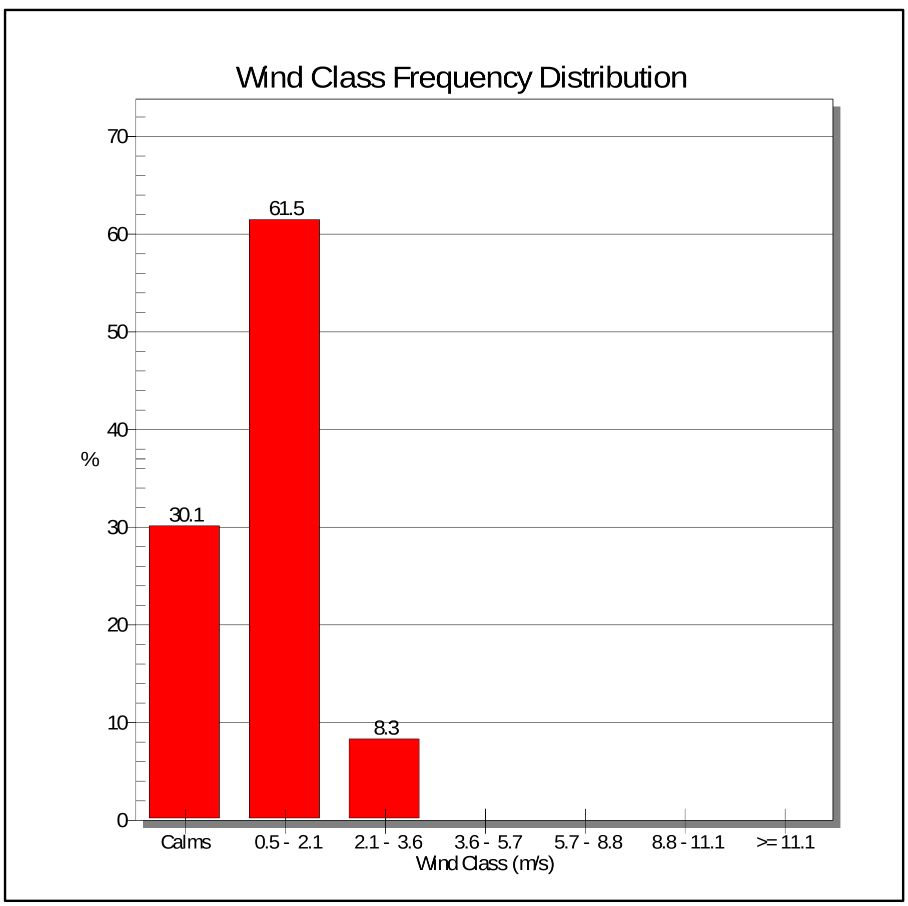
<u>October 1998:</u> Direction (blowing from) **Average Speed = 0.88 m/s**



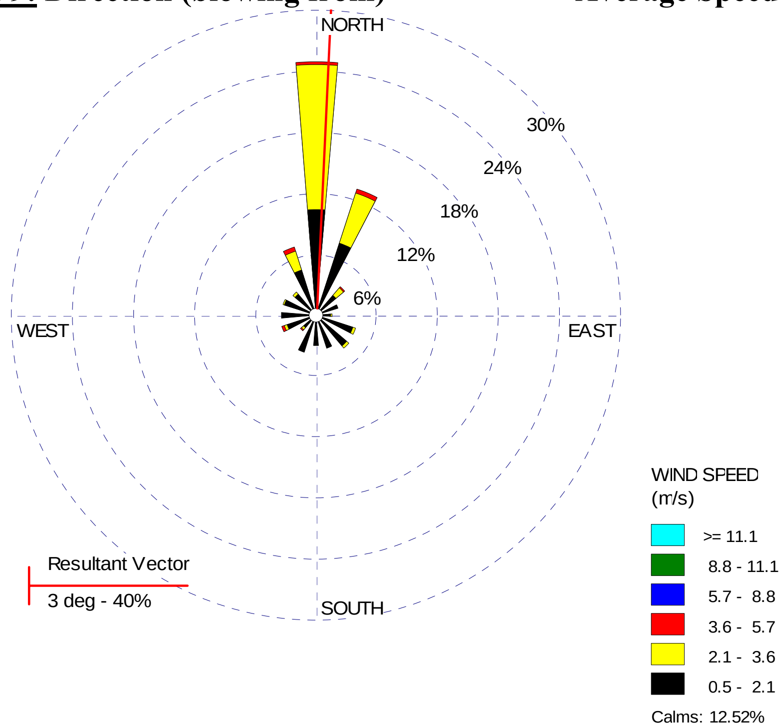


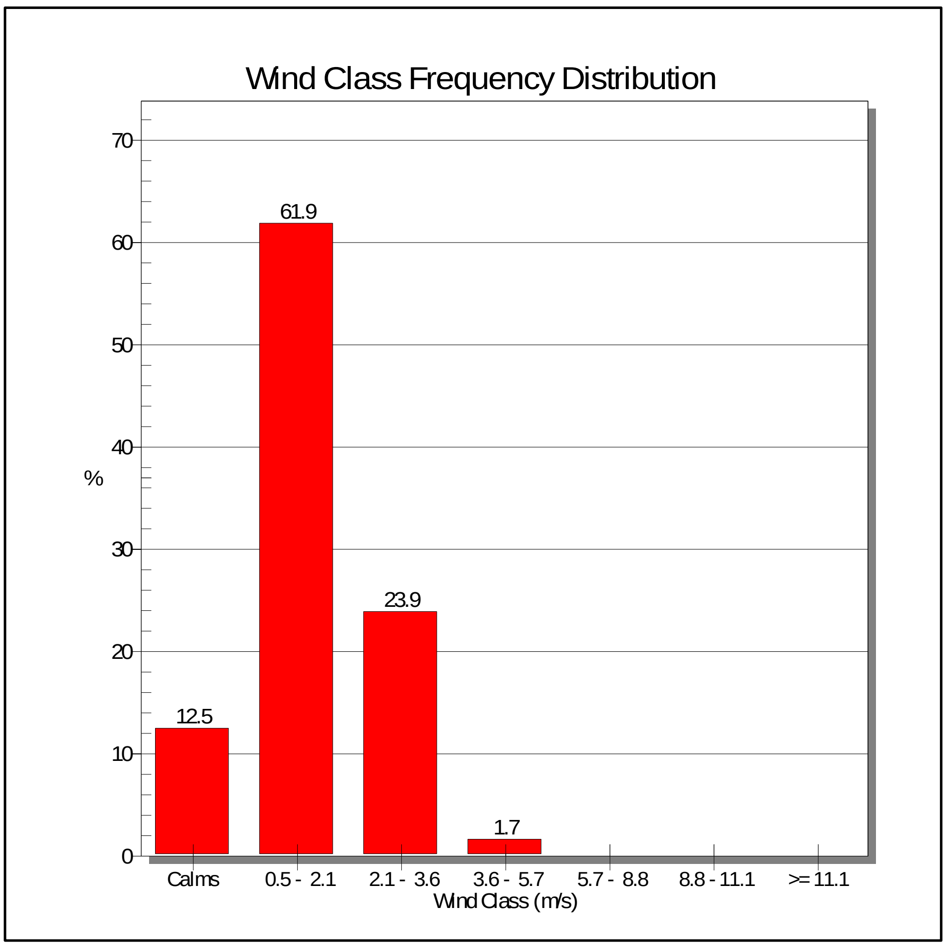
<u>November 1999:</u> Direction (blowing from) **Average Speed = 0.9 m/s**



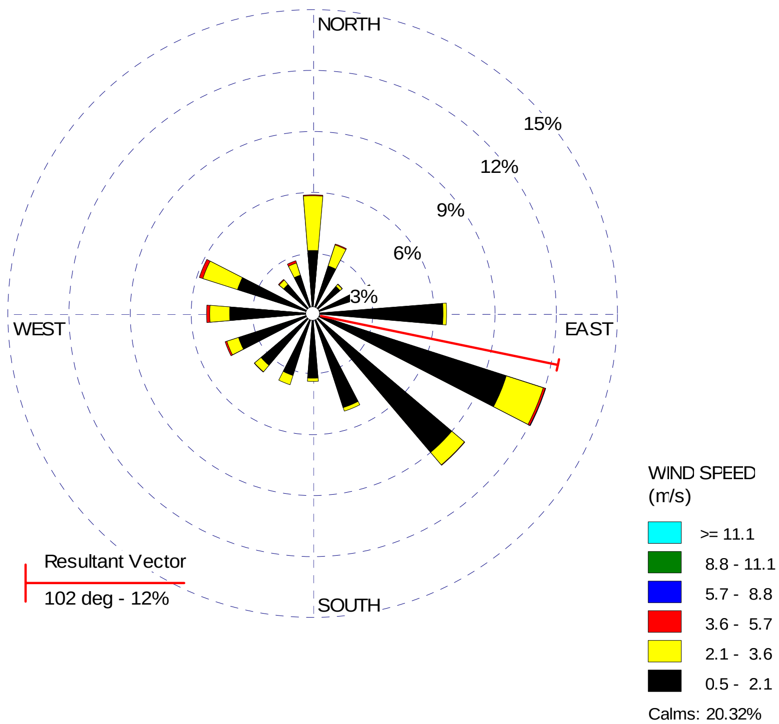


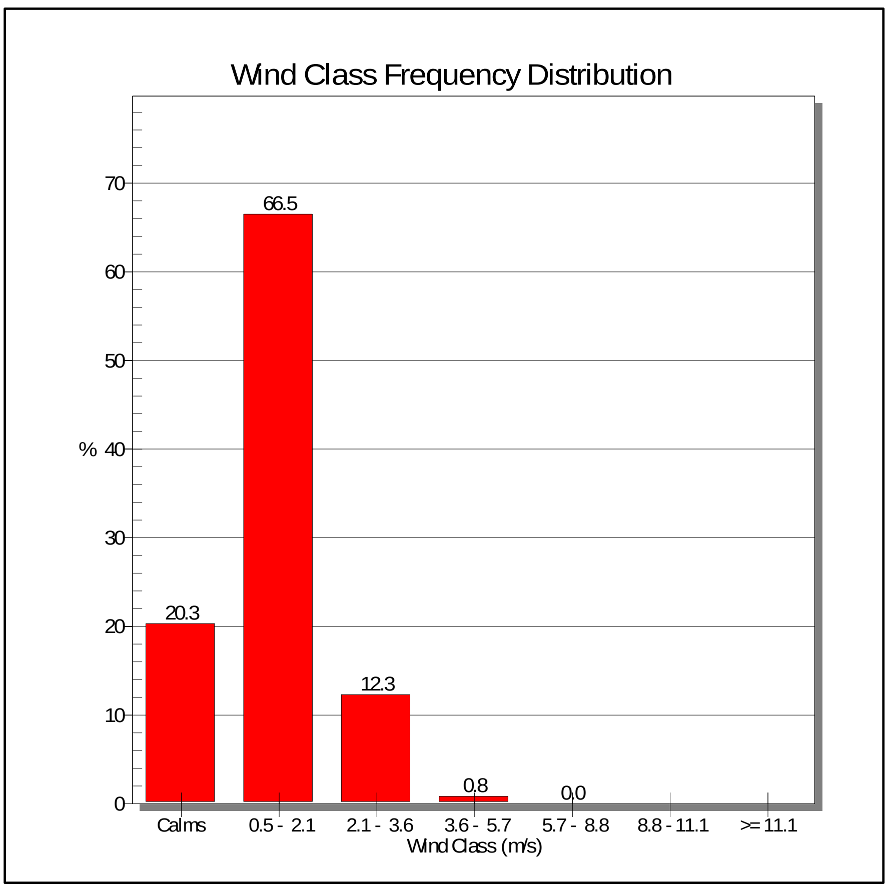
<u>December 1999:</u> Direction (blowing from) **Average Speed = 1.45 m/s**



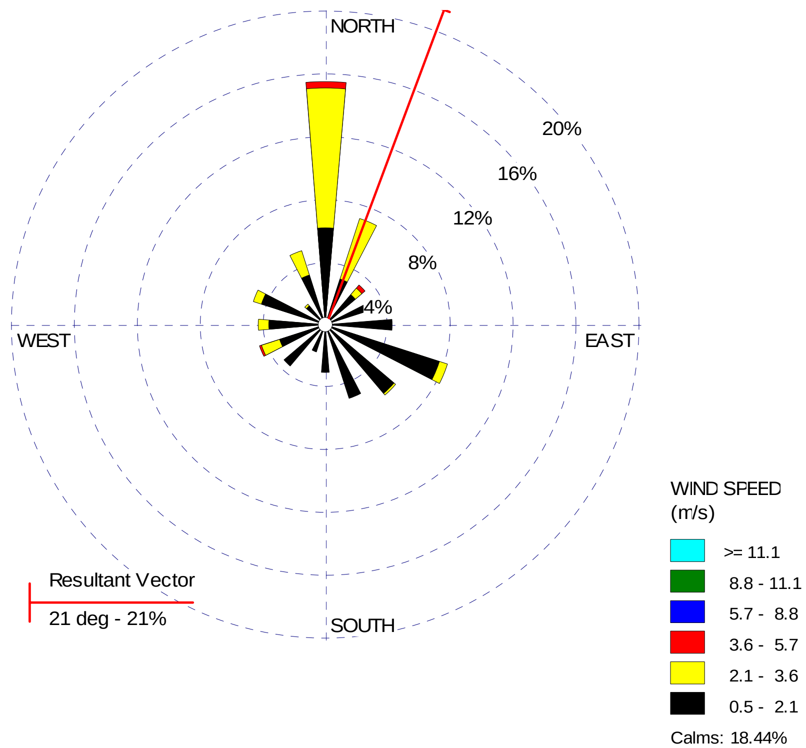


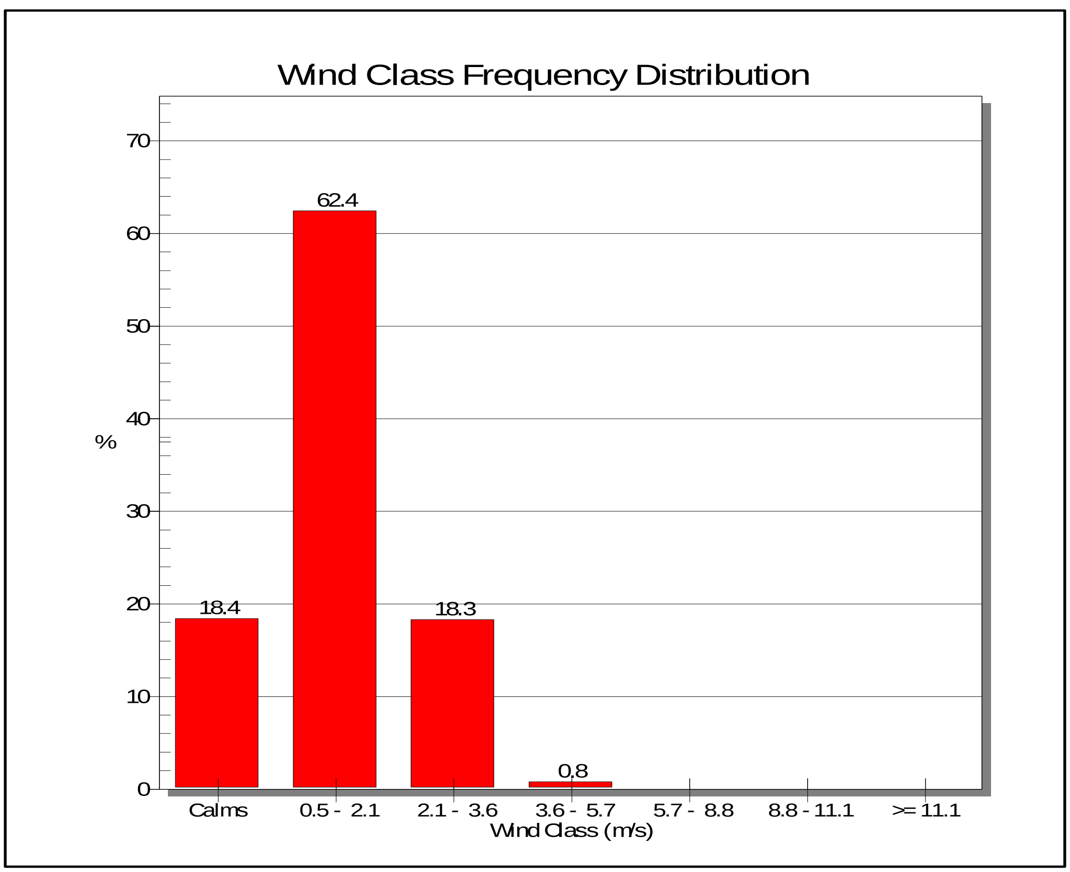
<u>Year 1998:</u> Direction (blowing from) **Average Speed = 1.13 m/s**



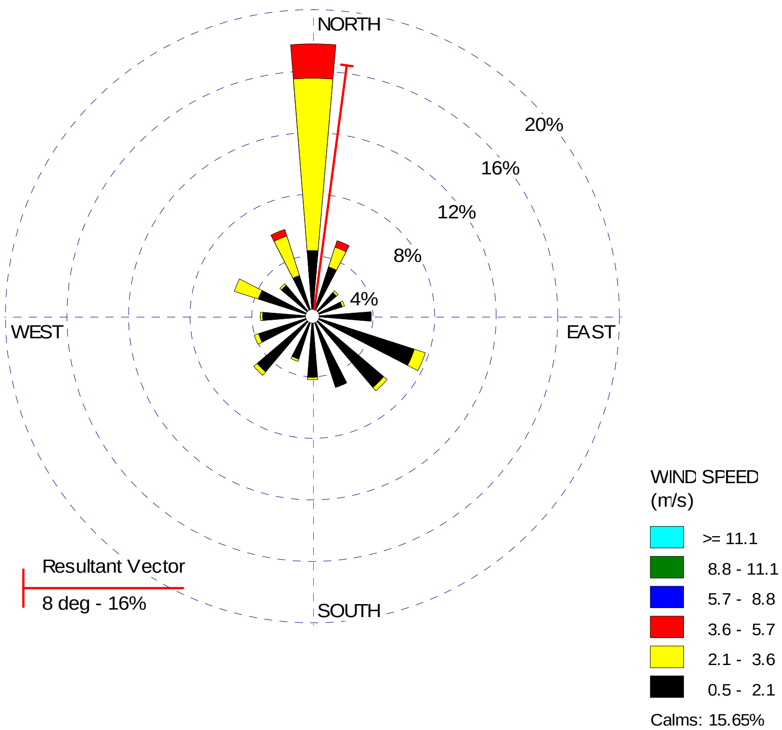


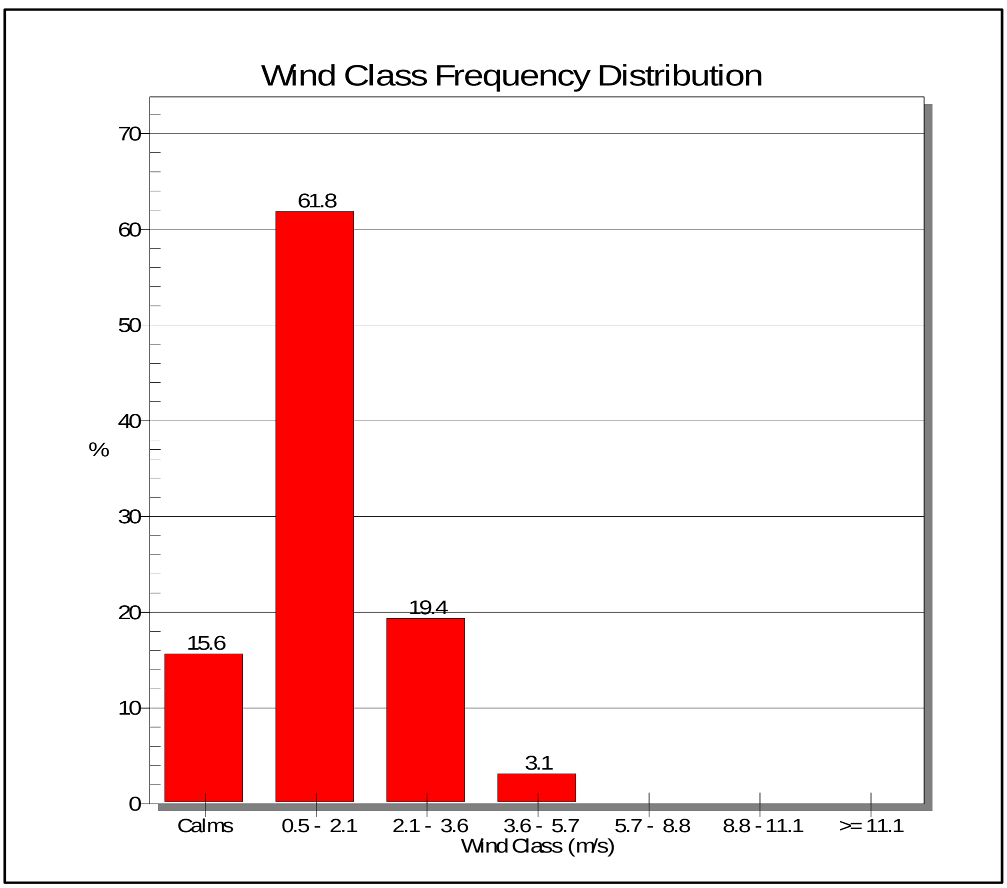
January 1999: Direction (blowing from) Average Speed = 1.21 m/s



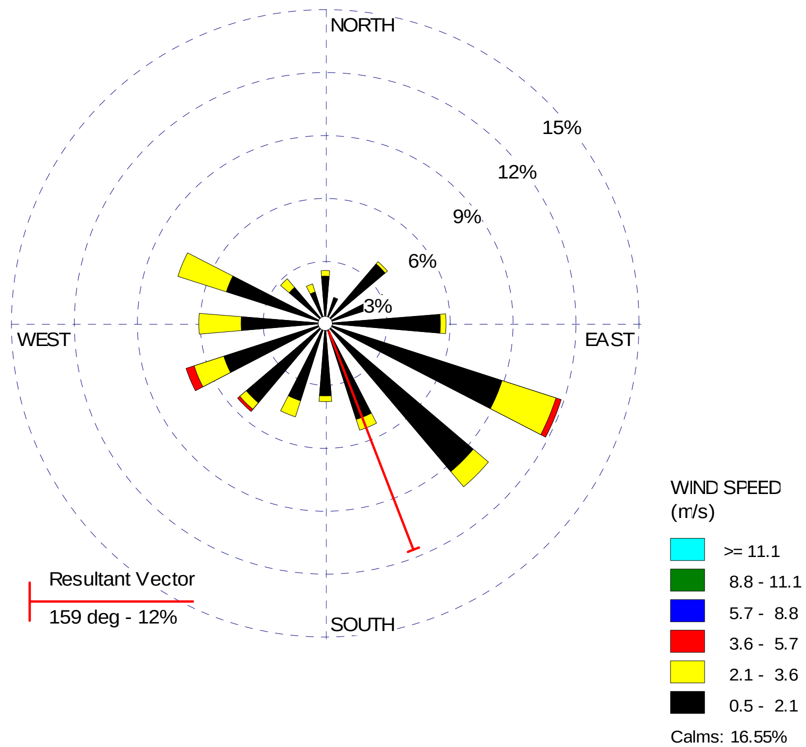


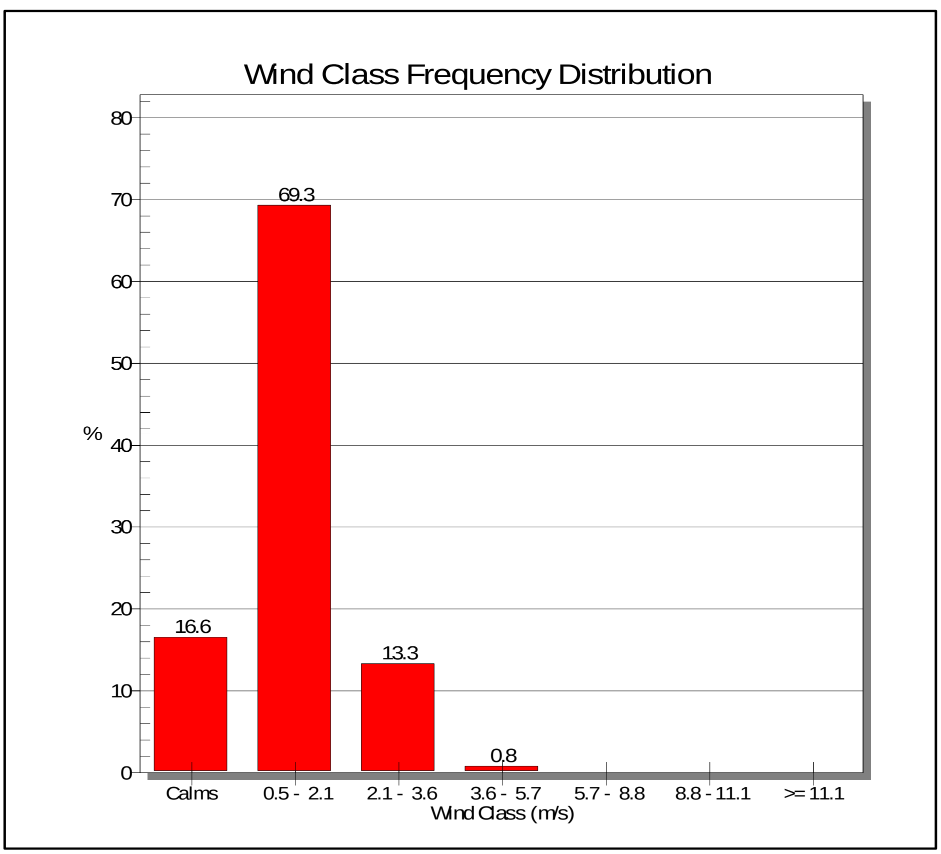
February 1999: Direction (blowing from) Average Speed = 1.39 m/s



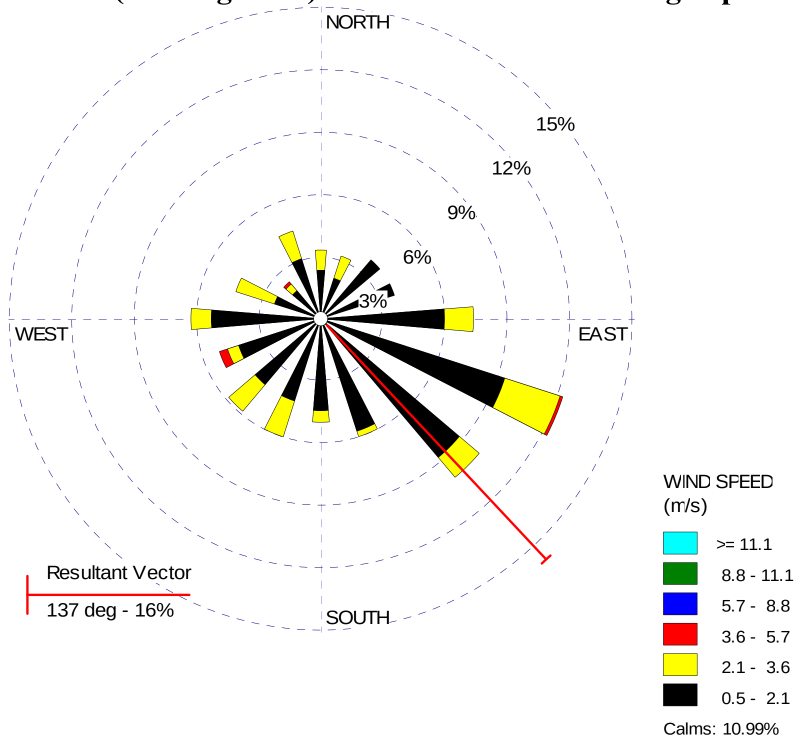


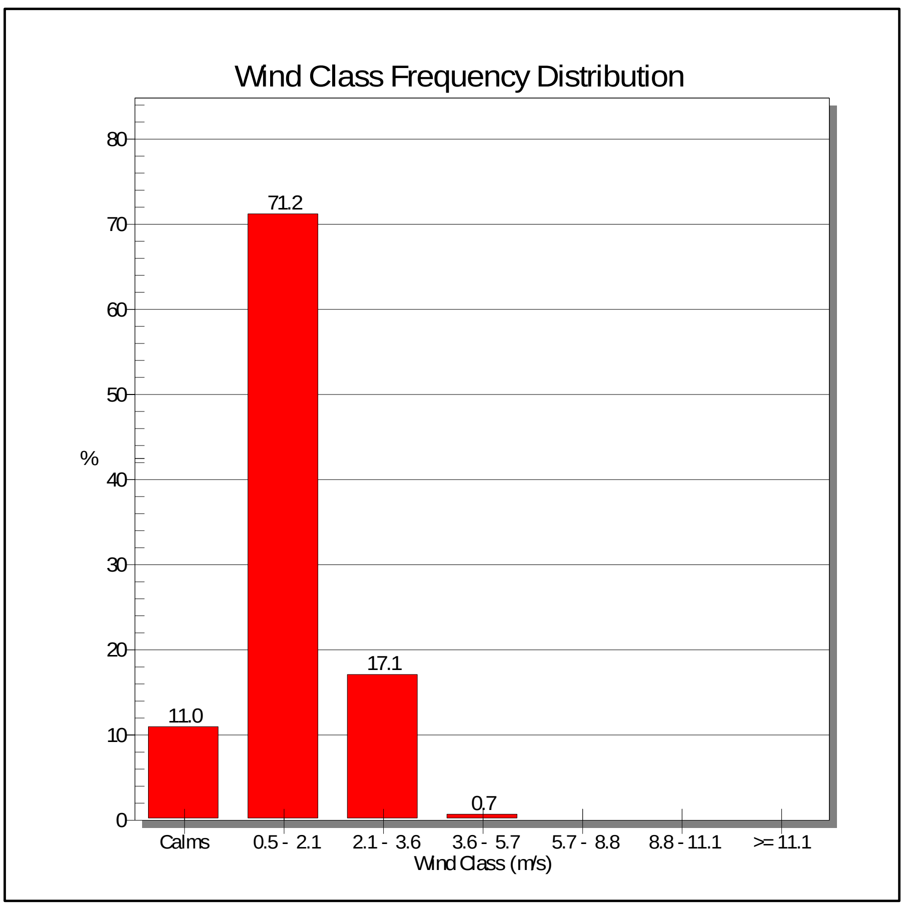
March 1999: Direction (blowing from) Average Speed = 1.19 m/s



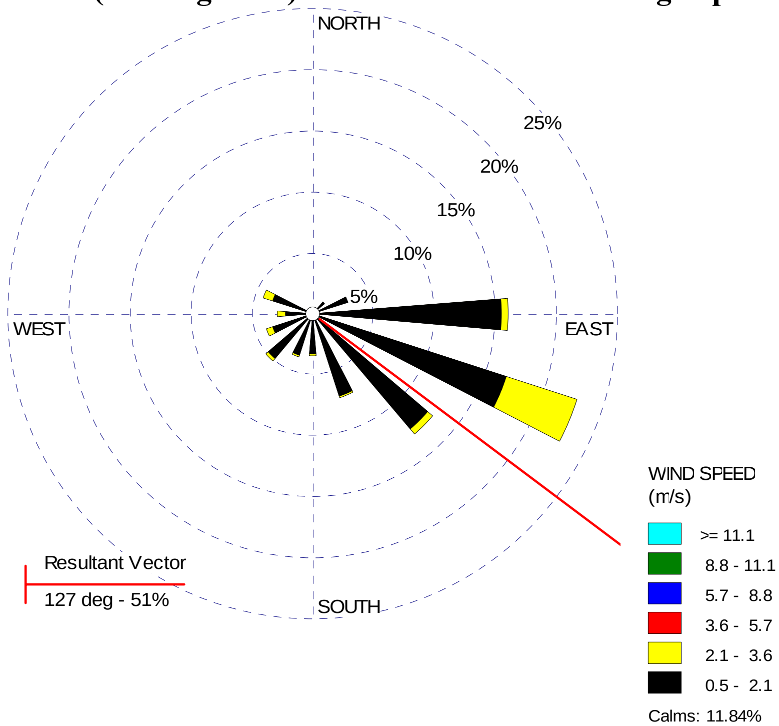


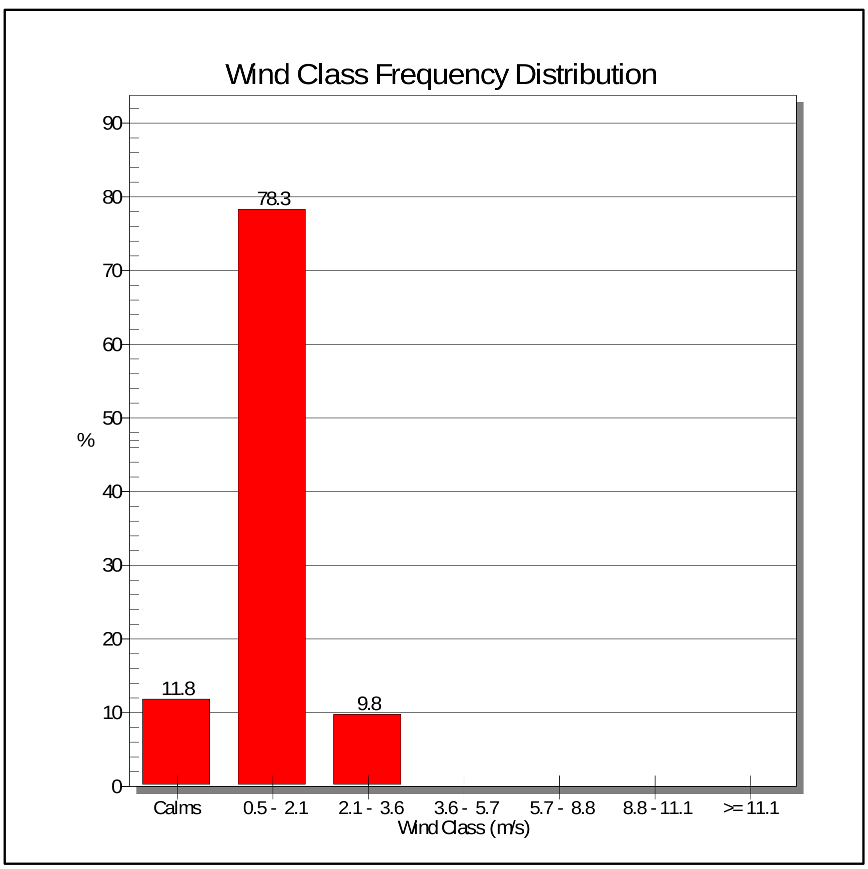
April 1999: **Direction (blowing from)** **Average Speed = 1.35 m/s**



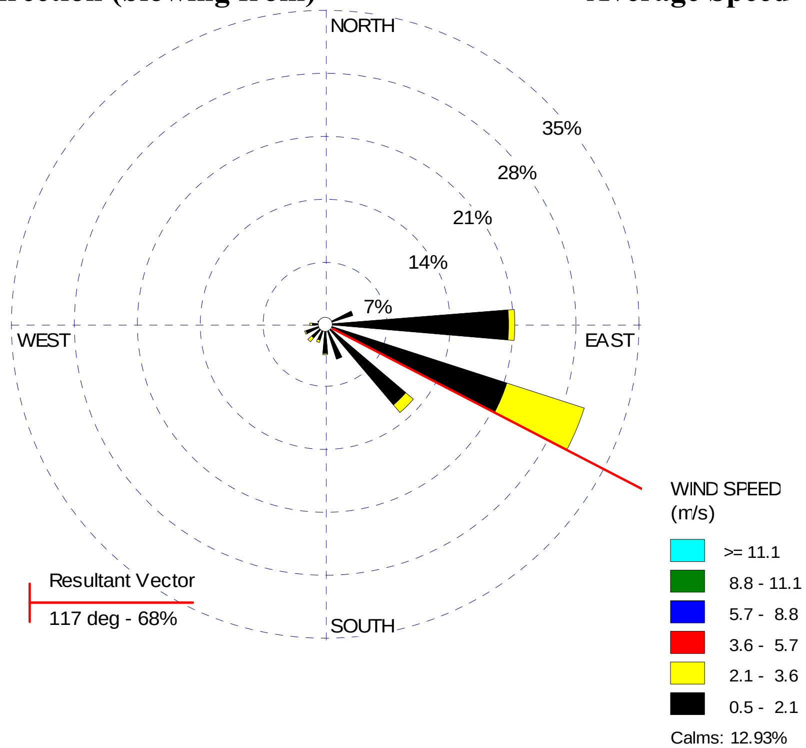


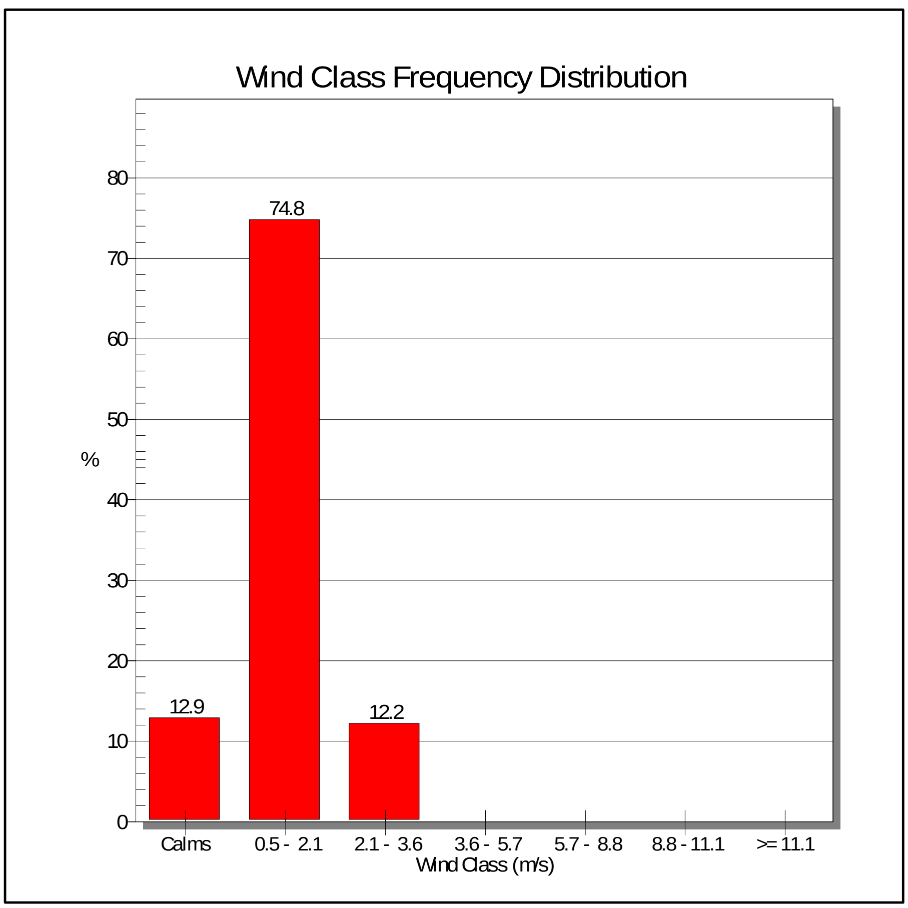
<u>May 1999:</u> Direction (blowing from) **Average Speed = 1.18 m/s**



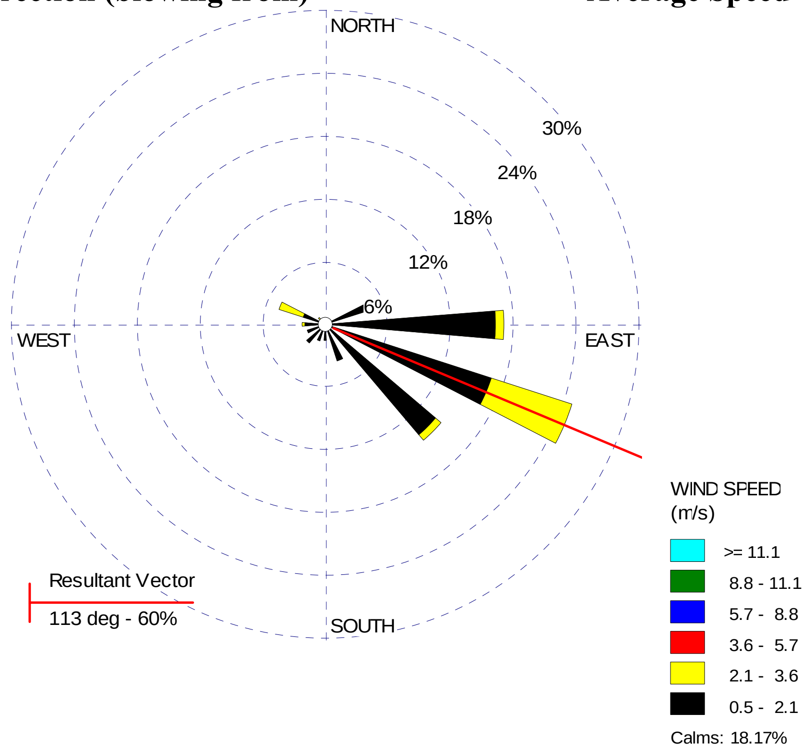


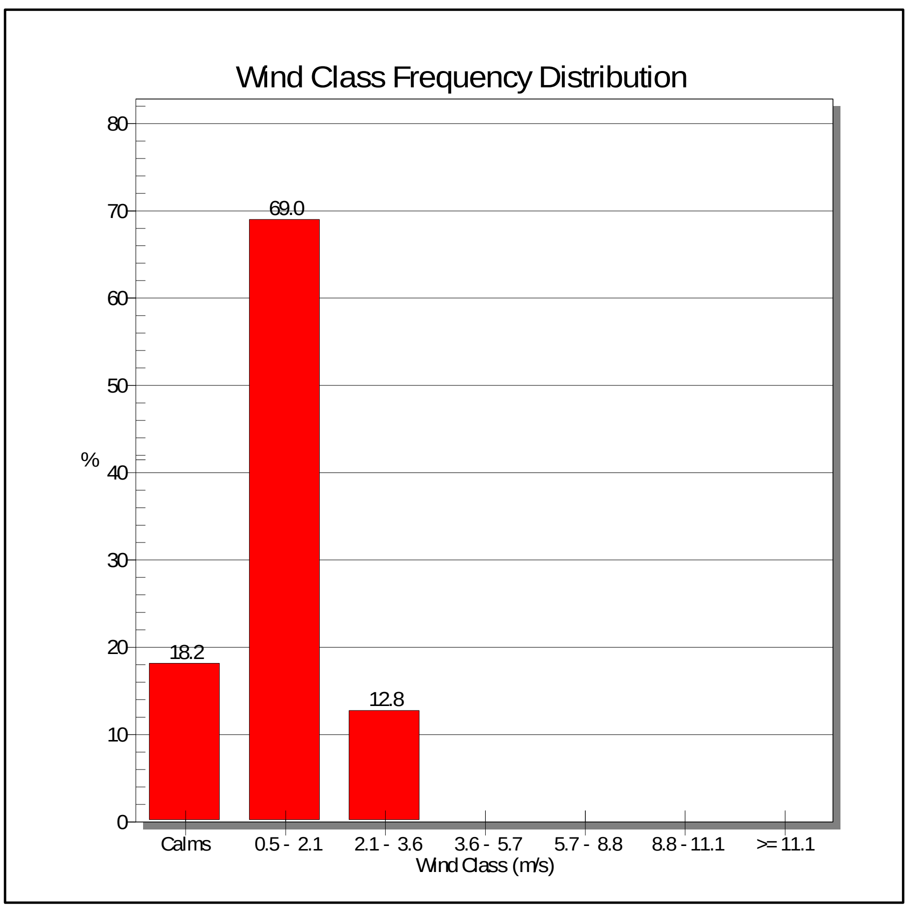
<u>June 1999:</u> Direction (blowing from) **Average Speed = 1.19 m/s**



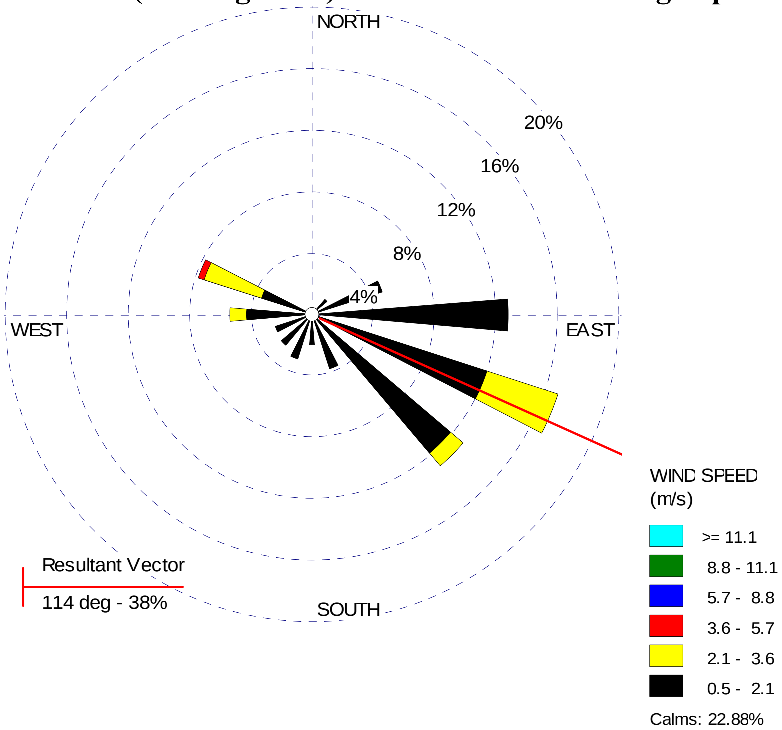


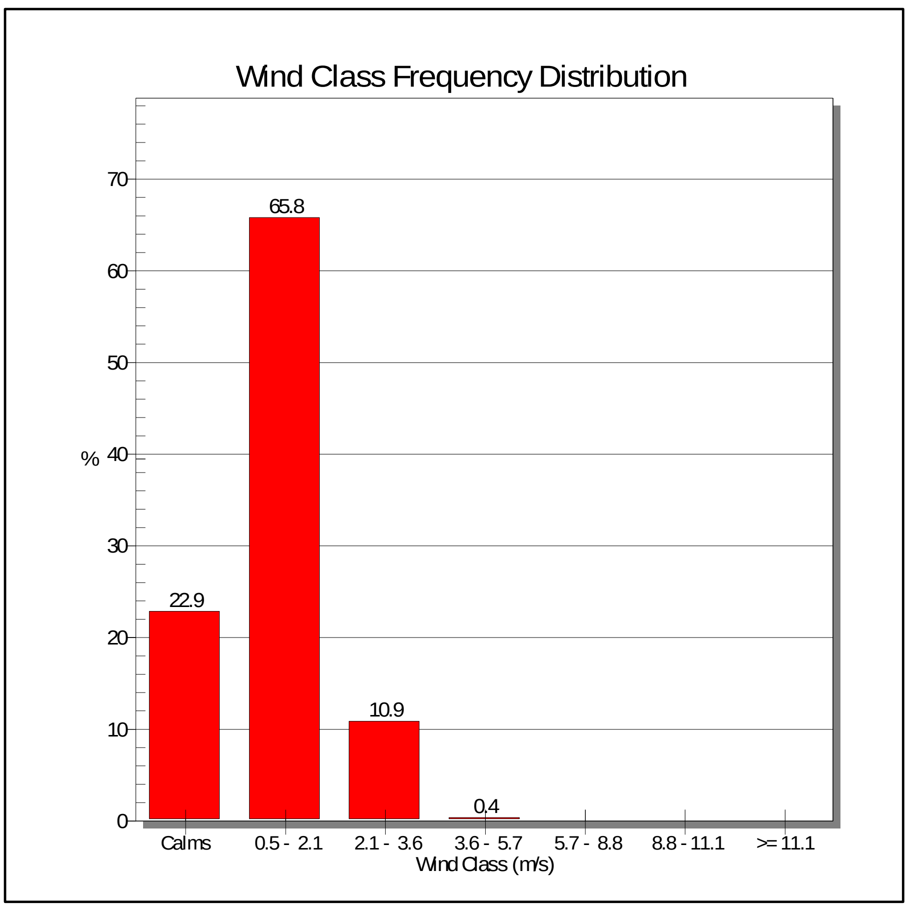
<u>July 1999:</u> Direction (blowing from) **Average Speed = 1.11 m/s**



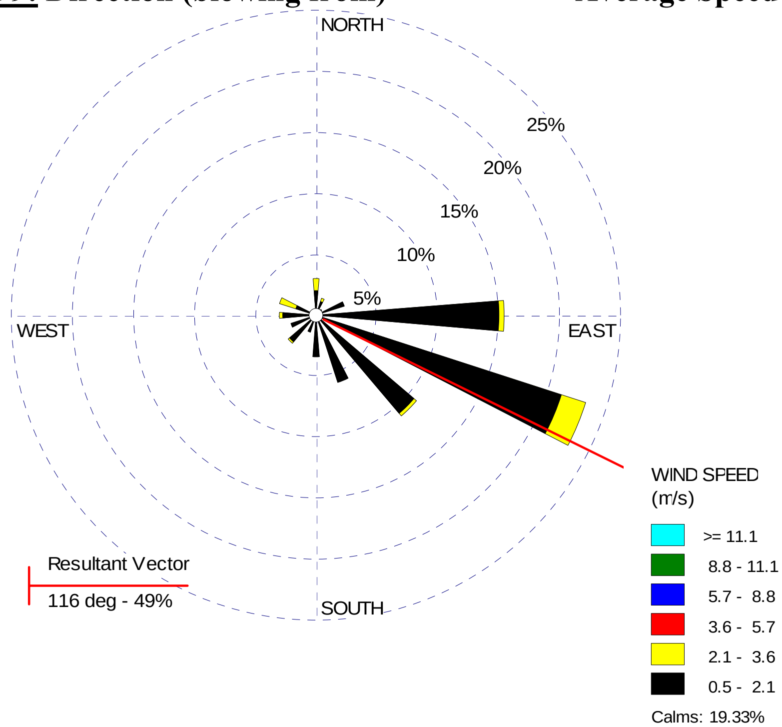


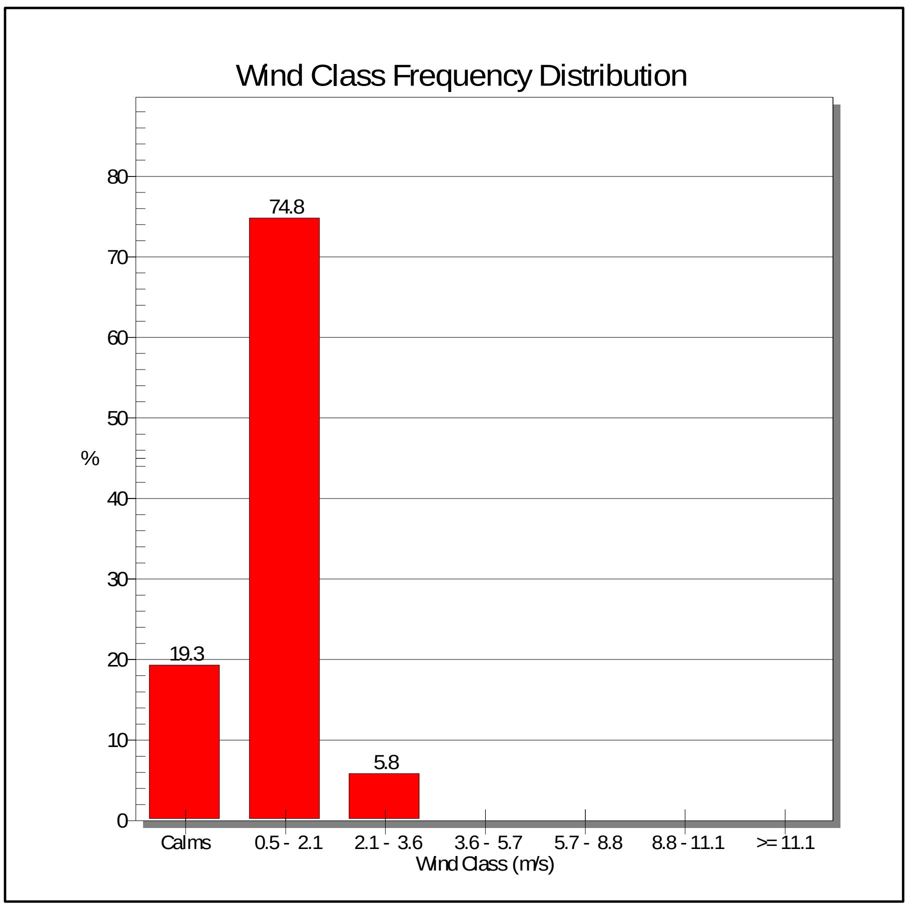
August 1999: **Direction (blowing from)** **Average Speed = 1.03 m/s**



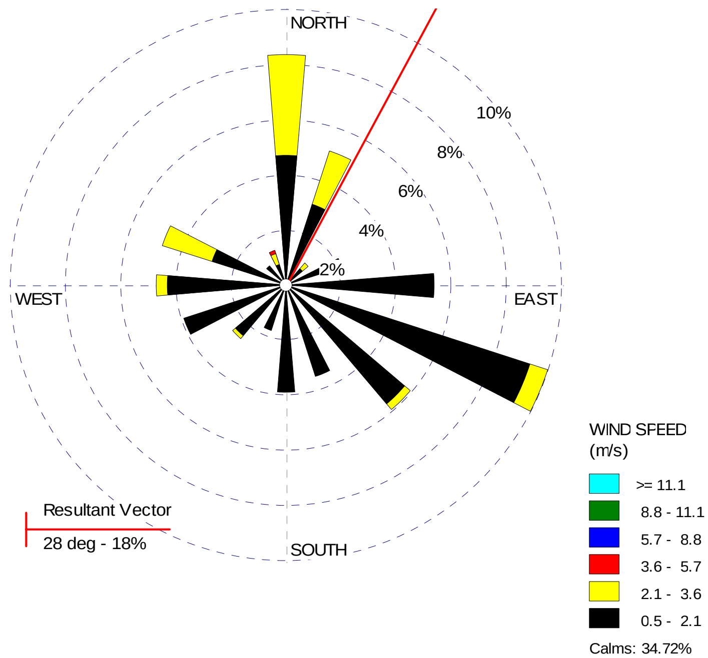


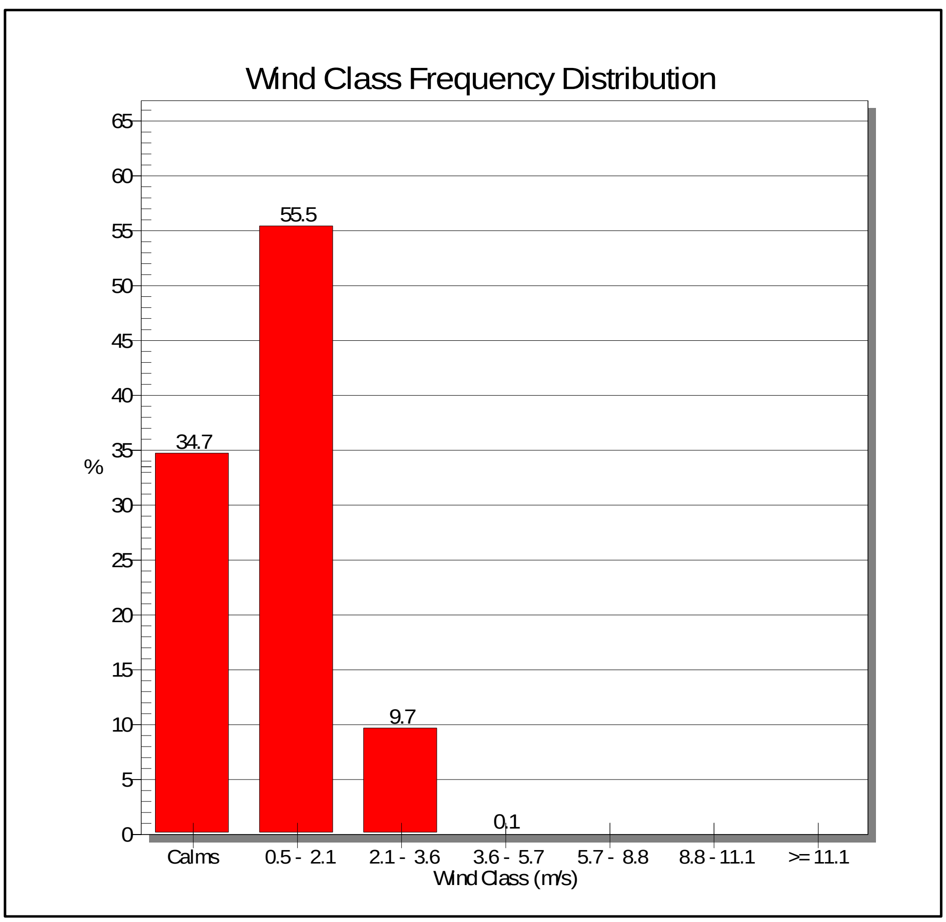
<u>September 1999:</u> Direction (blowing from) **Average Speed = 0.94 m/s**



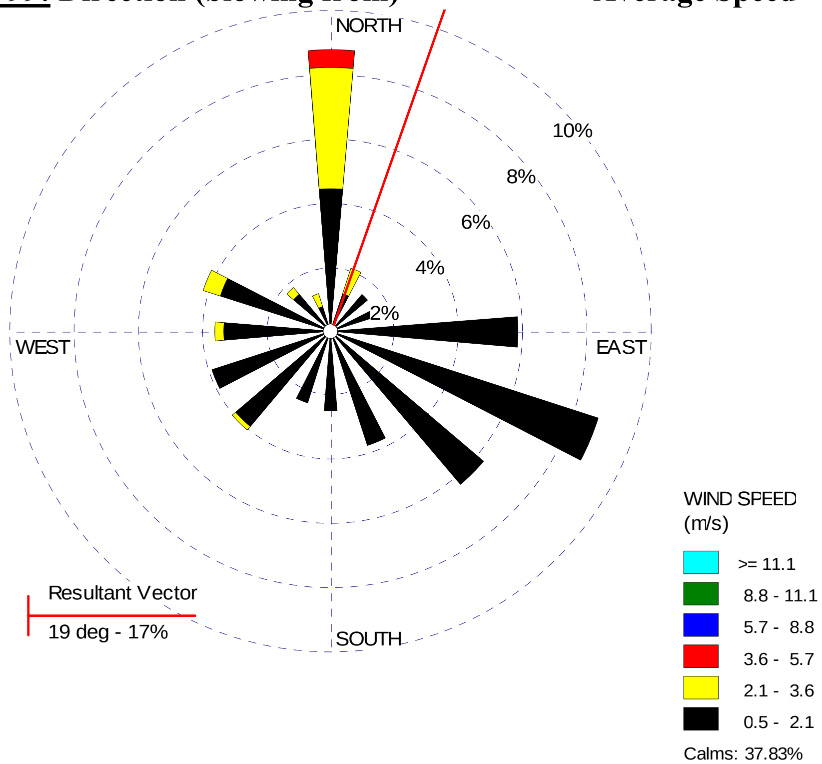


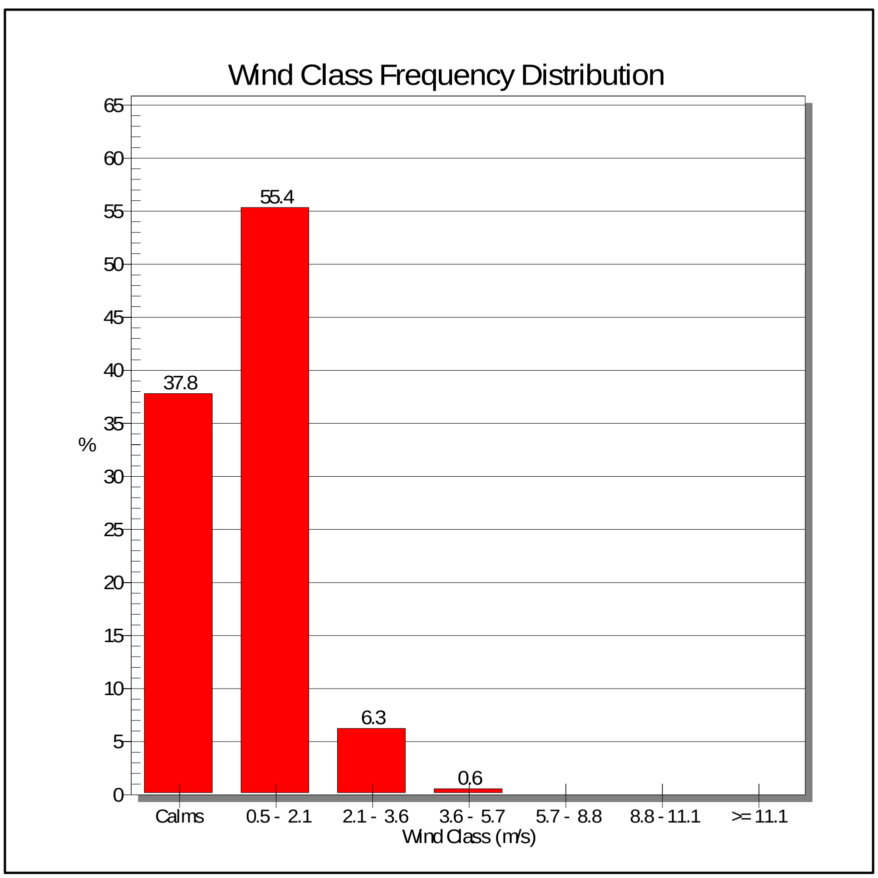
October 1999: Direction (blowing from) Average Speed = 0.88 m/s



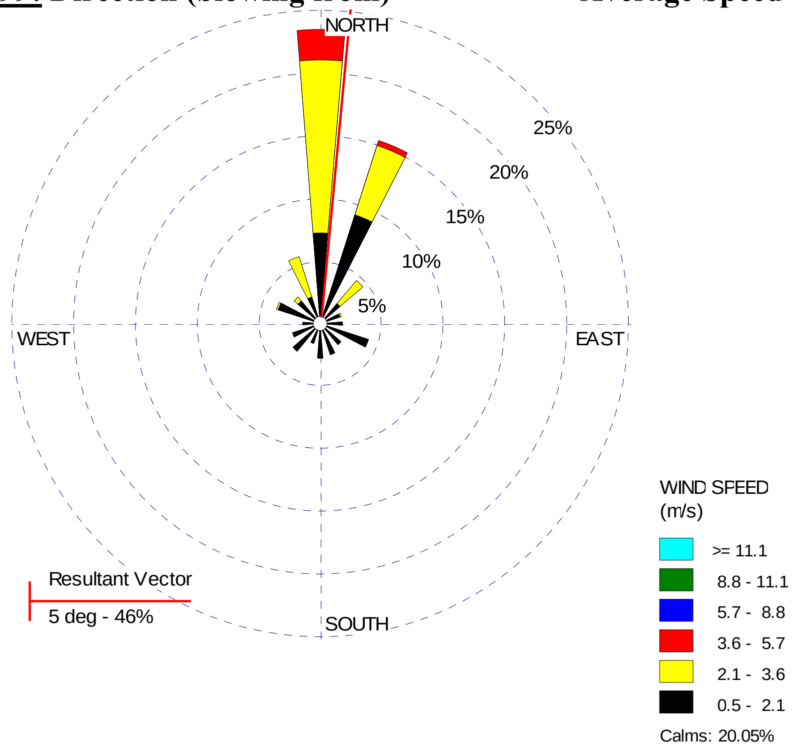


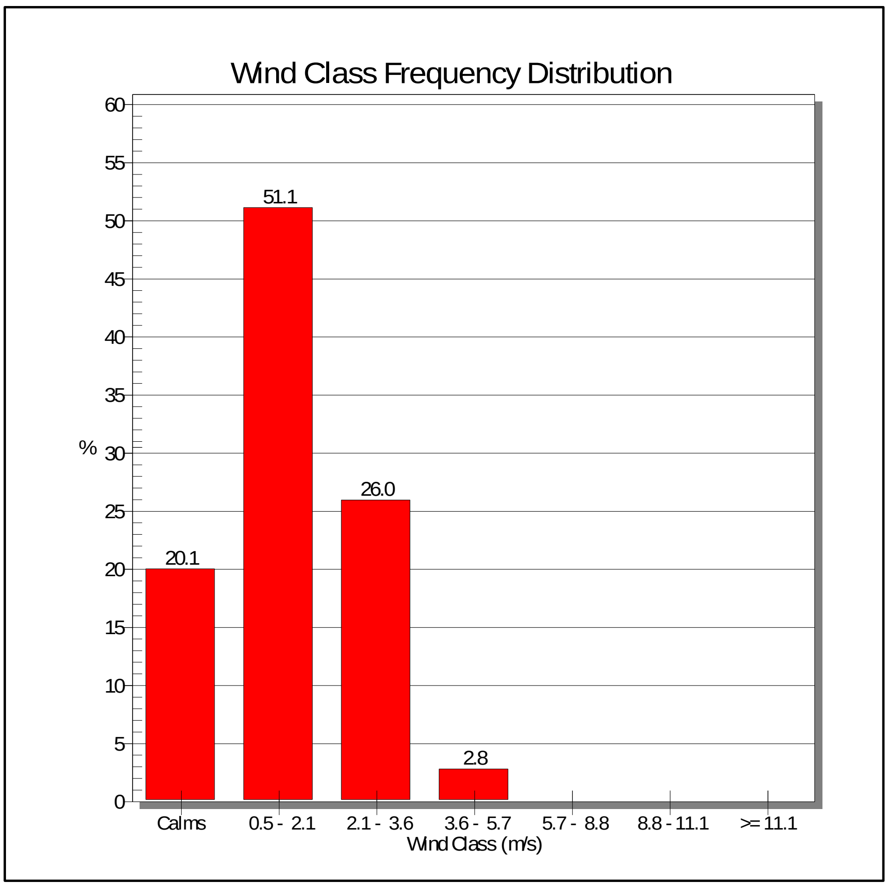
<u>November 1999:</u> Direction (blowing from) **Average Speed = 0.76 m/s**



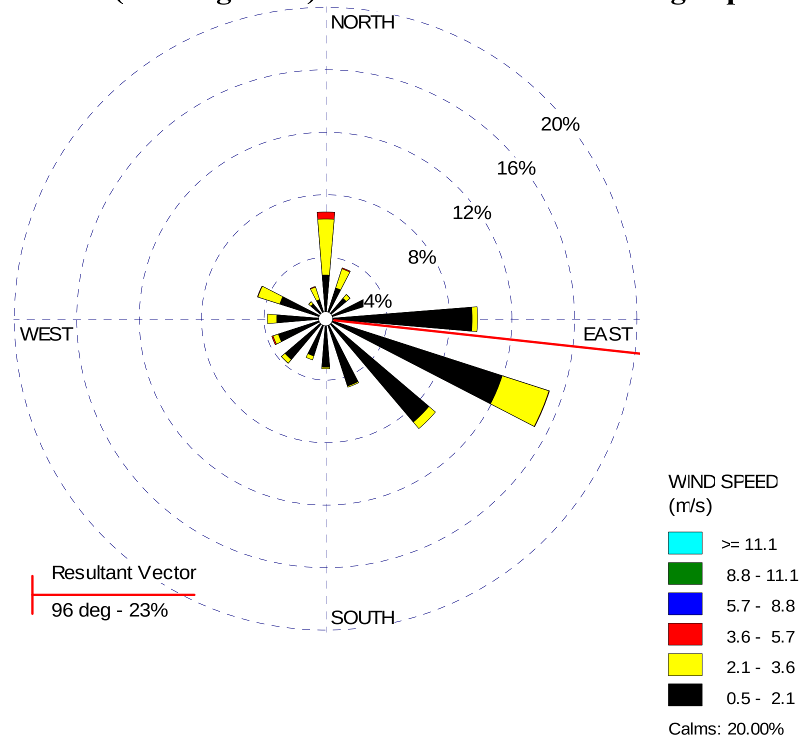


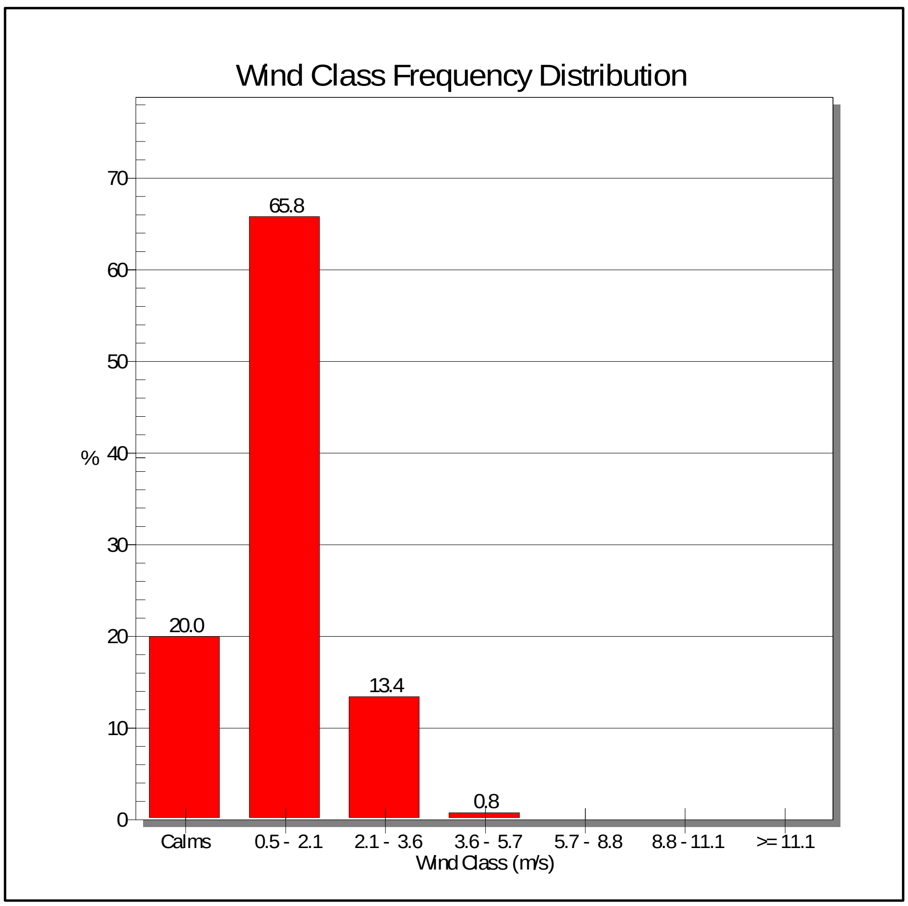
December 1999: **Direction (blowing from)** **Average Speed = 1.43 m/s**





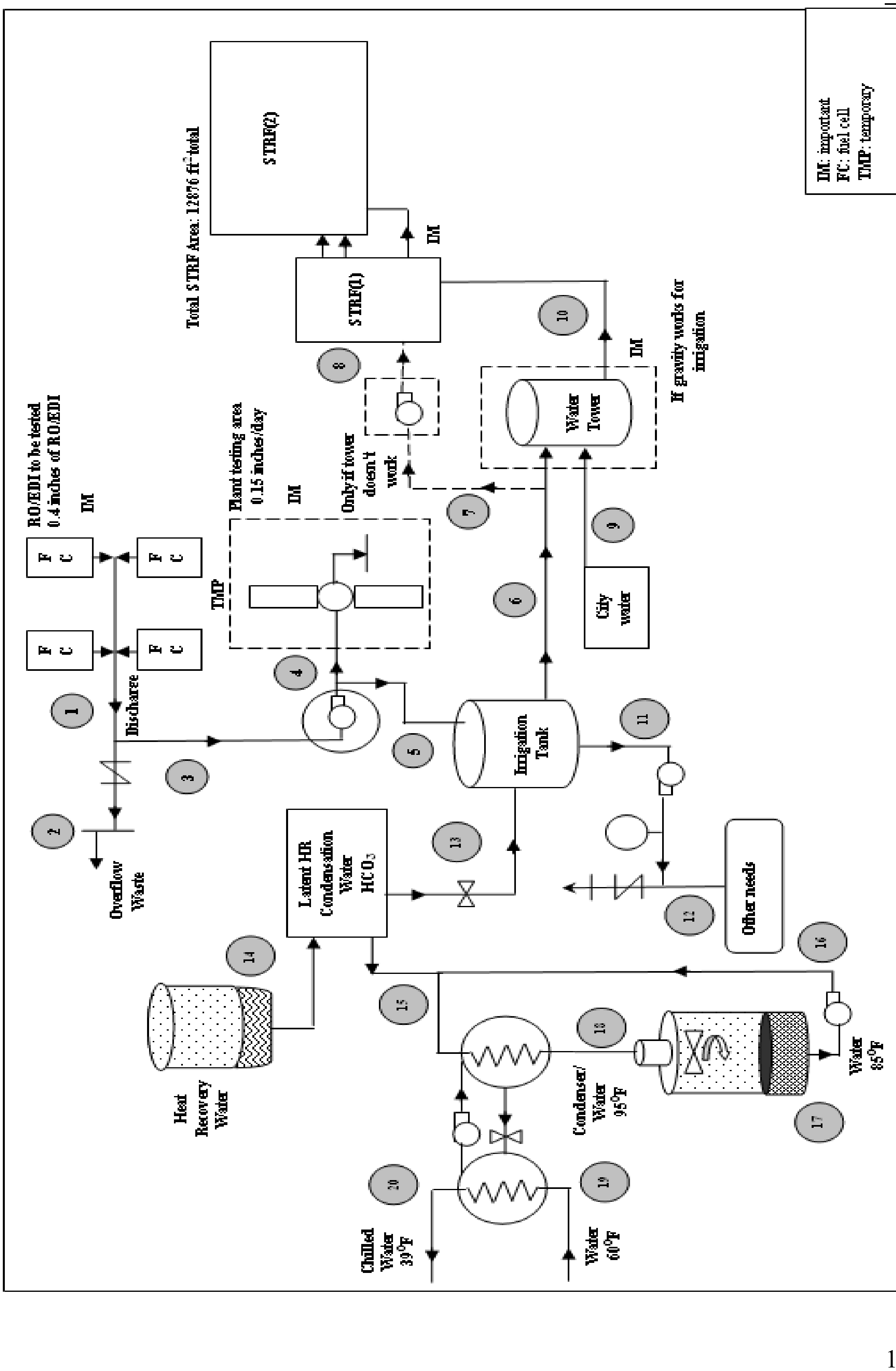
<u>Year 1999:</u> Direction (blowing from) **Average Speed = 1.14 m/s**



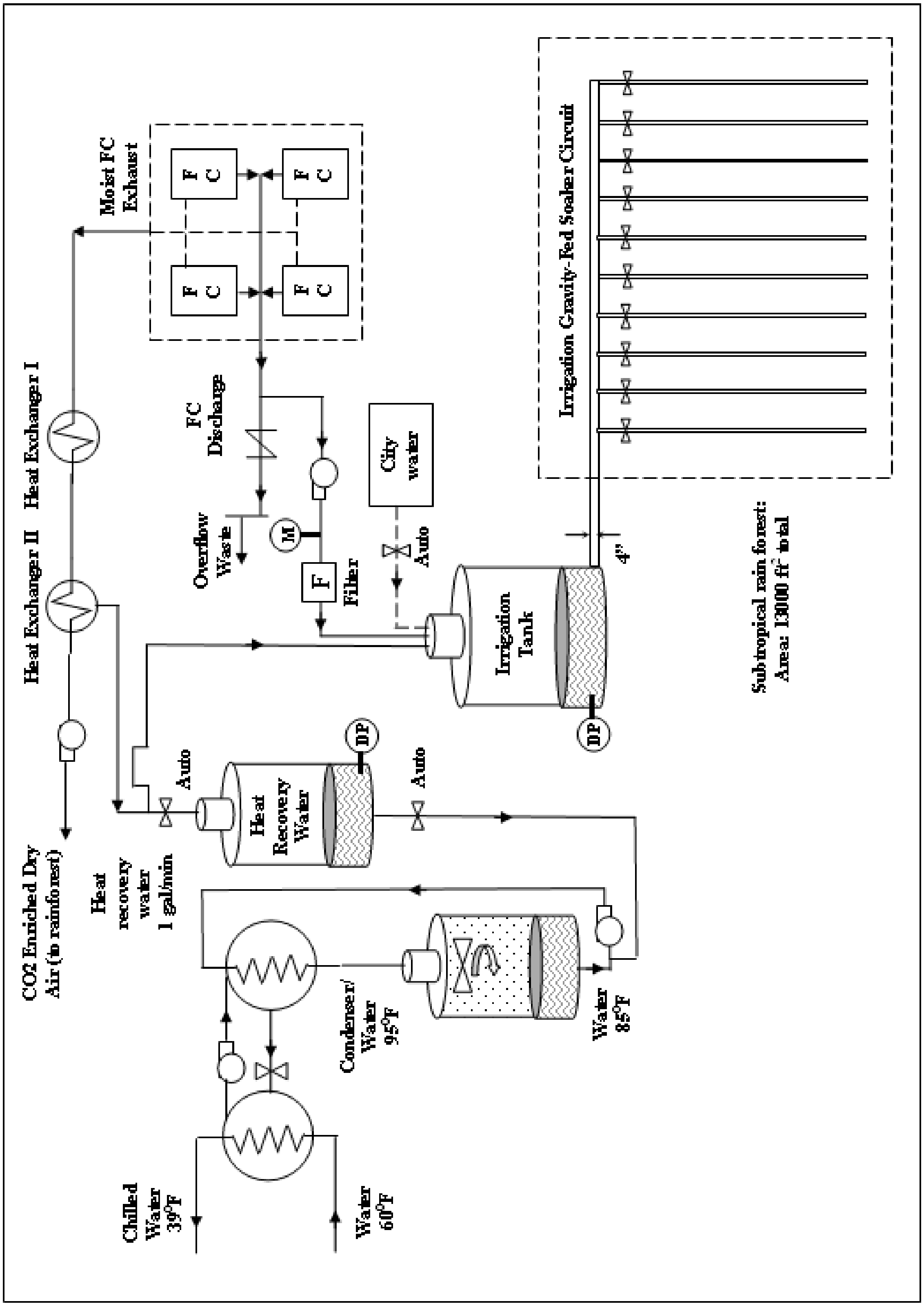


APPENDIX C

Preliminary Water Distribution System

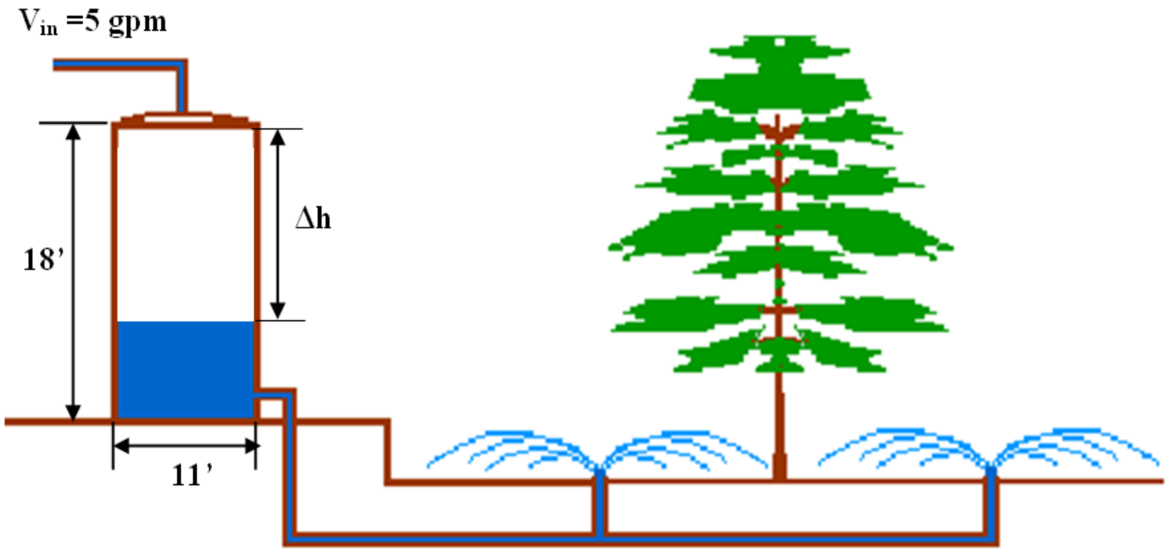


<u>**Finalized Water Distribution/ Irrigation System @ Fuel Cell**</u>



Irrigation orifice calculations

Given calculations were made in order to find the orifice size of the irrigation soaker system. Initial diagram and assumptions are listed below.



Preliminary Assumptions:

Irrigation time: 1.71 hours

Pipe length: 180 ft

Initial Conditions		
Cd	0.61	
Cc	1	
Cv	0.61	
Z_1	16	ft
Z_2	6	ft
A_t	95	ft^2
Δh	10	ft
g	32	ft/s^2
Volume	7106	gal
Pipe Length	220	ft
Re	2100	
h_f	5	ft
t	1.71	hours
	102.6	min
	6156	sec
Area(total)	15113	ft^2

$$t = \frac{2A_t\left(\sqrt{z_1} - \sqrt{z_2}\right)}{C_d A_0 \sqrt{2g}}$$

$$A_0 = \frac{2A_t\left(\sqrt{z_1} - \sqrt{z_2}\right)}{C_d\, t \sqrt{2g}}$$

Orifice calculations		
Ao	0.01	ft^2
d (total orifice diameter)	0.112	ft
	1.341	inches
# of holes	1	per 9 inch of piping
# of orifices	373	orifices
drill size	5/64	inch

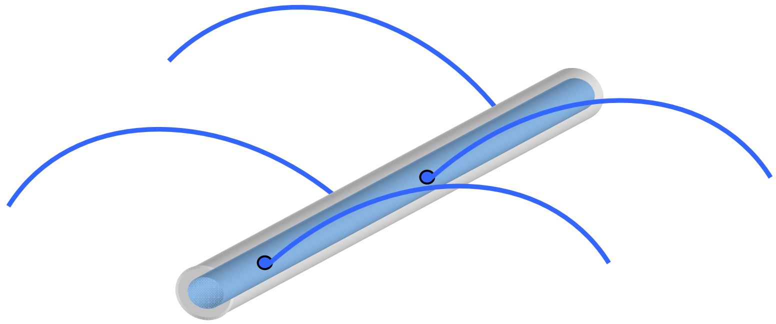
The size of the orifices was chosen to be 5/64". Next we check a friction loss @ 7106 gallons in 1.71 hours period of time:

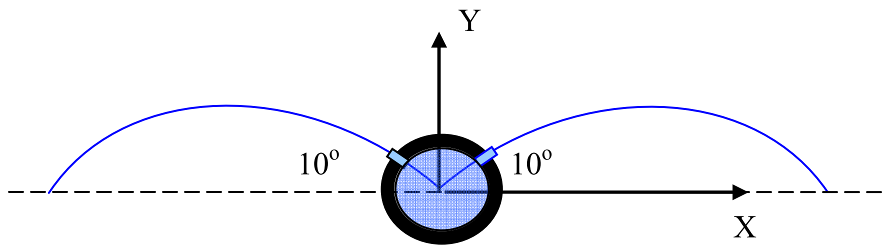
$$h_f = \frac{fLV^2}{2Dg}$$

- h_f is the head loss due to friction;
- L is the length of the pipe;
- D is the hydraulic diameter of the pipe
- V is the average velocity of the fluid flow
- g is the local acceleration due to gravity
- f is a Darcy friction factor

Check Friction Loss		
Flow Rate	70	GPM
	0.156	ft^3/sec
f	0.0305	
D	2.5	inch
	0.208	ft
V	4.575	
L	280	ft
h_f	14.35	

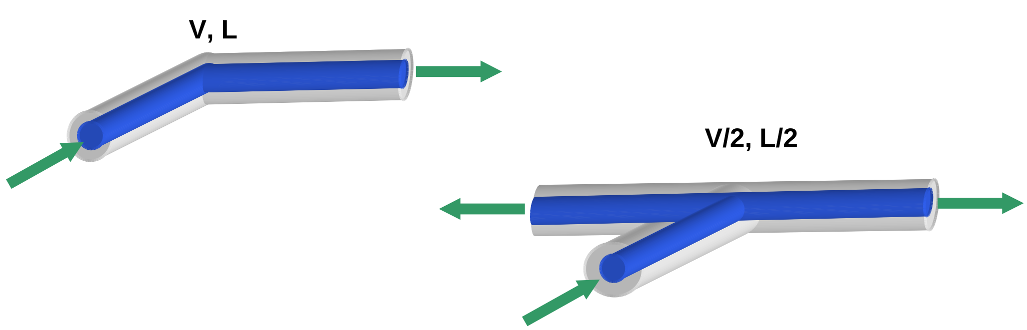
To check throw from 5/64" orifice:





Vo=Cvsqrt(2gh)		
Vo	19.8226537	ft/s
V_y	3.44216769	ft/s
T_{half}	0.107	s
T_{total}	0.215	s
V_x	19.5	ft/s
x	4.2	ft
Assumed coverage	3.5	ft
# of 2.5" circuits	9.3	circuits

It was found that h_f, the head loss due to friction, is relatively high for the design. We decided to place the main 3" pipe of each section in the middle of each irrigation section. It dramatically decreased head loss and allowed irrigation system to have 7 irrigation sections.



V @ 16ft	0.1914	ft^3/sec
	85.9157	GPM
V @ 6ft	0.1172	ft^3/sec
	52.6124	GPM

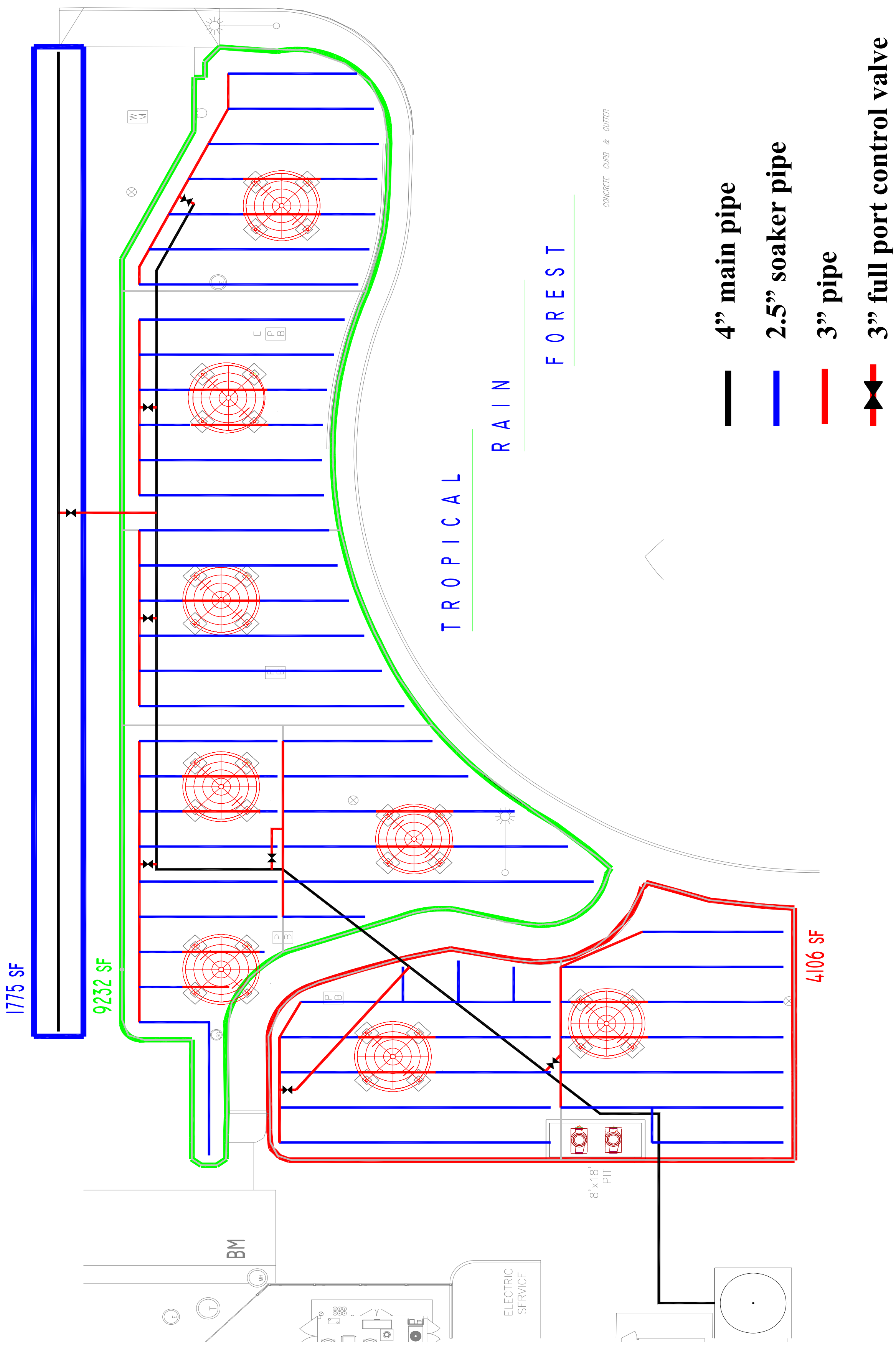
Check Friction Loss		
Flow Rate	85.9157	GPM
	0.1914	ft^3/sec
f	0.0305	
D	2.5000	inch
	0.2083	ft
V	5.6156	
L	280.0000	ft
h_f	20.1823	

Check Friction Loss		
Flow Rate	52.6124	GPM
	0.1172	ft^3/sec
f	0.0305	
D	2.5000	inch
	0.2083	ft
V	3.4388	
L	280.0000	ft
h_f	7.5684	

@ V/2 and L=150ft

Check Friction Loss		
Flow Rate	42.9579	GPM
	0.0957	ft^3/sec
f	0.0305	
D	2.5000	inch
	0.2083	ft
V	2.8078	
L	150.0000	ft
h_f	2.7030	

Check Friction Loss		
Flow Rate	26.3062	GPM
	0.0586	ft^3/sec
f	0.0305	
D	2.5000	inch
	0.2083	ft
V	1.7194	
L	150.0000	ft
h_f	1.0136	


1775 SF
9232 SF
4106 SF
TROPICAL
RAIN
FOREST
CONCRETE CURB & GUTTER
8'x18' PIT
BM
ELECTRIC SERVICE
4" main pipe
2.5" soaker pipe
3" pipe
3" full port control valve

APPENDIX D

There are three water sources that are going to be used for plant irrigation. The main source is the reverse osmosis/electro-deionization system (RO/EDI). The other two are heat exchanger evaporated water and cooling tower blowdown and evaporated water. Since fuel cell uses water softener, it was desired to find the precise chemical composition of the RO/EDI water in order to guarantee the plants well being. The RO/EDI water was sent to EMS Laboratories for analysis. The obtained chemical composition is given below as well as a table of the national secondary drinking water regulations for comparison.

List of National Secondary Drinking Water Regulations

Contaminant	**Secondary Standard**
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Preliminary Water Testing Results

09/14/2007 13:48 FAX 16267965282 EMS Labs 004

Page 2 of 4

EMS LABORATORIES CHEMISTRY REPORT

CLIENT: CSUN
LABORATORY NO: 115849

SAMPLE: Water
ANALYTE: Anions
METHOD: Ion Chromatograph

DATE RECEIVED: 9/4/07
DATE ANALYZED: 9/13/07

Sample ID	unit	F	Cl	Br	NO3	PO4	SO4
fuel cel	ppm	1.2	87	<0.5	3.6	<0.5	65
tap water	ppm	0.67	52	<0.5	2.2	<0.5	39
Reporting Limit	ppm	0.5	0.5	0.5	0.5	0.5	0.5

Chemist Lei Wang

Lei Wang, Ph.D.

EMS LABORATORIES 117 West Bellevue Drive / Pasadena CA 91105-2503 /626-568-4065

EMS LABORATORY REPORT

CLIENT: CSUN
LABORATORY ID: 115849
PROJECT NO: NA

MATRIX Waste water

ANALYTICAL METHOD: EPA 200.7
SM 3111B (K)
DATE OF ANALYSIS: 09-10-07

Sample ID	Ag (ppm)	Mn (ppm)	Fe (ppm)	Al (ppm)	Cu (ppm)	Zn (ppm)	K (ppm)
Fuel Cell	<0.02	<0.10	<0.20	<0.10	0.15	0.11	37
Tap Water	<0.02	<0.10	<0.20	<0.10	0.13	<0.10	3.1
Reporting Limit	0.02	0.10	0.20	0.10	0.10	0.10	0.02

Chemist: [signature]
Simona Fish

EMS LABORATORIES CHEMISTRY REPORT

CLIENT: CSUN
LABORATORY NO: 115849

SAMPLE: Water
ANALYTE: As Requested

DATE RECEIVED: 9/4/07
DATE ANALYZED: 9/11/07

Sample ID	pH	KCl (ppm)	Total Dissolved Solids (ppm)
fuel cell	7.89	70	443
tap water	7.69	5.9	258
Reporting Limit	NA	2	5
Method	SM4500HB	Calculation	SM2540C

Chemist
Lei Wang, Ph.D.

EMS LABORATORIES 117 West Bellevue Drive / Pasadena CA 91105-2503 / 626-568-4065

APPENDIX E

The twelve plants, used to test the fuel cell discharge water, were separated into four groups of three. One group was watered with only fuel cell water (FC group). The second group was watered with a carbon filtered discharge water (FFC group). The third group was watered with the mixture of the city's water and the discharge from the RO/EDI system (MW group). The last group was watered using the city's water (TW group). The plants in each group were numbered to correspond to how much liquid was given to each plant.

<u>FC(1-3)</u>: Out of the three RO/EDI discharge watering groups, FC1 plant did the best. The FC1 plant grew taller, recovered faster, and had more new branch growth than FC2 and FC3 plants.

The FC2 plant had some new growth, but not much and it did not grow outward very far. The FC3 plant had more new growth than the FC2 plant and grew out a lot more than FC1 and FC2 plants. The FC3 plant had some good growth; however, it did not grow as dense as FC1.

<u>FFC(1-3)</u>: Out of the filtered fuel cell water group, the FFC2 plant did the best out of the three plants. FFC1 plant had problems at the beginning, and there was a growth of clovers that sprouted in about a month of the experiment. The FFC1 plant died within the three month period we studied the plants, but the clovers grew large and healthy. The FFC2 plant grew taller and had some new limb growth and recovered from the sun damage that appeared on all plants from the experiment. The FFC2 plant did not grow outward very much and there was little new limb growth.

The FFC3 plant grew just as well as FFC2, except that FFC3 plant did not recover as well as FCC2 one. The FFC3 plant also had some browning in the limbs by the end of the third month. The FFC3 plant had some new limb growth and some new plant growth, as all plants had, but it did not grow out or up that much as others in the FFC group.

MW(1-3): Out of the plants watered by the mixed water, the MW3 plant grew the best. It recovered faster, had more growth upward and outward, more new growth, and was greener than MW1 and MW2 plants. The MW1 plant recovered fairly well from the sun damage but the new growth were sparse and one limb died entirely. There was a very small amount of limb expansion from MW1 plant. The MW2 plant recovered from the sun damage but had a small amount of new growth throughout the experiment. There was a very small amount of limb expansion from the MW2 plant and some of the outer limbs died by the end of the experiment.


The MW3 plant had a lot of new growth. It recovered fairly well from the sun damage. The plant also had a lot of limb expansion outward and upward. It grew fairly well, and the plant looked greener and healthier than the other MW plants.

<u>TW(1-3)</u>: Out of the TW (city tap water) group, the TW1 plant did the best. The TW plants did not recover as well as the other plant groups but TW1 plant did have one of the better growths out of all the tested plants. The TW1 plant grew greener, stayed healthier, recovered well, had more new growth, and had more limb growth than all the other TW plants.

The TW1 plant had a lot of new growth sprouting from the center root. Each limb grew more and the plant stayed green throughout the experiment. There was some sun damage but the plant overcame the damage and grew healthier limbs.

The TW2 plant was not as healthy as the other plants from the beginning. It always had a few brown limbs from the start of the experiment. Even though it had new growth but they never grew much. The plant never fully recovered from the sun damage; however, limbs had a similar look to their initial conditions.

The TW3 got the most sun damage out of all the plants. It did recover a little, but it hardly grew at all. There were new growth but they did not mature fast and stayed little. Throughout the experiment, the TW3 plant seemed like it can die at any time but the plant made it through the experiment.

New Growth: The "new growth" term is the number of the new limbs that the mother ferns produce. The new growth first looks like a small tentacles curled into each other (see picture). The number of the new growth that occurred throughout the experiment helped us to conclude how well the plant is doing.

Outward and Upward Growth:

Outward and upward growth describes the plant size change. Most of the plants did not grow outward much and some had a noticeable limb growth. The amount of outward and upward growth also helped us how to determine which plants grew best. One of the best examples is the FC3 plant that grew into the photo shots of the FFC1 plant (see picture).

APPENDIX F

Appendix shows the table of the plastic materials characteristics to compare them among each other and select proper material to be used for the cooling tower mesh. The selection is based on the available types of plastics manufactured and sourced commonly from the industry. The table compares and explains vital performance characteristics of plastics which are analyzed and compared with the design requirements of the cooling tower cover mesh.

Materials →			**NYLONS**			
Characteristics ↓	**Units**	**ABS**	**Nylon MD**	**Nylon 6**	**Nylon NSM**	**Nylon GSM**
Water Absorption (24hrs)	%	0.3	1.2	1.2	0.25	1.2
Water Absorption (sat)	%	0.7	6.5	9	7	6.5
Tensile Strength	PSI	6500	12500	12400	11000	12500
Flexural Strength	PSI	11000	16400	14000	16000	16400
Compressive Strength	PSI	6750	10,000	12,000	14,000	10000
Shear Strength	PSI	NA	11,000	9,600	10,000	11000
Impact Strength	Ft-lb/in	NA	0.8 - 1.0	1.2	0.5	0.8 - 1.0
Elongation at break	%	20	50	90	20	50
Modulus of Elasticity	PSI	320000	400000	410000	400000	400000
Density	Lb/cub in	0.037	0.041	0.0415	0.0415	0.0418
Coefficient of Friction		-	0.35	0.35	0.18	0.35
Wear factor	In-min/Ft-lb-hr	-	8	72	-	83
Abrasion resistance	-	-	-	54	-	-
Coefficient Of Thermal Expansion	In/In/F	4*10^5	$5.0x10^5$	$5.0x10^5$	$5.9x10^5$	$5.0x10^5$
Continuous Service Temperature (Air)	F	185	212	212	200	212
Deflection Temperature (264 PSI)	F	220	200	194	200	200

Melting Point	F	-	430	491	420	430
Deformation Under Load (2000 PSI, 122 °F)	%	-	0.75	2	-	0.75
Dielectric Strength	Volts/ Mil	450	550	400	-	550
Gas permeability (CO2)	-	-	-	-	-	-
Gas permeability (O2)	-	-	-	-	-	-

Materials→		**Polyethylene**		**Polysulfone**	**Polypropylene**	**Acetal**
Characteristics ↓	**Units**	**HDPE**	**UHMW**			
Water Absorption (24hrs)	%	0.3	0.3	0.3	0.008	0.25
Water Absorption (sat)	%	NA	0.1	-	-	0.9
Tensile Strength	PSI	4600	4,750	-	4,800	10,000
Flexural Strength	PSI	1400	3500	-	7,000	14,300
Compressive Strength	PSI	4,570	NA	4,000	6,720	18,000
Shear Strength	PSI	3,380		-	5,710	9,500
Impact Strength	Ft-lb/in	3	no break	1.2	1.9	1.5
Elongation at break	%	55	325	-	-	60
Modulus of Elasticity	PSI	170000	90000	360,000	190,000	450000
Density	Lb/cub in	0.34	0.34		0.032	0.051
Coefficient of Friction		NA	0.12		-	0.25
Wear factor	In-min/Ft-lb-hr	NA	111		-	216
Abrasion resistance		NA	10		-	137
Coefficient Of Thermal Expansion	In/In/F	1.25*E 4	7.2*E5	3.1×10^5	1.20×10^4	5.0×10^5
Continuous Service Temperature (Air)	F	180	160		-	180
Deflection Temperature (264 PSI)	F	151	116	345	-	260
Melting Point	F	NA	NA		-	347
Deformation Under Load (2000 PSI, 122 °F)	%	NA	7		-	0.6

Dielectric Strength	Volts/ Mil	500	NA	425	-	380
Gas permeability (CO2)	-	45	-	75	92	-
Gas permeability (O2)	-	10	-	15	28	-

Materials→		**PVC**	**PEEK**	**Teflon**	**Polycarbonate**
Characteristics ↓	**Units**				
Water Absorption (24hrs)	%	0.1	0.15	-	0.02
Water Absorption (sat)	%	-	-	-	-
Tensile Strength	PSI	7,000	14,500	3,350	10,500
Flexural Strength	PSI	12,500	24,650	no break	12,000
Compressive Strength	PSI	10,830	17,000	-	11,000
Shear Strength	PSI	9,240	7,690	-	9,200
Impact Strength	Ft-lb/in	1.3	1.6	-	13
Elongation at break	%	25	50	210	100
Modulus of Elasticity	PSI	410,000	580,000	70,000	320,000
Density	Lb/cub in	0.053	0.047	0.079	0.043
Coefficient of Friction		-	0.34	0.07	-
Wear factor	In-min/Ft-lb-hr	-	200	-	-
Abrasion resistance		-	55	78	-
Coefficient Of Thermal Expansion	In/In/F	7.3x10^5	2.6x10^5	6.5x10^5	3.9 x 10^5
Continuous Service Temperature (Air)	F	160	480	500	475
Deflection Temperature (264 PSI)	F	154	320	115	539
Melting Point	F	360	640	621	-
Deformation Under Load (2000 PSI, 122 °F)	%	-	-	5	-
Dielectric Strength	Volts/ Mil	552	-	-	840
Gas permeability (CO2)	-	10.2	-	-	85
Gas permeability (O2)	-	1.2	-	-	20

APPENDIX G

Soil analytical data for Rainforest

WALLACE LABORATORIES
365 Coral Circle
El Segundo, CA 90245
phone (310) 615-0116 fax (310) 640-6863

Summary Data

description	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Target
pH	8.13	7.73	7.95	7.73	7.82	7.67	7.78	7.85	6.5-7.9
lime	yes	low	yes	yes	yes	yes	yes	yes	no
salinity	0.47	0.45	0.69	1.14	0.75	2.37	0.48	1.30	0.5-3
chloride	7	19	36	4	10	62	18	191	<150
nitrate	8	2	4	122	40	277	4	7	10-30
phosphorus	2.9	34.9	4.7	3.7	3.7	6.5	6.3	6.8	8-20
potassium	131	175	175	246	161	169	207	157	60-180
iron	2.91	51.28	7.08	3.30	3.06	6.24	7.02	9.14	4-15
manganese	0.25	1.42	0.86	0.63	0.33	0.69	1.51	1.45	0.6-3
zinc	1.25	75.58	4.12	2.42	1.40	3.60	2.78	4.71	1-3
copper	2.92	53.22	5.58	6.97	4.94	6.12	7.63	6.67	0.2-3
boron	0.25	0.24	0.43	0.24	0.33	0.57	0.44	0.56	0.2-0.5
magnesium	112	106	127	132	130	161	135	122	25-100
sodium	88	57	144	56	86	144	118	186	<200
sulfur	8	14	25	13	11	30	11	35	25-100
molybdenum	0.05	0.21	0.18	0.27	0.18	0.22	0.24	0.24	
lead	0.71	20.79	1.92	1.99	1.25	6.80	3.19	4.04	

Topical plants are adapted to acidic, non-calcareous soils free of lime. These soils are alkaline and contain lime. Lime is a strong buffering agent that will maintain an alkaline status. There a few methods to work around the lime issue. Chelated iron such as Becker Underwood Sprint 138 Fe or other FeEDDHA chelated iron can be used to supply iron if inhibited. Additionally, acid pockets can be used to supply iron. Furthermore, non-calcareous soils can be used for part of the planting media.

The pH values range from 7.67 to 8.13. The ideal pH for tropical plants is about 6.0 to 6.5. The pH values can be partially reduced with the addition of gypsum (calcium sulfate) followed with leaching.

The salinity is not excessive. The values range from 0.45 millimho/cm to 2.37 millimho/cm in sample No. 6. Sample No. 6 contains high nitrogen which is the major source of salinity.

Nitrogen is low in samples 1, 2, 3, 7 and 8.

Phosphorus is low except in sample 2.

Potassium is sufficient.

Iron is low in samples 1, 4, and 5.

Manganese I slow in samples 1 and 5.

Zinc and copper are excessive in sample 2.

Neither sodium or magnesium are excessive.

Recommendations:

A non calcareous soil free from the presence of lime is best for acid-loving, tropical plants. Mexican Blue Palm, Date Palms, and Mediterranean Fan Palm are expected to tolerate the presence of lime. Lime is frequently present in the Mediterranean area.

Do not use sample No. 2. It contains toxic levels of zinc and copper.

Homogeneously blend the following materials into the more suitable soils. Rates are expressed per cubic yard:

Ammonium sulfate (21-0-0) – 1/4 pound where low

Potassium sulfate (0-0-50) – 1/4 pound

Triple superphosphate (0-45-0) – 1/4 pound

Agricultural gypsum – 1 pound

good quality organic soil amendment - about 15% by volume depending on the material, increase the soil organic matter to about 5% on a dry weight basis

Preleach prior to planting and reduce the pH to less than 7.5 before planting bamboo and other species which are very sensitive to alkalinity.

Soil amendment suggestions:

1. Humus material shall have an acid-soluble ash content of no less than 6% and no more than 20%.
2. The pH of the material shall be between 6 and 7.5.
3. The salt content shall be less than 10 millimho/cm @ 25° C on a saturated paste extract.
4. Boron content of the saturated extract shall be less than 1.0 parts per million.
5. Silicon content (acid-insoluble ash) shall be less than 50%.
6. Calcium carbonate shall not be present.
7. Types of acceptable products are composts, manures, mushroom composts, straw, alfalfa, peat mosses etc. low in salts, low in heavy metals, free from weed seeds, free of pathogens and other deleterious materials.
8. Composted wood products are conditionally acceptable [stable humus must be present]. Wood based products are not acceptable which are based on red wood or cedar.
9. Sludge-based materials are not acceptable.
10. Carbon: nitrogen ratio is less than 25:1.
11. The compost shall be aerobic without malodorous presence of decomposition products.

12. The maximum particle size shall be 0.5 inch, 80% or more shall pass a No. 4 screen for soil amending.

Maximum total permissible pollutant concentrations in amendment in parts per million on a dry weight basis:

arsenic	20	**copper**	150	**selenium**	50
cadmium	15	**lead**	200	**silver**	10
chromium	300	**mercury**	10	**vanadium**	500
cobalt	50	**molybdenum**	20	**zinc**	300
nickel	100				

Higher amounts of salinity or boron may be present if the soils are to be preleached to reduce the excess or if the plant species will tolerate the salinity and/or boron.

For site maintenance, apply ammonium sulfate (21-0-0) at 5 pounds per 1,000 square feet about once per quarter. This form of nitrogen acidifies soil. Monitor the site with periodic soil testing and leaf tissue/root tissue testing. Soil testing is predictive of plant growth. Plant tissue testing will indicate what mineral nutrition has occurred but will not tell why it is occurring. Apply other nutrients as needed based upon testing.

Acid-Pockets

Long-term available iron can be supplied for acid-loving plants with the use of acid pockets. Blend one pound of ferrous sulfate, one pound potassium sulfate (0-0-50), one pound ammonium sulfate (21-0-0), two pounds soil sulfur into one gallon of peat moss. Place one cupful of the acid pocket mix blended with one cupful of soil near each 1-gallon rootball -- two inches away from the rootball 12 inches deep below grade in the planting pit with two inches of unacidified soil separating the rootball from the acid mix. For larger transplants, use two cupfuls of the acid mix for five and fifteen gallons in two spots, two cupfuls of the acid mix in each of four spots for 24-inch to 48-inch boxes and four or more cupfuls of the acid mix for 60-inch and larger boxed transplants in eight spots. Blend an equal volume of soil with the special acid pocket mix. In non-irrigated sites, place the acid pockets at the same elevation as the bottom of the rootball. Place one foot below grade in irrigated sites. Place two inches outside the rootball footprint in all cases.

Chelated iron

Correct iron deficiency if it develops with Becker Underwood Sprint 138 Fe or other FeEDDHA chelated iron. Dissolve 2 tablespoonfuls in 5 gallons of water and drench partially dry soil.

More complete water analysis may be desirable for additional minerals. The reported minerals do not account for the reported TDS.

Suitable Import, Borrow Topsoil or Reclaimed soil

General - Topsoil shall be free of roots, clods, stones larger than 1-inch in the greatest dimension, pockets of coarse sand, noxious weeds, sticks, lumber, brush and other litter. It shall not be infested with nematodes or other undesirable disease-causing organisms such as insects and plant pathogens.

Topsoil shall be friable and have sufficient structure in order to give good tilth and aeration to the soil.

Gradation limits - soil shall be a sandy loam or loam. The definition of soil texture shall be the USDA classification scheme. Gravel over ¼-inch in diameter shall be less than 20% by weight.

Permeability Rate - Hydraulic conductivity rate shall be not less than one inch per hour nor more than 20 inches per hour when tested in accordance with the USDA Handbook Number 60, method 34b or other approved methods.

Fertility - The range of the essential elemental concentration in soil shall be as follows:

Ammonium Bicarbonate/DTPA Extraction parts per million (mg/kilogram)

	Dry weight basis
phosphorus	2 - 40
potassium	40 - 220
iron	2 - 35
manganese	0.3 - 6
zinc	0.6 - 8
copper	0.1 - 5
boron	0.2 - 1
magnesium	50 - 150
sodium	0 - 100
sulfur	25 - 500
molybdenum	0.1 – 2

Soil may need to be amended and conditioned to optimize plant growth. The above listed fertility is for soil selection.

Concentration of nutrients for final acceptance

Ammonium Bicarbonate/DTPA Extraction parts per million (mg/kilogram)

	Dry weight basis
phosphorus	10 - 40
potassium	100 - 220
iron	24- 35
manganese	0.6 - 6
zinc	1 - 8
copper	0.3 - 5
boron	0.2 - 1

magnesium	50 - 150
sodium	0 - 100
sulfur	25 - 500
molybdenum	0.1 - 2

Acidity - The soil pH range measured in the saturation extract (Method 21a, USDA Handbook Number 60) shall be 6.0 - 7.9.

Salinity - The salinity range measured in the saturation extract (Method 3a, USDA Handbook Number 60) shall be 0.5 - 2.5 dS/m.

Chloride - The maximum concentration of soluble chloride in the saturation extract (Method 3a, USDA Handbook Number 60) shall be 150 mg/l (parts per million).

Boron - The maximum concentration of soluble boron in the saturation extract (Method 3a, USDA Handbook Number 60) shall be 1 mg/l (parts per million).

Sodium Adsorption Ratio (SAR) - The maximum SAR shall be 3 measured per Method 20b, USDA Handbook Number 60.

Aluminum – Available aluminum measured with the Ammonium Bicarbonate/DTPA Extraction shall be less than 3 parts per million.

Soil Organic Matter Content - Sufficient soil organic matter shall be present to impart good physical soil properties but not be excessive to cause toxicity or cause excessive reduction in the volume of soil due to decomposition of organic matter. The desirable range is 3% to 5%. The carbon:nitrogen ratio should be about 10. A high carbon:nitrogen ratio can indicate the presence of hydrocarbons or non-humified organic matter.

Calcium Carbonate Content - Free calcium carbonate (lime) shall not be present.

Heavy Metals - The maximum permissible elemental concentration in the soil shall not exceed the following concentrations:

Ammonium Bicarbonate/DTPA Extraction parts per million (mg/kilogram)

	Dry weight basis
arsenic	1
cadmium	1
chromium	10
cobalt	2
lead	30
mercury	1
nickel	5
selenium	3
silver	0.5
vanadium	3

If the soil pH is between 6 and 7, the maximum permissible elemental concentration shall be reduced 50%. If the soil pH is less than 6.0, the maximum permissible elemental concentration shall be reduced 75%. No more than three metals shall be present at 50% or more of the above values.

Phytotoxic constituent, herbicides, hydrocarbons etc. - Germination and growth of monocots and dicots shall not be restricted more than 10%. Total petroleum hydrocarbons shall not exceed 50 mg/kg dry soil measured per the modified EPA Method No. 8015. Total aromatic volatile organic hydrocarbons (benzene, toluene, xylene and ethylbenzene) shall not exceed 0.5 mg/kg dry soil measured per EPA Methods No. 8020.

Sincerely,

Garn A. Wallace, Ph. D.

Executive Director

GAW:n

WALLACE LABS

365 Coral Circle

El Segundo, CA 90245

(310) 615-0116

SOILS REPORT

Print Date ##### Receive Date 3/7/08

Location Rainforest, P.O. No. 732691

Requester Edmond Noblejas, C.S.U.N.

graphic interpretation: * very low, ** low, *** moderate
* * * * high, * * * * * very high

ammonium bicarbonate/DTPA

extractable - mg/kg soil

Interpretation of data		08-70-10		08-70-11		08-70-12		08-70-13	
	Sample ID Number	1		2		3		4	
low medium high	**elements**		graphic		graphic		graphic		graphic
0 - 7 8-15 over 15	**phosphorus**	2.88	*	34.91	*****	4.68	**	3.70	**
0-60 60 -120 121-180	**potassium**	131.15	****	174.59	****	174.92	****	246.03	*****
0 - 4 4 - 10 over 10	**iron**	2.91	**	51.28	*****	7.08	***	3.30	**
0- 0.5 0.6- 1 over 1	**manganese**	0.25	*	1.42	****	0.86	***	0.63	***
0 - 1 1 - 1.5 over 1.5	**zinc**	1.25	***	75.58	*****	4.12	****	2.42	****
0- 0.2 0.3- 0.5 over 0.5	**copper**	2.92	****	53.22	*****	5.58	*****	6.97	*****
0- 0.2 0.2- 0.5 over 1	**boron**	0.25	***	0.24	***	0.43	***	0.24	***
ratio of calcium to magnesium	**calcium**	357.83	***	346.73	***	382.79	***	390.43	***
needs to be more than 2 or 3	**magnesium**	112.48	****	106.49	****	127.19	****	131.62	****
should be less than potassium	**sodium**	87.56	**	56.56	**	143.98	***	56.21	**
	sulfur	8.25	*	13.99	*	25.24	**	13.03	*
	molybdenum	0.05	***	0.21	****	0.18	****	0.27	****
	nickel	0.64	*	1.90	**	1.36	**	1.25	**
The following trace	**aluminum**	n d	*	n d	*	n d	*	n d	*
elements may be toxic	**arsenic**	0.10	*	0.21	*	0.09	*	0.20	*
The degree of toxicity	**barium**	0.98	*	0.99	*	0.85	*	0.85	*
depends upon the pH of	**cadmium**	0.36	*	1.19	**	0.56	*	0.93	*
the soil, soil texture,	**chromium**	n d	*	0.42	*	0.02	*	0.02	*
organic matter, and the	**cobalt**	0.03	*	n d	*	0.05	*	0.02	*
concentrations of the	**lead**	0.71	*	20.79	***	1.92	**	1.99	**
individual elements as well	**lithium**	0.20	*	0.31	*	0.24	*	0.22	*
as to their interactions	**mercury**	n d	*	n d	*	n d	*	n d	*
	selenium	n d	*	n d	*	n d	*	n d	*
The pH optimum depends	**silver**	n d	*	n d	*	n d	*	n d	*
upon soil organic	**strontium**	1.83	*	1.16	*	1.86	*	1.45	*
matter and clay content-	**tin**	n d	*	n d	*	n d	*	n d	*
for clay and loam soils:	**vanadium**	0.56	*	0.56	*	0.79	*	0.88	*
under 5.2 is too acidic									
6.5 to 7 is ideal	**Saturation Extract**								
over 8.0 is too alkaline	**pH value**	8.13	****	7.73	****	7.95	****	7.73	****
The ECe is a measure of	**ECe (milli-**	0.47	**	0.45	**	0.69	**	1.14	***
the soil salinity:	**mho/cm)**		millieq/l		millieq/l		millieq/l		millieq/l
1-2 affects a few plants	**calcium**	26.7	1.3	40.2	2.0	51.6	2.6	148.5	7.4

2-4 affects some plants,	magnesium	5.1	0.4	6.1	0.5	7.0	0.6	16.5	1.4
> 4 affects many plants.	sodium	57.9	2.5	37.9	1.6	78.6	3.4	45.5	2.0
	potassium	9.6	0.2	10.8	0.3	9.3	0.2	15.5	0.4
	cation sum		4.5		4.4		6.8		11.2
problems over 150 ppm	chloride	7	0.2	19	0.5	36	1.0	4	0.1
good 20 - 30 ppm	nitrate as N	8	0.6	2	0.1	4	0.3	122	8.7
	phosphorus as P	0.4	0.0	0.7	0.0	0.5	0.0	0.0	0.0
toxic over 800	sulfate as S	26.5	1.7	23.4	1.5	43.3	2.7	19.1	1.2
	anion sum		2.4		2.2		4.0		10.0
toxic over 1 for many plants	boron as B	0.40	**	0.37	**	0.40	**	0.31	**
increasing problems start at 3	SAR	2.7	**	1.5	*	2.7	**	0.9	*
est. gypsum requirement-lbs./1000 sq. ft.		15		10		24		10	
	relative infiltration rate	slow		very slow		very slow		slow/fair	
	estimated soil texture	sandy loam		sandy loam		sandy loam		loam	
	lime (calcium carbonate)	yes		low		yes		yes	
	organic matter	fair/low		fair/low		fair/low		fair/low	
	moisture content of soil	6.6%		15.4%		14.5%		11.9%	
	half saturation percentage	16.0%		22.6%		23.9%		22.6%	

WALLACE LABS	**SOILS REPORT**	Print Date #####	Receive Date	3/7/08
365 Coral Circle	Location	Rainforest, P.O. No. 732691		
El Segundo, CA 90245	Requester	Edmond Noblejas, C.S.U.N.		
(310) 615-0116	graphic interpretation: * very low, ** low, *** moderate			
	* * * * high, * * * * * very high			

ammonium bicarbonate/DTPA									
extractable - mg/kg soil	Sample ID Number	08-70-14		08-70-15		08-70-16		08-70-17	
Interpretation of data		5		6		7		8	
low medium high	**elements**		graphic		graphic		graphic		graphic
0 - 7 8-15 over 15	**phosphorus**	3.66	**	6.54	**	6.28	**	6.85	**
0-60 60 -120 121-180	**potassium**	161.07	****	169.45	****	207.32	*****	157.13	****
0 - 4 4 - 10 over 10	**iron**	3.06	**	6.24	***	7.02	***	9.14	***
0- 0.5 0.6- 1 over 1	**manganese**	0.33	**	0.69	***	1.51	****	1.45	****
0 - 1 1 - 1.5 over 1.5	**zinc**	1.40	***	3.60	****	2.78	****	4.71	****
0- 0.2 0.3- 0.5 over 0.5	**copper**	4.94	*****	6.12	*****	7.63	*****	6.67	*****
0- 0.2 0.2- 0.5 over 1	**boron**	0.33	***	0.57	****	0.44	***	0.56	****
ratio of calcium to magnesium	**calcium**	397.23	***	395.02	***	416.34	****	410.38	****
needs to be more than 2 or 3	**magnesium**	130.33	****	160.88	*****	135.49	****	122.21	****
should be less than potassium	**sodium**	85.90	**	143.96	***	117.67	***	186.41	***
	sulfur	10.84	*	29.84	**	11.47	*	35.36	**
	molybdenum	0.18	****	0.22	****	0.24	****	0.24	****
	nickel	0.97	*	1.04	**	1.75	**	1.13	**
The following trace	**aluminum**	n d	*	n d	*	n d	*	n d	*
elements may be toxic	**arsenic**	0.18	*	0.14	*	0.20	*	0.16	*

The degree of toxicity	barium	0.84	*	0.62	*	0.70	*	0.98	*
depends upon the pH of	cadmium	0.76	*	0.67	*	1.23	**	0.81	*
the soil, soil texture,	chromium	0.01	*	0.05	*	0.04	*	0.07	*
organic matter, and the	cobalt	0.05	*	0.03	*	0.05	*	0.04	*
concentrations of the	lead	1.25	**	6.80	***	3.19	**	4.04	**
individual elements as well	lithium	0.22	*	0.27	*	0.25	*	0.28	*
as to their interactions	mercury	n d	*	n d	*	n d	*	n d	*
	selenium	n d	*	n d	*	n d	*	n d	*
The pH optimum depends	silver	n d	*	n d	*	n d	*	n d	*
upon soil organic	strontium	1.81	*	1.83	*	1.59	*	1.85	*
matter and clay content-	tin	n d	*	n d	*	n d	*	n d	*
for clay and loam soils:	vanadium	0.91	*	0.81	*	0.89	*	0.86	*
under 5.2 is too acidic									
6.5 to 7 is ideal	Saturation Extract								
over 8.0 is too alkaline	pH value	7.82	****	7.67	****	7.78	****	7.85	****
The ECe is a measure of	ECe (milli-	0.75	**	2.37	****	0.48	**	1.30	***
the soil salinity:	mho/cm)		millieq/l		millieq/l		millieq/l		millieq/l
1-2 affects a few plants	calcium	76.3	3.8	300.1	15.0	34.6	1.7	111.1	5.6
2-4 affects some plants,	magnesium	10.0	0.8	36.3	3.0	6.6	0.5	14.0	1.2
> 4 affects many plants.	sodium	56.6	2.5	135.2	5.9	54.6	2.4	132.4	5.8
	potassium	8.2	0.2	17.5	0.4	7.3	0.2	9.4	0.2
	cation sum		7.3		24.3		4.8		12.7
problems over 150 ppm	chloride	10	0.3	62	1.8	18	0.5	191	5.4
good 20 - 30 ppm	nitrate as N	40	2.8	277	19.8	4	0.3	7	0.5
	phosphorus as P	0.2	0.0	0.8	0.0	0.3	0.0	0.1	0.0
toxic over 800	sulfate as S	21.1	1.3	60.1	3.8	27.0	1.7	68.2	4.3
	anion sum		4.4		25.3		2.5		10.1
toxic over 1 for many plants	boron as B	0.43	***	0.65	***	0.54	***	0.63	***
increasing problems start at 3	SAR	1.6	**	2.0	**	2.2	**	3.1	***
est. gypsum requirement-lbs./1000 sq. ft.		15		24		20		32	
	relative infiltration rate	slow/fair		slow/fair		very slow		slow/fair	
	estimated soil texture	loam		loam		clay loam		sandy loam	
	lime (calcium carbonate)	yes		yes		yes		yes	
	organic matter	fair/low		fair/low		fair/low		fair/low	
	moisture content of soil	14.5%		10.9%		14.3%		7.6%	
	half saturation percentage	24.2%		22.5%		24.9%		19.0%	

APPENDIX H

Surface Area of the Cooling Tower Cover

The following calculations show an estimate of the area of the cooling tower cover design, along with the different assumed shapes assumed. The four different designs considered for the below calculations are semi-sphere, semi-sphere over cylinder, conical, and cone over cylinder. The areas of all of the above estimated designs are based on assumptions made on the height, width etc. of each shape, according to the minimum area required for the design.

Test for the mesh hole size

Model 1: Semi sphere design			
Diameter of the cooling tower top surface (d)	=	100	in
	=	8.33	ft
Radius for the sphere (r)	=	5.166	ft
Surface Area = 4*pi*r^2	=	217.358	ft^2
(Since the cooling tower lid is half the sphere, the surface area for the sphere is divided by 2).			
Total Surface Area (T)	=	**167.6**	**ft^2**

Model 2: Semi sphere over cylinder design			
Diameter of the Cooling tower Top surface (d)	=	100	in
	=	8.33	ft
Radius (r)	=	4.166	ft
Assumed height of the cylinder (h)	=	3	ft
Surface Area S1 (Cylinder) (2*π*r*h)	=	78.4874	ft^2
Surface Area S2 (Semi-Sphere) (4*pi*r^2*0.5)	=	108.679	ft^2
Total Surface area (T) =S1 +S2	=	**187.167**	**ft^2**

Model 3: Conical design			
Diameter of the Cooling tower Top surface (d)	=	100	in
	=	8.33	ft

Radius (r)	=	4.166	ft
Assumed side of the cone (s)	=	5	feet
Surface Area S1 (Cone) (π*r*s)	=	65.4062	ft^2
Surface Area S2 (base of the cone) (π*r^2)	=	54.3396	ft^2
Total Surface area (T) =S1 +S2	**=**	**119.746**	**ft^2**

Model 4: Cone over cylinder design			
Diameter of the Cooling tower Top surface (d)	=	100	in
	=	8.33	ft
Radius (r)	=	4.166	ft
Assumed height of the cone (h)	=	2	ft
Assumed side of the cone (s)	=	4.5	ft
Assumed height of the cylinder (h)	=	3	ft
Surface Area S1 (Cone) (π*r*s)	=	58.8656	ft^2
Surface Area S1 (Cylinder) (2*π*r*h)	=	78.4874	ft^2
Total Surface area (T) =S1 +S2	**=**	**137.353**	**ft^2**

The height of either of the above designs could vary, thus varying the surface area. A better perspective for this can be achieved by drawing software models of the actual design.

APPENDIX I

CO_2 Ring Diffuser Orifice Sizing

Known:

Diameter Cooling Tower	14	ft
Perimeter Cooling Tower (Length of ring diffuser)	43.96	ft
Diameter ring diffuser	6	in
Available Pressure	0.3	in. w.g

$$h_f = \frac{f \cdot L \cdot V^2}{2 \cdot D \cdot g}$$

(Reference: Mechanical Engineering Manual for the P.E Exam, Michael R.Lindeburg

Eq. 17-28 p 17-7)

ε	0.0005	ft	(roughness value galvanized iron)
ε / D	0.001		
f	0.045		(assuming laminar flow with ε / D value)
D	6	in	(diameter of ring)
	0.500	ft	
L	6	ft	(1 ft. spacing between + equivalent length of 5 ft.)
g	32.2	ft/s^2	
area	0.19625	ft^2	

$$A_0 = \frac{Q}{C_f} \cdot \sqrt{\frac{\rho}{2 \cdot g \cdot h \cdot (\rho m - \rho)}}$$

(Reference: Mechanical Engineering Manual for the P.E Exam, Michael R.Lindeburg

Eq. 17.113 p 17-25)

Cf	0.65		(estimated)
ρm	62.3	lb/ft^3	(water)
ρ	0.074	lb/ft^3	(air at 80F)
g	32.2	ft/s^2	
Q	10	cfm	(individual orifice)

Ring Diffuser Calculations						**Varying h to Find Diameter of Orifice**						
Sizing Dist. Apart ft.	**CFM**	**v**	**hf**	**in. w.g/ 100'**	**P**	**Ao**	**Ao**	**D**	**h**	**h**		**Orifice Size**
		ft/s	**ft. w.g**		**in. w.g**	**ft^2**	**in^2**	**in.**	**in.**	**ft.**		**in.**
1	225	19.11	3.06	***0.367***	0.300	0.0080	1.16	***1.21***	0.225	0.01875	1.25	**1 1/4**
2	215	18.26	2.80	***0.335***	0.280	0.0084	1.21	***1.24***	0.205	0.0170727	1.25	**1 1/4**
3	205	17.41	2.54	***0.305***	0.262	0.0088	1.27	***1.27***	0.187	0.0155478	1.25	**1 1/4**
4	195	16.56	2.30	***0.276***	0.245	0.0093	1.33	***1.30***	0.170	0.014168	1.25	**1 1/4**
5	185	15.71	2.07	***0.248***	0.230	0.0097	1.40	***1.33***	0.155	0.0129261	1.375	**1 3/8**
6	175	14.86	1.85	***0.222***	0.217	0.0101	1.46	***1.36***	0.142	0.0118149	1.375	**1 3/8**
7	165	14.01	1.65	***0.198***	0.205	0.0106	1.52	***1.39***	0.130	0.010827	1.375	**1 3/8**
8	155	13.16	1.45	***0.174***	0.194	0.0110	1.59	***1.42***	0.119	0.0099552	1.375	**1 3/8**
9	145	12.31	1.27	***0.153***	0.185	0.0115	1.65	***1.45***	0.110	0.0091923	1.375	**1 3/8**
10	135	11.46	1.10	***0.132***	0.177	0.0119	1.72	***1.48***	0.102	0.008531	1.5	**1 1/2**
11	125	10.62	0.94	***0.113***	0.171	0.0123	1.78	***1.50***	0.096	0.007964	1.5	**1 1/2**
12	115	9.77	0.80	***0.096***	0.165	0.0127	1.83	***1.53***	0.090	0.0074842	1.5	**1 1/2**
13	105	8.92	0.67	***0.080***	0.160	0.0131	1.89	***1.55***	0.085	0.0070841	1.5	**1 1/2**
14	95	8.07	0.55	***0.065***	0.156	0.0134	1.93	***1.57***	0.081	0.0067566	1.5	**1 1/2**
15	85	7.22	0.44	***0.052***	0.153	0.0137	1.97	***1.58***	0.078	0.0064945	1.5	**1 1/2**
16	75	6.37	0.34	***0.041***	0.150	0.0139	2.00	***1.60***	0.075	0.0062903	1.625	**1 5/8**
17	65	5.52	0.26	***0.031***	0.149	0.0141	2.03	***1.61***	0.074	0.006137	1.625	**1 5/8**
18	55	4.67	0.18	***0.022***	0.147	0.0142	2.04	***1.61***	0.072	0.0060273	1.625	**1 5/8**
19	45	3.82	0.12	***0.015***	0.146	0.0143	2.06	***1.62***	0.071	0.0059538	1.625	**1 5/8**
20	35	2.97	0.07	***0.009***	0.146	0.0143	2.06	***1.62***	0.071	0.0059093	1.625	**1 5/8**
21	25	2.12	0.04	***0.005***	0.146	0.0144	2.07	***1.62***	0.071	0.0058867	1.625	**1 5/8**
22	15	1.27	0.01	***0.002***	0.146	0.0144	2.07	***1.62***	0.071	0.0058785	1.625	**1 5/8**

APPENDIX J

Plants selection

Name	Type	Height	Spacing
***Dialium guineense*(Velvet Tamarind)**	Evergreen Fruiting Tree	66 ft	Unknow n
***Artocarpus altilis*(Breadfruit)**	Evergreen Fruiting Tree	66 ft	30 ft
***Phoenix reclinata*(Senegal Date Palm)**	Tropicals and Tender Perennials, Palms	Over 40 ft	15 ft
***Bambusa oldhamii*(Giant Timber Bamboo)**	Ornamental Grasses and Bamboo	Over 40 ft	6 ft
***Inga edulis*(Ice Cream Bean)**	Trees, Edible Fuits and Nuts	Over 40 ft	Unknow n
***Oxyanthus pyriformis*(Zulu Loquat)**	Evergreen, flowering tall shrub or small tree	33 ft	Unknow n
***Bunchosia argentea*(Peanut Butter Tree)**	Edible Fruits and Nuts	33 ft	20 ft
***Tabebuia impetiginose*(Pink Trumpet Tree)**	Trees	30 ft	30 ft
***Brahea armata*(Mexican Blue Palm)**	Tropicals and Tender Perennials	30 ft	12 ft
***Livistona chinensis*(Chinese Fan Palm)**	Small Tree	30 ft	10 ft
***Callistemon viminalis*(Weeping Bottlebrush)**	Evergreen, small flowering tree	26 ft	20 ft
***Chamaerops Humilis*'Variegated'(Mediterranean Fan Palm)**	Palms	15 ft	12 ft
***Tibouchina urvilleana*(Glory Flower)**	Tropicals and Tender Perennials	15 ft	10 ft
***Brugmansia* 'Charles Grimaldi'(Angel's Trumpet)**	Flowering Tree	10 ft	8 ft
***Hamelia patens*(Firecracker Shrub)**	Tropicals and Tender Perennials	10 ft	6 ft
***Convallaria fruticosa* 'Tricolor'(Hawaiian Ti)**	Tropicals and Tender Perennials	6 ft	2 ft
***Alyogyne huegelii*(Blue Hibiscus)**	Shrubs, Tropicals and Tender Perennials	6 ft	6 ft

***Sanchezia speciosa*(Sanchezia)**	Shrubs	6 ft	6 ft
***Ruscus aculeatus*(Butcher's Broom)**	Shrubs	4 ft	3 ft
***Dianella tasmanica*(Tasman Flax Lily)**	Shrubs	3 ft	Unknow n
***Hibiscus schizopetalus*(Chinese Lanterns)**	Tropicals and Tender Perennials	3 ft	2 ft
***Strobilanthes dyerianus*(Persian Shield)**	Tropicals and Tender Perennials	3 ft	4 ft
***Asparagus densiflorus* 'Meyersii'(Foxtail Fern)**	Annuals, Groundcovers, Perennials	2 ft	2 ft
***Caladium bicolor*(Fancy-leafed Caladium)**	Bulbs, Tropicals and Tender Perennials	2 ft	1 ft

Plants Characteristics

Genus species	5 Letter Notation	Height (ft)	Width (ft)	Comments
Dialium guineense	Diagu	66	125	
Artocarpus alitilis	Artal	66	100	water-retentive
Filicium Decipiens	Filde	66	75	
Oxyanthus pyriformis	Oxypy	53	50	
Bunchosia argentea	Bunar	53	25	
Phoenix reclinata	Phore	40	15	Drought-tolerant requires consistently moist soil?
Bambusa oldhamii	Bamol	40	6	Avg water needs, do not overwater
Inga edulis	Inged	40		
Tabebuia impetiginosa	Tabim	30	30	Avg water needs, do not overwater
Brahea armata	Braar	30	12	Drought tolerant
Livistona chinensis	Livch	30	10	Drought tolerantavg water needs, do not overwater, sharp spines
Calisternon viminalis	Calvi	20	50	water-retentive
Chamaerops humilis	Chahu	15	12	Drought tolerant, avg water needs, sharp spines
Tibouchina urvilleana	Tibur	15	10	Avg water needs do not overwater
Megaskepasma erythrochlamys	Meger	15	6	Requires moist soil, do not let dry out

Thevetia peruviana	Thepe	12	8	Average water needs, water regularly, do not overwater, this plant is attractive to bees, butterflies, and/or birds
Brugmansia	Bru	10	8	Bees,butterflies,bird attractant Avg water needs do not overwater
Acalypha hispida	Acahi	10	6	Attractive to bees,butterflies, and birds, avg water needs do not overwater
Hamelia patens	Hampa	10	6	Average Water needs, water regularly, do not overwater
Acalypha wilkesiana	Acawi	8	6	Avg water needs do not overwater
Alyogyne huegelii	Alyhu	6	6	Attractive to bees,butterflies, and birds, avg water needs do not overwater
Sanchezia speciosa	Sansp	6	6	Avg water needs do not overwater, req. consistently moist soil
Cordyline fruticosa	Confr	6	2	
Ruscus aculeatus	Rusac	4	3	High moisture needs, sutiable for water gardens
Crinum amabile	Criam	3	3	Req consistently moist soil, do not let dry out between waterings, parts of plant poisonous if ingested
Strobilanthes dyerianus	Strdy	3	4	Avg water needs do not overwater
Hibisucus schizopetalus	Hibsc	3	2	
Dianella tasmanica	Diatas	3		Avg water needs, do not overwater
Asparagus densiflorus	Aspde	2	2	Avg water needs do not overwater Parts of plant are poisonous if ingested, handling plant may cause skin irritation or allergic reaction
Caladium bicolor	Calbi	1.5	0.75	

Volatile Organic Compounds (VOC) Plants List

Description: It was mentioned during the plant-choosing phase that, according to the South Coast Air Quality Management District, some plants emit dangerous Volatile Organic Compounds, or VOCs. Plants that exhibit a high amount of VOC emission should be excluded from the list of plants were are planning to use for the Subtropical Rainforest.

Known: South Coast Air Quality Management District, Certain plants emit VOCs

Unknown: Which plants to exclude from proposed list due to high VOC emission rate

Assumptions: Using references from Davd J. Nowak, Project Leader of the USDA Forest Service, Northeastern Research Station in Syracuse, NY, as well as an email from the South Coast Air Quality, we compiled a list of plants that we should not use due to high VOC emission (11, 12, and 13).

Conclusions:

List of the plants not to consider for rainforest project

1. From USDA study

Botanical Name	Common Name
Eucalyptus	Eucalyptus
Liquidambar	Sweetgum
Nyssa	Blackgum
Quercus	Oak
Robinia	Black locust
Casuarina	Beefwood
Platanus	Sycamore
Populus	Poplar
Salix	Willow

2. From South Coast Air Quality Management District

Botanical Name	Common Name
Arbutus unedo	Strawberry Tree

Cercis canadensis	Eastern Redbud
Cinamomum camphora	Camphor Tree
Citrus limon	Meyer Lemon
Fraxinus velutina	Modesto Ash
Hymenosporum flavum	Sweetshade
Jacaranda mimosifolia	Jacaranda
Lagerstroemia	Crape Myrtle
Pittosporum rhombifolia	Queensland Pittosporum
Podocarpus gracilior	Fern Pine
Pyrus calleryana	Flowering Pear
Ulmus americana	American Elm
Ulmus parvifolia	Chinese Elm
Zelkova serrata	Zelkova
Eriobotrya deflexa	Bronze Loquat
Eriobotrya japonica	Loquat
Prunnus avium	Bing Cherry
Prunas densiflora	Red Pine
Pinus pinea	Italian Stone Pine
Laurus nobilis	Sweet Bay
Pinus radiata	Monterey
Cedrus atlantica	Atlas Cedar
Ginkgo biloba	Maidenhair Tree

APPENDIX K

Weight of Biochar Being 3% of Total Volume of the Subtropical Rainforest

Finding total volume of Subtropical Rainforest:

Total Subtropical Rainforest area = 13,000 ft^2

Depth of excavation = 9 inches

12 inches = 1 foot

9 inches x (1 foot / 12 inches) = .75 feet

Total Subtropical Rainforest Volume = 13,000 ft^2 x .75 feet

Total Subtropical Rainforest Volume = 9,750 ft^3

Finding 3% of the Subtropical Rainforest Volume:

3% of 9,750 ft^3 = 0.03 x 9,750 ft^3 = 292.5 ft^3

3% of Total Subtropical Rainforest Volume = 292.5 ft^3

Finding weight (in lbs) of Biochar equivalent of 5% of Total Subtropical Rainforest Volume:

Biochar Density is listed to be 250 – 350 kg/m^3 in MSDS sheet by DynaMotive Energy Systems Corporation (attached)

3% of Total Subtropical Rainforest Volume = 292.5 ft^3

Converting Density of Biochar from 250 kg/M^3 to lbs / ft^3 :

2.20462262 lbs = 1 kg

1 m^3 = 35.3146667 ft^3

250 kg/M^3 x (2.2046226 lbs / 1 kg) x (1 m^3 / 35.3146667 ft^3) = 15.6069901 lbs / ft^3

Biochar Density x 5% Volume of Total Volume = Mass (Weight) of Biochar

For 250 kg/ M^3 Density:

15.6069901 lbs / ft^3 x (292.5 ft^3) = 4,565.04460425 lbs

Conclusion:

Mr. Tom Bourchard quoted the biochar to have a density of 250 kg/M^3 while the MSDS sheet quotes the density to be 250-350 kg / M^3. Assuming that the density of the biochar is 250 kg/M^3 we calculated how many barrels this would take, if each barrel contains approximately 121 lbs:

4,565.04460425 lbs x (1 barrel / 121 lbs) = **38 barrels**

References:

1. Free Air CO2 Enrichment
http://cdiac.esd.ornl.gov/programs/FACE/face.html

2. Wind rose
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