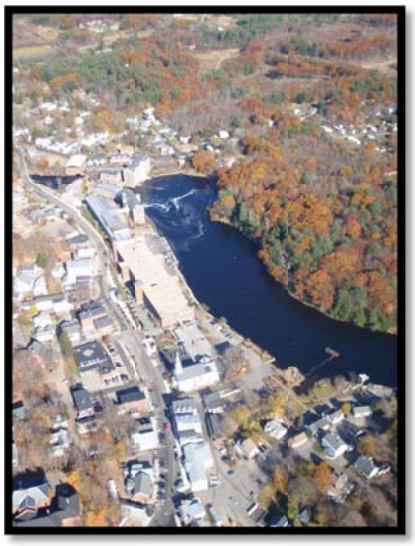
Examination of Thermal Impacts From Stormwater Best Management Practices



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Examination of Thermal Impacts from Stormwater Best Management Practices

Final Report by the University of New Hampshire Stormwater Center

TASK 1: MONITORING OF BMP SYSTEM PERFORMANCE

EXECUTIVE SUMMARY

This study examines 4 years of runoff temperature data for a range of stormwater best management practices (BMPs) in relation to established environmental indicators for a study in Durham, NH. Stormwater BMPs examined include conventional, Low Impact Development, and manufactured treatment designs. Systems examined included a Bioretention, a Gravel Wetland, a Storm Tech Isolator Row, an ADS Infiltration System, a Hydrodynamic Separator, a Vegetated Swale, a Detention Pond, and a Retention Pond. Surface systems that are exposed to direct sunlight have been shown to increase already elevated summer runoff temperatures, while other systems that provide treatment by infiltration and filtration can moderate runoff temperatures by thermal exchange with cool subsurface materials. The storm sewer system evaluated in this study as an influent control saw an annual average event mean temperature (EMT) greater than the mean groundwater temperature of 47°F that commonly feeds coldwater streams. The examination of BMPs indicates that outflow from the larger surface systems exhibits greater thermal variations than water typical of untreated runoff drained from parking lot areas, and larger subsurface systems exhibited greater thermal buffering, with outflows consistent with groundwater temperature.

Surface Systems - Thermal Extremes

The summer event mean temperatures (EMTs) of the two stormwater ponds, Vegetated Swale, and HDS systems, indicate that they provide little, to no reduction or buffering of high runoff temperatures. The Retention and Detention ponds have the largest variation in EMTs. The Retention Pond is the only system to exceed both the Upper Optimum Limit (UOL) and the Lethal Limit of 80°F, however, the Detention Pond with a maximum EMT of 79.4^{o}F comes very close. The permanent pool of water in the Retention Pond appears to act as a heat sink during periods of extreme heat.

The Vegetated Swale and the HDS also show variability in EMTs, but not as pronounced as the two ponds. The HDS system has a 35.0% chance of exceeding the UOL, which is the highest exceedance value for any of the systems. This high exceedance value indicates that the HDS is not buffering the thermal energy as well as some of the other systems. The maximum HDS EMT (75.0^{o}F) is still lower than that of the Runoff, Retention Pond, and Detention Pond. Unlike the ponds, the HDS systems do not appear to be increasing the temperature of the stormwater.

Filtration and Infiltration Systems - Thermal Buffers

Subsurface filtration and infiltration systems showed the strongest ability to buffer temperature variations. The Gravel Wetland, the ADS Infiltration System, and the StormTech Isolator Row (STIR), have a strong capacity to act as thermal buffers. The Bioretention system did not elevate runoff temperatures, showed minor buffering capacity, and was consistently cooler in the summer and warmer in the winter than the Runoff. The data suggests that these subsurface systems are, on average, reducing the summer temperatures and increasing the winter temperatures of the runoff to near the average groundwater temperature of 47°F. The two subsurface infiltration systems, ADS and STIR, are the only systems with mean July temperatures within the optimum zone of 45°F to 65°F for coldwater aquatic species. All other systems fall within the stress zone for aquatic species, between 65°F and 80°F.

Although the Gravel Wetland has a large surface area, the filtration practices incorporated into the system to treat the stormwater runoff gives the Gravel Wetland a "deeper" footprint than the large surface systems such as the ponds. The mean July temperature of the Gravel Wetland is just above the UOL at 66°F.

The Gravel Wetland, ADS and STIR systems have the lowest exceedance values of the UOL. At 13.0% for the Gravel Wetland, 5.0% for the ADS, and 1.5% for the STIR, these values indicate that these systems do an excellent job of buffering runoff temperature and could provide protection to coldwater streams from discharge of stormwater exceeding the upper optimum limit of 65°F. In addition, the data for these systems suggest that these subsurface systems, on average, reduce the summer temperatures and increase the winter temperatures of the runoff to near the average groundwater temperature of 47°F.

INTRODUCTION

This research project was designed to study the thermal characteristics of stormwater runoff in the northeast, and the thermal impacts from stormwater best management practices normally installed to address stormwater volume and pollutants other than temperature (e.g., sediments and nutrients). Results of this research are needed to inform the appropriate choice and design of stormwater BMPs in sensitive, threatened, or impaired watersheds or ecological areas.

As urbanization and build-out occurs the thermal regime of the surrounding environment is altered. Heated stormwater runoff flows into receiving waters where it mixes, and potentially increases the base temperature of the surface water in lakes, streams, and estuaries. The amount of heat transferred, and the degree of thermal pollution is of great importance for fisheries management and the ecological integrity of receiving waters. Coldwater fisheries in particular are sensitive to thermal pollution.

The increase in thermal energy in stormwater runoff is primarily a product of the increase in impervious cover of the surrounding area. Impervious surfaces can be generalized as any constructed surface that inhibits the infiltration of stormwater runoff (e.g. building rooftops, roads, parking lots, and sidewalks), (Kieser et al. 2003). Impervious cover (IC) absorbs and emits heat, creating air and surface temperatures that are significantly higher than those of rural

areas (Arya 2001). An increase in IC also results in additional surface runoff. The combination of these two phenomena creates a larger volume of runoff with increased temperatures.
The darker the impervious surface (e.g. asphalt, some roofing materials), when compared to a natural surface, the greater the heat absorption from solar radiation. The ratio of the amount of solar radiation reflected from a surface to the total solar radiation received by the surface is referred to as the albedo, or solar reflectance of the material. Darker surfaces tend to have low solar reflectance, as the material has absorbed most of the solar radiation. Fresh asphalt for example, has a solar reflectance value of 0.05. A lighter surface, such as white Portland cement concrete, has an average solar reflectance of 0.75 (PCA, 2010). The surface runoff absorbs the heat retained by the darker materials as it flows across.

BACKGROUND

Stormwater Best Management Practices (BMPs) have historically been used to reduce the peak flow rates of stormwater runoff through large volume storage and outlet controls that release detained volumes slowly over time. This approach effectively regulates peak flow but is not specifically designed for overall runoff reductions, water quality treatment, or temperature buffering. The Energy Independence and Security Act of 2007 (EISA) requires all federally funded building projects greater than 5,000 square feet to recreate predevelopment hydrologic conditions, including temperature.

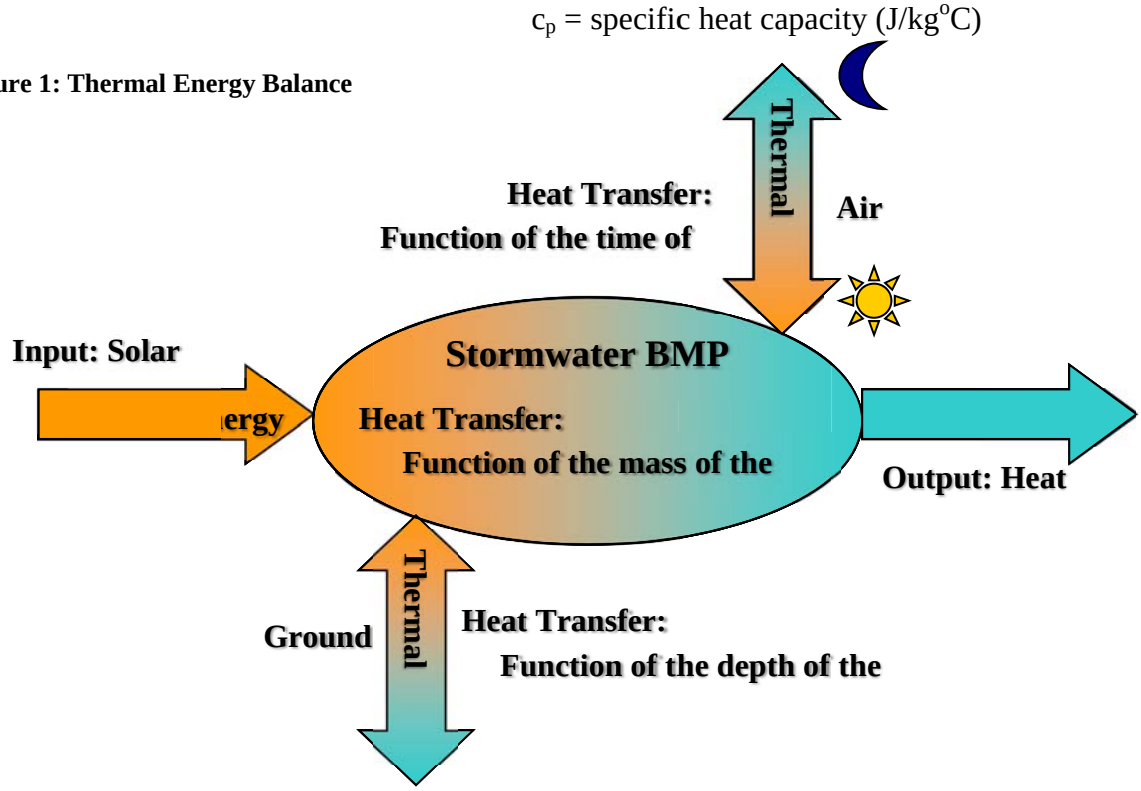
Heat is considered a pollutant under Section 502(6) of the Clean Water Act and temperature is a very important factor in the chemical and biological processes of organisms (Roa Espinosa et al. 2003). Certain biological activities, such as reproduction and spawning of organisms may be very sensitive to changes in temperature.

Equation 1: Heat Capacity

$$C_{th} = m * c_p$$

C_{th} = heat capacity (J/^{o}C)
m = mass of the system (kg)
c_p = specific heat capacity (J/kg^{o}C)

Figure 1: Thermal Energy Balance



LITERATURE REVIEW

Kieser et al. 2003 reported that summer stormwater runoff temperatures have increased because of the increase in urban impervious surfaces and in the unshaded ponds and channels that characterize conventional stormwater BMP systems. Water temperature dictates many aspects of the health and ecology of the stream corridor (Wehrly et al. 2003). In many cases, the temperature of the stormwater runoff is increased twice before it enters the receiving waters. The temperature of the stormwater is increased first by contact with impervious surfaces, and then again in the stormwater ponds that hold the stormwater being treated. Kieser, et al (2003) reported temperature equivalent values of 74°F in runoff from a 79-acre site in Portage Michigan. This was 40°F higher than the average air temperature recorded in the study.

Coldwater ecosystems are susceptible to impacts caused by the increase in stormwater runoff temperatures during the summer months. The narrow temperature margin at which the coldwater aquatic life can thrive limits the ability of the coldwater ecosystem to assimilate these increases of temperatures. Generally, three temperature indices are considered for coldwater ecosystems. The lower optimum level is around 45 degrees Fahrenheit, the upper optimum level is around 65 degrees Fahrenheit, and the lethal limit for most coldwater aquatic species hovers just below 80 degrees Fahrenheit (Dorava et al. 2003). The range between the upper optimum limit and the lower optimum limit is sometimes referred to as the 'optimum zone' where coldwater aquatic life tends to thrive. The next zone, commonly known as the 'stress zone', is between the upper optimum limit and the lethal limit. The longer the fish and other aquatic life remain in the stream water that has reached this temperature range, the more likely the fish will become stressed. The coldwater species inhabiting the stream will generally move away from areas in the stream that have reached the 'stress zone', if the lethal limit is reached, the fish will die, or they will simply not move into that area. However, the entire thermal regime should be considered when the health of the stream ecosystem is monitored. The natural differences play a vital role in the activity of coldwater species for migration and reproduction (Macri 2006). It may be less important to maintain a constant outflow temperature for a stormwater BMP, than to maintain the natural balance of temperature and flow that meets the natural thermal regime of the receiving waters. Another factor associated with temperature, and the health of the coldwater species, is the relationship between temperature and dissolved oxygen (DO). As the temperature of the water increases, the amount of DO decreases. DO is vital in the survival and continued growth of many coldwater species.

STUDY DESIGN

In order to design the treatment of stormwater runoff which will reduce or minimize the impact the runoff has on vulnerable waterbodies, it may be necessary to design the post-treatment discharge to mimic the natural thermal regime of the receiving water. For this reason, the study design includes three subprojects:

1. Use of existing data from the University of New Hampshire Stormwater Center (UNHSC) on the storm characteristics for 120 monitored storms;
2. Instream monitoring of three natural streams located in areas with different levels of urbanization;

3. Monitoring and analysis of temperature in actual stormwater runoff from a large parking lot, before and after distribution to and treatment by eight different stormwater BMP systems.

NATURAL THERMAL REGIME ASSESSMENT

A stream's thermal regime can be described by "its components of magnitude, frequency, duration, timing and rate of change." (Olden and Naiman, 2010) Temperature regimes play a vital role in the life cycles of the species living within this stream ecosystem; affecting such life processes as reproduction, feeding, and other basic survival needs in temperature sensitive species. Mean July temperatures are one commonly chosen metric to describe the health of the stream during a period of low streamflow and high water use. (Zorn et al., 2008) However, other elements of a stream's thermal regime such as frequency and duration are also key. A separate study in 2009 examined the temperature regime characteristics of high-quality coldwater streams in New England (Jacobs 2011). This project examined the temperature regime characteristics results from several years of hourly data from sites in New Hampshire and Massachusetts. Monthly data summaries conducted for approximately 100 sites that support coldwater species (present) and approximately 40 sites that do not support coldwater species are compared. One of the outcomes of this EPA-funded work is an analysis of the thermal regimes of streams in New Hampshire and Massachusetts that support coldwater biota. The following three natural streams are presented to illustrate what a natural thermal regime of a cold or cool water stream might look like:

1. College Brook (moderately impacted, both upstream and downstream of campus),
2. Oyster River (moderately impacted), and
3. Wednesday Hill Brook (minimally impacted).

College Brook is a first order stream, with a drainage area of about 740 acres located on the University of New Hampshire (UNH) campus. The brook is separated into two segments, an upstream section, and a downstream section. The monitoring station is located in a downstream section of College Brook, with an impervious cover of 23%, as well as nine upstream road crossings. The Oyster River is a first order stream segment monitored in the upper reach. These two streams are presented as examples of moderately impacted streams, while the Wednesday Hill Brook is presented as a less impacted stream.

Wednesday Hill Brook is also a first order stream with a drainage area of about 250 acres, of which, only 14% is impervious, and has no upstream road crossings. Wednesday Hill Brook is located a few miles west of the UNH campus, near James Farm.

SITE DESCRIPTION AND RUNOFF

The study site is located at the University of New Hampshire Stormwater Center (UNHSC) field facility. The data in this report reflect events monitored between 2004 and 2008. The UNHSC is located on the perimeter of a 9-acre (900 parking spaces) commuter parking lot at the University of New Hampshire (UNH) in Durham, NH. The parking lot, installed in 1996, is made of standard dense mix asphalt, is curbed, and is used to near capacity throughout the academic year. Activity is a combination of passenger vehicles, and routine bus traffic. The time of concentration is 22 minutes from the most hydrological distant point at approximately 1,200 feet from the outfall, with surface slopes varying between 1.5% and 2.5%. The stormwater

runoff is collected into 16 catch basins and then routed through a system of reinforced concrete pipes increasing in sizes as the flow moves downstream from 12" to 36". The 16 catch basins are placed approximately every 150 feet and are connected in-line with the downstream catch basins. At the head of the site, the flow is equally distributed to the eight BMPs connected in a parallel configuration to deliver "dirty stormwater" to each device. The site is designed to mitigate any significant transmission impacts such as sedimentation from the distribution system or routing of the hydrograph. The treated stormwater from each BMP is then fed by gravity to a sampling gallery where sampling and flow monitoring is performed (Roseen et al. 2006). For the purposes of this study, "runoff" refers to the storm flows as they are monitored at the inlet to each BMP. This is important to note, as the runoff temperature was not measured as it left the pavement surface, and is likely buffered by the 1200 feet of upstream piping.

SYSTEM DESCRIPTIONS

Each of the systems included in this study is discussed below. The full descriptions of each system can be found in the biannual reports of the UNHSC[1].

The design volumes used in sizing stormwater BMPs include the water quality volume (WQv) which is equivalent to the runoff volume of one inch of rainfall over the drainage area. The channel protection volume (CPv), is equivalent to the runoff volume generated by the 2-year, 24-hour rainfall event, also referred to as the Q2. The third design volume, the conveyance protection volume, (Qp) is equivalent to the runoff volume generated by the 10-year, 24-hour rainfall event, and is often referred to as the Q10.

Retention Pond

The retention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to hold a resident pool of water. The system was installed below the water table and maintains a permanent pool of water. The native clay soil effectively acts as a lining for the system. Side slopes were stabilized with grass, and the spillways with stone and geotextile. The system is designed to treat the water quality volume (WQv), and the channel protection volumes (CPv) are conveyed through the system within 24 to 48 hours. During conveyance protection volume (Qp) rain events, stormwater is conveyed through a bypass.

Detention Pond

The detention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to the hold the water quality volume (WQv). It was installed in native clay soil, which effectively acts as a lining for the system. Side slopes were stabilized with grass, and spillways with stone and geotextile. The system is designed to treat the water quality volume. Channel protection volumes (CPv) are conveyed through the system within 24 to 48 hours. During conveyance protection volume (Qp) rain events, stormwater is conveyed through the system, and bypasses the water quality treatment process.

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[1]UNHSC 2005 Biannual Report http://www.unh.edu/erg/cstev/pubs_specs_info/annual_data_report_06.pdf
UNHSC 2007 Biannual Report http://www.unh.edu/erg/cstev/2007_stormwater_annual_report.pdf
UNHSC 2009 Biannual Report http://www.unh.edu/erg/cstev/pubs_specs_info/2009_unhsc_report.pdf

Gravel Wetland

The UNHSC gravel wetland has a rectangular 5,450 ft^2 foot print and can accommodate runoff from up to one acre of impervious surface. It includes a pretreatment sedimentation forebay that preserves the filter media, followed by two flow-through treatment basins. (Other pretreatment approaches may be used.)

Each treatment basin is topped with eight inches of wetland soil. The native clay soil, in which the subsurface gravel wetland was constructed, acts as a liner. The sides of the system were lined with geotextile to prevent the clay soil from invading the subsurface gravel wetland. The subsurface gravel wetland is designed to retain and filter the water quality volume (WQv) retaining10 percent in the forebay and 45 percent in each treatment basin. It can detain a channel protection volume (CPv) of 4,600 cubic feet, and release it over 24 to 48 hours. The conveyance protection volume (Qp) is bypassed. For small, frequent storms, each treatment basin filters 100 percent of the influent it receives. For larger storms that do not exceed design volume, stormwater bypasses the first treatment basin and is processed by the second. When storms exceed the design volume, the first inch of rain (first flush) is treated, while the excess is routed to conveyance structures or receiving waters.

Bioretention

The bioretention system is comprised of a sedimentation forebay and a bioretention filtration basin. The basin is filled with a bioretention soil mix 30 inches in thickness, and consisting of 60 percent sand, 20 percent woodchips, ten percent compost, and 10 percent native soil. The filtration basin is well vegetated. Vegetation was selected for flood and drought tolerance, the capacity for maximum ground cover, and aesthetics.

Vegetated Swale

The vegetated swale evaluated at the UNHSC should not be confused with the more complex "water quality swales," or "bioswales," which are often designed with modified soils and sub drains. It is a trapezoidal channel designed for minimal slope and maximum permissible flow velocity. Its ability to remove pollutants is modest at best, and is vulnerable to large, high-velocity storm flows.

Typically, state design criteria for all swales, including those that are vegetated, specifies slopes of less than one percent, and flow velocities of less than one foot per second for Qp and lower flows. Other common sizing criteria, such as water quality volume (WQv), channel protection volume (CPv), and conveyance protection volume (Qp), were not used in the design of this system at the UNHSC.

Hydrodynamic Separators

Hydrodynamic separators (HDS) are small, flow-through devices that remove sediment, trap debris, and separate floating oils from runoff. UNHSC evaluated four HDS designs from 2004 through 2006: the VortSentry, the Continuous Deflection Separator (CDS), the V2B1, and the Aqua-Swirl.

The design and specification of HDS devices varies, and is developed by the manufacturer in accordance with local watershed conditions and target water quality treatment objectives. Often, these systems are designed to replace or retrofit existing catch basins.

ADS Infiltration System

The ADS Infiltration System is an infiltration unit (IU) that performs much like a leach field. The unit is made of high-density polyethylene (HDPE) pipe and is designed to bear loads consistent with those experienced by parking lots. The system manufacturer designs each unit in accordance with local watershed conditions and target treatment objectives.

The IU consists of three, 40-foot sections of 48-inch diameter, perforated HDPE pipe, laid over an infiltration base composed of two feet of medium to coarse sand. The top and sides of the excavation are wrapped in non-woven geotextile to protect the system from the lateral migration of fine particles from the surrounding soil. The bottom of the treatment unit is not lined, to prevent premature clogging of the system from fines caught in the liner, carried by runoff.

Stormwater flows of one cubic foot per second (cfs) enter the IU. Flows exceeding one cfs flow directly into the IU. During channel protection volume (Q2) events, stormwater fills the IU, which typically drains over a 24- to 48- hour period. During ten-a year (Q10) event, stormwater fills the IU, and then discharges directly to the surface, largely bypassing treatment.

StormTech Isolator Row

The StormTech Isolator Row is a manufactured system designed to provide subsurface water quality treatment and easy access for maintenance. The Isolator Row consists of a series of StormTech chambers installed over a layer of woven geotextile, which sits on a crushed stone infiltration bed surrounded with filter fabric. The bed is directly connected to an upstream manhole for maintenance access and large storm bypass.

Chamber units are made of high-density polyethylene (HDPE) pipe and are designed to bear loads consistent with those experienced by parking lots. The UNHSC chamber dimensions are 51 x 30 x 85.4 inches (width x height x length) and are laid over woven geotextile, which rests on an infiltration base composed of one foot of three quarter inch crushed stone. The entire excavation is then wrapped in nonwoven geotextile to protect the system from the migration of fine particles from the surrounding soil.

Stormwater flows of up to one cubic foot per second (cfs) enter the system through an upstream manhole or other flow diverter. A bypass is incorporated in the StormTech system where flows exceeding the design rate are bypassed around the device and flow directly into adjacent chambers that can be sized to treat the CPv and Qp.

MATERIALS AND METHODS

Site Data Collection

Data have been collected at the UNHSC field research facility since 2004. Because systems are periodically changed, the length of record for each system ranges from 2 years and up. Real-

time sample monitoring occurred at the entrance and exit of each BMP and was performed using a YSI Model 600XL multi-parameter sonde, recording pH, temperature, dissolved oxygen, and conductivity at 5 minute regular intervals. This study evaluated data from a retention pond, detention pond, gravel wetland, bioretention, vegetated swale, hydrodynamic separators, and two subsurface infiltration units. All data were collected in accordance with the site QAPP (UNHSC Roseen et al 2008).

Data Analysis

A compilation of the data for this study was selected over 4 years (2005-2008), and has resulted in a database with over 40 million data points. For this research, data selection was based upon the examination of the storm hydrograph; specifically hydrographs that were bounded by baseline flows. On average, four base line flow data points were selected before and after each storm to avoid cutting the storm short. Base line flow was defined as the base flow of the system, or zero prior to the start of the storm. The start of the storm began at the first increase in flow and ended when the flow receded to the base line flow criteria. The storms selected were the storms that the UNHSC sampled for other water quality concerns, and the storm occurring at least 1.5 days after the site-sampled storm. For example, a storm was selected by the UNHSC for sampling, and further analysis, and this storm would be called "Storm 1," the next UNHSC sampled storm would be called "Storm 2", but if a storm occurred at least 1.5 days after Storm 1, but ended 1.5 days before Storm 2, it would be called "Storm 1a". Therefore, in a perfect year, each Storm #, would be followed be a Storm #a. These storms were selected to describe the storms of any given year. The storms sampled by the UNHSC were chosen to further explain the water quality concerns of those storms, and the second set of storms, the storms following the site-sampled storms, were chosen to strengthen the data set. This method was chosen to make sure variability and randomness remained intact so as not to be biased towards large or small storms and was verified by performing statistical tests described in the following section. On average, the site-sampled storms and the storms immediately after had one and a half antecedent dry days (Table 13). Storm data were gathered by analysis of both hydrograph and tabular data sets. Additional data were selected if another storm occurred less than 1.5 days after the end of the previous storm. Nonzero data, which appear as gaps in the data, resulting from instrument malfunction, loss of power to the equipment, or other issues, were identified and eliminated before analyzing the datasets.

The flow-weighted temperature for each storm was calculated as the event mean temperature (EMT) (Deletic 1998, Kieser et al 2003). The event mean temperature is congruous to the event mean concentrations (EMCs) calculated for other stormwater pollutants, which are widely used in the performance monitoring of stormwater BMPs. EMTs were determined for approximately 24 storms for eight systems.

Equation 2: Event Mean Temperature

$$EMT = \frac{\int_{O}^{T} t(t)q(t)dt}{\int_{O}^{T} q(t)dt}$$

EMT = event mean temperature (^{o}F)
T = Flow Duration (min)
t(t) = Flow Temperature (^{o}F)
q(t) = Flow (gpm)

This research employed statistical methods consistent with data analysis by the International Stormwater BMP Database. Each BMP study in the Database contains a Detailed Statistical Analysis Report for each monitored parameter to provide guidance about the efficiency of the practice. The descriptive statistics used to represent these data include 1) cumulative distribution functions, 2) time series analysis, 3) quartile assessments of the EMTs, and 4) the frequency distributions of the real-time temperatures of the storms for each system. The cumulative distribution functions, time series analyses, and quartile assessments were used to describe the EMTs of each system, and to compare them to that of the runoff. The frequency distribution describes the real-time storm data, focusing on the temperatures recorded during each selected storm event. The cumulative distribution function describes the non-exceedance probability that a certain value will occur. For example, the runoff has a 69% probability of not exceeding an EMT of 60°F. A time series analysis of the data can show trends and seasonality of the data. Quartile assessment illustrates the population differences by use of spread, skewness, and potential outliers without performing an analysis of the normalcy of distribution. The frequency distribution is used to show the range and frequency of the real-time temperatures (non-flow weighted), and illustrates the seasonality of the temperatures. Other, non-statistical methods were also employed to analyze the thermal impacts of the stormwater BMPs. As discussed above, the mean July temperature of coldwater streams is often used by regulatory agencies to determine the health of the stream. The mean July temperatures of each system analyzed were calculated using the real-time temperature data. The second non-statistical method used was the calculation of a thermal load from each stormwater BMP, for each storm. The calculation of the thermal loading for each system is described further on in this report. This metric is intended to be used as a design tool to determine the effluent requirements of the chosen stormwater BMP.

RESULTS AND DISCUSSION

Effluent event mean temperatures for eight stormwater best management practices were compared to the event mean temperatures for untreated stormwater distribution over a 4 year period (2004 through 2008). The influent flow and temperature data were measured at a central distribution point. Effluent from three distinctly different types of stormwater treatment systems were analyzed: conventional systems (a detention pond, retention pond, and a vegetated swale); low impact development systems (gravel wetland, and a bioretention); and manufactured devices (hydrodynamic separators (3), the ADS infiltration unit, and the StormTech Isolator Row).

The data are presented as an annual summary and as seasonal data. The annual summary illustrates the average annual effect the system has on the thermal energy of the stormwater. However, this analysis is not able to demonstrate the effectiveness of the stormwater BMPs during the seasons. For example, the median and mean of the average annual EMT will be muted when compared to that of the summer months, and the opposite could be true during the winter months. The seasons were chosen by dividing the year into two equal sections. The summer months are considered to be April through September, and the winter months are October through March.

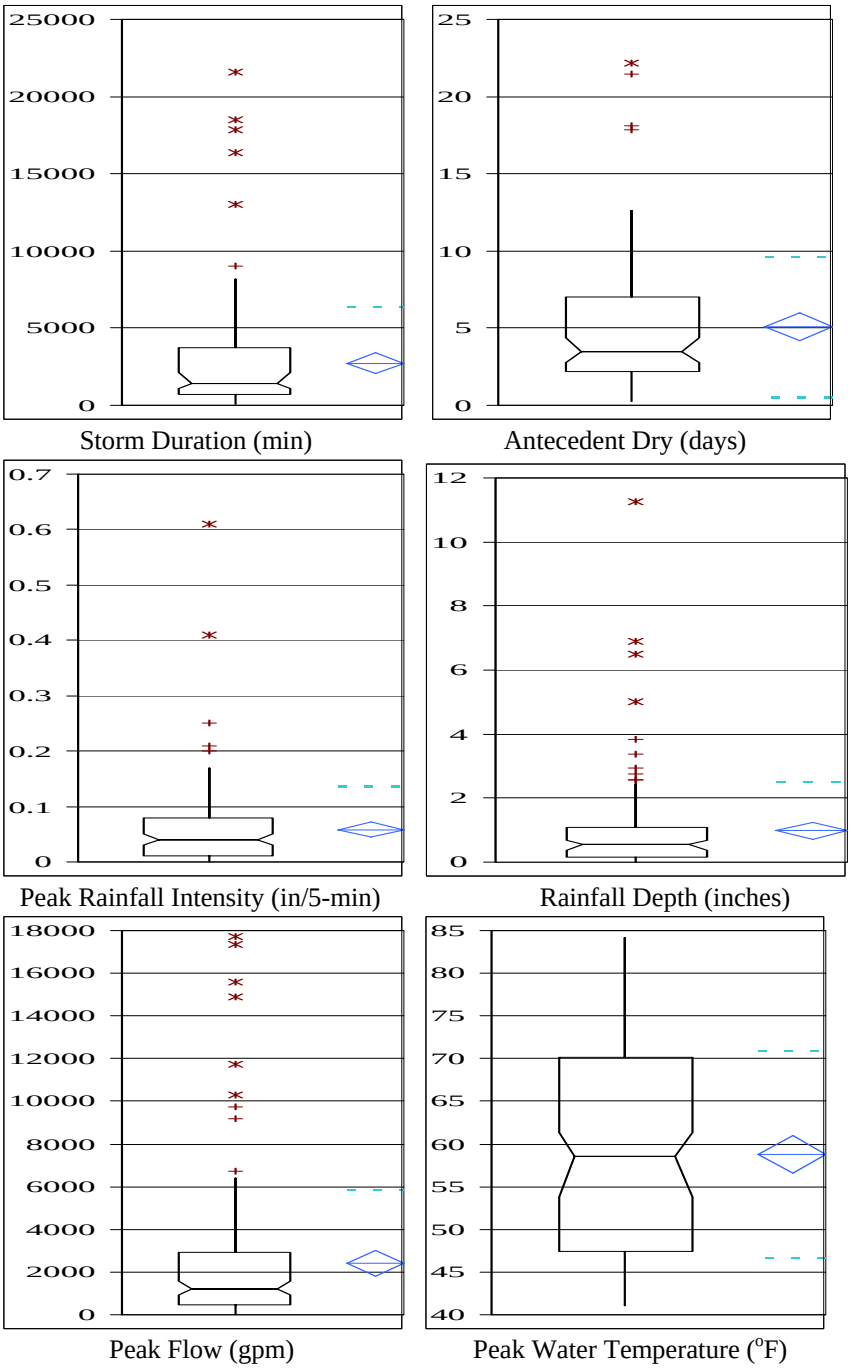
In addition to comparing the EMTs of each system to that of the inlet runoff control, the EMTs of the systems are compared to temperature data collected at several streams in the southeast

region of New Hampshire. These streams include College Brook, Wednesday Hill Brook, and an upstream section of the Oyster River. The temperature data collected from each stream range from December 2007 through January 2010. Comparison of regional stream temperatures to influent and effluent temperatures from stormwater BMPs is not a direct relationship, because 1) it is a comparison of EMTs to real-time stream temperatures, and 2) the time of record may differ for the streams and the stormwater BMPs. However, this comparison can be used as an indication of how the stormwater BMPs are performing in relation to these natural streams.

Figure 2 shows a quartile assessment of six storm characteristics: storm duration, antecedent dry days, peak rainfall intensity, rainfall depth, peak flow, and peak water temperature of the runoff. A more detailed table of the storm characteristics can be found in Appendix A. A regression analysis was performed with an analysis of variance (ANOVA) for four of the storm characteristics, storm duration, peak intensity, rainfall depth, and peak temperature. The analysis was done for both summer and winter months. The analysis of the summer months, shown in Figure 3, identifies the storm duration, rainfall depth, and peak temperature, as significant factors, individually, during the summer months. During the winter months, only the rainfall depth and the peak temperatures are significant factors. The storm duration is no longer a significant factor affecting the EMTs during the winter months.

Individually during the summer months, storm duration, rainfall depth, and peak temperatures are the most significant factors affecting the EMT of the runoff. However, when analyzed collectively, only the storm duration, and the peak temperature significantly affect the EMT of the runoff. During the winter months however, the same factors that are individually significant (rainfall depth and peak temperature), are also collectively significant.

Figure 2: Distribution of Storm Characteristics for 120 Monitored Storms[2]



[2] Storm Characteristic Key: the mean and 95% C.I. are shown as the diamond on the right hand side of each figure; the standard deviation about the mean is shown as the dashed lines above and below the mean diamond; outliers are shown as * or + above the quartile plot; maximum and minimum values are represented by the top and bottom of the vertical line centered on the quartile plot; the 25th and 75th percentiles are represented as the top and bottom of the quartile "box"; the upper and lower bounds of the 95% C.I. about the median is shown as the points of indentation in the quartile "box"; and the median is the horizontal line within the quartile "box" where the upper and lower bounds of the 95% C.I. about the mean intersect.

Figure 3: Summer Storm Characteristic Correlations

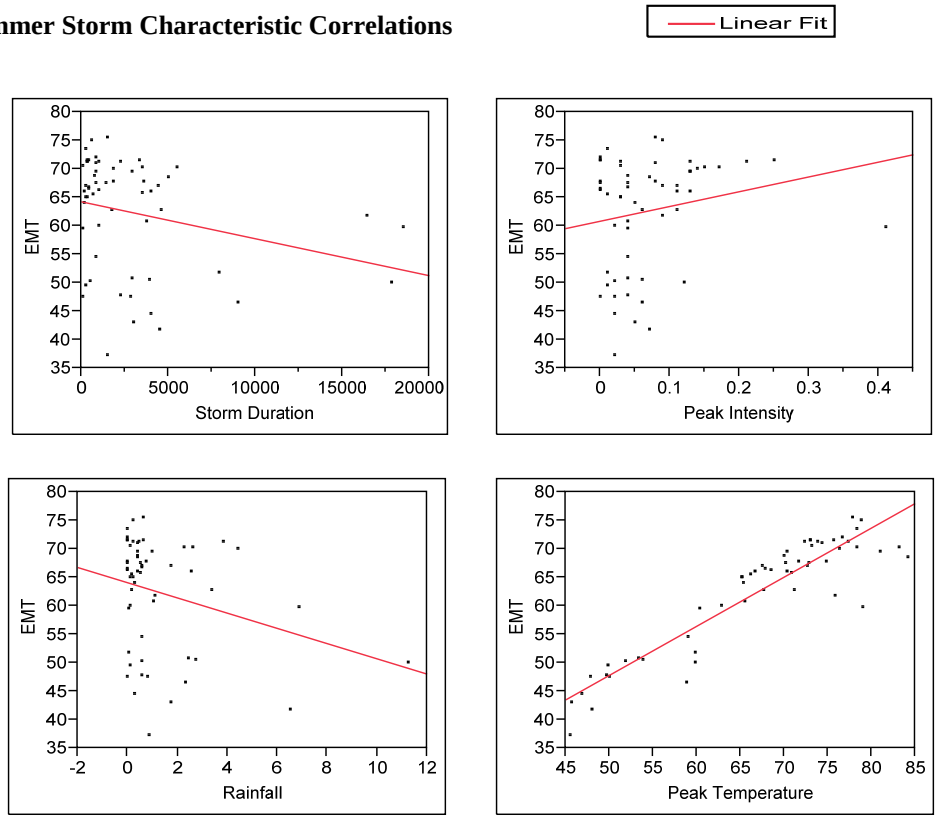


Table 1: Summer Storm Characteristic Correlations

Storm Duration

Parameter Estimates:		Y = 64.4 - 0.0007X		R^2 = 0.072
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	64.366951	1.534517	41.95	<.0001*
Slope	-0.00066	0.000316	-2.09	0.0410*

Peak Intensity

Parameter Estimates:		Y = 60.7 + 26.1X		R^2 = 0.037
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	60.741892	1.749546	34.72	<.0001*
Slope	26.114865	17.74189	1.47	0.1466

Rainfall Depth

Parameter Estimates:		Y = 64.1 - 1.3X		R^2 = 0.076
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	64.110373	1.455453	44.05	<.0001*
Slope	-1.340661	0.625787	-2.14	0.0365*

Peak Temperature

Parameter Estimates:		Y = 4.8 + 0.86X		R^2 = 0.838
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.807992	3.431693	1.40	0.1667
Slope	0.8613772	0.050633	17.01	<.0001*

Figure 4: Winter Storm Characteristic Correlations

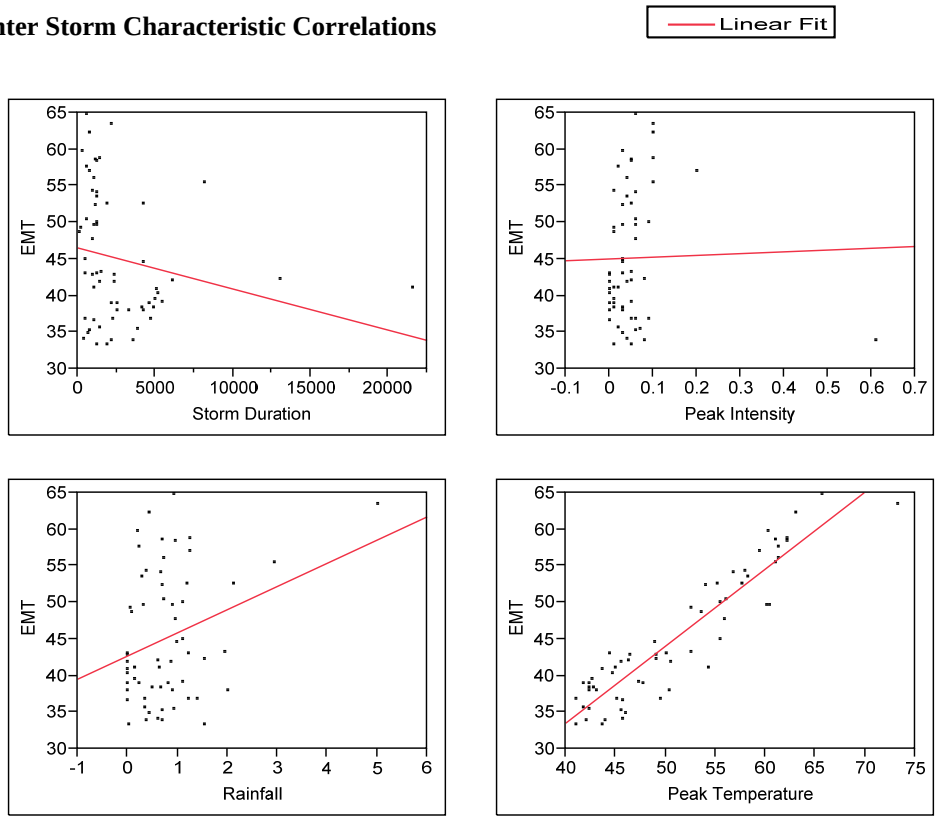


Table 2: Winter Storm Characteristic Correlations

Storm Duration

Parameter Estimates:	Y = 46.6 - 0.0006X			R^2 = 0.045
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	46.589619	1.411759	33.00	<.0001*
Slope	-0.00056	0.000334	-1.68	0.0990

Peak Intensity

Parameter Estimates:	Y = 45.0 + 2.5X			R^2 = 0.0001
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	44.979622	1.326939	33.90	<.0001*
Slope	2.5365977	14.07318	0.18	0.8576

Rainfall Depth

Parameter Estimates:	Y = 42.7 + 3.2X			R^2 = 0.087
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	42.656314	1.484241	28.74	<.0001*
Slope	3.1753451	1.326157	2.39	0.0198*

Peak Temperature

Parameter Estimates:	Y = -8.7 + 1.1X			R^2 = 0.860
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-8.72192	2.832738	-3.08	0.0031*
Slope	1.0541914	0.054862	19.22	<.0001*

Figure 5: Annual Quartile Distributions for Event Mean Temperatures[3]

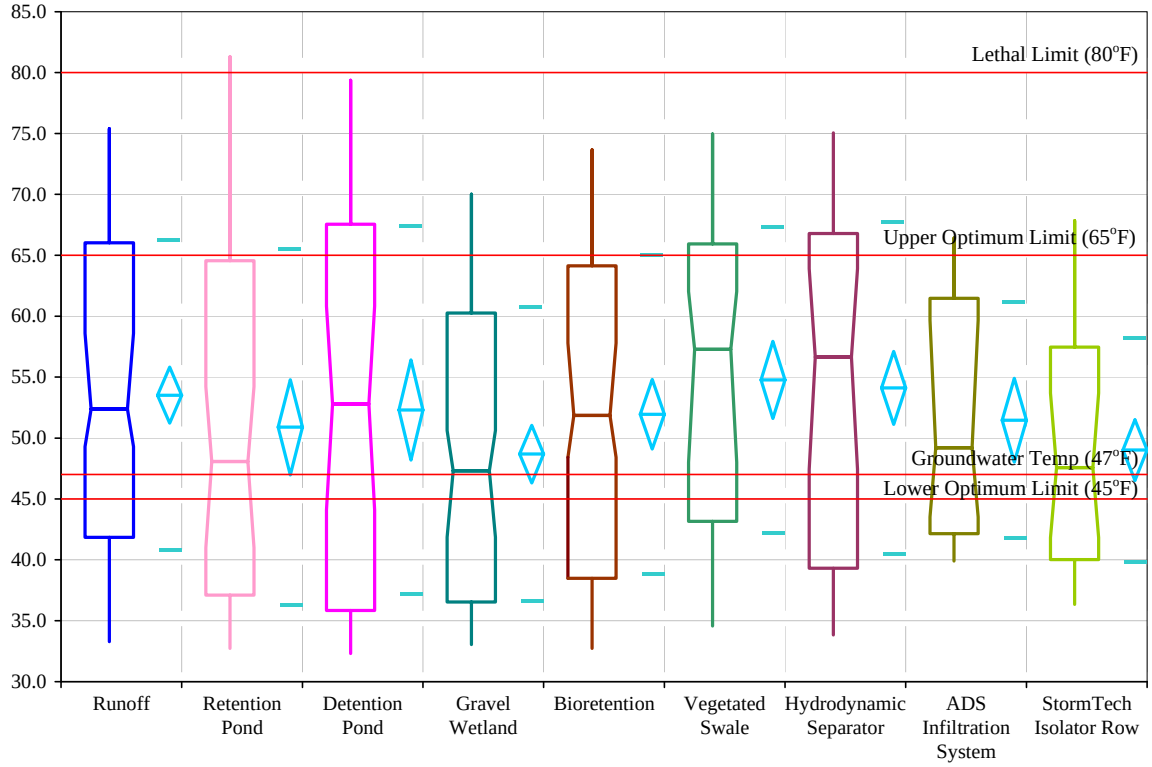


Table 3: Annual Quartile Assessment Summary

ANNUAL DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	120	56	54	102	83	63	82	33	55
	Minimum	33.3	32.7	32.3	33.0	32.7	34.6	33.8	39.9	36.3
	25th Percentile	41.8	37.1	35.8	36.5	38.5	43.2	39.3	42.2	40.0
	Median	52.4	48.1	52.8	47.3	51.8	57.3	56.6	49.2	47.6
	75th Percentile	66.0	64.6	67.6	60.3	64.1	65.9	66.8	61.5	57.5
	Maximum	75.4	81.3	79.4	70.0	73.7	75.0	75.0	66.4	67.8
	Standard Deviation	12.7	14.6	15.1	12.0	13.1	12.6	13.6	9.7	9.2
	Mean	53.5	50.9	52.3	48.7	51.9	54.8	54.1	51.5	49.0

Annual Quartile Assessment

Examination of the EMTs of Runoff values and eight different stormwater BMP systems by annual quartiles (Figure 5, Table 3) shows that the median runoff value of 52.4°F, (41.8°F_{q1}, 66.0°F_{q3})[4] is highly variable. The maximum and minimum values of 75.4°F and 33.3°F respectively, emphasize this point. It is important to remember that the Runoff values reported

[3] The y-axis shows Event Mean Temperatures (°F). Interpretation of Figures 9, 10, and 11 is the same as described earlier for Figure 2.

[4] EMT values reported within parentheses are, q1 = the first quartile or the 25th percentile, q3 = the third quartile or the 75th percentile. This reporting style follows throughout the annual and seasonal quartile assessments.

are based on monitoring runoff that has been conveyed by a large subsurface piping network to the monitoring location.

The annual median Detention Pond EMT is 52.8^{o}F (35.8^{o}F$_{q1}$, 67.6^{o}F$_{q3}$), which is similar to the untreated runoff EMT of 52.4^{o}F . The Retention Pond has an annual median EMT of 48.1^{o}F (37.1^{o}F$_{q1}$, 64.6^{o}F$_{q3}$). The Retention Pond also has both the lowest and highest individual storm EMT. These data indicate that the practice of maintaining a permanent pool of water to mitigate stormwater runoff effects has a counterproductive impact on the EMT of the stormwater in the basin. The median Vegetated Swale EMT was 57.3^{o}F (43.2^{o}F$_{q1}$, 65.9^{o}F$_{q3}$). While the maximum value is slightly lower than the two ponds, the median value of the Vegetated Swale is the highest median system value.

The median Gravel Wetland EMT was 47.3^{o}F (36.5^{o}F$_{q1}$, 60.3^{o}F$_{q3}$) which is lower than either the untreated runoff or the pond. The Gravel Wetland has a smaller spread of EMTs falling into the interquartile range than the data from the Runoff, indicating the buffering of runoff temperatures. The median EMT of the bioretention system is 51.8^{o}F (38.5^{o}F$_{q1}$, 64.1^{o}F$_{q3}$) and shows less variability, as well as lower maximum EMTs than the Runoff.

The Hydrodynamic Separator EMTs were similar to the Vegetated Swale and did not appear to provide much buffering of the stormwater runoff temperatures. With a median EMT of 56.6^{o}F (39.3^{o}F$_{q1}$, 66.8^{o}F$_{q3}$), the HDS systems had higher EMTs and large variations similar to the Runoff. The two manufactured subsurface infiltration units, the ADS Infiltration System (ADS), and the StormTech Isolator Row (STIR), showed less variability than the Runoff EMTs.

Seasonal Quartile Assessment

The data were also analyzed as seasonal data sets to examine trends in summer and winter. The Runoff during the summer months (Figure 6, Table 4) shows a median EMT of 66.2^{o}F (54.2^{o}F$_{q1}$, 70.2^{o}F$_{q3}$). During the winter months, (Table 5, Figure 7) the Runoff shows a median EMT of 42.5^{o}F, (38.0^{o}F$_{q1}$, 52.5^{o}F$_{q3}$). Comparing these values to the annual values described earlier, it is apparent that the annual statistics do not have the ability to illustrate seasonal trends.

During the summer months, the Detention Pond has a smaller variation in EMT than the Retention Pond, which implies that storage of water in the Retention Pond is increasing temperatures of the stormwater while it passes through the system. The thermal energy balance of a system (
Figure 1) can explain this effect, where the variables that allow for heat transfer, such as surface exposure, the system mass, and the system depth are no longer adequate to mitigate the runoff temperatures. The Vegetated Swale, as stated previously, acts much like the Detention Pond, showing little to no buffering of the stormwater temperature from the Runoff.

The summer data for the Gravel Wetland have a median EMT of 60.9^{o}F (48.8^{o}F$_{q1}$, 66.0^{o}F$_{q3}$). The lower first quartile implies that the Gravel Wetland is buffering the temperature from the Runoff during the summer months. The Bioretention system has a summer median EMT of 63.9^{o}F (56.3^{o}F$_{q1}$, 67.1^{o}F$_{q3}$) and demonstrates a similar, but reduced buffering trend.

Figure 6: Summer Quartile Distributions for Event Mean Temperatures3

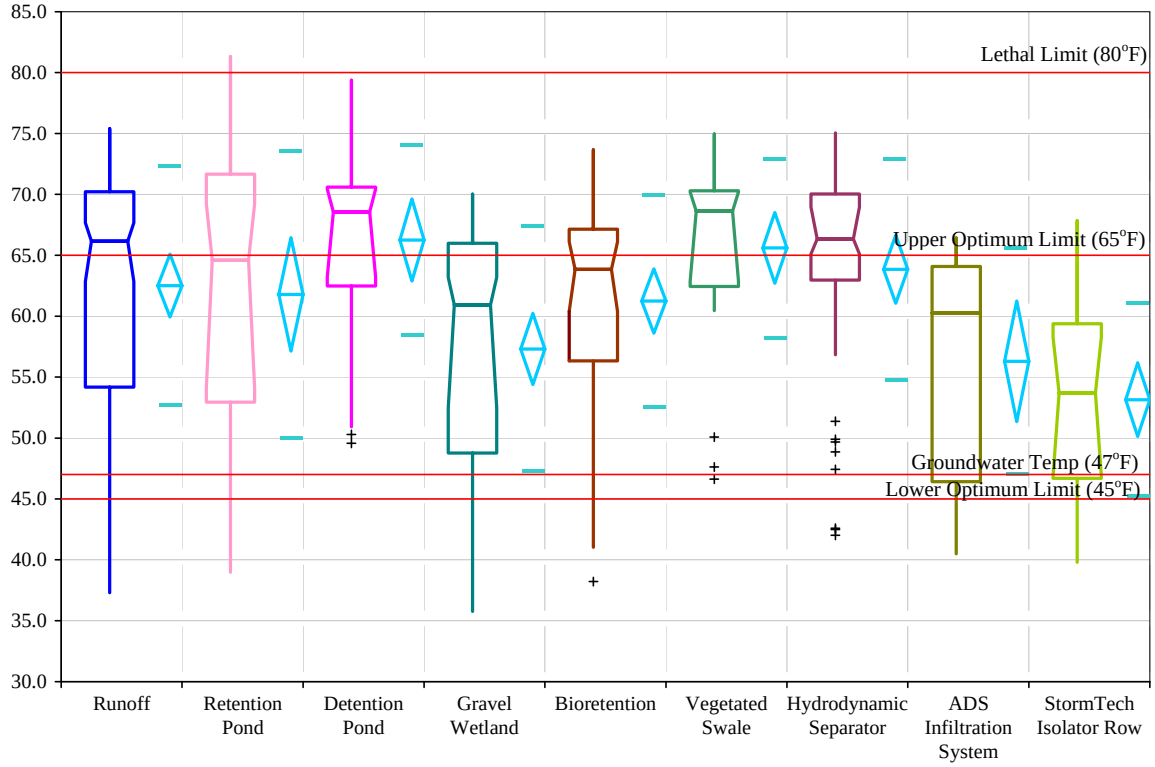


Table 4: Summer Quartile Assessment Summary

SUMMER DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	58	27	23	48	44	27	43	16	29
	Minimum	37.3	32.7	32.3	33.0	32.7	34.6	42.0	40.5	39.8
	25th Percentile	54.2	52.9	62.5	48.8	56.3	62.4	63.0	46.4	46.7
	Median	66.2	64.6	68.6	60.9	63.9	68.6	66.3	60.3	53.7
	75th Percentile	70.2	71.7	70.6	66.0	67.1	70.3	70.0	64.1	59.4
	Maximum	75.4	81.3	79.4	70.0	73.7	75.0	75.0	66.4	67.8
	Standard Deviation	9.8	11.8	7.8	10.1	8.7	7.3	9.1	9.3	7.9
	Mean	62.5	61.8	66.3	57.3	61.2	65.6	63.8	56.3	53.2
Mean July Temperatures (°F)		67.1	77.9	72.2	66.0	67.7	70.3	69.8	63.4	58.5

The HDS systems follow a similar trend as the Runoff data, with the exception of the first quartile, which is higher than the Runoff and approaching the UOL for coldwater streams. Both subsurface infiltration systems show a strong ability to buffer and mitigate the thermal energy of the influent stormwater runoff before it discharges to the receiving waters. The STIR had a median summer EMT lower than either the Gravel Wetland or the ADS system; the STIR also has a slightly smaller interquartile range 53.7°F (46.7°F_{q1}, 59.4°F_{q3}). All of these EMTs fall within the optimal zone for coldwater streams.

The winter data for the Retention Pond have a median EMT of 39.0°F (33.9°F_{q1}, 47.2°F_{q3}), while the Detention Pond shows a median EMT of 38.7°F (33.3°F_{q1}, 50.4°F_{q3}). Contrasting the

Figure 7: Winter Quartile Distributions of Event Mean Temperatures3

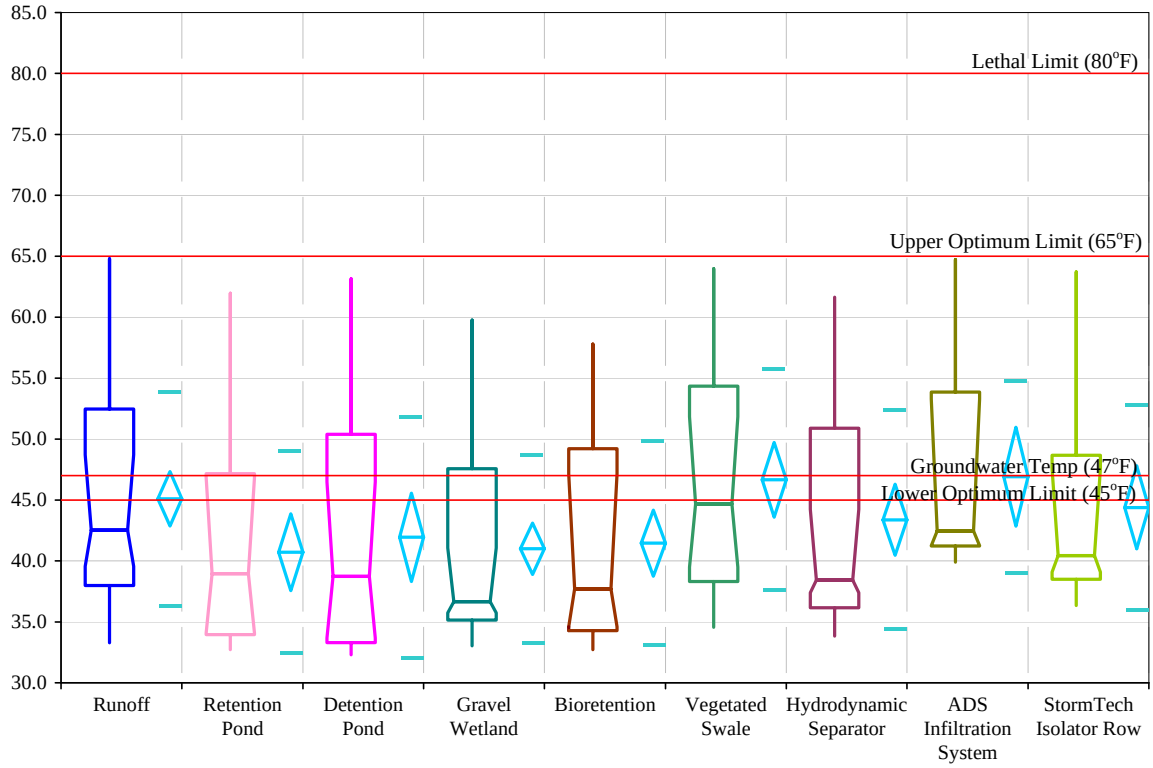


Table 5: Winter Quartile Assessment Summary

WINTER DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	62	29	31	54	39	36	39	17	26
	Minimum	33.3	32.7	32.3	33.0	32.7	34.6	33.8	39.9	36.3
	25th Percentile	38.0	33.9	33.3	35.1	34.3	38.3	36.2	41.2	38.5
	Median	42.5	39.0	38.7	36.7	37.7	44.7	38.4	42.5	40.4
	75th Percentile	52.5	47.2	50.4	47.6	49.2	54.3	50.9	53.9	48.7
	Maximum	64.8	62.0	63.1	59.8	57.8	64.0	61.6	64.7	63.7
	Standard Deviation	8.8	8.3	9.9	7.7	8.4	9.1	9.0	7.9	8.4
	Mean	45.1	40.7	41.9	41.0	41.5	46.7	43.4	46.9	44.4

conclusions made from the summer data, the Detention Pond has a larger variation in stormwater temperatures than the Retention Pond, which implies that the permanent pool of water in the Retention Pond is cooler than the influent stormwater. The data for the Gravel Wetland and the Bioretention show similar trends during the winter months, both systems having medians and first quartile values well below the lower optimum limit.

The winter data for the ADS system have a median EMT of 42.5°F (47.2°F_{q1}, 53.9°F_{q3}) showing that the ADS system is better than the Gravel Wetland buffering and mitigating the colder influent stormwater runoff during the winter months. The STIR system has a median winter EMT lower than either the Gravel Wetland or the ADS system. At 40.4°F (38.5°F_{q1}, 48.7°F_{q3})

these cooler numbers appear similar to the HDS systems, and show that the STIR is doing less to buffer the temperature of the stormwater runoff during the winter months.

Time Series Analysis

The data presented in the time series plots, (Figure 19, Figure 20, Figure 21) show the yearly and seasonal trends in the EMTs for the Runoff data and eight stormwater BMP systems. The yearly trends appear to be consistent over the course of the four years of record. The EMTs never exceed the 76°F mark, the threshold for the 'stress zone' for coldwater aquatic life. The data from the Retention Pond also show the same trends, but in the summer months, EMTs exceed 80°F in at least one storm showing an additional increase in the temperature of the stormwater runoff while it is within the Retention Pond. During the summer months, April to September, the EMT of the Retention Pond is greater than that of the Runoff. This observation coincides with Galli (1990) who suggested that the runoff from urbanized areas during the summer months provided large temperature variations to ponds and subsequently to the receiving waters. The Detention Pond and the Vegetated Swale follow a similar pattern as the Runoff EMTs, with occasional differences, suggesting that these two systems neither buffer nor increase the temperatures of the stormwater. The Gravel Wetland data show a smoother curve, indicating buffering of the temperature. While the Bioretention closely follows the pattern of the Gravel Wetland there is greater variance in the EMTs over the 4 years of record, indicating that the system is not buffering the temperature of the stormwater as efficiently as the Gravel Wetland. The HDS systems show the same pattern as the Runoff, with large spikes in EMTs, and are warmer than the Runoff during most of the summer months. The HDS systems appear to be just as susceptible to air temperature variations as the Runoff or stormwater ponds. The two subsurface systems, the ADS, and the STIR, while generally cooler than the Runoff throughout the year, still show some substantial spikes in the EMTs during the summer months.

Annual Cumulative Distribution Functions

Temperature indices may be used to evaluate the likely survival of temperature sensitive organisms. Figure 8, Figure 9, and Figure 10 show the annual cumulative distribution functions (CDFs) for the EMTs of the Runoff and the eight systems. The exceedance values of the Upper Optimum Level (UOL) of 65°F for the annual assessment are shown in Table 6. The only system that exceeds the Lethal Limit of 80°F is the Retention Pond, ($p = 0.5\%$). The data from

Figure 8 interestingly show that the Retention Pond has a tendency towards lower EMT values than the Runoff until about 70°F. The Detention Pond shows a similar tendency until 65°F. The points where the pond moves away from the CDF of the runoff potentially indicates the limit of the ponds ability to buffer any additional increase in stormwater runoff temperatures. Both the subsurface infiltration systems are cooler roughly 75% of the time. The subsurface infiltration systems are warmer than the Runoff, up until about 40°F, and then are cooler, implying that these systems mitigate both hot and cold runoff with a tendency towards the average annual groundwater temperature of 47°F (Heath 1983).

Figure 8: Annual Cumulative Distribution Function for Event Mean Temperatures

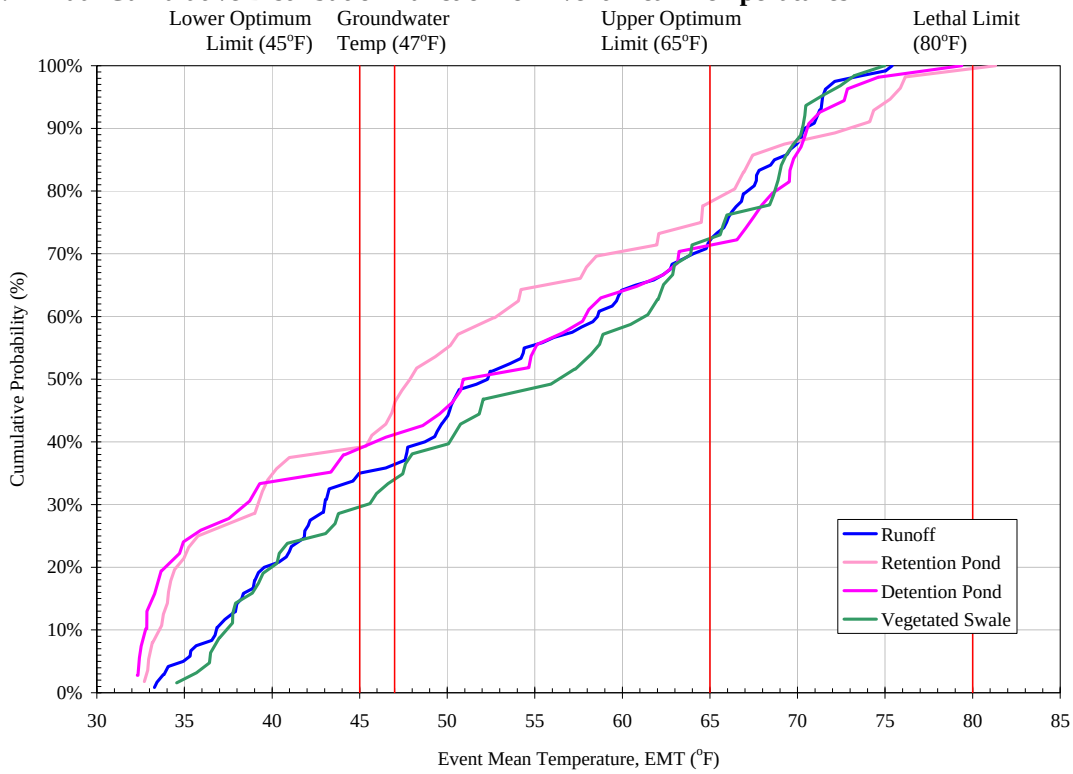


Figure 9: Annual Cumulative Distribution Function for Event Mean Temperatures

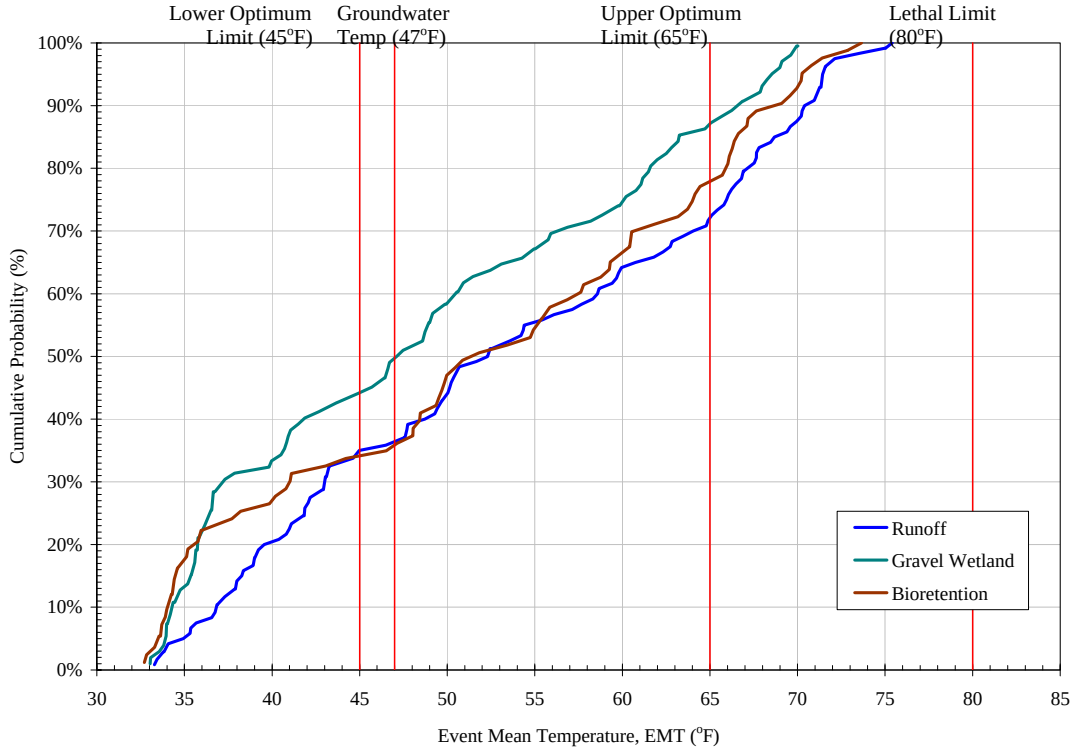


Figure 10: Annual Cumulative Distribution Function for Event Mean Temperatures

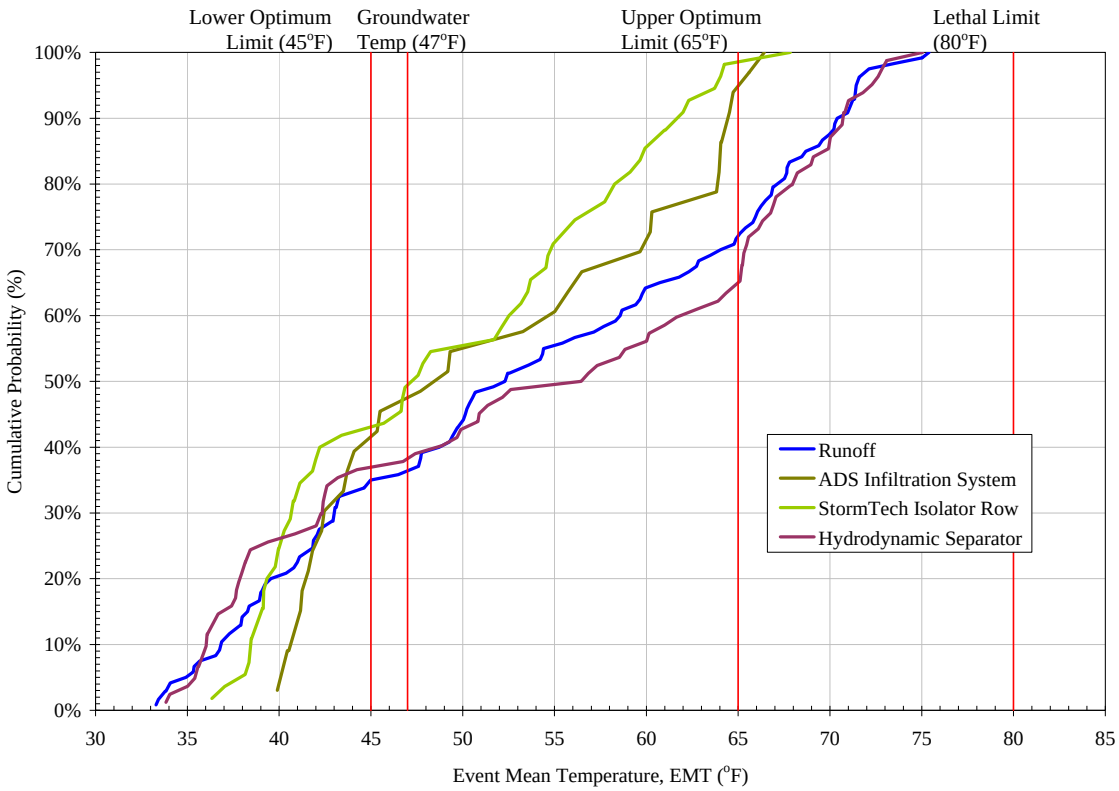


Table 6: Summary Observations for Annual Event Mean Temperature

FULL DATA SET	% Exceedance		Maximum EMT	Mean July Temperature
System	Upper Optimum Limit (65°F)	Lethality Limit (80°F)		
Runoff	27.5%		75.4°F	67.1°F
Retention Pond	21.0%	0.5%	81.3°F	77.9°F
Detention Pond	28.5%		79.4°F	72.2°F
Gravel Wetland	13.0%		70.0°F	66.0°F
Bioretention	22.0%		73.7°F	67.7°F
Vegetated Swale	27.5%		75.0°F	70.3°F
Hydrodynamic Separator	35.0%		75.0°F	69.0°F
ADS Infiltration System	5.0%		66.4 F	63.4°F
StormTech Isolator Row	1.5%		67.8 F	58.5°F

Seasonal Cumulative Distributions Functions

The data are broken into the two six month seasons to examine the effects the systems have on the temperature of the stormwater during the warm and cold months of the year. Figure 11, Figure 12, and Figure 13 show the summer CDFs for the EMTs, and Table 7 shows the exceedance values of the systems for the UOL at 65°F for the summer months. The CDFs for the winter months below in Figure 14Figure 15Figure 16 illustrate the probability of an EMT not to be exceeded. The CFDs show, that during the winter months the EMTs of all the systems never exceed the UOL. Table 8 shows the maximum EMTs for each system during the winter months.

In the summer months of April to September, the mean EMT of effluent from the Detention Pond is warmer than the untreated Runoff; the Vegetated Swale is, for the majority of the storms, warmer than the Runoff. The Retention Pond remains cooler than the Runoff until it reaches 70°F. The Detention Pond and the Vegetated Swale both reach the UOL at about the same exceedance of 65% and 63%; whereas the Retention Pond reaches the UOL at 44% exceedance showing the Retention Pond actually buffering the temperature of the stormwater runoff more than those two systems at temperatures below 70°F. However, the Retention Pond is the only system to rise above the Lethal Limit (LL) of 80°F; reinforcing the assumption that the larger surface systems will see greater variations in stormwater temperatures during the warmer summer months. The Gravel Wetland effluent was cooler with 27% of the EMTs above the UOL. The Bioretention also buffers high temperatures. The HDS systems show either no buffering or an increase in the temperature of the stormwater runoff. The subsurface infiltration systems (ADS and STIR) both show a strong buffering of Runoff temperatures, with 9% and 4% of the EMTs above the UOL respectively.

During the winter months of October through March, both the Retention and Detention ponds were always cooler than the Runoff EMTs. The Gravel Wetland and the Bioretention systems are also both consistently cooler, showing little moderation of cold temperatures. During the winter months, the subsurface infiltration units have warmer EMTs towards the lower end of the spectrum, showing their ability to moderate the colder temperatures towards the average annual groundwater temperature.

Frequency Distributions

In Figure 22, Figure 23, and Figure 24, the frequencies of the recorded real-time temperatures during the storm events are shown to display the range of temperatures experienced by the systems over the monitoring period. These real-time temperatures are not flow-weighted and therefore have a wider range of values than the EMTs discussed earlier. The Runoff data show a distribution with a majority of temperatures around 41°F and 42°F. The remainder of the temperatures appears uniformly distributed. The Retention and Detention ponds appear bimodal, with a peak slightly above 32°F near the freezing temperature of water. The Gravel Wetland has a distribution similar to that of the Runoff, but with a larger range of temperatures at lower values. The distribution of the Gravel Wetland illustrates a buffering of the higher temperatures from the Runoff. The Bioretention and Vegetated Swale have similar distributions, with a peak at the lower temperatures, followed by a second peak around the UOL. Neither system exceeds

Figure 11: Summer Cumulative Distribution Function for Event Mean Temperatures

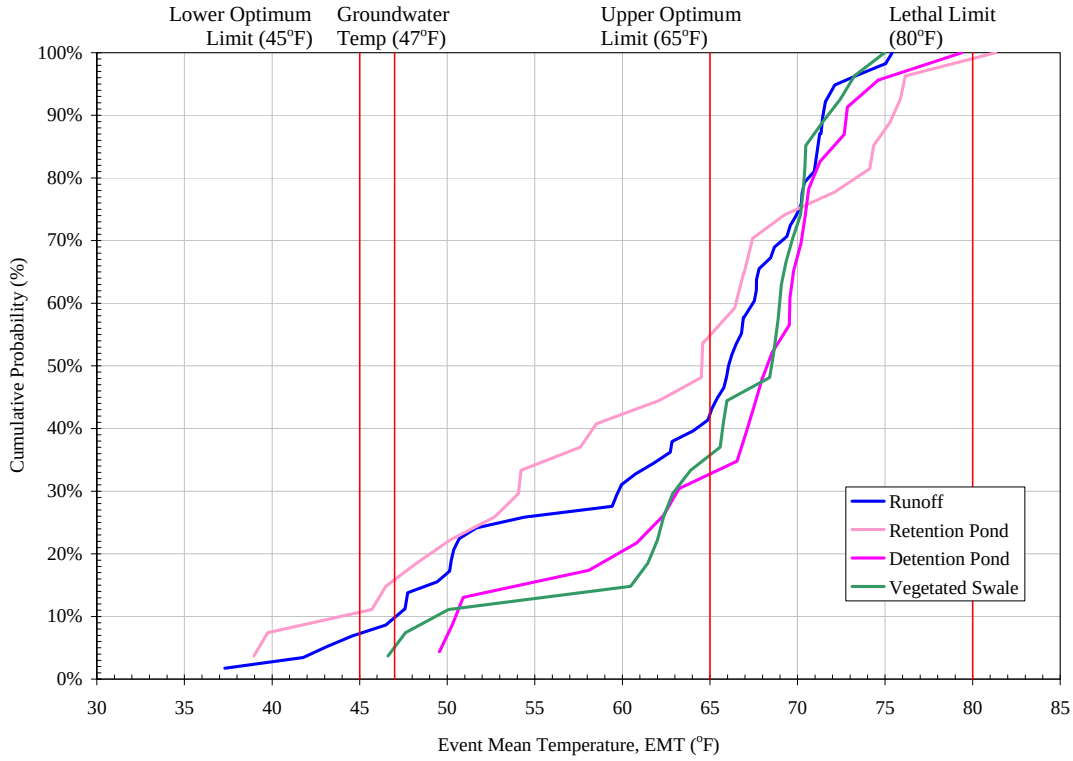


Figure 12: Summer Cumulative Distribution Function for Event Mean Temperatures

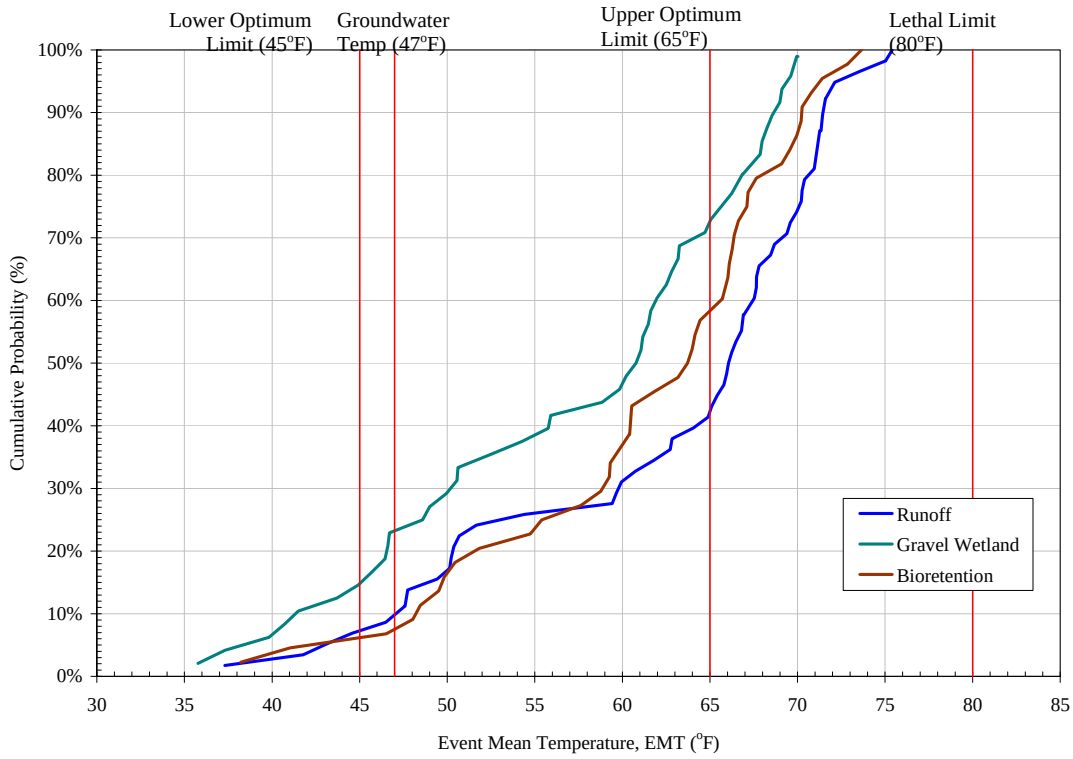


Figure 13: Summer Cumulative Distribution Function for Event Mean Temperatures

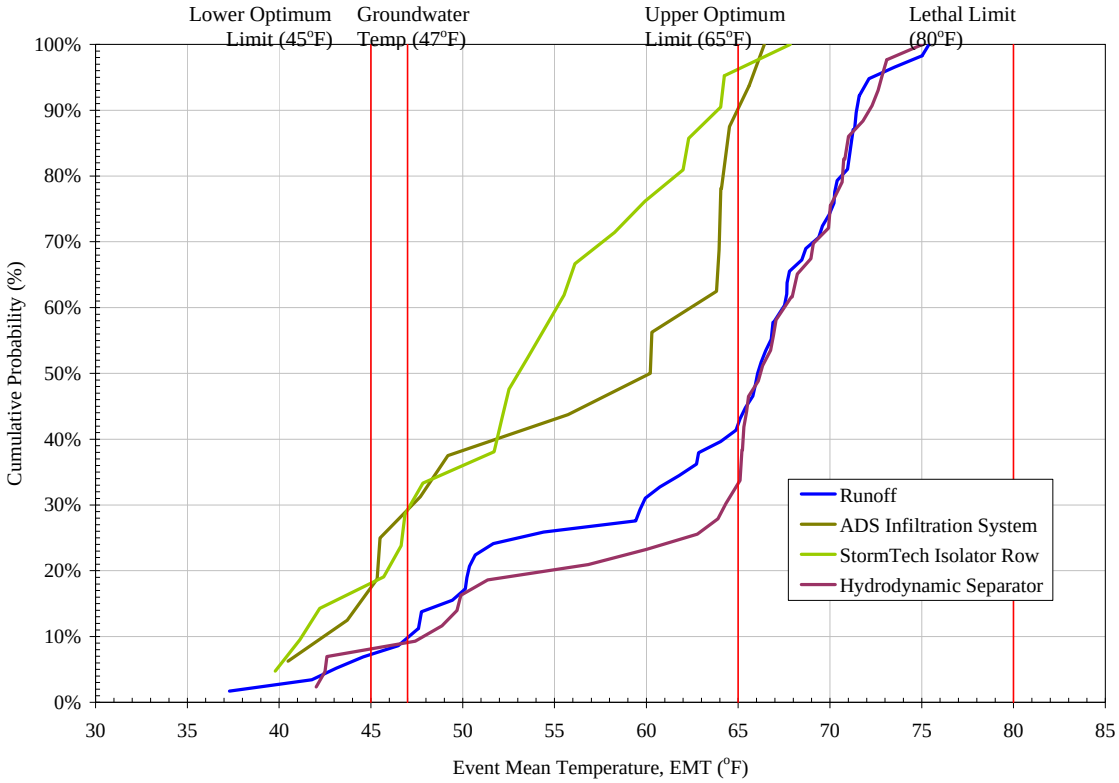


Table 7: Summary Observations for Summer Event Mean Temperature

SUMMER DATA SET	% Exceedance		Maximum Summer EMT	Mean July Temperature
System	Upper Optimum Limit (65°F)	Lethality Limit (80°F)		
Runoff	58.0%		75.4°F	67.1°F
Retention Pond	44.0%	1.0%	81.3 F	77.9°F
Detention Pond	63.0%		79.4°F	72.2°F
Gravel Wetland	27.0%		70.0°F	66.0°F
Bioretention	41.5%		73.7°F	67.7°F
Vegetated Swale	65.0%		75.0°F	70.3°F
Hydrodynamic Separator	66.0%		75.0°F	69.0°F
ADS Infiltration System	9.0%		66.4°F	63.4°F
StormTech Isolator Row	4.0%		67.8°F	58.5°F

Figure 14: Winter Cumulative Distribution Function for Event Mean Temperatures

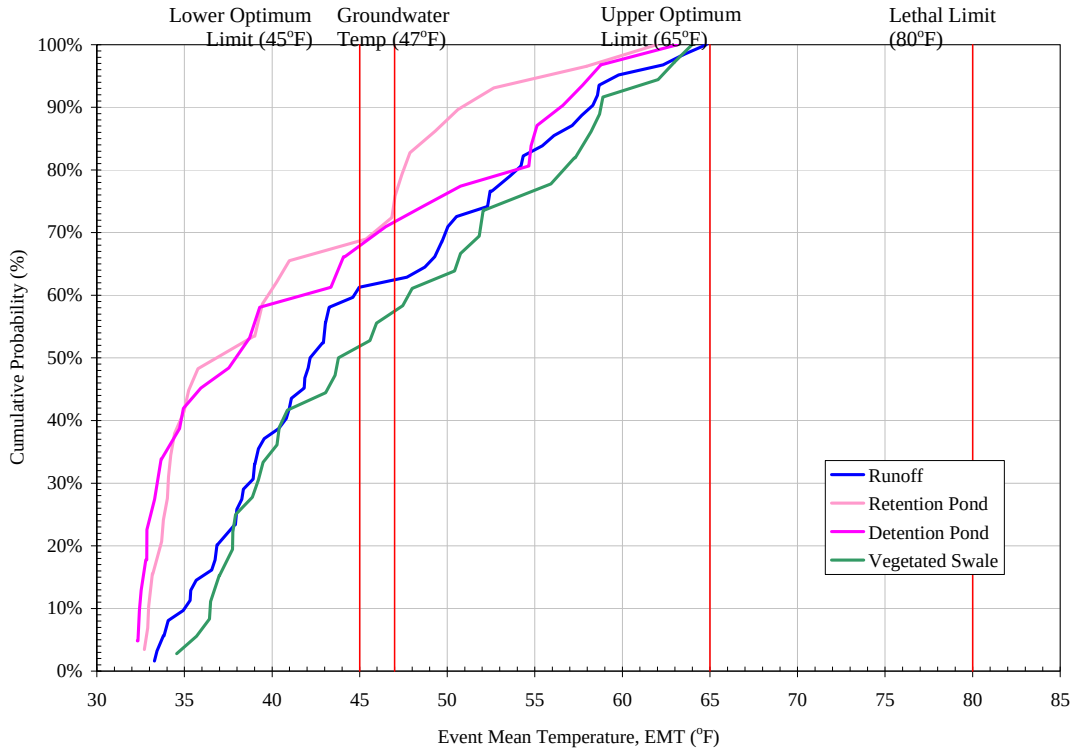


Figure 15: Winter Cumulative Distribution Function for Event Mean Temperatures

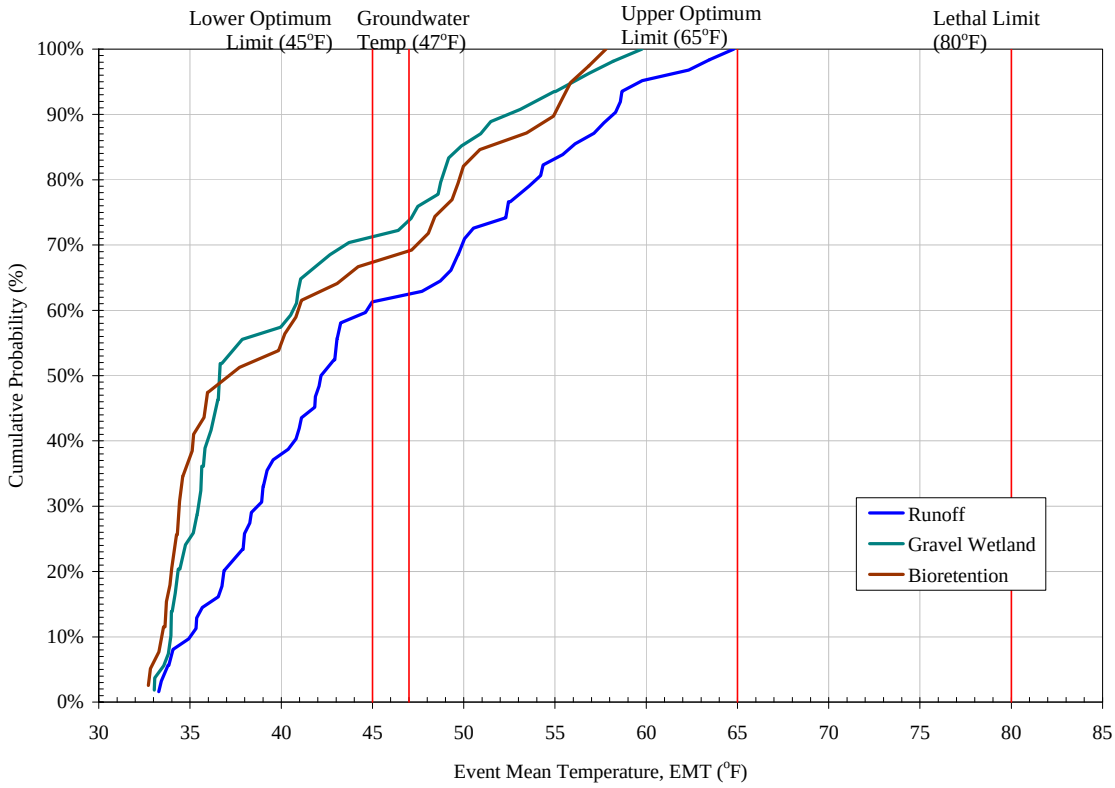


Figure 16: Winter Cumulative Distribution Function for Event Mean Temperatures

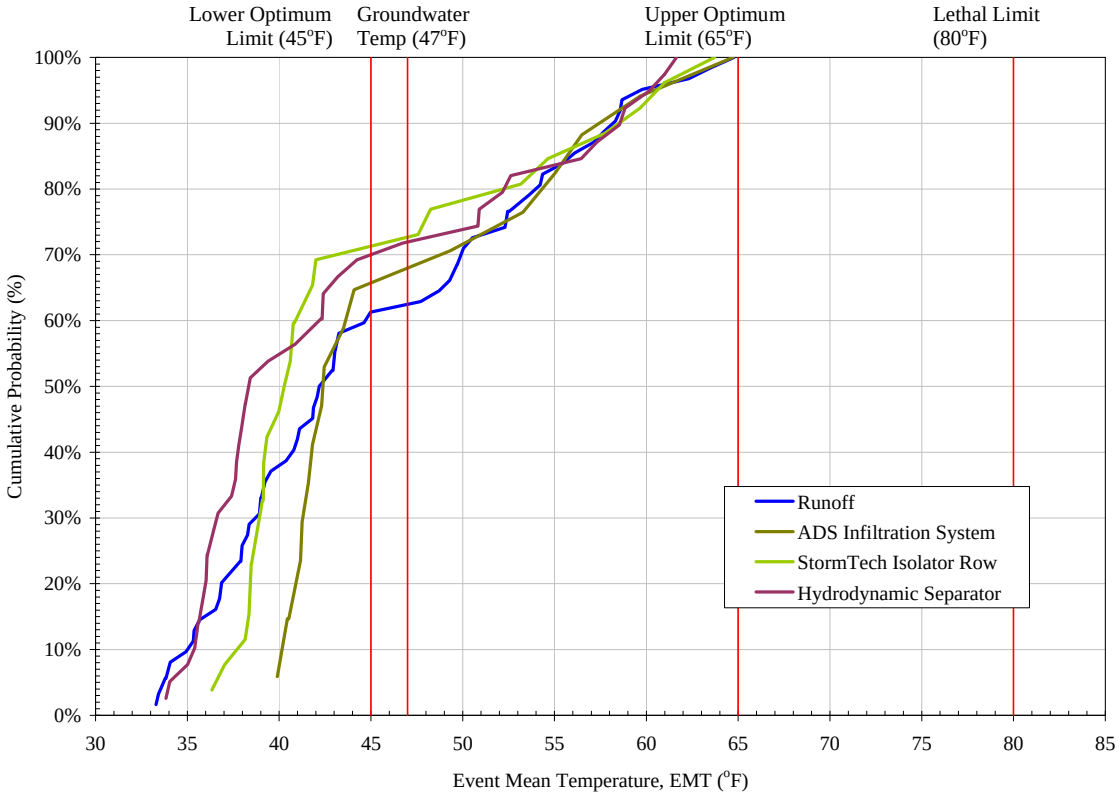


Table 8: Summary Observations for Winter Event Mean Temperature

WINTER DATA SET System	Maximum Winter EMT
Runoff	64.8°F
Retention Pond	62.0°F
Detention Pond	63.1°F
Gravel Wetland	59.8°F
Bioretention	57.8°F
Vegetated Swale	64.0°F
Hydrodynamic Separator	61.6°F
ADS Infiltration System	64.7°F
StormTech Isolator Row	63.7°F

the LL of 80°F. The HDS systems show a range of temperatures, with less variation at about the same range as the ponds. This illustrates the importance of the depth of the system with respect to its ability to mitigate, rather than increase runoff temperatures, as the ponds appear more likely to do. The ADS and STIR systems have two large peaks. The first, and largest, around 42°F, is very near the annual average groundwater temperature of 47°F., which shows the ability of the subsurface systems to mitigate runoff temperatures.

Natural Streams and Mixing

The cumulative distribution of temperature in the three natural streams (including two segments of College Brook) studied is shown in Table 9 and figure 17. College Brook upstream has temperatures that exceed 65°F 11% of the time. Oyster River falls very close to College Brook with an exceedance of 14%. Wednesday Hill Brook is least affected with an exceedance of 3% of the time. At the other end of the spectrum, College Brook upstream and Oyster River both have an LOL non-exceedance of 45%, and Wednesday Hill Brook at 50%. This LOL is more important during the cold winter months.

Figure 18, presents the streams in combination with 4 BMPs (Gravel Wetland, STIR, Detention Pond, and Vegetated Swale). Both of the stormwater systems with infiltration fall within the range of temperature distribution of the two streams while also in the optimum zone for aquatic species. The Pond and Swale show trends towards warmer temperatures, well beyond the upper range of the impacted stream. The two LID systems show a median temperature equivalent to groundwater (47 °F) whereas the median value for the pond is equivalent to the impacted stream (51°F) and the swale at 56.5 °F.

Table 9 shows the mean July temperature of College Brook was 66.3°F, statistically different from that of Wednesday Hill Brook, which had a mean July temperature of 61.2°F. All of the systems have mean July temperatures statistically different from both streams. All of the systems have thermal regimes statistically different from Wednesday Hill Brook, with only the Detention Pond differing from College Brook.

Table 9: CDF Summary of Natural Stream vs. BMP

Stream or System	% Exceedance		Maximum Value†	Mean July Temperature
	LOL* (45°F)	UOL** (65°F)	(°F)	(°F)
College Brook - u/s	55%	11%	80	66.3
College Brook - d/s	58%	17%	80	67.3
Wednesday Hill Brook	50%	3%	90	61.2
Oyster River	55%	14%	79	66.5
Detention Pond	61%	28%	79	72.2
Gravel Wetland	56%	13%	70	66.0
Vegetated Swale	70%	27%	75	70.3
StormTech Isolator Row	56%	1%	68	58.5

*LOL – Lower Optimum Limit
**UOL – Upper Optimum Limit
† Values listed for streams are direct temperature measurements, while values for the stormwater BMPs are EMTs.

Figure 17: Cumulative Distribution of Natural Streams

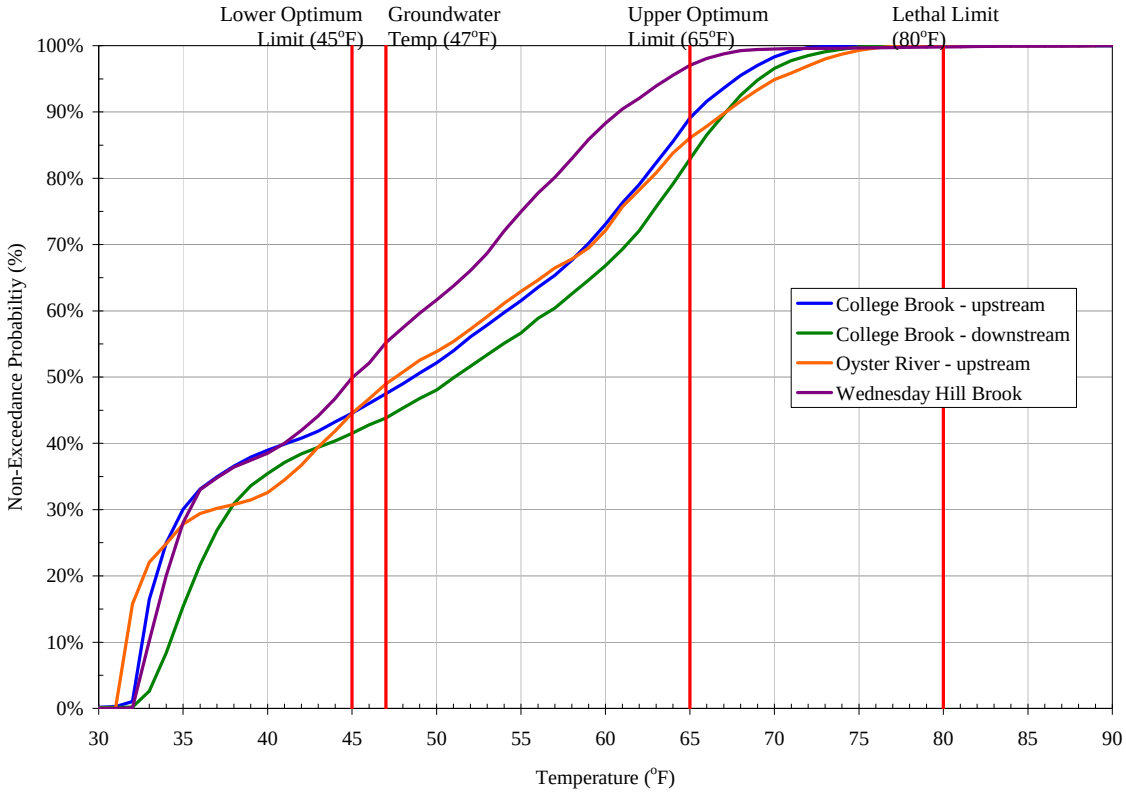
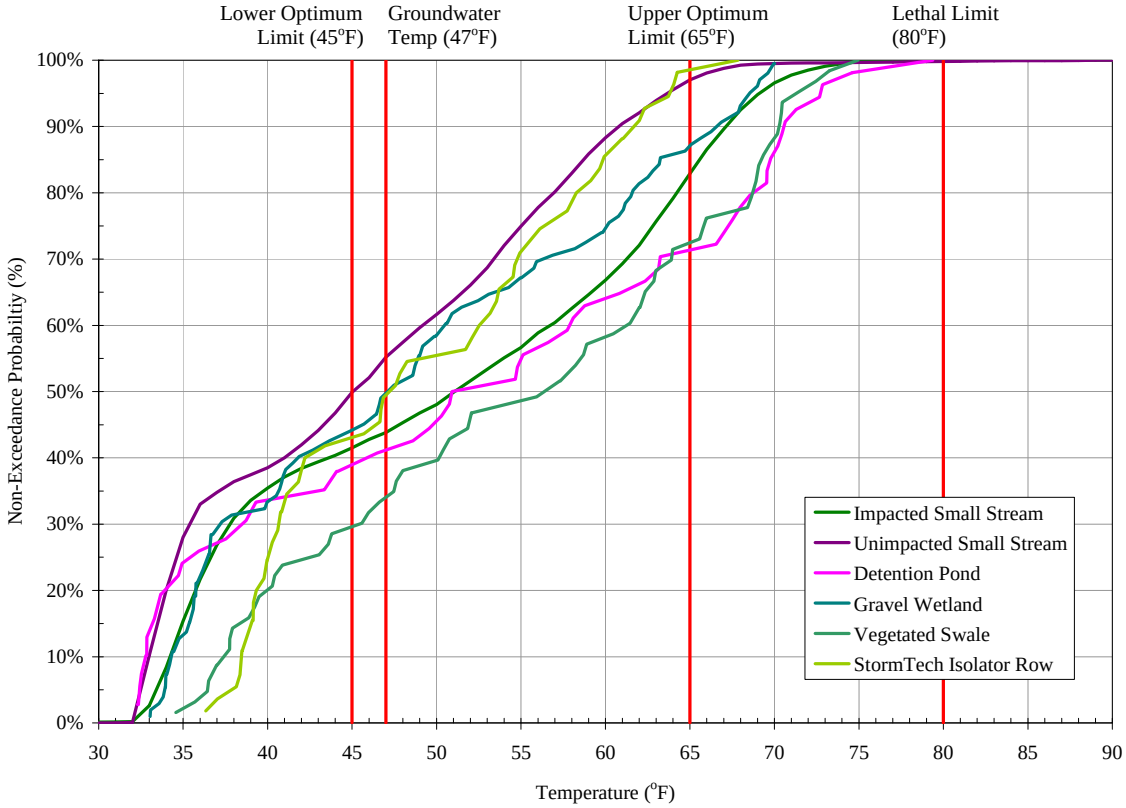


Figure 18: Cumulative Distribution of Natural Streams vs. Stormwater BMPs



SUMMARY

Stormwater BMP Event Mean Temperature

The results of this study demonstrate a range of thermal impacts from stormwater BMPs. The large surface systems have the greatest thermal extremes, whereas the large subsurface systems have the greatest thermal buffering. Overall infiltration and filtration systems at minimum have little effect upon the runoff temperature and at most have substantial buffering capacity. The Gravel Wetland and to a lesser extent the Bioretention have a large surface area, but because the filtration practices have a deep subsurface footprint they buffer runoff temperatures. The permanent pool of water in the Retention Pond appears to act as a heat sink during periods of extreme heat.

The Gravel Wetland, the ADS, and the STIR, have a strong capacity to act as thermal buffers. In addition, the data for these systems suggest that these subsurface systems, on average, reduce the summer temperatures and increase the winter temperatures of the runoff to near the average groundwater temperature of 47°F. The annual comparison of the influent EMTs to the effluent EMTs of the ADS and STIR systems (Figure 27) show these systems near average groundwater temperature. The regression lines for these systems cross a line of no effect for the ADS at 47.3^{o}F and the STIR at 47.5^{o}F. The summer EMTs of the two stormwater ponds, Vegetated Swale, and HDS systems, indicate that they provide little, to no reduction or buffering of high runoff temperatures. In contrast, the Gravel Wetland and STIR reduce runoff temperatures during the summer months. The Bioretention system did not elevate runoff temperatures and showed minor buffering capacity, and was consistently cooler in the summer and warmer in the winter than the Runoff. The Bioretention, and the HDS, as well as the Gravel Wetland, ADS, and STIR systems all have summer mean values that fall within the optimal zone for coldwater streams.

The Retention and Detention ponds have the largest variation in EMTs. The Vegetated Swale and the HDS also show variability, but not as pronounced as the two ponds. The STIR also shows high values, but did not exceed the values of the runoff during the summer months.

The Retention Pond is the only system to exceed both the Upper Optimum Limit (UOL) and the Lethal Limit of 80°F, however, the Detention Pond with a maximum EMT of 79.4^{o}F comes very close. The HDS system has a 35.0% chance of exceeding the UOL, which is the highest exceedance value for any of the systems. This high exceedance value indicates that the HDS is not buffering the thermal energy as well as some of the other systems. The maximum HDS EMT (75.0^{o}F) is still lower than that of the Runoff, Retention Pond, and Detention Pond. Therefore, unlike the ponds, the HDS systems do not appear to be increasing the temperature of the stormwater. The Gravel Wetland, ADS and STIR systems have the lowest exceedance values of the UOL. At 13.0% for the Gravel Wetland, 5.0% for the ADS, and 1.5% for the STIR, these values indicate that these systems do an excellent job of buffering runoff temperature and could provide protection to coldwater streams from discharge of stormwater exceeding the upper optimum limit of 65°F..

The natural thermal regime of a receiving stream is possibly the most important metric to compare with the EMTs of the stormwater BMPs. The best method would incorporate a wide

range of metrics for determining the impact of the BMP on the receiving stream. The mean July temperatures of the systems are all within the stress zone for aquatic species, between 65°F and 80°F, with the exception of the two subsurface infiltration systems, which fall within the optimum zone of 45°F to 65°F for coldwater aquatic species. The mean July temperature of the Gravel Wetland is just above the UOL at 66°F, illustrating that the deeper systems of the ADS and STIR systems are able to buffer the runoff temperatures more effectively.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The influence of a stormwater BMP upon runoff temperature is directly related to its degree of exposure to solar radiation. The temperature of runoff is affected within the stormwater BMP systems by its exposure to the air, the depth of the system, and the mass, or size of the system. The larger the system is, the greater the capability it has to exacerbate or mitigate the temperatures.

Surface systems that are exposed to direct sunlight have been shown to increase already elevated summer runoff temperatures. During the summer months, we can expect to see an increase in stormwater temperatures within the systems that have a large surface area. Conventional stormwater BMPs that include detention or retention of stormwater at the surface appear to exacerbate the temperature variations and extremes. These ponded water systems function as heat sinks during the summer months and a form of heat loss during winter.
In contrast, systems that provide treatment by infiltration and filtration can moderate runoff temperatures by thermal exchange with cool subsurface materials. Stormwater BMPs that incorporate filtration appear to be exceptionally effective for mitigation of temperature. The degree of exchange is largely a function of the hydraulic loading rate. The physical dimensions of treatment cells can also affect the temperature of systems. Deeper systems have greater capability to buffer temperatures, and systems with a large subsurface footprint appear to have the greatest ability to mitigate runoff temperatures. These systems will be able to buffer the warm summer runoff, as well as the cool winter runoff, yielding effluent temperatures near the average groundwater temperature. The filtration systems examined are listed from *most effective to* least effective at mitigating runoff temperatures: StormTech Isolator Row, ADS Infiltration System, Gravel Wetland, Bioretention.

Future Research

This data set could be expanded to include additional systems monitored at the UNHSC site over their respective life spans. In particular, porous pavements (porous asphalt, pervious concrete, and pavers) could be added to the list. Future research and data analysis could further explore the connection between BMP correlation of runoff temperatures and changes to and mitigation of receiving stream thermal regimes. The information could supplement the UNHSC data with data collected for various stream types. These data will be used to examine thermal regimes for the various stream types with respect to thermal performance characteristics. Such comparisons could include BMP specific temperature related thermal impact curves (BTU/Acre/Second) for various stream types. The correlation would be normalized to a specific discharge of a receiving stream such that impacts could be scaled for varying stream sizes.

Figure 19: Time Series of Event Mean Temperatures for a Gravel Wetland and Bioretention

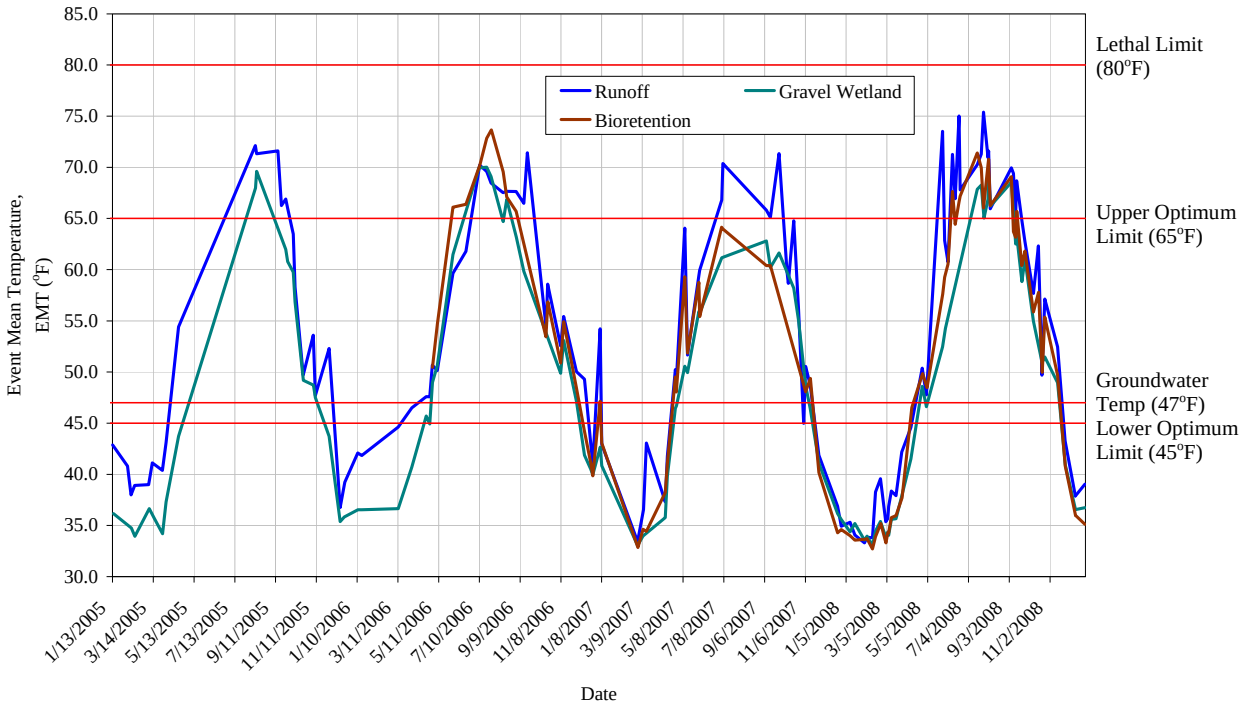


Figure 20: Time Series of Event Mean Temperatures for Ponds and Swale

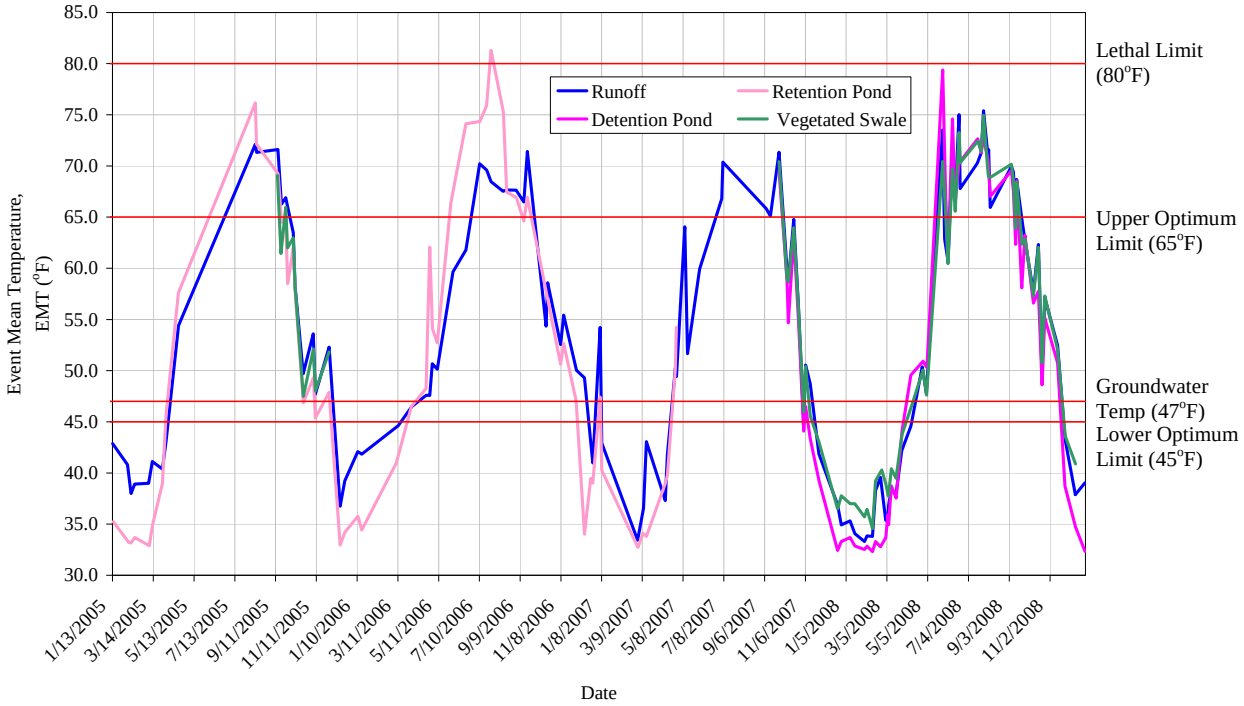


Figure 21: Time Series of Event Mean Temperatures for Hydrodynamic Separator, ADS Infiltration System, and a StormTech Isolator Row

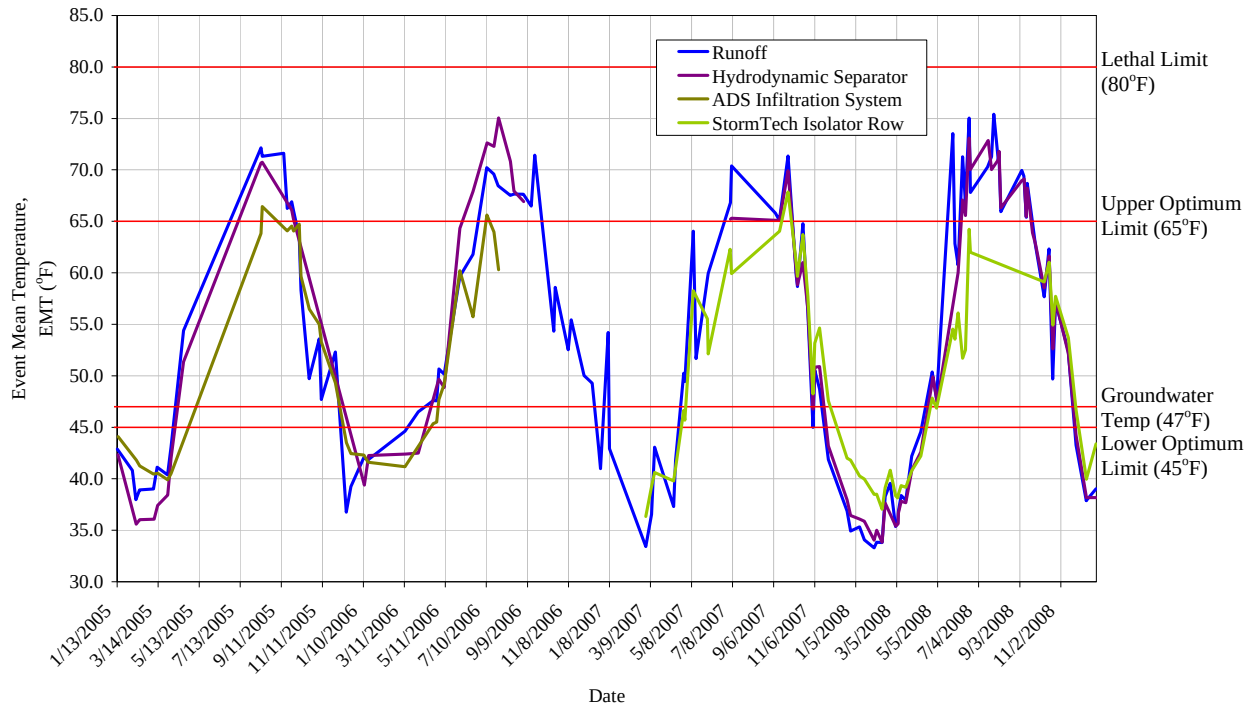


Figure 22: Frequency Distribution of Ponds and Swale for Real-Time Temperatures

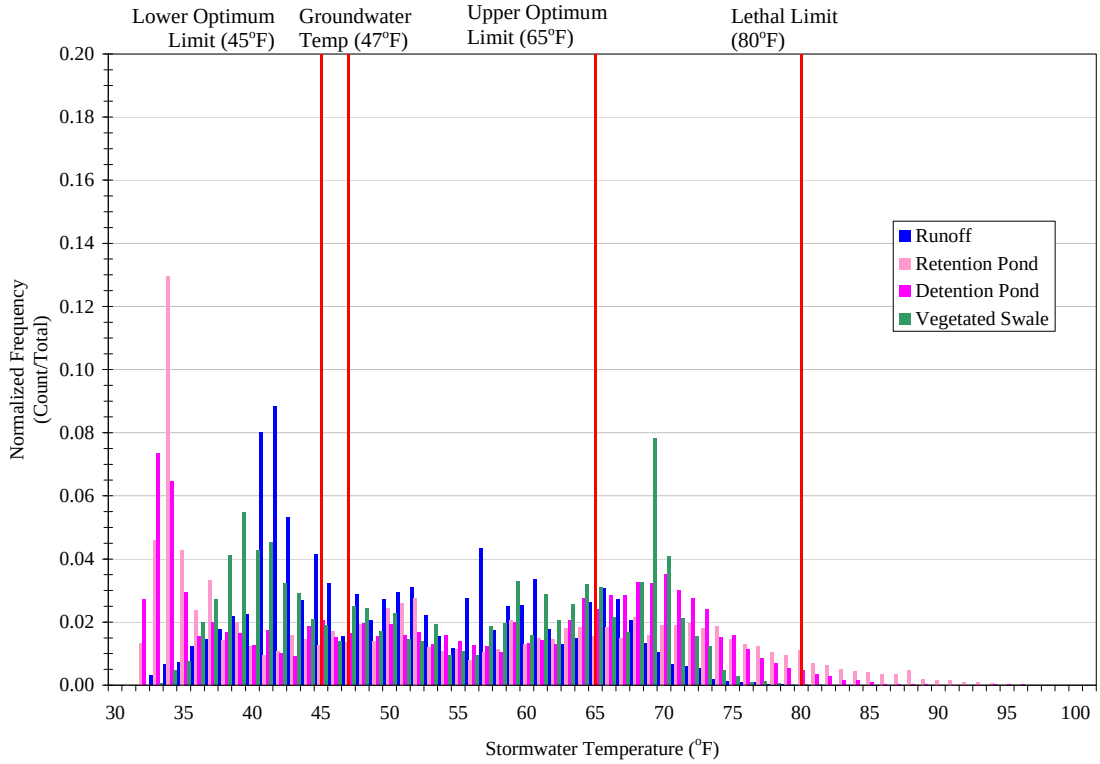


Figure 23: Frequency Distribution for Real-Time Temperatures for a Gravel Wetland and Bioretention

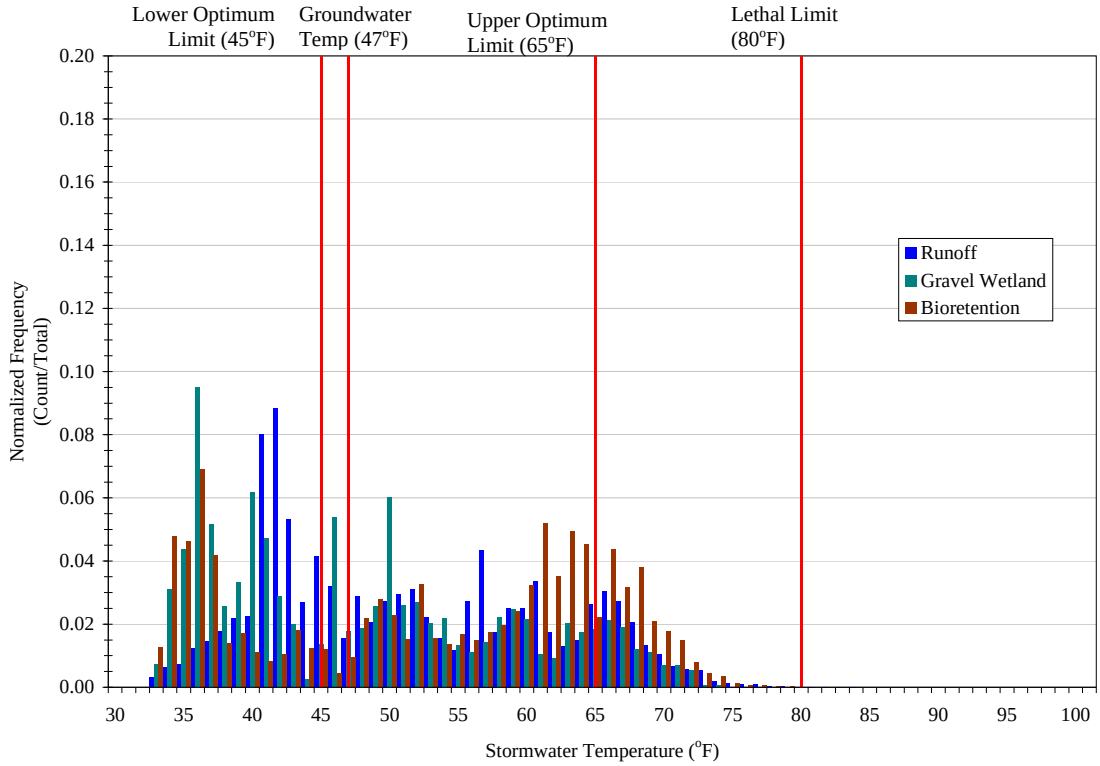


Figure 24: Frequency Distribution for Real-Time Temperatures for Hydrodynamic Separator, ADS Infiltration System, and a StormTech Isolator Row

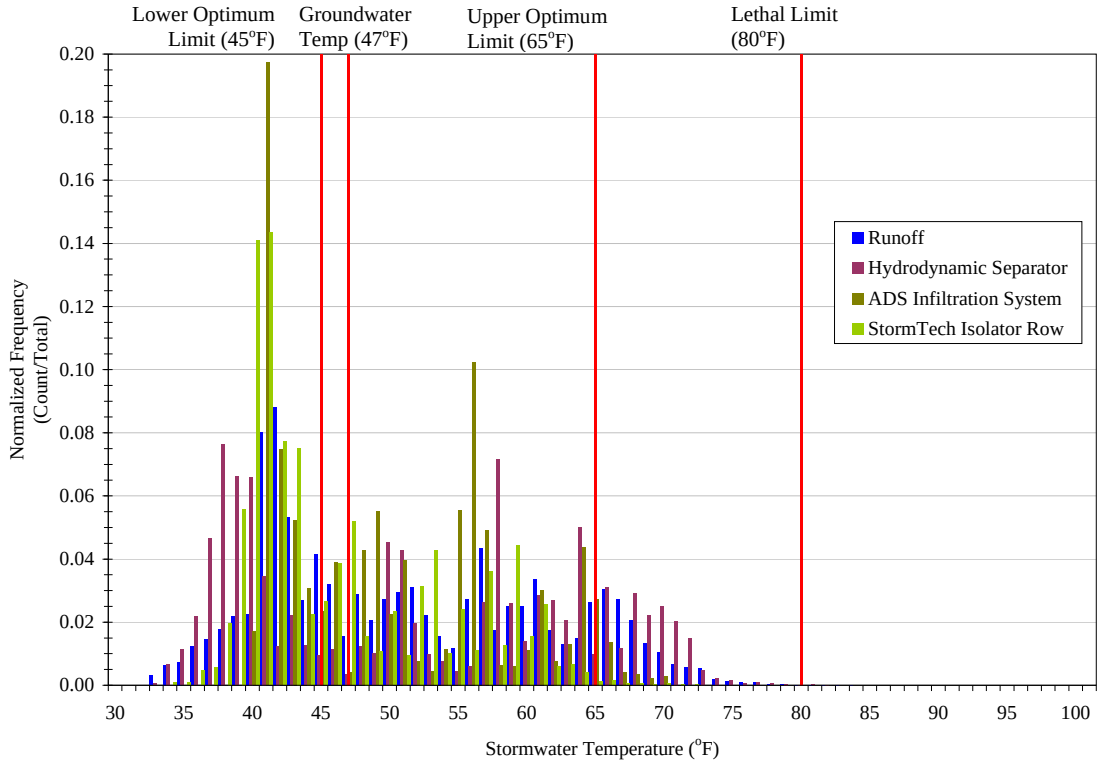


Figure 25: Regression of Event Mean Temperature for Conventional System Performance (Annual)

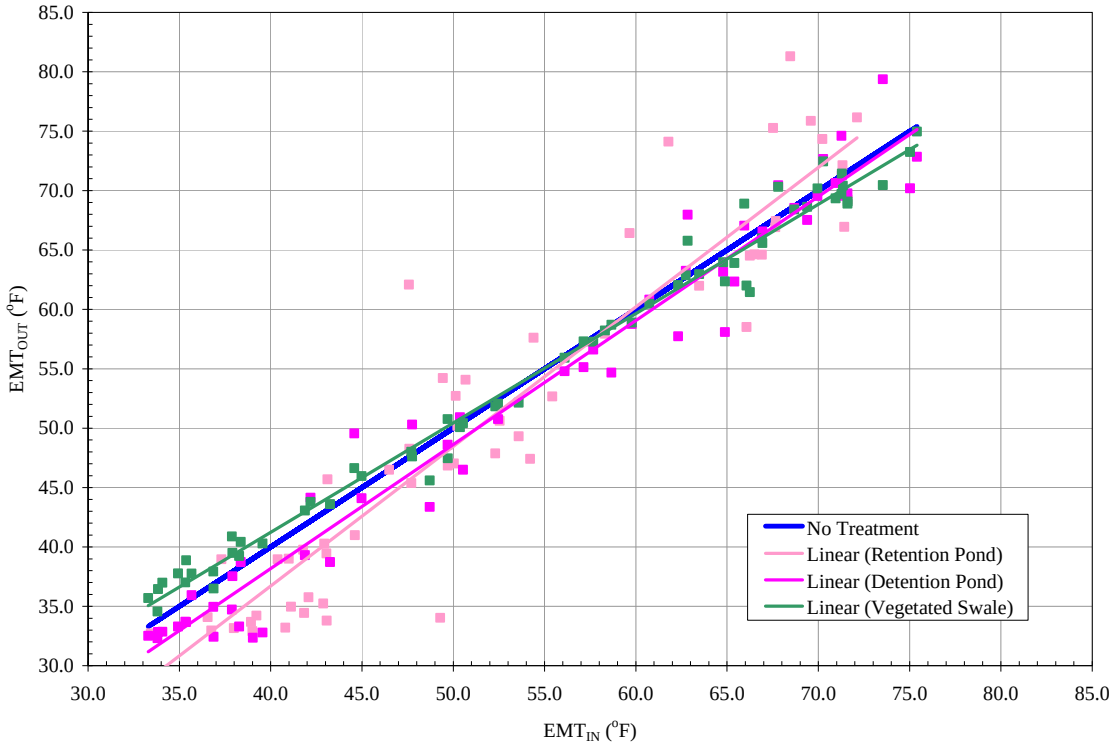


Figure 26: Regression of Event Mean Temperature for LID System Performance (Annual)

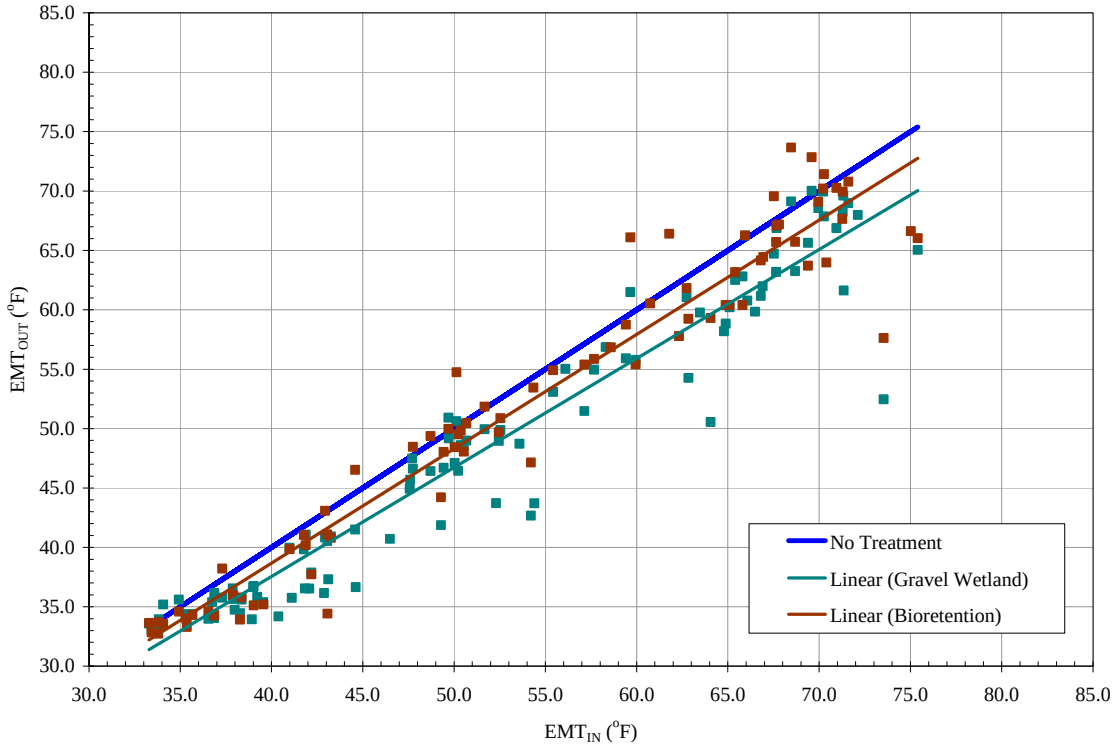


Figure 27: Regression of Event Mean Temperature for Manufactured Systems Performance (Annual)

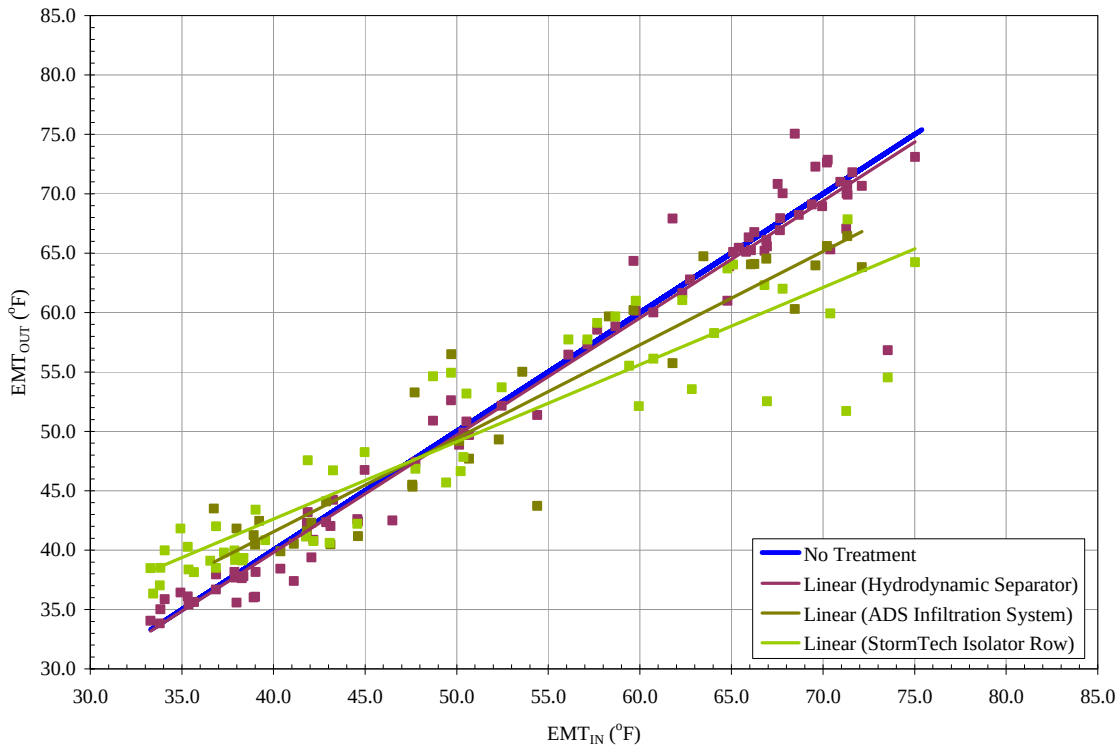


Table 10: Linear Regressions of Event Mean Temperature for Annual

System	Equation	R^2
Retention Pond	Y = -10.2 + 1.2X	0.88
Detention Pond	Y = -3.6 + 1.0X	0.97
Gravel Wetland	Y = 0.8 + 0.9X	0.93
Bioretention	Y = 0.2 + 1.0X	0.94
Vegetated Swale	Y = 4.4 + 0.9X	0.99
HDS	Y = 0.3 + 1.0X	0.96
ADS	Y = 10.1 + 0.8X	0.88
STIR	Y = 16.6 + 0.6X	0.83

Figure 28: Regression of Event Mean Temperature for Conventional Systems Performance (Summer)

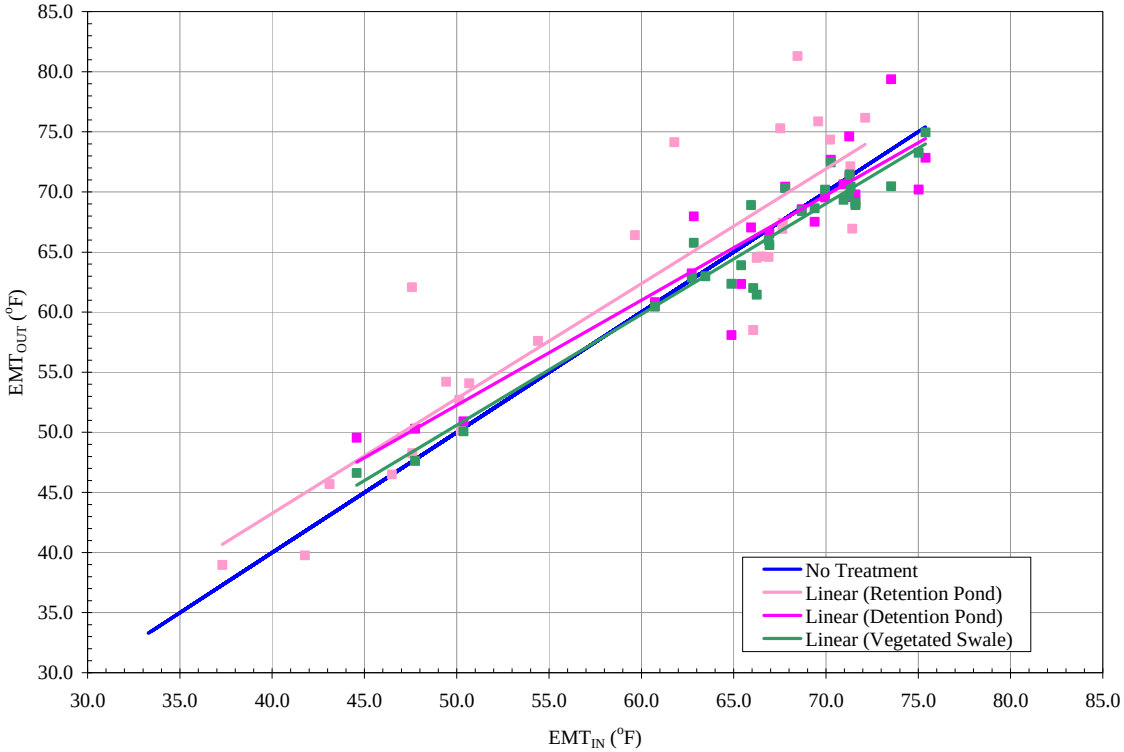


Figure 29: Regression of Event Mean Temperature for LID Systems Performance (Summer)

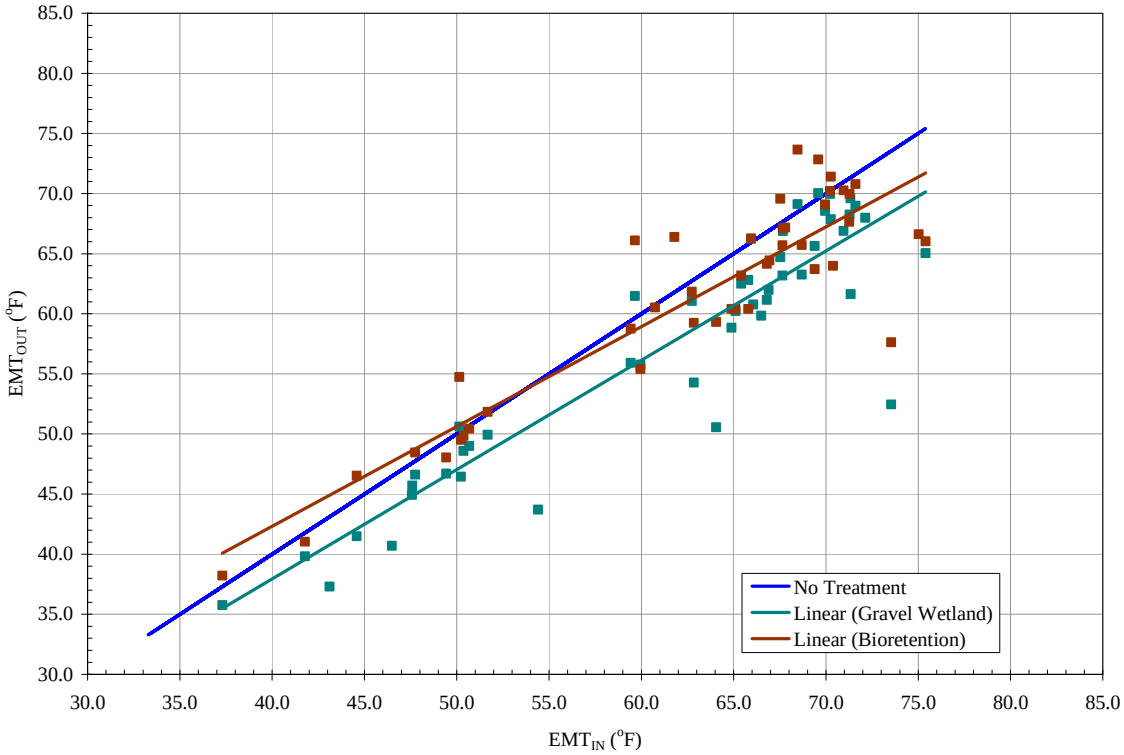


Figure 30: Regression of Event Mean Temperature for Manufactured Systems Performance (Summer)

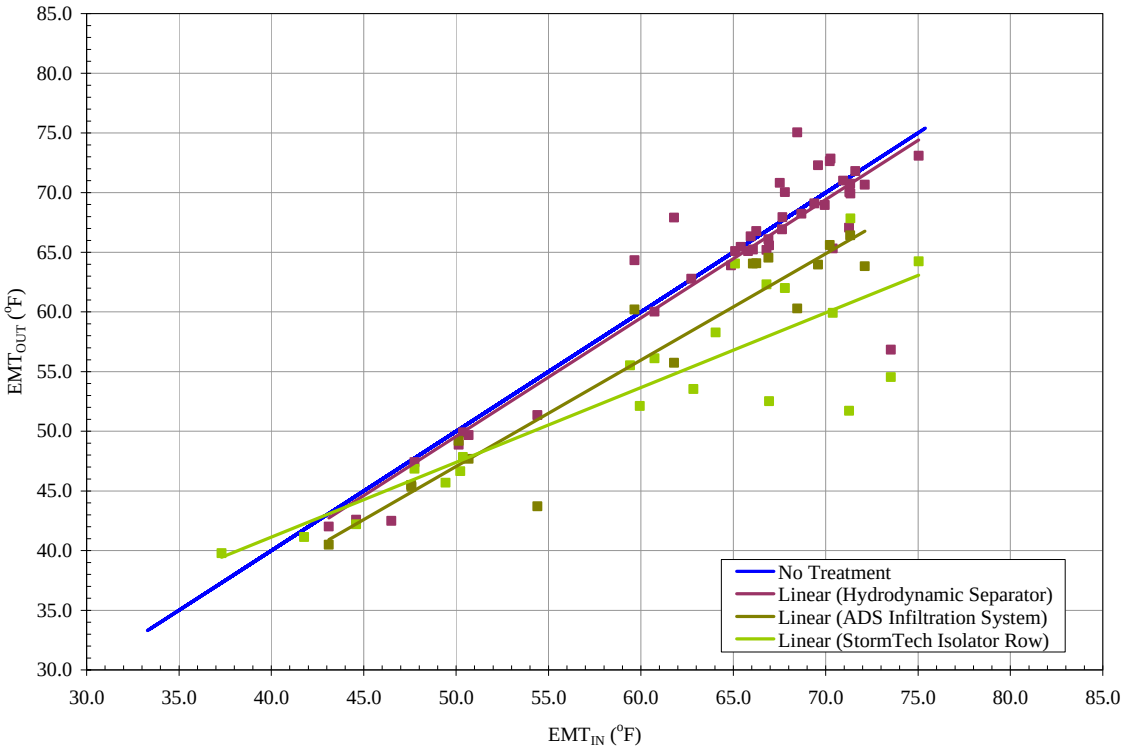


Table 11: Linear Regression of Event Mean Temperature for Summer

System	Equation	R^2
Retention Pond	Y = 5.1 + 1.0X	0.80
Detention Pond	Y = 8.6 + 0.9X	0.86
Gravel Wetland	Y =1.5 + 0.9X	0.85
Bioretention	Y = 9.1 + 0.8X	0.82
Vegetated Swale	Y = 4.5 + 0.9X	0.93
HDS	Y = -0.1 + 1.0X	0.86
ADS	Y = 2.5 + 0.9X	0.91
STIR	Y = 16.1 + 0.6X	0.75

Figure 31: Regression of Event Mean Temperature for Conventional Systems Performance (Winter)

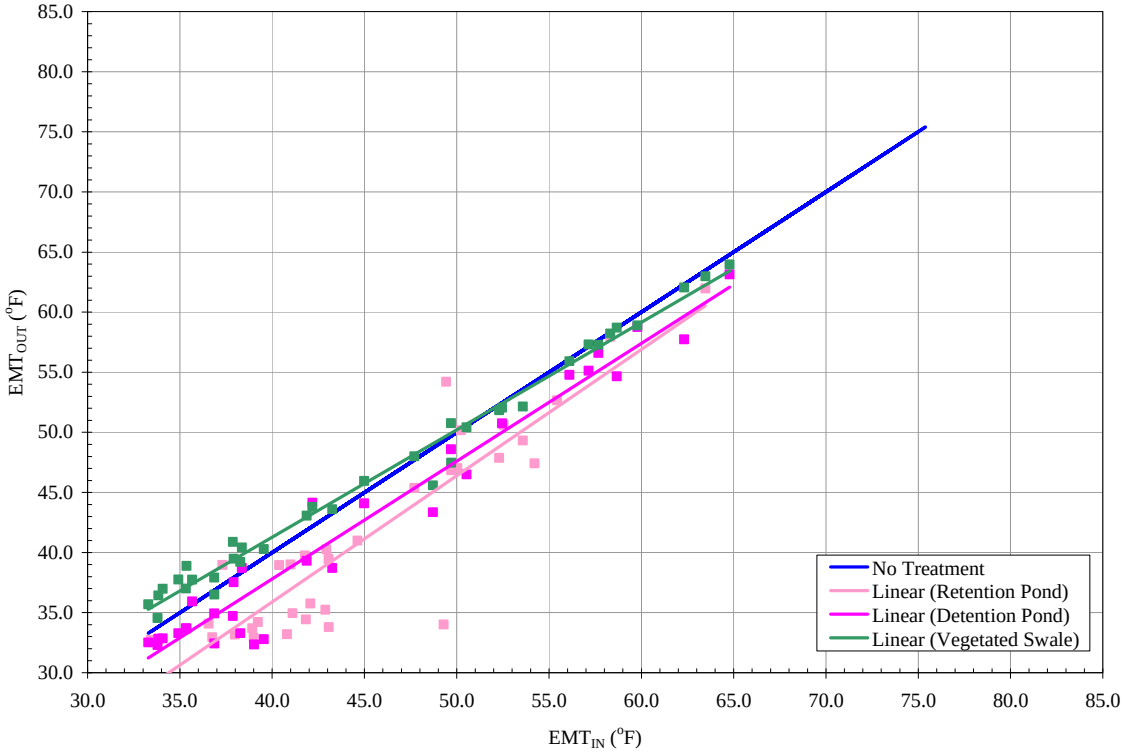


Figure 32: Regression of Event Mean Temperature for LID Systems Performance (Winter)

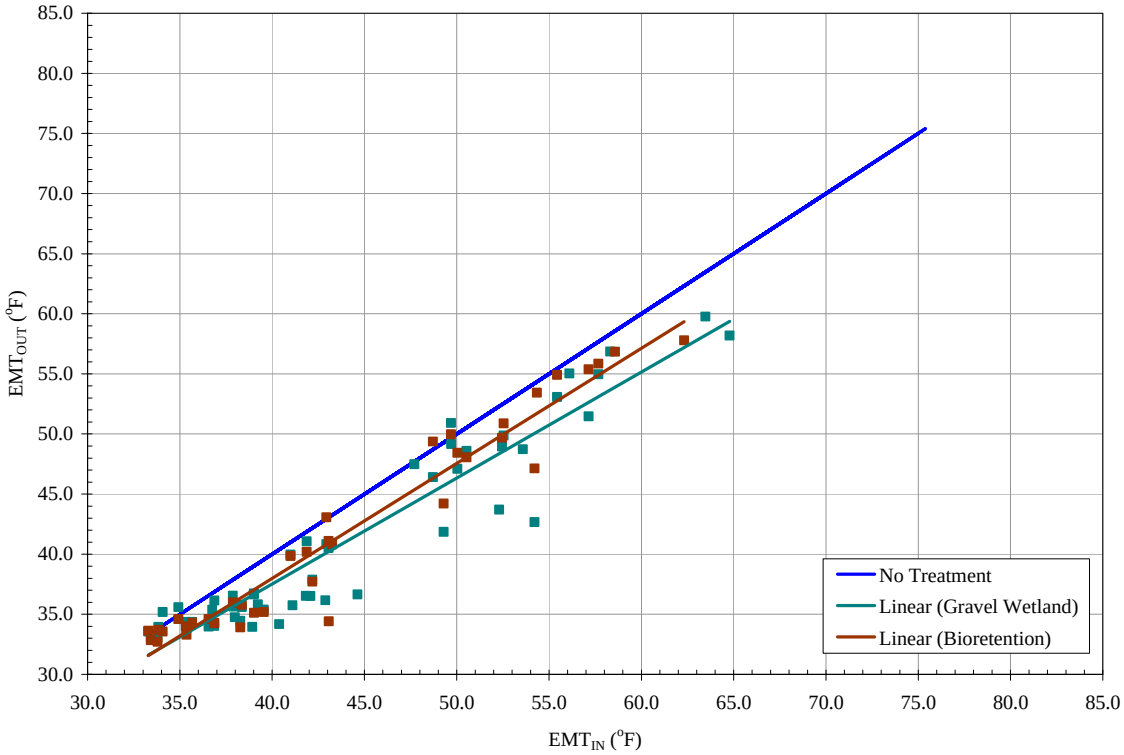


Figure 33: Regression of Event Mean Temperature for Manufactured Systems Performance (Winter)

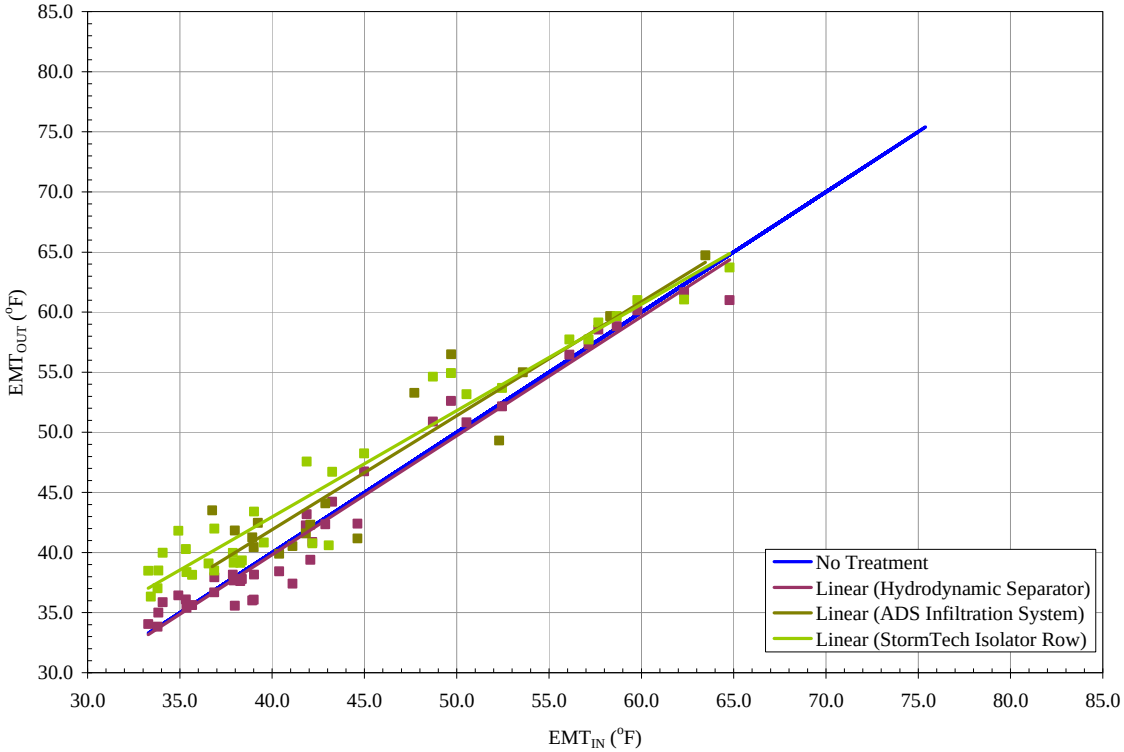


Table 12: Linear Regressions of Event Mean Temperature for Winter

System	Equation	R^2
Retention Pond	Y = -6.1 + 1.1X	0.82
Detention Pond	Y = -1.53 + 1.0X	0.96
Gravel Wetland	Y = 2.2 + 0.9X	0.90
Bioretention	Y = -0.3 + 1.0X	0.95
Vegetated Swale	Y = 5.5 + 0.9X	0.99
HDS	Y = 0.2 + 1.0X	0.97
ADS	Y = 4.0 + 0.9X	0.86
STIR	Y = 7.6 + 0.9X	0.95

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TASK 2: OUTREACH AND EDUCATION

Workshop

A 3 hour workshop will be hosted to present research findings for two thermal related research efforts. Details and announcement listed below.
http://www.unh.edu/unhsc/thermal-workshop-announcement

Thermal Impacts of Stormwater BMPs, Thermal Regimes of Northeast Streams, and their Nexus
Thursday, February 17th, 2011 1230-330PM
Location: Hugh Gregg Coastal Conservation Center, 89 Depot Road, Greenland, NH
Presented by
UNH Stormwater Center, Environmental Research Group, and NH Coastal Training Program

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What: How does stormwater runoff impact stream temperature?
This workshop will present research results examining thermal characteristics as they relate to surface waters and runoff in the built and natural environment, an important issue facing the Northeast. As a watershed is developed, and impervious surface area increases, stormwater runoff can be a significant, or even the primary source of water to a surface water body. Small streams in New England are highly sensitive to changes in temperature. Increased temperature damages cold water fisheries, and altered temperature regimes interfere with spawning and migration patterns. Drs. Roseen, Ballestero and Watts are characterizing the thermal signature of stormwater runoff. Dr. Jacobs has explored the thermal regimes of streams throughout NH and MA. Recently, these teams have begun to combine their findings to determine the impact of specific stormwater management strategies on a range of stream types. This workshop will present the results of these ongoing research programs.

Workshop Partners: Robert Roseen, Jennifer Jacobs, Alison Watts, Tom Ballestero, Jamie Houle, Steve Miller (CTP Partner), Ralph Abele (EPA)

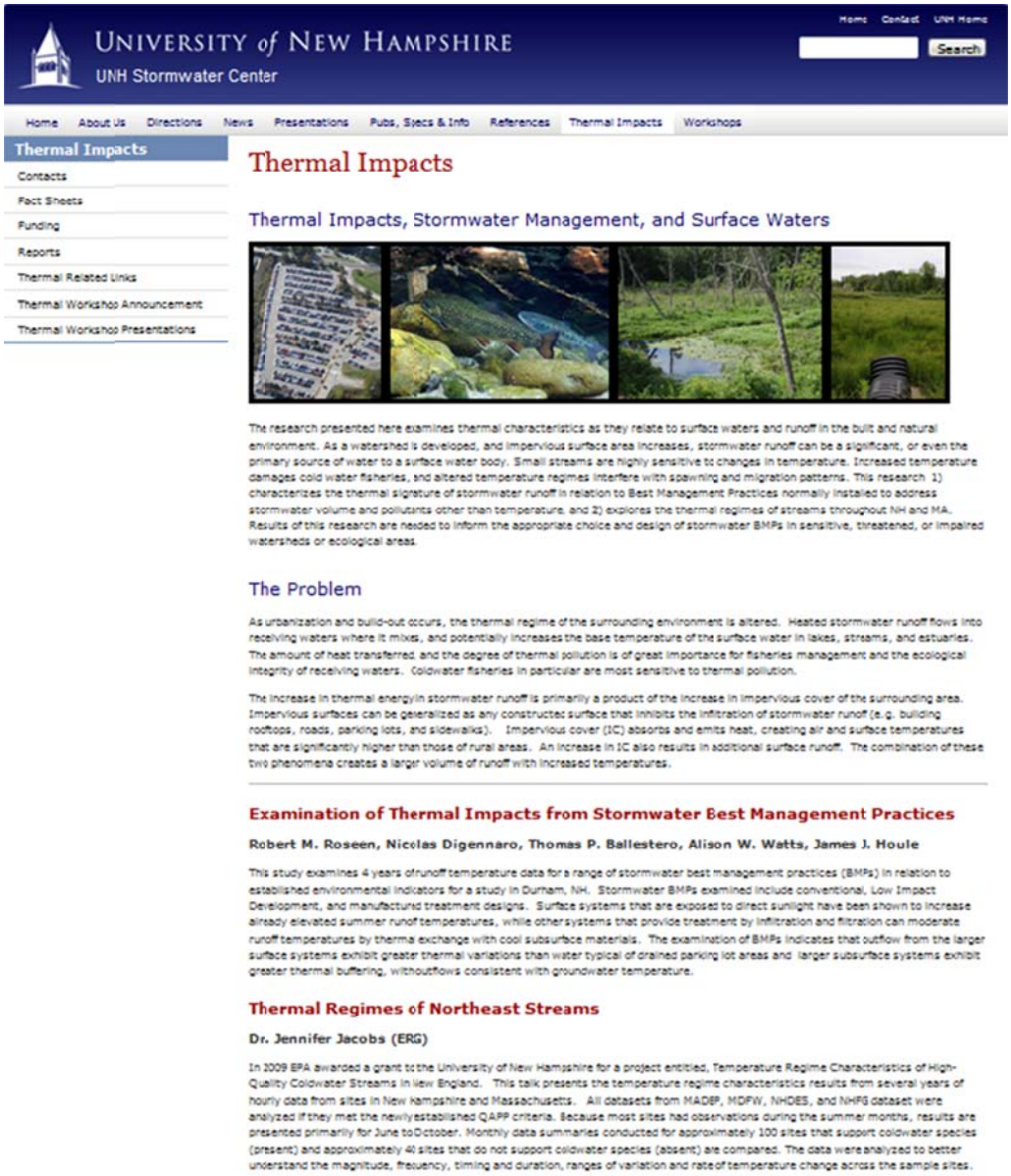
Agenda:
1. Introduction - Ralph Abele (EPA) (15 min)
2. Thermal Regimes of Northeast Streams – Jennifer Jacobs (ERG) (25 min)
3. Thermal Impacts of Stormwater BMPs – Robert Roseen (UNHSC) (25 min)
4. Persistence Characteristics of Stormwater BMPs – Tom Ballestero (UNHSC) (25 min)
5. Developing Models for Stormwater Thermal Impacts on Stream Temperature Regimes---Alison Watts (UNHSC) (25 min)
6. Next Steps to Quantifying and Mitigating Stormwater impacts on Streams (10 min)
7. Closing & Sponsor acknowledgements (5 min)

Registration: For more information goto http://www.unh.edu/unhsc/thermal.
To register online goto http://www.erg.unh.edu/stormwater/Onlinereg/register.asp
Or contact Maddy Wasiewski at 603-862-2206. There is no cost to this workshop.

Logistics: Parking is available on site. The workshop is located 89 Depot Road, Greenland, NH 03840.

Web page

A webpage was constructed to host electronically project related materials. The website was broadened to include related research by Dr. Jennifer Jacobs titled *Draft-Temperature Regime Characteristics of High-Quality Coldwater Streams in New England* funded by the US EPA Region 1 TMDL Program. Resources available include summary information, a project fact sheet, final reports, workshop materials, and related links. The webpage can be found at http://www.unh.edu/unhsc/thermal/



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Thermal Impacts

Thermal Impacts, Stormwater Management, and Surface Waters

The research presented here examines thermal characteristics as they relate to surface waters and runoff in the built and natural environment. As a watershed is developed, and impervious surface area increases, stormwater runoff can be a significant, or even the primary source of water to a surface water body. Small streams are highly sensitive to changes in temperature. Increased temperature damages cold water fisheries, and altered temperature regimes interfere with spawning and migration patterns. This research 1) characterizes the thermal signature of stormwater runoff in relation to Best Management Practices normally installed to address stormwater volume and pollutants other than temperature, and 2) explores the thermal regimes of streams throughout NH and MA. Results of this research are needed to inform the appropriate choice and design of stormwater BMPs in sensitive, threatened, or impaired watersheds or ecological areas.

The Problem

As urbanization and build-out occurs, the thermal regime of the surrounding environment is altered. Heated stormwater runoff flows into receiving waters where it mixes, and potentially increases the base temperature of the surface water in lakes, streams, and estuaries. The amount of heat transferred and the degree of thermal pollution is of great importance for fisheries management and the ecological integrity of receiving waters. Coldwater fisheries in particular are most sensitive to thermal pollution.

The increase in thermal energy in stormwater runoff is primarily a product of the increase in impervious cover of the surrounding area. Impervious surfaces can be generalized as any constructed surface that inhibits the infiltration of stormwater runoff (e.g. building rooftops, roads, parking lots, and sidewalks). Impervious cover (IC) absorbs and emits heat, creating air and surface temperatures that are significantly higher than those of rural areas. An increase in IC also results in additional surface runoff. The combination of these two phenomena creates a larger volume of runoff with increased temperatures.

Examination of Thermal Impacts from Stormwater Best Management Practices

Robert M. Roseen, Nicolas Digennaro, Thomas P. Ballestero, Alison W. Watts, James J. Houle

This study examines 4 years of runoff temperature data for a range of stormwater best management practices (BMPs) in relation to established environmental indicators for a study in Durham, NH. Stormwater BMPs examined include conventional, Low Impact Development, and manufactured treatment designs. Surface systems that are exposed to direct sunlight have been shown to increase already elevated summer runoff temperatures, while other systems that provide treatment by infiltration and filtration can moderate runoff temperatures by thermal exchange with cool subsurface materials. The examination of BMPs indicates that outflow from the larger surface systems exhibit greater thermal variations than water typical of drained parking lot areas and larger subsurface systems exhibit greater thermal buffering, with outflows consistent with groundwater temperature.

Thermal Regimes of Northeast Streams

Dr. Jennifer Jacobs (ERG)

In 2009 EPA awarded a grant to the University of New Hampshire for a project entitled, Temperature Regime Characteristics of High-Quality Coldwater Streams in New England. This talk presents the temperature regime characteristics results from several years of hourly data from sites in New Hampshire and Massachusetts. All datasets from MADEP, MDFW, NHDES, and NHFG dataset were analyzed if they met the newly established QAPP criteria. Because most sites had observations during the summer months, results are presented primarily for June to October. Monthly data summaries conducted for approximately 100 sites that support coldwater species (present) and approximately 40 sites that do not support coldwater species (absent) are compared. The data were analyzed to better understand the magnitude, frequency, timing and duration, ranges of variation and rate of temperature change across the sample sites.

APPENDIX A: STORM CHARACTERISTICS

Table 13: Storm Characteristics

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[1]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record	mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	EMT Fahrenheit
1	1	01/13/2005	2,365	N/A	0.00	0.00	3,871	46.4	42.9
1a	2	02/04/2005	5,070	N/A	0.00	0.00	202	43.7	40.8
2	3	02/09/2005	3,325	N/A	0.00	0.00	814	43.0	38.0
2a	4	02/14/2005	4,595	N/A	0.00	0.00	906	42.4	38.9
3	5	03/07/2005	2,110	0.85	0.01	0.80	429	41.7	39.0
3a	6	03/13/2005	21,595	0.25	0.01	0.14	261	45.0	41.1
4	7	03/28/2005	5,190	N/A	0.00	0.00	1,408	44.6	40.4
5	8	04/02/2005	2,985	1.06	0.05	1.71	1,305	45.7	43.1
5a	9	04/20/2005	855	8.16	0.04	0.58	350	59.0	54.4
6	10	08/12/2005	855	N/A	0.00	0.00	2,420	76.6	72.1
6a	11	08/14/2005	985	N/A	0.00	0.00	1,213	77.4	71.3
7	12	09/15/2005	3,325	N/A	0.00	0.00	4,767	75.7	71.6
7a	13	09/20/2005	960	N/A	0.00	0.00	114	68.5	66.3
8	14	09/26/2005	290	N/A	0.09	0.58	1,778	67.5	66.9
8a	15	09/29/2005	145	1.23	0.13	0.38	2,298	66.6	66.1
9	16	10/08/2005	2,130	8.31	0.10	5.00	3,792	73.2	63.5
9a	17	10/10/2005	1,195	1.51	0.05	0.94	1,636	62.1	58.3
10	18	10/22/2005	1,260	4.52	0.06	0.90	1,365	60.4	49.7
11	19	11/06/2005	1,240	14.52	0.04	0.29	1,205	58.3	53.6
11a	20	11/09/2005	925	2.66	0.06	0.94	1,527	55.9	47.7
12	21	11/30/2005	1,140	1.10	0.03	0.69	1,057	54.0	52.3
13	22	12/16/2005	4,680	5.79	0.06	1.38	1,086	49.5	36.8
13a	23	12/23/2005	5,400	7.26	0.05	1.09	1,377	47.3	39.2

Event Label	Event No.	Date	Storm Duration	Antecedent Dry**Error! Bookmark not defined.**	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
14	24	01/11/2006	6,060	2.37	0.05	0.59	1,984	46.2	42.1
14a	25	01/17/2006	2,325	N/A	0.00	0.00	2,309	45.5	41.8
15	26	03/12/2006	4,245	2.19	0.03	0.99	1,139	48.9	44.6
16	27	04/01/2006	9,025	18.11	0.06	2.29	2,728	58.8	46.5
17	28	04/23/2006	2,800	9.69	0.02	0.78	1,228	50.0	47.6
17a	29	04/28/2006	95	N/A	0.00	0.00	456	47.8	47.6
18	30	05/01/2006	2,905	N/A	0.04	2.43	1,923	53.4	50.7
18a	31	05/09/2006	17,855	5.89	0.12	11.25	5,817	59.9	50.1
19	32	06/01/2006	18,515	5.93	0.41	6.89	14,887	79.0	59.7
20	33	06/20/2006	16,395	5.27	0.09	1.08	3,348	75.9	61.8
20a	34	07/11/2006	3,490	11.69	0.15	2.28	9,755	78.3	70.2
21	35	07/21/2006	2,875	8.18	0.13	0.95	4,951	81.0	69.6
21a	36	07/28/2006	5,000	5.47	0.07	0.38	4,044	84.2	68.5
22	37	08/14/2006	1,385	N/A	0.00	0.00	15,571	72.9	67.5
22a	38	08/20/2006	1,860	N/A	0.00	0.00	9,203	71.6	67.7
23	39	09/03/2006	810	N/A	0.04	0.48	4,070	70.2	67.6
24	40	09/14/2006	380	N/A	0.00	0.00	738	67.8	66.5
24a	41	09/19/2006	430	N/A	0.00	0.00	2,438	73.0	71.4
25	42	10/17/2006	960	4.85	0.01	0.36	661	57.9	54.3
25a	43	10/20/2006	1,135	1.69	0.05	0.70	1,778	61.0	58.6
26	44	11/08/2006	1,860	N/A	0.05	2.12	2,181	55.2	52.5
26a	45	11/12/2006	8,195	3.46	0.10	2.95	4,882	61.0	55.4
27	46	12/01/2006	1,235	2.19	0.09	1.09	3,783	55.4	50.0
27a	47	12/13/2006	225	11.75	0.01	0.05	328	52.5	49.3
28	48	12/22/2006	1,200	9.09	0.03	1.21	1,576	50.0	43.1
28a	49	12/25/2006	1,060	2.40	0.02	0.62	933	54.3	41.0

Event Label	Event No.	Date	Storm Duration	Antecedent Dry**Error! Bookmark not defined.**	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
29	50	01/05/2007	1,200	3.51	0.06	0.66	1,271	56.8	54.2
29a	51	01/08/2007	960	1.39	0.00	0.00	688	49.1	42.9
30	52	03/02/2007	1,900	12.66	0.05	1.55	558	41.0	33.4
31	53	03/10/2007	1,075	7.81	0.00	0.00	116	45.7	36.6
31a	54	03/15/2007	460	N/A	0.00	0.00	10	44.4	43.1
32	55	04/12/2007	1,530	4.82	0.02	0.84	214	45.5	37.3
32a	56	04/15/2007	4,520	1.80	0.07	6.49	2,830	48.0	41.8
33	57	04/27/2007	490	8.06	0.02	0.54	328	51.8	50.2
33a	58	04/29/2007	260	1.27	0.01	0.11	40	49.8	49.4
34	59	05/11/2007	180	10.74	0.05	0.26	2,029	65.3	64.1
34a	60	05/15/2007	7,945	3.92	0.01	0.04	2,984	59.9	51.7
35	61	06/01/2007	105	0.26	0.04	0.07	332	60.4	59.4
35	62	06/02/2007	975	1.10	0.02	0.10	32	62.8	59.9
36	63	07/04/2007	435	21.45	0.04	0.55	839	67.5	66.8
36a	64	07/06/2007	110	1.44	0.03	0.11	243	73.2	70.4
37	65	09/09/2007	3,525	22.19	0.11	0.48	4,604	70.9	65.8
37a	66	09/15/2007	365	3.49	0.03	0.23	261	65.1	65.1
38	67	09/27/2007	370	12.48	0.13	0.47	3,903	72.3	71.3
39	68	10/09/2007	285	1.52	0.03	0.19	546	60.3	59.8
39a	69	10/11/2007	1,450	1.54	0.10	1.26	4,252	62.1	58.7
40	70	10/19/2007	555	7.00	0.06	0.93	2,171	65.7	64.8
41	71	10/27/2007	1,040	1.70	0.04	0.72	502	61.3	56.1
42	72	11/03/2007	500	6.27	0.03	1.10	491	55.4	45.0
43	73	11/06/2007	560	2.36	0.06	0.71	1,410	56.1	50.5
43a	74	11/13/2007	125	5.60	0.01	0.08	11	53.6	48.7
44	75	11/26/2007	1,410	3.64	0.04	0.87	379	50.5	41.9
45	76	12/23/2007	475	11.67	0.09	0.33	2,090	45.1	36.9
46	77	12/29/2007	695	0.47	0.03	0.42	211	46.0	34.9

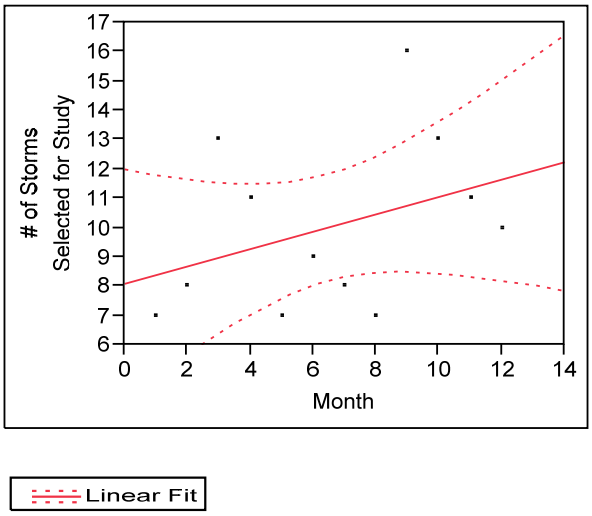
Event Label	Event No.	Date	Storm Duration	Antecedent Dry**Error! Bookmark not defined.**	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
47	78	01/11/2008	730	1.61	0.06	0.69	708	45.5	35.3
48	79	01/18/2008	345	2.66	0.04	0.59	328	45.7	34.1
49	80	02/01/2008	1,265	2.52	0.01	0.01	502	43.7	33.3
50	81	02/05/2008	2,195	2.74	0.08	0.37	308	43.9	33.8
51	82	02/13/2008	3,580	3.22	0.61	0.69	724	42.1	33.8
51a	83	02/17/2008	4,140	3.34	0.03	0.49	449	42.8	38.3
52	84	02/25/2008	4,980	2.37	0.01	0.14	11	42.6	39.6
53	85	03/04/2008	3,840	2.94	0.07	0.93	958	42.4	35.4
54	86	03/07/2008	1,380	2.49	0.02	0.35	300	41.7	35.7
55	87	03/08/2008	2,275	0.38	0.05	1.21	974	41.0	36.9
55a	88	03/12/2008	4,920	3.58	0.01	0.66	214	42.4	38.4
56	89	03/19/2008	2,520	2.75	0.03	0.91	505	42.3	37.9
56a	90	03/28/2008	13,020	7.86	0.08	1.55	982	49.1	42.2
57	91	04/10/2008	4,020	6.39	0.02	0.28	191	46.8	44.6
58	92	04/27/2008	3,900	15.10	0.06	2.74	2,266	53.8	50.4
58a	93	05/03/2008	2,280	3.00	0.04	0.55	1,340	49.6	47.8
59	94	05/27/2008	270	5.59	0.01	0.01	583	78.4	73.5
60	95	05/30/2008	1,785	3.95	0.06	0.13	1,257	71.2	62.8
61	96	06/04/2008	3,780	3.73	0.04	1.01	1,050	65.5	60.7
62	97	06/10/2008	345	3.84	0.03	0.21	589	72.3	71.3
63	98	06/14/2008	4,450	4.01	0.11	1.71	5,918	72.7	66.9
64	99	06/20/2008	560	2.22	0.09	0.20	3,358	78.8	75.0
64a	100	06/22/2008	3,600	1.86	0.08	0.77	3,278	74.8	67.8
65	101	07/17/2008	5,460	4.37	0.17	2.58	17,731	83.1	70.3
66	102	07/23/2008	2,280	2.10	0.21	3.84	17,354	73.8	71.3
66a	103	07/27/2008	1,500	2.18	0.08	0.61	10,281	77.9	75.4
67	104	08/02/2008	840	1.95	0.08	0.38	3,040	74.3	71.0

Event Label	Event No.	Date	Storm Duration	Antecedent Dry**Error! Bookmark not defined.**	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
68	105	08/03/2008	360	0.55	0.25	0.65	11,751	73.0	71.6
68a	106	08/06/2008	4,020	2.60	0.11	2.56	3,897	70.3	65.9
69	107	09/06/2008	1,860	17.84	0.14	4.40	6,727	76.3	70.0
70	108	09/09/2008	840	2.31	0.13	0.38	2,832	70.3	69.4
70a	109	09/12/2008	660	3.11	0.01	0.15	91	66.2	65.4
71	110	09/14/2008	780	1.28	0.04	0.39	886	70.0	68.7
71a	111	09/21/2008	240	7.48	0.03	0.09	272	65.1	64.9
72	112	09/26/2008	4,615	4.32	0.11	3.38	4,513	67.6	62.7
72a	113	10/09/2008	540	2.98	0.02	0.22	380	61.3	57.7
73	114	10/16/2008	780	7.06	0.10	0.44	2,726	63.0	62.3
74	115	10/21/2008	1,000	4.89	0.03	0.30	483	60.1	49.7
74a	116	10/25/2008	705	3.60	0.20	1.26	6,408	59.4	57.1
75	117	11/13/2008	4,220	2.15	0.05	1.18	582	57.7	52.5
75a	118	11/24/2008	1,510	8.62	0.05	1.96	1,163	52.5	43.3
76	119	12/10/2008	4,260	8.47	0.03	1.99	1,127	50.4	37.9
76a	120	12/24/2008	2,520	2.84	0.01	0.23	409	47.7	39.0

	Storm Duration	Antecedent Dry**Error! Bookmark not defined.**	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
							EMT
	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
Minimum	95	0.25	0.00	0.00	10	41.0	33.3
25th Percentile	702	2.17	0.01	0.14	476	47.6	41.9
Median	1,398	3.50	0.04	0.57	1,209	58.6	52.4
75th Percentile	3,645	7.01	0.08	1.08	2,870	70.1	66.0
Maximum	21,595	22.19	0.61	11.25	17,731	84.2	75.4
Mean	2,730	5.06	0.06	0.98	2,422	58.8	53.5
Standard Deviation	3,647	4.53	0.08	1.53	3,408	12.1	12.7

APPENDIX B: STORM DISTRIBUTION STATISTICS

Bivariate Fit of # of Storms Selected for Study By Month



Linear Fit: Y = 8.1 + 0.29X

Summary of Fit	
RSquare	0.134083
RSquare Adj	0.047492
Root Mean Square Error	2.822487
Mean of Response	10
Observations (or Sum Wgts)	12

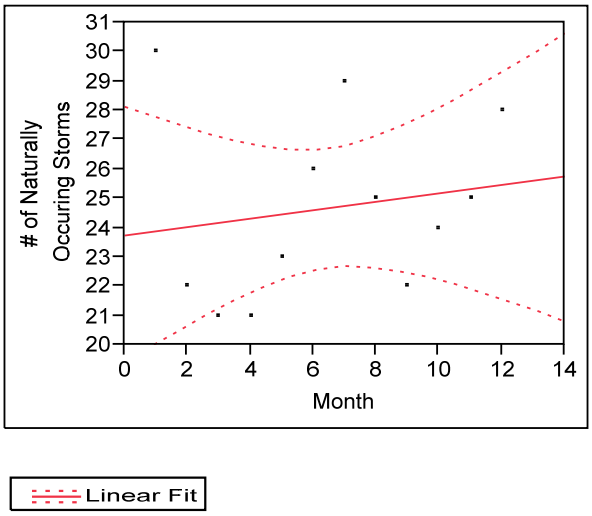
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	12.335664	12.3357	1.5485
Error	10	79.664336	7.9664	**Prob > F**
C. Total	11	92.000000		0.2417

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	8.0909091	1.737121	4.66	0.0009*
Month	0.2937063	0.236028	1.24	0.2417

Bivariate Fit of # of Naturally Occurring Storms By Month



Linear Fit: Y = 23.8 + 0.14X

Summary of Fit	
RSquare	0.026725
RSquare Adj	-0.0706
Root Mean Square Error	3.1917
Mean of Response	24.66667
Observations (or Sum Wgts)	12

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2.79720	2.7972	0.2746
Error	10	101.86946	10.1869	**Prob > F**
C. Total	11	104.66667		0.6117

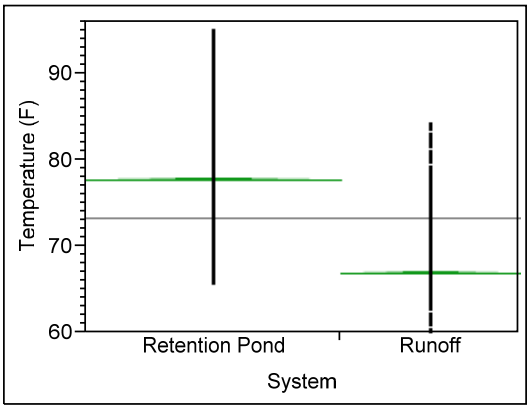
Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	23.757576	1.964355	12.09	<.0001*
Month	0.1398601	0.266903	0.52	0.6117

APPENDIX C: MEAN JULY STATISTICS

Retention Pond

Mean July Temperatures



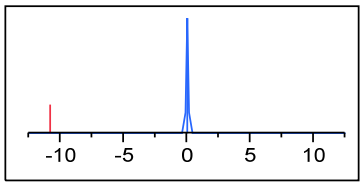
Oneway Anova

Summary of Fit	
Rsquare	0.50831
Adj Rsquare	0.508262
Root Mean Square Error	5.229293
Mean of Response	73.43639
Observations (or Sum Wgts)	10275

t Test: Runoff-Retention Pond

Assuming equal variances

Difference	-10.802	t Ratio	-103.054
Std Err Dif	0.105	DF	10273
Upper CL Dif	-10.596	Prob > |t|	0.0000*
Lower CL Dif	-11.007	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	290415.50	290416	10620.23	0.0000*
Error	10273	280920.42	27		
C. Total	10274	571335.92			

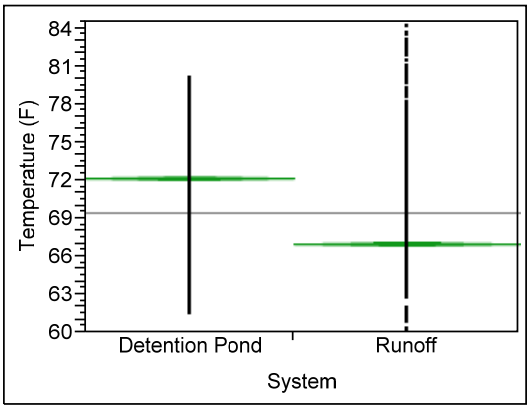
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Retention Pond	6043	77.8854	0.06727	77.754	78.017
Runoff	4232	67.0835	0.08038	66.926	67.241

Std Error uses a pooled estimate of error variance

Detention Pond

Mean July Temperatures



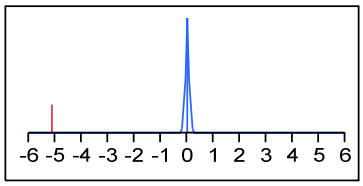
Oneway Anova

Summary of Fit	
Rsquare	0.36025
Adj Rsquare	0.360171
Root Mean Square Error	3.42455
Mean of Response	69.54284
Observations (or Sum Wgts)	8109

t Test: Runoff-Detention Pond

Assuming equal variances

Difference	-5.1439	t Ratio	-67.5658
Std Err Dif	0.0761	DF	8107
Upper CL Dif	-4.9947	Prob > |t|	0.0000*
Lower CL Dif	-5.2931	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
System	1	53537.83	53537.8	4565.137	0.0000*
Error	8107	95075.17	11.7		
C. Total	8108	148613.00			

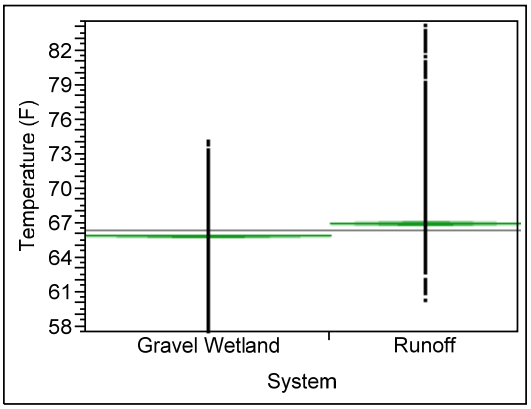
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Detention Pond	3877	72.2274	0.05500	72.120	72.335
Runoff	4232	67.0835	0.05264	66.980	67.187

Std Error uses a pooled estimate of error variance

Gravel Wetland

Mean July Temperatures



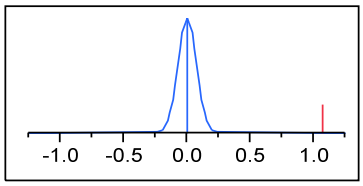
Oneway Anova

Summary of Fit	
Rsquare	0.02056
Adj Rsquare	0.020459
Root Mean Square Error	3.641098
Mean of Response	66.48324
Observations (or Sum Wgts)	9712

t Test: Runoff-Gravel Wetland

Assuming equal variances

Difference	1.06379	t Ratio	14.27689
Std Err Dif	0.07451	DF	9710
Upper CL Dif	1.20985	Prob > |t|	<.0001*
Lower CL Dif	0.91774	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	2702.29	2702.29	203.8296	<.0001*
Error	9710	128731.26	13.26		
C. Total	9711	131433.55			

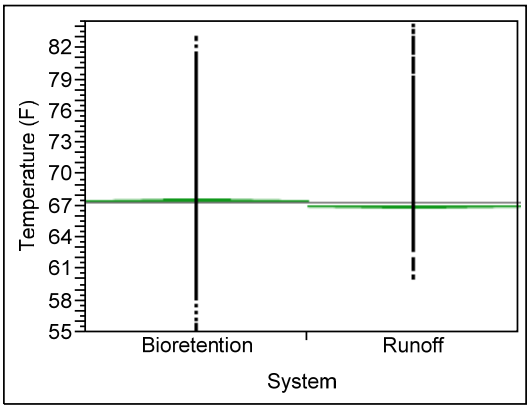
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Gravel Wetland	5480	66.0197	0.04919	65.923	66.116
Runoff	4232	67.0835	0.05597	66.974	67.193

Std Error uses a pooled estimate of error variance

Bioretention

Mean July Temperatures



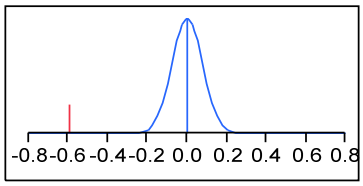
Oneway Anova

Summary of Fit	
Rsquare	0.006991
Adj Rsquare	0.006877
Root Mean Square Error	3.568833
Mean of Response	67.39082
Observations (or Sum Wgts)	8691

t Test: Runoff-Bioretention

Assuming equal variances

Difference	-0.59902	t Ratio	-7.82123
Std Err Dif	0.07659	DF	8689
Upper CL Dif	-0.44889	Prob > |t|	<.0001*
Lower CL Dif	-0.74916	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	779.12	779.116	61.1716	<.0001*
Error	8689	110668.05	12.737		
C. Total	8690	111447.17			

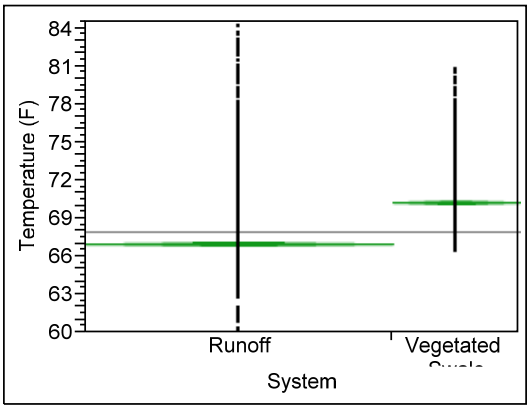
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Bioretention	4459	67.6825	0.05345	67.578	67.787
Runoff	4232	67.0835	0.05486	66.976	67.191

Std Error uses a pooled estimate of error variance

Vegetated Swale

Mean July Temperatures



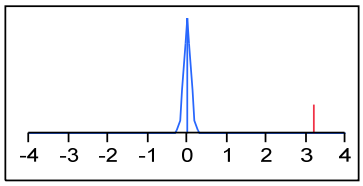
Oneway Anova

Summary of Fit	
Rsquare	0.174919
Adj Rsquare	0.174782
Root Mean Square Error	3.181354
Mean of Response	68.02823
Observations (or Sum Wgts)	5993

t Test: Vegetated Swale-Runoff

Assuming equal variances

Difference	3.21515	t Ratio	35.63857
Std Err Dif	0.09022	DF	5991
Upper CL Dif	3.39201	Prob > |t|	<.0001*
Lower CL Dif	3.03830	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	12854.771	12854.8	1270.107	<.0001*
Error	5991	60634.972	10.1		
C. Total	5992	73489.743			

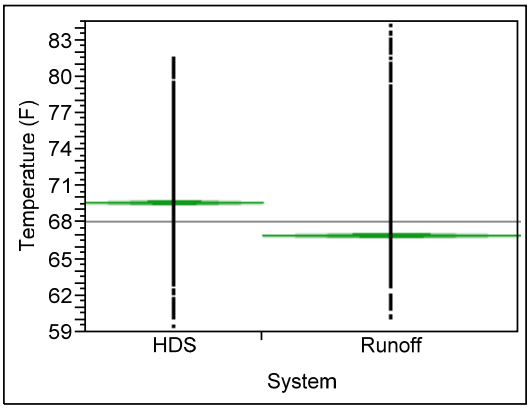
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Runoff	4232	67.0835	0.04890	66.988	67.179
Vegetated Swale	1761	70.2986	0.07581	70.150	70.447

Std Error uses a pooled estimate of error variance

Hydrodynamic Separators

Mean July Temperatures



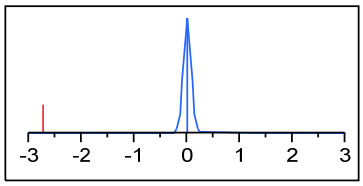
Oneway Anova

Summary of Fit	
Rsquare	0.15513
Adj Rsquare	0.155012
Root Mean Square Error	3.123216
Mean of Response	68.19404
Observations (or Sum Wgts)	7147

t Test: Runoff-HDS

Assuming equal variances

Difference	-2.7229	t Ratio	-36.2205
Std Err Dif	0.0752	DF	7145
Upper CL Dif	-2.5755	Prob > |t|	0.0000*
Lower CL Dif	-2.8702	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	12797.118	12797.1	1311.922	<.0001*
Error	7145	69695.748	9.8		
C. Total	7146	82492.866			

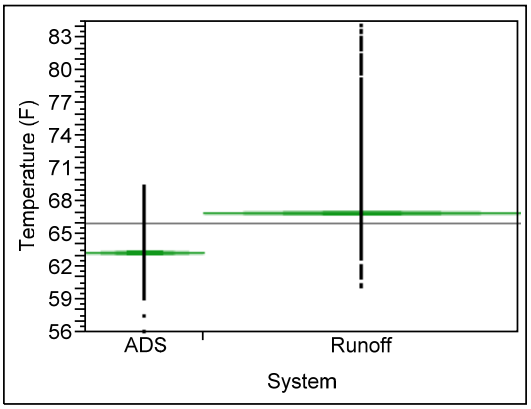
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
HDS	2915	69.8063	0.05785	69.693	69.920
Runoff	4232	67.0835	0.04801	66.989	67.178

Std Error uses a pooled estimate of error variance

ADS Infiltration System

Mean July Temperatures



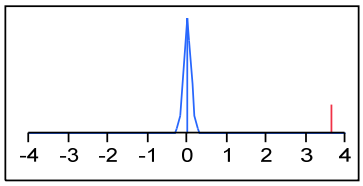
Oneway Anova

Summary of Fit	
Rsquare	0.196402
Adj Rsquare	0.196264
Root Mean Square Error	3.271096
Mean of Response	66.09805
Observations (or Sum Wgts)	5804

t Test: Runoff-ADS

Assuming equal variances

Difference	3.63832	t Ratio	37.65674
Std Err Dif	0.09662	DF	5802
Upper CL Dif	3.82772	Prob > |t|	<.0001*
Lower CL Dif	3.44891	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	15173.019	15173.0	1418.030	<.0001*
Error	5802	62081.809	10.7		
C. Total	5803	77254.828			

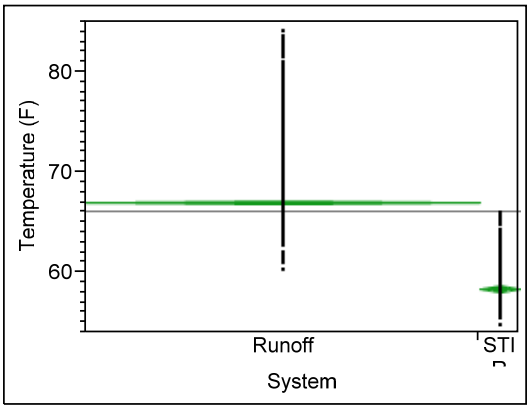
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
ADS	1572	63.4452	0.08250	63.283	63.607
Runoff	4232	67.0835	0.05028	66.985	67.182

Std Error uses a pooled estimate of error variance

StormTech Isolator Row

Mean July Temperatures



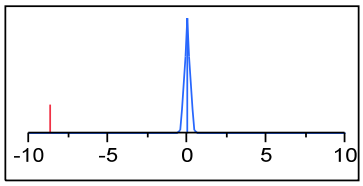
Oneway Anova

Summary of Fit	
Rsquare	0.342459
Adj Rsquare	0.342317
Root Mean Square Error	3.436255
Mean of Response	66.29963
Observations (or Sum Wgts)	4655

t Test: STIR-Runoff

Assuming equal variances

Difference	-8.6260	t Ratio	-49.2276
Std Err Dif	0.1752	DF	4653
Upper CL Dif	-8.2825	Prob > |t|	0.0000*
Lower CL Dif	-8.9696	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	28614.680	28614.7	2423.361	0.0000*
Error	4653	54941.930	11.8		
C. Total	4654	83556.609			

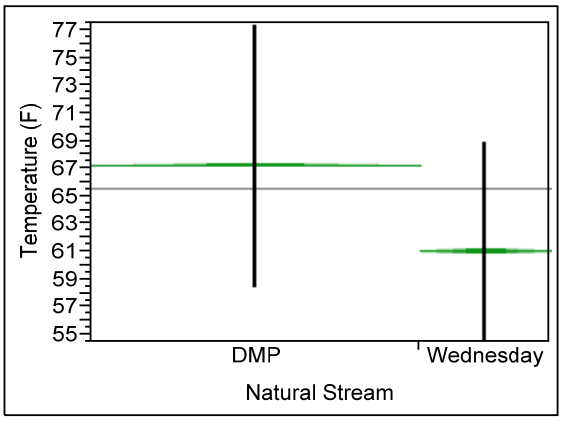
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Runoff	4232	67.0835	0.05282	66.980	67.187
STIR	423	58.4574	0.16708	58.130	58.785

Std Error uses a pooled estimate of error variance

College Brook (d/s) vs. Wednesday Hill Brook

Mean July Temperature



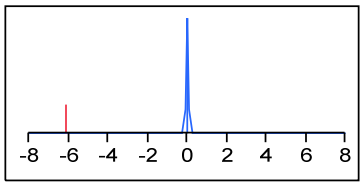
Oneway Anova

Summary of Fit	
Rsquare	0.419558
Adj Rsquare	0.419503
Root Mean Square Error	3.279109
Mean of Response	65.56336
Observations (or Sum Wgts)	10412

t Test: Wednesday-DMP

Assuming equal variances

Difference	-6.1699	t Ratio	-86.7446
Std Err Dif	0.0711	DF	10410
Upper CL Dif	-6.0305	Prob > |t|	0.0000*
Lower CL Dif	-6.3093	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	80908.90	80908.9	7524.622	0.0000*
Error	10410	111934.09	10.8		
C. Total	10411	192842.99			

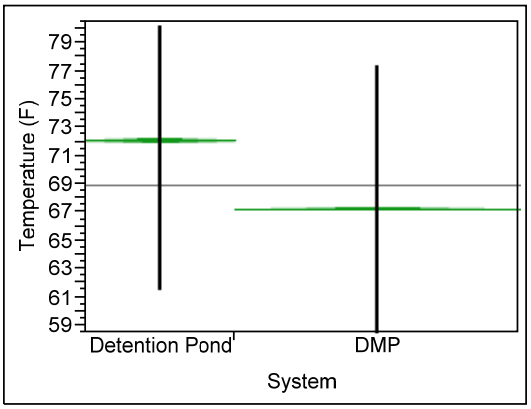
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
DMP	7436	67.3269	0.03803	67.252	67.401
Wednesday	2976	61.1570	0.06011	61.039	61.275

Std Error uses a pooled estimate of error variance

Detention Pond vs. College Brook (d/s)

Mean July Temperature



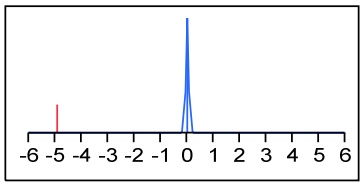
Oneway Anova

Summary of Fit	
Rsquare	0.325457
Adj Rsquare	0.325398
Root Mean Square Error	3.348716
Mean of Response	69.00629
Observations (or Sum Wgts)	11313

t Test: DMP-Detention Pond

Assuming equal variances

Difference	-4.9005	t Ratio	-73.8742
Std Err Dif	0.0663	DF	11311
Upper CL Dif	-4.7705	Prob > |t|	0.0000*
Lower CL Dif	-5.0306	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	61198.71	61198.7	5457.398	0.0000*
Error	11311	126840.40	11.2		
C. Total	11312	188039.11			

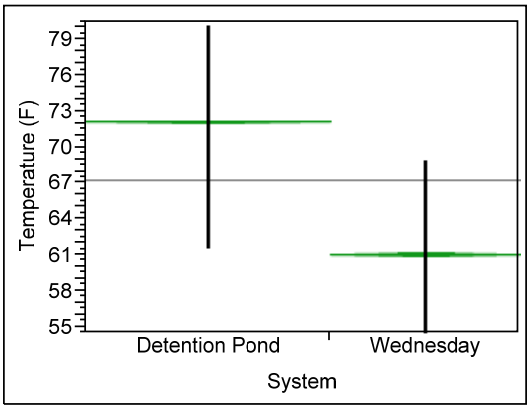
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Detention Pond	3877	72.2274	0.05378	72.122	72.333
DMP	7436	67.3269	0.03883	67.251	67.403

Std Error uses a pooled estimate of error variance

Detention Pond vs. Wednesday Hill Brook

Mean July Temperature



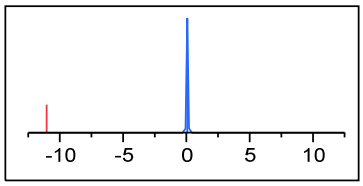
Oneway Anova

Summary of Fit	
Rsquare	0.743364
Adj Rsquare	0.743326
Root Mean Square Error	3.224556
Mean of Response	67.41992
Observations (or Sum Wgts)	6853

t Test: Wednesday-Detention Pond

Assuming equal variances

Difference	-11.070	t Ratio	-140.87
Std Err Dif	0.079	DF	6851
Upper CL Dif	-10.916	Prob > |t|	0.0000*
Lower CL Dif	-11.224	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	206337.18	206337	19844.38	0.0000*
Error	6851	71235.07	10		
C. Total	6852	277572.25			

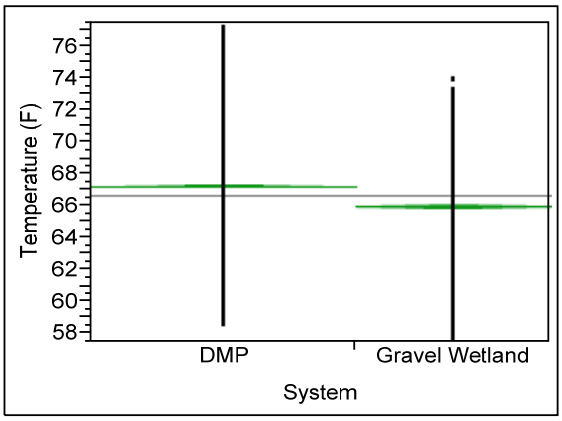
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Detention Pond	3877	72.2274	0.05179	72.126	72.329
Wednesday	2976	61.1570	0.05911	61.041	61.273

Std Error uses a pooled estimate of error variance

Gravel Wetland vs. College Brook (d/s)

Mean July Temperature



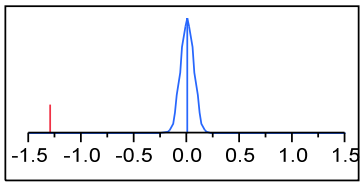
Oneway Anova

Summary of Fit	
Rsquare	0.032497
Adj Rsquare	0.032423
Root Mean Square Error	3.525351
Mean of Response	66.77226
Observations (or Sum Wgts)	12916

t Test: Gravel Wetland-DMP

Assuming equal variances

Difference	-1.3072	t Ratio	-20.8271
Std Err Dif	0.0628	DF	12914
Upper CL Dif	-1.1842	Prob > |t|	0.0000*
Lower CL Dif	-1.4302	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	5390.91	5390.91	433.7681	<.0001*
Error	12914	160496.50	12.43		
C. Total	12915	165887.41			

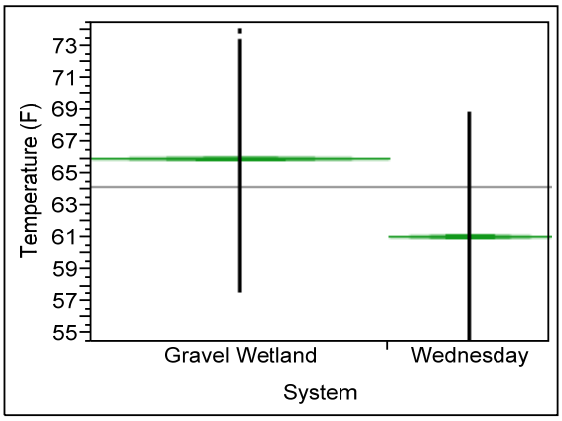
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
DMP	7436	67.3269	0.04088	67.247	67.407
Gravel Wetland	5480	66.0197	0.04762	65.926	66.113

Std Error uses a pooled estimate of error variance

Gravel Wetland vs. Wednesday Hill Brook

Mean July Temperature



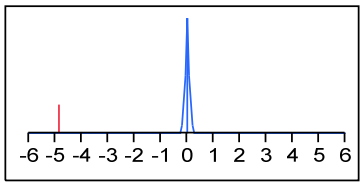
Oneway Anova

Summary of Fit	
Rsquare	0.30303
Adj Rsquare	0.302947
Root Mean Square Error	3.522397
Mean of Response	64.3083
Observations (or Sum Wgts)	8456

t Test: Wednesday-Gravel Wetland

Assuming equal variances

Difference	-4.8627	t Ratio	-60.6271
Std Err Dif	0.0802	DF	8454
Upper CL Dif	-4.7055	Prob > |t|	0.0000*
Lower CL Dif	-5.0200	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	45604.70	45604.7	3675.640	0.0000*
Error	8454	104891.16	12.4		
C. Total	8455	150495.86			

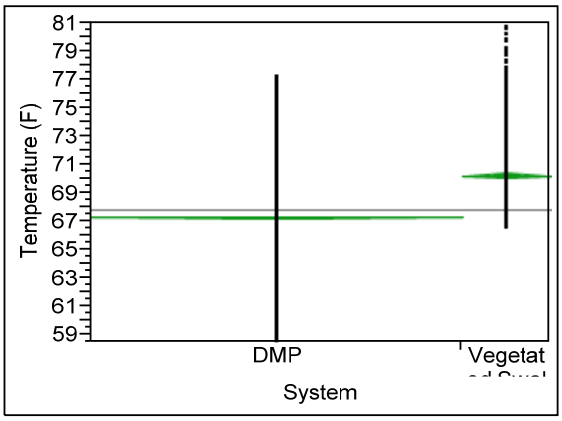
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Gravel Wetland	5480	66.0197	0.04758	65.926	66.113
Wednesday	2976	61.1570	0.06457	61.030	61.284

Std Error uses a pooled estimate of error variance

Vegetated Swale vs. College Brook (d/s)

Mean July Temperature



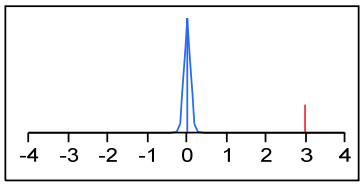
Oneway Anova

Summary of Fit	
Rsquare	0.119784
Adj Rsquare	0.119688
Root Mean Square Error	3.17001
Mean of Response	67.89589
Observations (or Sum Wgts)	9197

t Test: Vegetated Swale-DMP

Assuming equal variances

Difference	2.97177	t Ratio	35.3737
Std Err Dif	0.08401	DF	9195
Upper CL Dif	3.13645	Prob > |t|	<.0001*
Lower CL Dif	2.80709	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	12574.26	12574.3	1251.299	<.0001*
Error	9195	92400.21	10.0		
C. Total	9196	104974.46			

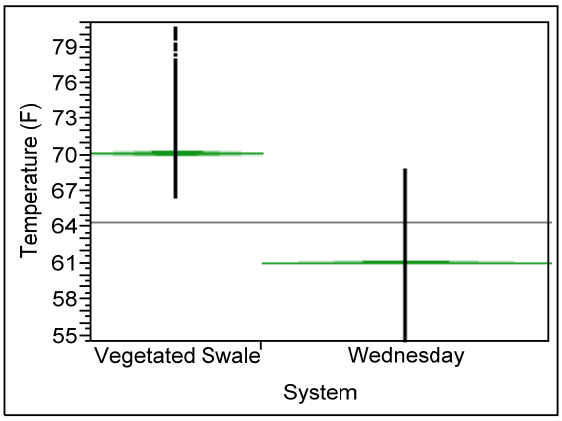
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
DMP	7436	67.3269	0.03676	67.255	67.399
Vegetated Swale	1761	70.2986	0.07554	70.151	70.447

Std Error uses a pooled estimate of error variance

Vegetated Swale vs. Wednesday Hill Brook

Mean July Temperature



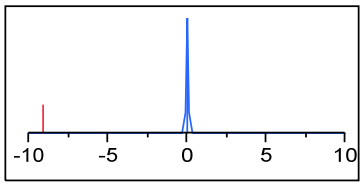
Oneway Anova

Summary of Fit	
Rsquare	0.715325
Adj Rsquare	0.715265
Root Mean Square Error	2.787621
Mean of Response	64.55541
Observations (or Sum Wgts)	4737

t Test: Wednesday-Vegetated Swale

Assuming equal variances

Difference	-9.1417	t Ratio	-109.078
Std Err Dif	0.0838	DF	4735
Upper CL Dif	-8.9774	Prob > |t|	0.0000*
Lower CL Dif	-9.3060	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	92457.27	92457.3	11897.99	0.0000*
Error	4735	36794.87	7.8		
C. Total	4736	129252.14			

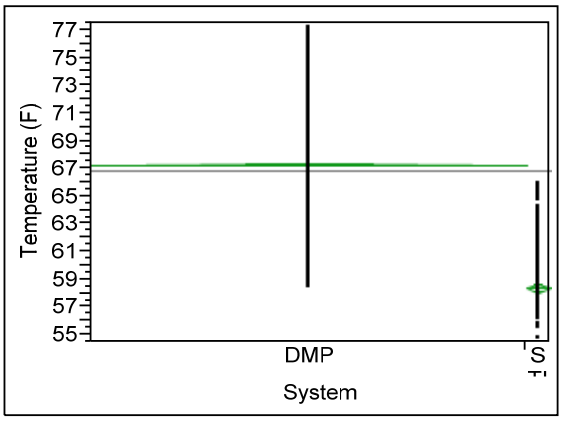
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Vegetated Swale	1761	70.2986	0.06643	70.168	70.429
Wednesday	2976	61.1570	0.05110	61.057	61.257

Std Error uses a pooled estimate of error variance

StormTech Isolator Row vs. College Brook (d/s)

Mean July Temperature



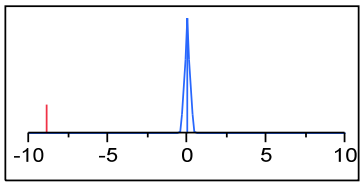
Oneway Anova

Summary of Fit	
Rsquare	0.266388
Adj Rsquare	0.266295
Root Mean Square Error	3.321996
Mean of Response	66.84948
Observations (or Sum Wgts)	7859

t Test: STIR-DMP

Assuming equal variances

Difference	-8.8694	t Ratio	-53.4137
Std Err Dif	0.1661	DF	7857
Upper CL Dif	-8.5439	Prob > |t|	0.0000*
Lower CL Dif	-9.1949	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	31484.96	31485.0	2853.021	0.0000*
Error	7857	86707.17	11.0		
C. Total	7858	118192.13			

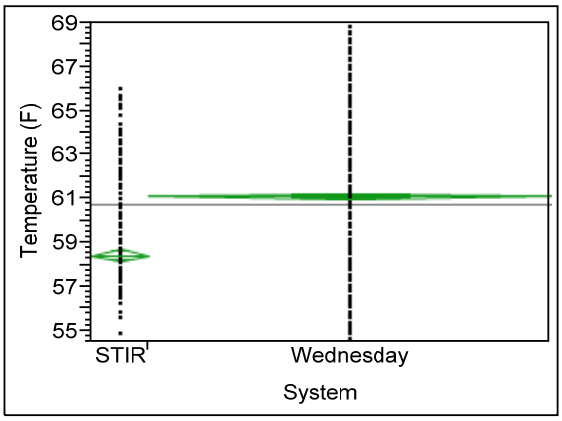
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
DMP	7436	67.3269	0.03852	67.251	67.402
STIR	423	58.4574	0.16152	58.141	58.774

Std Error uses a pooled estimate of error variance

StormTech Isolator Row vs. Wednesday Hill Brook

Mean July Temperature



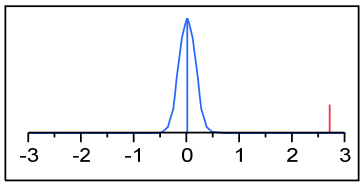
Oneway Anova

Summary of Fit	
Rsquare	0.079848
Adj Rsquare	0.079577
Root Mean Square Error	3.025835
Mean of Response	60.82101
Observations (or Sum Wgts)	3399

t Test: Wednesday-STIR

Assuming equal variances

Difference	2.69951	t Ratio	17.16922
Std Err Dif	0.15723	DF	3397
Upper CL Dif	3.00778	Prob > |t|	<.0001*
Lower CL Dif	2.39123	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	2698.930	2698.93	294.7822	<.0001*
Error	3397	31101.830	9.16		
C. Total	3398	33800.760			

Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
STIR	423	58.4574	0.14712	58.169	58.746
Wednesday	2976	61.1570	0.05547	61.048	61.266

Std Error uses a pooled estimate of error variance

APPENDIX D: SYSTEM CDF STATISTICS

(Annual, Summer, Winter)

Retention Pond (Annual)

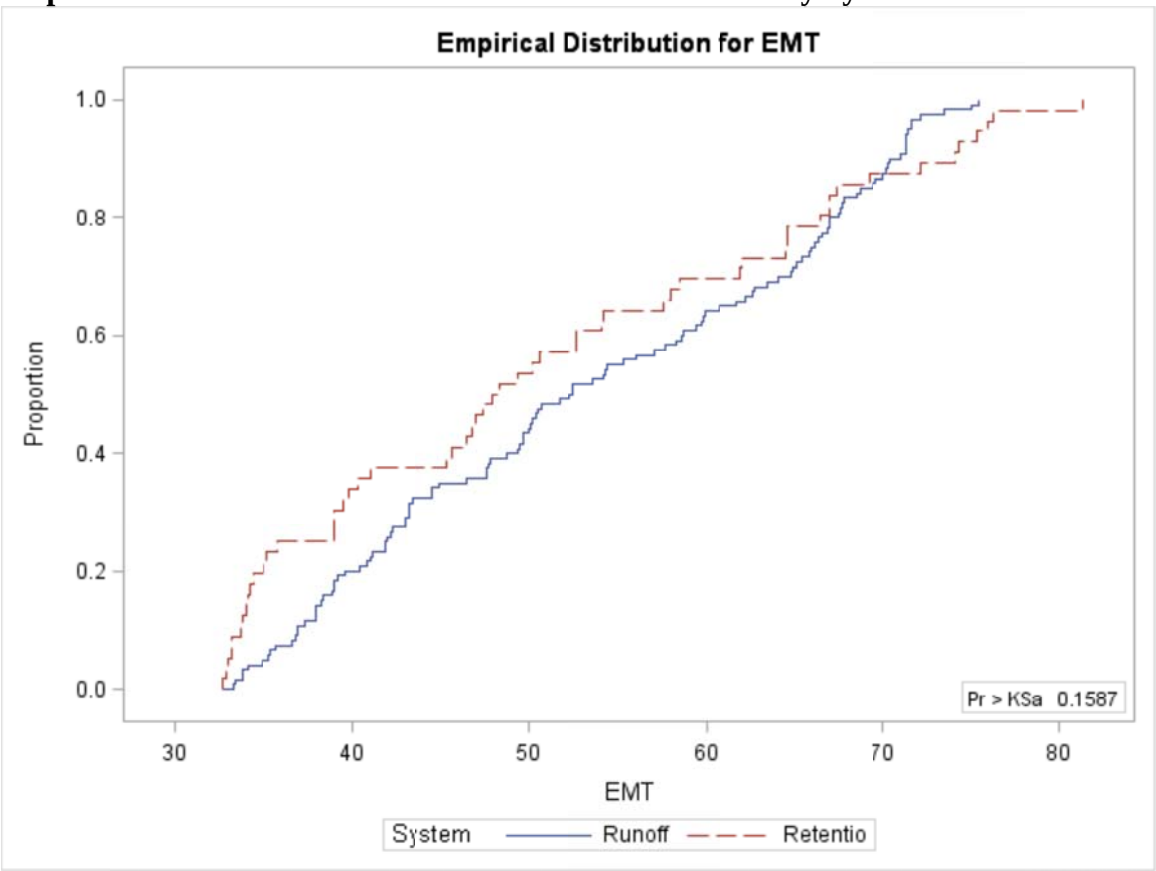
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.05	-0.6349
Retention Pond	56	0.23214	0.92934
Total	176	0.10795	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.084837	D	0.182143
KSa	1.125487	Pr > KSa	0.1587

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Annual)

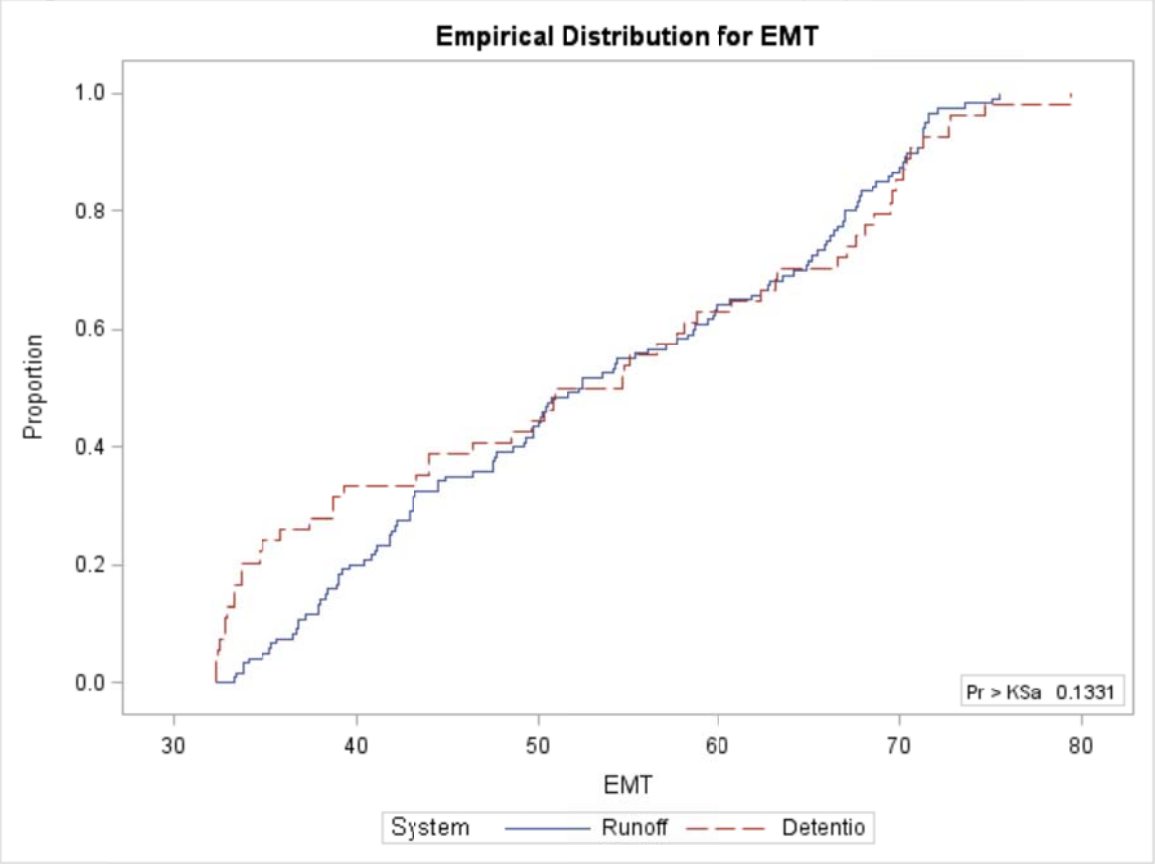
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.05	-0.6485
Detention Pond	54	0.24074	0.96666
Total	174	0.1092	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.088243	D	0.190741
KSa	1.164009	Pr > KSa	0.1331

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

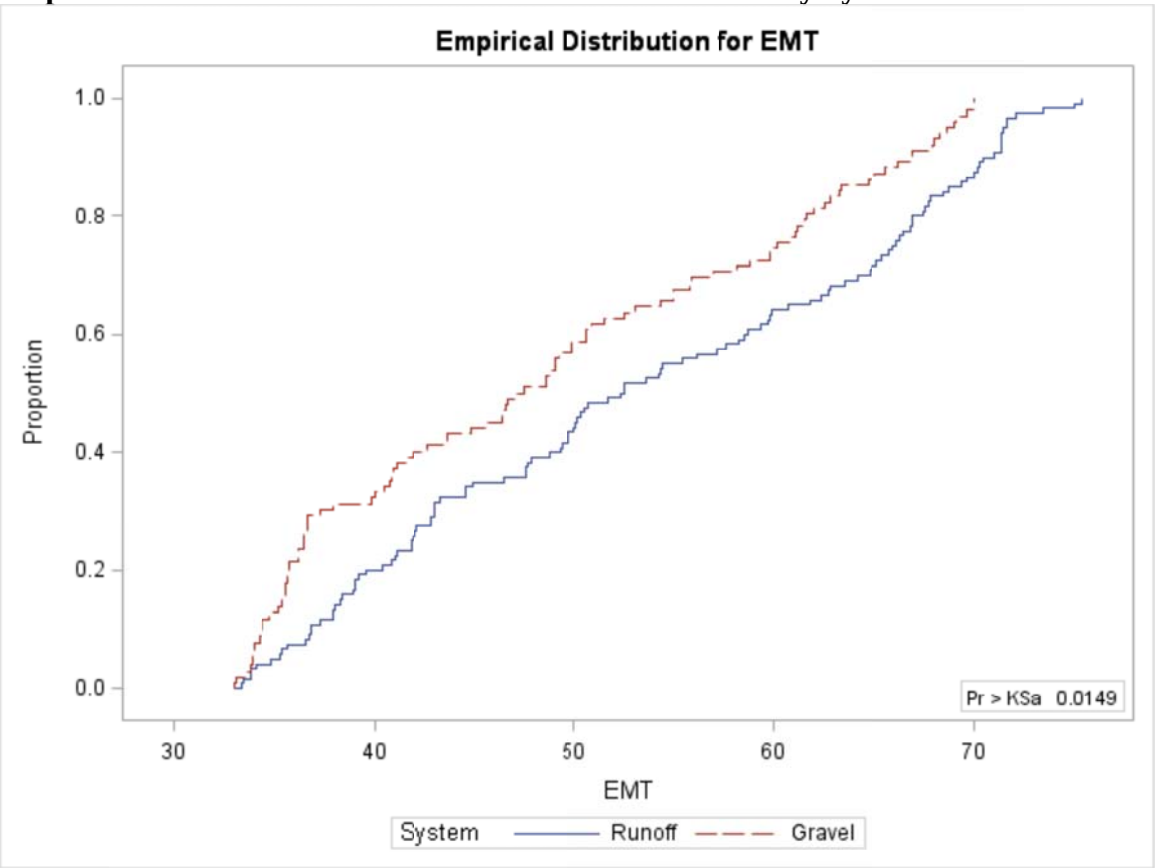
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.08333	-1.0609
Gravel Wetland	102	0.29412	1.15071
Total	222	0.18018	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.105045	D	0.210784
KSa	1.565138	Pr > KSa	0.0149

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

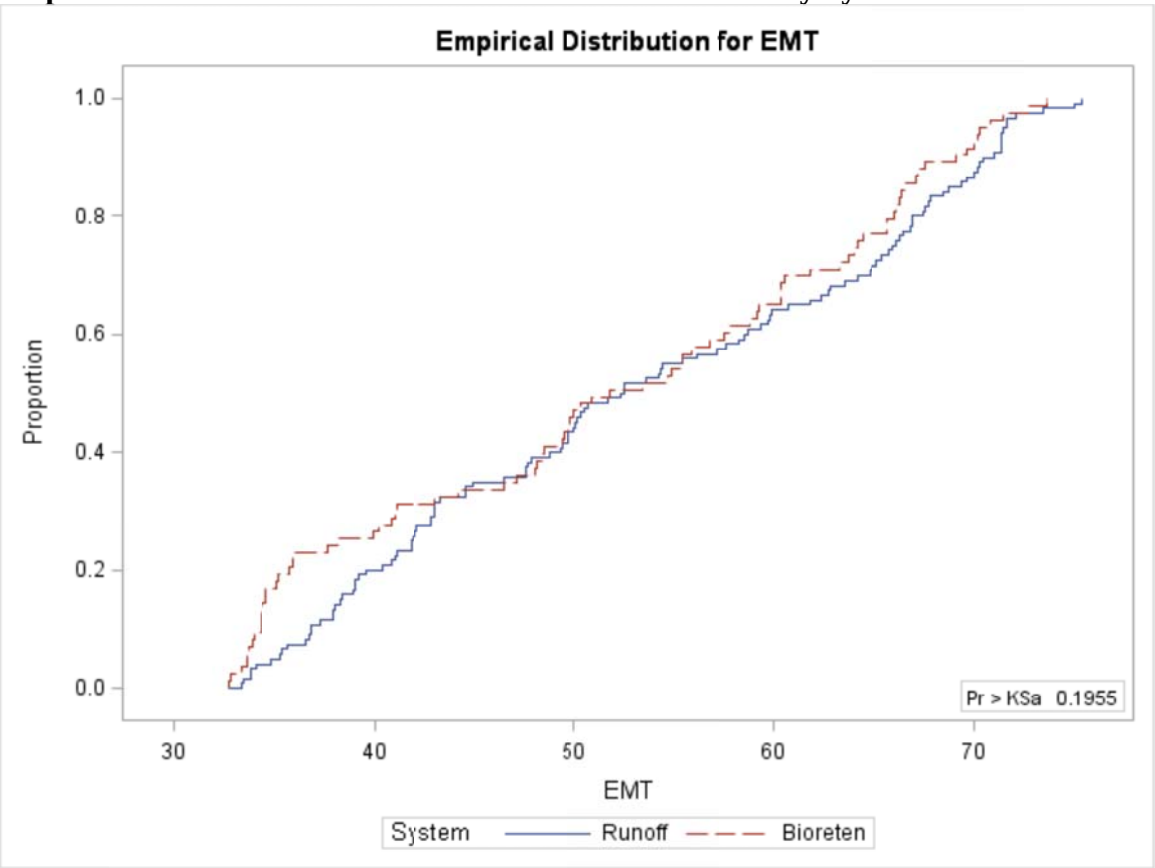
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.075	-0.6894
Bioretention	83	0.22892	0.82891
Total	203	0.13793	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.075669	D	0.153916
KSa	1.078113	Pr > KSa	0.1955

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

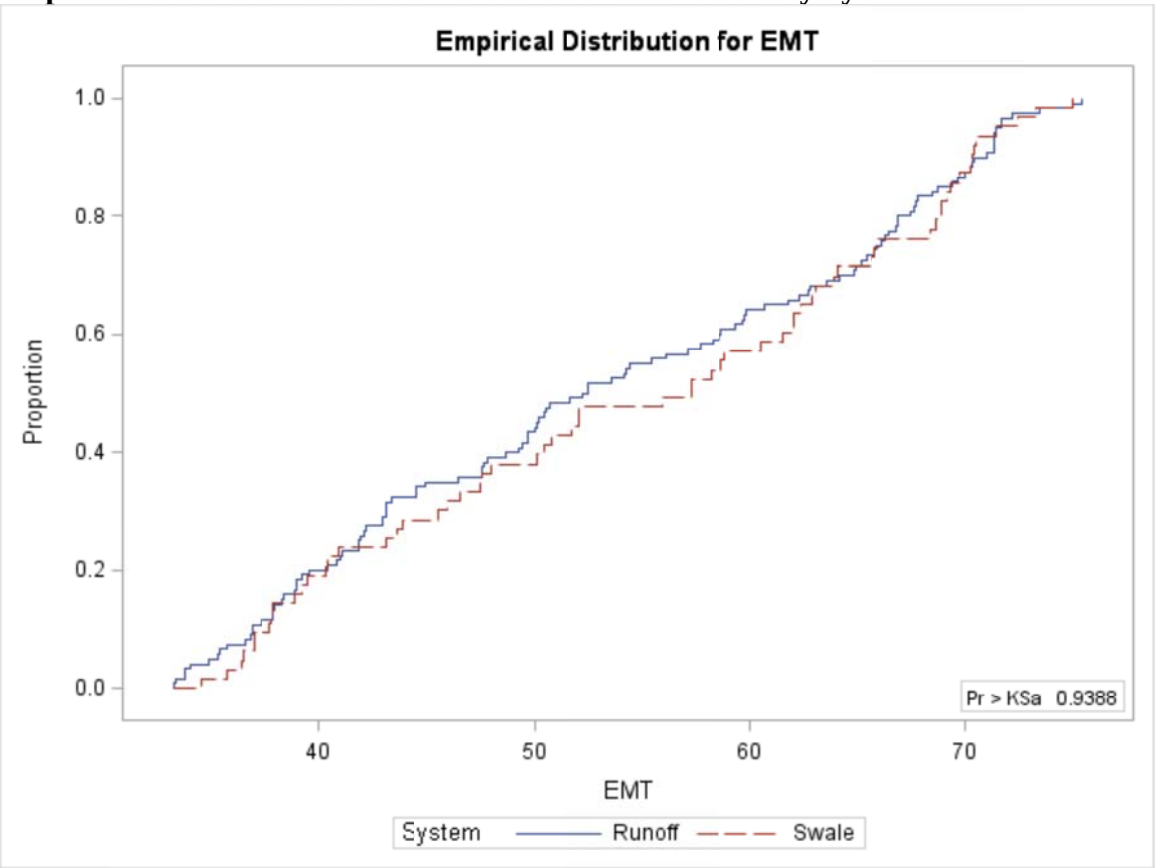
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.575	0.31277
Vegetated Swale	63	0.49206	-0.4317
Total	183	0.54645	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.039405	D	0.082937
KSa	0.533066	Pr > KSa	0.9388

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

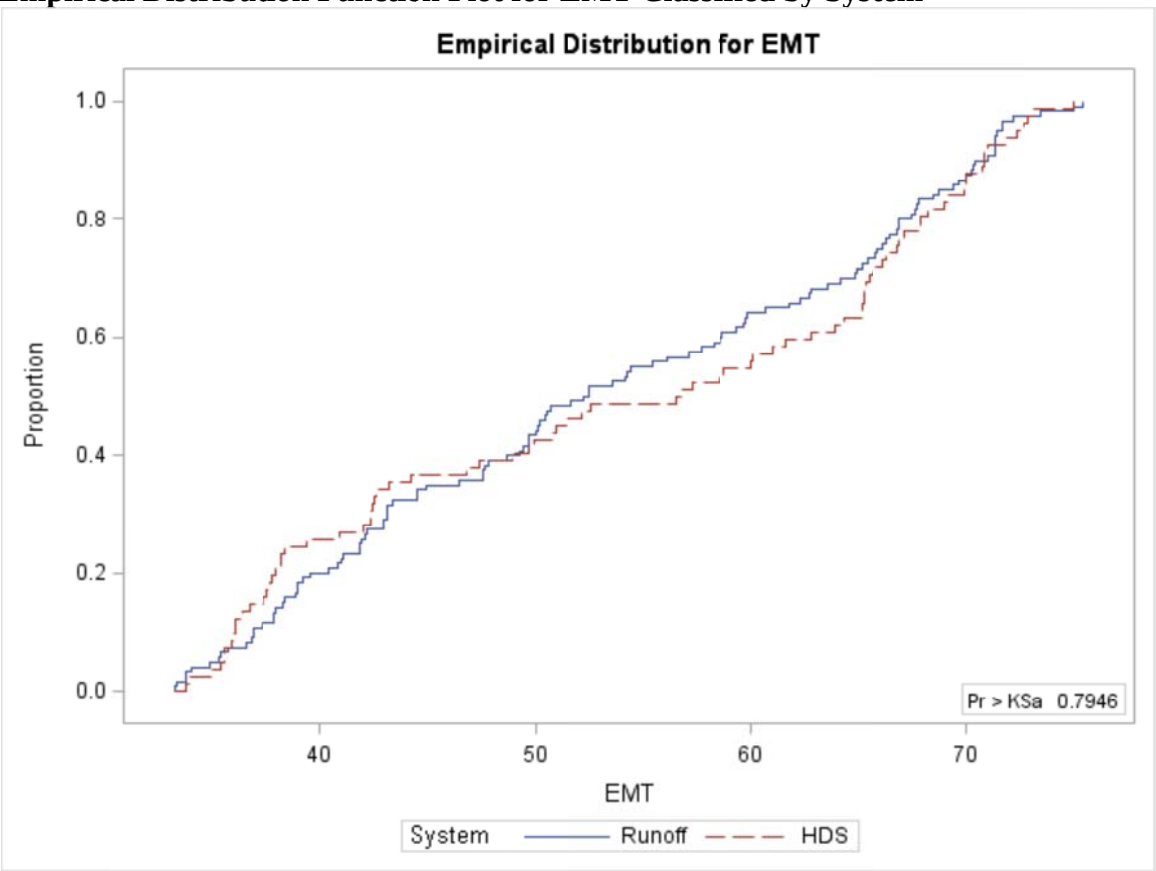
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.64167	0.41305
HDS	82	0.54878	-0.4997
Total	202	0.60396	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.045614	D	0.092886
KSa	0.648295	Pr > KSa	0.7946

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

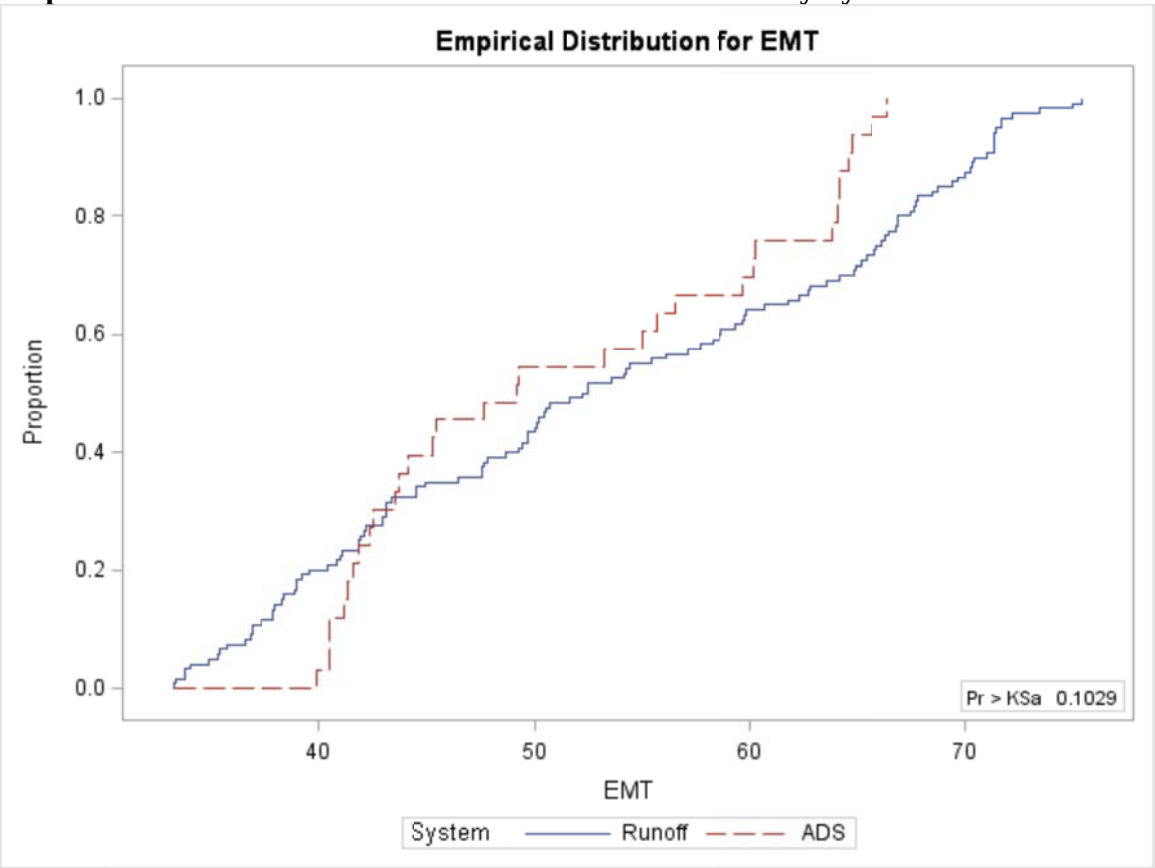
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.7	-0.5656
ADS	33	0.93939	1.0786
Total	153	0.75163	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.098462	D	0.239394
KSa	1.217910	Pr > KSa	0.1029

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

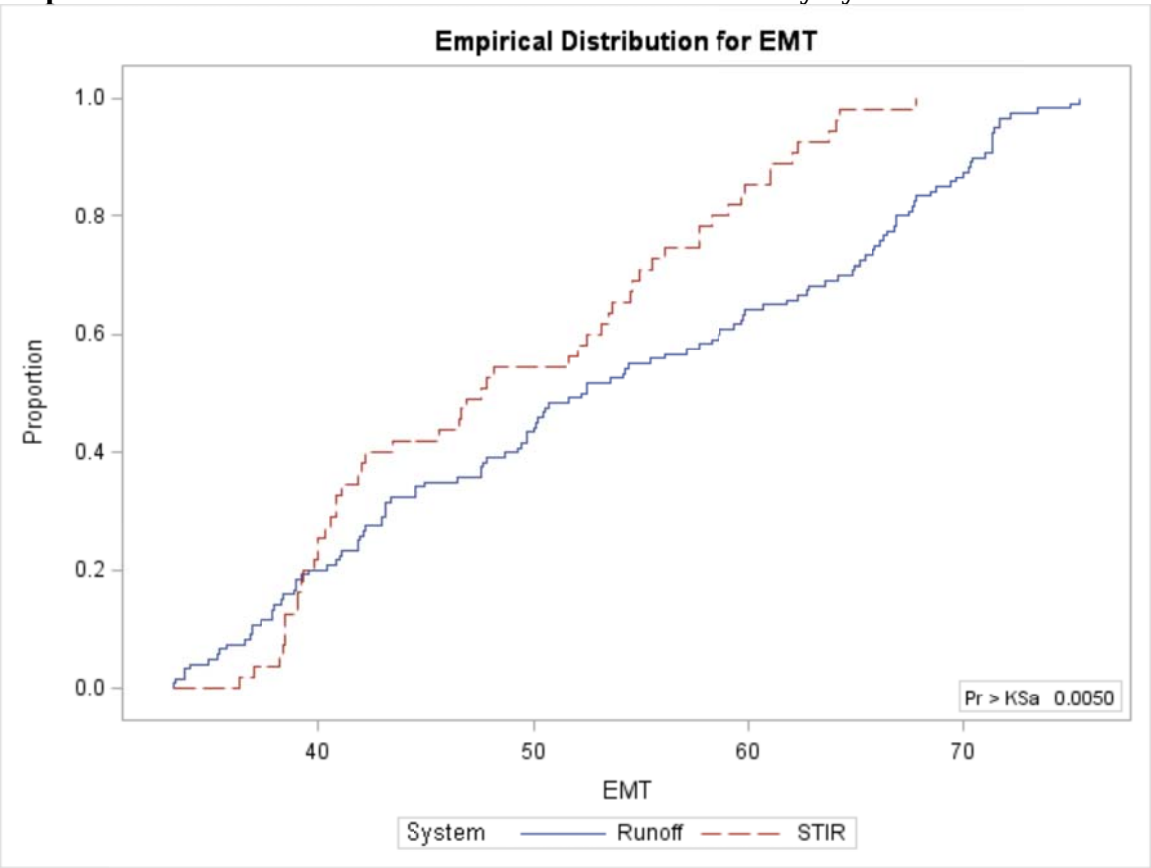
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.7	-0.9703
STIR	55	0.98182	1.43316
Total	175	0.78857	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.130829	D	0.281818
KSa	1.730701	Pr > KSa	0.0050

Empirical Distribution Function Plot for EMT Classified by System



Retention Pond (Summer)

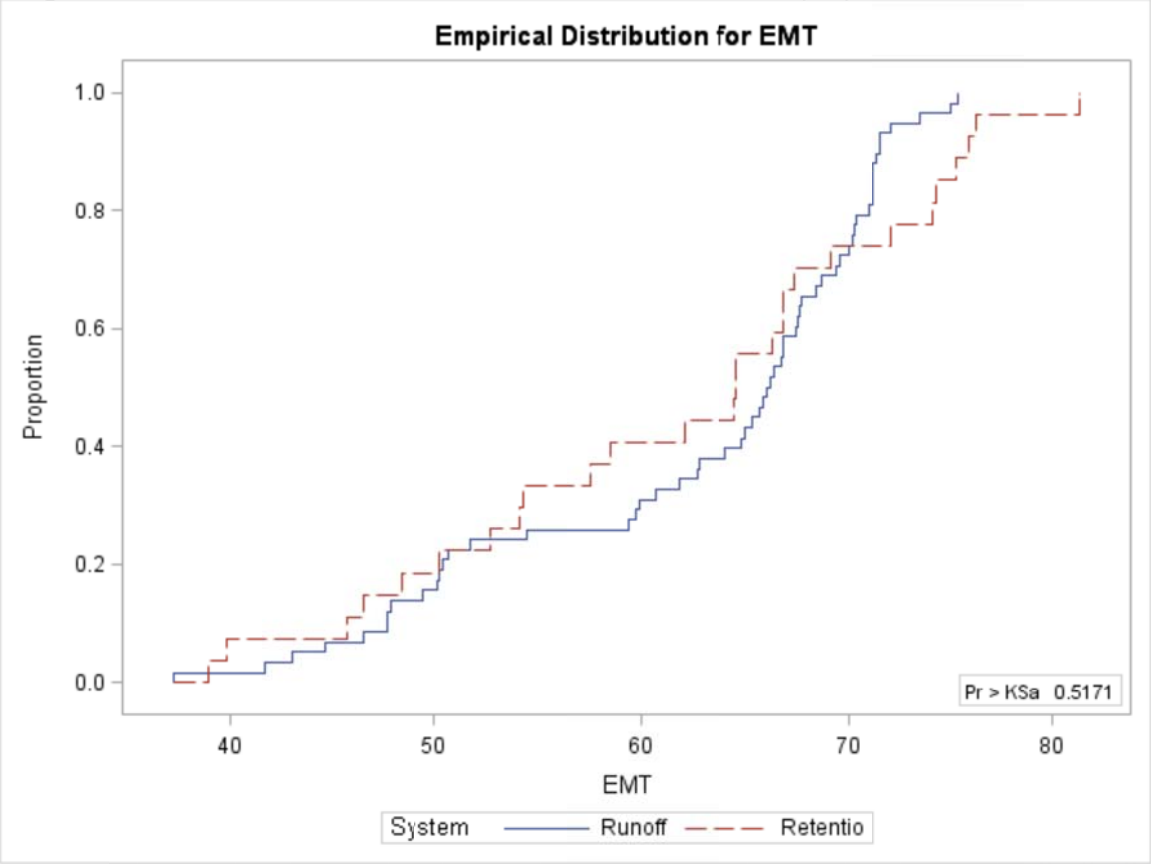
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.93103	0.46034
Retention Pond	27	0.74074	-0.6747
Total	85	0.87059	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.088593	D	0.190294
KSa	0.816791	Pr > KSa	0.5171

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

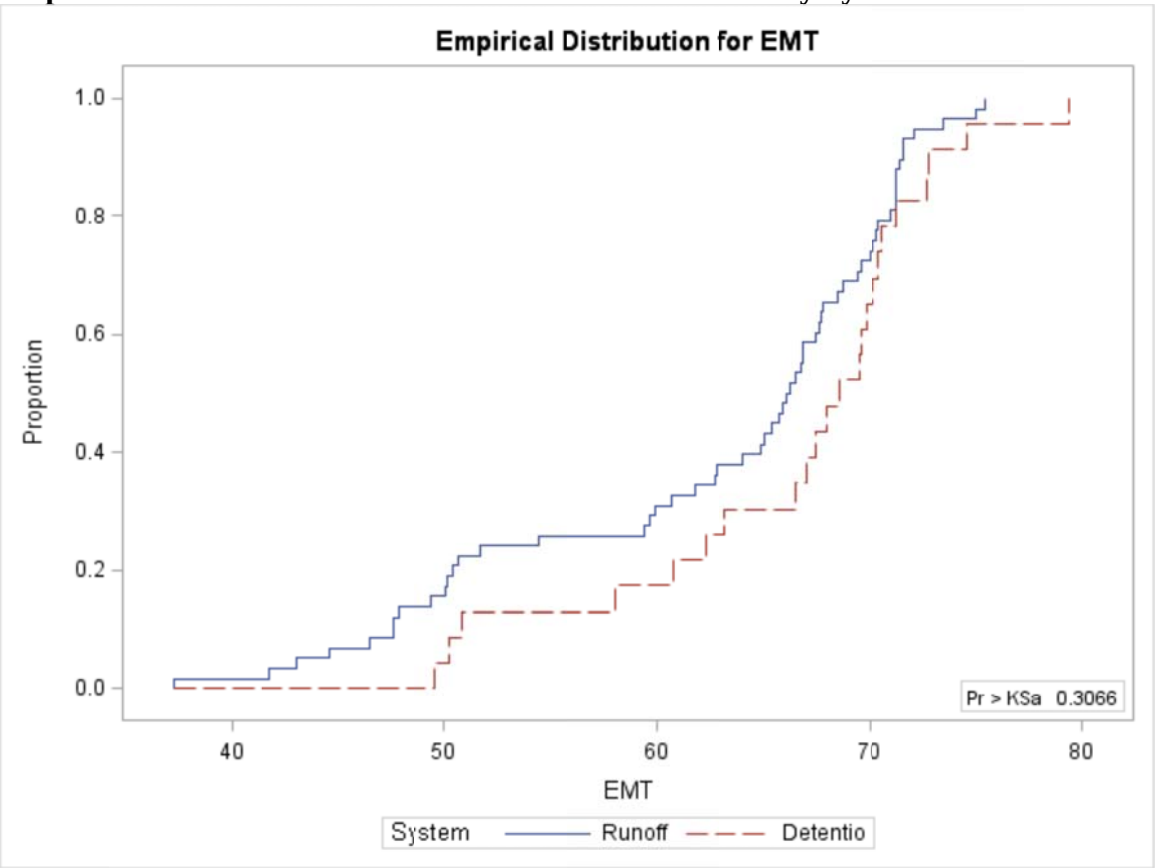
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.58621	0.5155
Detention Pond	23	0.34783	-0.8186
Total	81	0.51852	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.107489	D	0.238381
KSa	0.967401	Pr > KSa	0.3066

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

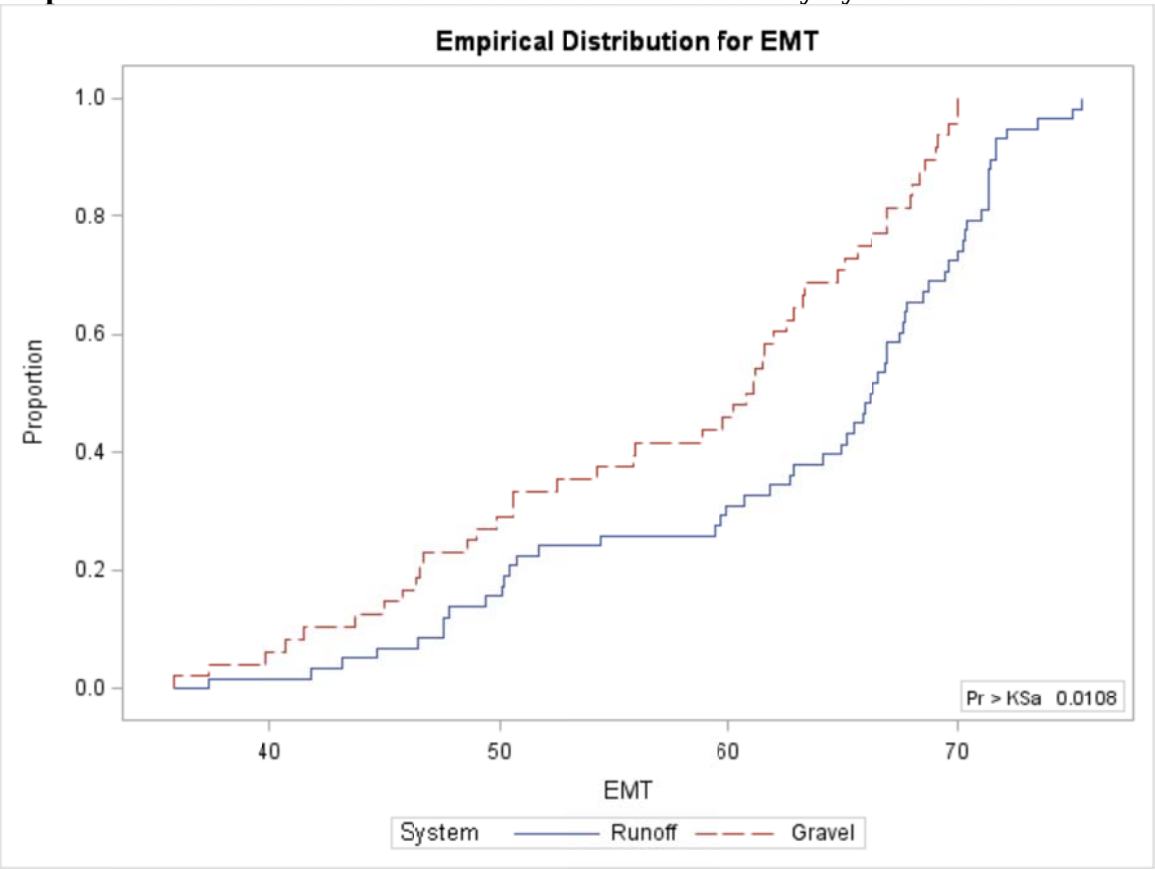
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.41379	-1.0876
Gravel Wetland	48	0.72917	1.19555
Total	106	0.5566	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.156984	D	0.315374
KSa	1.616244	Pr > KSa	0.0108

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

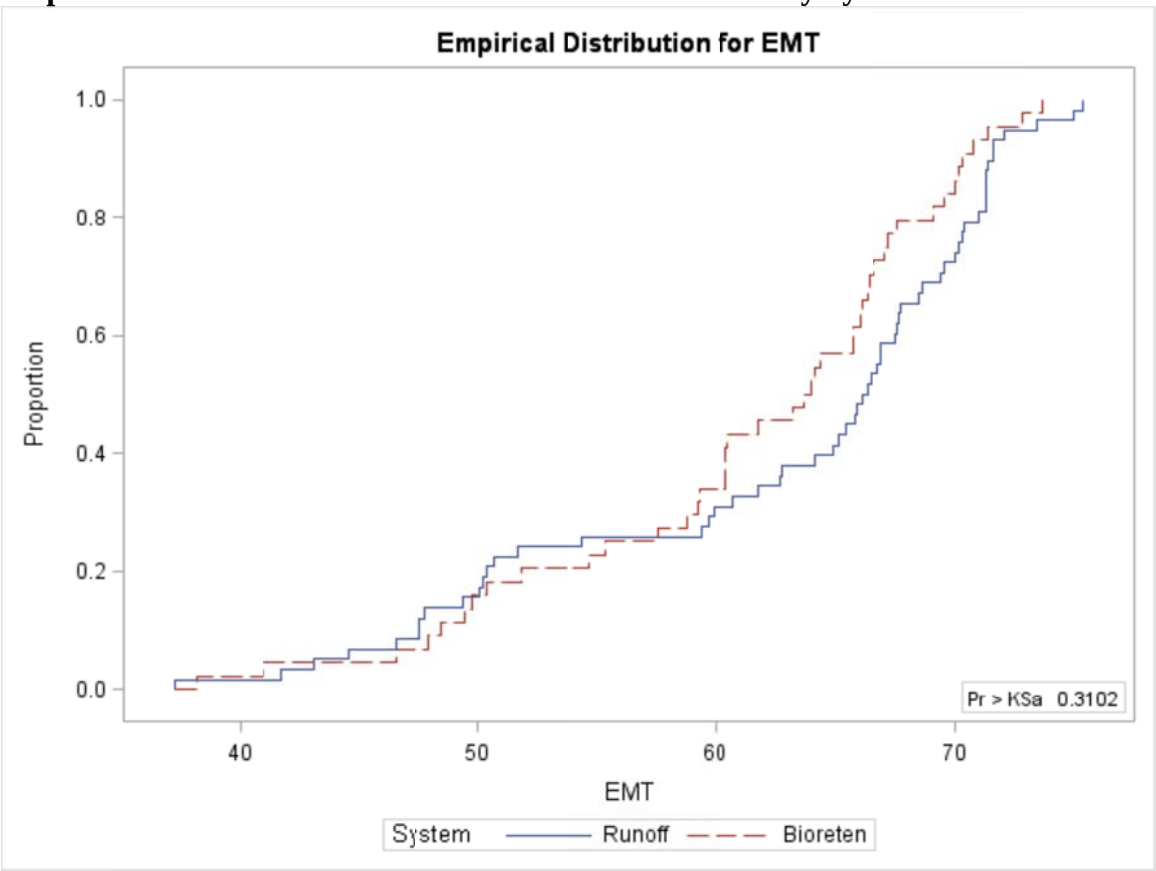
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.53448	-0.6334
Bioretention	44	0.72727	0.72717
Total	102	0.61765	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.095483	D	0.192790
KSa	0.964328	Pr > KSa	0.3102

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

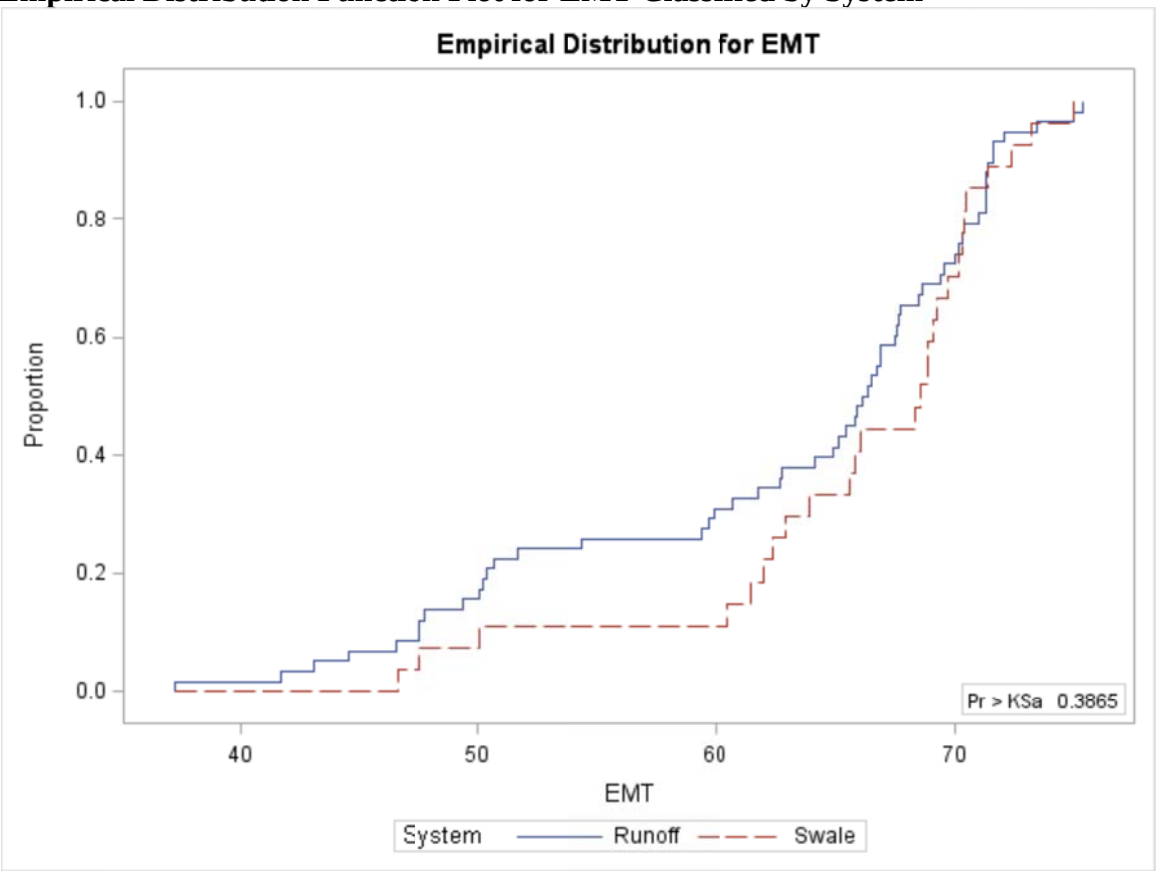
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.65517	0.50978
Vegetated Swale	27	0.44444	-0.7472
Total	85	0.58824	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.098107	D	0.210728
KSa	0.904500	Pr > KSa	0.3865

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

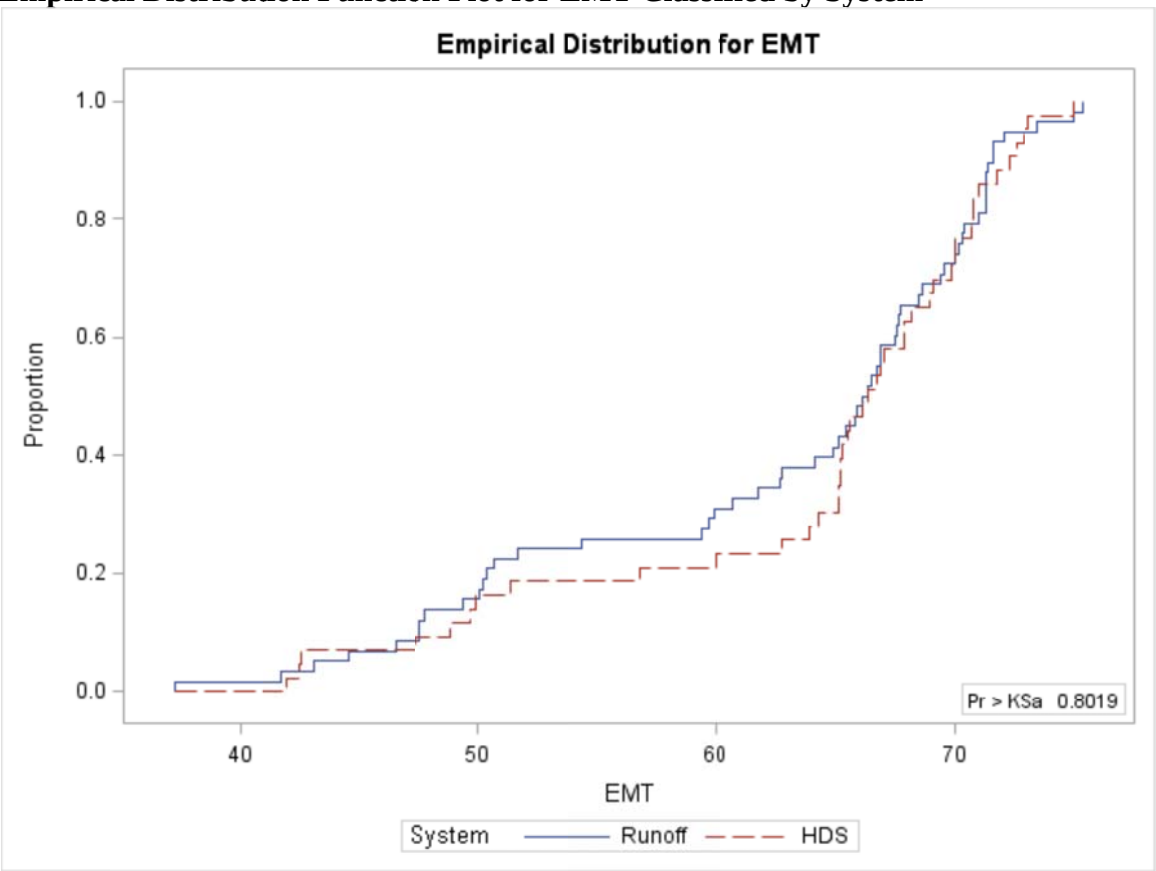
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.36207	0.41992
HDS	43	0.23256	-0.4877
Total	101	0.30693	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.064037	D	0.129511
KSa	0.643567	Pr > KSa	0.8019

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

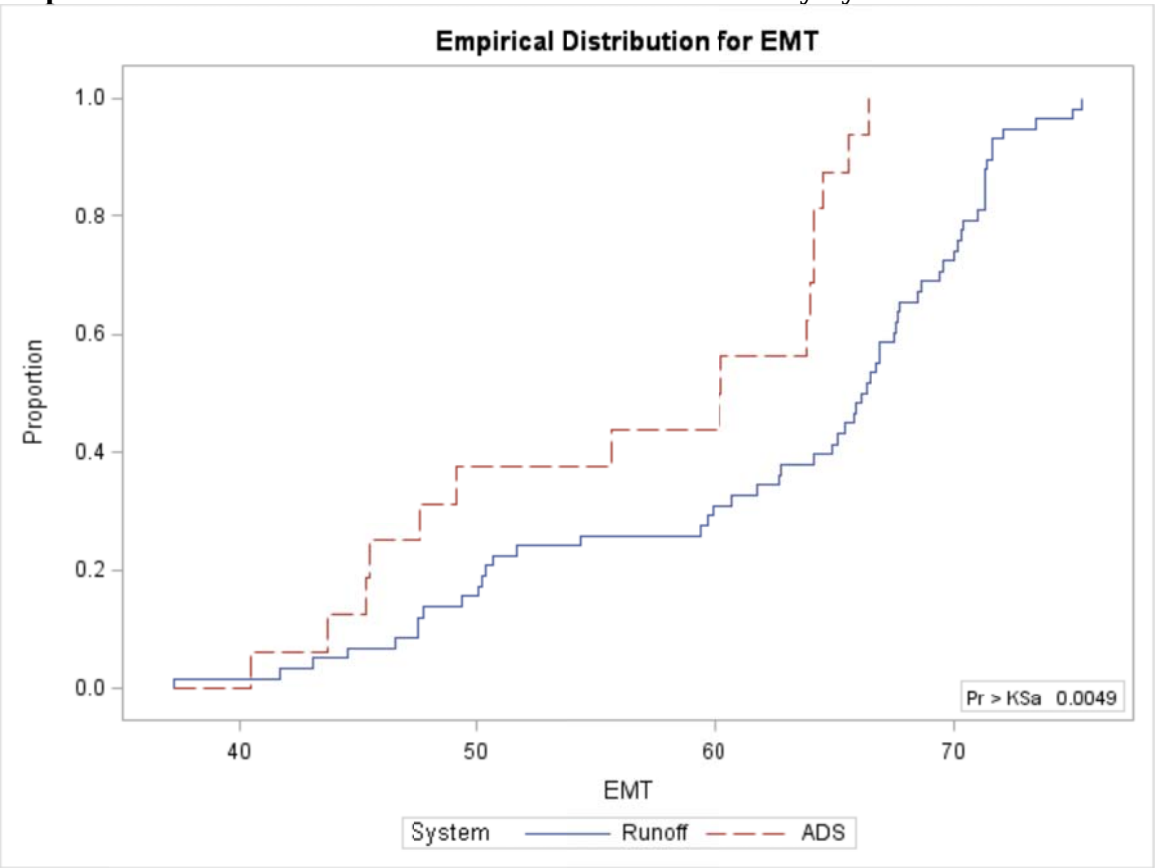
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.44828	-0.8056
ADS	16	0.9375	1.53378
Total	74	0.55405	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.201396	D	0.489224
KSa	1.732471	Pr > KSa	0.0049

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

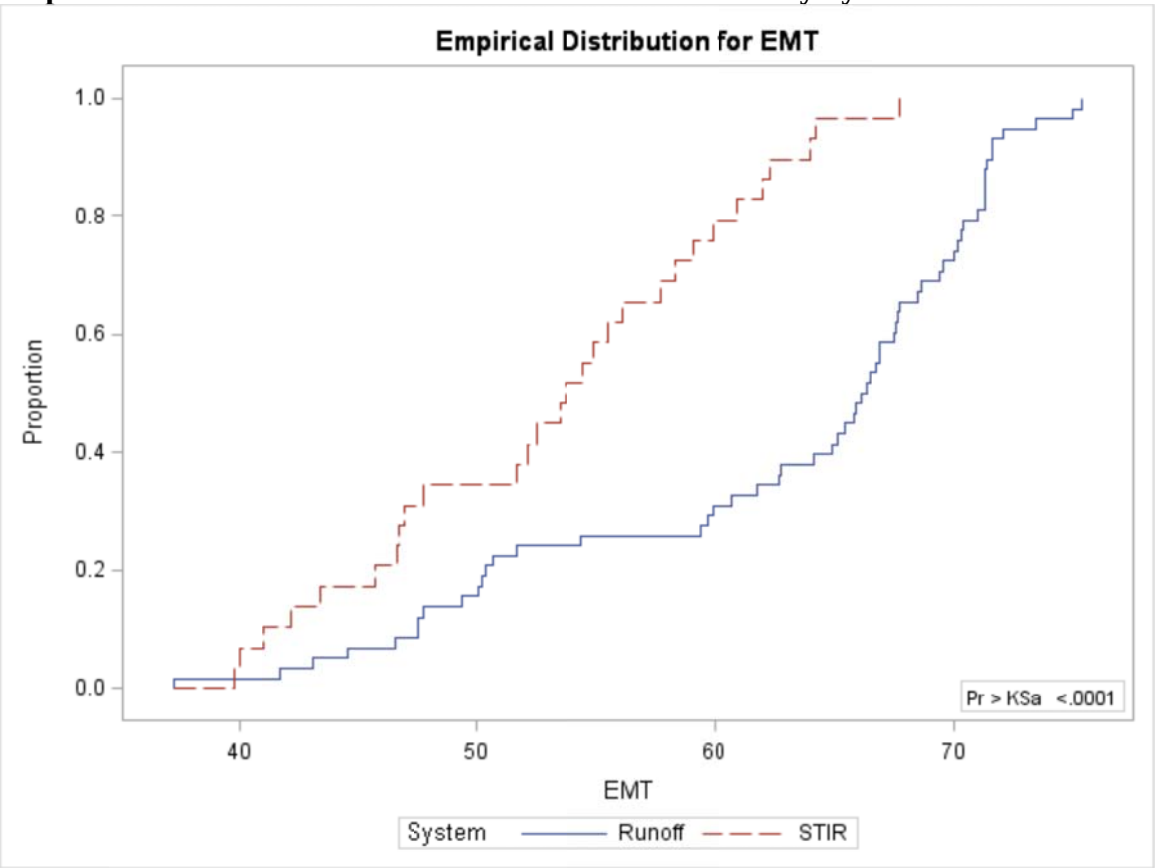
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.39655	-1.4444
STIR	29	0.96552	2.04265
Total	87	0.58621	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.268213	D	0.568966
KSa	2.501724	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Retention Pond (Winter)

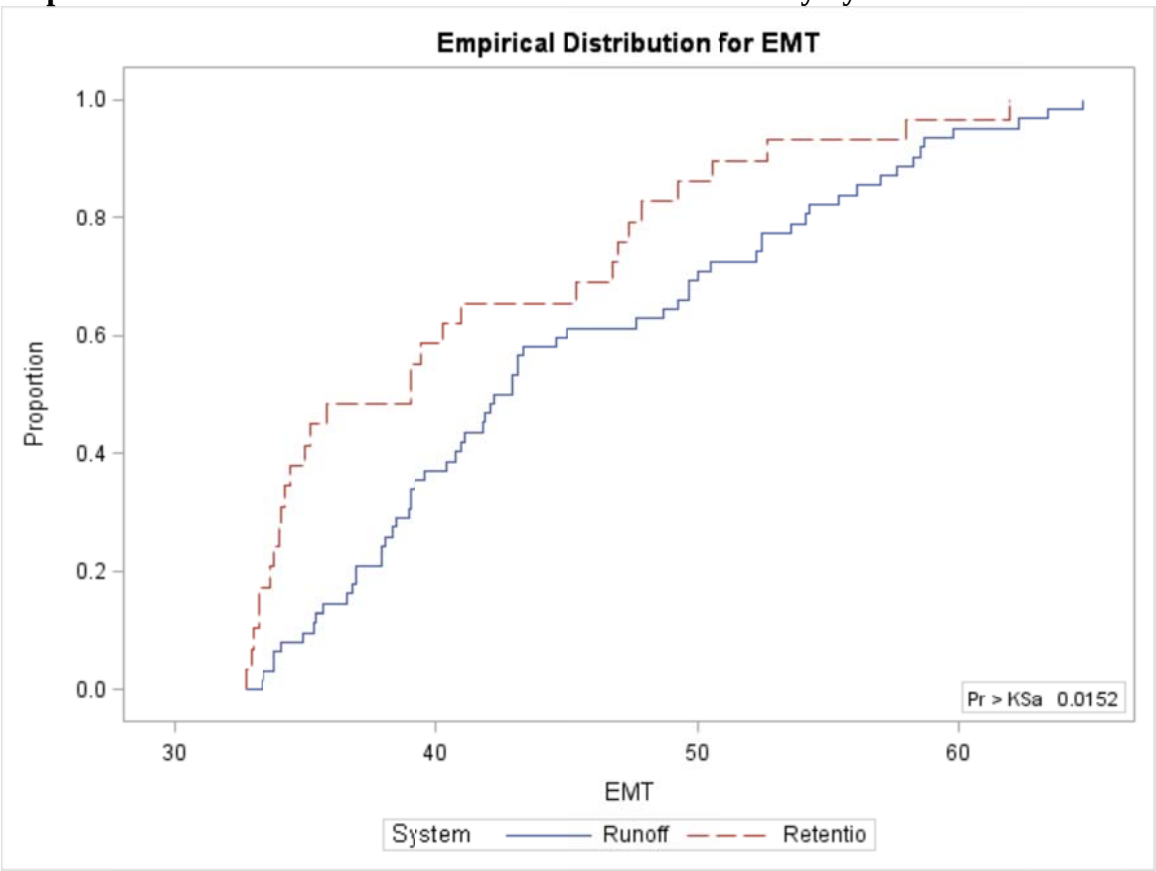
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.09677	-0.882
Retention Pond	29	0.44828	1.28966
Total	91	0.20879	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.163788	D	0.351502
KSa	1.562433	Pr > KSa	0.0152

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Winter)

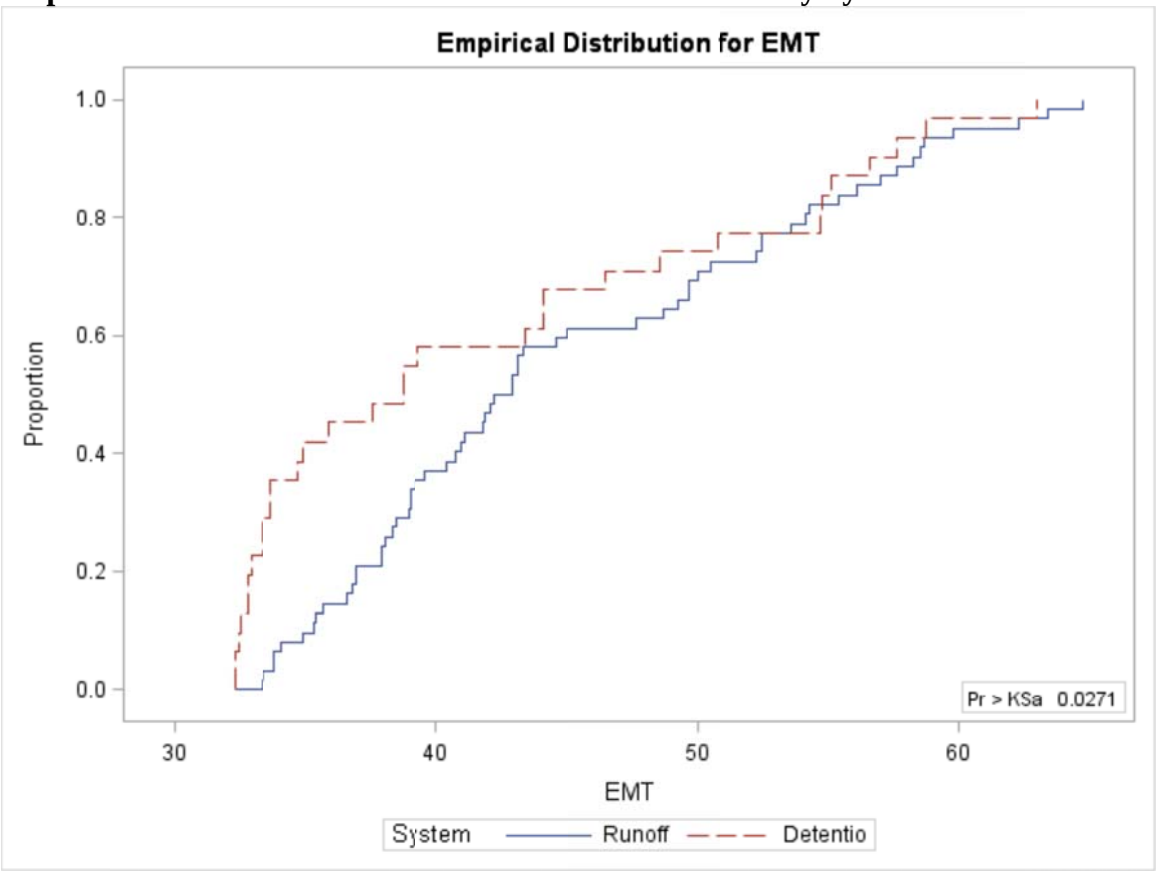
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.03226	-0.8467
Detention Pond	31	0.35484	1.19737
Total	93	0.13978	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.152066	D	0.322581
KSa	1.466471	Pr > KSa	0.0271

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

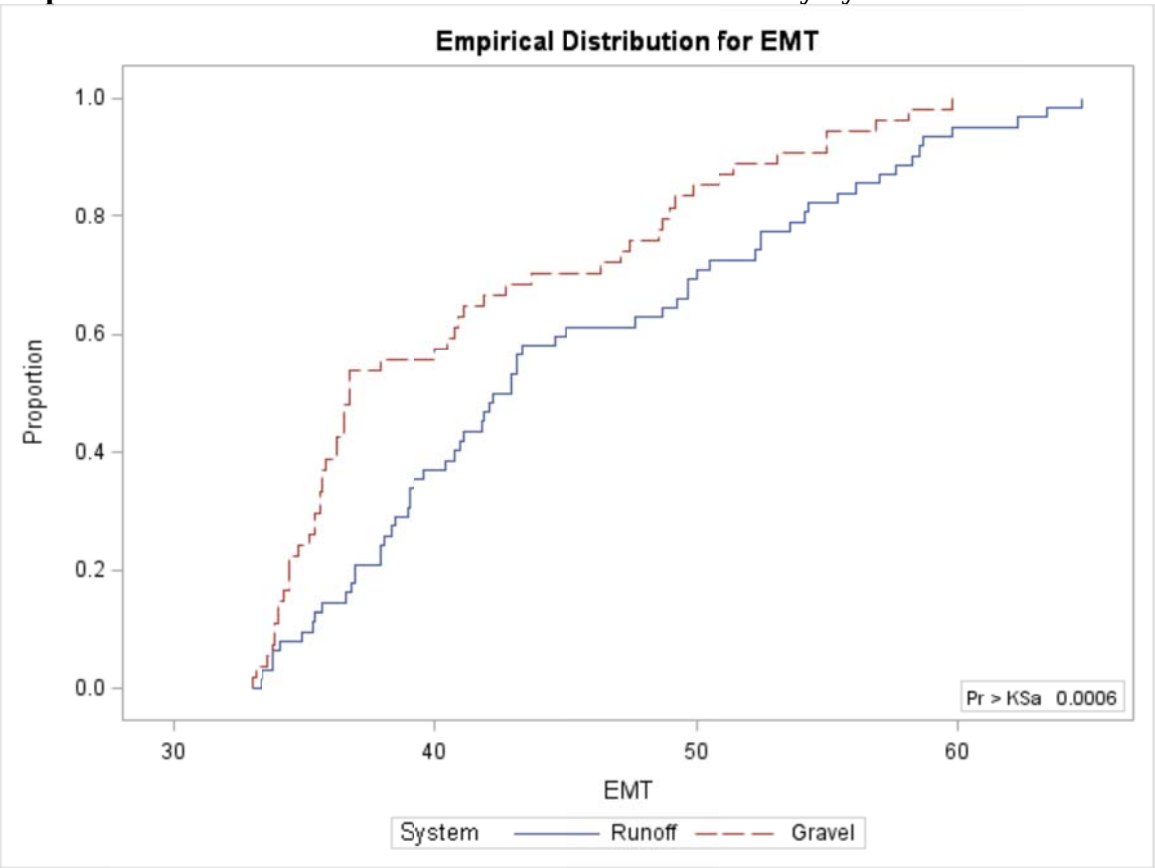
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.16129	-1.3773
Gravel Wetland	54	0.53704	1.47579
Total	116	0.33621	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.187426	D	0.375747
KSa	2.018640	Pr > KSa	0.0006

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

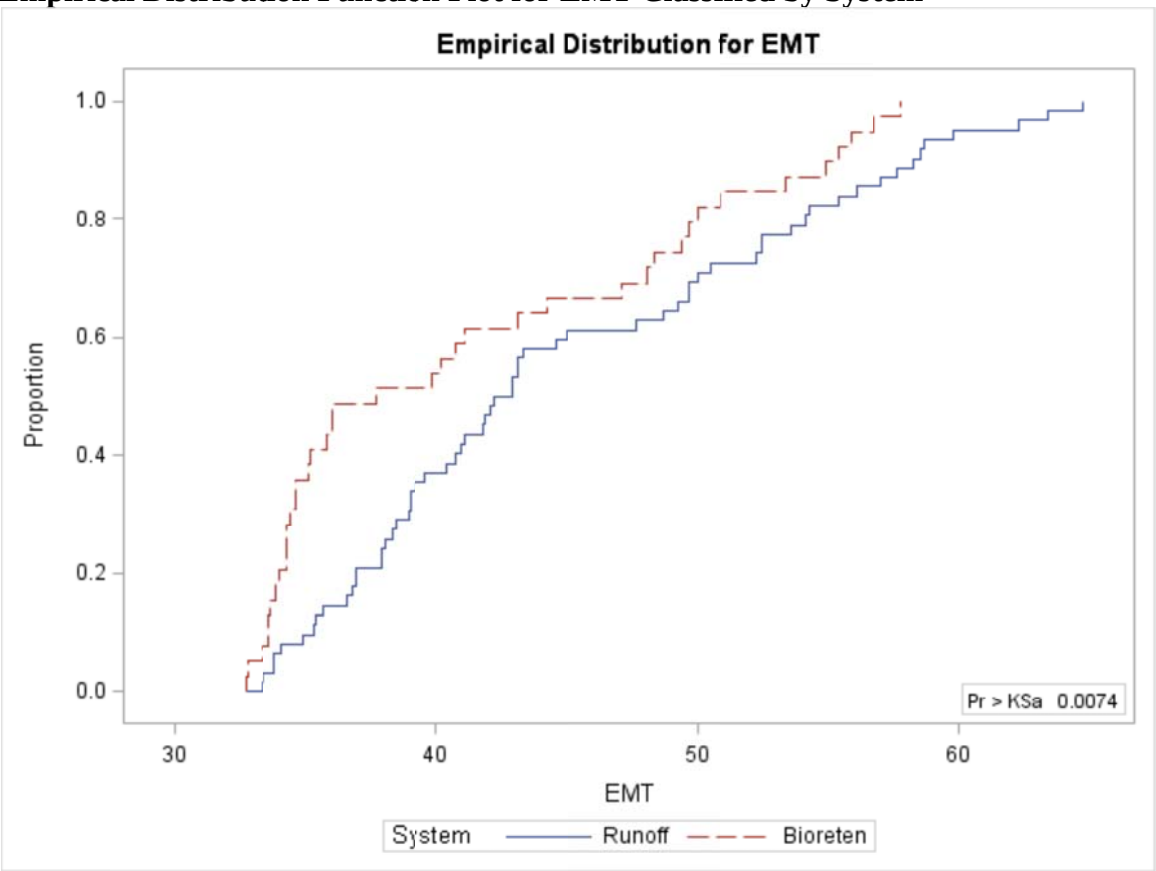
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.14516	-1.0399
Bioretention	39	0.48718	1.31115
Total	101	0.27723	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.166516	D	0.342018
KSa	1.673465	Pr > KSa	0.0074

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

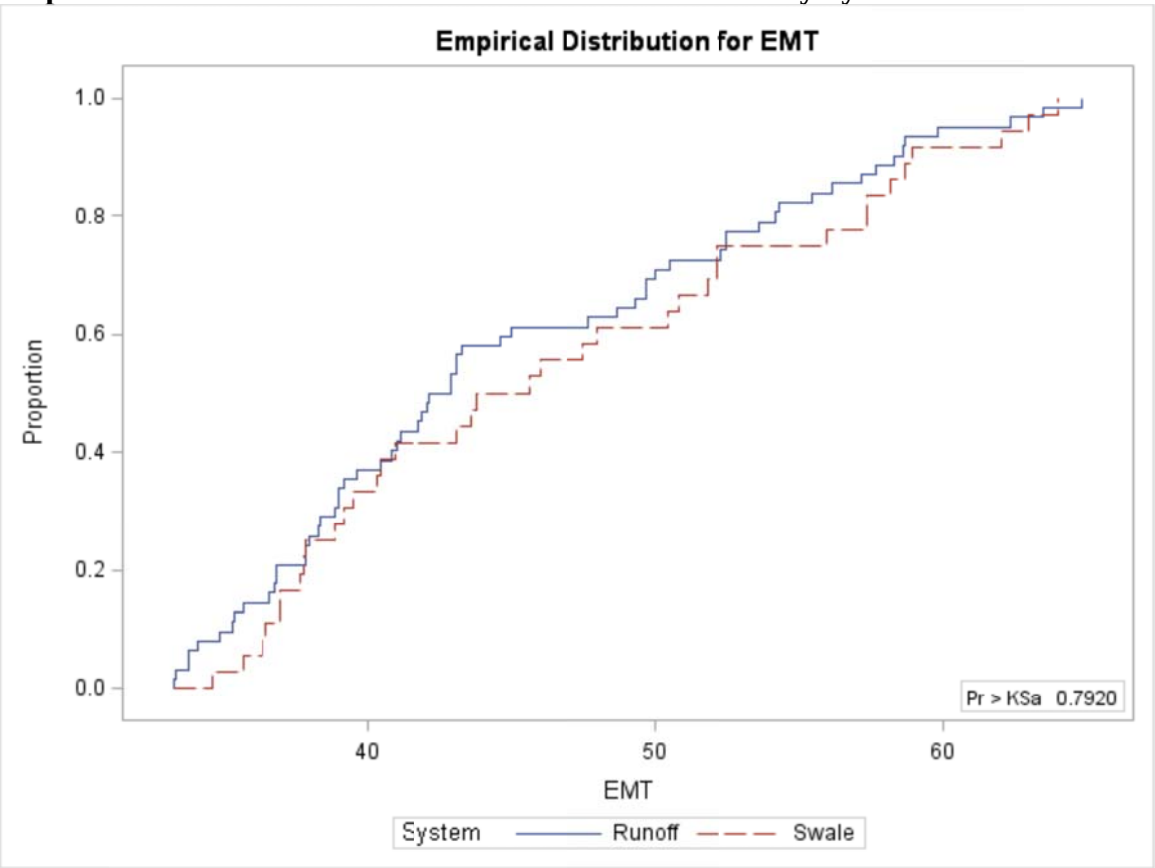
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.58065	0.39396
Vegetated Swale	36	0.44444	-0.517
Total	98	0.53061	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.065660	D	0.136201
KSa	0.650000	Pr > KSa	0.7920

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

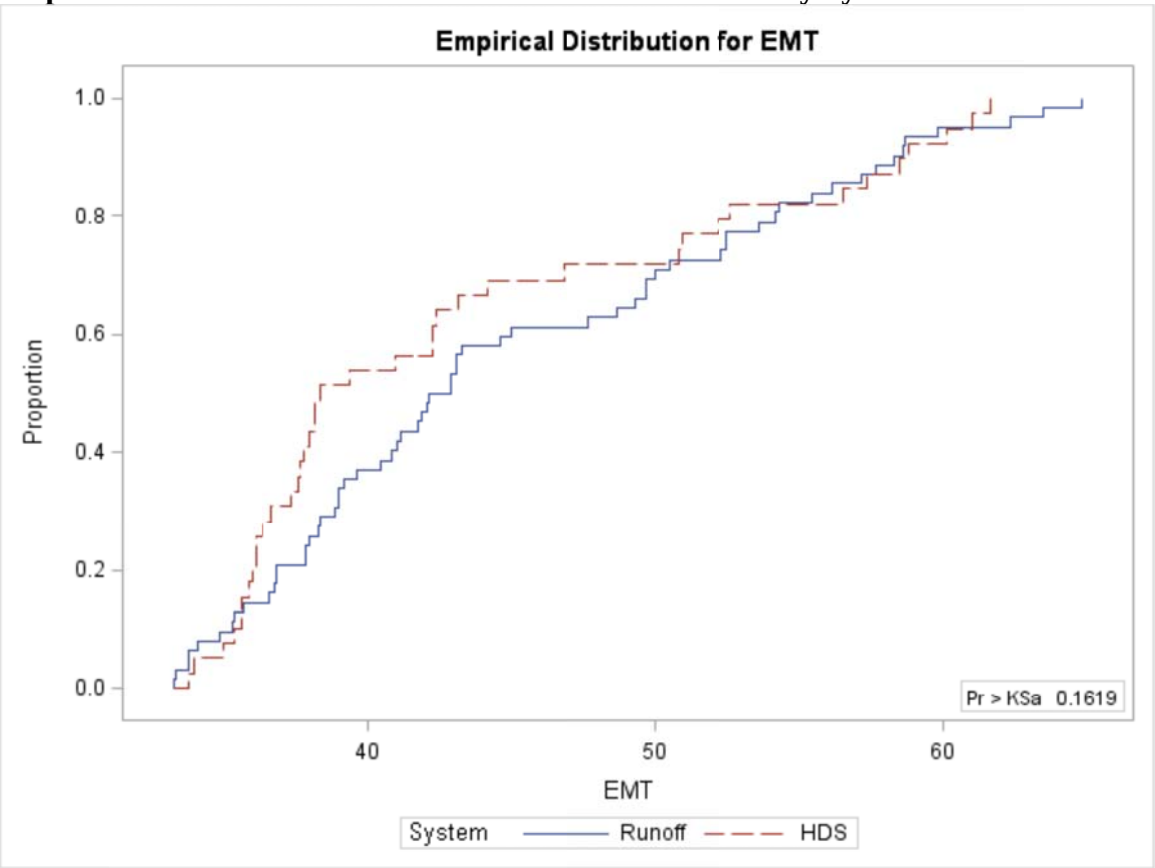
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.25806	-0.6966
HDS	39	0.48718	0.87833
Total	101	0.34653	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.111548	D	0.229115
KSa	1.121040	Pr > KSa	0.1619

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

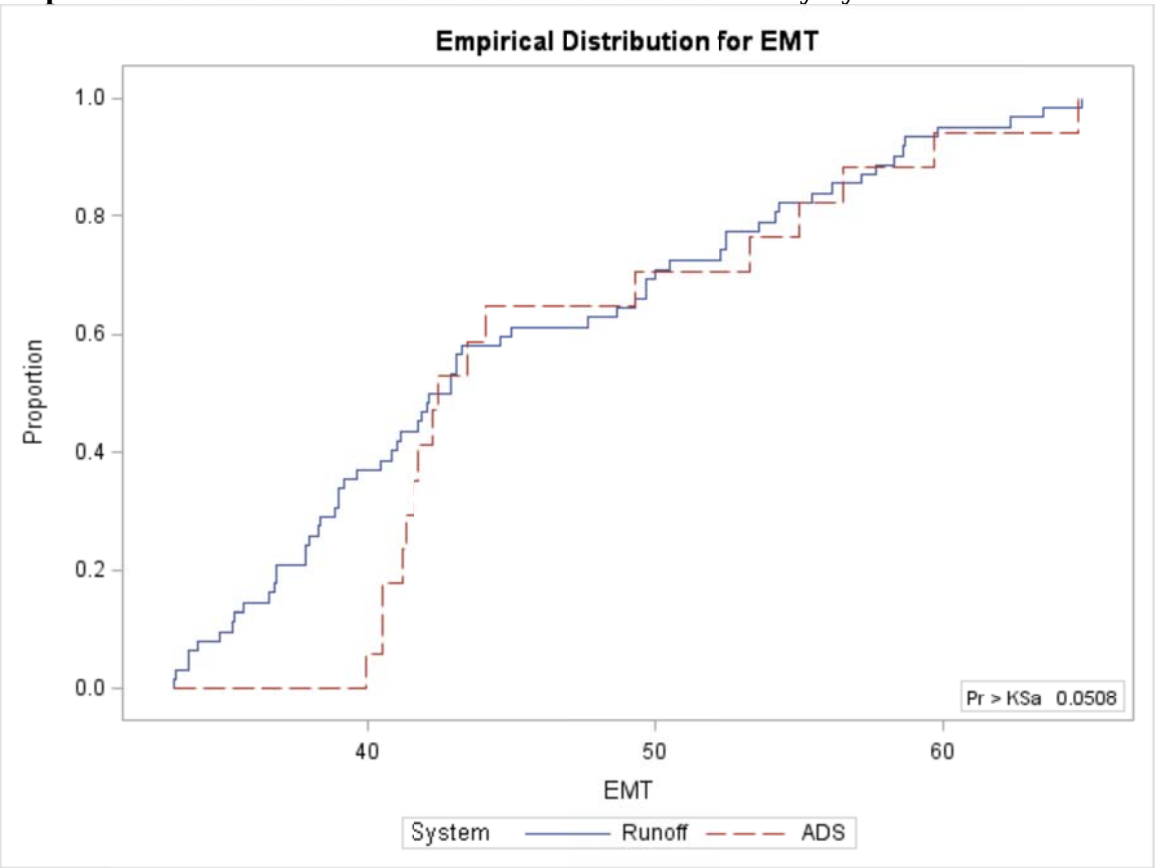
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.37097	0.62857
ADS	17	0	-1.2004
Total	79	0.29114	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.152451	D	0.370968
KSa	1.355011	Pr > KSa	0.0508

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

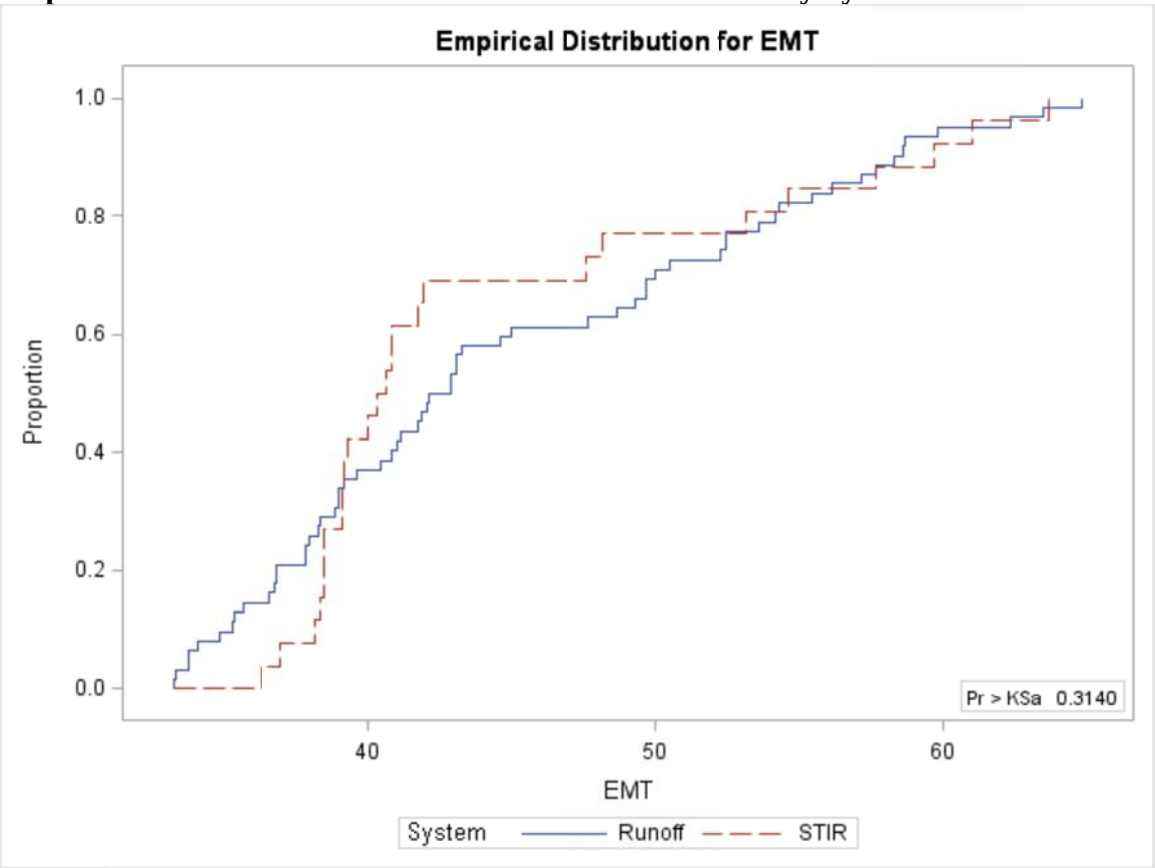
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.46774	-0.5224
STIR	26	0.69231	0.80675
Total	88	0.53409	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.102457	D	0.224566
KSa	0.961136	Pr > KSa	0.3140

Empirical Distribution Function Plot for EMT Classified by System



College Brook (d/s) vs. Wednesday Hill Brook (Annual)

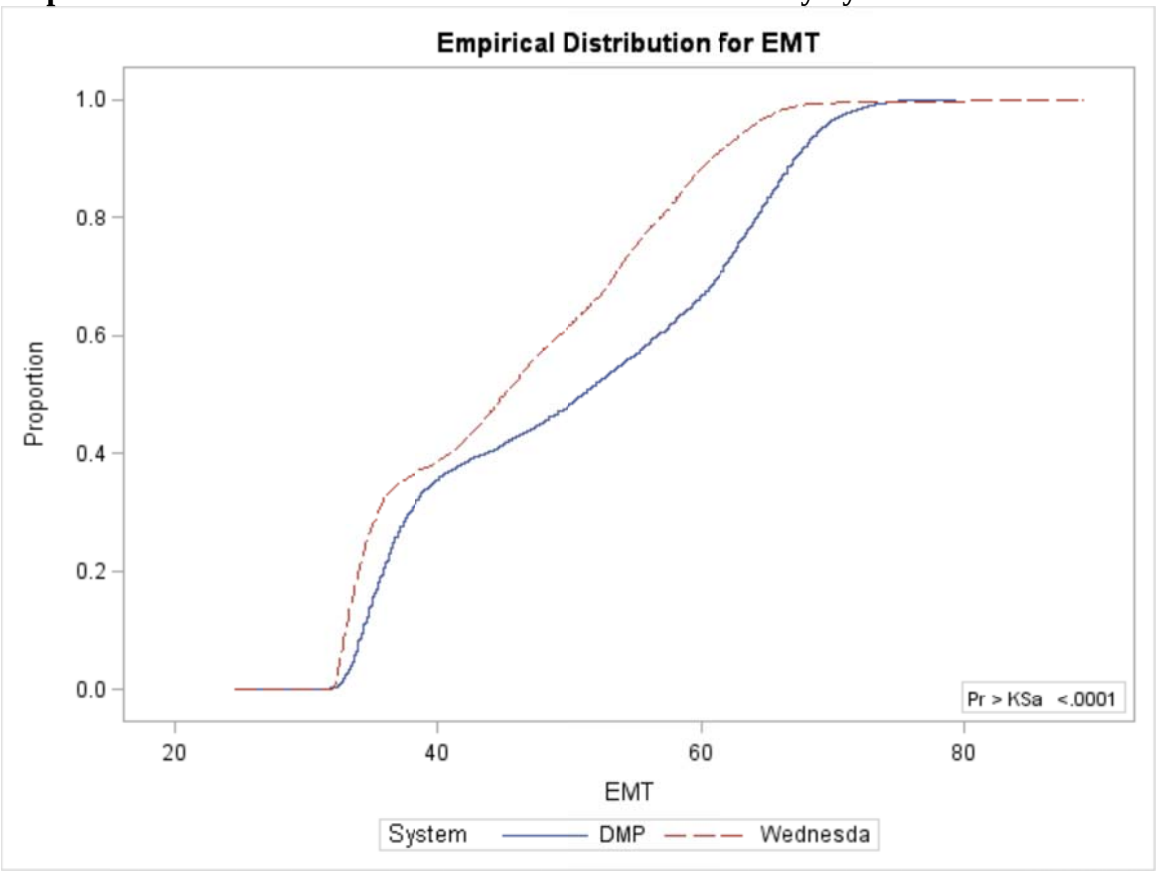
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
DMP	86056	0.6764	-21.733
Wednesday	44539	0.89362	30.2088
Total	130595	0.75048	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.102978	D	0.217225
KSa	37.214008	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



College Brook (d/s) vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

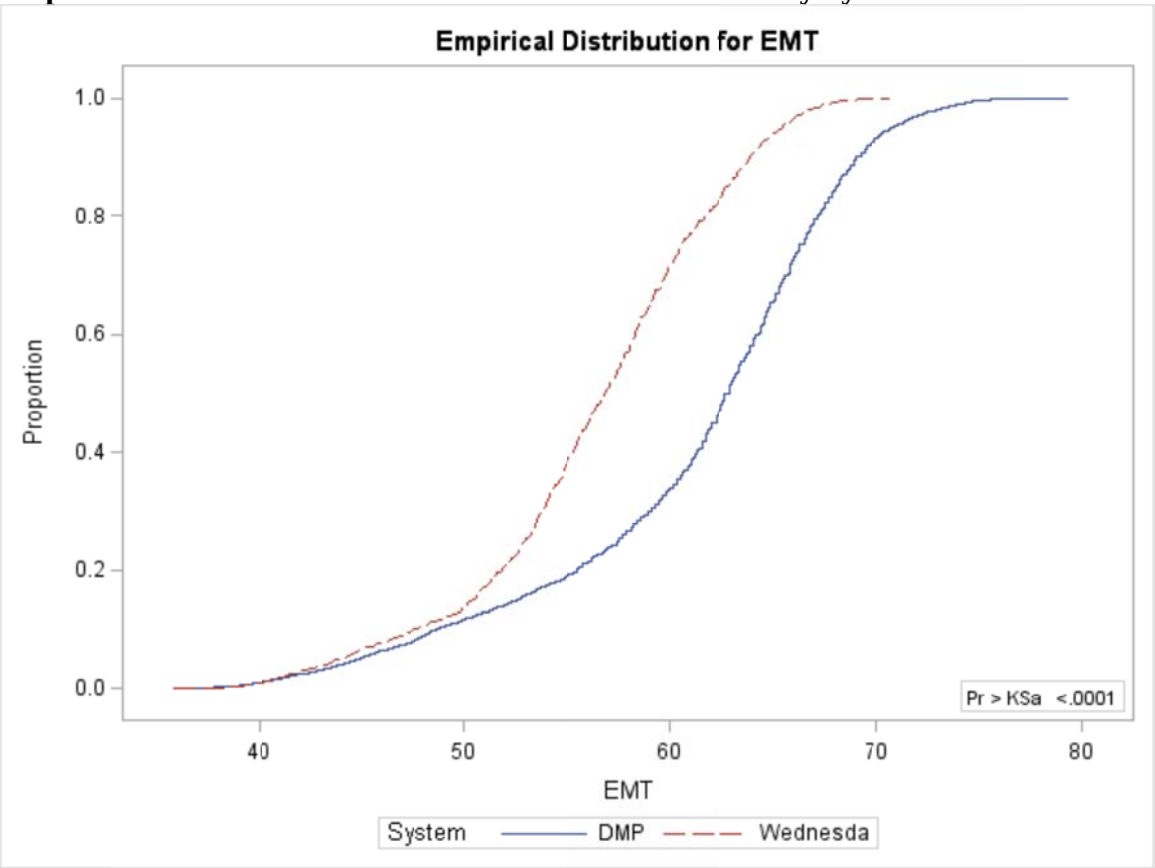
System	N	EDF at Maximum	Deviation from Mean at Maximum
DMP	42900	0.36981	-23.138
Wednesday	17068	0.7623	36.6824
Total	59968	0.48152	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.177104	D	0.392490
KSa	43.369958	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs College Brook (d/s) Annual

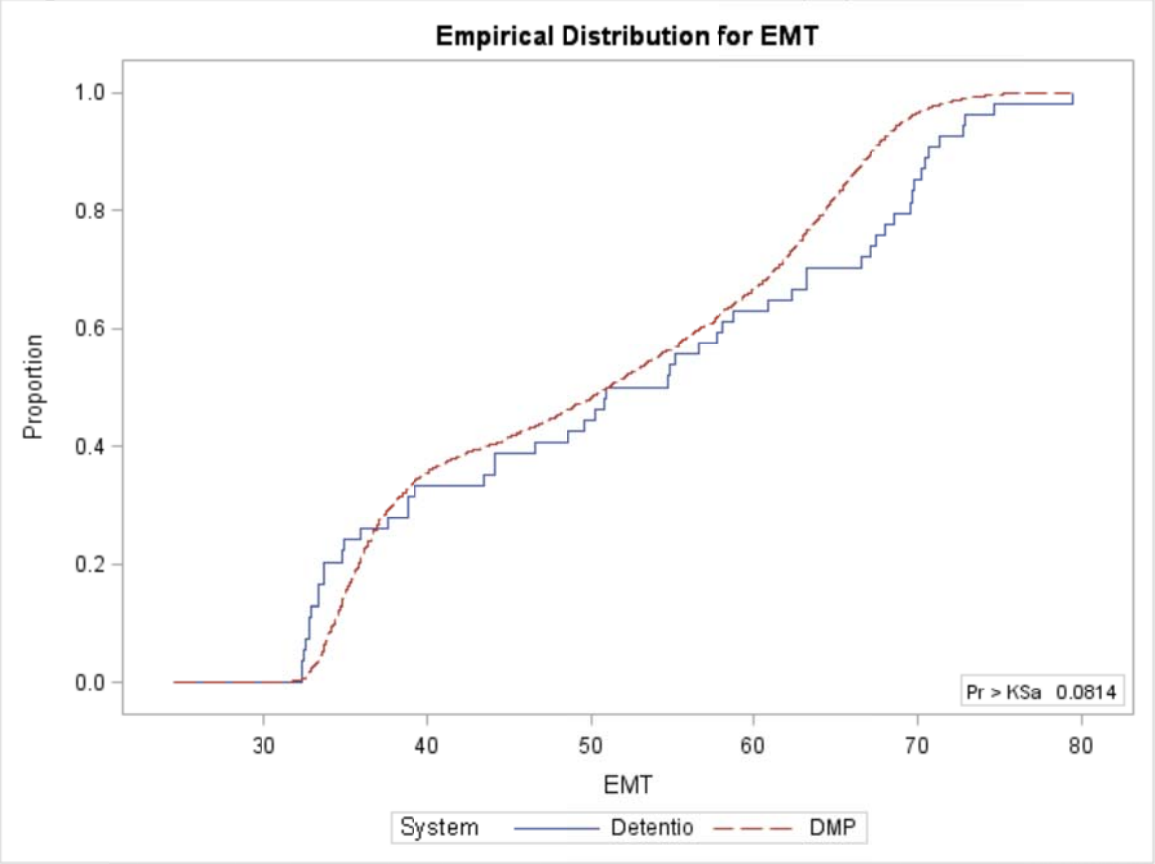
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	54	0.7037	-1.2648
DMP	86056	0.87593	0.03168
Total	86110	0.87582	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.004312	D	0.172226
KSa	1.265200	Pr > KSa	0.0814

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. College Brook (d/s) (Summer)

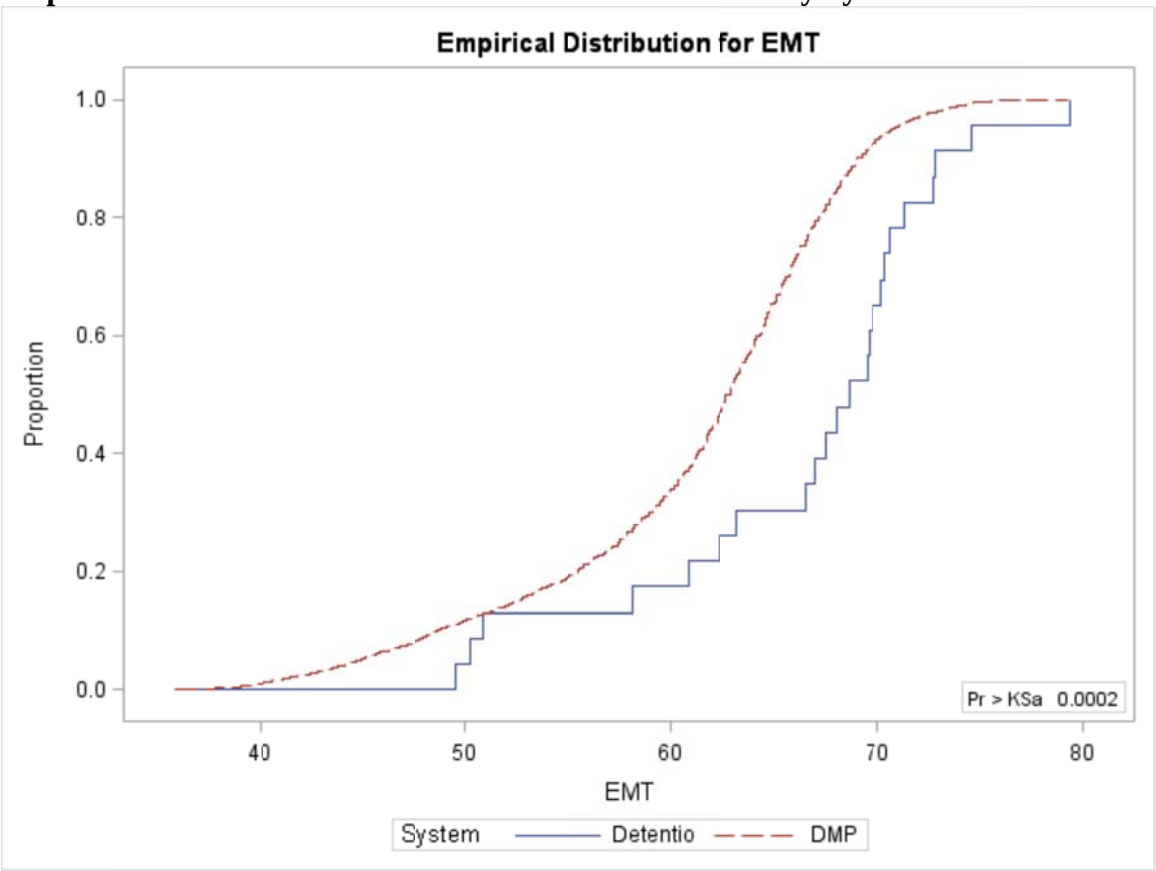
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	23	0.30435	-2.1416
DMP	42900	0.75114	0.04959
Total	42923	0.7509	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.010340	D	0.446794
KSa	2.142176	Pr > KSa	0.0002

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. Wednesday Hill Brook (Annual)

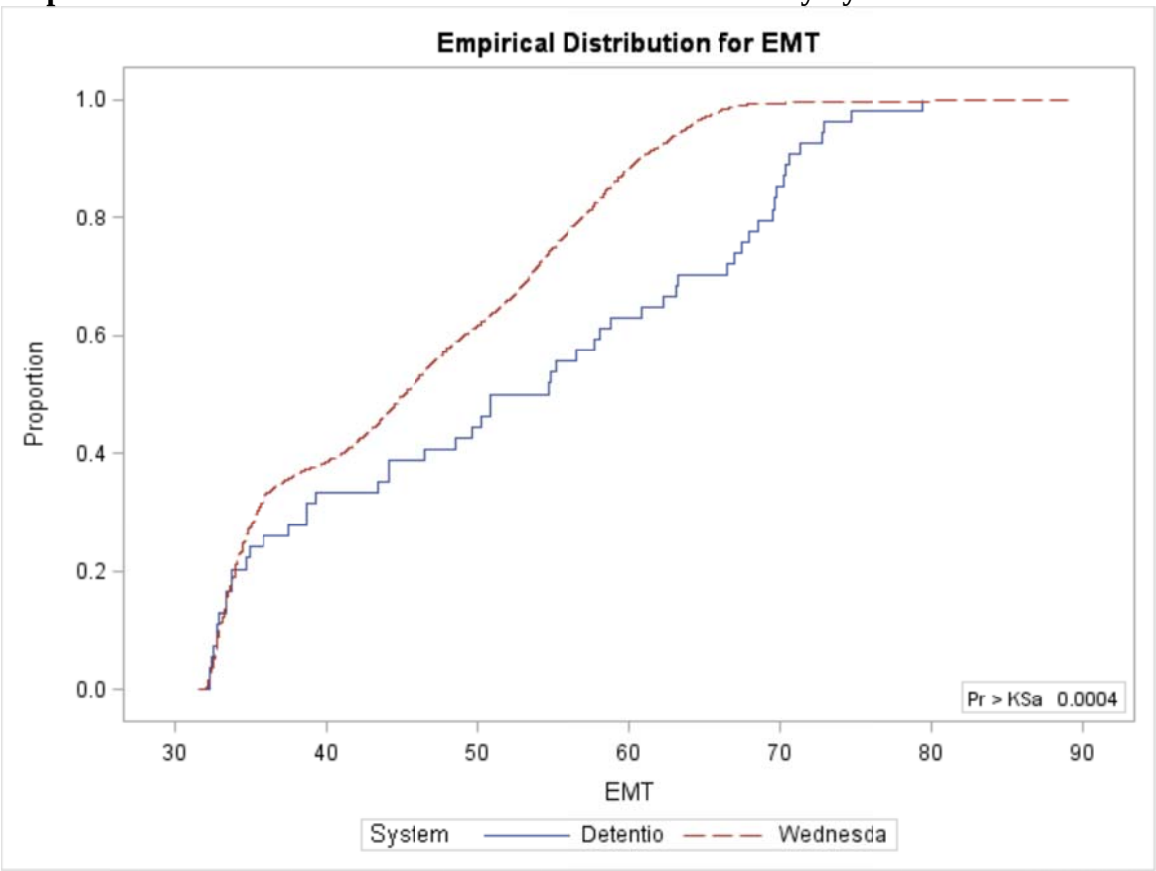
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	54	0.7037	-2.0628
Wednesday	44539	0.98475	0.07183
Total	44593	0.98441	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.009774	D	0.281051
KSa	2.064045	Pr > KSa	0.0004

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. Wednesday Hill Brook (Summer)

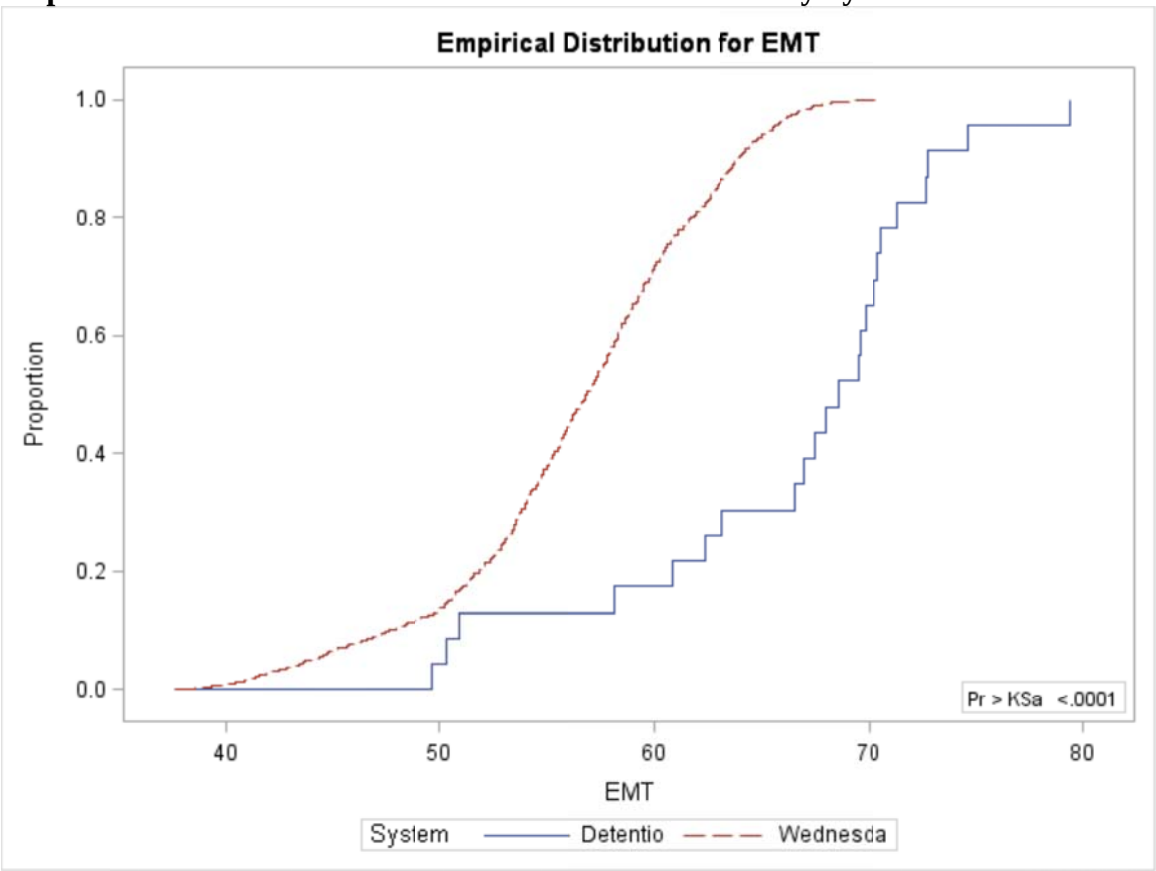
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	23	0.30435	-3.2122
Wednesday	17068	0.97504	0.11792
Total	17091	0.97414	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.024587	D	0.670693
KSa	3.214366	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. College Brook (d/s) (Annual)

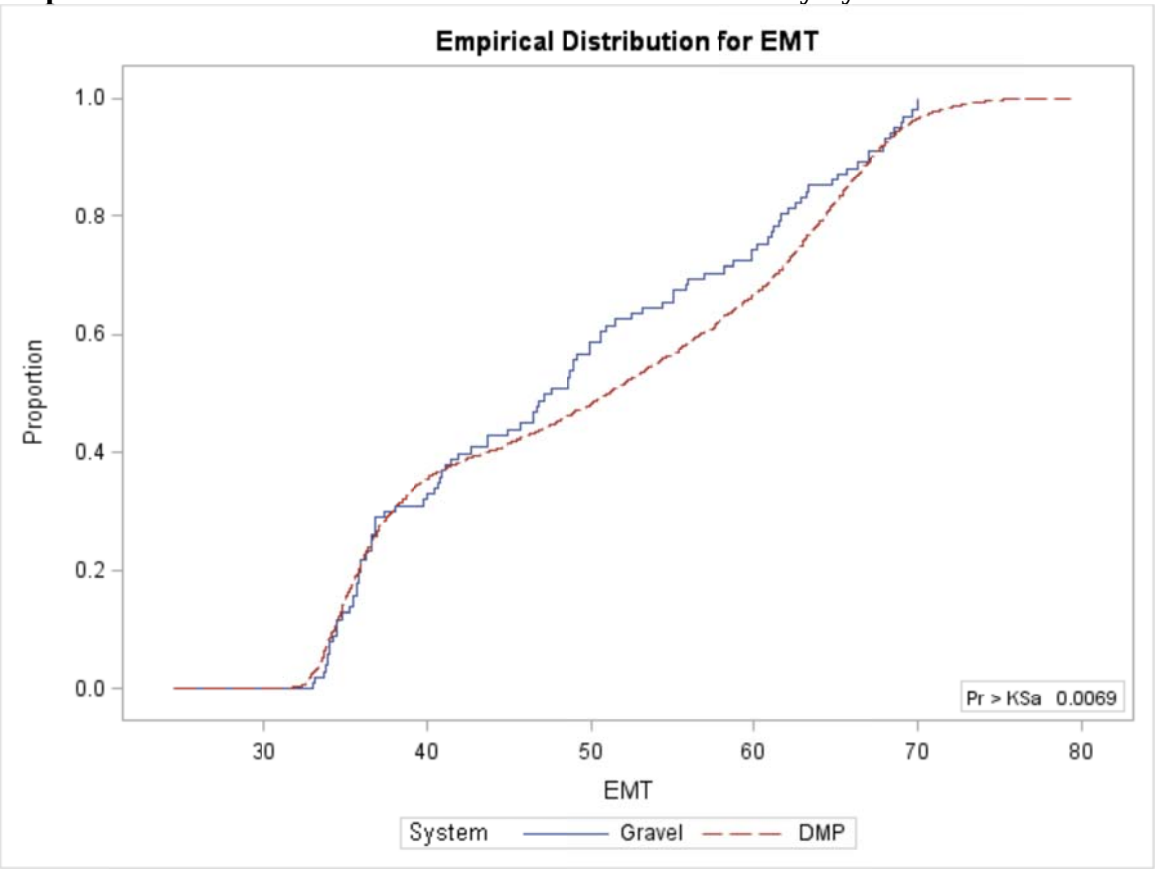
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	203	0.61576	1.68204
DMP	172111	0.49757	-0.0578
Total	172314	0.49771	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.004054	D	0.118195
KSa	1.683029	Pr > KSa	0.0069

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. College Brook (d/s) (Summer)

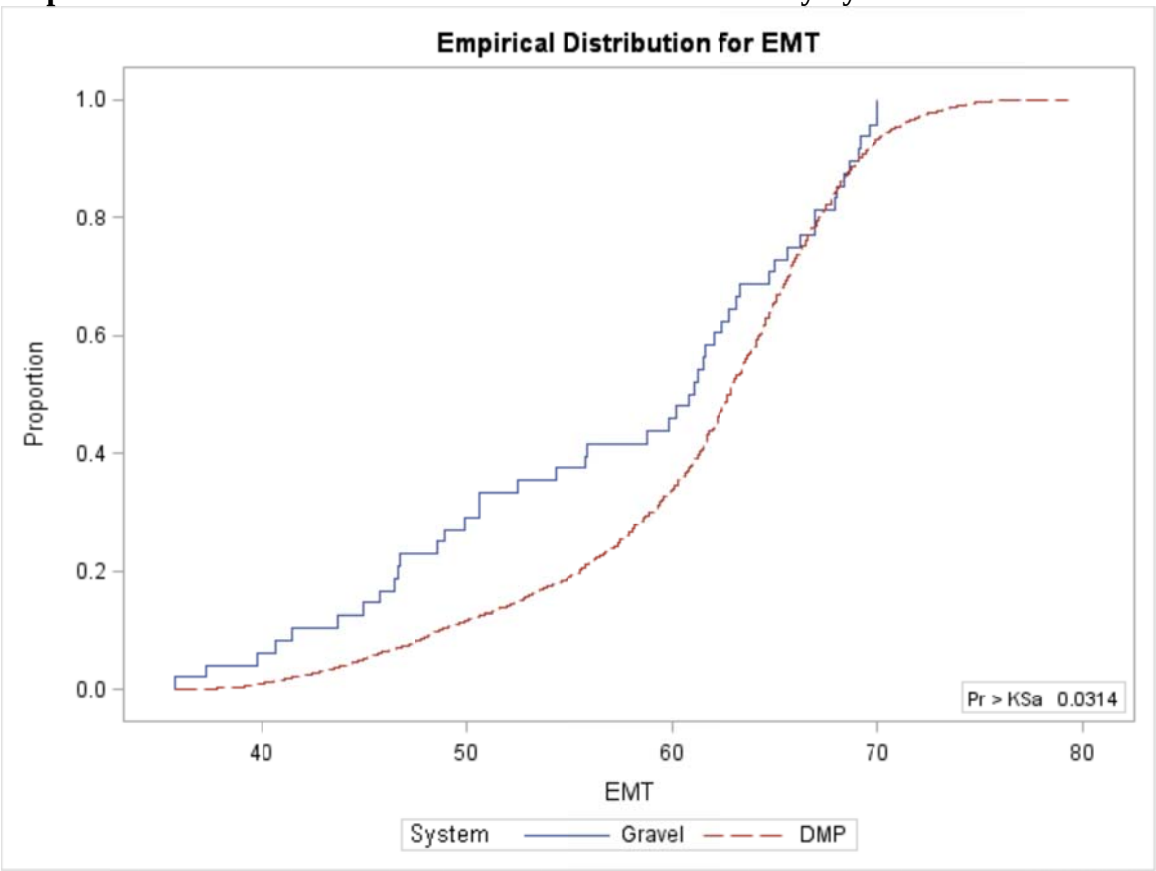
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	48	0.33333	1.44055
DMP	42900	0.12517	-0.0482
Total	42948	0.12541	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.006955	D	0.208159
KSa	1.441358	Pr > KSa	0.0314

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. Wednesday Hill Brook (Annual)

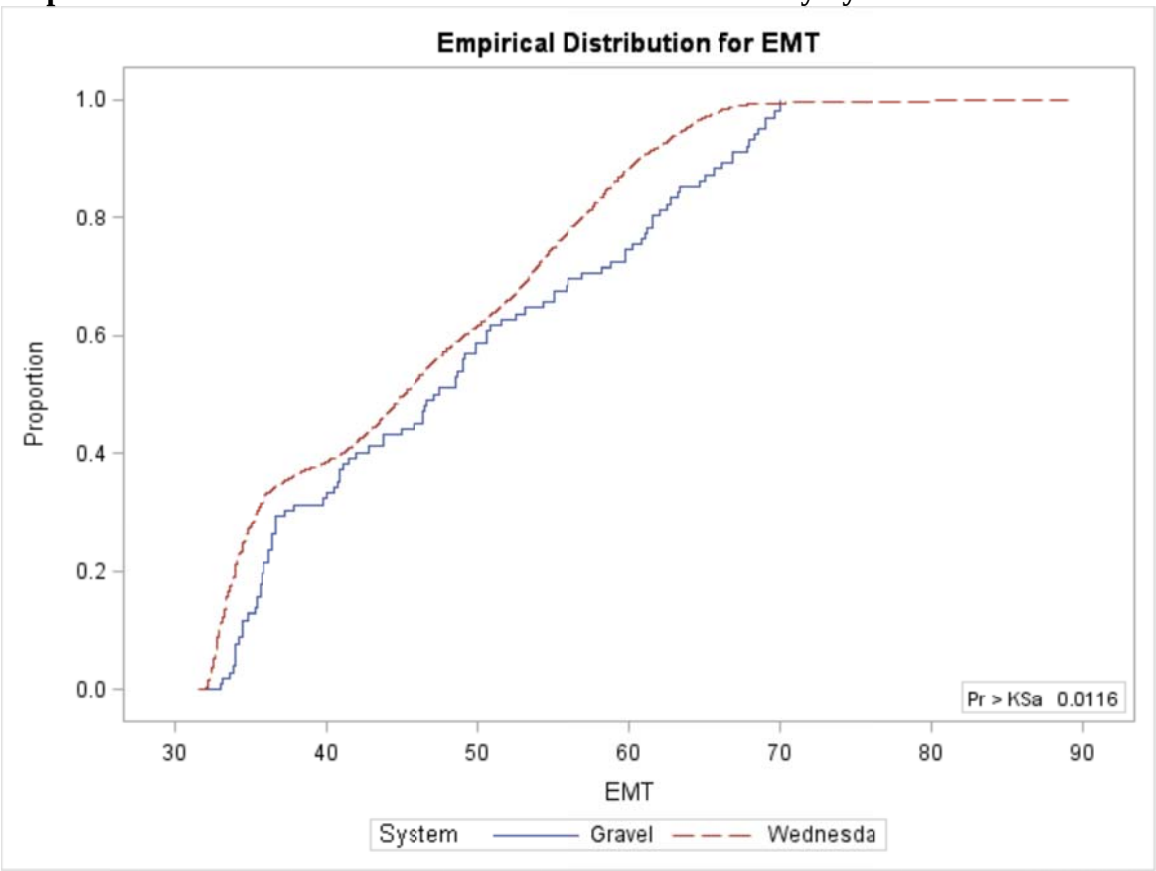
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	102	0.13725	-1.6029
Wednesday	44539	0.29632	0.07671
Total	44641	0.29596	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.007595	D	0.159070
KSa	1.604688	Pr > KSa	0.0116

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. Wednesday Hill Brook (Summer)

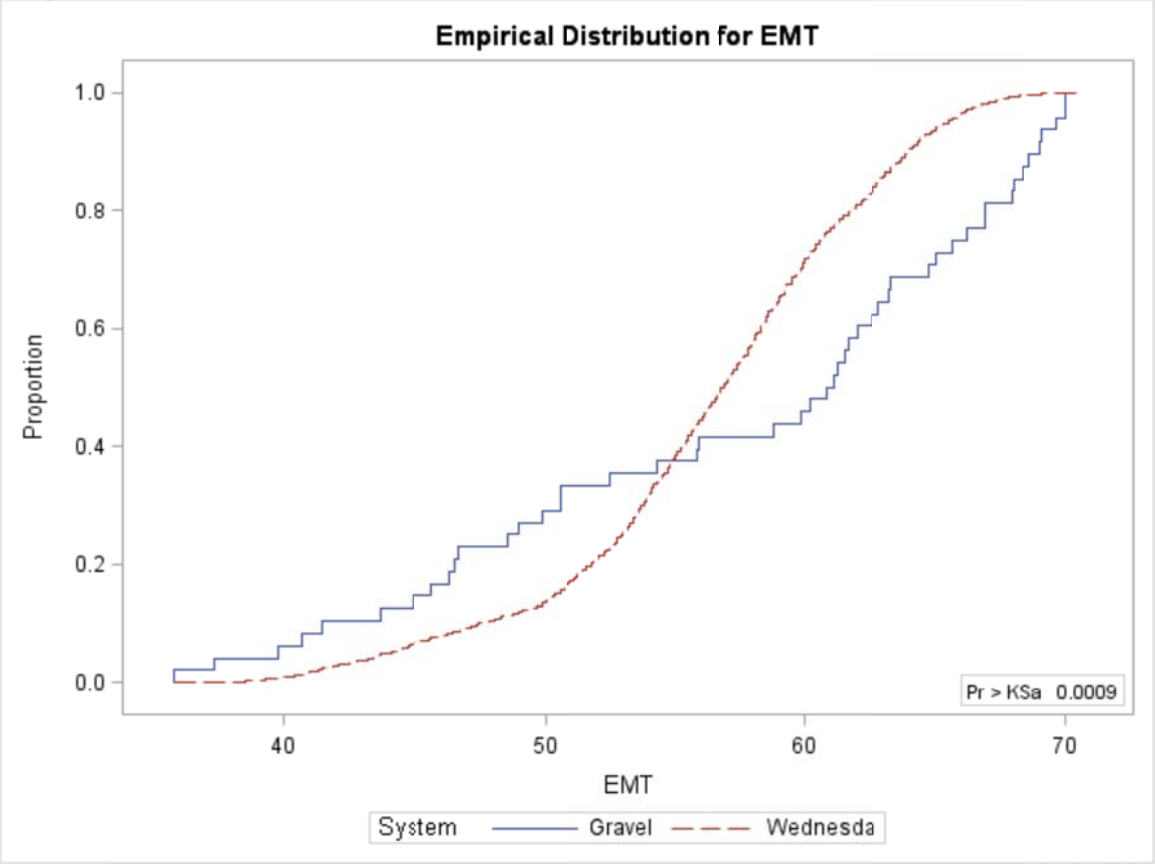
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	48	0.47917	-1.9561
Wednesday	17068	0.7623	0.10374
Total	17116	0.76151	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.014973	D	0.283137
KSa	1.958879	Pr > KSa	0.0009

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. College Brook (d/s) (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

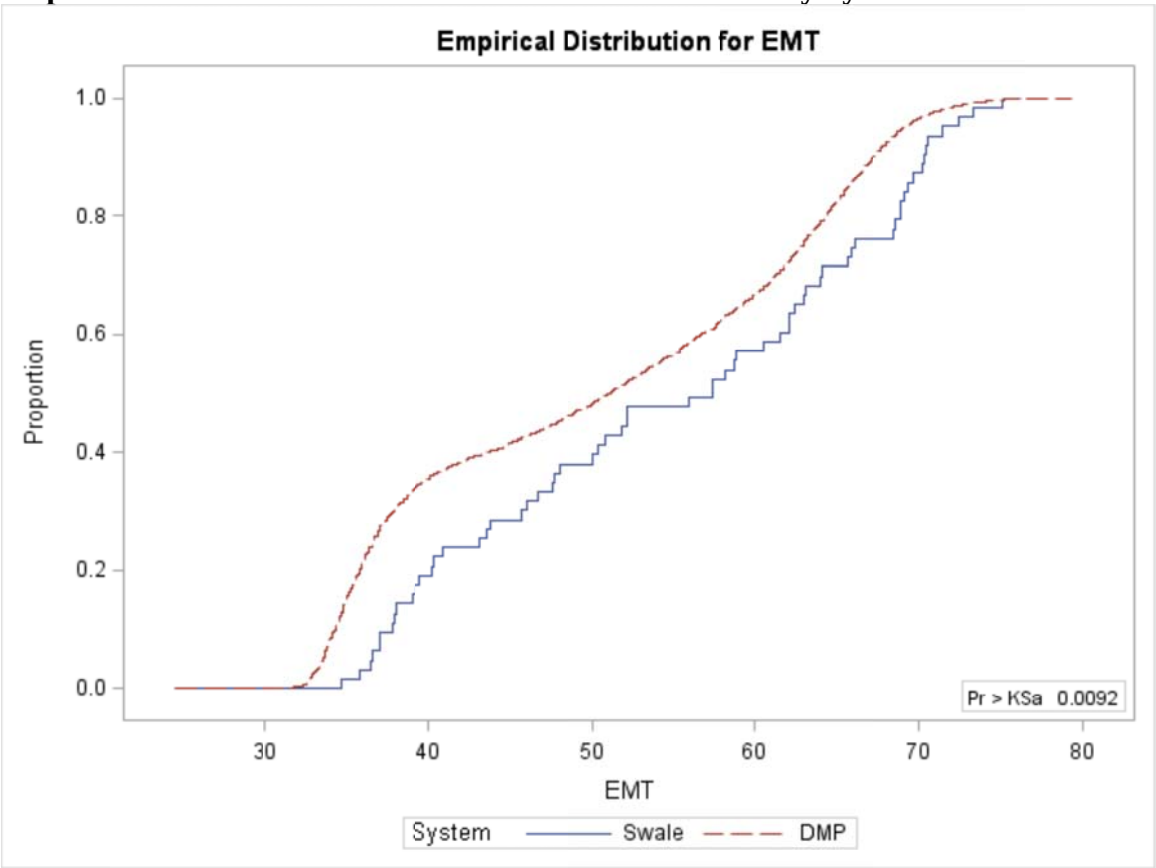
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	63	0.03175	-1.6403
DMP	86056	0.23855	0.04438
Total	86119	0.2384	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.005592	D	0.206808
KSa	1.640887	Pr > KSa	0.0092

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. College Brook (d/s) (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

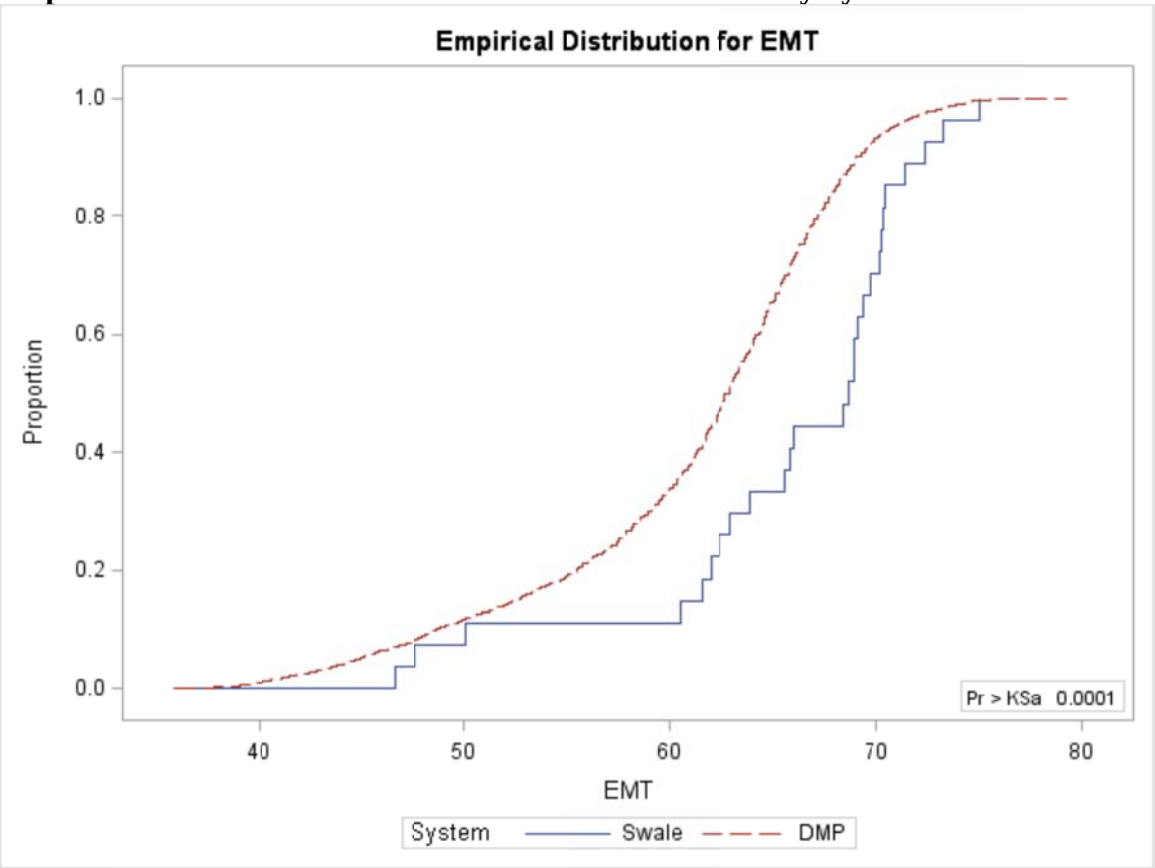
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	27	0.44444	-2.2047
DMP	42900	0.869	0.05531
Total	42927	0.86873	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.010644	D	0.424553
KSa	2.205349	Pr > KSa	0.0001

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. Wednesday Hill Brook (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

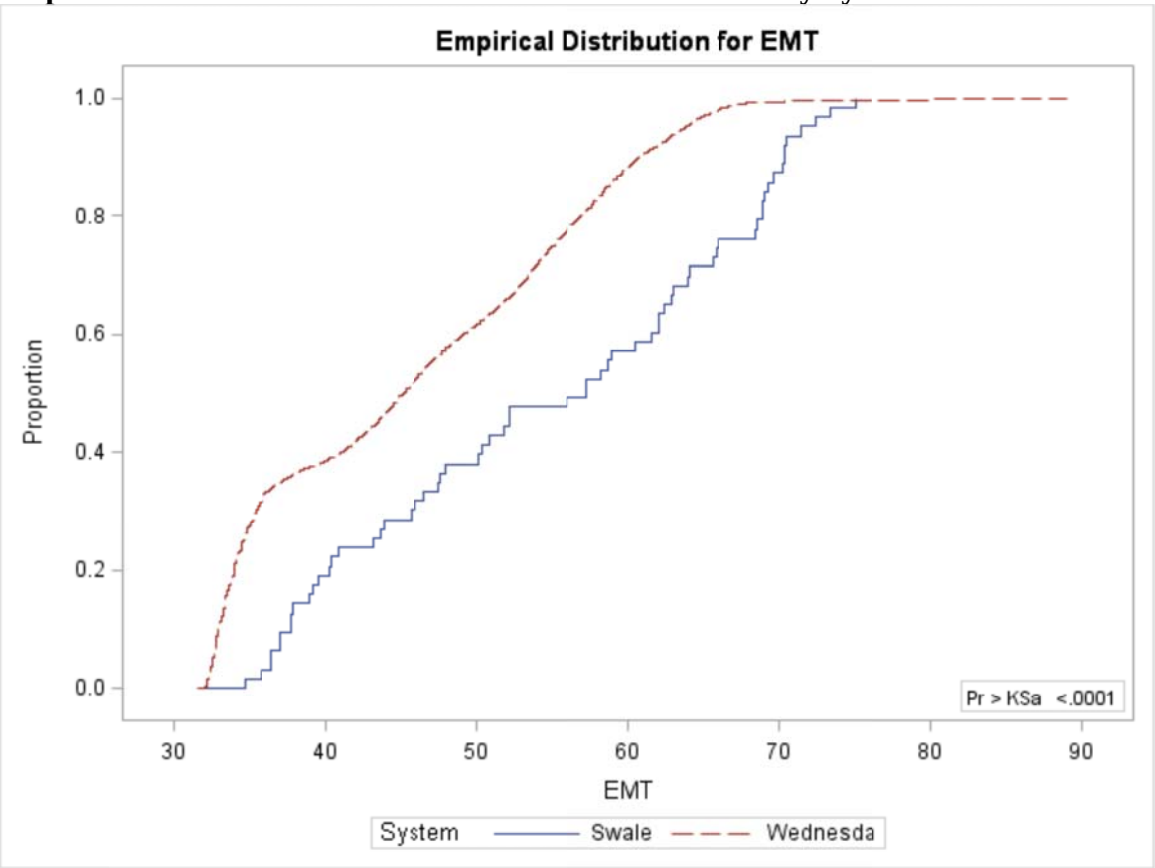
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	63	0.5873	-2.5809
Wednesday	44538	0.91293	0.09707
Total	44601	0.91247	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.012230	D	0.325627
KSa	2.582756	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

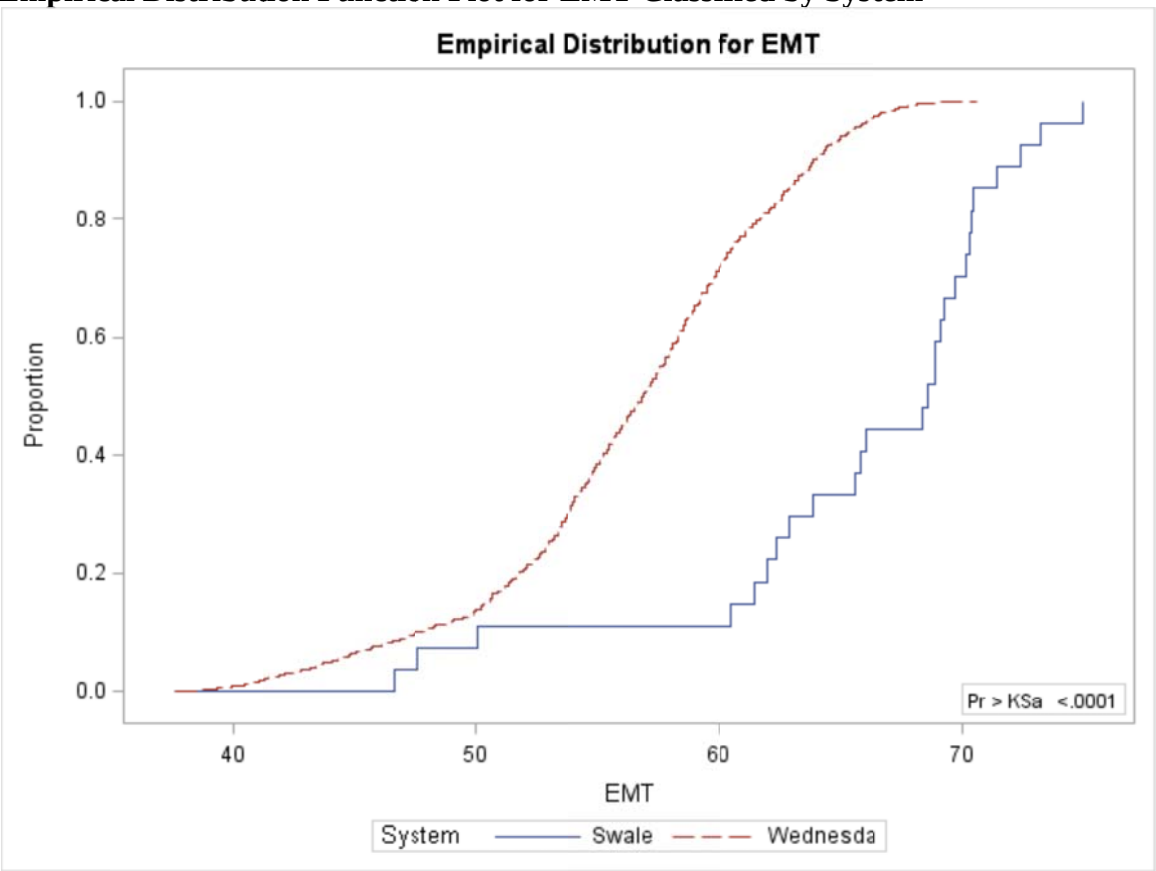
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	27	0.14815	-3.3409
Wednesday	17068	0.79213	0.13288
Total	17095	0.79111	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.025573	D	0.643977
KSa	3.343562	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. College Brook (d/s) (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

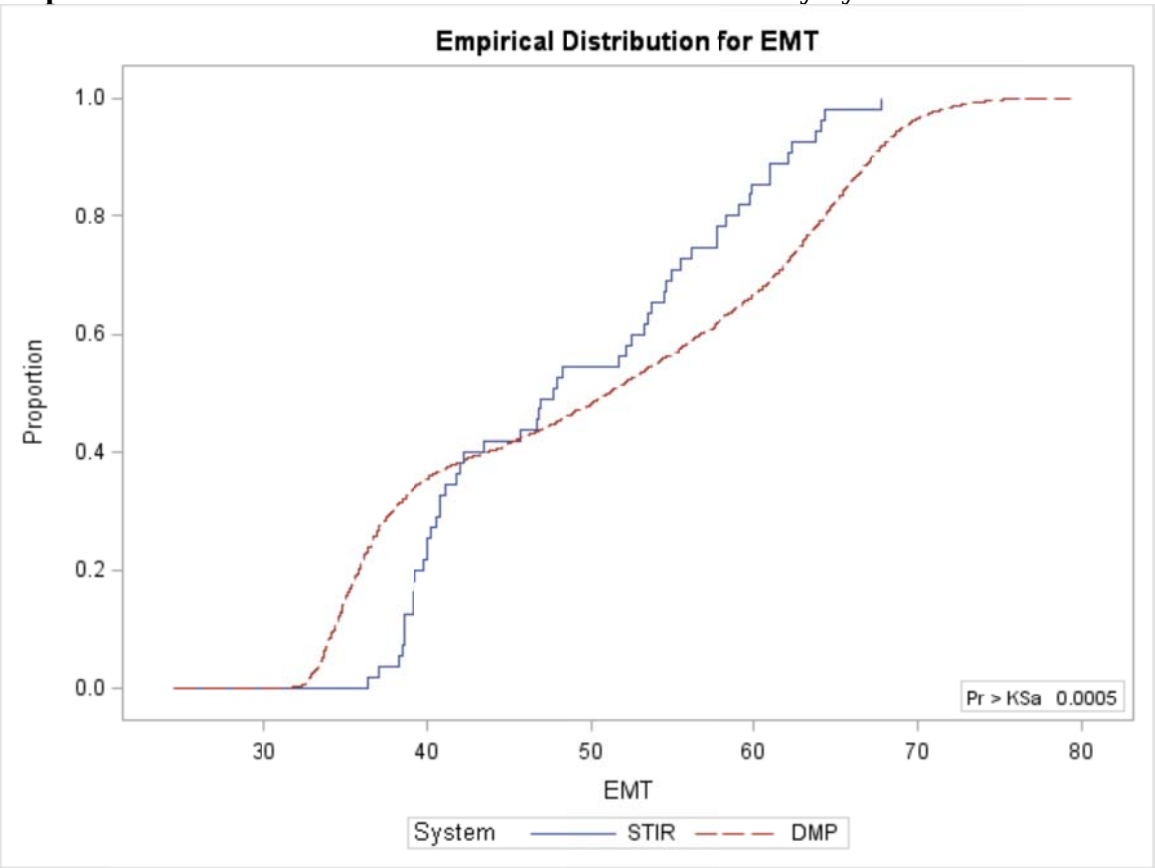
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	55	0.03636	-2.0357
DMP	86056	0.31103	0.05146
Total	86111	0.31085	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.006939	D	0.274666
KSa	2.036330	Pr > KSa	0.0005

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. College Brook (d/s) (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

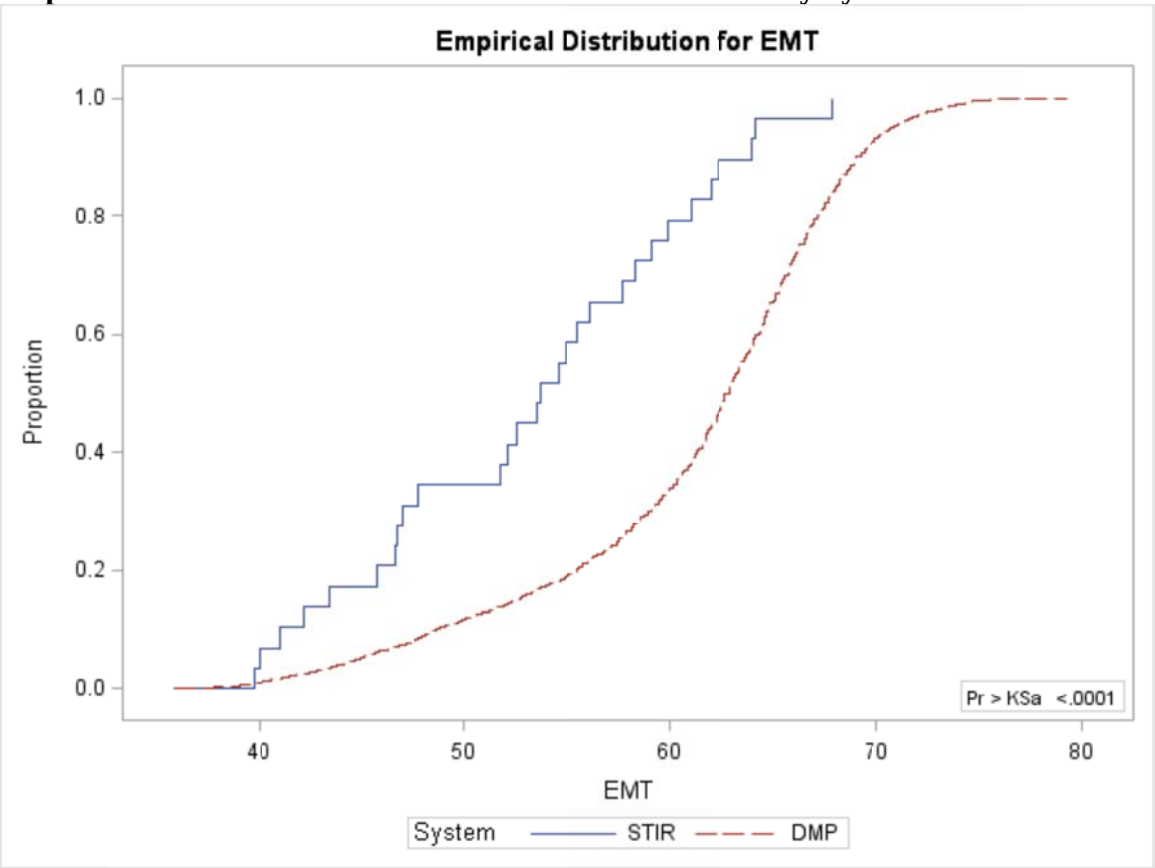
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	29	0.7931	2.45256
DMP	42900	0.33737	-0.0638
Total	42929	0.33767	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.011841	D	0.455737
KSa	2.453392	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. Wednesday Hill Brook (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

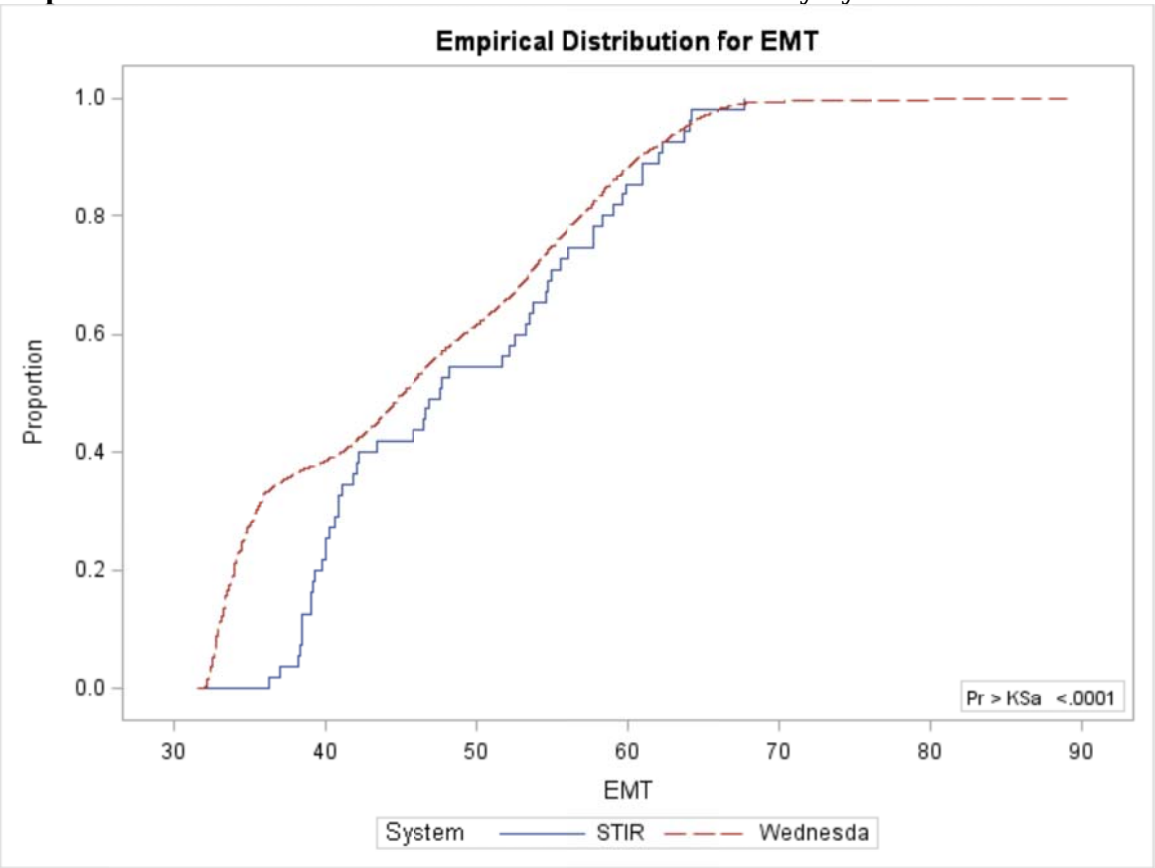
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	55	0	-2.4806
Wednesday	44539	0.3349	0.08717
Total	44594	0.33448	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.011754	D	0.334898
KSa	2.482134	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

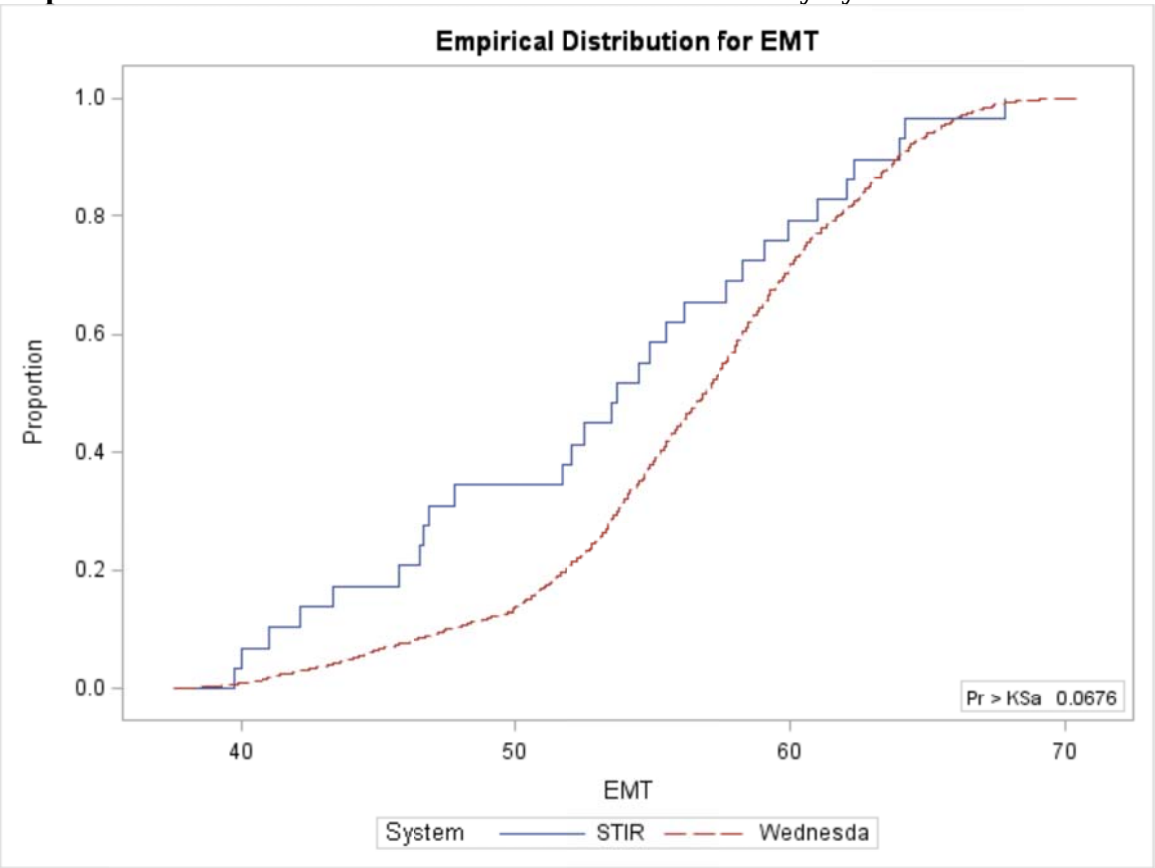
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	29	0.34483	1.30039
Wednesday	17068	0.10294	-0.0536
Total	17097	0.10335	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.009954	D	0.241886
KSa	1.301493	Pr > KSa	0.0676

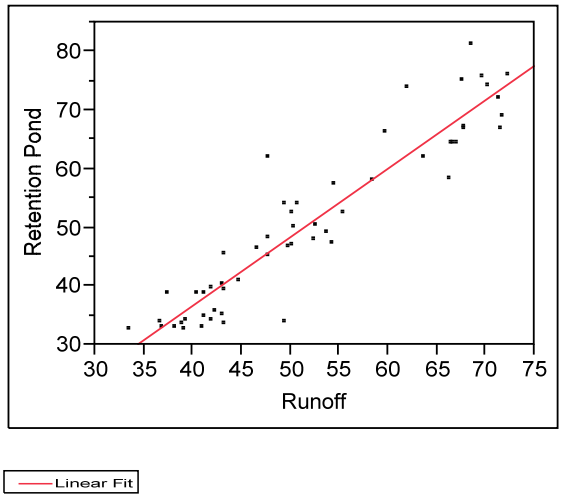
Empirical Distribution Function Plot for EMT Classified by System



APPENDIX E: SYSTEM TREATMENT STATISTICS

(Annual, Summer, Winter)

Bivariate Fit of Retention Pond By Runoff (Annual)



Linear Fit: Retention Pond = -10.23365 + 1.1738466*Runoff

Summary of Fit	
RSquare	0.878613
RSquare Adj	0.876365
Root Mean Square Error	5.135817
Mean of Response	50.88393
Observations (or Sum Wgts)	56

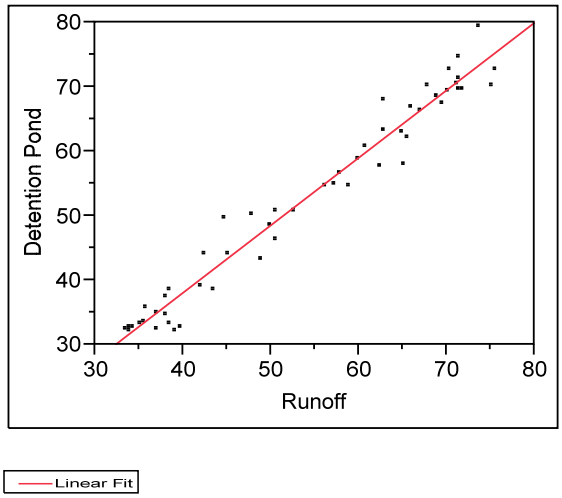
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	10309.518	10309.5	390.8582
Error	54	1424.338	26.4	**Prob > F**
C. Total	55	11733.856		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-10.23365	3.166674	-3.23	0.0021*
Slope	1.1738466	0.059375	19.77	<.0001*

Bivariate Fit of Detention Pond By Runoff (Annual)



Linear Fit: Detention Pond = -3.631256 + 1.044837*Runoff

Summary of Fit	
RSquare	0.966596
RSquare Adj	0.965953
Root Mean Square Error	2.785725
Mean of Response	52.29074
Observations (or Sum Wgts)	54

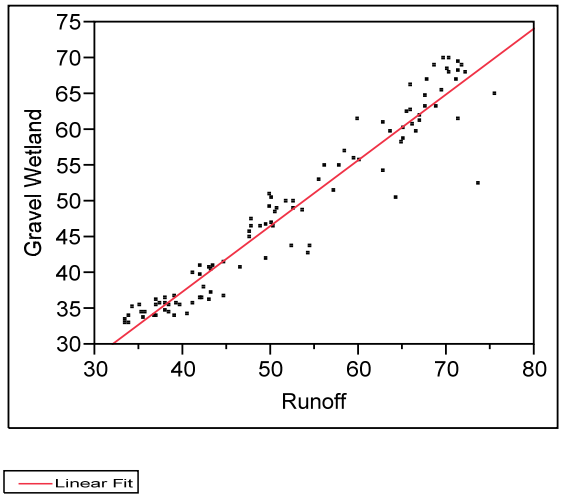
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	11676.692	11676.7	1504.677
Error	52	403.534	7.8	**Prob > F**
C. Total	53	12080.225		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-3.631256	1.490662	-2.44	0.0183*
Slope	1.044837	0.026936	38.79	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Annual)



Linear Fit: Gravel Wetland = 0.8089851 + 0.9184349*Runoff

Summary of Fit	
RSquare	0.930068
RSquare Adj	0.929368
Root Mean Square Error	3.202597
Mean of Response	48.67745
Observations (or Sum Wgts)	102

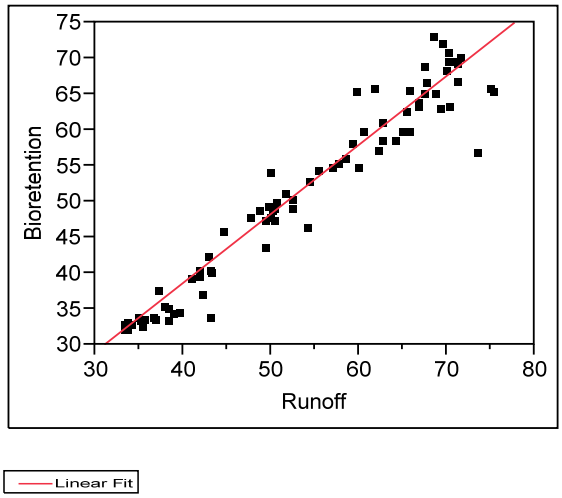
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	13640.875	13640.9	1329.957
Error	100	1025.663	10.3	**Prob > F**
C. Total	101	14666.538		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.8089851	1.350356	0.60	0.5505
Slope	0.9184349	0.025184	36.47	<.0001*

Bivariate Fit of Bioretention By Runoff (Annual)



Linear Fit: Bioretention = 0.1509641 + 0.9629206*Runoff

Summary of Fit	
RSquare	0.940743
RSquare Adj	0.940012
Root Mean Square Error	3.198489
Mean of Response	51.94217
Observations (or Sum Wgts)	83

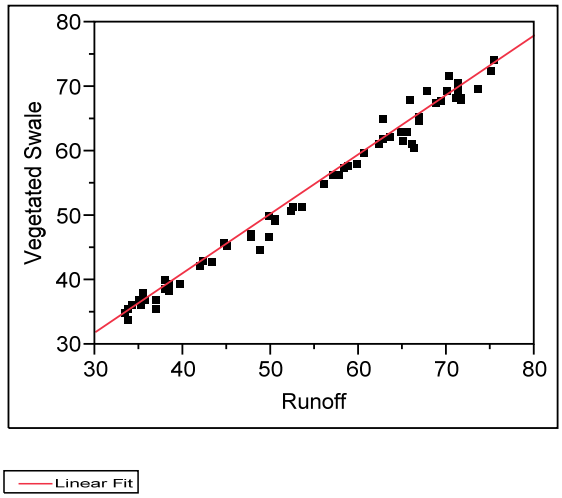
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	13155.566	13155.6	1285.938
Error	81	828.657	10.2	**Prob > F**
C. Total	82	13984.222		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.1509641	1.486321	0.10	0.9193
Slope	0.9629206	0.026852	35.86	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Annual)



Linear Fit: Vegetated Swale = 4.3812395 + 0.9210901*Runoff

Summary of Fit	
RSquare	0.985943
RSquare Adj	0.985712
Root Mean Square Error	1.503185
Mean of Response	54.78095
Observations (or Sum Wgts)	63

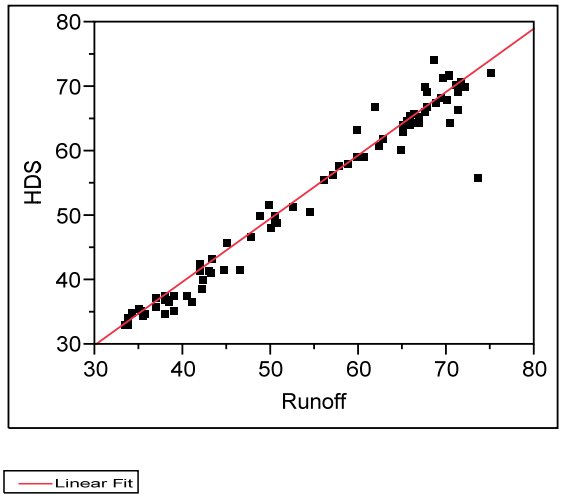
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	9667.4037	9667.40	4278.436
Error	61	137.8334	2.26	**Prob > F**
C. Total	62	9805.2371		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.3812395	0.793455	5.52	<.0001*
Slope	0.9210901	0.014082	65.41	<.0001*

Bivariate Fit of HDS By Runoff (Annual)



Linear Fit: HDS = 0.2914269 + 0.9874263*Runoff

Summary of Fit	
RSquare	0.960432
RSquare Adj	0.959938
Root Mean Square Error	2.731432
Mean of Response	54.11098
Observations (or Sum Wgts)	82

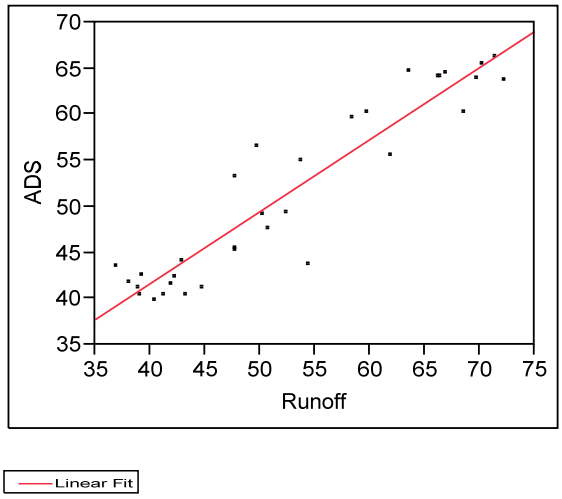
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	14487.642	14487.6	1941.855
Error	80	596.858	7.5	**Prob > F**
C. Total	81	15084.500		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.2914269	1.258023	0.23	0.8174
Slope	0.9874263	0.022408	44.07	<.0001*

Bivariate Fit of ADS By Runoff (Annual)



Linear Fit: ADS = 10.119814 + 0.785959*Runoff

Summary of Fit	
RSquare	0.884098
RSquare Adj	0.880359
Root Mean Square Error	3.355553
Mean of Response	51.46364
Observations (or Sum Wgts)	33

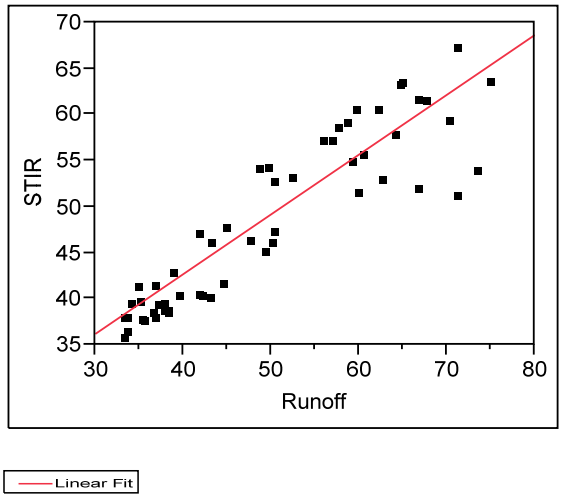
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2662.5646	2662.56	236.4678
Error	31	349.0518	11.26	**Prob > F**
C. Total	32	3011.6164		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	10.119814	2.751313	3.68	0.0009*
Slope	0.785959	0.051111	15.38	<.0001*

Bivariate Fit of STIR By Runoff (Annual)



Linear Fit: STIR = 16.622529 + 0.6496884*Runoff

Summary of Fit	
RSquare	0.832033
RSquare Adj	0.828864
Root Mean Square Error	3.801779
Mean of Response	49.00182
Observations (or Sum Wgts)	55

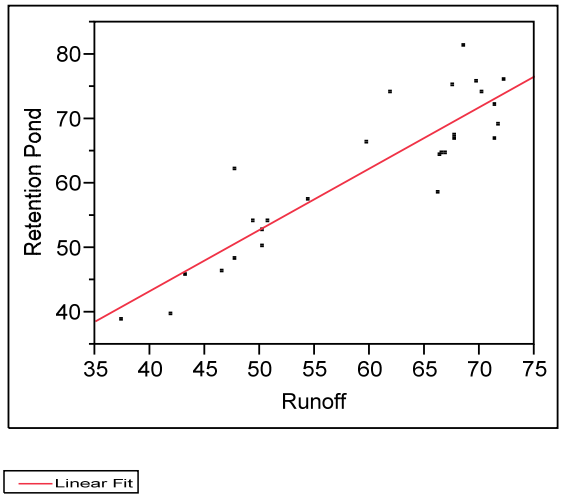
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	3794.6131	3794.61	262.5390
Error	53	766.0367	14.45	**Prob > F**
C. Total	54	4560.6498		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	16.622529	2.063049	8.06	<.0001*
Slope	0.6496884	0.040097	16.20	<.0001*

Bivariate Fit of Retention Pond By Runoff (Summer)



Linear Fit: Retention Pond = 5.1139311 + 0.9543647*Runoff

Summary of Fit	
RSquare	0.804643
RSquare Adj	0.796828
Root Mean Square Error	5.309062
Mean of Response	61.79259
Observations (or Sum Wgts)	27

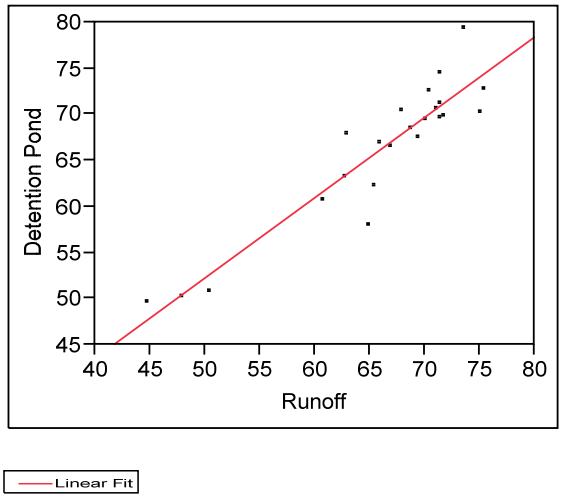
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2902.3451	2902.35	102.9707
Error	25	704.6534	28.19	**Prob > F**
C. Total	26	3606.9985		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	5.1139311	5.678191	0.90	0.3764
Slope	0.9543647	0.09405	10.15	<.0001*

Bivariate Fit of Detention Pond By Runoff (Summer)



Linear Fit: Detention Pond = 8.5917393 + 0.8731744*Runoff

Summary of Fit	
RSquare	0.858822
RSquare Adj	0.852099
Root Mean Square Error	2.998999
Mean of Response	66.24783
Observations (or Sum Wgts)	23

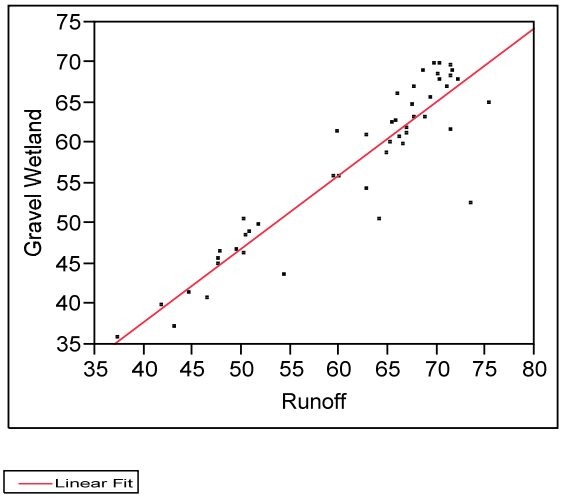
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1148.9635	1148.96	127.7479
Error	21	188.8739	8.99	**Prob > F**
C. Total	22	1337.8374		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	8.5917393	5.139339	1.67	0.1094
Slope	0.8731744	0.077255	11.30	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Summer)



Linear Fit: Gravel Wetland = 1.5244308 + 0.9101106*Runoff

Summary of Fit	
RSquare	0.85045
RSquare Adj	0.847199
Root Mean Square Error	3.931838
Mean of Response	57.31042
Observations (or Sum Wgts)	48

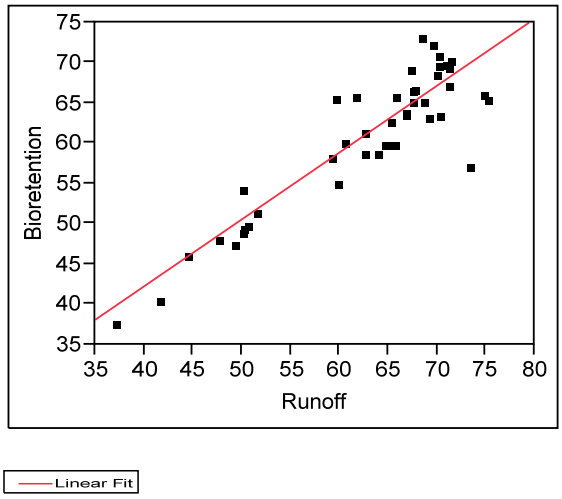
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	4044.0145	4044.01	261.5901
Error	46	711.1303	15.46	**Prob > F**
C. Total	47	4755.1448		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	1.5244308	3.495545	0.44	0.6648
Slope	0.9101106	0.056271	16.17	<.0001*

Bivariate Fit of Bioretention By Runoff (Summer)



Linear Fit: Bioretention = 9.058345 + 0.8309381*Runoff

Summary of Fit	
RSquare	0.820936
RSquare Adj	0.816673
Root Mean Square Error	3.719493
Mean of Response	61.23182
Observations (or Sum Wgts)	44

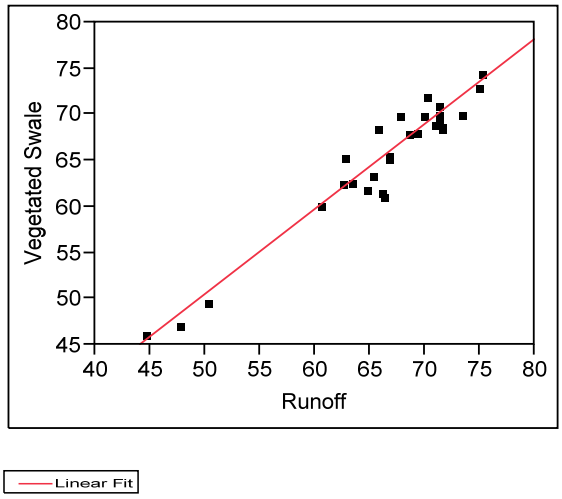
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2663.9012	2663.90	192.5532
Error	42	581.0542	13.83	**Prob > F**
C. Total	43	3244.9555		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	9.058345	3.801466	2.38	0.0218*
Slope	0.8309381	0.059882	13.88	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Summer)



Linear Fit: Vegetated Swale = 4.4954229 + 0.9219298*Runoff

Summary of Fit	
RSquare	0.93281
RSquare Adj	0.930225
Root Mean Square Error	1.907102
Mean of Response	65.51071
Observations (or Sum Wgts)	28

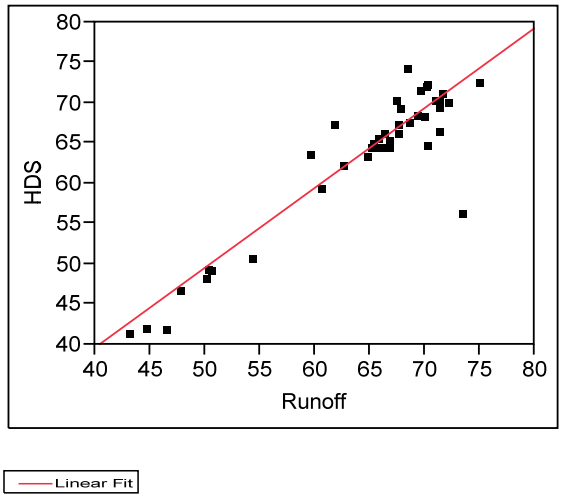
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1312.8238	1312.82	360.9596
Error	26	94.5630	3.64	**Prob > F**
C. Total	27	1407.3868		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.4954229	3.231671	1.39	0.1760
Slope	0.9219298	0.048525	19.00	<.0001*

Bivariate Fit of HDS By Runoff (Summer)



Linear Fit: HDS = -0.051621 + 0.9923862*Runoff

Summary of Fit	
RSquare	0.856128
RSquare Adj	0.852618
Root Mean Square Error	3.486735
Mean of Response	63.84651
Observations (or Sum Wgts)	43

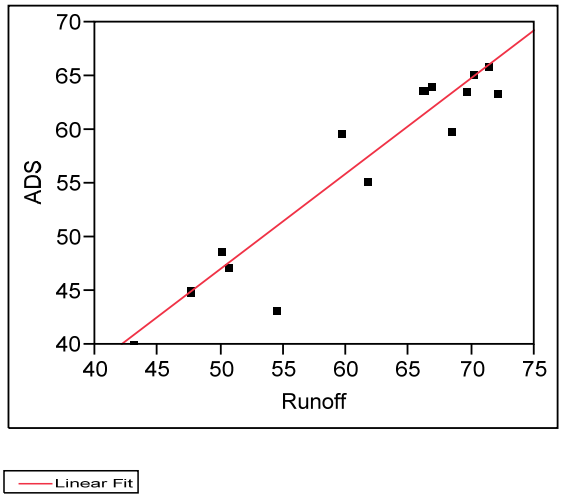
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2966.0769	2966.08	243.9746
Error	41	498.4501	12.16	**Prob > F**
C. Total	42	3464.5270		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.051621	4.125283	-0.01	0.9901
Slope	0.9923862	0.063534	15.62	<.0001*

Bivariate Fit of ADS By Runoff (Summer)



Linear Fit: ADS = 2.4593616 + 0.8915634*Runoff

Summary of Fit	
RSquare	0.906722
RSquare Adj	0.90006
Root Mean Square Error	2.937305
Mean of Response	56.2875
Observations (or Sum Wgts)	16

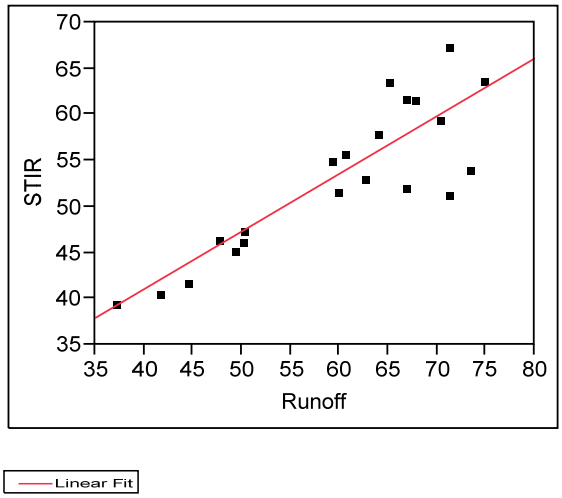
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1174.1488	1174.15	136.0896
Error	14	120.7887	8.63	**Prob > F**
C. Total	15	1294.9375		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	2.4593616	4.672271	0.53	0.6069
Slope	0.8915634	0.076426	11.67	<.0001*

Bivariate Fit of STIR By Runoff (Summer)



Linear Fit: STIR = 16.080377 + 0.6261935*Runoff

Summary of Fit	
RSquare	0.748607
RSquare Adj	0.735376
Root Mean Square Error	4.170378
Mean of Response	53.54762
Observations (or Sum Wgts)	21

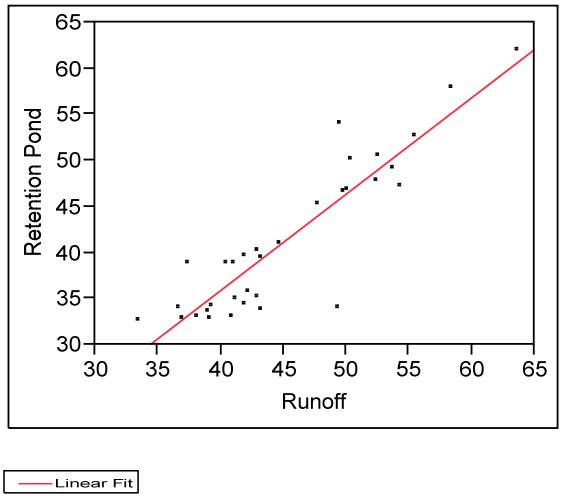
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	984.0234	984.023	56.5789
Error	19	330.4490	17.392	**Prob > F**
C. Total	20	1314.4724		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	16.080377	5.063542	3.18	0.0050*
Slope	0.6261935	0.083249	7.52	<.0001*

Bivariate Fit of Retention Pond By Runoff (Winter)



Linear Fit: Retention Pond = -6.116877 + 1.0504775*Runoff

Summary of Fit	
RSquare	0.816229
RSquare Adj	0.810301
Root Mean Square Error	3.599096
Mean of Response	41.34242
Observations (or Sum Wgts)	33

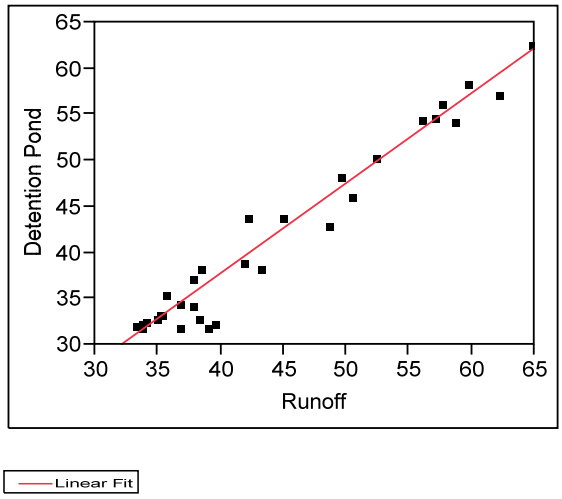
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1783.5424	1783.54	137.6882
Error	31	401.5582	12.95	**Prob > F**
C. Total	32	2185.1006		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-6.116877	4.092814	-1.49	0.1451
Slope	1.0504775	0.089524	11.73	<.0001*

Bivariate Fit of Detention Pond By Runoff (Winter)



Linear Fit: Detention Pond = -1.467563 + 0.9810386*Runoff

Summary of Fit	
RSquare	0.956849
RSquare Adj	0.955361
Root Mean Square Error	2.090773
Mean of Response	41.93548
Observations (or Sum Wgts)	31

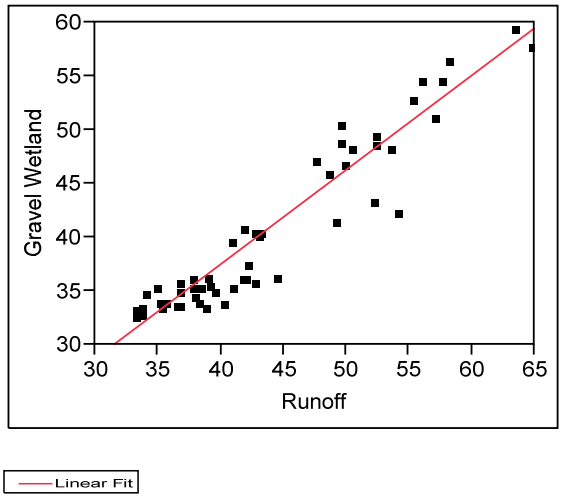
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2811.0424	2811.04	643.0633
Error	29	126.7686	4.37	**Prob > F**
C. Total	30	2937.8110		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-1.467563	1.752274	-0.84	0.4092
Slope	0.9810386	0.038686	25.36	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Winter)



Linear Fit: Gravel Wetland = 2.19138 + 0.8828414*Runoff

Summary of Fit	
RSquare	0.903066
RSquare Adj	0.901202
Root Mean Square Error	2.424819
Mean of Response	41.0037
Observations (or Sum Wgts)	54

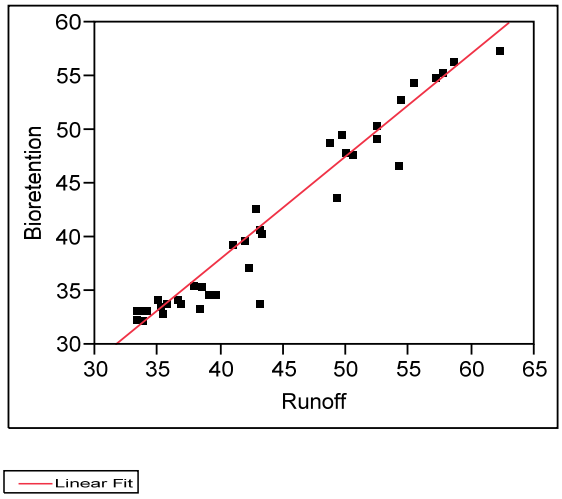
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2848.4325	2848.43	484.4483
Error	52	305.7467	5.88	**Prob > F**
C. Total	53	3154.1793		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	2.19138	1.793988	1.22	0.2274
Slope	0.8828414	0.040111	22.01	<.0001*

Bivariate Fit of Bioretention By Runoff (Winter)



Linear Fit: Bioretention = -0.32904 + 0.9578798*Runoff

Summary of Fit	
RSquare	0.945722
RSquare Adj	0.944255
Root Mean Square Error	1.974744
Mean of Response	41.46154
Observations (or Sum Wgts)	39

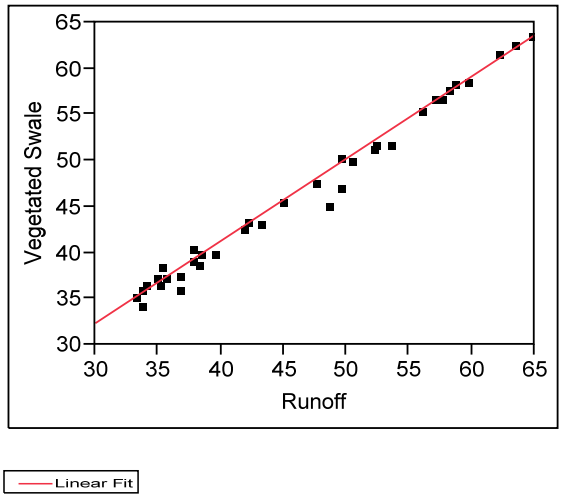
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2513.9866	2513.99	644.6757
Error	37	144.2857	3.90	**Prob > F**
C. Total	38	2658.2723		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.32904	1.676016	-0.20	0.8454
Slope	0.9578798	0.037726	25.39	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Winter)



Linear Fit: Vegetated Swale = 5.4855815 + 0.8943165*Runoff

Summary of Fit	
RSquare	0.986289
RSquare Adj	0.985886
Root Mean Square Error	1.075783
Mean of Response	46.66389
Observations (or Sum Wgts)	36

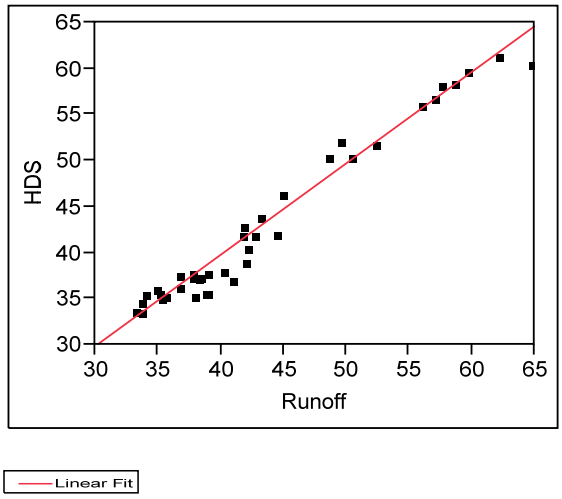
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2830.5545	2830.55	2445.805
Error	34	39.3485	1.16	**Prob > F**
C. Total	35	2869.9031		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	5.4855815	0.851726	6.44	<.0001*
Slope	0.8943165	0.018083	49.46	<.0001*

Bivariate Fit of HDS By Runoff (Winter)



Linear Fit: HDS = 0.2275004 + 0.9894911*Runoff

Summary of Fit	
RSquare	0.967789
RSquare Adj	0.966919
Root Mean Square Error	1.629708
Mean of Response	43.37692
Observations (or Sum Wgts)	39

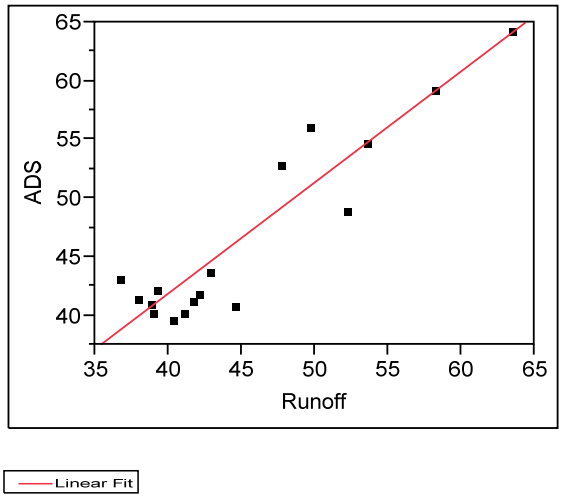
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2952.5592	2952.56	1111.678
Error	37	98.2700	2.66	**Prob > F**
C. Total	38	3050.8292		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.2275004	1.320201	0.17	0.8641
Slope	0.9894911	0.029677	33.34	<.0001*

Bivariate Fit of ADS By Runoff (Winter)



Linear Fit: ADS = 4.0369877 + 0.9469687*Runoff

Summary of Fit	
RSquare	0.863447
RSquare Adj	0.854343
Root Mean Square Error	3.008071
Mean of Response	46.92353
Observations (or Sum Wgts)	17

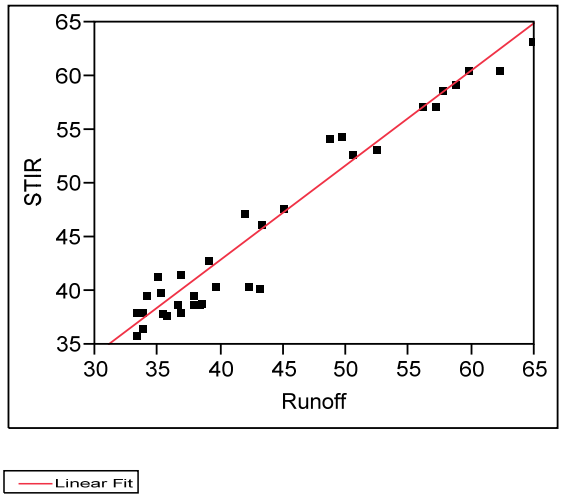
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	858.22326	858.223	94.8471
Error	15	135.72733	9.048	**Prob > F**
C. Total	16	993.95059		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.0369877	4.463636	0.90	0.3801
Slope	0.9469687	0.097235	9.74	<.0001*

Bivariate Fit of STIR By Runoff (Winter)



Linear Fit: STIR = 7.6352601 + 0.8830669*Runoff

Summary of Fit	
RSquare	0.946079
RSquare Adj	0.944394
Root Mean Square Error	2.070518
Mean of Response	46.19412
Observations (or Sum Wgts)	34

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2407.0134	2407.01	561.4624
Error	32	137.1854	4.29	**Prob > F**
C. Total	33	2544.1988		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	7.6352601	1.665578	4.58	<.0001*
Slope	0.8830669	0.037268	23.70	<.0001*

APPENDIX F: CALCULATION OF AN EVENT MEAN TEMPERATURE

Calculating an Event Mean Temperature for a Single Storm

The event mean temperature is congruous to the event mean concentration calculated for other stormwater pollutants. To calculate this metric each storm is separated from the database with the data for the time, flow, and temperature. The data is compiled into 5-minute intervals, so for each 5-minute interval, a volume, and a volume-temperature value was calculated.

The Volume Equation below is the method used to calculate the 5-minute volume values. It is the value of the following time stamp subtracted by the value of the current time stamp, multiplied by the correction value of 1,440 minutes per day to convert the time into the correct unit of minutes. That is then multiplied by the average of the two corresponding flow values of the time stamps. This process is repeated for the entirety of the storm duration, and then the values are summed together for a total storm volume.

The 5-minute volume-temperature value is calculated by multiplying the 5-minute volume value with the average of the 5-minute temperature values. This again, is done for the entirety of the storm duration and the values summed together for a total storm volume-temperature value.

Then using the total volume value, and the total volume-temperature value, an EMT is calculated using the Tabular Equation below. The resulting EMT has units of Fahrenheit, but is now weighted by the flow through the system. Table 1 shows the steps, as they would appear in the data analysis files created to calculate EMTs for each storm.

Table 14: Example Tabular EMT Calculation

Date	Flow	Temperature	Volume	Volume*Temperature
1	**11**	**21**		
2	**12**	**22**	=1440*(**2**-**1**)*[(**11**+**12**)/2]	=Volume * [(**21**+**22**)/2]
3	**13**	**23**	=1440*(**3**-**2**)*[(**12**+**13**)/2]	=Volume * [(**22**+**23**)/2]
4	**14**	**24**	=1440*(**3**-**4**)*[(**13**+**14**)/2]	=Volume * [(**23**+**24**)/2]

Graphical Equation:

$$EMT = \frac{\int_O t(t)q(t)dt}{\int_O^T q(t)dt}$$

EMT = Event Mean Temperature (^oF)

T = Flow Duration (min)

t(t) = Flow Temperature (^oF)

q(t) = Flow (gpm)

Tabular Equation:

$$EMT = \frac{\sum Vol * Temp}{\sum Vol}$$

EMT = Event Mean Temperature (^oF)

Vol = 5-min Flow Volume (gal)
Temp = 5-min Flow Temperature (^{o}F)

Volume Equation:

$$V = 1440 \times (t_{i+1} - t_i) \times \left(\frac{Q_i + Q_{i+1}}{2} \right)$$

V = Flow Volume (gal)
t = time (day)
Q = Flow (gpm)