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Quantitative Comparison of Two National Weather Service Snow Models in the New York City Reservoir Watersheds

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ABSTRACT

The SNOW-17 model is utilized by the River Forecast Centers of the National Oceanic and Atmospheric Administration (NOAA)/ National Weather Service (NWS) to estimate the snow water equivalent (SWE) of their forecast watersheds. The National Operational Hydrologic Remote Sensing Center (NOHRSC) of the NWS utilizes the SNODAS model to create nationwide estimates of snow water equivalent as well as other snow pack parameters. This study compares output from these two NWS models with snow surveys conducted in the reservoir watersheds of Cannonsville, Pepacton, Neversink, Rondout, Schoharie, and Ashokan by the New York City Department of Environmental Protection (NYCDEP). The time period used for this study is from 2004 through 2008 during the months of January through April. For this study, only the SWE estimates of the models and surveys are compared instead of snow depth, as the physical volume of water is more pertinent to the management of water levels in the reservoirs. The NYCDEP SWE data are compared on a basin wide level with SWE output from both models, and also a point basis with the grids developed by the SNODAS model. A linear regression analysis, the Mann-Whitney test and time trend analysis are all used to determine how the models compare to the survey data and if there is any seasonality or basin trends exhibited by the models. Results indicate that differences between the model and survey data are most likely a function of differences in survey location density and discrepancies in defined basin extent. It is still unclear whether lack of survey points at higher elevations has any direct effect on differences with model data. In the future, it is suggested that those basins whose RFC defined extent do not match the NYCDEP extent should modify or combine output from the separate basins to remain consistent when comparing SWE estimates with the NYCDEP.

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1. Introduction

The New York City water supply system consists of the reservoir system east of the Hudson River known as the Croton watershed and those reservoirs west of the Hudson known as the Catskill/Delaware watersheds. This paper examines two National Weather Service (NWS) snow models in the Catskill/Delaware watersheds only, consisting of six main reservoirs: Ashokan, Cannonsville, Neversink, Pepacton, Rondout, and Schoharie (Fig.1).

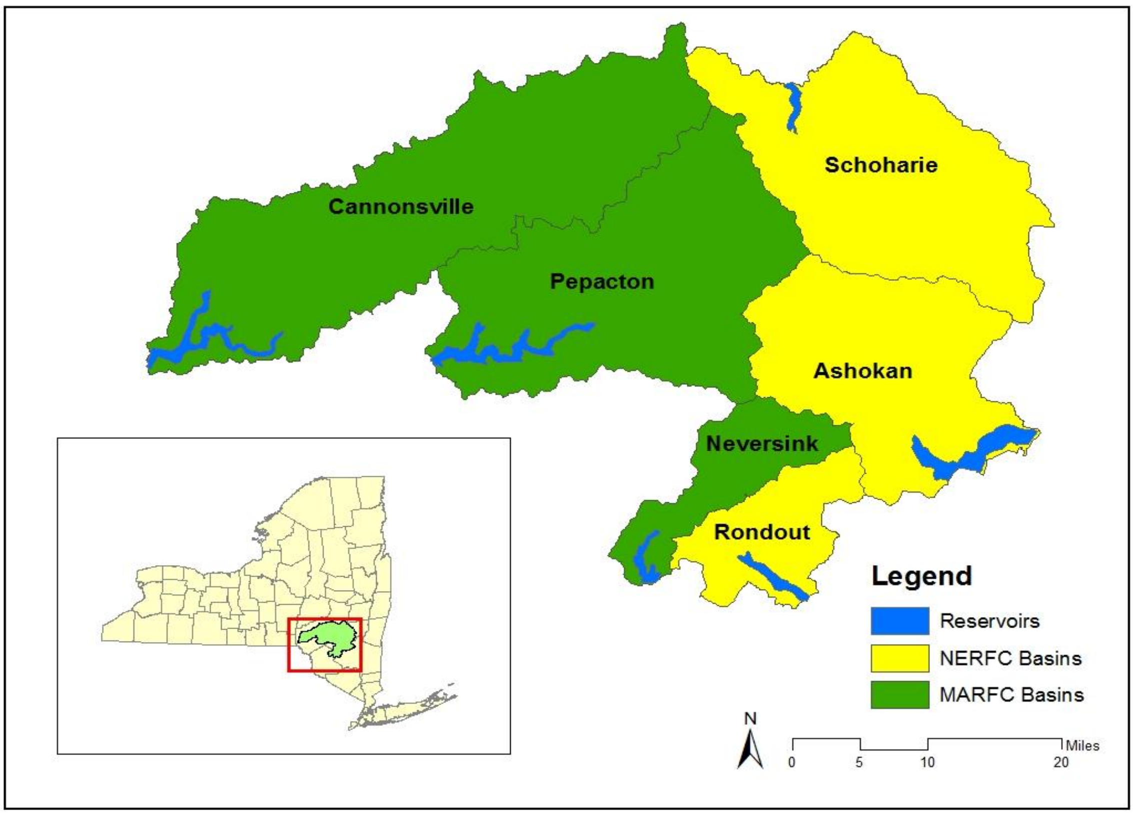

Figure 1. Location of the Catskill/Delaware reservoir system. MARFC and NERFC refer to the corresponding River Forecast Centers of the NWS, which will be explained in a subsequent section.

Ashokan reservoir was placed into service in 1915 and at full capacity holds 122.9 billion gallons and provides the city of New York with 40% of its water during non-drought periods. Ashokan receives water not only from its drainage basin totaling 255 square miles, but also water flowing from Schoharie reservoir. Cannonsville reservoir was placed into service in 1964 and holds 95.7 billion gallons at full capacity. It is the newest of the reservoirs, and also has the largest drainage area at 455 square miles. Neversink reservoir is one of the smallest reservoirs, draining an area of 92 square miles and holding 34.9 billion gallons at full capacity. Pepacton reservoir is the largest by volume of water, holding 140.2 billion gallons at full capacity, draining an area of 371 square miles, and responsible for delivering 25% of the daily flow into the New York City. Rondout reservoir also has a small drainage area at 95 square miles, and holds 49.6 billion gallons at full capacity. However, it receives water not only from its own watershed but also receives flow from Pepacton, Cannonsville, and Neversink reservoirs, making it an important component of the City's water supply system. Schoharie reservoir drains a fairly large area at 316 square miles and holds 17.6 billion gallons of water at full capacity (available online at: http://www.nyc.gov/html/dep/html/watershed_protection/reservoirs.shtml).

Considerable effort is invested in estimating snow water equivalent in the areas of the NYC reservoir watersheds for a number of reasons. During the winter, accurate snow water equivalent (SWE) values are needed in order to determine the relative volume of water "in situ" in the watersheds compared to the current levels in the reservoirs. The SWE values that are obtained by the NYCDEP snow surveys are ultimately converted to billions of gallons of water present in the reservoir watersheds (J. Porter, personal communication). This estimate of water volume is important for planning releases of water from the reservoirs in order to maintain ideal levels in the reservoir. If there are significant amounts of SWE present throughout the watershed and a heavy rain event is anticipated, better flood management can be provided with the advanced knowledge of the relative amount of water contained in the reservoir and the watershed itself.

There are currently three different sources of SWE estimation for the Catskill/Delaware watershed system. Two are snow models run within the National Weather Service and the third is the NYCDEP snow surveys. The SNOW-17 model is used by the River Forecast Centers (RFC) of the Weather service to forecast for their area of responsibility. The SNODAS model is utilized by the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the NWS for nation-wide estimates of many snow characteristics, including SWE.

The six reservoirs that make up the Catskill system straddle a boundary between the Middle Atlantic River Forecast Center (MARFC) and the Northeast River Forecast Center (NERFC) of the National Weather Service (Fig. 1). Cannonsville, Pepacton and Neversink reservoirs fall under the forecast area of MARFC and Ashokan, Rondout and Schoharie are in the NERFC forecast area. NOHRSC is responsible for providing nationwide forecasts and thus covers all the Catskill/Delaware reservoir system watersheds.

The purpose of this study is to compare the NWS snow model output to ground point observations of SWE from the NYCDEP surveys in the basins. However, the reader should keep in mind that the NYCDEP snow surveys themselves are not perfect, and a discrepancy between the models and survey may not necessarily reveal error in the model, but could also be the result of inaccuracies in the survey data such as elevation and survey location density differences. The next three sub- sections provide more detail as to how the snow models operate as well as more information on how the snow surveys are conducted. Section 2 describes the format and source of the data used in the study. Section 3 provides background on the methods used to analyze the data as well as the results. Section 4 provides interpretation of the results and recommendations on possible improvements for estimating SWE in the Catskill reservoir system and an appendix with the graphs created for this study has been included at the end of the paper.

a) SNOW-17

The SNOW-17 model is an index snow accumulation and ablation model used by the RFCs of the National Weather Service to forecast snow cover for their area of responsibility (Anderson 1973). SNOW-17 is used to estimate current SWE conditions, and is run using ensemble forecasts to produce SWE estimates for up to 168 hours into the future at 6 hour time intervals (T. Rodgers, personal communication).This model was specifically designed for use in river forecasting and as such is applied basin-wide to model the outflow from snow cover, as well as amount of snow, generally for a 6 hour period (Anderson 2006). The main input parameters used to determine the energy exchange across the snow-air interface are temperature and precipitation (Anderson 2006). There are several reasons why temperature is used as the main driver for modeling snow cover. First, air temperature is easy to measure. Second, temperature data are readily available for real-time operational use of the model and also on a historical basis for model calibration. Third, the spatial variability of temperature is often easier to estimate than other meteorological variables and lastly temperature is a fairly easy variable to forecast with some degree of accuracy (Anderson 2006). During the study period of 2004 through 2008, the precipitation and temperature data is calculated similarly for both RFCs. The data is then input into SNOW-17 using a basin average MAT (mean areal temperature) and MAPX (mean areal precipitation) values, which are generated from quality controlled field gage data (T. Rodgers and R. Shedd, personal communication).

Although air temperature changes with some degree based on land cover, the largest variability occurs with changes in elevation and to account for this, areas with large elevation gradients are split into different elevation zones in the model (Anderson 2006). The only basins in the Catskill system that have been split into different elevation zones are parts of the basins for Schoharie reservoir and Ashokan reservoir; the division occurs at 2500 ft in elevation. To forecast stream flow for Schoharie reservoir, SNOW-17 forecasts stream flow and SWE for the Schoharie Creek basin at Prattsville, which contains two elevation zones, and then routes water downstream into the Schoharie Creek at Gilboa Dam basin (T. Econopouly 2010, personal communication). The modeled SWE from the upstream and downstream basins are not combined.

b) SNODAS

The Snow Data and Assimilation System (SNODAS) model is utilized by the National Operational Hydrologic Remote Sensing Center (NOHRSC) to create nationwide estimates of snow cover characteristics such as snow depth, snow water equivalent, snow pack temperature, melt rates and sublimation losses (Carroll et al. 2006). It is a spatially uncoupled, vertically distributed, energy and mass balance snow model that assimilates data in many different forms that NOHRSC receives. According to Carroll et al. (2006), the SNODAS model is:

"…[F]orced by hourly, 1 km^2, gridded, meteorological input data downscaled from mesoscale NWP model (RUC2) analyses with the three major-layer state variables of water content, internal energy, and thickness. It generates total snow water equivalent, snowpack thickness, and energy content of the pack along with a number of energy and mass fluxes at the snow surface and between the snow and soil layers."

The model is run nearly in real time, with hourly updates and a 1km by 1km grid spacing. The SNODAS model ingests observations of snowpack characteristics from multiple sources including cooperative observers, airborne snow surveys, satellites and weather prediction models. Along with dynamic inputs to the SNODAS model, additional fixed data are utilized such as digital elevation data, the associated slope and aspect, forest cover, and soil information (Carroll et al. 2006).

2. NYCDEP snow survey data and basin characteristics

The New York City Department of Environmental Protection (NYCDEP) conducts snow surveys on an approximate two-week basis during the months of January to April. Data for April is irregular year to year because the date of the last survey is dependent on how long there is measurable snow cover. There are sets of points for each of the reservoir basins where snow cores are taken manually for snow water

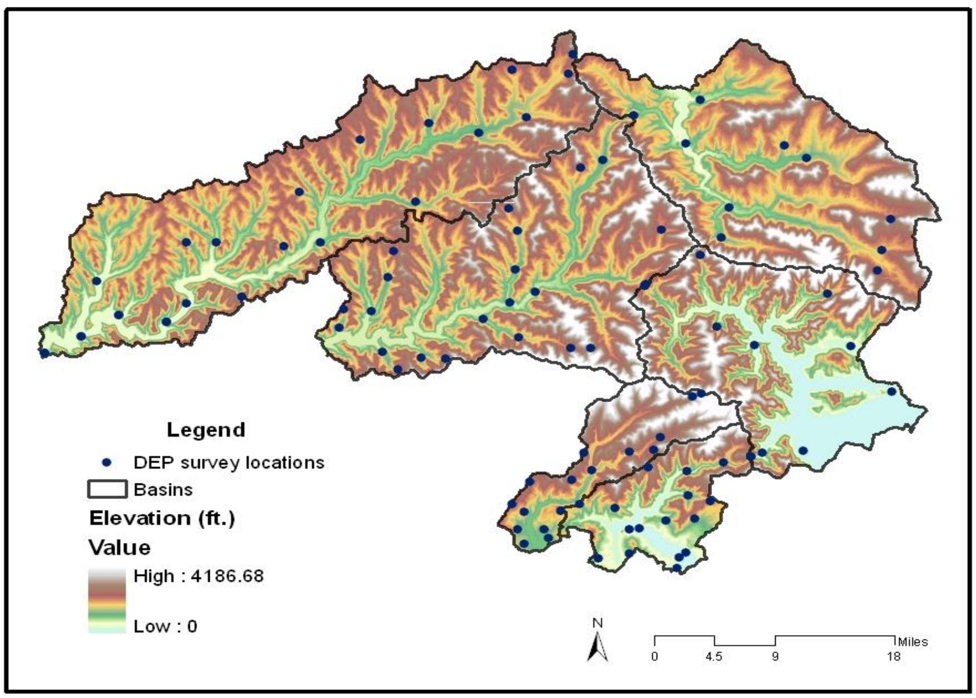

Figure 2. Map of basin elevation and static survey point locations.

equivalent (SWE) and snow depth; these cores are taken at the same point locations for every year of the study (Fig. 2). To estimate the SWE on a basin wide level, NYCDEP takes a simple arithmetic average of the survey point values contained in the watershed (J. Porter 2010, personal communication).

a) *Elevation*

Table 1 displays the average elevation of each of the reservoir basins, as well as the average elevation of the NYCDEP survey points. The value for the basin is determined by averaging the DEM grid cells for the extent of the basin. The average elevation for the survey points is calculated by finding the average of the individual point elevations, taken from the DEM data. There is considerable difference between the average of the DEP points and of the basins; the average elevation of the points is consistently less than the average of the basin from the DEM.

Due to the lack of SWE sampling at higher elevations, a study by Elder et al. (1991) was examined, which discusses the factors contributing to SWE distribution in an alpine watershed to determine an optimum SWE sampling technique. This study used linear regression plots to directly examine the relationship between SWE and elevation. Each plot created for the watershed contained the elevation of the sampling point plotted on the x- axis and observed SWE on the y-axis. For the first year of the study (1986 water year), which was a year characterized by heavy precipitation, the plots of elevation and SWE showed no apparent relationship. For the second and third years (1987 and 1988 water years), both with a much lower than normal precipitation record, relationships between SWE and elevation were also weak (Elder et al. 1991). It is important to note that the elevation ranged from 9187 ft. to 11208 ft. above sea level for the alpine basin and the total relief for the basin was 2087 ft. The total relief for the reservoir basins in the Catskills for this study is 3596 ft above sea level and the highest point elevations in the watersheds do not exceed 4200 ft above sea level. Though the basin used in the Elder et al. (1991) study is very different from the Catskills climatically and geographically, this was the only study found that directly examined the relationship between SWE and elevation. Thus, the linear regression method employed to determine correlation of SWE and elevation is used in this study for the basins in the Catskills.

Based on the work of Elder et al. (1991), linear regression plots were created for each of the six reservoir

Table 1. Differences in elevation of DEP point data and DEM data.

Basin	DEM Average Elevation (ft)	DEP Point Average Elevation (ft.)	Difference (ft)
Schoharie	2073.2	1611.2	461.9
Rondout	1714.6	1414.0	300.9
Pepacton	2077.4	1730.3	347.1
Neversink	2322.2	1926.8	395.3
Cannonsville	1875.7	1487.5	388.1
Ashokan	1768.0	1476.4	291.7

watersheds in this study, one for a period of relatively little SWE (0-1.0 inch), one of moderate SWE (1.0-3.0 inches) and higher SWE (3.0+ inches) from January and February 2004. The resulting regression plots for each of the basins produced only one plot with a statistically significant positive linear relationship between elevation and SWE, based on the Pearson- product moment correlation (Havlicek et al. 1988). The fact that there are few statistically significant regression values for the plots indicates that the relationship between SWE and elevation is complex and difficult to predict. This is only a preliminary comparison of SWE and elevation, and a complete investigation would require comparison for every survey date during the study period in order to more accurately determine the nature of SWE at high and low elevations. However, data in this comparison and from the Elder et al (1991) study indicate that though it seems intuitive that a lack of points at higher elevations may result in lower SWE estimates, elevation and SWE appear to not have a direct positive relationship. Other factors like aspect, land use and wind affected areas most likely exert large control over SWE distribution as well.

To determine if there is a relationship between a basin's elevation difference and model difference, the Spearman coefficient of rank correlation test was utilized. The Spearman coefficient determines the nature of association between pairs of data points (Gibbons 1976). First, the difference between the DEP survey points' average elevation and DEM average basin elevation is calculated. Second, the number of positive differences is assigned to each basin for SNOW-17 and SNODAS; this is also done separately for negative differences. The elevation differences and the positive or negative differences are then ranked highest to lowest. For each basin the difference between each of the numerical ranks is calculated and the Spearman coefficient test utilizes this difference. The coefficient was calculated four different times, twice for each model to test positive and negative occurrences separately with elevation difference. For each test there were a total of six data points corresponding to each basin in each set of data to compare.

A table of Spearman coefficient values in Gibbons (1976) was consulted; the value of the coefficient has to be greater than 0.771 for six pairs of data points in order for there to be a statistically significant relationship between the sets of data at the 95% confidence interval. Of the four coefficients calculated, none showed a statistically significant correlation between the number of over/under estimations by the model and elevation difference. However, the coefficients for the test for both SNODAS and SNOW-17 had positive values when the elevation difference was tested with a positive model difference. The coefficients for each of the models were negative when elevation difference was tested with number of negative model differences. A negative coefficient value indicates there is an inverse relationship; meaning that as elevation difference between survey points and DEM data increase, the frequency of negative model/ survey differences decreases. Likewise a positive value indicates that in this case as elevation difference increases for a basin, frequency of positive differences increases. It should be noted that although there is not a statistically significant correlation between the data being tested, the calculated coefficient values provide some insight into how the data is behaving.

b) Land use

In regards to basin aspect, the differences between directions north, northeast, east, etc., for each of the basins are very small. The percentage of each aspect for each of the basins ranges between 10%-14% for each direction, with little variation between basins. The proportion of NYCDEP survey points' aspects ranges slightly for each basin, however the differences are relatively small compared to the ranges for the DEM data. Pie charts depicting the aspect of the basin survey points are presented in Appendix I. There are also some slight differences between the basins for land use. All six of the basins contain a majority of forested land, at 69% or greater, and the second most common land use type is pasture/hay. Cannonsville basin shows the largest difference between land use types, with 69% forested and 19% pasture/ hay. The remaining basins have a minimum of 84% forest cover, and a maximum 94% forest cover, with the remaining land use types making up a small percentage of basins. Pie charts for land use characteristics of the basins on a whole and the survey points can be found in Appendix II.

Another component of the relationship between the DEP survey points and the reservoir watersheds is the density of survey locations per basin. Table 2 shows how survey location distributions are different for each of the 6 reservoirs basins. The resultant square miles represented by a survey point was determined by dividing the total area of a basin by the total number of survey locations within the basin. Schoharie basin has the lowest density of survey points at 31.6 square miles/ point while Rondout has the highest density of points at 5.9 square miles/ point.

Table 2. DEP survey point density.

Basin	# of DEP Survey Points	Area (sq. miles)	Sq. miles/point
Ashokan	11	225	20.5
Schoharie	10	316	31.6
Neversink	15	92	6.1
Rondout	16	95	5.9
Cannonsville	24	455	19.0
Pepacton	23	371	16.1

3. Use of survey data and models in subsequent comparisons

Before data for comparison of the models to the snow surveys are presented, the reader must understand the nature of the data and the relationship between the models and the surveys. First, basin estimates of SWE based on NYCDEP surveys are taken into account when running both SNOW-17 and SNODAS. Forecasters at both NERFC and MARFC have the ability to examine DEP survey data on a point or basin average basis. The survey data are quality controlled and the decision is made whether to modify model output (P. Cognitore and R.Shedd, personal communication). In addition to forecasters at the RFC using the survey data as a guide for model output of SNOW-17, NOHRSC creates special basin estimates for the NYCDEP reservoirs. It is also important to note that when a DEP survey is complete, the observed data are also ingested into SNODAS (A. Sawyer, personal communication). Second, over the past few years there has been increasing coordination and communication between the RFCs and NOHRSC. SNOW-17 and SNODAS estimates of SWE are compared to determine degree of correlation and thus potential accuracy in results; forecasters using SNOW-17 may adjust snow water equivalent based on these comparisons (A. Sawyer, personal communication).

It is important for the reader to realize that any subsequent comparison of the model to the survey data is not to determine which model is "better" or "closer" the DEP survey estimates. Any statement of positive or negative differences in the models is relative to the DEP data, which is most likely not completely error free. The use of positive or negative difference is only to provide a description of model behavior relative to the survey data over the basins and periods studied.

The use of statistical tests in this study to determine any degree of association between data sets is also done with a caveat in mind. The tests are used to provide another source of data to support any statistically significant relationship between data instead of just relying on observing data behavior alone. Many statistical tests assume that the samples of data are independent, which is not the case in study. Though there are interdependencies in the data sets, the nature of the data representing the same physical characteristic (SWE), implies that the data set values should be similar. So, though application of these tests for the survey and model data may not be absolutely perfect, the tests may indicate the strength of the similar nature between data sets. Presenting a study without statistical analysis would only involve qualitative comparison instead of more quantifiable results.

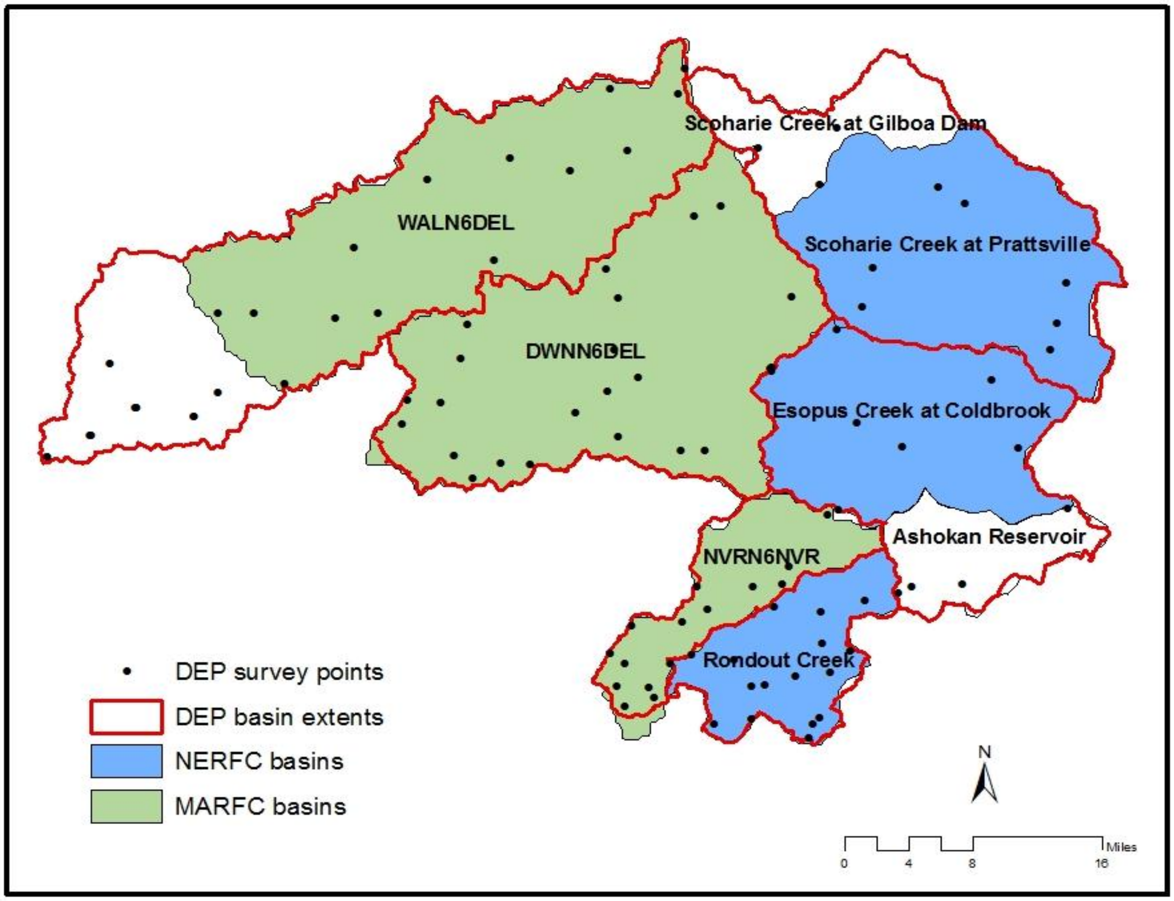

Figure 3. Basin extents for the DEP surveys and the RFCs. SWE estimates from SNOW-17 were provided from the blue basins for NERFC, and green basins are the extents of SWE basin estimates from MARFC. The red lines indicate the extent of the basins for the NYCDEP surveys.

One problem with the data that was not realized until data comparison was completed, is that the extent for each of the reservoir basins is not equivalent between the RFCs and the NYCDEP. As Figure 3 shows, the extents of the basins for Cannonsville, Schoharie and Ashokan basins are not the same between the DEP data and the SNOW-17 data from the RFCs. However, the number of survey points that do not fall under the extent for each of the RFC basins is relatively small. There are 6 survey locations for Cannonsville, 4 for Ashokan and 3 for Schoharie that lie outside the extents of the SNOW-17 basins. Based on these differences in extents, and further comparison between survey and SNOW-17 model data for Cannonsville, Schoharie and Ashokan reservoir may be less reliable than data comparison for other basins. The linear regression plots and statistical tests contain basin average SWE values from the NYCDEP and each RFC, so the specific survey locations that do not fall under the RFC boundary cannot be removed. Therefore, results from these basins should be weighted less heavily than results from the other basin where the extents are identical (Pepacton, Neversink and Rondout).

4. Data sources and methods used

The sources of SWE used for this study were provided from multiple sources from the National Weather Service as well as NYCDEP. The data for SNOW-17 came from MARFC in the form of a daily "snapshot" or picture of associated SWE values for the basins from 2004 - 2008 and for NERFC in the form of a table. NERFC began archiving their data in March 2004, so data was used from 2005 through 2008. The SNODAS data was provided by NOHRSC in the form of GIS raster files for the entire country. Work was done with GIS software to extract information from the datasets and convert the units to inches. NYCDEP provided SWE measurements for each survey location, the calculated basin arithmetic averages, and a table on the survey point characteristics. Since the SNOW-17 model output is by basin, the basin average of the SNODAS grid data was calculated by performing a simple arithmetic average within the reservoir boundaries in GIS software. The averages obtained from performing this calculation with GIS were nearly identical to the basin average calculated by NOHRSC, typically only different by a few hundredths of an inch. SWE values for a particular day from the SNODAS output can be found at the NOHRSC website (available online at: http://www.nohrsc.noaa.gov/interactive/html/basin.html?rfc =NYCDEP).

Land use data and Digital Elevation Model (DEM) 10 meter by 10 meter data was obtained from the Cornell University Geospatial Information Repository (CUGIR) online (available online at: http://cugir.mannlib.cornell.edu). GIS files of the basin extent were provided by NYCDEP so that calculations of basin elevation and land use could be done.

A mathematics professor and a geographical statistics professor were consulted to determine an appropriate statistical test for the data. Although there are considerable interdependencies in the data, statistical tests are performed as a guideline for the correlation of data between the models. Statistical tests have assumptions such as normality, symmetrical distributions or similar shape distributions to other data sets. The distribution characteristics of the data sets in this study are very different when compared basin to basin or even by RFC; hence one test could not be applied for all calculations. Although using a different test for each basin that fit the particular conditions posed by the basin was considered, it was viewed as undesirable for consistency of the results and thus was not used in this study. As the model data can be expected to be reasonably close to the survey data, the Mann- Whitney test was applied to determine if there was a statistically significant difference between the means of the survey and model data for SNOW-17 as well as SNODAS. The data were grouped together by River Forecast Center and also as a complete list of all the data points; the Mann-Whitney test was applied for each model in both cases. To determine how strong a relationship exists between the model and survey data, regression plots of the data were made for the data by basin and by River Forecast Center. For each particular year, a time trend analysis graph was created to track the differences between each of the models and the survey data through time.

5. Results: Regression and statistical tests

First, the results of the linear regression tests will be discussed. Due to the fact that the snow models are modeling the same snow conditions that the surveys are sampling, it can be expected that the model output should be fairly close to the survey data. A linear regression plot will show if there is an expected positive linear relationship between the model and survey data. The NYCDEP SWE data is plotted on the x-axis as the independent variable, and the data from either SNOW-17 or SNODAS is plotted on the y-axis as the dependent variable. A best-fit line was included with its equation and the R-squared (or r value) value for each plot. To determine if there is a statistically significant relationship between the model and survey data, the Pearson product-moment correlation coefficient was computed and interpreted. The Pearson Critical r value is determined from the number of data points and the corresponding degree of freedom of the data set. Once the degree of freedom is known, the critical r value can be determined from the appropriate alpha level; which was set in this case to 0.05.

Table 3. Summary of r values from regression plots and corresponding Pearson critical r values for basins. Critical r values are determined from the degree of freedom of the data set. Values from Havlicek et al. (1988).

Regression Plot	*n* value	*r* value	Pearson Critical *r* value	Positive Relationship Present?
Cannonsville				
SNOW-17	27	0.850	0.381	Yes
SNODAS	27	0.803	0.381	Yes
Neversink				
SNOW-17	29	0.696	0.367	Yes
SNODAS	29	0.737	0.367	Yes
Pepacton				
SNOW-17	27	0.864	0.381	Yes
SNODAS	27	0.714	0.381	Yes
Ashokan				
SNOW-17	21	0.571	0.433	Yes
SNODAS	21	0.394	0.433	No
Rondout				
SNOW-17	22	0.675	0.423	Yes
SNODAS	22	0.594	0.423	Yes
Schoharie				
SNOW-17	21	0.401	0.433	No
SNODAS	21	0.629	0.433	Yes

If the r value for the regression plot is greater than the Pearson Critical r value with an alpha of 0.05, the relationship between the data is accurate 95% of the time. If the r value from the regression plot is less than the critical r value, then the relationship indicated by the r value does not hold for the data 95% of the time (Havlicek et al. 1988). The regression plots can be found in Appendix III, while a table is provided here to summarize the r values.

Table 4. Summary of r values from regression plots and corresponding Pearson critical r values. Values from Havlicek et al. (1988).

Regression Plot	***n* value**	***r* value**	**Pearson Critical *r* value**	**Positive Relationship Present?**
MARFC Basins				
SNOW-17	82	0.701	0.217	Yes
SNODAS	82	0.760	0.217	Yes
NERFC Basins				
SNOW-17	62	0.480	0.250	Yes
SNODAS	62	0.499	0.250	Yes

For the regression plots of all the data grouped by RFC, there is a statistically significant positive linear relationship between the model and survey data.

For the regression plots of the basins individually, most exhibit the same statistically significant positive linear relationship. However the r values of the regression plots for the SNODAS data for Ashokan, and the SNOW-17 data for Schoharie were less than the Pearson Critical r value. This indicates that there is not a statistically significant positive linear relationship.

Being that the model data should be fairly close to the survey data, the Mann-Whitney test is utilized to determine if there is a statistically significant difference between the means of two sets of data, in this case model and survey data (Weiss 2008). The test was applied to the data grouped by RFC and also the total of the data points from both the models and the NYCDEP. The Mann-Whitney is a fairly robust non-parametric test that does not require the data to be normally distributed, however it does require the data being tested to have similarly shaped distributions (Weiss 2008). The test is set up so that the null hypothesis is that the means of two data sets are equal, or there is no difference between model and survey data. The alternative hypothesis is that they are not equal, or that there is a statistically significant difference between the model and survey data. Histograms of the data for each analysis were created and it was determined that the shapes were similar, so the test could be applied. A confidence interval of 95% (or a p-value of 0.05) was used to determine if the relationship between the data tested was statistically significant. For each of the tests, the resultant p-value was greater than 0.05, so there is failure to reject the null hypothesis, or no statistically significant difference between the mean of the survey data and the mean of the model data for each

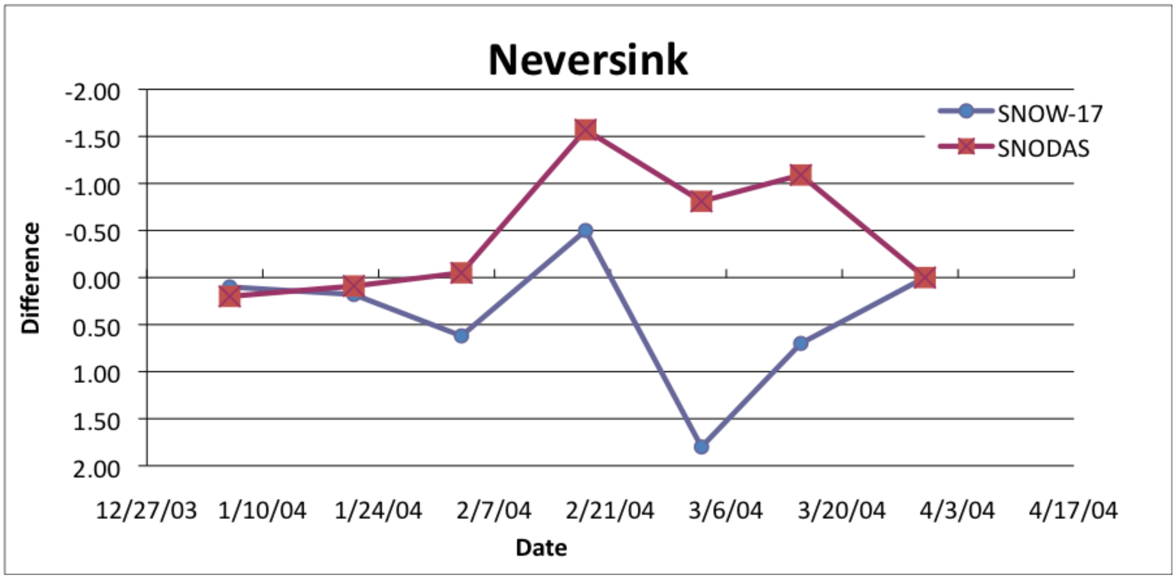

Figure 4. Time trend graph of Neversink Reservoir for 2004.

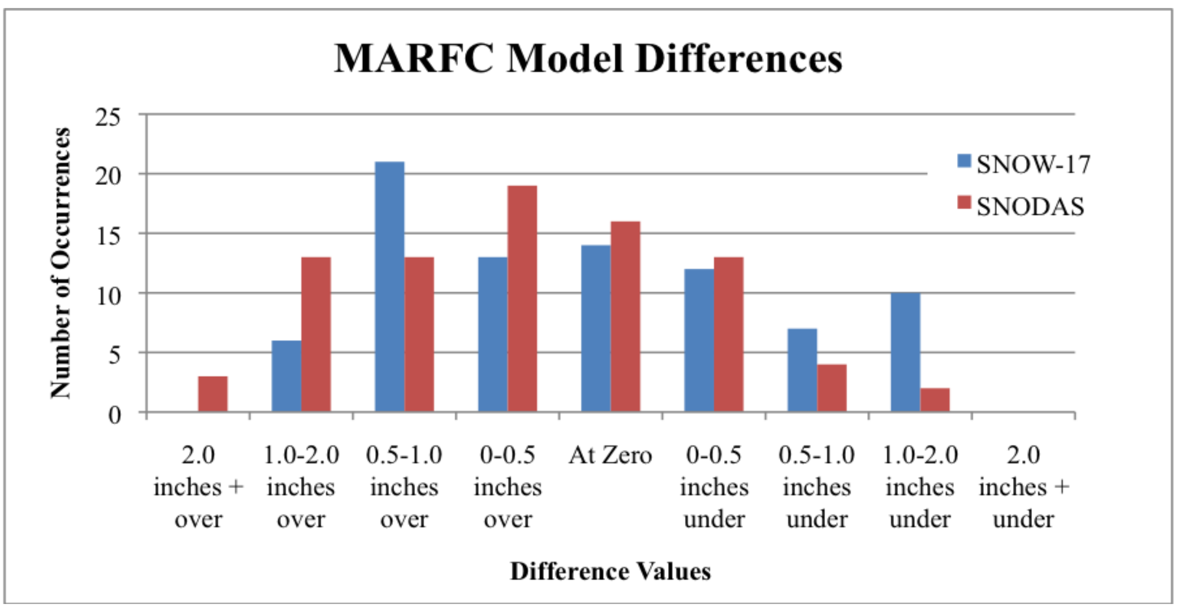

Figure 5. Model differences for all three basins in MARFC area (2004-2008).

grouping.

6. Results- time trend analysis

For time series comparison, the difference between the NYCDEP survey and model data was calculated by subtracting the modeled value from the observed value for each survey date. A resulting positive value means that the model predicted too much SWE compared to the NYCDEP survey data, and a negative difference indicates the model predicted less SWE than indicated by the NYCDEP data. These differences are then graphed as a function of the survey dates, and a track of the differences for each year for each basin can be obtained. Time trend analysis is particularly useful in this study for two reasons. The behavior of the models can be observed as a function of the progression of time, and also as a function of the temperature that was

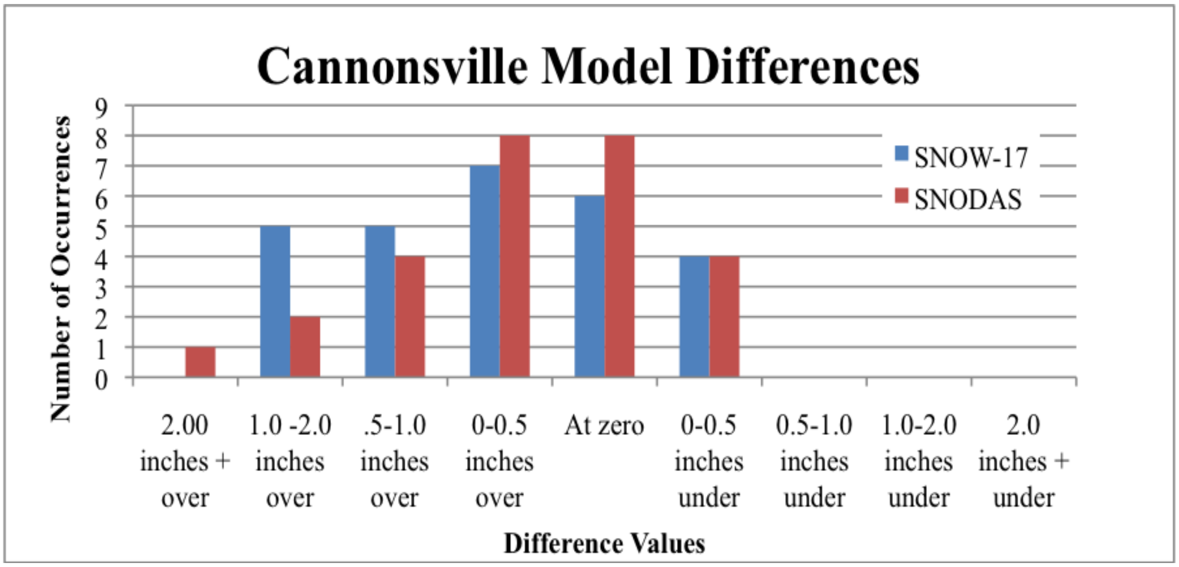

Figure 6. Model differences for Cannonsville basin (2004-2008).

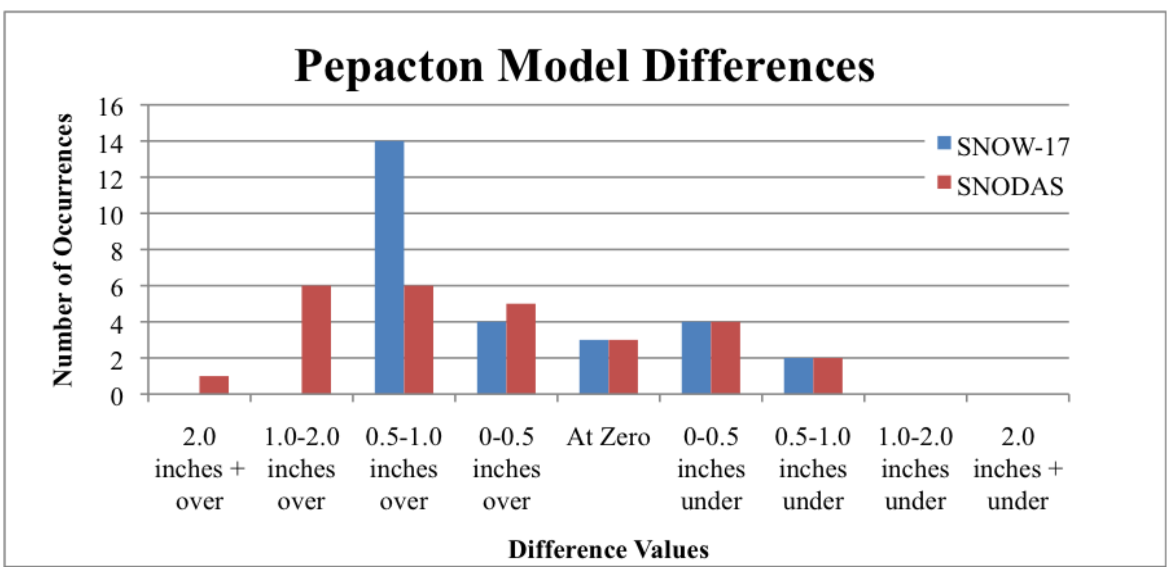

Figure 7. Model differences for Pepacton basin (2004-2008).

influencing the models. Temperature may be a large component of model/survey differences, and so the data observations from Delhi are used as an approximate estimation of whether temperatures were significantly warm or cold.

Figure 4 depicts a sample of the type of graph generated when graphing the model differences as a function of time. The zero value of the y-axis corresponds to no difference between the model and the survey data. As a result of the subtraction of the model data from the survey data, a negative value indicates the model produced more SWE than the NYCDEP survey data, and a positive value indicates the model produced less SWE. Both of the differences for SNOW-17 and SNODAS are placed on the same graph so that the models' behavior can be readily compared to each other.

Due to the complexity of comparing positive and negative differences of the models, tables were

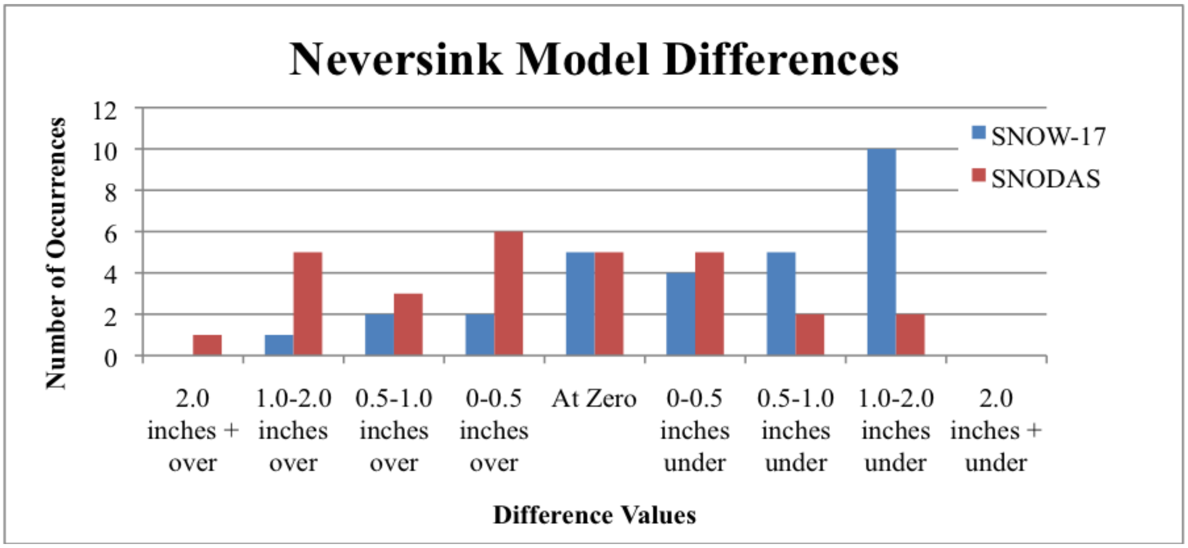

Figure 8. Model differences for Neversink basin (2005-2008).

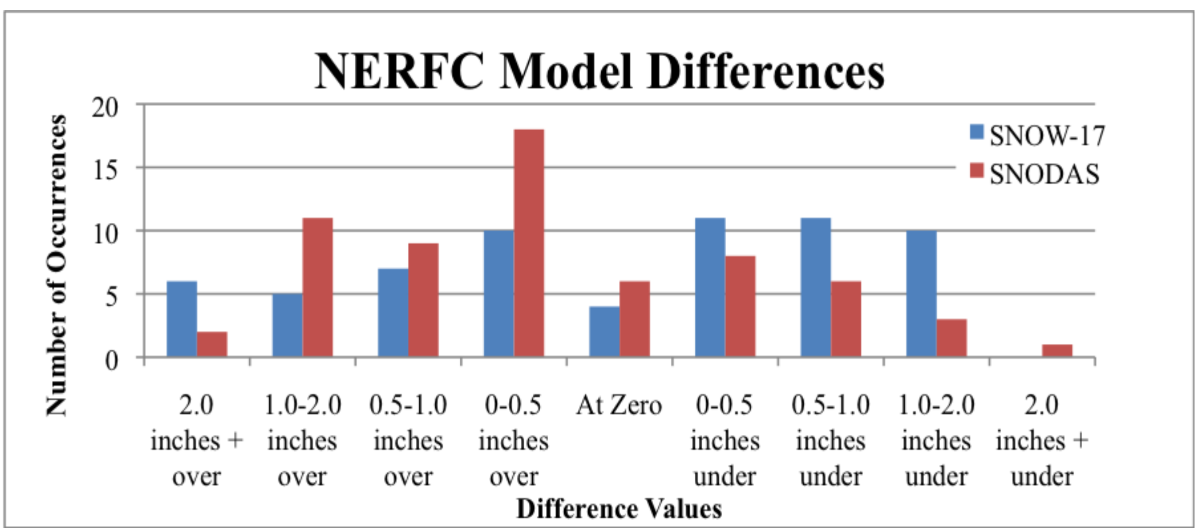

Figure 9. Model Differences for NERFC basins (2005 – 2008).

created for the MARFC and NERFC basins and the basins individually for all years of data. The differences between the two models and the DEP data were broken up into classes such as 0.5 - 1.0 inch over or under for example.

a) MARFC basins

Figure 5 shows the combined differences of Cannonsville, Neversink and Pepacton reservoirs for all years of the study period. It is clear that both the models tend to exhibit positive SWE differences when compared to the values obtained by the NYCDEP. The spread between most of the other classes.

For the Cannonsville reservoir there is a somewhat similar story, as both the models generally exhibited positive differences. In Figure 6, for SNOW-17 the number of occurrences is spread mostly between the classes of positive differences. For NOHRSC the majority of occurrences were either at zero difference, or just slightly over. The story is similar for the Pepacton reservoir basin, depicted in Figure 7. Most of the differences for both the models were positive, indicating the models were producing more SWE than

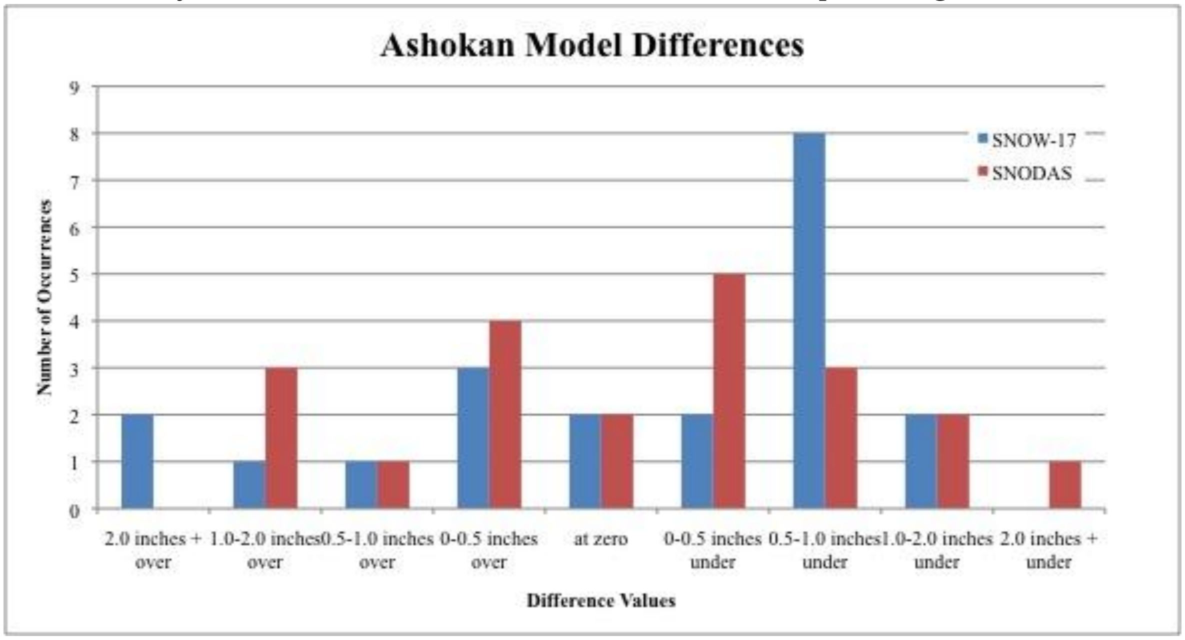

Figure 10. Model differences for Ashokan reservoir basin (2005-2008).

SNODAS model estimated higher than the survey estimates slightly more at 48 occurrences than the 40 occurrences of SNOW-17. The SNOW-17 model showed positive differences for 0.5 - 1.0 inches most frequently, the majority of the rest of the occurrences spread fairly evenly between 0 - 0.5 inches over, zero, 0 - 0.5 inches under. The SNODAS model had a slight majority in the 0 - 0.5 inches over class, with a fairly even the surveys, with less negative differences present. For SNOW-17 the majority of occurrences were for 0.5 - 1.0 inches over, while for SNODAS there was no real majority of for any of the classes. The differences for Neversink basin, Figure 8, however deviated from the results of Cannonsville and Pepacton. SNODAS model generally showed positive differences while SNOW-17 showed a marked tendency to have negative differences with 19 occurrences. The largest majority of negative differences for SNOW-17 occurred in the range of 1.0 - 2.0 inches, while SNODAS showed no real majority of occurrences for any particular range of values.

b) NERFC basins

Figure 9 shows the model differences for Ashokan, Rondout and Schoharie reservoir basins. It appears when examining the graph that the compared to the SNODAS model. Also, SNOW-17 shows a majority of occurrences for 0.5 - 1.0 inches under. For Rondout reservoir basin in Figure 11, there is a more obvious difference between the models. SNOW-17 has a majority of negative differences, double the occurrences of positive differences.

However, SNODAS shows a clear majority of positive differences. Schoharie basin is slightly different from either Ashokan or Rondout, as shown in

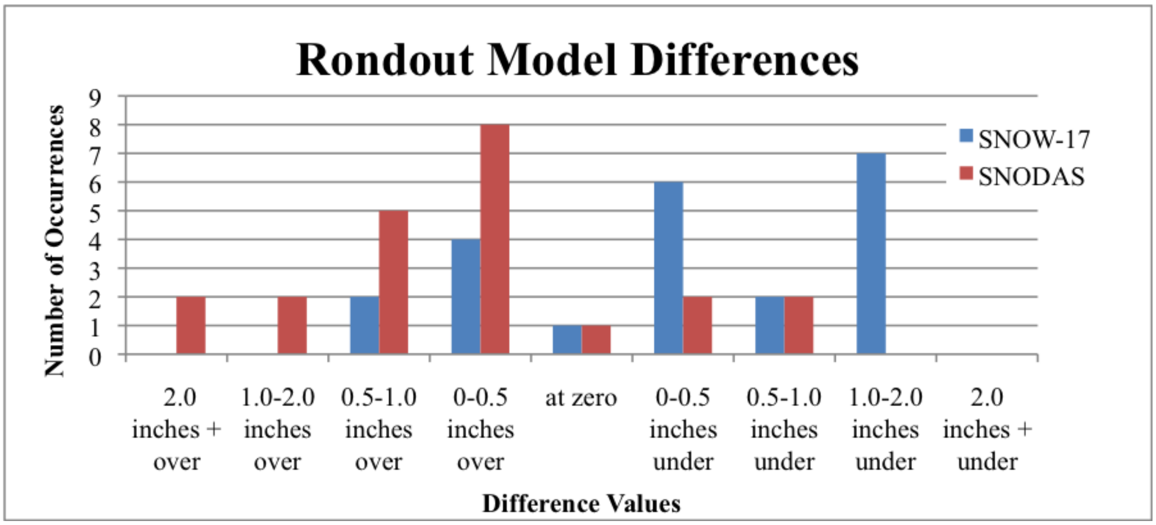

Figure 11. Model differences for Rondout reservoir basin (2005-2008).

SNODAS model tends to have positive differences compared to the survey data and the SNOW-17 model tends to have negative differences in the NERFC basins. SNOW-17 had more of an even spread between observed values, with 40 negative and 28 positive differences, with no real majority of occurrences in any one category. SNODAS had 40 positive and 18 negative differences with the largest majority of occurrences for 0 to 0.5 inches over and 1.0 - 2.0 inches over. The differences for the Ashokan reservoir are graphed in Figure 10. For Ashokan both the models show a slight majority of negative differences, with SNOW-17 having slightly more when Figure 12. SNOW-17 has a fairly even spread of observations across the positive difference categories with 4 occurrences of 2.0 inches + over, while SNODAS has a majority of values at 0 - 0.5 inches over and 1.0 - 2.0 inches over.

7. Weather and model behavior

To approximate the kind of weather occurring at the time, observations from a NWS cooperative observer located in Delhi, NY (approximately 13 miles north of Pepacton reservoir) were consulted. It cannot be expected that the observations in Delhi are an accurate representation of

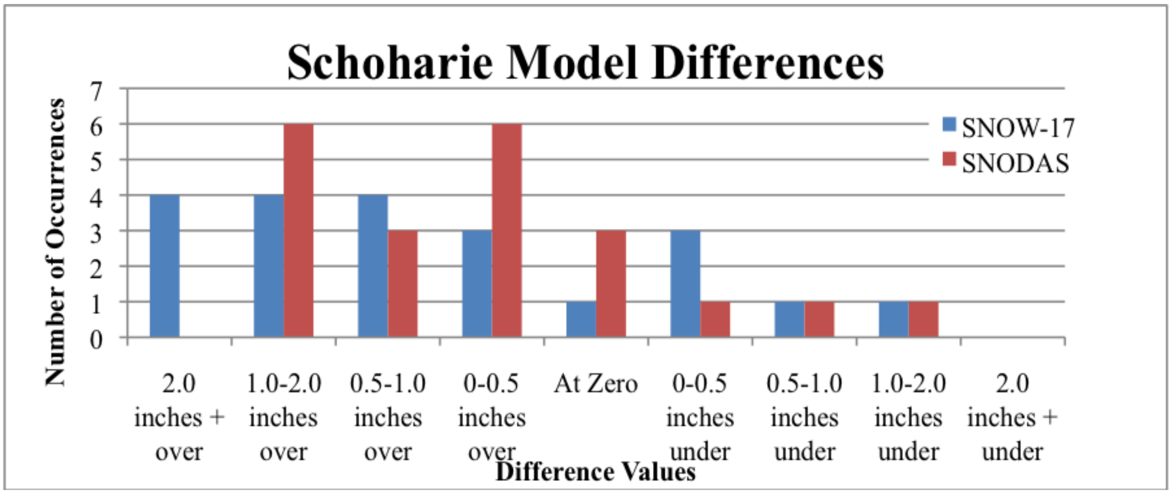

Figure 12. Model differences for Schoharie reservoir basin (2005-2008).

conditions across all six of the NYCDEP reservoir basins. There are many factors that influence the behavior of the models as well as snow characteristics, including temperature and precipitation. Using temperature information is not only convenient due to the cooperative observer data availability, but is important in model operation, especially SNOW-17. The temperature observations approximately a week prior to each survey date were analyzed and the model data for those survey dates with unseasonably warm temperatures were extracted and graphed. For the purposes of this study, unseasonably warm is defined as an extended period (approximately 3 days to 5 days) of temperatures around 40-44 °F or above. The average/ normal monthly temperature for the cooperative observer location is 20.9 °F for January, 23.0 °F for February, 32.2 °F for March, and 43.2 °F for April. These averages/ normals are calculated from the data from 1971-2000 (cooperative observer raw data). Choosing 40–44 °F or above as the threshold for an extended warm period ensures that most areas of the reservoir watersheds were most likely above freezing. The remaining data corresponding to lower, closer to normal temperatures were also graphed. Table 5 summarizes the graphs for warm weather data as well as the more near normal temperature data. A black X represents all the data, a red X represents warm weather data and a blue X represents remaining weather data. For the SNODAS model it appears that the general trend is for positive difference, indicating the model produced more SWE than the surveys during warm and near normal/colder weather conditions in most basins. This could imply that SNODAS is not as easily affected by fluctuations in temperature. Ashokan deviates slightly in that there is a spread of positive and negative differences for all data and near normal/colder weather data, while warm weather data indicate negative differences. For SNOW-17 the data are a little less straightforward. For Cannonsville, Pepacton and Schoharie basins there seems to be a trend of positive model difference for all data and warm weather data, while near normal/colder weather data has a fairly even spread. Neversink, Ashokan and Rondout basins however indicate a trend of negative model difference for all data, as well as warm and cold weather data

Table 5. Table summarizing model behavior for each basin individually as well as grouped by RFC. Over means positive difference, under means negative difference and even means and an even distribution of positive and negative differences for a particular dataset.

	SNOW-17			**SNODAS**		
	Over	Even	Under	Over	Even	Under
Cannonsville	XXX			XXX		
Neversink			XXX	XX		X
Pepacton	XX	X		XX	X	
Ashokan		X	XX		XX	X
Rondout			XXX	XXX		
Schoharie	XX	X		XXX		
MARFC	XX	X		XXX		
NERFC		X	XX	XXX		

with two occurrences of even spread of positive and negative differences.

8. Interpretations and suggestions for increased accuracy in SWE estimates

Based on the previous examinations of the data, there are a few changes that could be made to increase accuracy of SWE estimates for both models and surveys. An important basin characteristic is elevation. One initial thought on possible reasons for the difference in R-squared values for each RFC may be due to the higher elevations in the NERFC basins; Schoharie and Ashokan reservoir basins are split into different elevation zones for analysis in SNOW-17. It is not to say that splitting a watershed into different elevation zones for analysis in SNOW-17 results in worse estimations, it may be that the SNOW-17 values are closer to the actual SWE present. However the resultant difference between the DEP data and SNOW-17 data may be enhanced due to the relative poor coverage of DEP locations in a higher terrain setting. Table 1 from Section 1 shows a summary of the DEP points per basin and the corresponding basins. Ashokan reservoir basin is approximately 2.5 times larger in area as Neversink basin, yet it contains less survey points. This also applies to a greater extent to Schoharie reservoir basin that has an even greater area than Ashokan, but the least number of survey points out of all the basins. It may be this underrepresentation by the DEP survey points for the Ashokan and Schoharie basins that caused the poor correlations seen in Table 2 for NERFC. Thus the higher difference may be driven by lack of points in the DEP data plus the discrepancy in basin extents defined by the RFCs and the NYCDEP that result in poor R-squared values for the NERFC reservoir watersheds.

The discrepancy in basin extent shown in Figure 3 also points to a problem with comparison between the NYCDEP and the RFCs. During the recent past, there has been increased coordination between the NYCDEP and the RFCs about the SWE estimates for the reservoir basins. Modifications to SNOW-17 SWE estimates were made based on survey estimates that contain survey points outside the basin extents used in SNOW-17 analysis. In the future, adjustments should be made to account for the fact that a reservoir basin estimate from the NYCDEP does not cover the same areas as a reservoir basin estimate in SNOW-17 for Cannonsville, Ashokan and Schoharie basins. Results could be combined from the two RFC basins that fall within the DEP defined basin extent of Cannonsville, Schoharie and Ashokan reservoirs in order to obtain SWE estimates for a basin that is identical to the basins defined by the NYCDEP.

Figure 13 shows the positive/ negative difference occurrences for each of the basins plotted with elevation difference between DEM data and survey points for the SNOW-17 model. Figure 14 is a graph of the same data for the SNODAS model. From these graphs it seems that there is a slight majority of positive model differences for large elevation differences for SNODAS, and to a lesser degree with SNOW-17. One possibility that could be causing observed SNOW-17 negative differences of SWE in Ashokan reservoir basin is the number of DEP survey points used in determining average SWE in Ashokan reservoir basin. It is clear from Figure 3 that Ashokan reservoir basin has less survey points than the surrounding

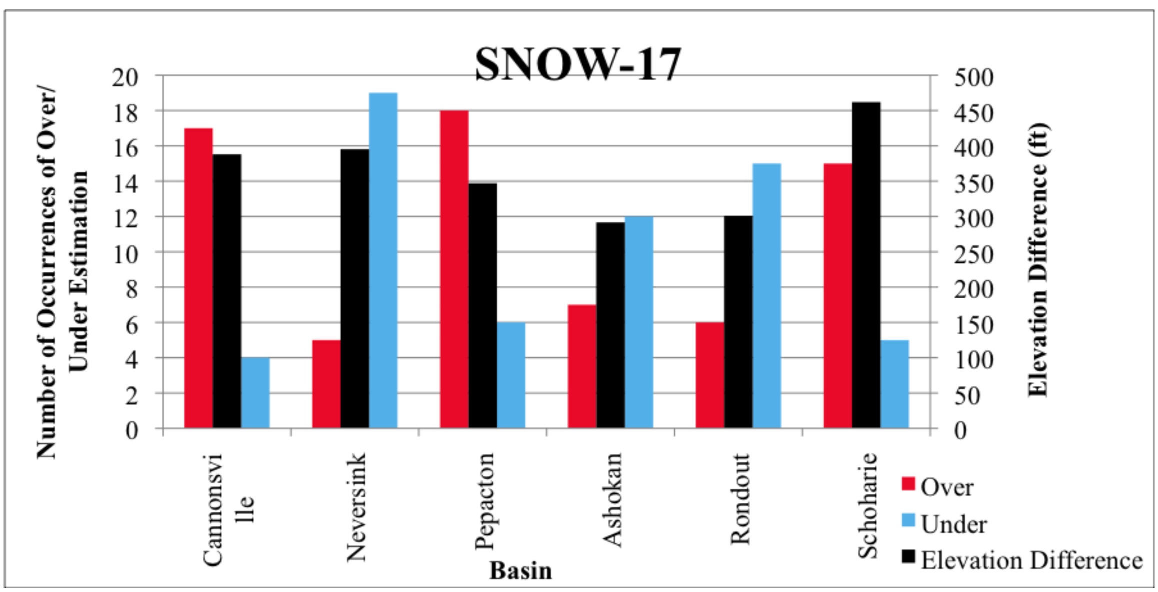

Figure 13. Graph of model differences with elevation difference for SNOW-17.

Neversink and Rondout basins.

SNOW-17 has also shown a deviation in behavior for Neversink basin when compared to Cannonsville and Pepacton basins. Observed SNOW-17 data tended to show negative model differences compared to the DEP data in Neversink basin while positive differences were noted in the other two basins. One possible cause of this could be due to the high elevations found in this basin. According to Table 1, Neversink basin has the highest average elevation, calculated at 2322 ft. above sea level. However this basin is not split into different elevation zones when using SNOW-17. The model may be estimating less SWE than the surveys are estimating due to the fact that the high elevation may not be accurately represented in analysis within the model. One possible solution would be to calibrate the model for an additional elevation zone similar to Ashokan and Schoharie reservoir basins to allow for potentially more accurate modeling at higher elevations.

The consistent observed positive difference in the SNODAS model data and in some cases for the SNOW-17 model data may be more a result of lack of representation in DEP survey point data than significant model differences. The average elevations of the survey points were lower than the average elevation of the basin from DEM data for every reservoir basin (Table 1). Although adding more points to every basin would be ideal, it may not be practical as snow surveys take considerable time, effort and resources. Moving current survey points to higher elevations for Cannonsville, Neversink, Pepacton and Rondout reservoirs may result in more representative SWE values for DEP estimates and thus closer correlation with the models. In the case of Ashokan and Schoharie basins however the low number of points warrants that some should be added, ideally at higher elevations to help create a more complete estimate of SWE across the watershed.

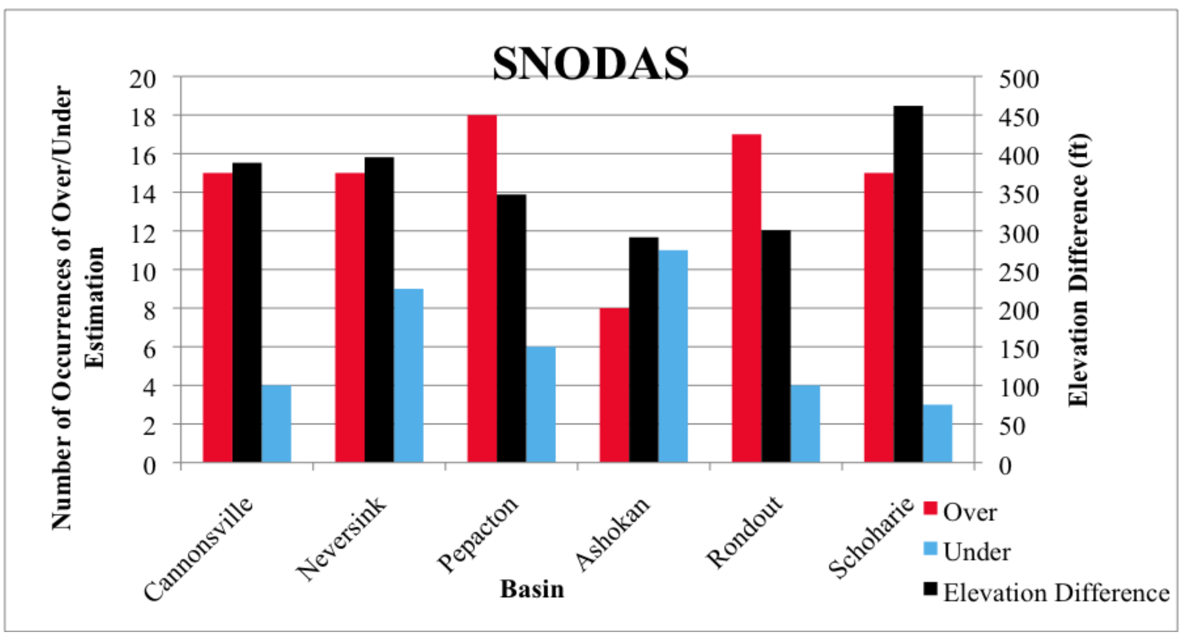

Figure 14. Graph of model differences with elevation difference for SNODAS.

Another technique that may provide more accurate SWE estimates is to change the way that the NYCDEP calculates their basin average SWE estimates. The current method is to employ a simple arithmetic average of SWE at all the survey points for a basin. Changing to a method such as the Thiessen polygon method could provide more accurate SWE estimates as this takes into account how much land is represented by a particular survey point, based on the proximity of the neighboring points. There are also a number of interpolation techniques in the GIS environment that would allow for the creation of a basin surface map of SWE. These surface maps can then be averaged to the extent of the basins, which may produce a more representative basin SWE estimate from the survey points point data.

9. Conclusions

It is apparent from the statistical tests and graphs of data that this is a complicated issue that contains many facets, each of which require additional study to determine how large a role they play. From this preliminary examination it appears that each model behaves slightly different in the context of the NYC water supply watersheds due to a number of variables including weather, temperature, elevation and the model parameters themselves. However when the models are compared to the NYCDEP snow survey data it becomes apparent that there are differences between the models from basin to basin. These differences may be attributed to survey location density inconsistencies, lack of locations at higher elevations and discrepancy in basin extent between survey data and RFC data. The average elevation of the DEP survey points were lower than the average elevation of the basin (from DEM data) for all six basins used in this study. Even though using the technique outlined by Elder et al. (1991) showed that there is no discernable positive relationship between survey location elevation and SWE, a survey that contains locations that are more representative of basin elevation conditions may result in estimates that are closer to model output.

Statistical methods show that there was no significant difference between the model data and survey data, and that there is a slight positive correlation between elevation difference (Table 1) and model overestimation, and a slight inverse relationship with elevation difference and model underestimation. However it should be noted again that these positive and negative correlations from the Spearman coefficient test are not statistically significant. When the models are analyzed basin by basin, SNODAS most consistently exhibits positive differences, while SNOW-17 is variable. The same also applies for model behavior based on the weather at the time (Table 4). SNODAS still overestimates a majority of the time, and SNOW-17 is variable, though there seems to be a slight tendency for positive differences during warm weather and negative differences during colder weather.

As discussed earlier, the main issues with the survey data are the lack of points at higher elevations in the watersheds, and the lack of density of points in Ashokan and Schoharie basins compared to other basins (Table 2). The discrepancy between model and survey data in Neversink basin may be caused by the lack of elevation division when running the SNOW-17 model to account for the high elevations across the basin.

Calculating an average NYCDEP SWE value for each basin using a method that takes into account the land represented by each survey point may also produce better SWE estimates. Addressing these issues in the future may help reconcile the differences between the snow models and the NYCDEP snow surveys and provide more accurate SWE estimates.

Acknowledgments

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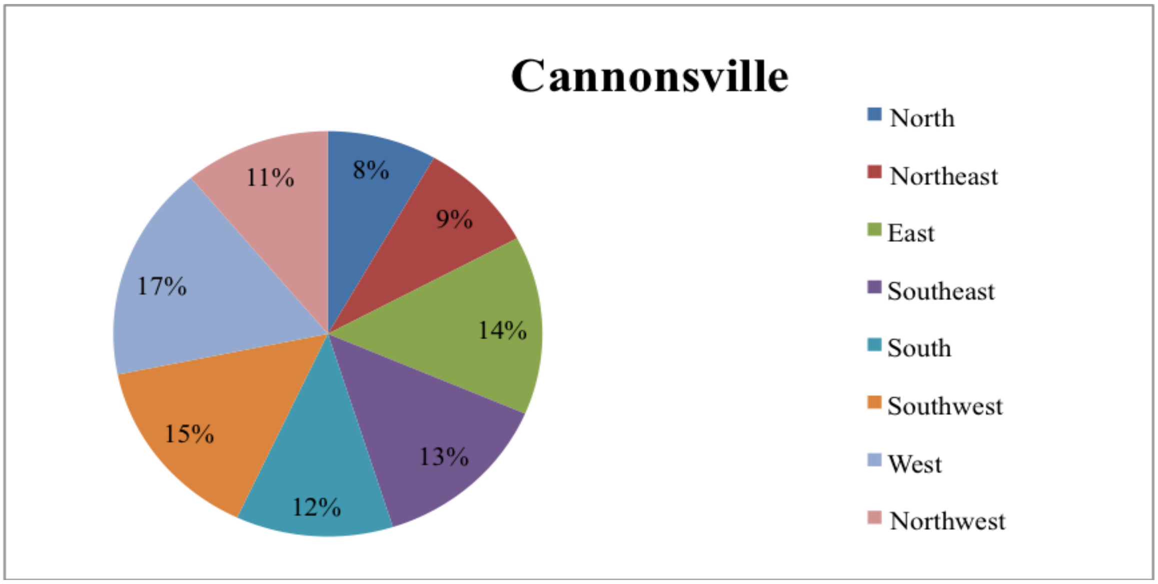
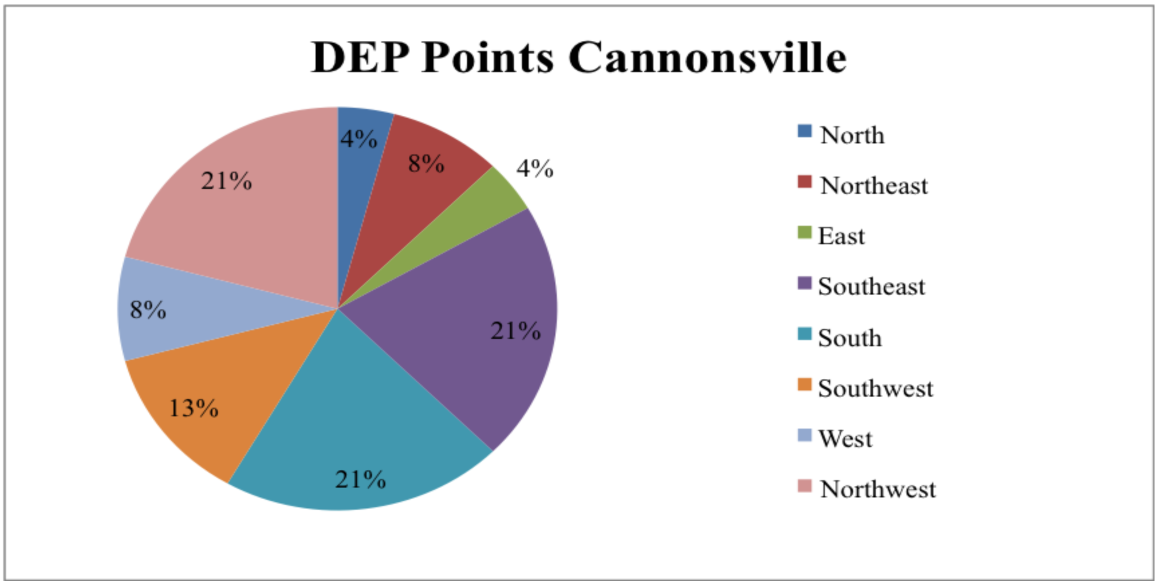
Appendix I

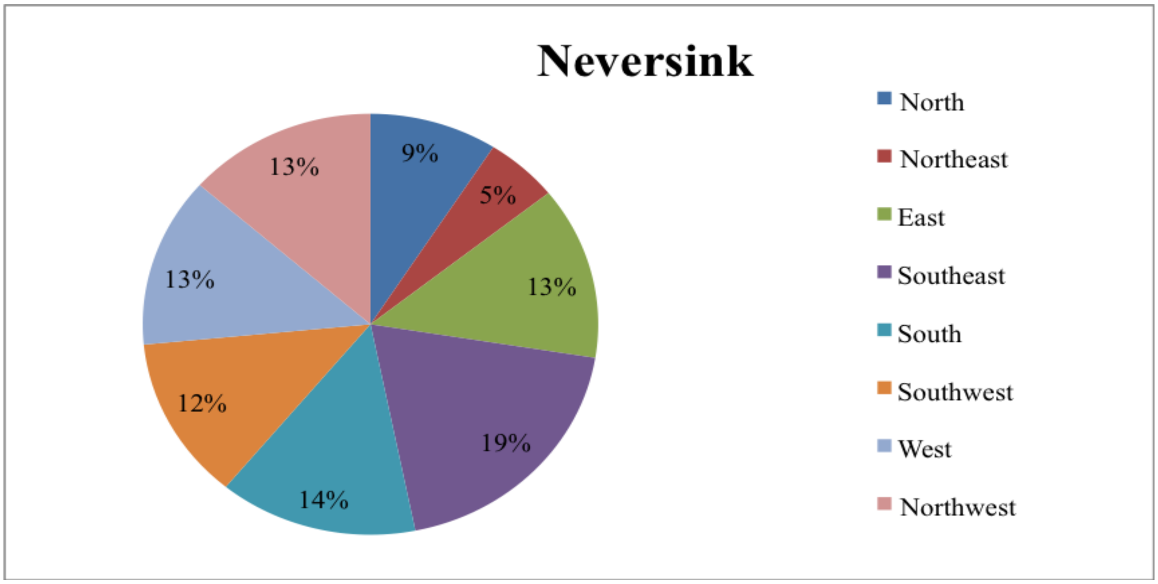
MARFC Basins Aspect Comparison (Values Rounded to Nearest Whole Percent)

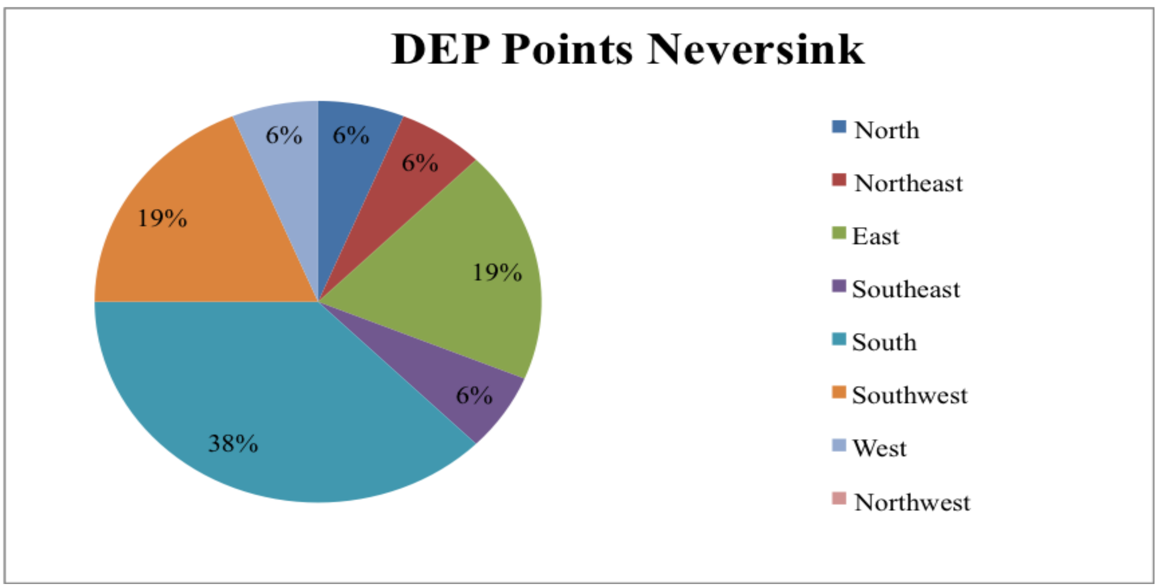
Cannonsville



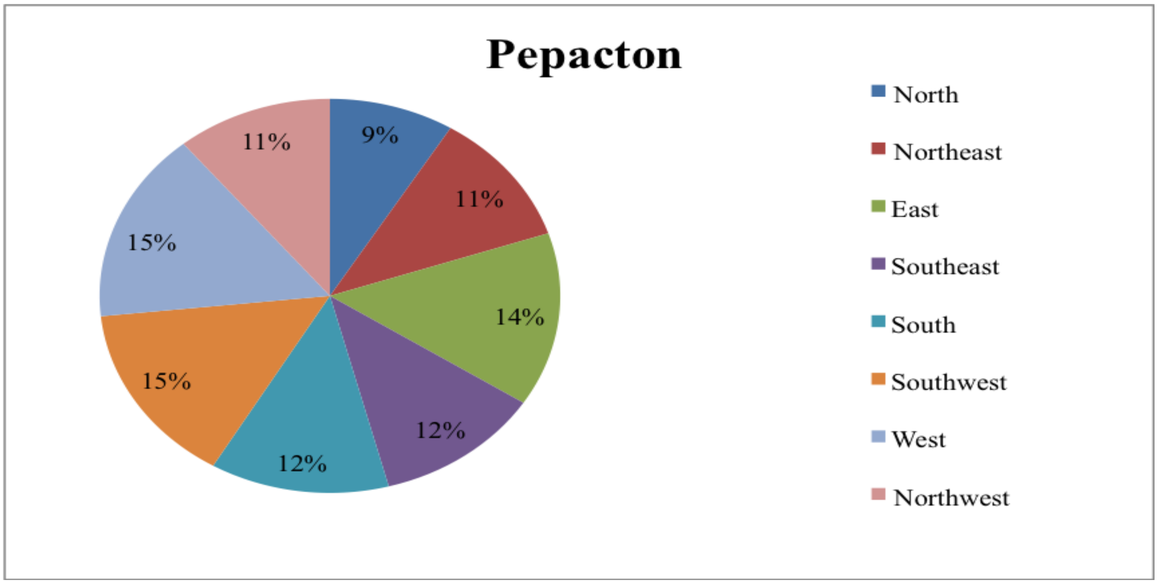


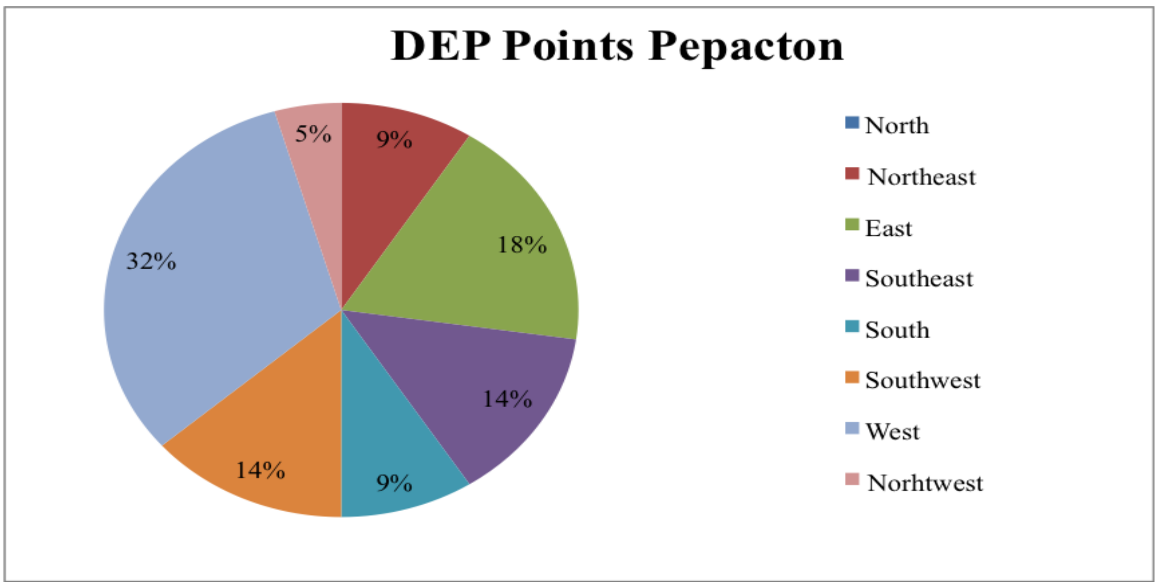
Neversink


Neversink
9%
5%
13%
19%
14%
12%
13%
13%
North
Northeast
East
Southeast
South
Southwest
West
Northwest


DEP Points Neversink
6%
6%
19%
6%
38%
19%
6%
North
Northeast
East
Southeast
South
Southwest
West
Northwest

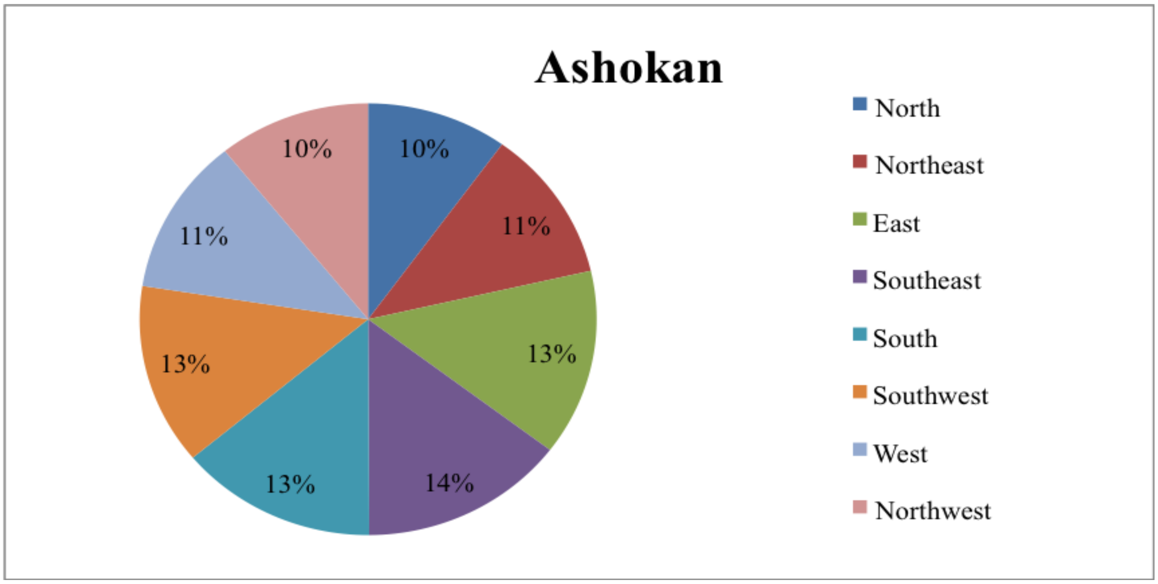
Pepacton

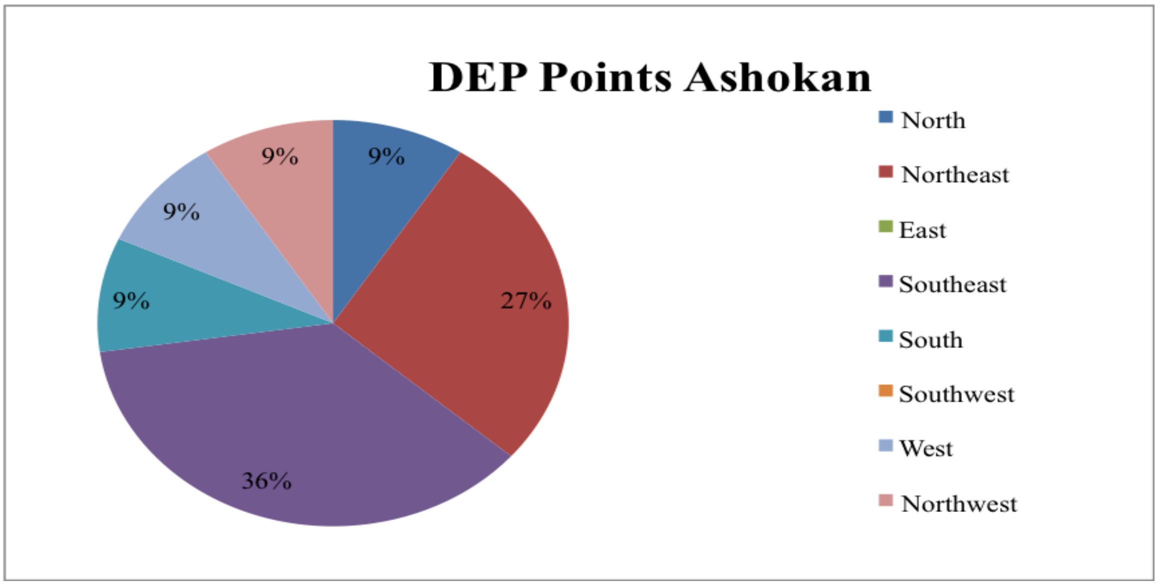

Pepacton
9%
11%
14%
12%
12%
15%
15%
11%
North
Northeast
East
Southeast
South
Southwest
West
Northwest


DEP Points Pepacton
5%
9%
18%
14%
9%
14%
32%
North
Northeast
East
Southeast
South
Southwest
West
Norhtwest

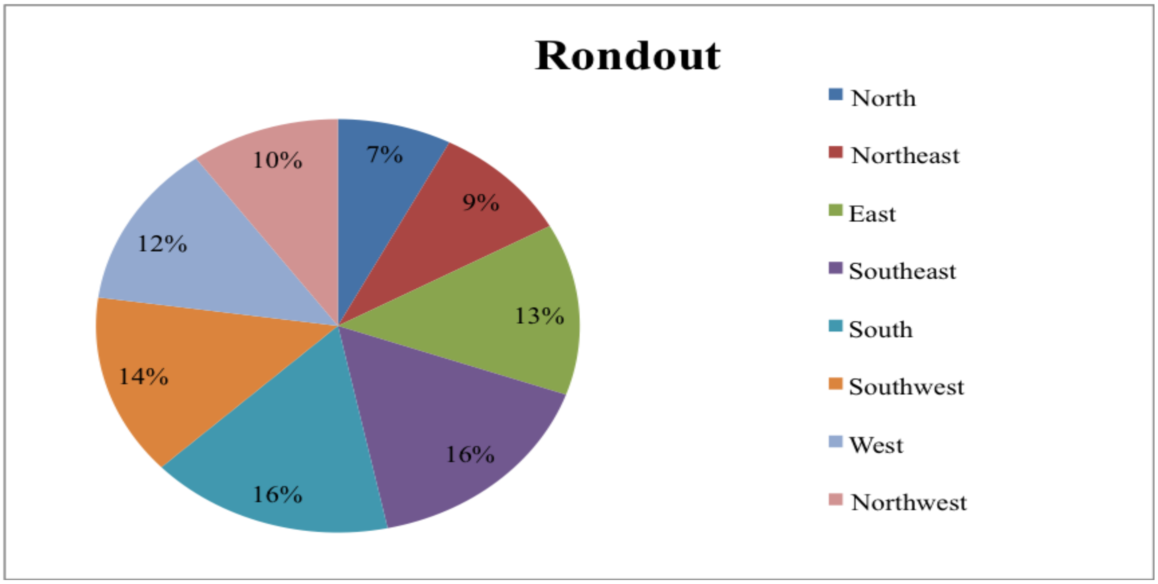
NERFC Basins Aspect Comparison (Values Rounded to Nearest Whole Percent)

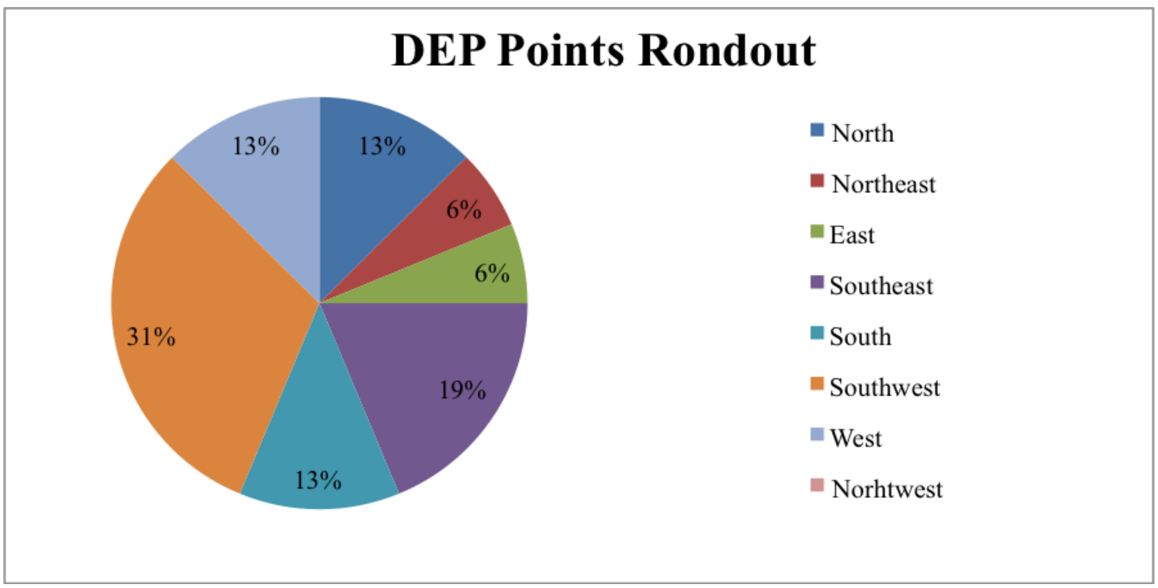
Ashokan



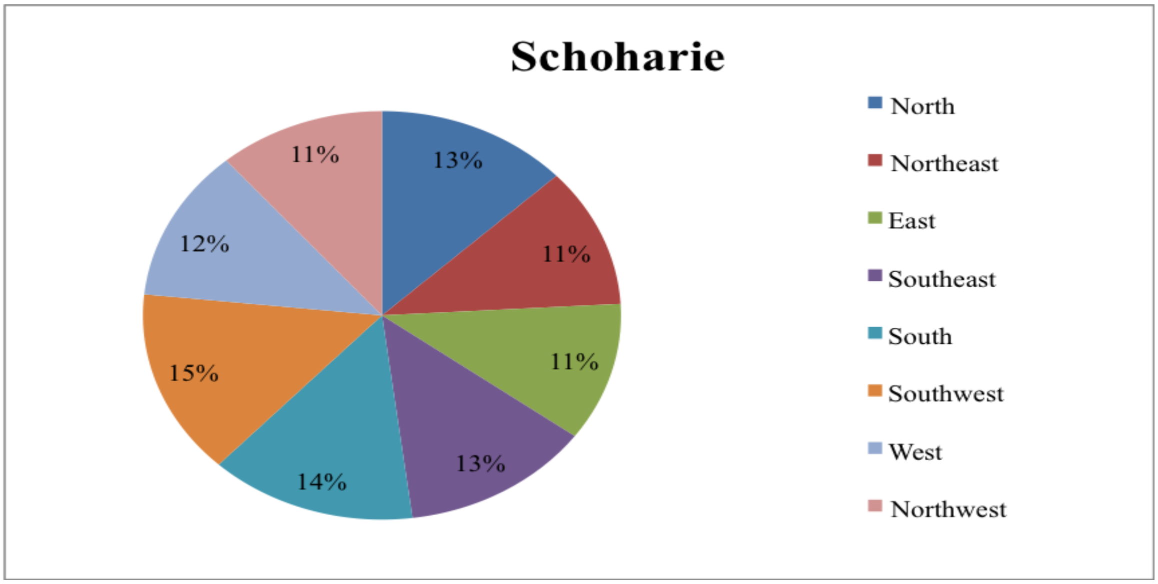


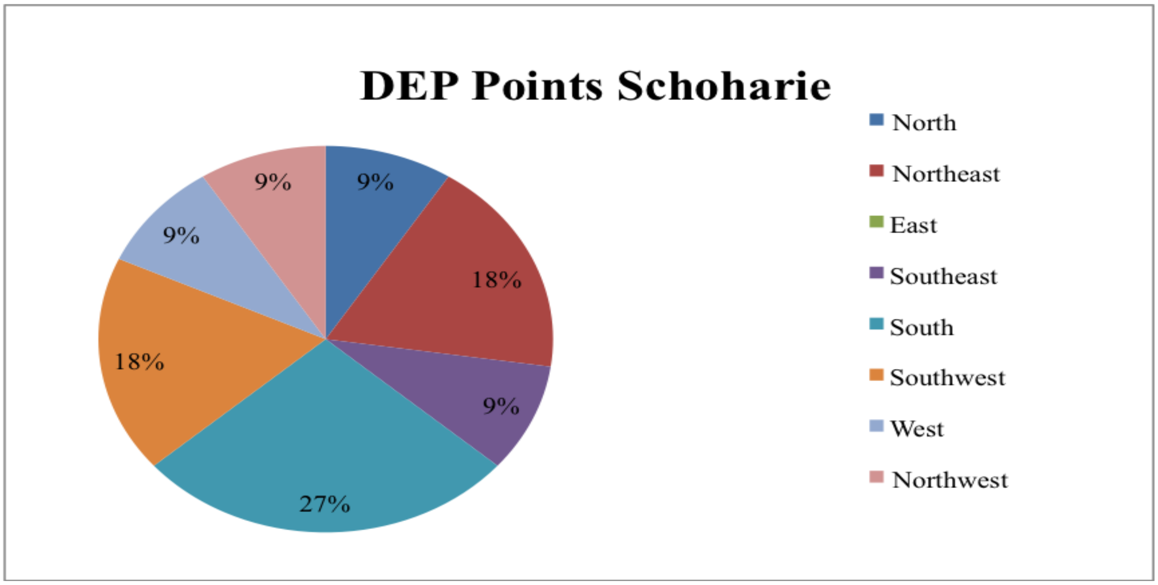
Rondout


Rondout
7%
9%
13%
16%
16%
14%
12%
10%
North
Northeast
East
Southeast
South
Southwest
West
Northwest


DEP Points Rondout
13%
6%
6%
19%
13%
31%
13%
North
Northeast
East
Southeast
South
Southwest
West
Norhtwest

Schoharie

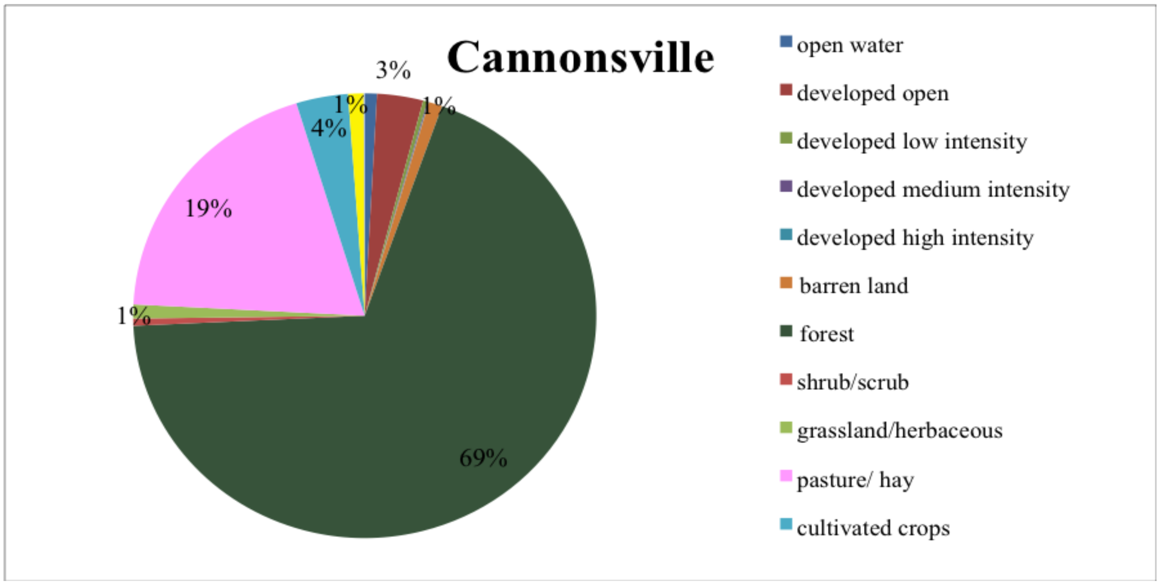

Schoharie
13%
11%
11%
13%
14%
15%
12%
11%
North
Northeast
East
Southeast
South
Southwest
West
Northwest

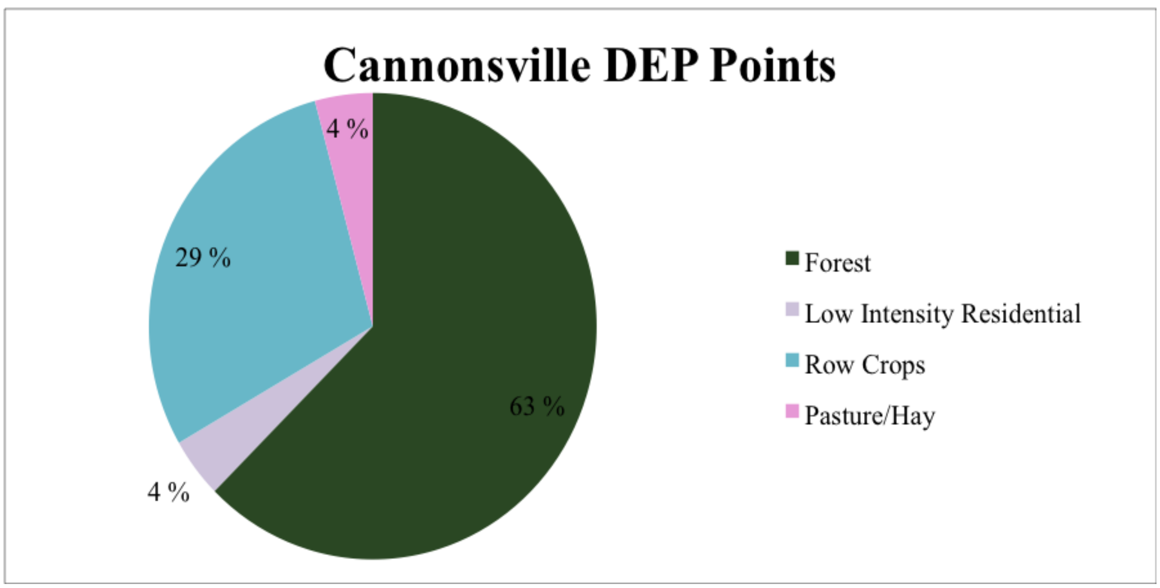

DEP Points Schoharie
9%
18%
9%
27%
18%
9%
9%
North
Northeast
East
Southeast
South
Southwest
West
Northwest

Appendix II

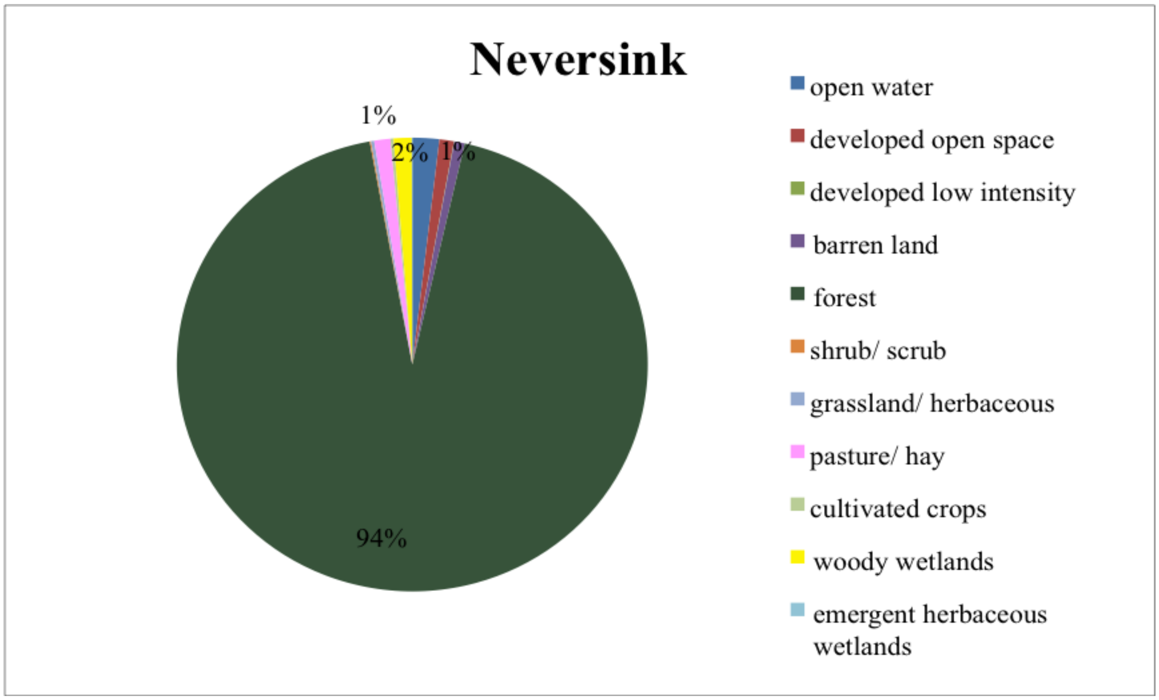
MARFC Basins Land Use Comparison (Values Rounded to Nearest Whole Percent)

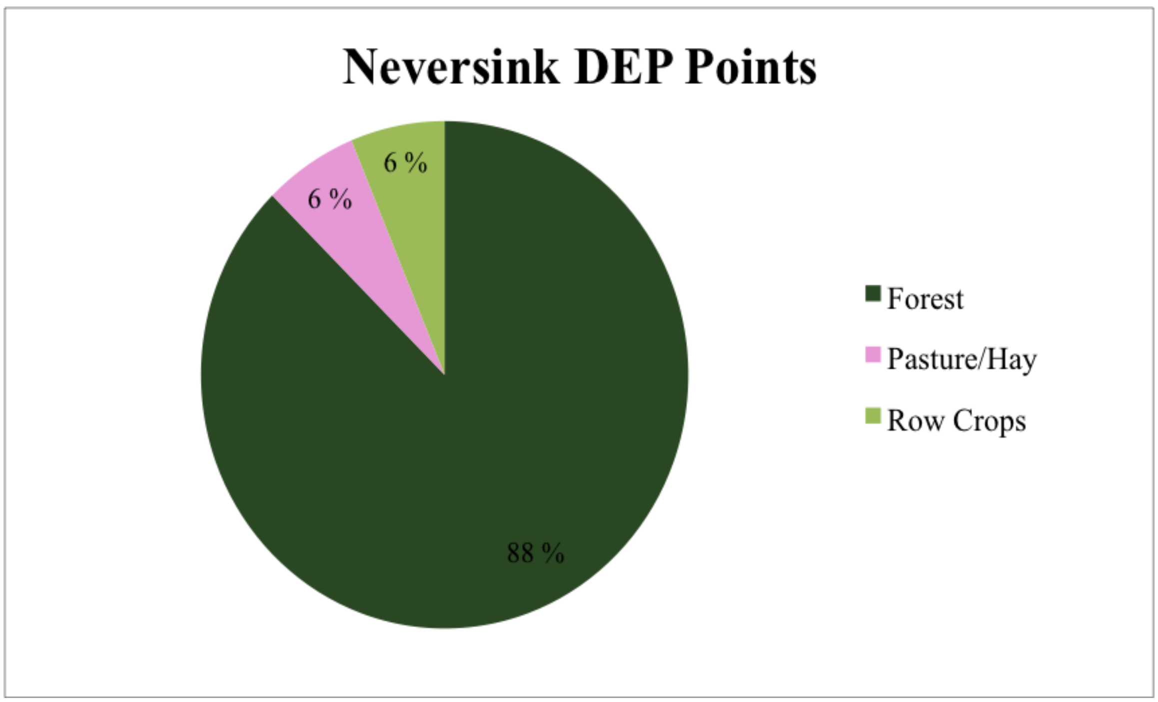
Cannonsville



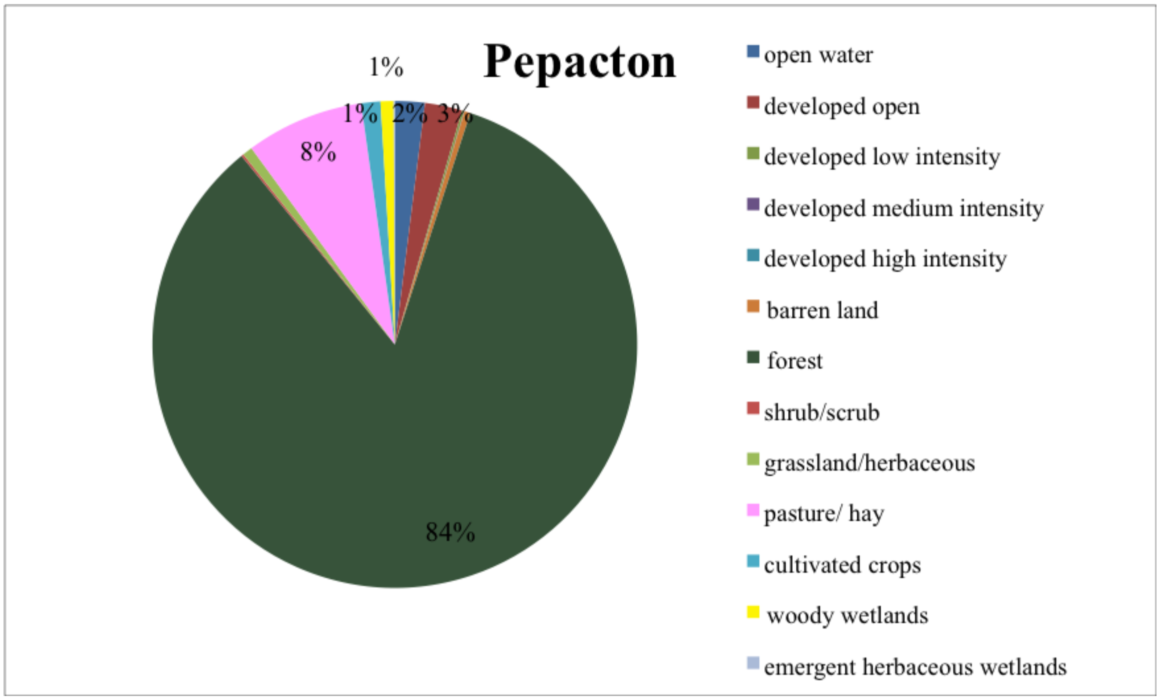


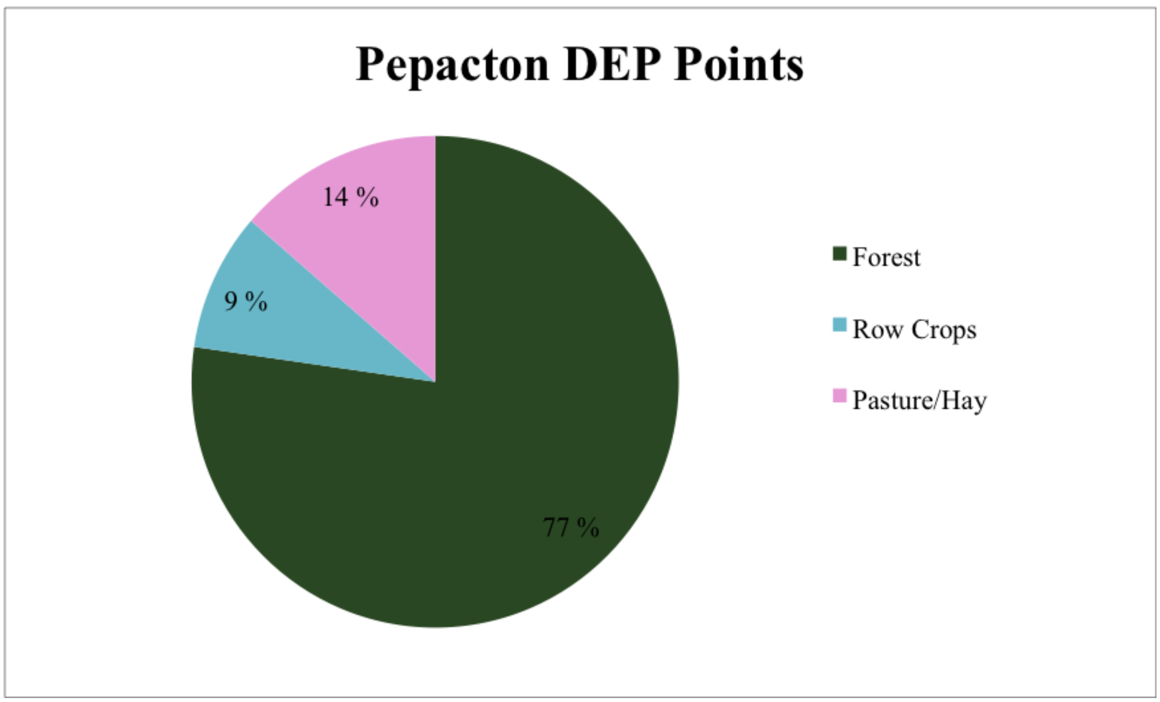
Neversink


Neversink
1%
2%
1%
94%
open water
developed open space
developed low intensity
barren land
forest
shrub/ scrub
grassland/ herbaceous
pasture/ hay
cultivated crops
woody wetlands
emergent herbaceous wetlands


Neversink DEP Points
6 %
6 %
88 %
Forest
Pasture/Hay
Row Crops

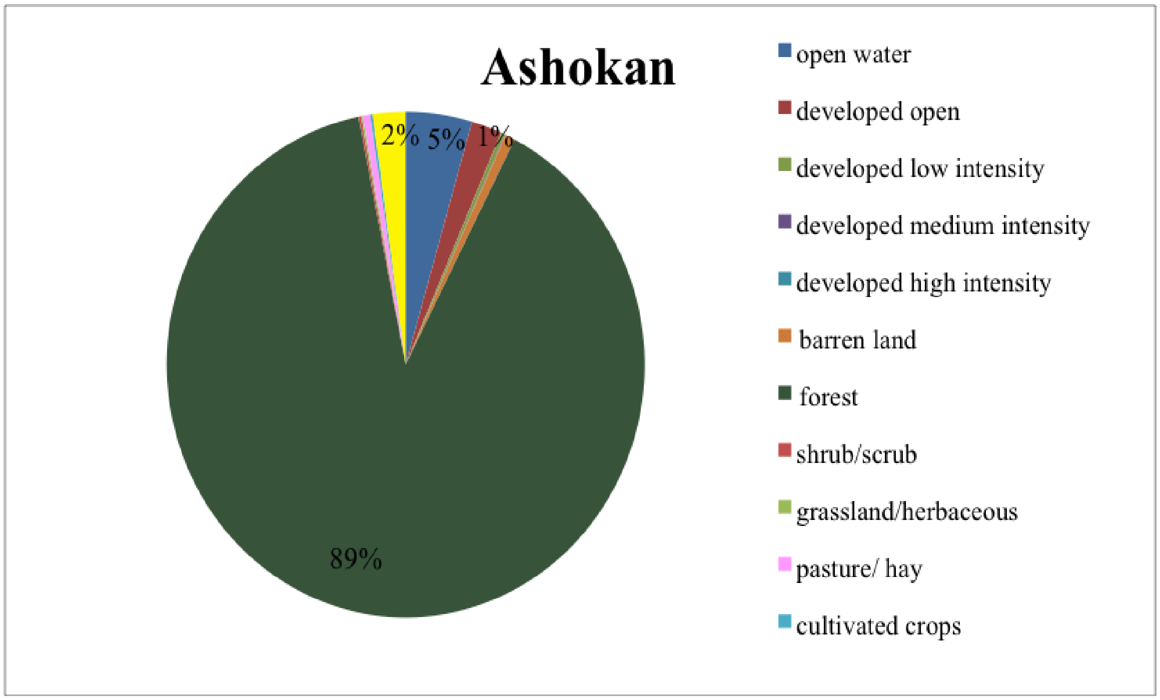
Pepacton

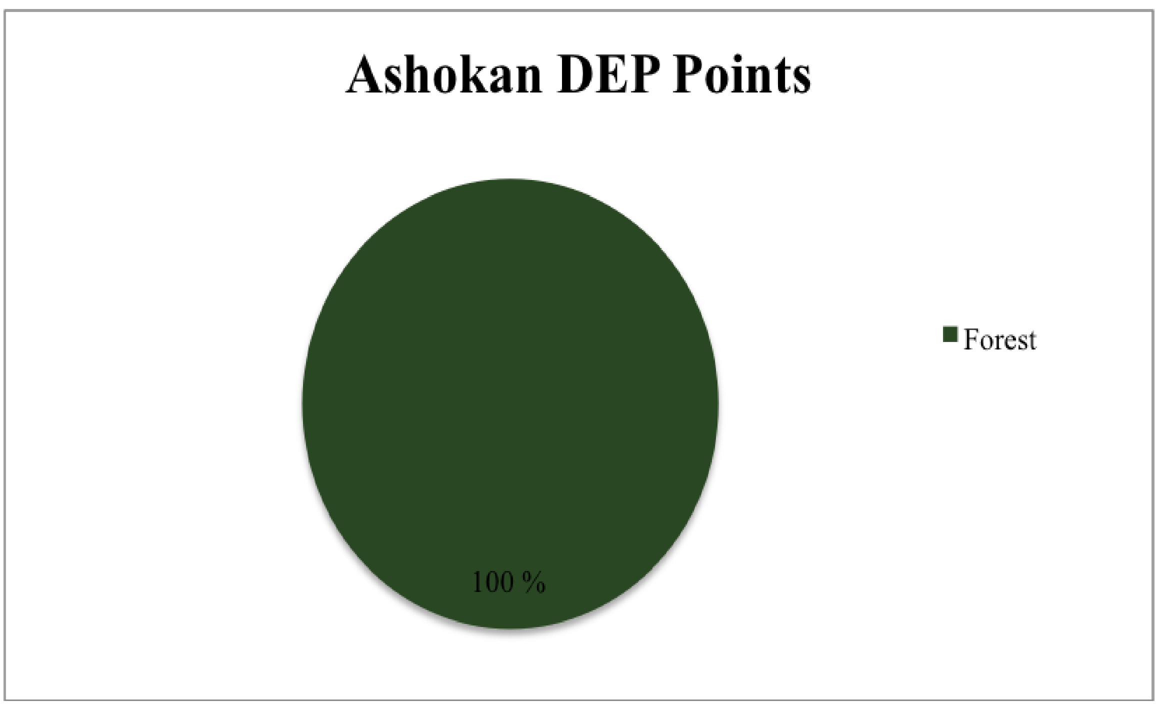

Pepacton
1%
1%
2%
3%
8%
84%
open water
developed open
developed low intensity
developed medium intensity
developed high intensity
barren land
forest
shrub/scrub
grassland/herbaceous
pasture/ hay
cultivated crops
woody wetlands
emergent herbaceous wetlands


Pepacton DEP Points
14 %
9 %
77 %
Forest
Row Crops
Pasture/Hay

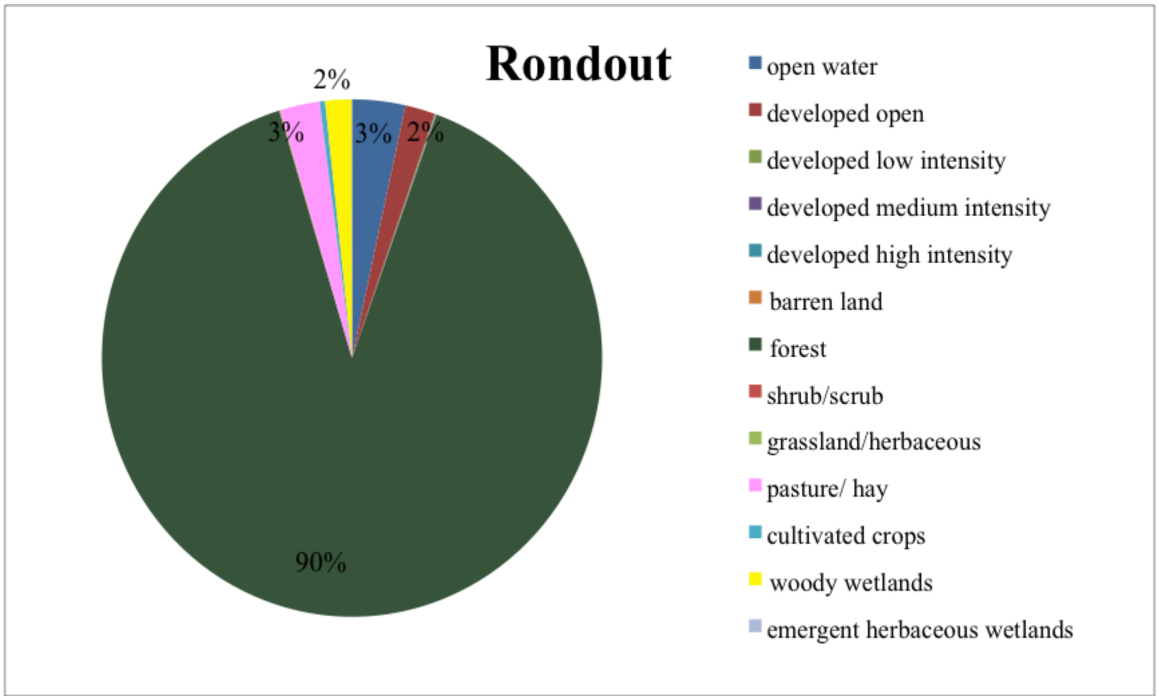
NERFC Basin Land Use Comparison

Ashokan

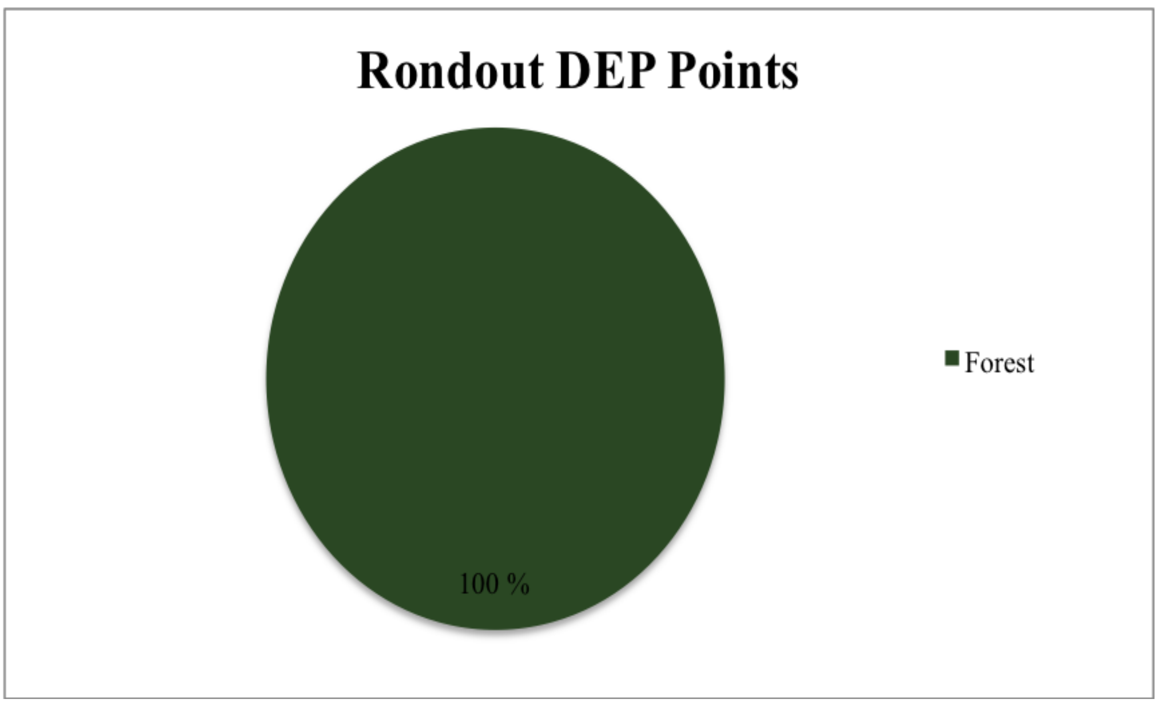




Rondout

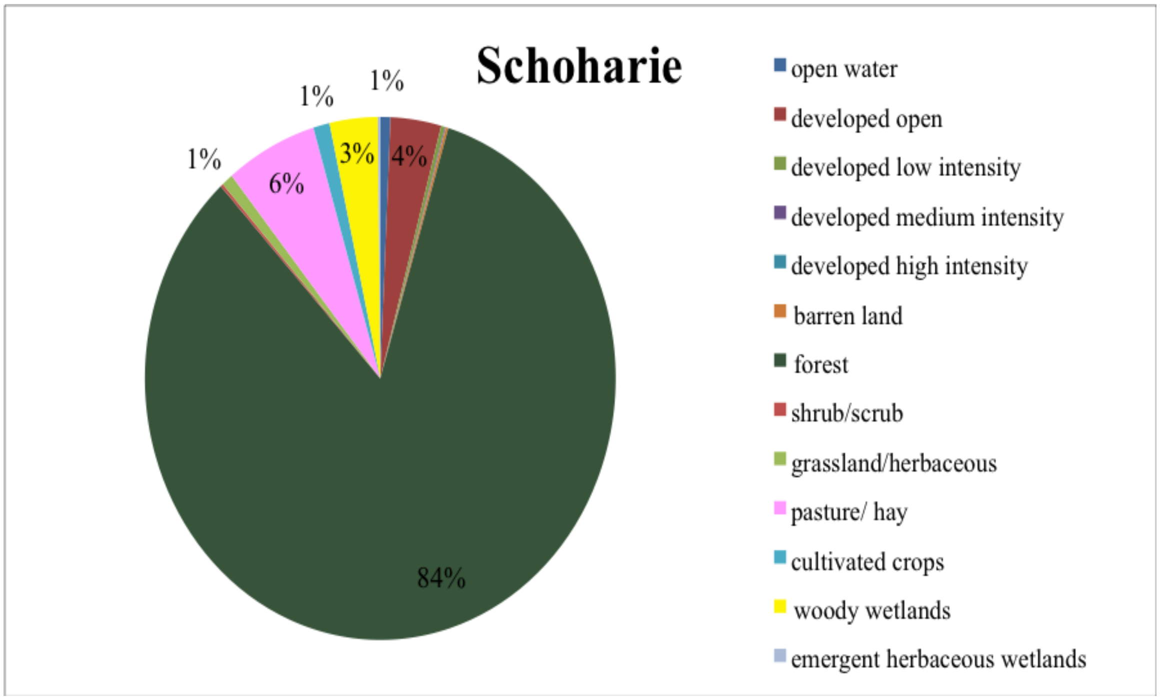


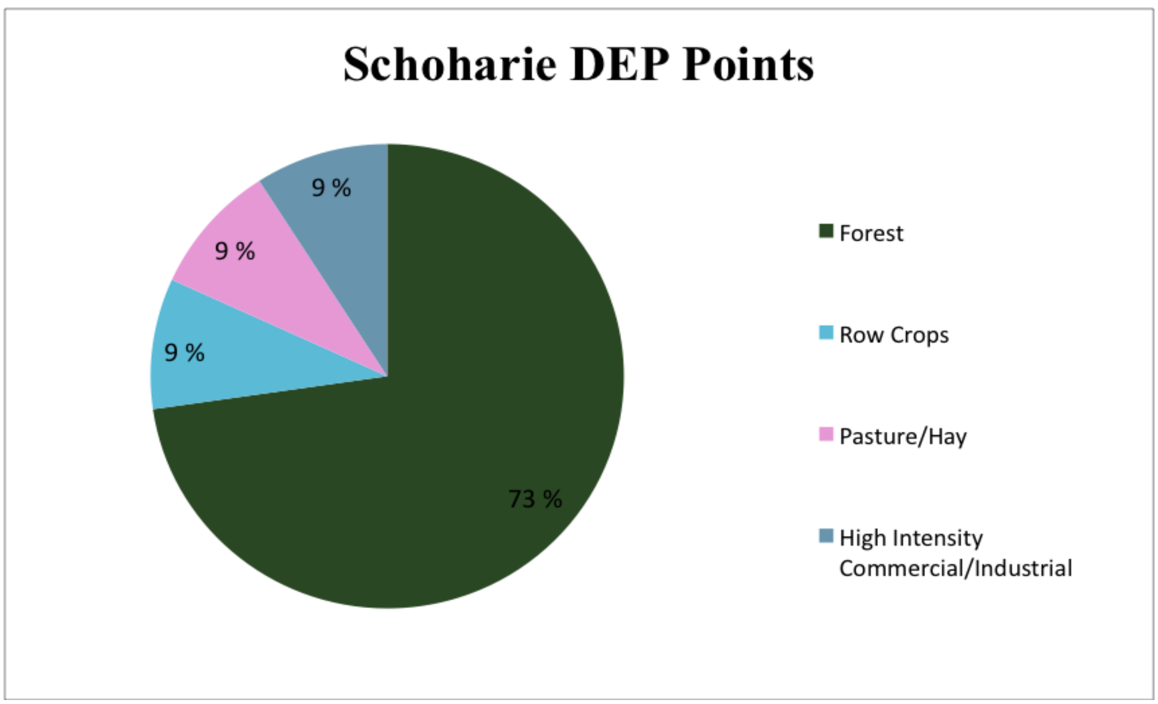
Rondout
2%
3%
3%
2%
90%
open water
developed open
developed low intensity
developed medium intensity
developed high intensity
barren land
forest
shrub/scrub
grassland/herbaceous
pasture/ hay
cultivated crops
woody wetlands
emergent herbaceous wetlands



Rondout DEP Points
100 %
Forest

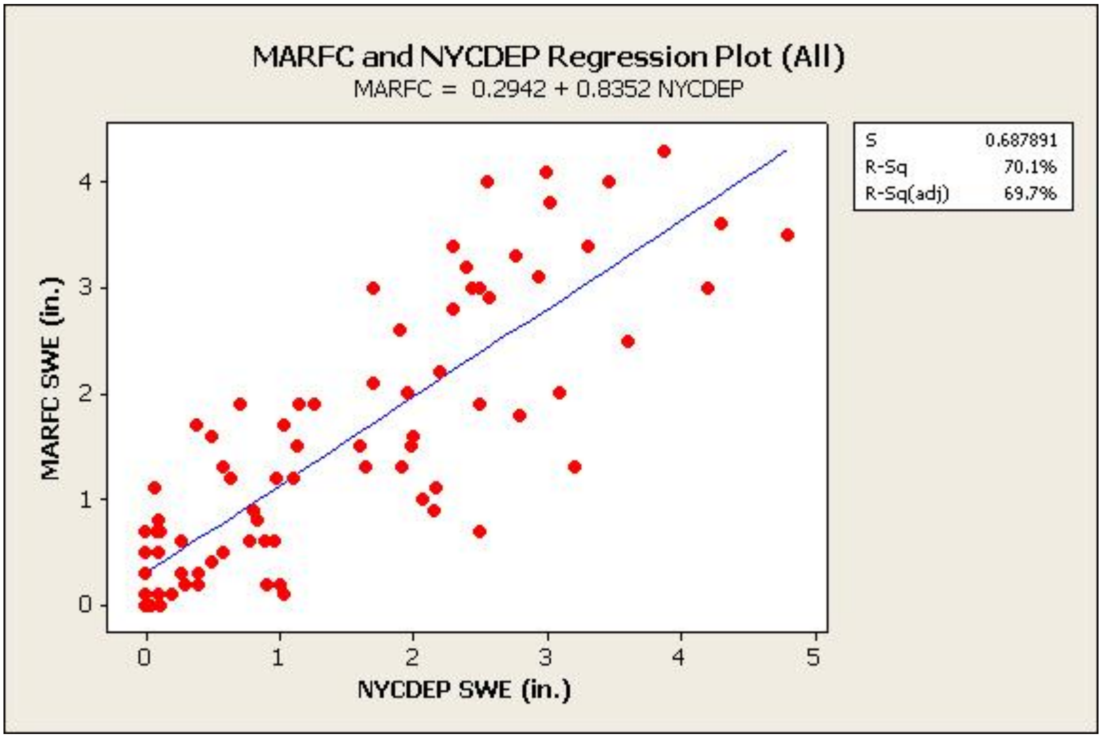
Schoharie


Schoharie
1%
1%
1%
3%
4%
6%
84%
open water
developed open
developed low intensity
developed medium intensity
developed high intensity
barren land
forest
shrub/scrub
grassland/herbaceous
pasture/ hay
cultivated crops
woody wetlands
emergent herbaceous wetlands

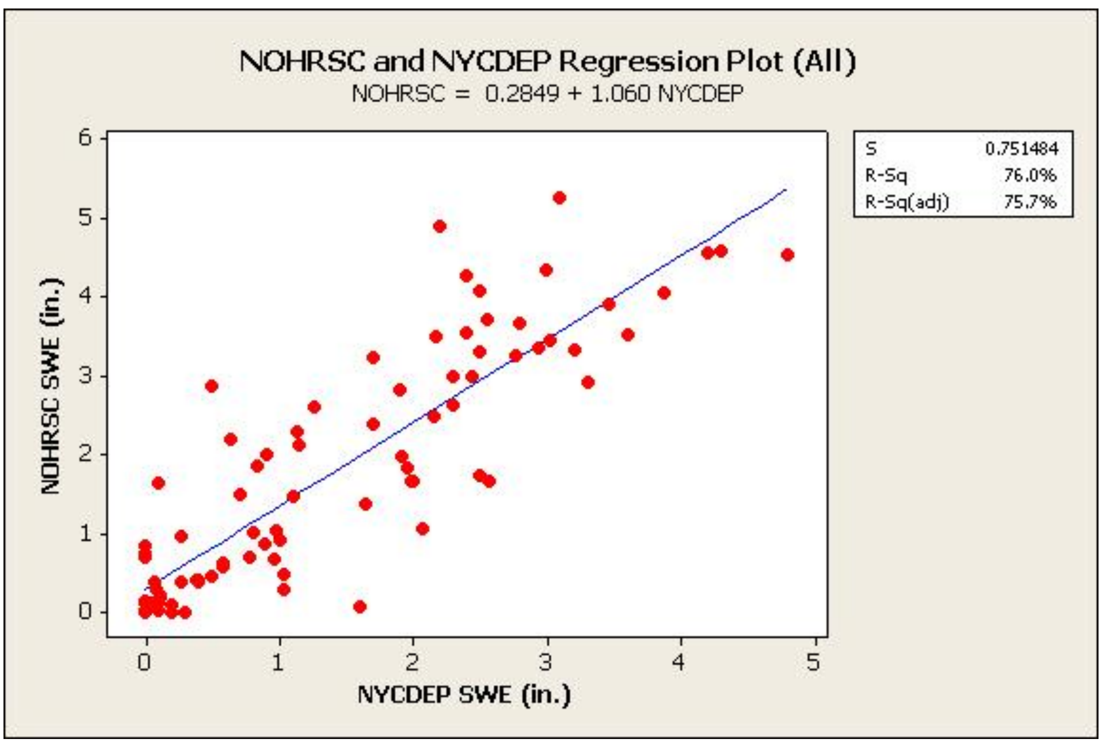

Schoharie DEP Points
9 %
9 %
9 %
73 %
Forest
Row Crops
Pasture/Hay
High Intensity Commercial/Industrial

Appendix III

MARFC Basins (Cannonsville, Neversink, and Pepacton)

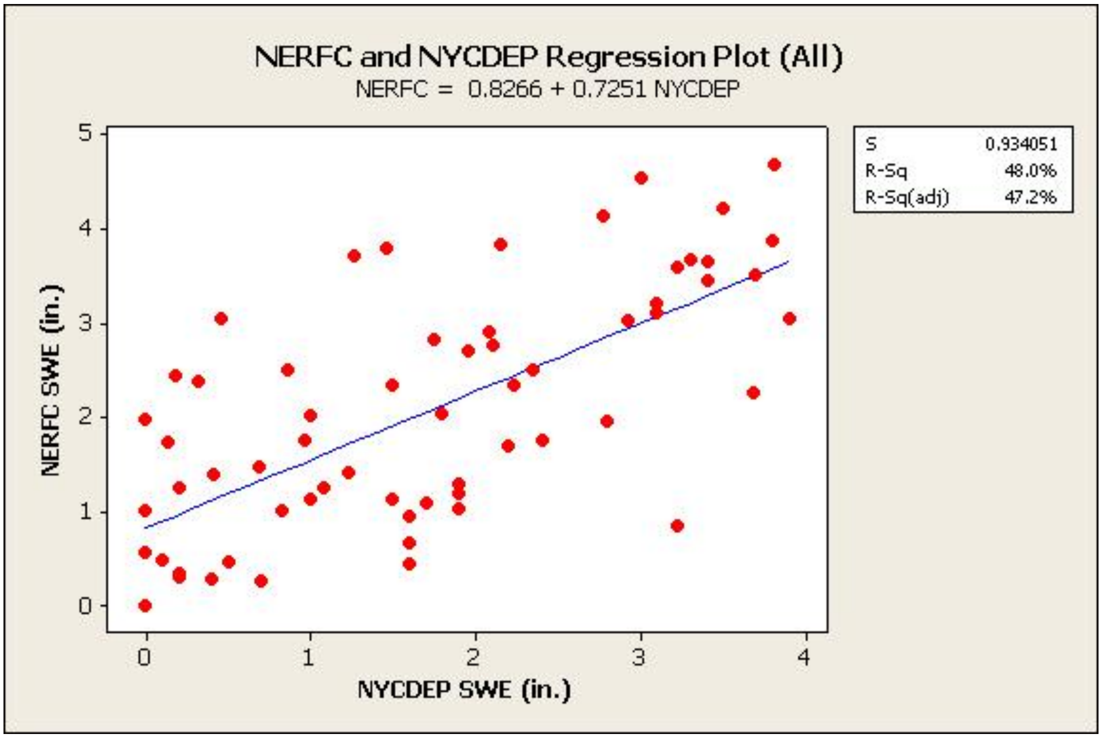


SNOW-17 and NYCDEP Regression Plot- MARFC basins.

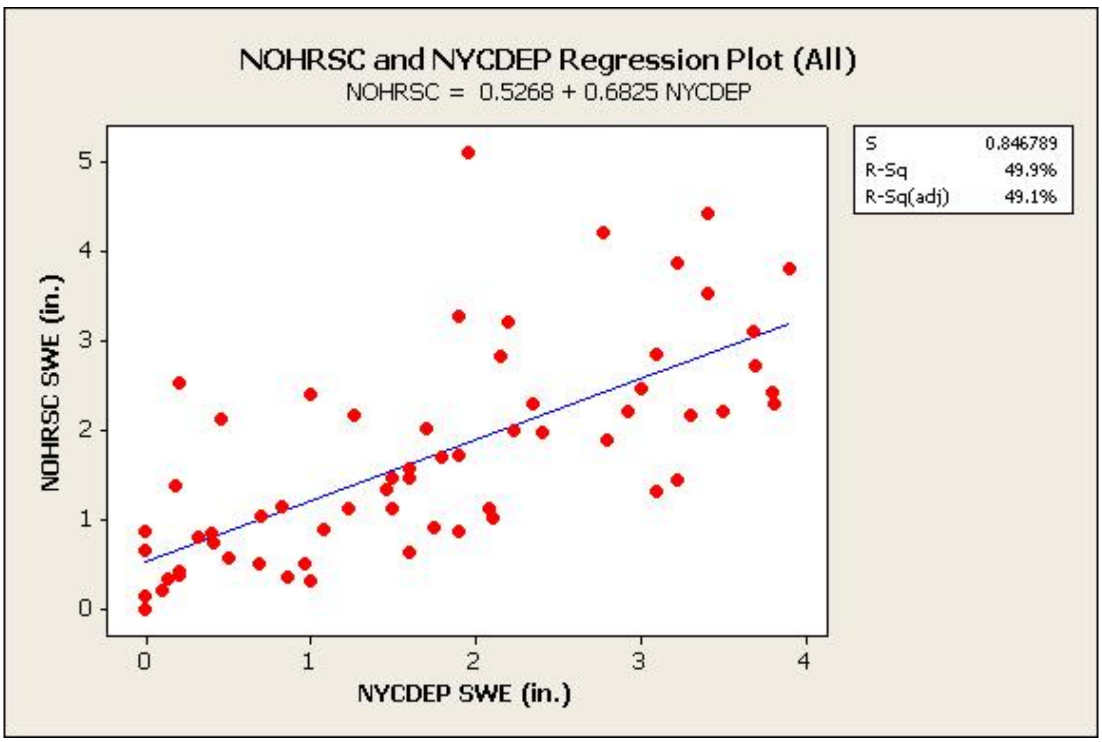


SNODAS and NYCDEP Regression Plot- MARFC basins.

NERFC Basins (Ashokan, Rondout and Schoharie)

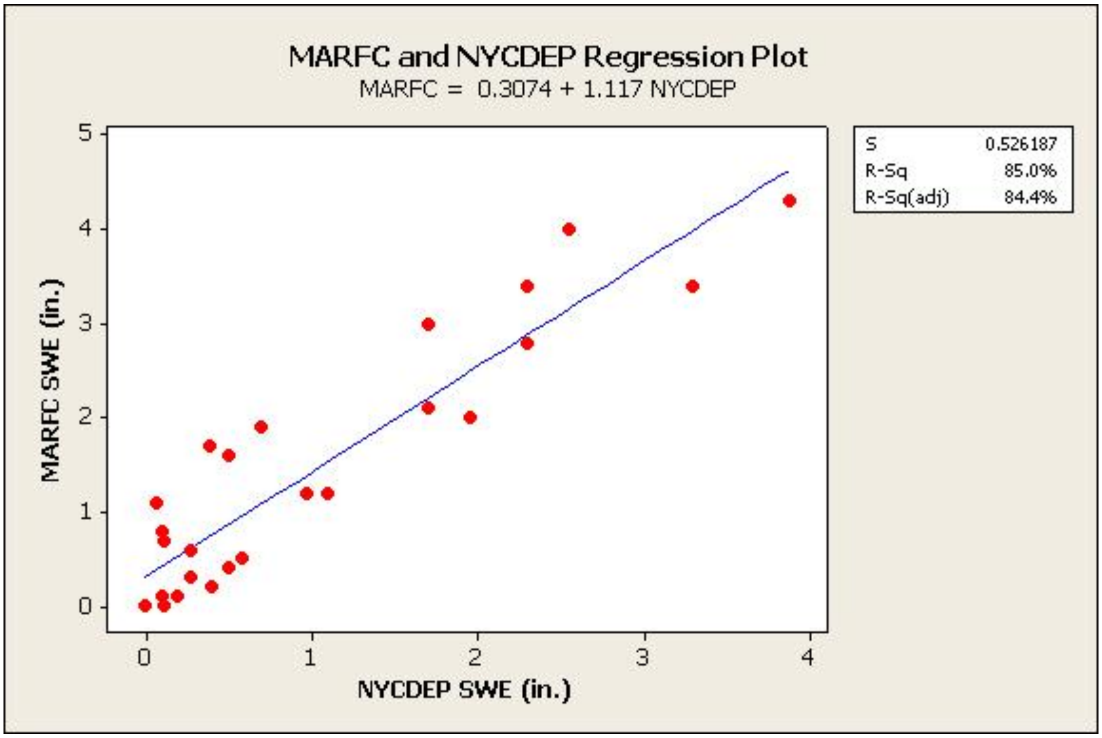


SNOW-17 and NYCDEP Regression Plot- NERFC basins.

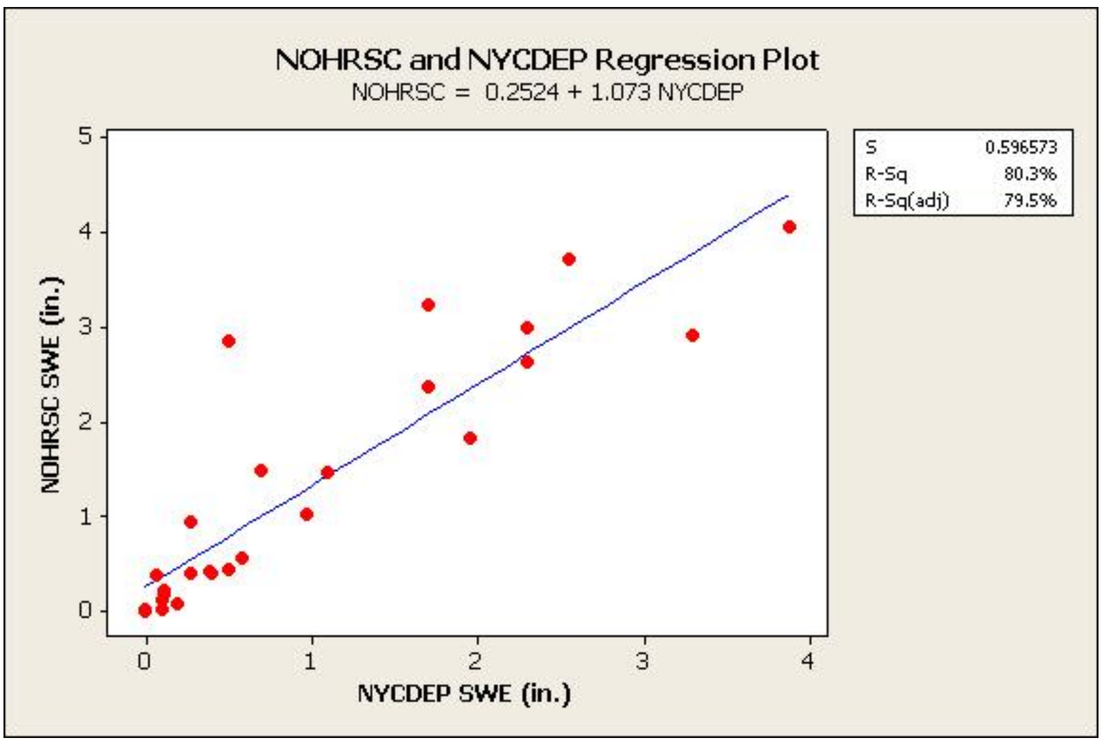


SNODAS and NYCDEP Regression Plot- NERFC basins.

Cannonsville

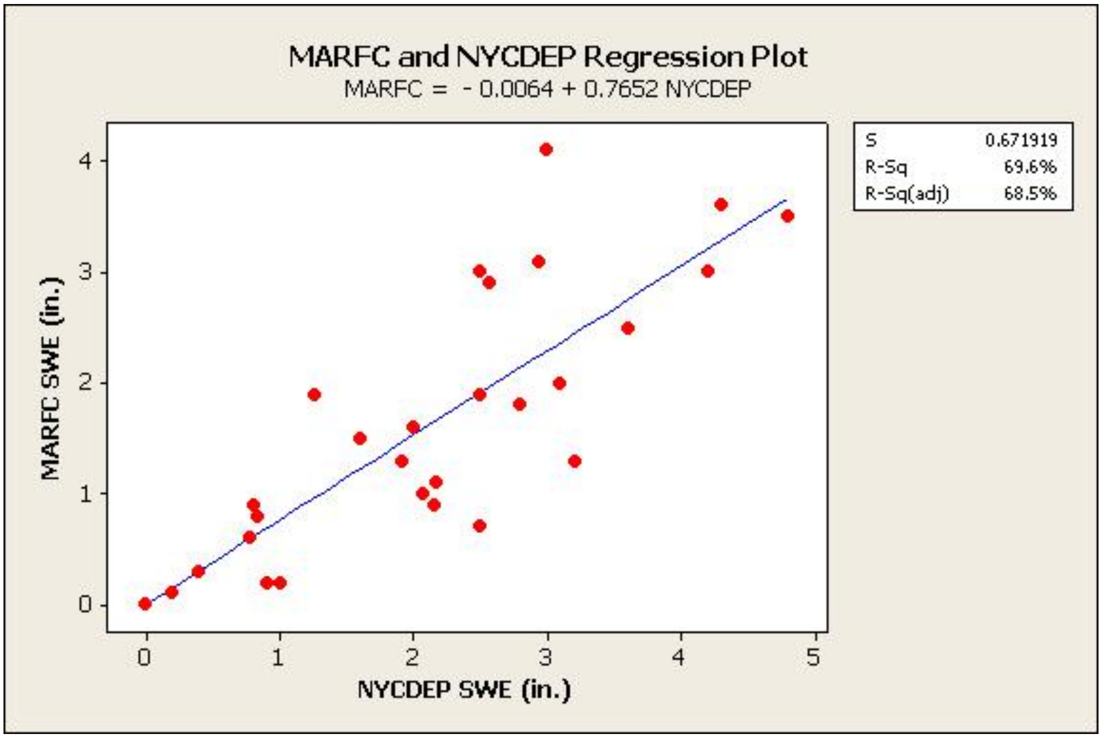


SNOW-17 and NYCDEP Regression Plot for Cannonsville reservoir basin.

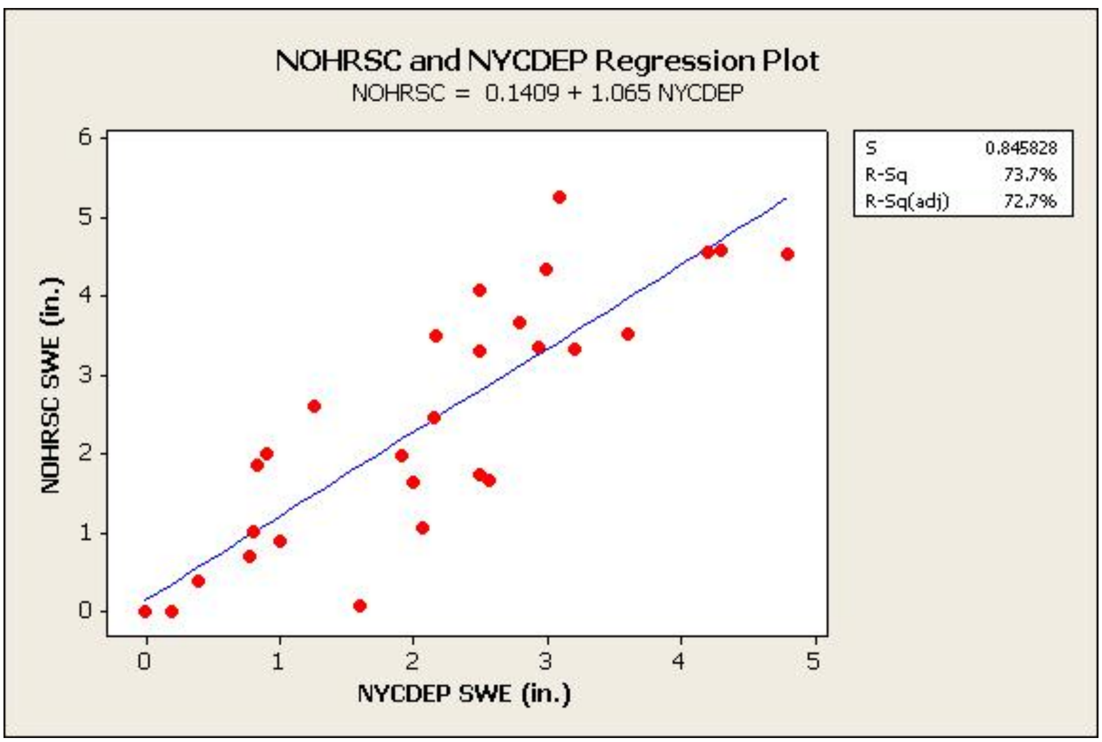


SNODAS and NYCDEP Regression Plot for Cannonsville reservoir basin.

Neversink

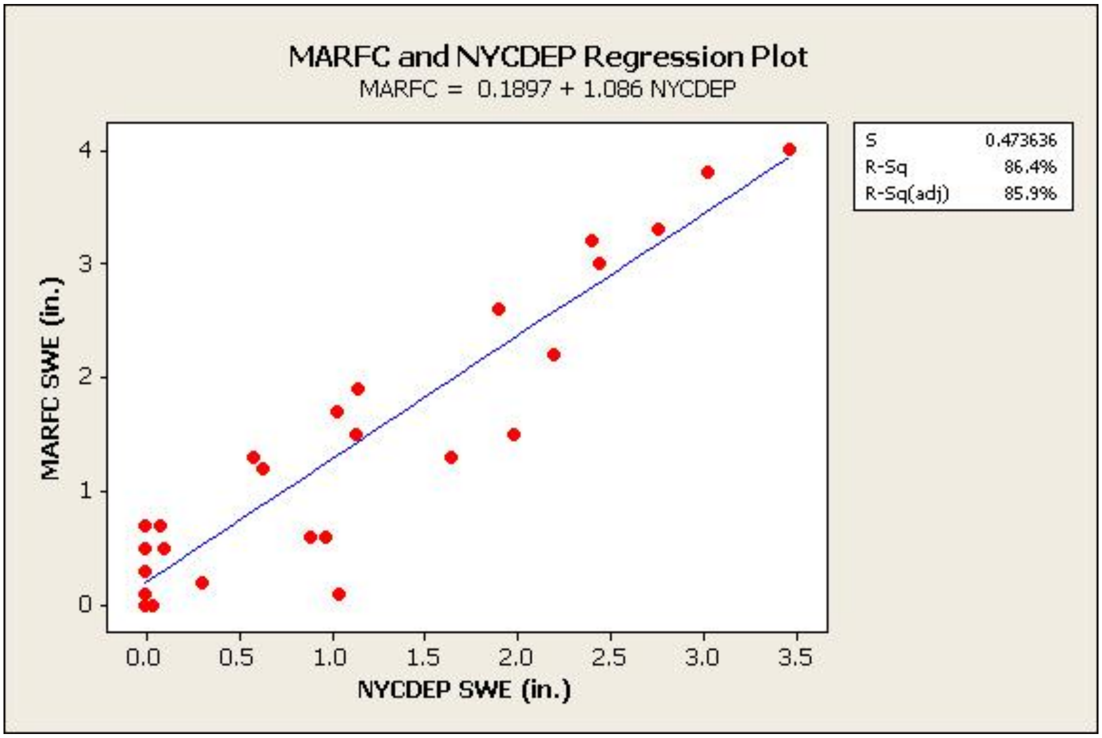


SNOW-17 and NYCDEP Regression Plot for Neversink reservoir basin.

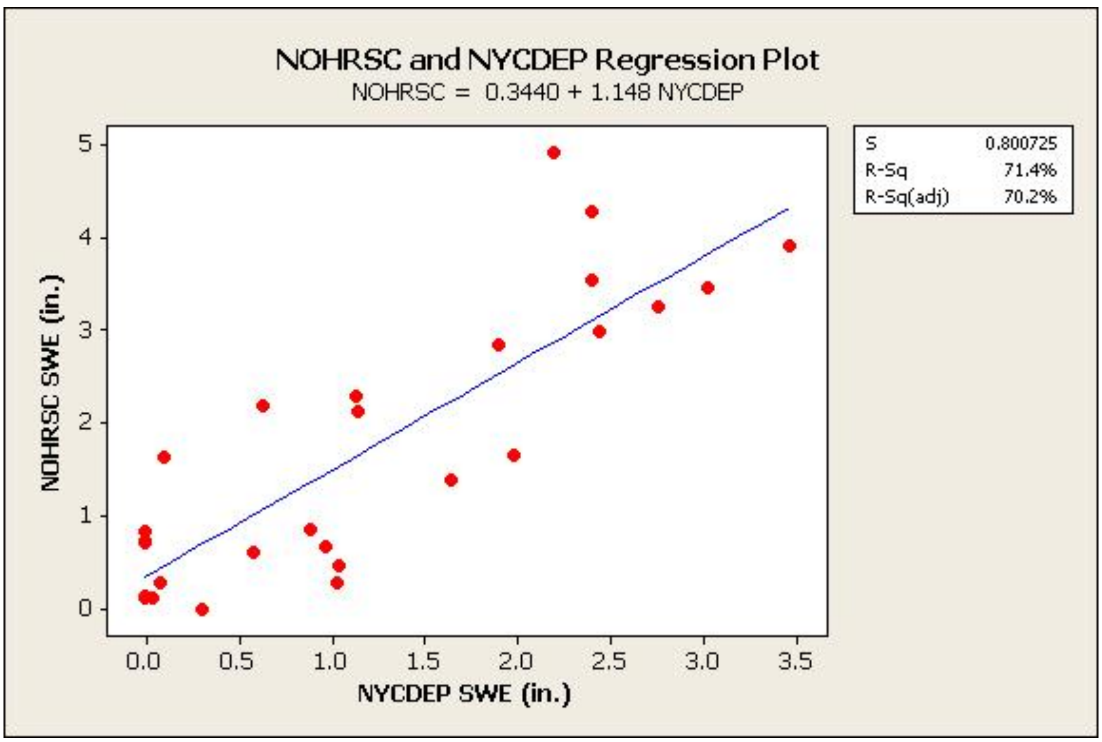


SNODAS and NYCDEP Regression Plot for Neversink reservoir basin.

Pepacton

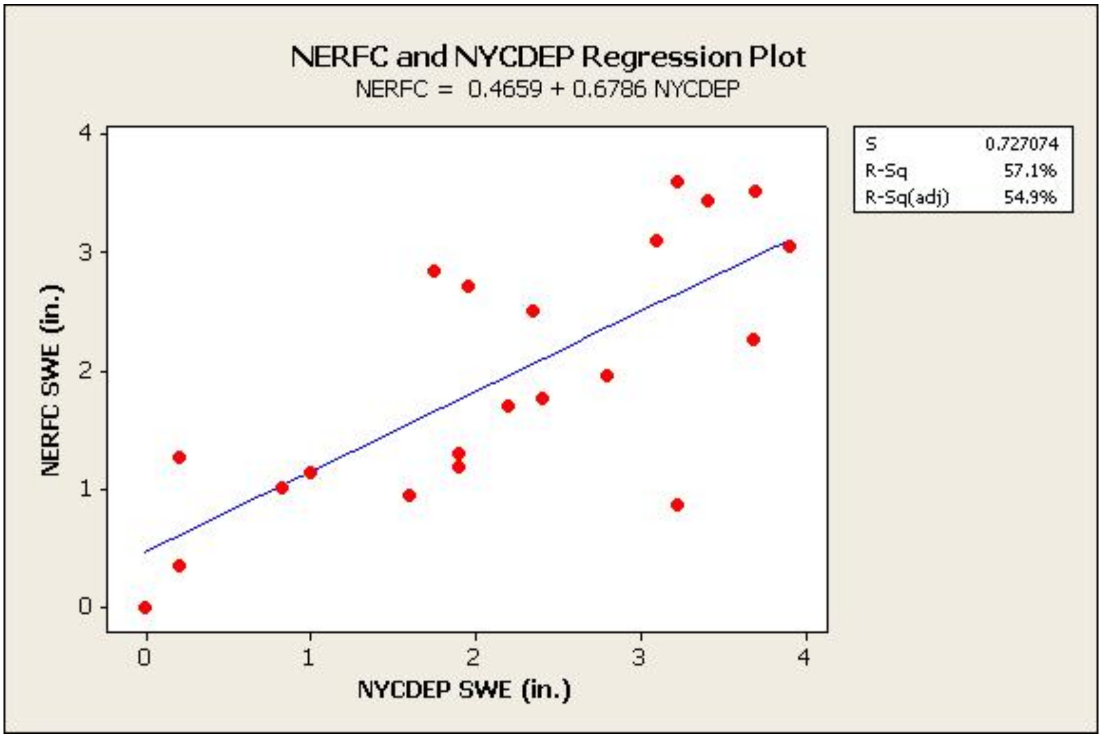


SNOW-17 and NYCDEP Regression Plot for Pepacton basin.

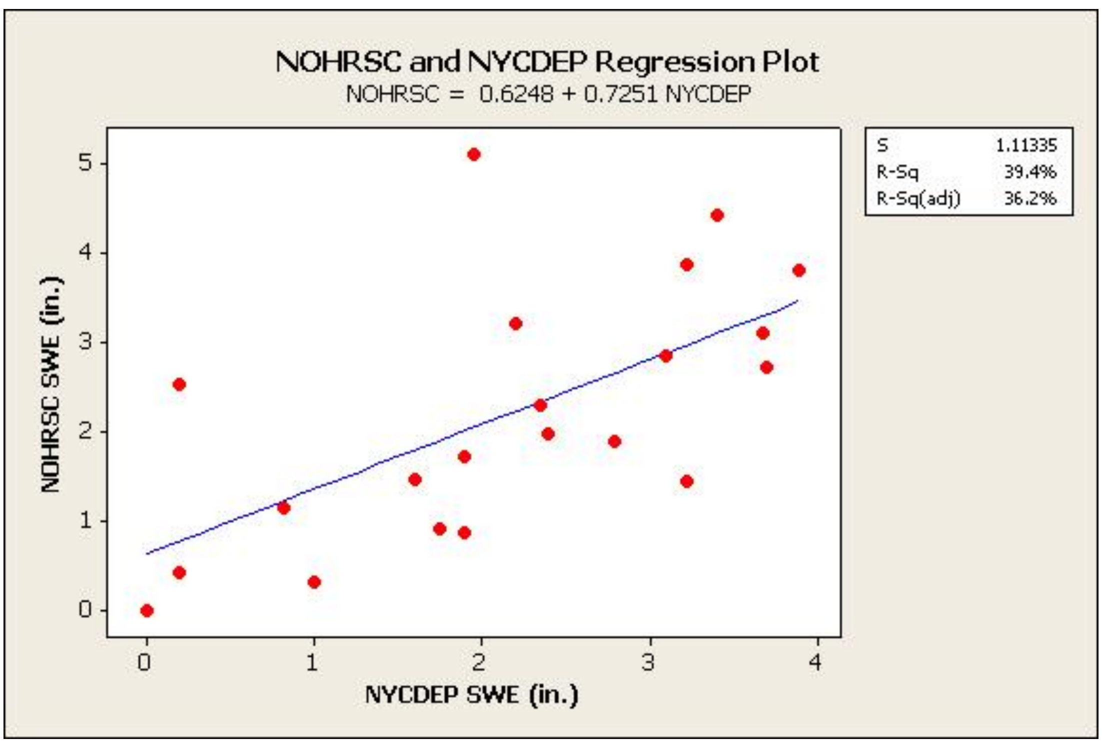


SNODAS and NYCDEP Regression Plot for Pepacton basin.

Ashokan

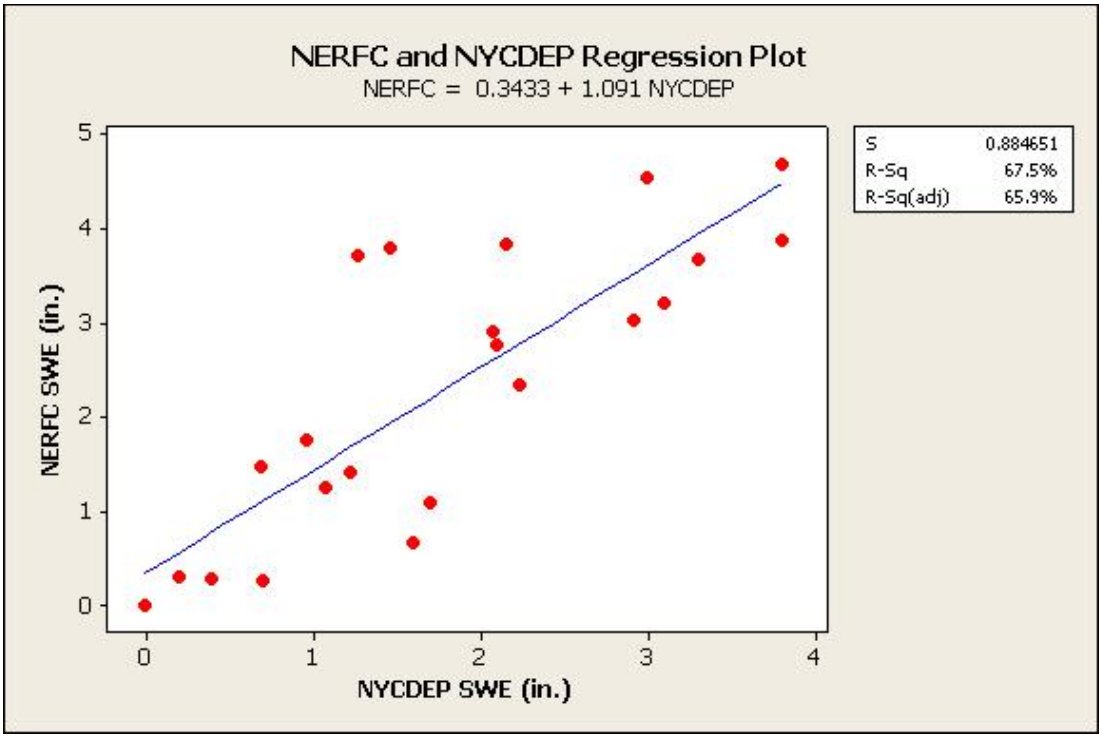


SNOW-17 and NYCDEP Regression Plot of Ashokan basin.

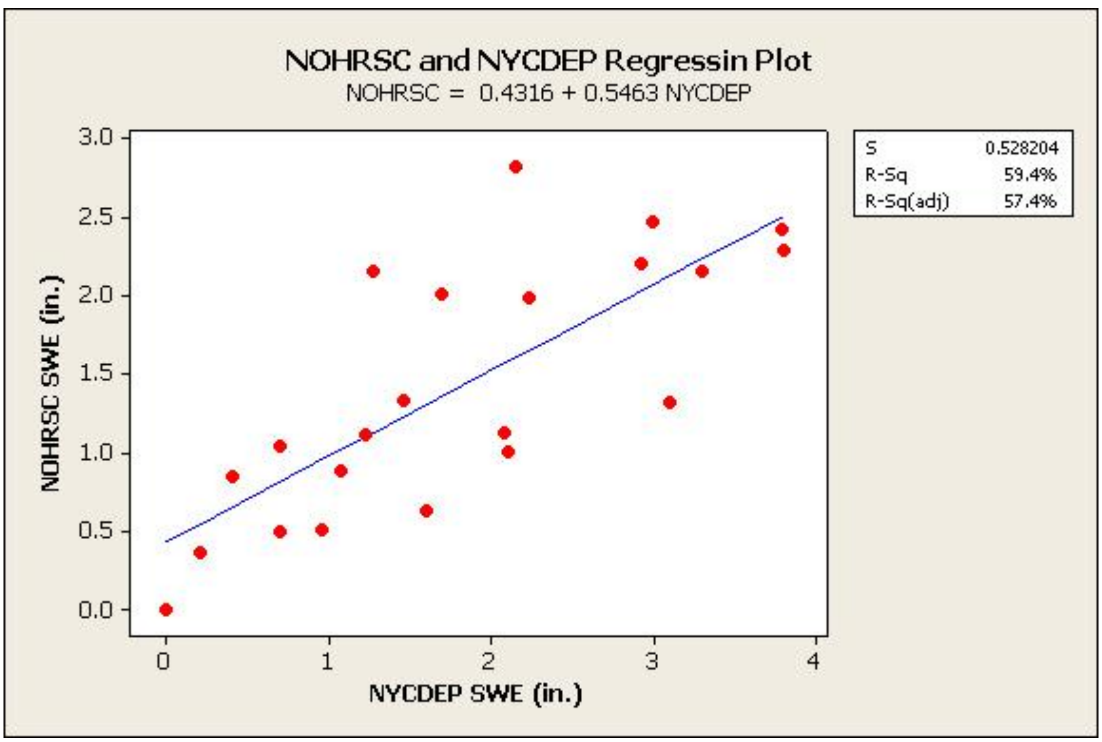


SNODAS and NYCDEP Regression Plot of Ashokan basin.

Rondout

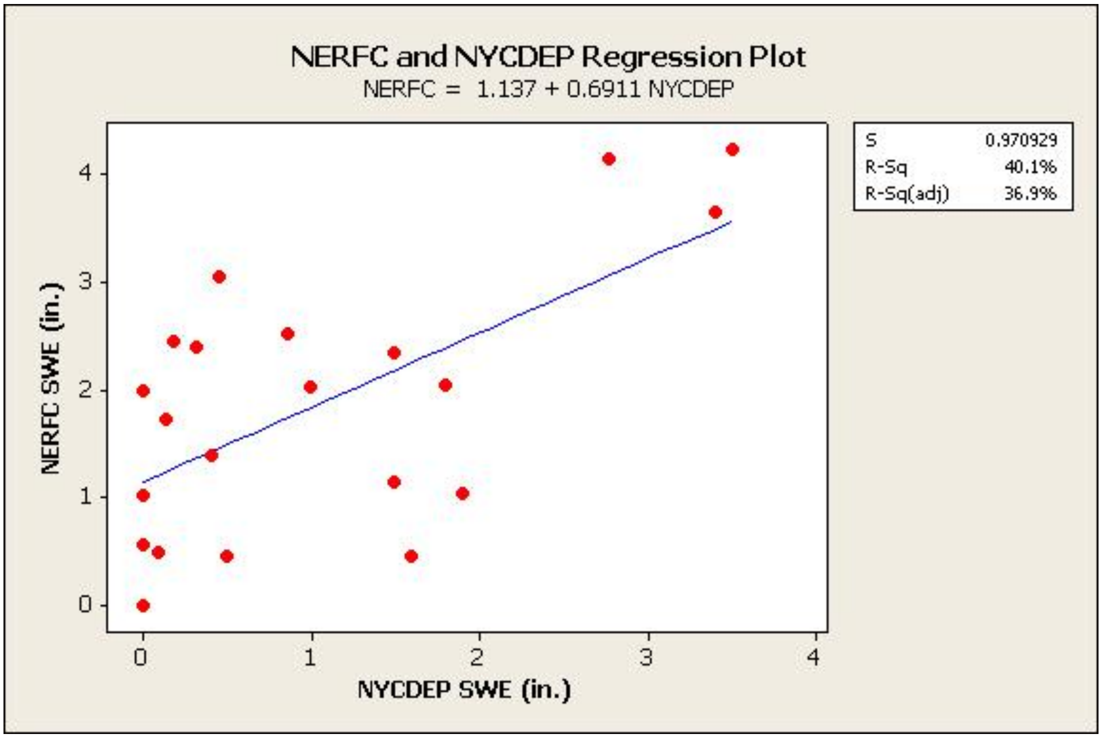


SNOW-17 and NYCDEP Regression plot for Rondout basin.

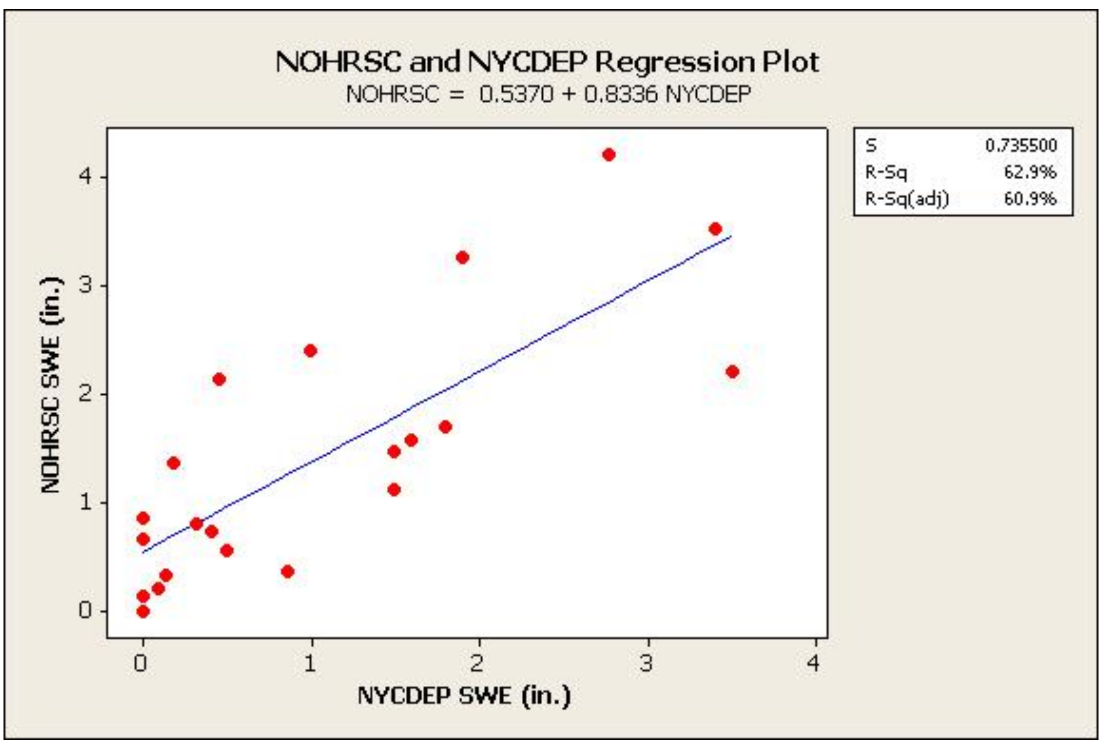


SNODAS and NYCDEP Regression plot for Rondout basin.

Schoharie

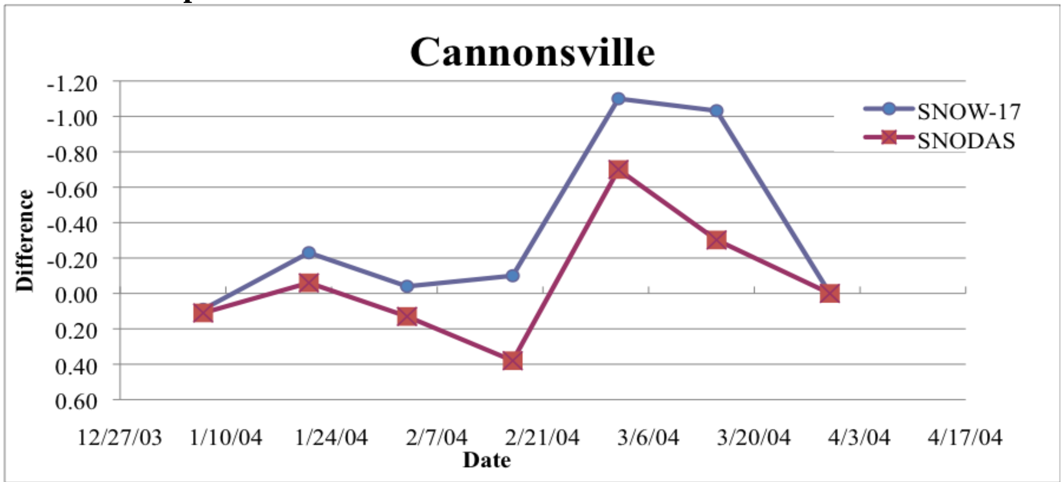


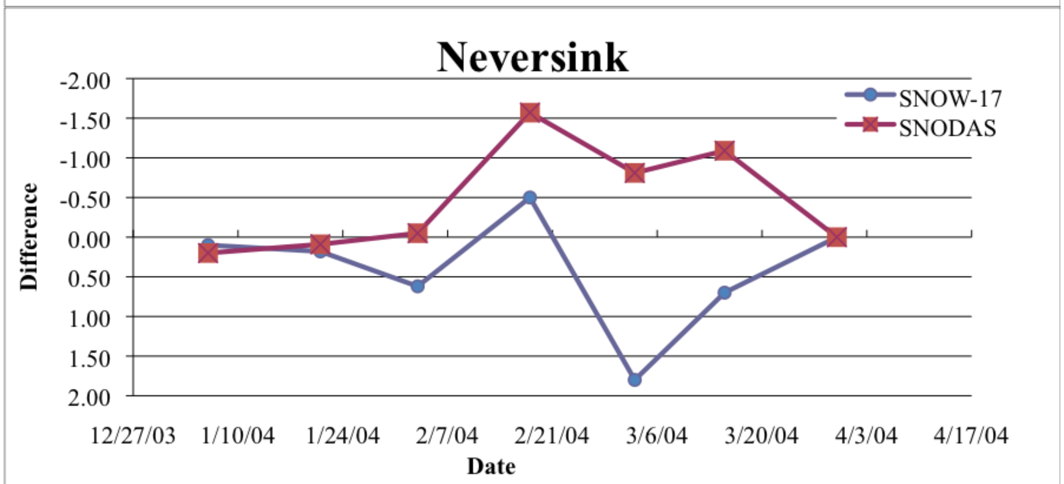
SNOW-17 and NYCDEP Regression plot for Schoharie basin.

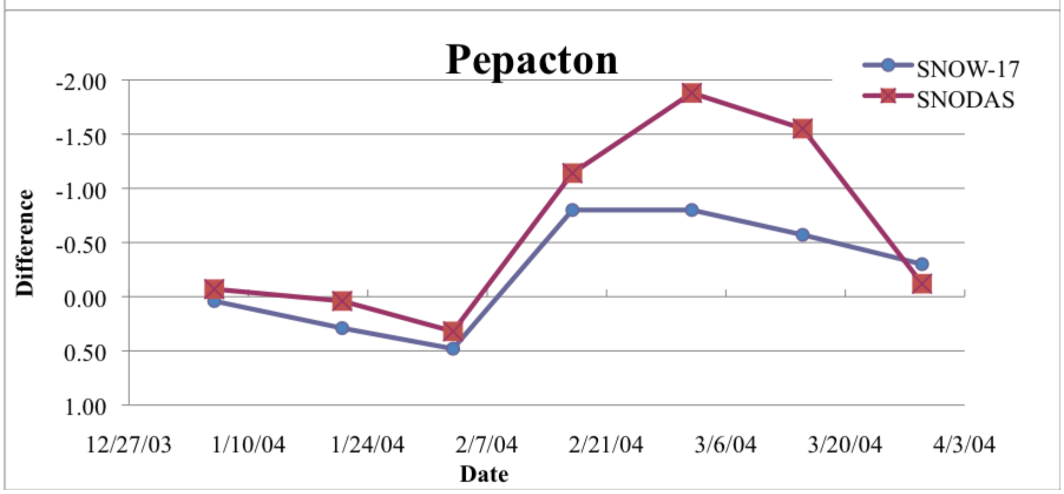


SNODAS and NYCDEP Regression plot for Schoharie basin.

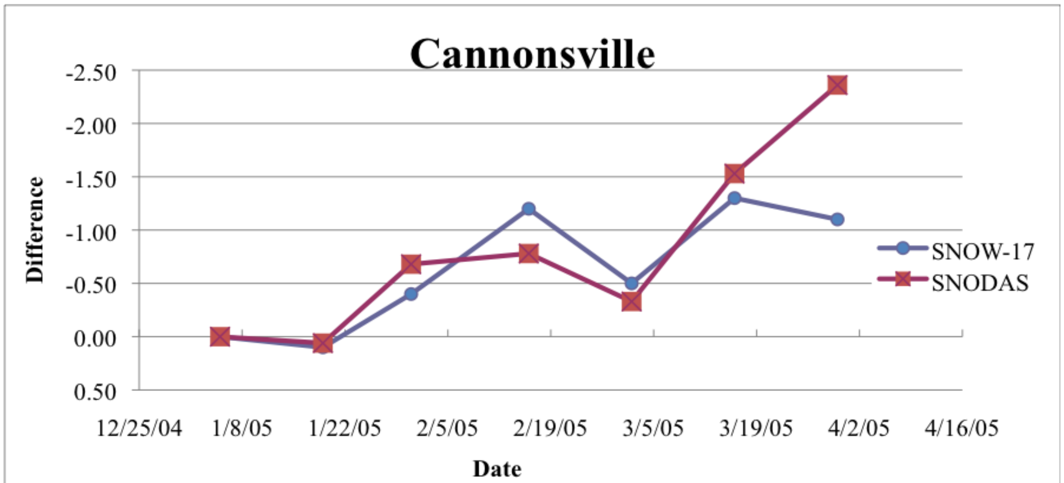
Appendix IV
Time Trend Graphs- MARFC 2004

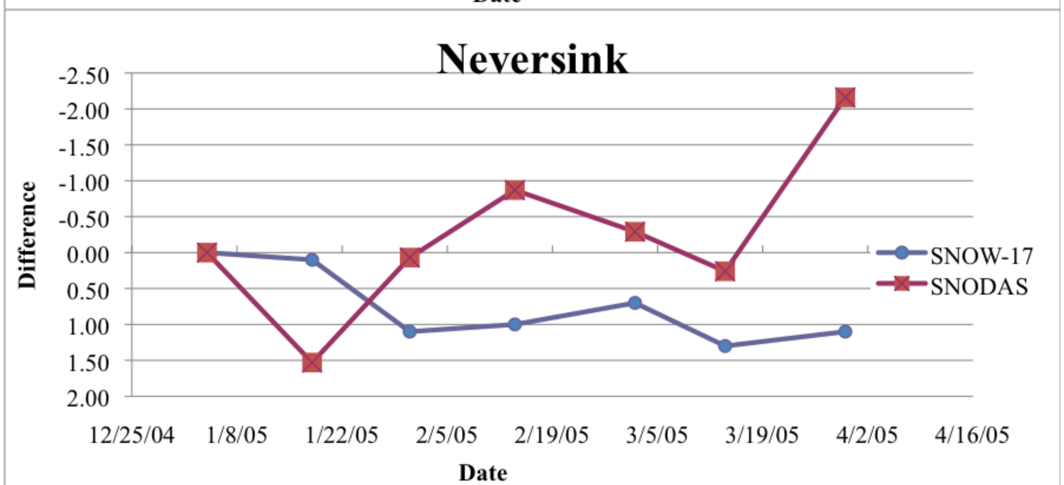


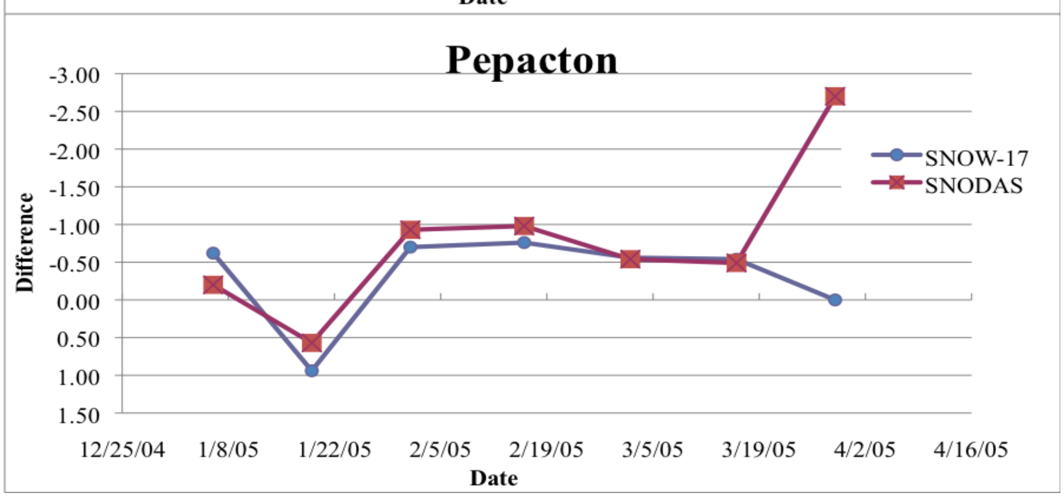




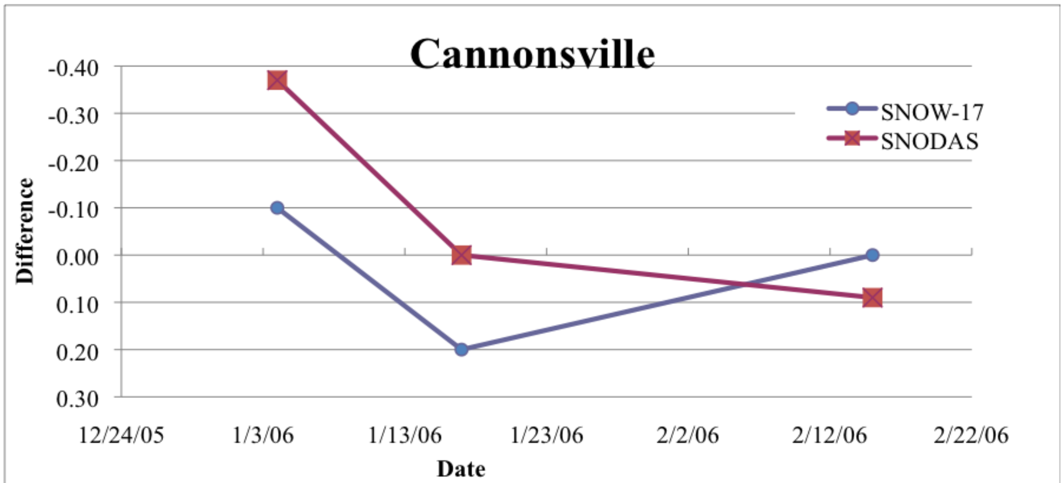
MARFC 2005


Cannonsville
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
Difference
12/25/04
1/8/05
1/22/05
2/5/05
2/19/05
3/5/05
3/19/05
4/2/05
4/16/05
Date
SNOW-17
SNODAS

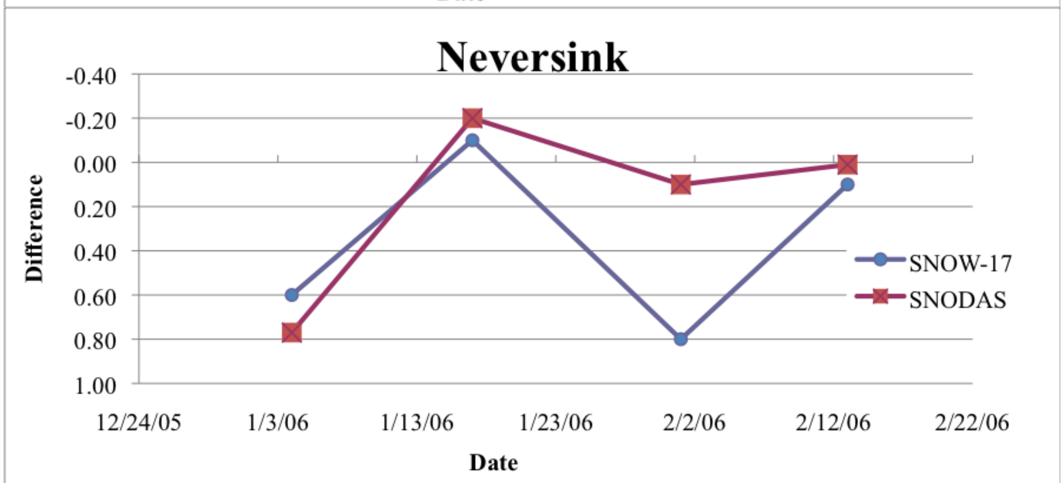

Neversink
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
Difference
12/25/04
1/8/05
1/22/05
2/5/05
2/19/05
3/5/05
3/19/05
4/2/05
4/16/05
Date
SNOW-17
SNODAS


Pepacton
-3.00
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
Difference
12/25/04
1/8/05
1/22/05
2/5/05
2/19/05
3/5/05
3/19/05
4/2/05
4/16/05
Date
SNOW-17
SNODAS

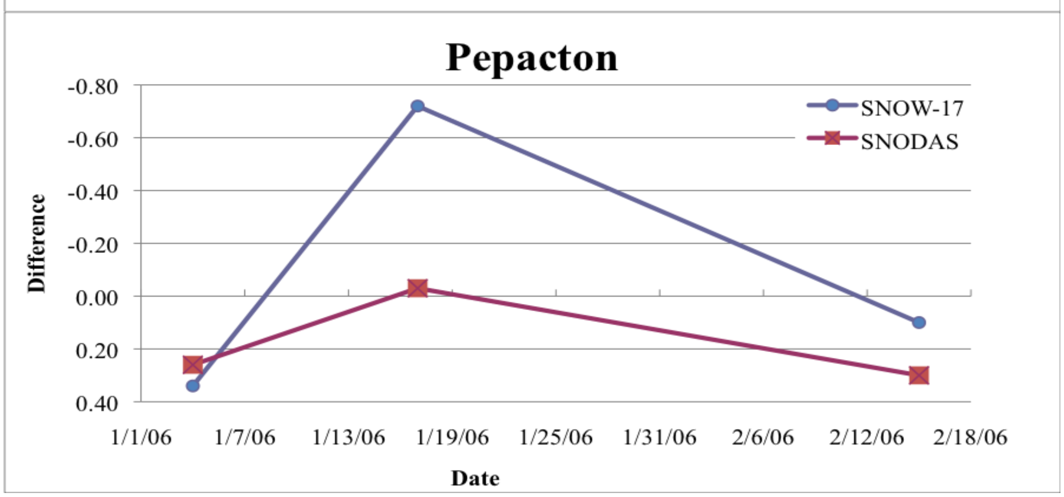
MARFC 2006



Cannonsville
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
Difference
12/24/05
1/3/06
1/13/06
1/23/06
2/2/06
2/12/06
2/22/06
Date
SNOW-17
SNODAS

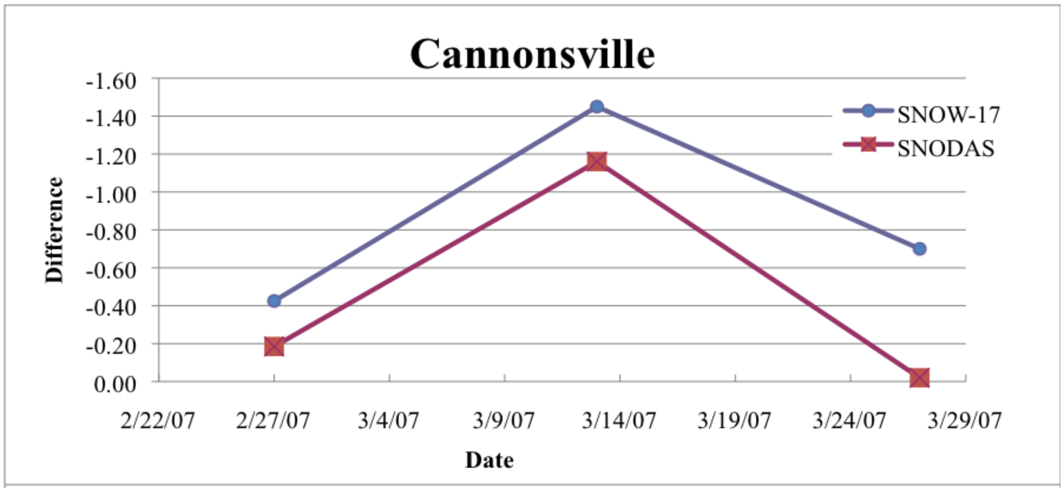


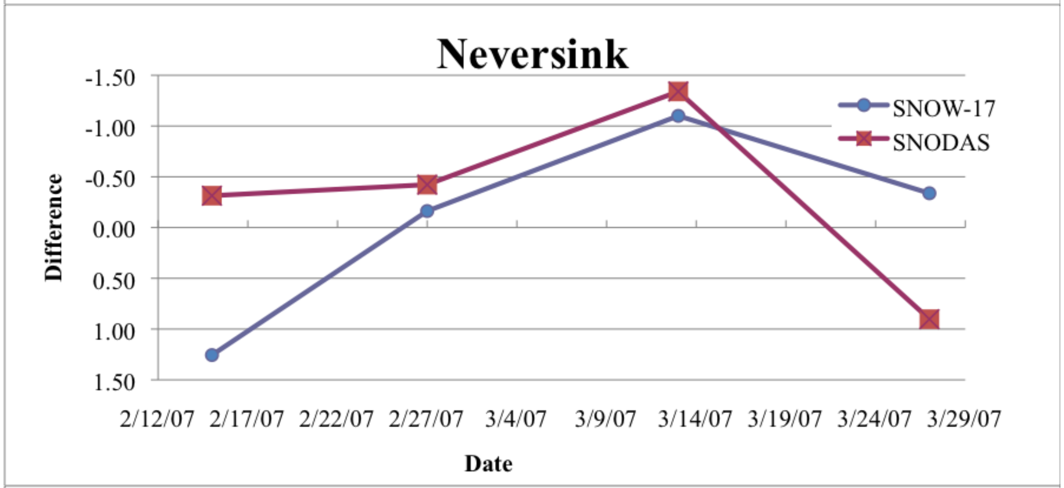
Neversink
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
1.00
Difference
12/24/05
1/3/06
1/13/06
1/23/06
2/2/06
2/12/06
2/22/06
Date
SNOW-17
SNODAS

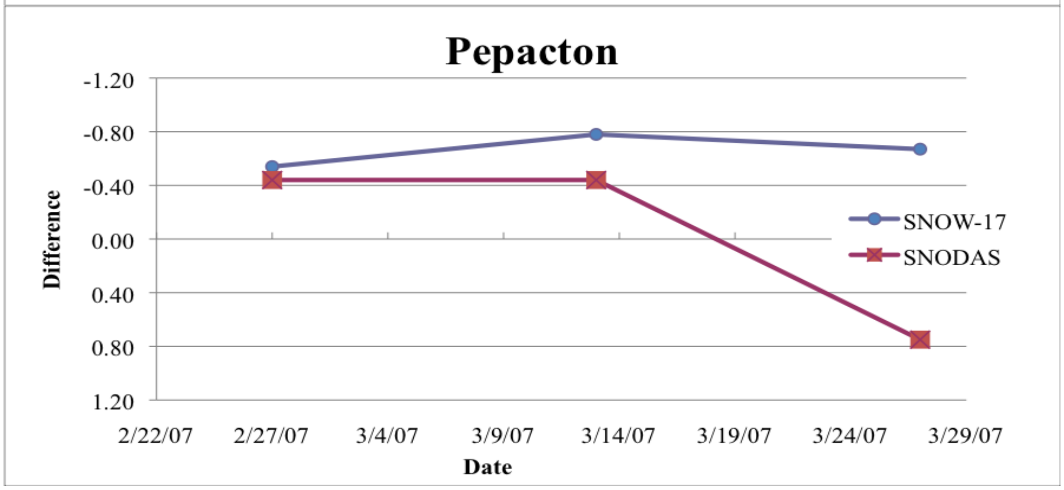


Pepacton
-0.80
-0.60
-0.40
-0.20
0.00
0.20
0.40
Difference
1/1/06
1/7/06
1/13/06
1/19/06
1/25/06
1/31/06
2/6/06
2/12/06
2/18/06
Date
SNOW-17
SNODAS

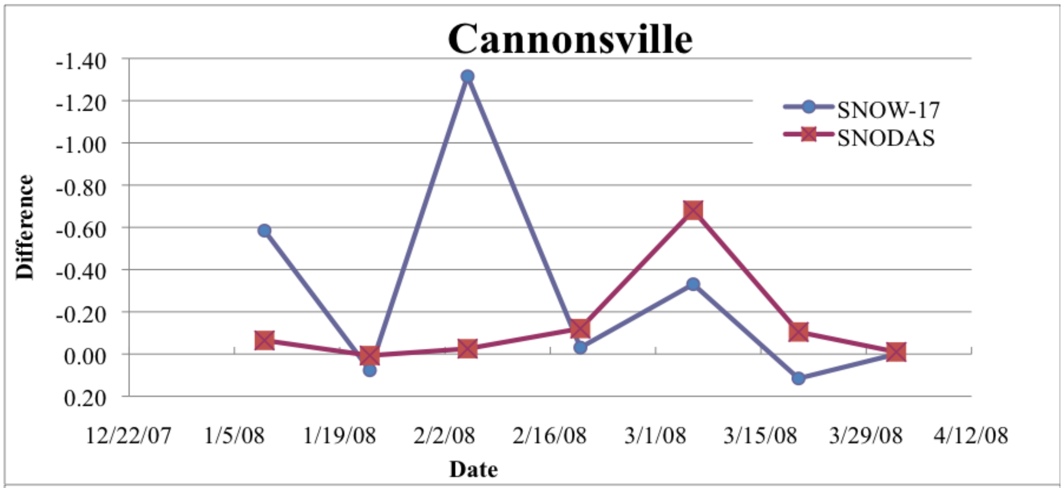
MARFC 2007


Cannonsville
-1.60
-1.40
-1.20
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
Difference
2/22/07
2/27/07
3/4/07
3/9/07
3/14/07
3/19/07
3/24/07
3/29/07
Date
SNOW-17
SNODAS

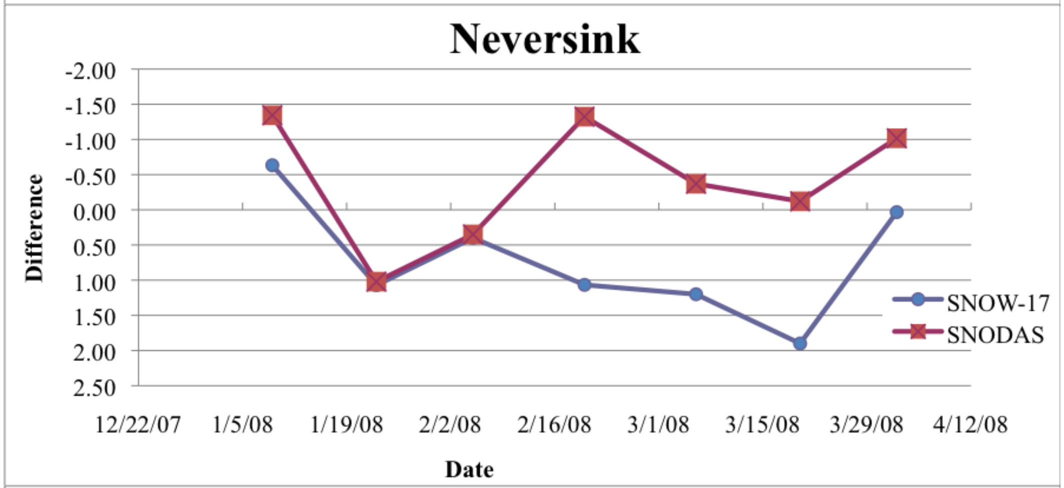

Neversink
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
Difference
2/12/07
2/17/07
2/22/07
2/27/07
3/4/07
3/9/07
3/14/07
3/19/07
3/24/07
3/29/07
Date
SNOW-17
SNODAS


Pepacton
-1.20
-0.80
-0.40
0.00
0.40
0.80
1.20
Difference
2/22/07
2/27/07
3/4/07
3/9/07
3/14/07
3/19/07
3/24/07
3/29/07
Date
SNOW-17
SNODAS

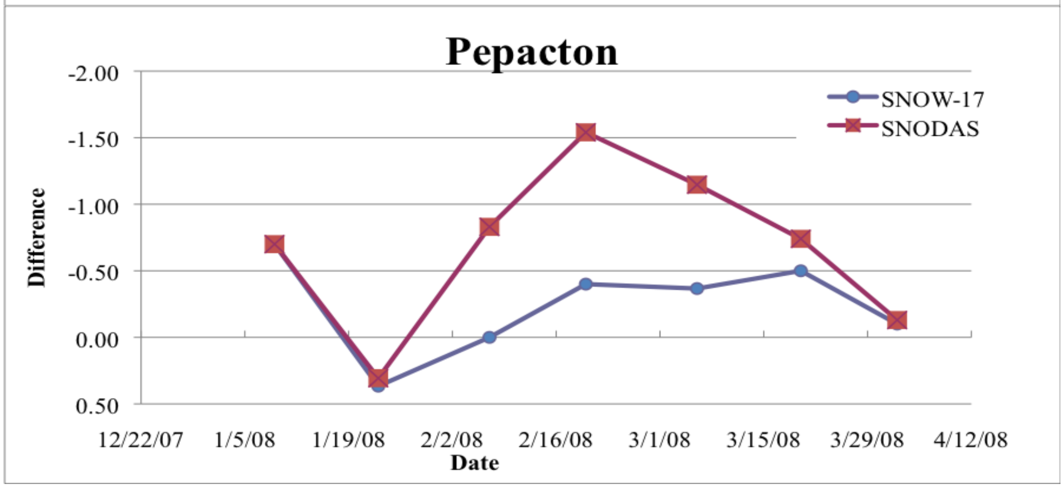
MARFC 2008



Cannonsville
-1.40
-1.20
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
0.20
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

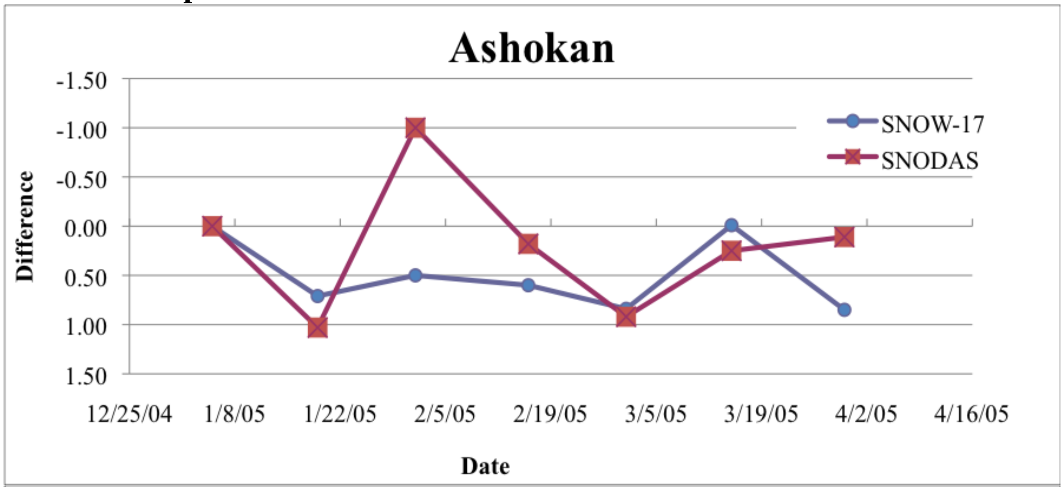


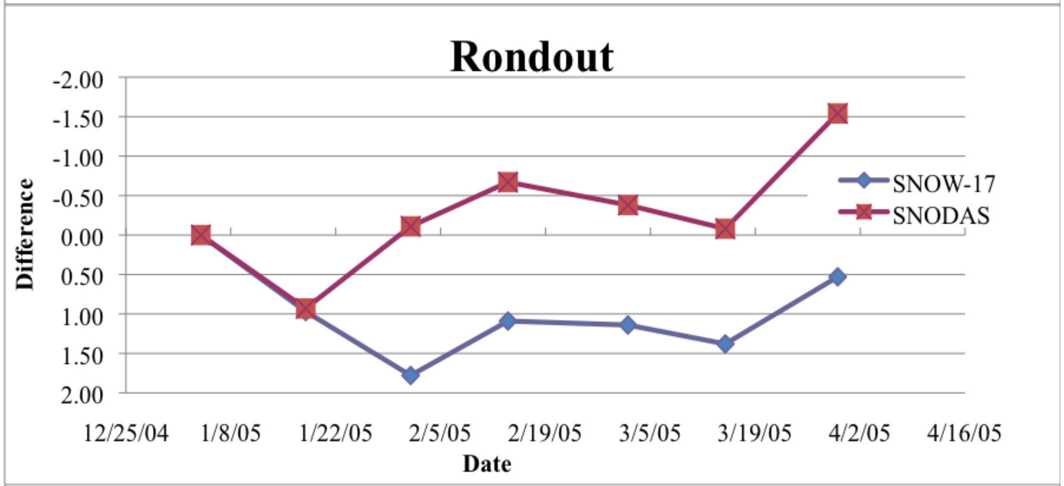
Neversink
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

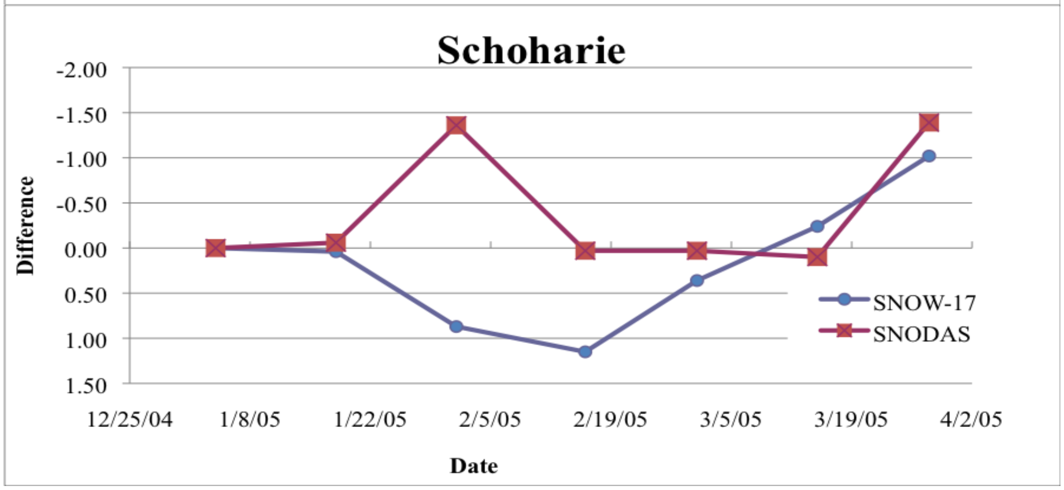


Pepacton
-2.00
-1.50
-1.00
-0.50
0.00
0.50
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

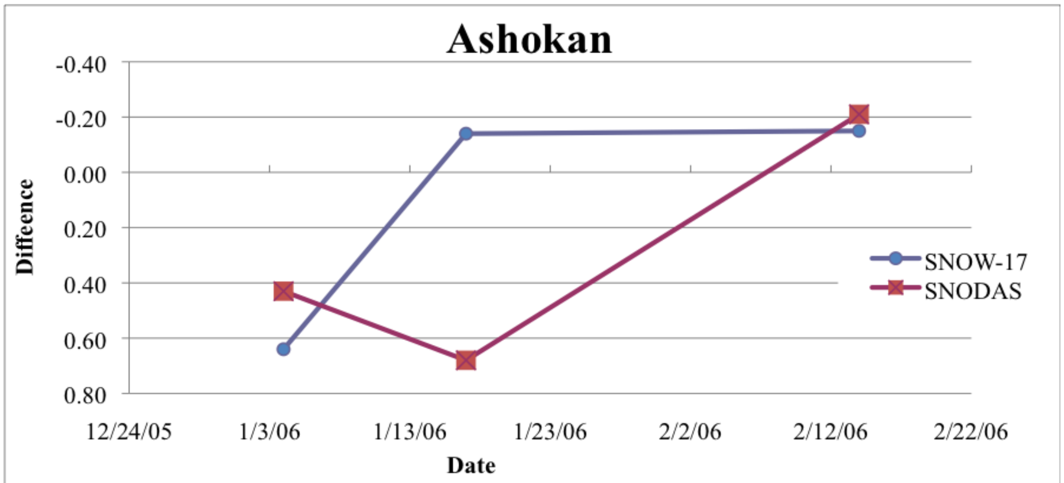
Time Trend Graphs- NERFC 2005



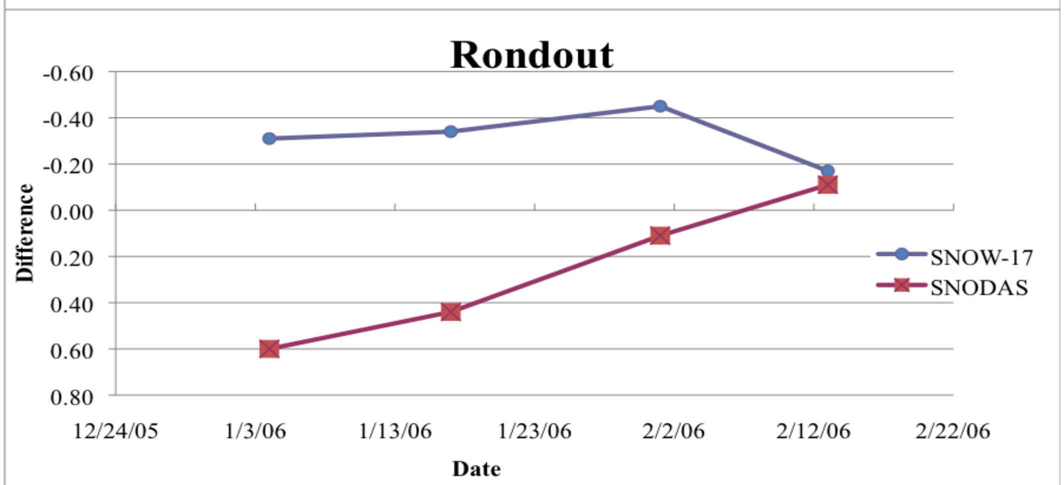




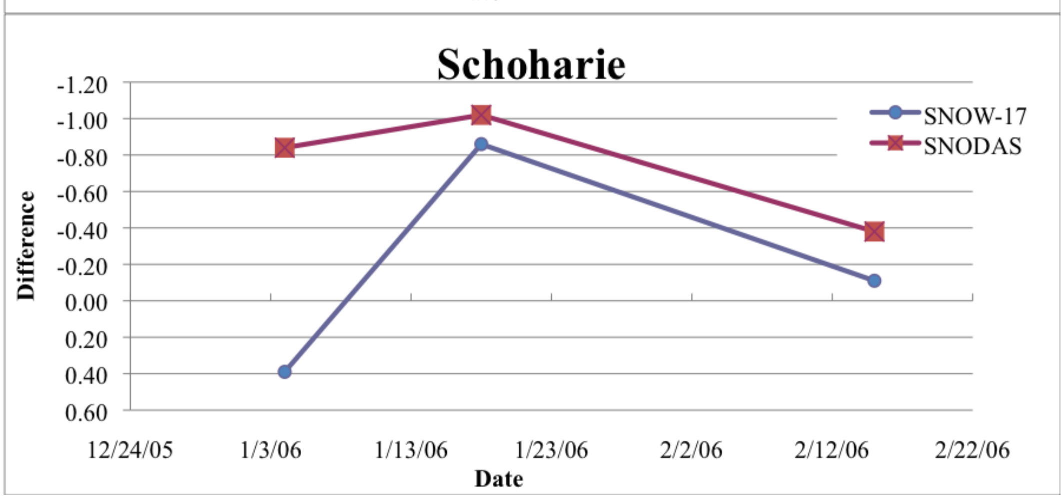
NERFC 2006



Ashokan
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
Diffeence
12/24/05
1/3/06
1/13/06
1/23/06
2/2/06
2/12/06
2/22/06
Date
SNOW-17
SNODAS

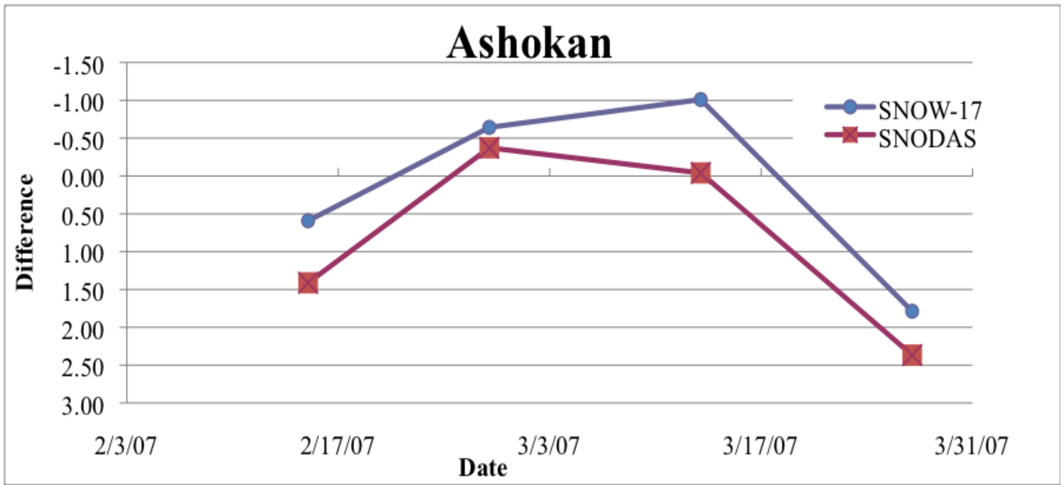


Rondout
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
Difference
12/24/05
1/3/06
1/13/06
1/23/06
2/2/06
2/12/06
2/22/06
Date
SNOW-17
SNODAS

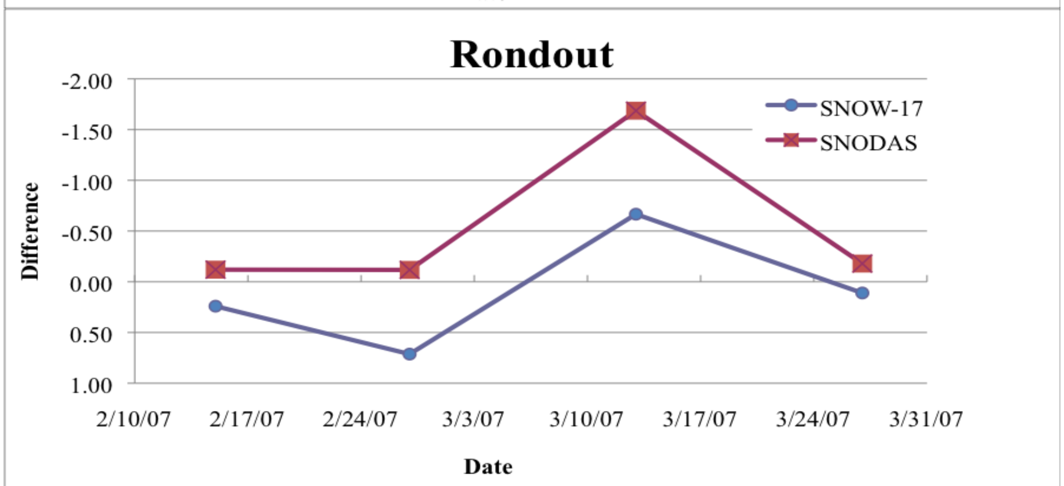


Schoharie
-1.20
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
Difference
12/24/05
1/3/06
1/13/06
1/23/06
2/2/06
2/12/06
2/22/06
Date
SNOW-17
SNODAS

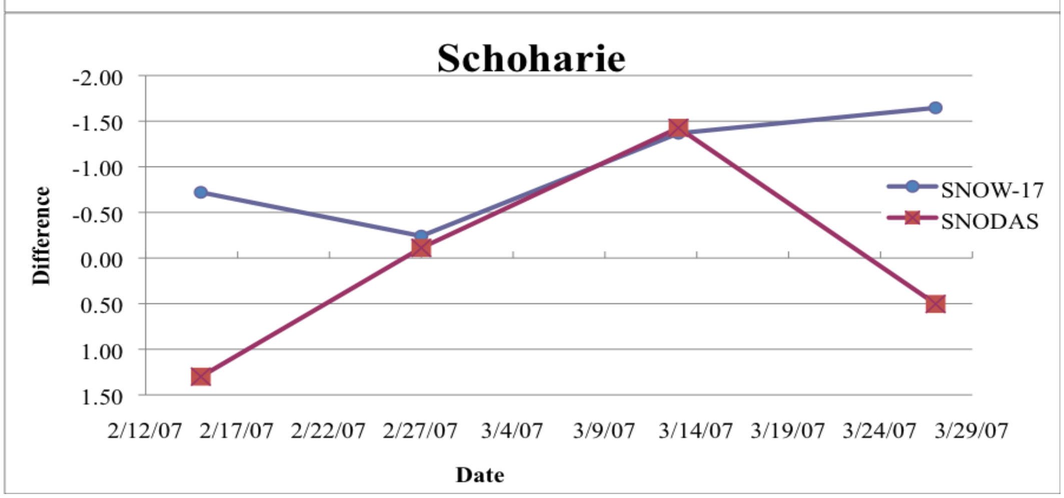
NERFC 2007



Ashokan
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Difference
SNOW-17
SNODAS
2/3/07
2/17/07
3/3/07
3/17/07
3/31/07
Date

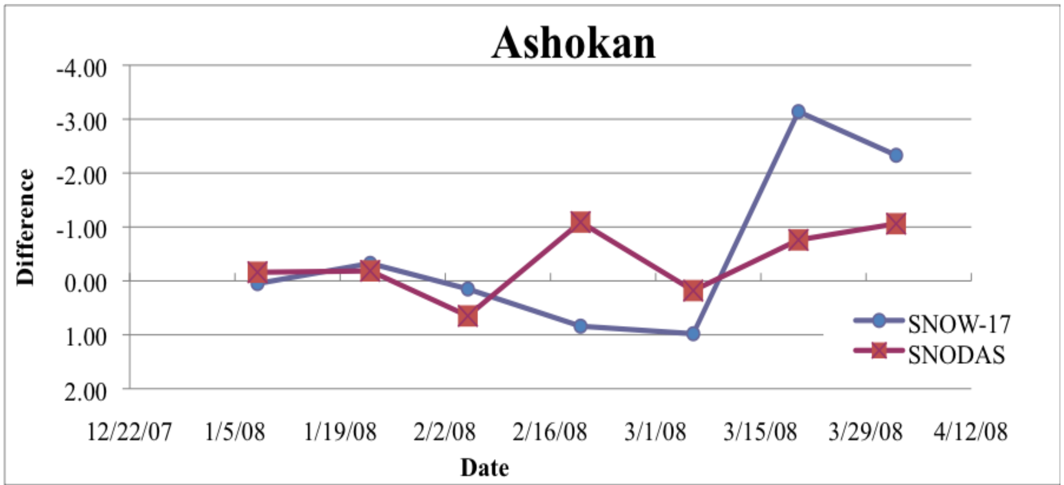


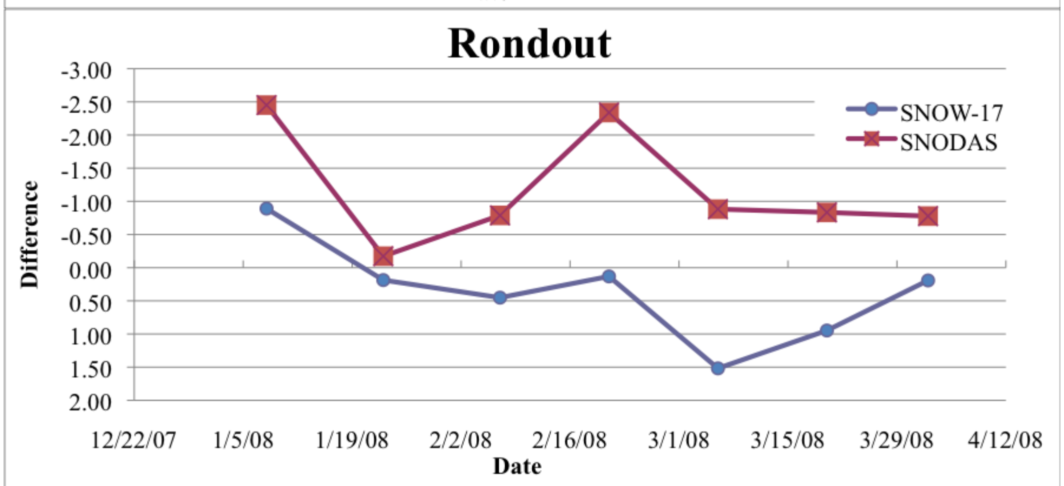
Rondout
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
Difference
SNOW-17
SNODAS
2/10/07
2/17/07
2/24/07
3/3/07
3/10/07
3/17/07
3/24/07
3/31/07
Date

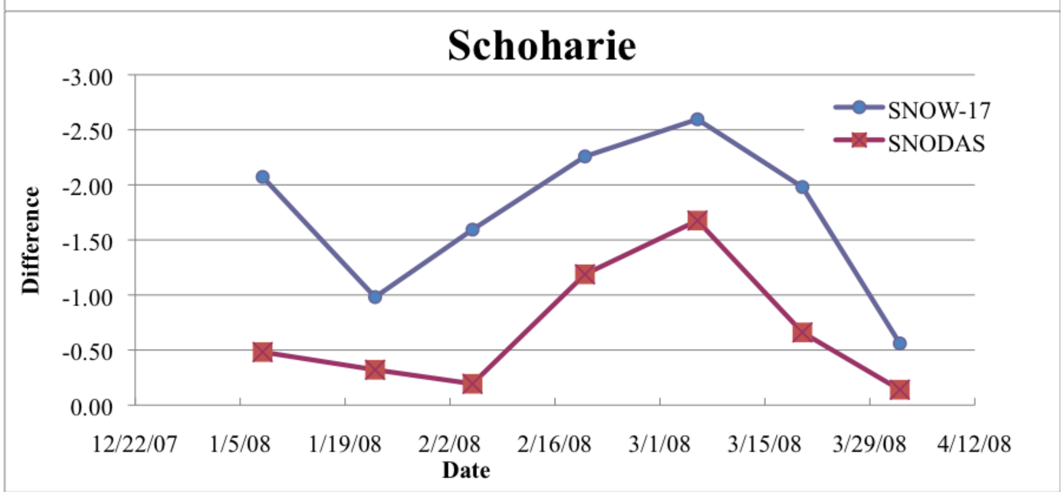


Schoharie
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
Difference
SNOW-17
SNODAS
2/12/07
2/17/07
2/22/07
2/27/07
3/4/07
3/9/07
3/14/07
3/19/07
3/24/07
3/29/07
Date

NERFC 2008

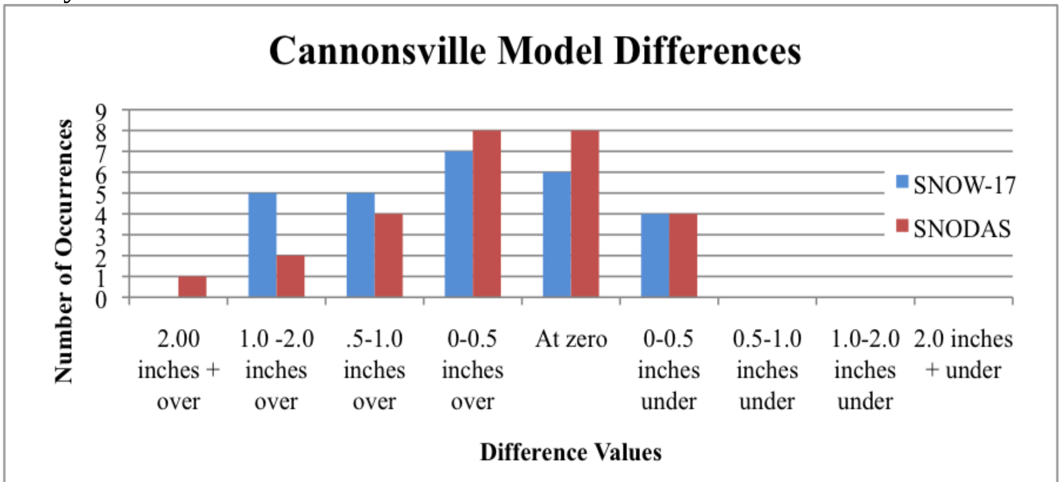

Ashokan
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

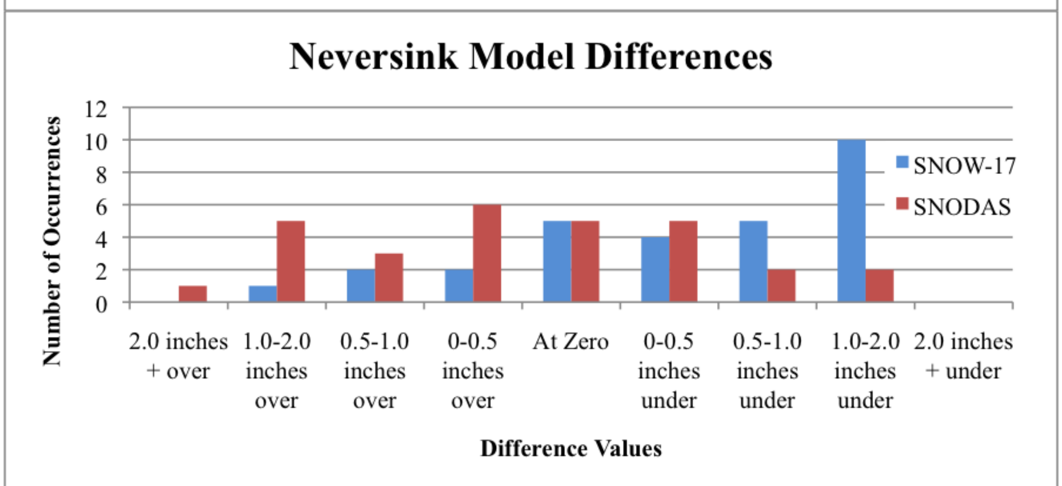

Rondout
-3.00
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

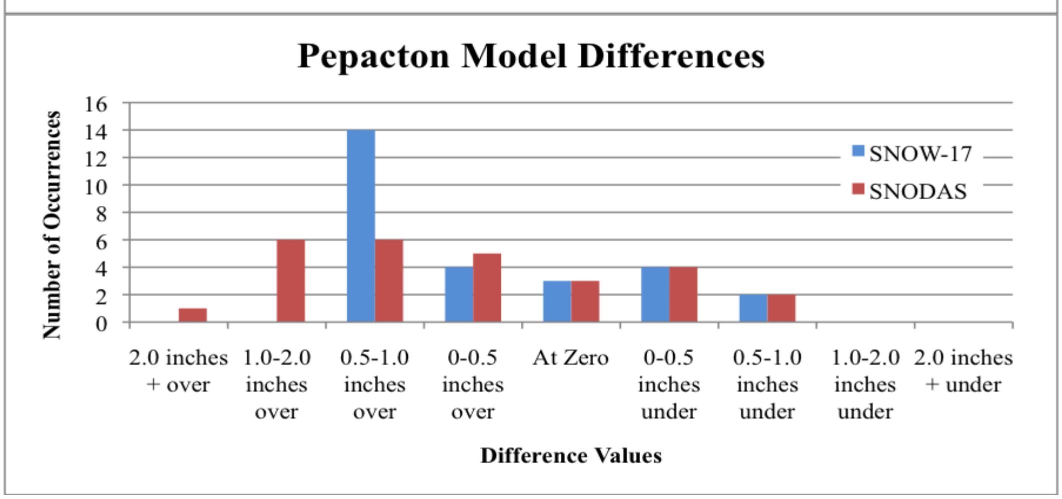

Schoharie
-3.00
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
Difference
12/22/07
1/5/08
1/19/08
2/2/08
2/16/08
3/1/08
3/15/08
3/29/08
4/12/08
Date
SNOW-17
SNODAS

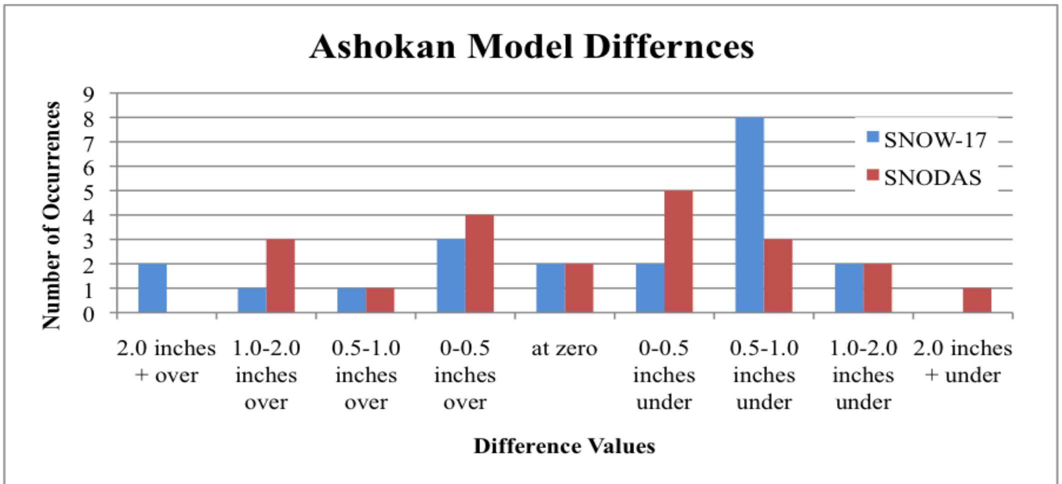
Appendix V

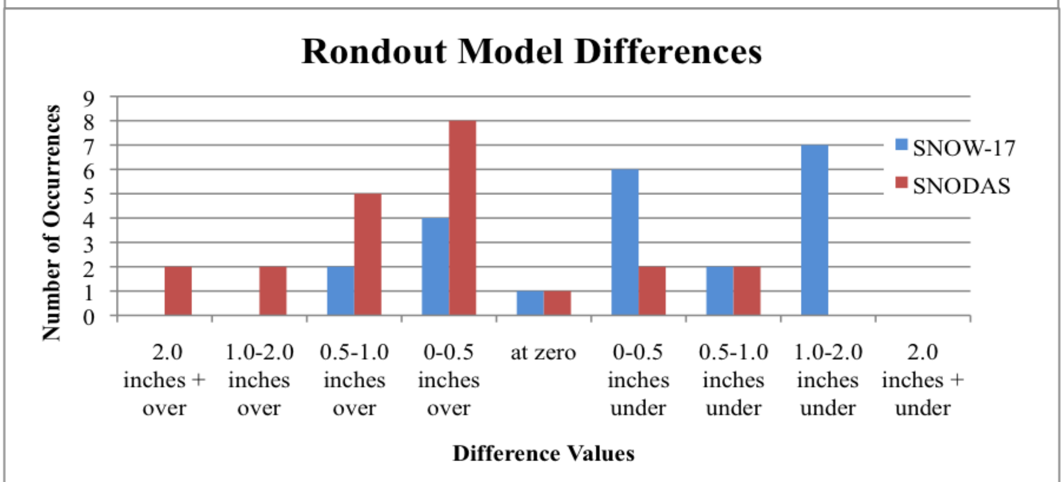
Summary of Over and Under- estimations of models in each reservoir watershed

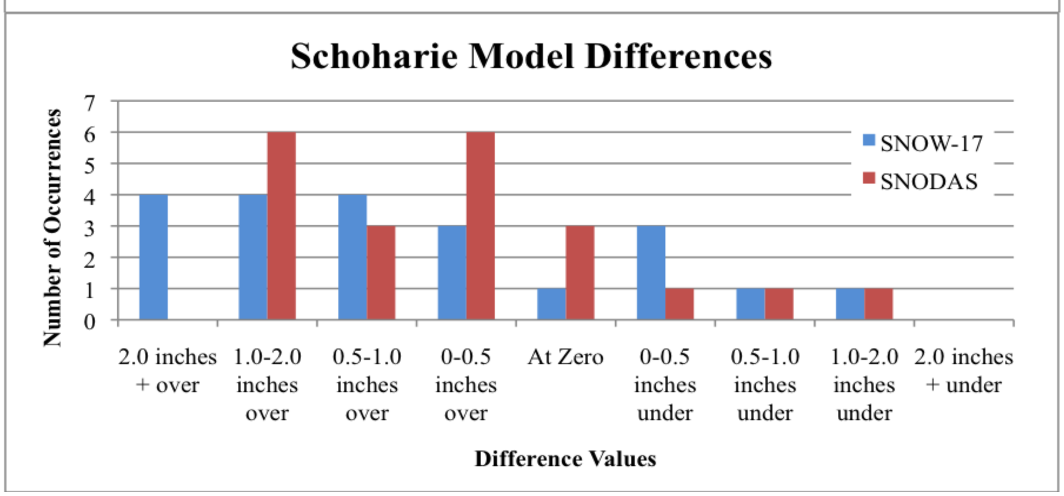


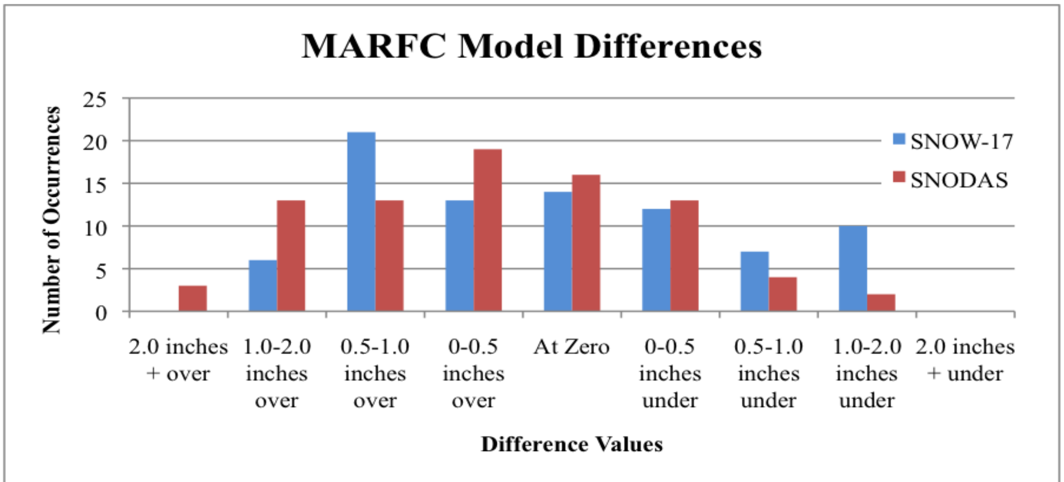


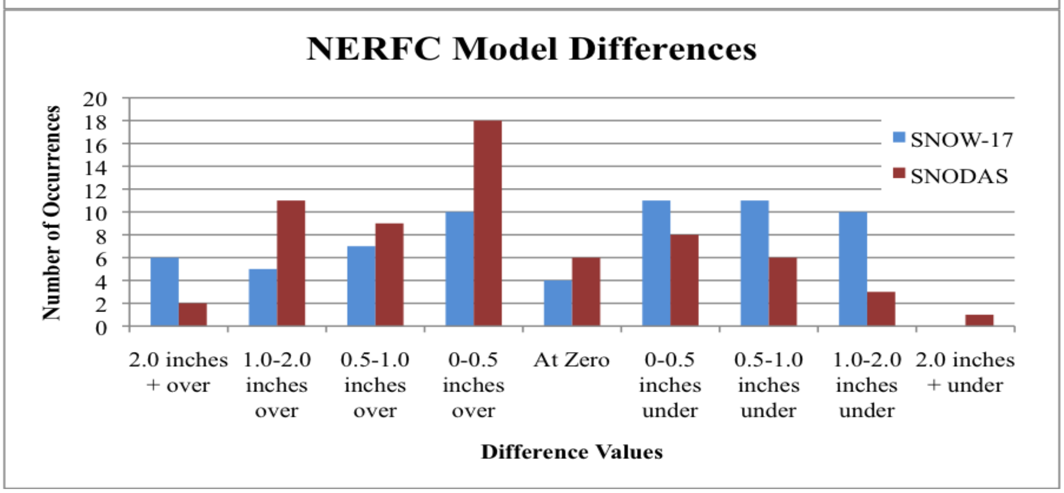



Ashokan Model Differnces
Number of Occurrences
0
1
2
3
4
5
6
7
8
9
SNOW-17
SNODAS
2.0 inches + over
1.0-2.0 inches over
0.5-1.0 inches over
0-0.5 inches over
at zero
0-0.5 inches under
0.5-1.0 inches under
1.0-2.0 inches under
2.0 inches + under
Difference Values


Rondout Model Differences
Number of Occurrences
0
1
2
3
4
5
6
7
8
9
SNOW-17
SNODAS
2.0 inches + over
1.0-2.0 inches over
0.5-1.0 inches over
0-0.5 inches over
at zero
0-0.5 inches under
0.5-1.0 inches under
1.0-2.0 inches under
2.0 inches + under
Difference Values


Schoharie Model Differences
Number of Occurrences
0
1
2
3
4
5
6
7
SNOW-17
SNODAS
2.0 inches + over
1.0-2.0 inches over
0.5-1.0 inches over
0-0.5 inches over
At Zero
0-0.5 inches under
0.5-1.0 inches under
1.0-2.0 inches under
2.0 inches + under
Difference Values


MARFC Model Differences
Number of Occurrences
25
20
15
10
5
0
SNOW-17
SNODAS
2.0 inches + over
1.0-2.0 inches over
0.5-1.0 inches over
0-0.5 inches over
At Zero
0-0.5 inches under
0.5-1.0 inches under
1.0-2.0 inches under
2.0 inches + under
Difference Values


NERFC Model Differences
Number of Occurrences
20
18
16
14
12
10
8
6
4
2
0
SNOW-17
SNODAS
2.0 inches + over
1.0-2.0 inches over
0.5-1.0 inches over
0-0.5 inches over
At Zero
0-0.5 inches under
0.5-1.0 inches under
1.0-2.0 inches under
2.0 inches + under
Difference Values