A Preliminary Evaluation Of The Effects Of The Spruce Peak Development In Relation To Surface Water Flow

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Abstract

The watershed of the West Branch of the Little River and eight unnamed tributaries is currently undergoing significant changes with regard to land-use and land-cover. The Mount Mansfield Company Inc. has began a massive expansion of its facilities. This development includes the construction of 403 residential dwellings, an 18-hole golf course, and several large commercial buildings, as well as expanded ski trails and snow making capabilities, all occurring on previously forested land.

The objective of this report is to create a pre-development history with regard to the surface hydrology of the Spruce Peak Basin. This history includes seasonal variation and precipitation patterns as they relate to discharge. This history will be used during post-development as a basis for comparison when determining the impact of the development on surface waters leaving the basin.

Discharge, precipitation, temperature, and the depth of the snow pack were the four variables used to identify seasonal variation and trends. Graphical analyses revealed three unique connections between the variables. The discharge record correlated with the precipitation record during the summer months. During the winter months, the precipitation record correlated with the building of the snow pack. This relationship was temperature dependant. The increased discharge in early spring correlated with the decreasing depth of the snow pack. This relationship was also temperature dependant.

Hypothesis

The development at Spruce Peak will alter (increase or decrease) the natural flow of surface waters discharged from the watershed. This alteration of surface flow within the watershed has the potential to interfere with natural processes downstream.

Introduction

The number of hydrologic problems recognized in the world increases daily, especially as areas experience increased development and changing land-use practices (Stone, 1999). The problem may be one of too little water: inadequate quantity or quality of surface water or ground water (Stone, 1999). Conversely, the problem may be one of too much water, as in controlling run-off or ground water inflow at a mine or construction site (Stone, 1999). This study is especially important for the Spruce Peak area because of its' location within a state forest. Developers, industry executives, and the growing population as a whole are moving into our countries national forests with little regard for the environmental impact such actions have associated with them. Whatever the intent of the developer or private citizen (natural resource harvesting, tourism destination, home construction) our national and state forests need to be protected. A large-scale development, such as the Spruce Peak ski resort village, within a pristine environment, such as the Mt. Mansfield State Forest, has the potential to inflict significant and permanent damage. This project focuses on one aspect of the range of potential damages that can be inflicted; that is the surface water flow dynamic.

The objective of this project is to determine the hydrologic history (pre-development) of the Spruce Peak watershed and to complete an evaluation of the proposed development plan. The identified seasonal variations and patterns with regard to the four variables used in this preliminary evaluation are intended to be used during post-development as a basis for comparison when determining how the development has affected the surface water flow within the watershed. Differences in seasonal variation and identified patterns in a secondary, post-development analysis, will reveal the impact the development has had on the Spruce Peak Basin. Analysis of the Spruce Peak watershed will include an assessment of the hydrologic history of surface water flow prior to development. This history will identify patterns of precipitation and their correlation with stream discharge. Snow pack and daily average temperature are also taken into consideration when making these correlations.

These correlations can be used to identify seasonal variations and trends over time. The deduction is made that any alteration in discharge trends, in a local stream (the West Branch of the Little River) identified during the secondary, post-development analysis, that differ from the trends identified in the pre-development analysis are related to the impact of the development on the Spruce Peak Basin.

ANALYSIS OF THE SPRUCE PEAK DEVELOPMENT PLAN

Long before there was skiing, Mt. Mansfield was a tourist destination. In the late 1800's, the Summit House atop Vermont's highest mountain drew such summer guests as the Rossevelts and the Vanderbilts (Spruce Peak, 2005). Over time The Mt. Mansfield area evolved into a thriving winter and summer time tourist destination. Prior to the proposed development, tourists spent their nights in the Town of Stowe, spending only part of the day in the sensitive alpine environment of Mt. Mansfield. Tourists would visit the alpine area of the ski resort during the day to participate in snow sport activities. After the development is complete, tourists will be spending all 24-hours of the day in this sensitive environment, both day and night, essentially doubling the amount of time for anthropogenic interference with regard to sensitive nature of this alpine environment. The introduction of t-bars, ski lifts, and gondolas attracted even more people to enjoy the pristine environment located on and around Mt. Mansfield, which increased the potential for anthropogenic alterations to this environment, such as increased litter and higher CO_2 emissions from motor vehicles. Currently a proposal, on behalf of the Mount Mansfield Company Inc., to construct a ski resort village within the sensitive environment of Mt. Mansfield and Spruce Peak has been approved. The village is to be located at the base of Spruce Peak, the smaller but still impressive mountain located next to Mt. Mansfield. The proposal includes, but is not limited to; homes, condos, retail shops, restaurants, more ski trails and lifts, and a 18-hole golf course. The development site is estimated to cover approximately 1,500 acres of previously forested land. The development has already begun.

The groundbreaking ceremony took place in 2003. The tentative completion date for the Spruce Peak Village is 2014. The Spruce Hamlet is the name given to the development. The following Tables and Figures in this section will outline the development plan as described in the Act 250 permitting process, as well as the proposed time-line and site plan. The Act 250 permit is a requirement (among other permits needed) for the lawful completion of this development on the behalf of the Mount Mansfield Company Inc. These records are available to the public and were obtained through the Stowe Zoning Board.

The proposed development is extensive. Not only will more buildings be added to the area, old structures will be upgraded, and expanded such as the AIG Dorm expansion and the renovation of the Big and Little Spruce chair lifts. 1,500 acres will be clear-cut in order to make room for this project.

The West Branch of the Little River and several of its un-named tributaries will potentially be affected by this development. Figure 2 is the developer's site map. The red line in Figure 2 highlights the West Branch of the Little River. Several of the buildings and the golf course will be in close proximity the river. The change in land cover from forest to pavement or building foundation may alter (increase) the amount of run-off entering the West Branch at these locations. Specifically, areas previously (pre-development) available for groundwater recharge will become impermeable. Conversely, the construction of sewers and drainage channels, may again alter (decrease), the amount of water that would have entered the Little River via natural processes if the development was not present. Table 1 outlines the proposed development. Table 2 identifies the types and dimensions of buildings and other structures that will be constructed with in the watershed of the West Branch. Table 2 can be used in conjunction with Figure 2 to identify structures depicted on the site map. Table 3 shows a timeline of the construction. The construction will be completed in three phases. Phase one will consist of clearing the land of vegetation and large boulders. Phase two will prep the land for road and building foundation construction via grading. Phase three will be the physical construction of buildings. This information will be valuable when determining the impact of the development during the time of construction.

Figure 1. Artist Rendition of Spruce Peak Village

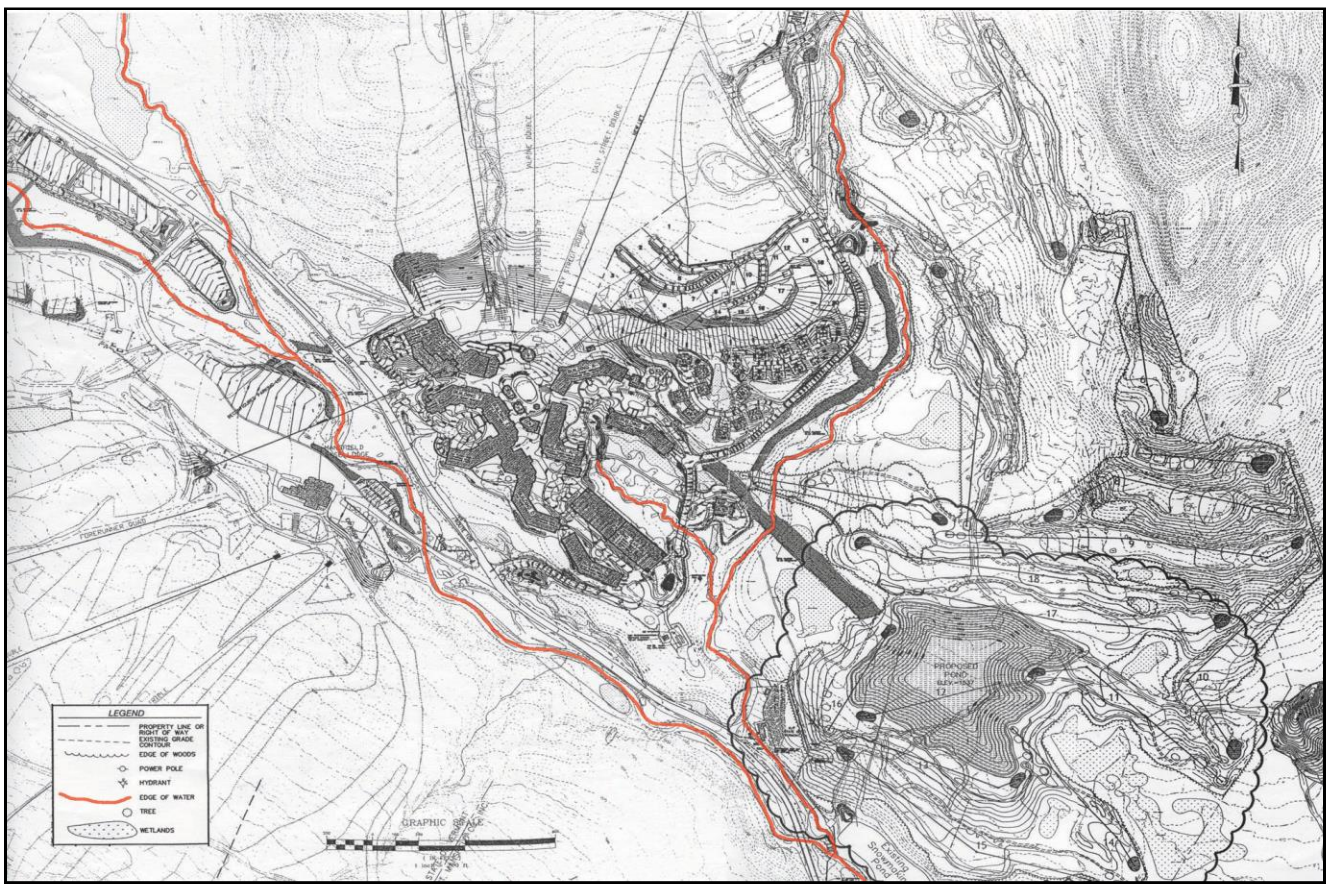
(Spruce Peak, 2005)

Table 1. The Spruce Hamlet (Proposed Development)

a. 371 residential units (403 minus the 12 mountain cabin units approved by DRB 8-5-03 and the 20 single family lots previously approved) The units will be located in 7 buildings in the hamlet core as well as the remaining 26 mountain cabin units.
b. Commercial buildings including the Preview Center
c. A Parking Garage
d. Spa, Performing Arts Center (not separate buildings), and a community pool
e. The Spruce Base Lodge
f. Utility farm and telecommunications buildings
g. An 18-hole golf course, club house and maintenance facility
h. Expanded snowmaking pump house
i. The Tom Lot snowmaking reservoir (Golf Course Reservoir)
j. Six ski lifts (Big Spruce replacement, Mid Spruce, Ski School Beginner, Easy Street, Little Spruce replacement, and the Spruce-Mansfield Transfer)
k. Three Parking lots at the base of Mt. Mansfield
l. Two new Spruce ski trails
m. Two Mountain maintenance facilities
n. Expanded employee housing at the AIG Dorm

(Act 250, 2003)

Figure 2. Spruce Peak Development Site Map



NOTE: Red line indicates the West Branch of the Little River.

(Act 250, 2003)

Table 2. Residential Buildings (Condos, Hotel, Town Houses, and Mt. Cabins) Dimensions, sq. footage, and unit designation.

Building or Equipment Name	Unit Type	Dimensions	Square footage
Hotel	Hotel	392’ - 0” L x 370’ - 0” W	-
Mt. Mansfield Club	-	392’ - 0” L x 370’ - 0” W	95,725
A-1	Condos	368’- 0” L x 142’ - 0” W	112, 672
A-2	Condos	320’- 0” L x 194’ - 0” W	116, 550
B	Condos	324’- 0” L x 126’ - 0” W	107, 840
C	Condos	332’ - 0” L x 163’ - 0” W	93, 593
D	Condos	558’ - 0” L x 156’ - 0” W	165,864
Mt. Cabins	Residence	-	-
Hill Side Town Homes A&B	Residence	50’ - 0” L x 45’ - 0” W	90,626
Hill Side Town Homes C & D	Residence	50’ - 0” L x 45’ - 0” W	90,626
Employee Housing (AIG Dorm)	Dorm	-	7,300

Note: Hotel and Mt. Mansfield Club are located in the same building

(Act 250, 2003)

Table 3. Development Construction Time-line

Start And Completion Dates(Year)	Construction Type (Road, Building, etc.)	Project / Construction / Development Summary
2003 / 2004	Road	Big Spruce access road
2003 / 2004	Road	Main Entrance to Big Spruce access road intersection
2003 / 2004	Road	Single family lot roadways
2003 / 2004	Lot	Single family lots
2003 / 2004	Pedestrian walk way	Pedestrian access corridor from parking garage area to Spruce Day Lodge
2003 / 2004	Grading	Surface preparation of parking garage site for temporary parking
2003 / 2006	Municipalities	Primary water, sewer and storm water lines
2003 / 2006	Utilities	Primary gas, electric, communication lines
2003 / 2005	Snowmaking	Install Spruce feed replacement snowmaking lines
2003 / 2005	Ski trail / snowmaking	Beginner ski trail and snowmaking equipment
2003 / 2007	Building	Construction of townhouses
2003 / 2005	Pond construction	Spruce Golf Course snowmaking pond
2003 / 2005	Site Work	Gravel extraction and open categorical disposal site
2003 / 2008	Golf course	Spruce Golf Course
2004 / 2005	Chair Lift	Replace Little Spruce lift
2004 / 2005	Snowmaking	Final connections and mechanical from existing snowmaking pond to golf course pond
2004/ 2014	Snowmaking	Install Spruce snowmaking
2004 / 2005	Snowmaking	Install new weir, intake and replace pond liner
2004 / 2005	Snowmaking	Install primary pumping expansion Phase1
2004 / 2005	Chair lift	Install beginner trail lift
2004 / 2008	Building	Hotel, Mansfield Club, and Spa
2004 / 2008	Building	Spruce Base Lodge
2004 / 2008	Building	Building A-1
2004 / 2005	Building	Mansfield maintenance facility

2004 / 2008	Landscaping	Stowe Club and Hamlet green / skating area

Table 3. Development Construction Time-line (Continued)

Start and Completion Dates(year)	Construction Type (road, Building, etc.)	Project / Construction/ Development Summary
2004 / 2005	Road	Roadway to building A-1, B & A-2 from Big Spruce access road
2004 / 2008	Building	AIG Dorm expansion
2004 / 2006	Chair lift	Big Spruce Lift replacement
2005 / 2008	Snowmaking	Install final mechanicals for primary pumping station expansion
2005 / 2008	Snowmaking	Construct Spruce maintenance facility & phase 1 booster pump station
2007 / 2009	Snowmaking and trail construction	Big Spruce trails and snowmaking
2005 / 2008	Building	Building A-2
2006 / 2008	Chair lift	Transfer lift
2006 / 2008	Chair lift	Easy alpine lift
2005 / 2008	Building	Construct Golf Course maintenance facility
2006 / 2007	Snowmaking	Tom Lot snowmaking pond
2005 / 2011	Building	Retail buildings
2006 / 2008	Parking lot	New Mansfield parking lots (3)
2007 / 2011	Pool	Pool building and community pool area
2007	Parking lot	Pave unpaved section of Mansfield parking lot
2007 / 2010	Building	Building D
2007 / 2010	Building	Performing arts center
2006 / 2008	Building	Golf Club building
2009 / 2012	Building	Building B
2010 / 2014	Parking garage	Parking garage
2010 / 2014	Building	Building C
2014	Chair lift	Mid Spruce chair lift

(Act 250, 2003)

Defining The Study Area & Inventory Of Available Equipment

The study area was determined based on the location of the development in question. The Spruce Peak development located at the base of Spruce Peak, defined a general area of study. To better define this area, the stream networks around Spruce Peak were identified. Once the stream networks and the development were located, the appropriate watershed was delineated. The watershed, which included stream networks and the development site, defined the boundary of the study area. Once the preliminary study area had been defined, data collection stations (weather stations and stream discharge stations) within the study area were identified. With the knowledge of what type, and the locations of, data collection stations located within or in close proximity to the study area, a more accurate study area will be defined. The type of data provided by the collection stations also indicated what type of analyses were able to be conducted in relation to the hydrologic history of the study area.

METHODS FOR HAND DRAWN WATERSHED DELINEATION:

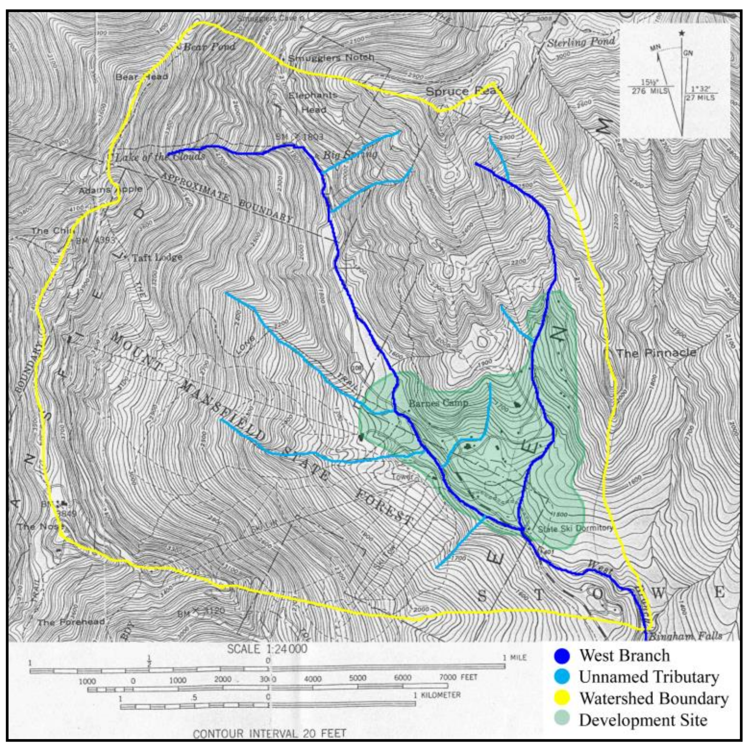
Using the United States Department Of The Interior Geological Survey, 7.5 minute series (topographical) map of the Mount Mansfield quadrangle, with a scale of 1:24,000, the development site and associated river network were located. After the general area was located on the map described above, the following steps were conducted, resulting in the creation of the watershed boundary, which defined the preliminary study area.

- Located the development site by rough estimate using development street address. Correlated this address with roads printed on the topographical map. Identified ski trails present on map aided in the estimation of the location of the development site.
- Using a blue colored pencil, all surface waters present on the map were traced.
- Identified a confluence (area of discharge for the basin of interest) that encompassed all significant stream networks.
- Delineated the watershed boundary using a yellow colored pencil.
    - Using the contour lines present on the topographic map, the area of discharge or stream network confluence was identified; this point was located on a stream leaving the basin (point of lowest elevation)
    - The peak of the basin (point of highest elevation) was also identified.
    - By following the ridgeline from the point of highest elevation to the point of lowest elevation, drawing the boundary perpendicular to the contour lines, the watershed boundary was defined.
        - NOTE: All Streams located in the stream network associated with the identified point of discharge for the basin did not cross the watershed boundary.
        - All streams that were not contained within the watershed boundary were erased to identify the stream network of interest.

ANALYSIS OF PRELIMINARY WATERSHED:

Figure 3 shows the preliminary delineation of the watershed (hand drawn method) which encompasses the West Branch of the Little River and eight unnamed tributaries. The point of discharge or confluence used in the preliminary watershed delineation was Bingham Falls. The development site was also located within the watershed boundary. An investigation regarding the data collection sites available within the study area was conducted. A stream gauge was present on the West Branch of the Little River, located approximately a ¼ mile up stream of Bingham Falls. After all of the available data collection sites (stream gauge stations, and meteorological stations) were located, the Arc G.I.S. program was used to replicate an exact

Figure 3. West Branch Watershed (Hand drawn method)



representation of the study area, which included the locations of all relevant equipment.

EQUIPMENT USED FOR DATA COLLECTION:

The preliminary delineation of the study area allowed for an investigation in relation to the data collection sites in the area. The USGS, NOAA(NWS), and VMC websites provided information relating to the number, location, and type of data collected by stations operated by each organization respectively. This investigation revealed two weather stations located within the preliminary watershed, a third in close proximity, and a fourth approximately ten miles southwest of the study area, as well as a stream discharge gauge station. The information provided by the four weather stations consisted of hourly temperature and precipitation data. The Mount Mansfield Summit station also provided a snow depth measurement. The stream gauge station located on the West Branch of the Little River provided the daily average discharge for the Spruce Peak Basin in cubic feet per second (cfs). This station was located just above Bingham Falls, relatively close to the point of discharge used in the preliminary delineation of the watershed, thus, when the watershed was re-delineated using the gauge station on the West Branch of the Little River as the area of discharge for the Spruce Peak Basin, the overall shape and size of the watershed was not significantly altered. Table 4 contains information relating to all of the collection sites used for data collection.

Table 4. Data Collection Site Information

Station	Per of Record Used	Data Type & Associated Units	UTM Coordinates	Source Information
(West Branch) Little River	10/1/200 to 9/30/04	Stream discharge (cfs)	Long. 72°46′31 W Lat. 44°31′29 N Elv. 1400 ft (426.7m)	U.S.G.S. web site (Download)
Mt. Mansfield Summit	1954 to present	Daily Temp (F°) Daily Precip (snow, inches) Snow Pack (inches)	Long. 72°37′ W Lat. 44°32′ N Elv. 3950 ft (1204m)	VT. Monitoring Co-op Judy Rosovsky Personal (CD-R)
Mt. Mansfield East	1/1/2001 to 8/2/2005	Hourly Temp (F°) Hourly Precip (rain, inches)	Long. 72°797′ W Lat. 44° 518′ N Elv. 2900 ft (884m)	VT. Monitoring Co-op Judy Rosovsky Personal (CD-R)
Mt. Mansfield West	1/1/2000 to 12/31/2005	Hourly Temp (F°) Hourly Precip (rain, inches)	Long. 72° 826′ W Lat. 44° 523′ N Elv. 2900 ft (884m)	VT. Monitoring Co-op Judy Rosovsky Personal (CD-R)
Morrisville-Stowe State Airport (PROXY)	1/1/2000 to 12/31/2005	Hourly Temp (F°) Hourly Precip (rain, inches)	Long. 44°32′ W Lat. 72°37′ N Elv. 731.9 ft (223.1m)	National Weather Service (NWS) Tania Bacchus Personal (CD-R)

G.I.S. WATERSHED DELINEATION:

Using the gauge station located on the West Branch of the Little River as the point of discharge for the Spruce Peak Basin, an accurate map of the watershed was generated using the Arc G.I.S. program. As a result of moving the point of discharge to the location of the gauge station when re-delineating the watershed, only the area monitored by the station was considered part of the watershed. After this map was generated, the exact location of all weather stations was identified using the UTM coordinates provided in Table 4. The overall result of this process was an accurate map of the study area and all associated locations of data collection sites.

METHODS FOR G.I.S WATERSHED DELINEATION:

The Arc G.I.S. program used computer-generated imagery as input layers. These layers were available through the Vermont Center for Geographic Information (vcgi). These input layers were available for a variety of different data types. With regard to this project, the following was needed to complete the watershed delineation: digital elevation model (DEM), stream networks, and a UTM grid. By overlaying these layers, a computer-generated version of a topographic map was compiled. Once this computer-generated version of a topographic map was generated, all of the required information for the watershed delineation was in place.

The input data for each of the layers covers the entire state of Vermont and in some cases parts of New Hampshire and New York. To limit these layers to the study area, a shape file was generated. This shape file was its own layer and was used to clip all other layers to its specific shape and size, which only contained the study area. Now that all of the desired layers needed to complete the watershed delineation had been restricted to the general study area, the watershed delineation began. The following steps were conducted to delineate the watershed of interest.

- The special analyst and hydrology toolbar were turn on.
- From the hydrology toolbar *flow direction* was selected using the *DEM* as the input layer, the output layer was f*low direction 1.*
- *Identify sinks* was then selected using *flow direction 1* as the input layer, the output layer was *identified sinks 1.*
- The *fill sinks* tool was then selected using the *DEM* as the input layer, the output layer was *filled sinks 1.*
- A new *flow direction* was generated using *filled sinks 1* as the input layer, the output layer was *flow direction 2.*
- Using *flow direction 2* as the input layer, a *flow accumulation* grid was created using the hydrology toolbar.
- Using the *watershed tool* on the hydrology toolbar, *flow direction 2* and the *flow accumulation grid* were the selected layers used to delineate the watershed.
- The watershed has now been delineated.

Now an accurate depiction of the watershed for the Spruce Peak Basin has been generated, using the stream gauge station as the point of discharge for the Spruce Peak Basin, the UTM grid can be used to locate the sites of the weather stations and development based on their UTM coordinates.

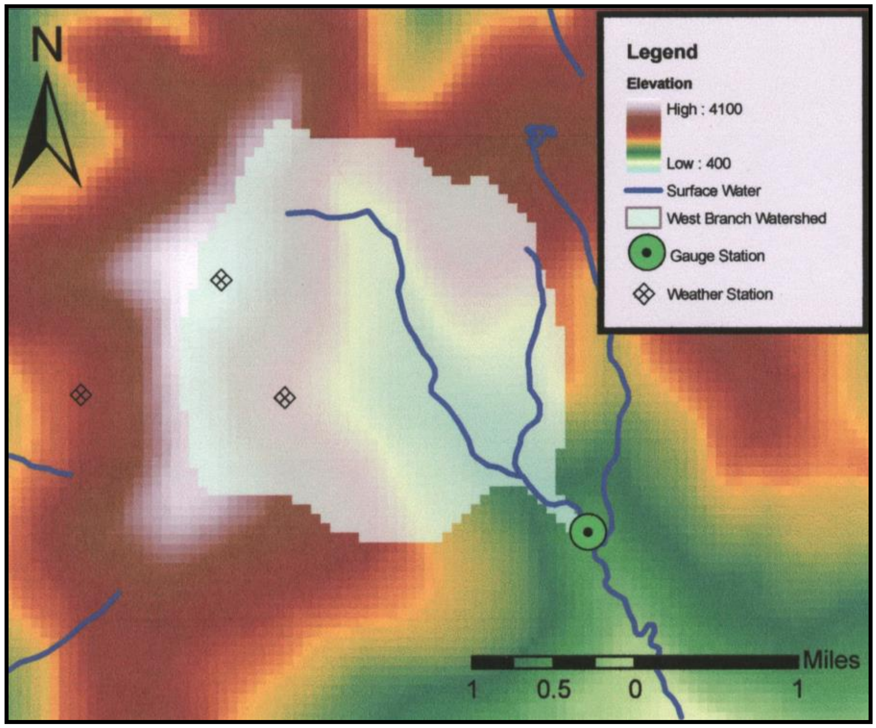
- Two more shape files were created, one for the gauge station and another for weather stations.
- Each of these layers were edited by using the *create new feature* option on the editor toolbar, the new features created were the locations of the data collection sites.
- The final step was to make the watershed layer %50 transparent so the topography could still be seen below.

- A Legend, North Arrow, and Scale Bar were then generated and placed within the body of the map.

ANALYSIS OF G.I.S GENERATED WATERSHED:

The Arc GIS program provides Meta Data relating to the images generated by the different layers. The most significant information generated by the Meta Data of this graphic was the area of the watershed, which was 4.68 square miles. This information will be useful later in the report. Form this more accurate depiction of the watershed; the data collection sites were accurately located. The development was also contained within the watershed boundary. Figure 4 is the graphic that was generated. This graphic represents elevation on a color scale, the locations of the West branch and other surface waters within the outlying area, the location of weather stations, the location of the gauge station, and most importantly the area covered by the watershed.

Figure 4. GIS Generated Watershed Delineation



Evaluation Of Data

In order to evaluate the quality of the data, a master data sheet was created. This master data sheet contained all of the relevant information necessary to complete the hydrologic history of the pre-development era of the Spruce Peak Basin encompassing a time frame from the start of 2000 through the end of 2005. The master data sheet was generated in Excel. The overall format of the master data sheet can be seen in Table 5. All data sets were in Excel or tab-separated format, enabling them to be complied in one data sheet; however, the data was recorded in different time intervals (ie: Daily or hourly averages) with respect to the different stations.

Table 5. Master Data Sheet Headings

Station	MM Summit	MM Summit	MM Summit	MM East	MM East	MM West	MM West	MV/ST Airport (PROXY)	MV/ST Airport (PROXY)	Little River Discharge

Date	Daily Precip (inches)	Daily Avg. Temp (F°)	Snow Depth (inches)	Daily Precip (inches)	Daily Avg. Temp (F°)	Daily Precip (inches)	Daily Avg. Temp (F°)	Daily Precip (inches)	Daily Avg. Temp (F°)	Daily Avg. Discharge (cfs)

DISCHARGE DATA:

The discharge from the West Branch of the Little River was recorded in the form of daily average discharge, with the units cfs. This data was available on the United States Geological Survey (USGS) website and was downloaded from the Internet in tab-separated format. The tab-separated format enabled this data to be input into an Excel spreadsheet. The data was of high quality and had few occurrences of missing data. Because the main goal of this project relates to surface water flow and the discharge data was in daily averages, all other data was formatted to correlate with the time interval of daily averages.

MOUNT MANSFIELD EAST AND WEST DATA:

The Mount Mansfield East (MME) and West (MMW) weather stations are maintained and operated by the Vermont Monitoring Cooperative (VMC). This data was available through request in Excel format via a CD-R. The records consisted of hourly temperature and precipitation data. The units associated with temperature were degrees Fahrenheit and the units associated with precipitation were inches of liquid water. With regard to precipitation, these stations were only equipped with rain gauges. As a result, large holes in the precipitation record were present during the winter months. Because the time interval of record was hourly, the data had to be calculated into daily averages / totals. The daily average temperature for any given day was achieved by summing all of the temperature readings for each hour of a single day and dividing by the number of hours recorded (24). The daily amount of precipitation was achieved by summing the hourly amounts of precipitation for each day. The adjusted data was then input into the master data sheet for their respective dates.

MOUNT MANSFIELD SUMMIT DATA:

The Mount Mansfield Summit (MMS) station is also maintained and operated by VMC. The data for this station was again available by request in Excel format via CD-R. The Summit station records temperature and precipitation in the same units as MMW and MME. MMS also records the depth of the snow pack, recorded in inches. The time interval for the Summit data was in daily average format for temperature, precipitation, and snow pack. With regard to precipitation, the MMS station was equipped with a snow gauge; however, the snow gauge raised two problems with the data. First, the snow gauge records inches of snow, which did not accurately reflect the water equivalent of the precipitation event. To convert the amount of snow captured by the gauge into the snow-water equivalent, the amount of snow captured by the gauge had to be divided by ten. The second problem raised by the use of a snow gauge was the period during which it could record precipitation events. Data collection for the MMS station was limited to the winter months, or only when precipitation fell in the form of snow. This created a large gap in the period of record during the summer months. After all necessary conversions were made, the MMS data was input into the master datasheet.

MORRISVILLE-STOWE STATE AIRPORT (PROXY STATION) DATA:

After reviewing the master datasheet once the discharge, MME, MMW, and MMS data was input, the overall dataset still contained holes. In order to fill these holes to generate a more complete period of record a proxy station was needed. The closest station to the study area was located at the Morrisville-Stowe State Airport. This station is operated by the National Weather Service (NWS). The data was available by request in Excel format via a CD-R. The data contained temperature and precipitation information in hourly increments. The units associated with temperature and precipitation were consistent with the units from all of the other stations used in the analysis. The same method used to convert the MME and MMW hourly data into daily averages and daily totals was performed on the Morrisville-Stowe data. As with the discharge, MMW, MME, and MMS, the Morrisville-Stowe data was input into the master data sheet.

MASTER DATASHEET:

With all of the desired information regarding temperature, precipitation, snow pack, and discharge input into the master datasheet, an analysis of the data was conducted. The data from the weather stations was limited to the length of the period of record of the discharge from the West Branch of the Little River. This period starts on October 1, 2001 and ends on September 30, 2004. The analysis revealed a corresponding temperature and precipitation data point from one or more of the four weather stations, which occurred on a concurrent date of the discharge record.

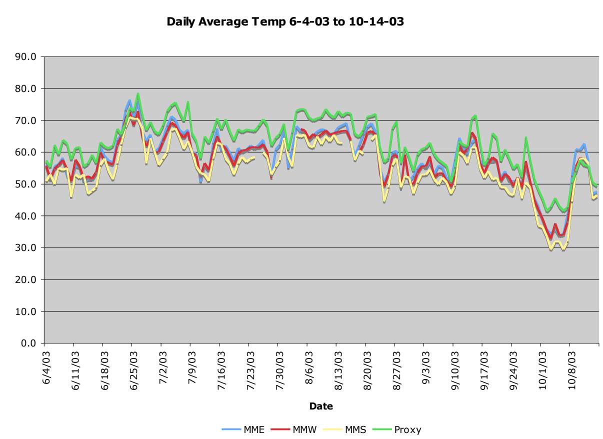
The desired data set consisted of one consistent record of precipitation and temperature that could correlate with discharge and snow pack. In order to obtain this consistent data set, pieces from each of the four weather station datasets were combined to form one dataset for temperature and one dataset for precipitation. These datasets relied mostly on MME data because the elevation of this station was the closest to the mean elevation of the watershed. When holes in the MME data were present, they were filled with data from MMW. Holes still persisted, they were filled with MMS data first. The Morrisville-Stowe (proxy) station filled all remaining holes. Justification for this method can be viewed graphically in Figure 5.

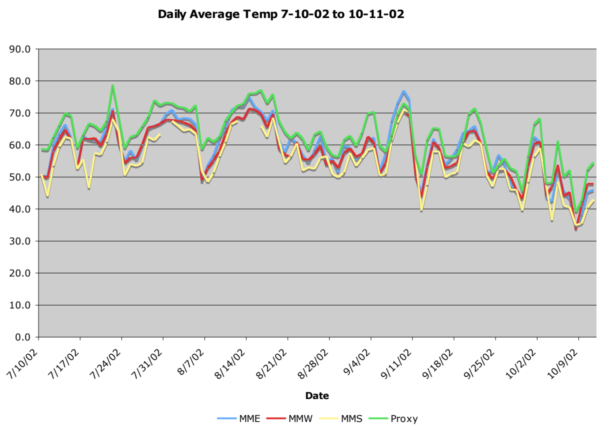
TEMPATURE ANALYSIS METHOD JUSTIFICATION:

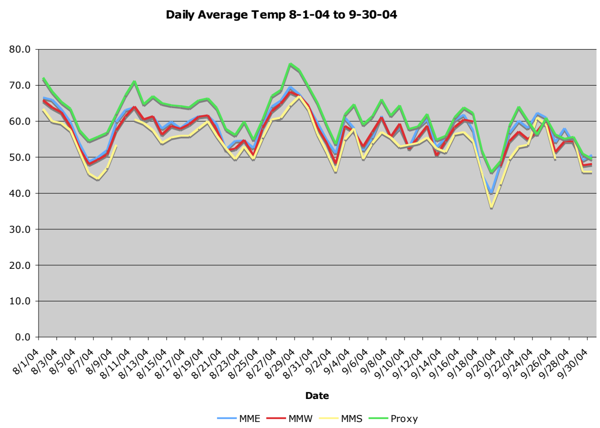
Concurrent dates that contain a period of record with regard to temperature from each of the four stations were graphed simultaneously (on one graph). Some of the dates present (the 2005 data) was not used in the overall precipitation analysis; however, the data was still valuable when justifying the method used. For all four graphs in Figure 5, temperature records were overlaid on one another to reveal if the same trends and/or patterns in fluctuation were present. The span of dates used was: 7-10-02 to 10-11-02, 6-4-03 to 10-14-03, 8-1-04 to 9-30-04, and 6-4-05 to 8-3-05. The graphical analysis revealed that indeed the same trends and/or patterns in temperature fluctuation were present; however, the range of actual temperatures varied slightly. This slight variation on the recorded temperatures can be attributed to elevation and ground cover. Temperature variation between MME and MMW, located at relatively similar elevation, did not show significant variation. The temperatures at the MMS station were consistently four to five degrees cooler on average than MME and MMW. The cooler temperatures at this station were consistent with higher elevations. Conversely the temperatures at the Morrisville-Stowe State Airport (proxy) station were consistently four to five degrees warmer on average than the record temperatures at the MME and MMW stations. The warmer temperatures at this station were consistent with lower elevations. In addition to the difference in elevation, the Proxy station was surrounded by blacktop, a dark shade that reflects more infrared (heat) radiation from the Earth surface.

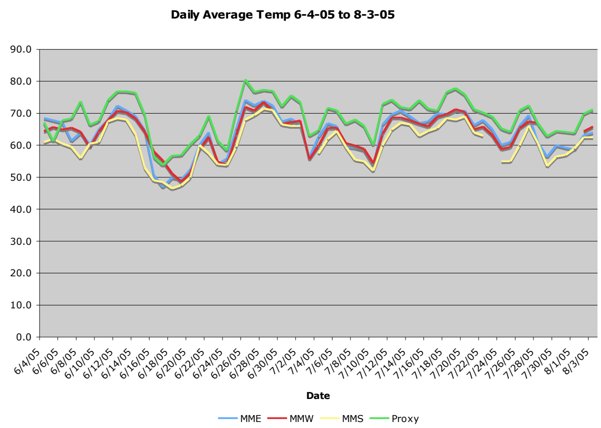
Overall the graphical analysis, with regard to temperature, indicated that the same trends and/or patterns were present on concurrent dates for all four stations. Despite the variance of ten degrees for any given day between the MMS and Proxy stations, the proposed method for the temperature analysis in connection to precipitation, snow pack and discharge identified no significant problems.

Figures 5. Daily Average Temperature For Corresponding dates from MME, MMW, MMS, and Proxy Stations





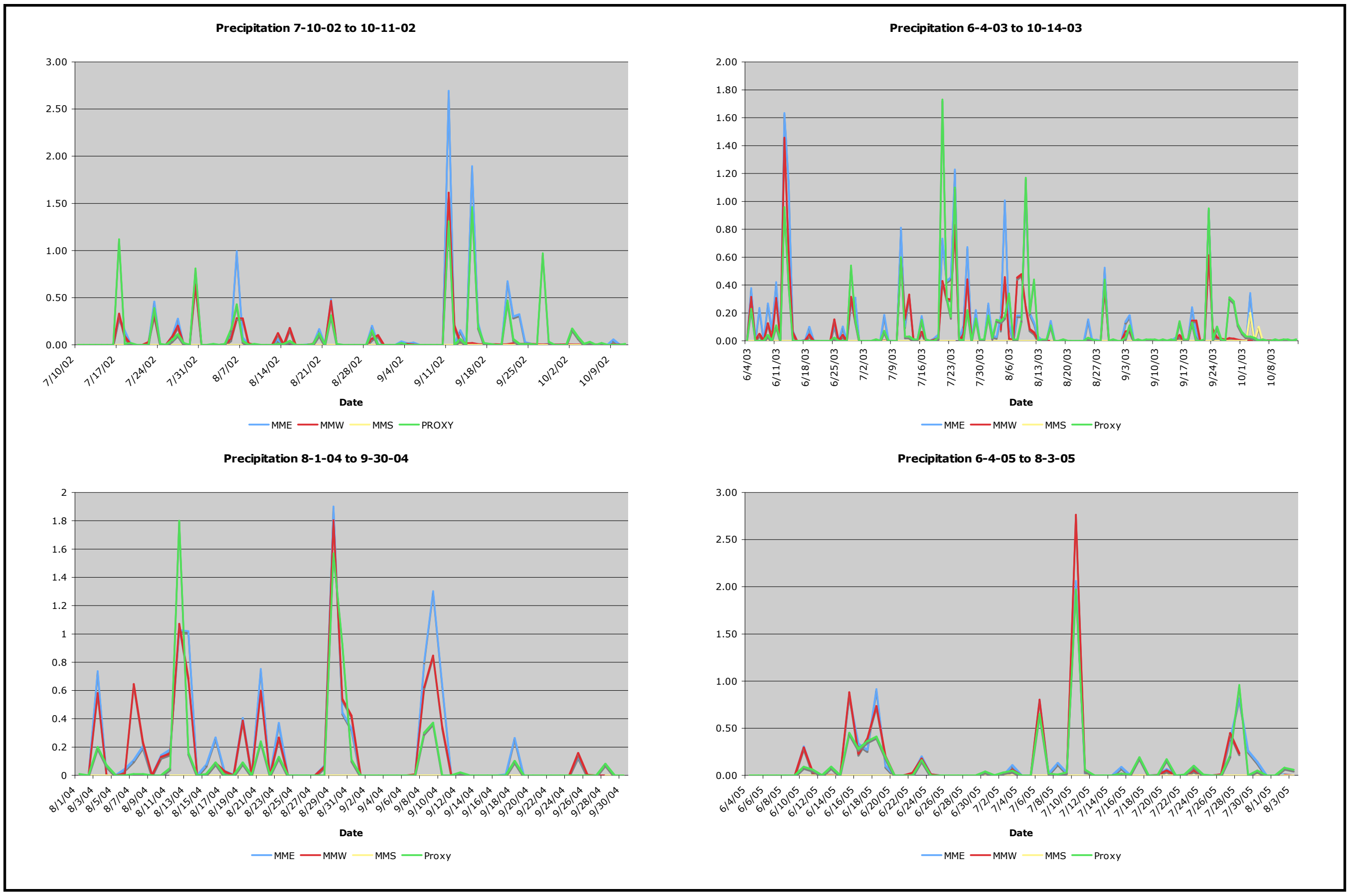




PRECIPITATION ANALYSIS METHOD JUSTIFICATION:

Precipitation events are local and variable (Ahrens, 2003). In addition, elevation and topography play a role in the amount and likelihood of a precipitation event occurring (Ahrens, 2003). The four weather stations used in the precipitation analysis were located in different locations and elevations. This resulted in different amounts and in some cases different types of precipitation occurring on concurrent dates. The equipment used to measure precipitation at the four stations varies respectively. The MME and MMW stations were equipped with rain gauges only. The MMS station was only equipped with a snow gauge, which did not record the snow-water equivalent of a precipitation event. In addition, there is no current scientifically sound method for converting snow amounts to their respective snow-water equivalents. The Morrisville-Stowe State Airport (proxy) station was equipped with a heated rain gauge. This allowed for the measurement of precipitation in liquid form year-round, generating the snow-water equivalent at the time of record if the precipitation event occurred as snow.

Figure 6. Daily Precipitation For Corresponding dates from MME, MMW, MMS, and Proxy Stations



Despite the nature of precipitation with respect to form, topography, and elevation; the method of creating one consistent record from pieces of data from each of the four stations was still justified. A graphical analysis for dates when all four stations recorded a precipitation event supports this method. The dates used are consistent with the dates used for the temperature analysis method justification. Figure 6 shows correlations of precipitation events for the four stations. Identifiable trends and/or patterns are clearly visible. A precipitation event occurring at one of the four stations registers at the other three, even though the specific amount varied slightly. Precipitation events do not show up on the MMS station because the concurrent dates when all for stations recorded an event occurred during the summer months, thus, none of the events noted consisted of precipitation in the form of snow. The nature of precipitation made the use of this method a bit more difficult; however, this method gave a broader spectrum of precipitation events with respect to the watershed.

<u>Hydrologic History Of The Study Area</u>

(Precipitation Analysis As It Relates To Discharge, Snow Pack, And Temperature)

This analysis will identify precipitation patterns and seasonal variations as they relate to the discharge record from the West Branch of the Little River. Correlations were made via graphical analyses. These analyses will be used as a basis for comparison when determining the impact of the development after all construction has been completed. The patterns and trends identified in this report will be compared to the results of a secondary analysis conducted after the completion of the development.

METHODS:

The 22,030 data points organized within the master data sheet were used to generate yearly and monthly graphs of precipitation, temperature, snow pack, and discharge. From the master data sheet approximately 200 graphs were generated. The record of discharge from the West Branch of the Little River was graphed in its entirety. Graphs were generated for precipitation, temperature and snow pack, only for the concurrent dates of the discharge record. The overall analyses covered the time period starting on October 1, 2000 and continue through September 30, 2004. The overall analysis was conducted over a 48-month, 4-year period. Graphs were generated individually with respect to each variable (temperature, precipitation, snow pack, and discharge). A preliminary analysis of the graphs for each of the variables was conducted prior to making any connections between one variable to another.

Precipitation events were the first to be correlated with the discharge record. This analysis was conducted taking into account the significance of a spike or absence of a spike in the discharge record as it related to the severity (amount) of the precipitation event. The precipitation analysis could only be used for precipitation falling in the form of rain. The reason for this limitation was because of the nature of the weather station's equipment in the study area. The weather stations (MME and MMW) used rain gauges only (with the exception of the proxy station which used a heated rain gauge and MMS which was equipped with only a snow gauge). This limitation of the data collection devices prevented correlations from being made if the precipitation event occurred in the form of snow, a result of the absence of a proven method for converting snow amounts to their respective snow-water equivalents. The correlations made between precipitation and discharges were expected to be limited to the late spring, summer and early fall seasons.

During the early spring, late fall and winter months, precipitation fell in the form of snow. Even though the method of dividing the snow amount measured by the MMS station snow gauge by 10 to obtain a rough snow-water equivalent of precipitation events, these events were not expected to be reflected in the discharge record, a result of temperatures being below freezing, thus, the precipitation was held on the surface with limited mobility taking until temperatures rise before the event was reflected in the discharge record. Instead of correlating precipitation events to discharge, they were correlated to snow pack.

When precipitation was correlated to the depth of the snow pack, temperature became a significant factor, especially when snowmelt was taken into consideration. A decline in the snow pack via higher daily average temperatures, affected the amount of water discharged from the basin, thus snow pack and temperature was correlated with the discharge record. Snow that was precipitated as late as November may not be reflected in the discharge record until the end of April of the following year because of the limited mobility of snow when temperatures are below freezing. The window or lag-time is much greater for snow than it is for rain.

NOTE: *All analyses conducted used graphs generated on a monthly time scale; however, in the interest of space within the manuscript, all figures regarding the variables for the analyses are presented in a yearly format.*

DISCHARGE:

Monthly graphs were generated for the graphical analysis. The analysis was broken into yearly sections. These yearly sections start at the beginning of November and end at the conclusion of October, a result of the limited time frame the gauge station was in operation. Low flow for the analysis was defined as the daily average discharge amounts not exceeding 25 cfs.

***November*:** November showed consistent low flow for all four years. The number of spikes in the discharge record numbered between 1 and 3. The intensity of these spikes ranged from 26 cfs in 2000 to 190 cfs in 2003. The majority of the increases in discharge above low flow, were not significant ranging from 26 cfs to 56 cfs.

December: December was another month where the discharge was considerably low. No significant spikes were present. The number of spikes ranged from 0 to 2. The range of discharge above the low flow amount was not significant for any of the recorded spikes.

January: January’s flow was considerably low. No spikes were present for any of the years of record analyzed.

February: February was another month that exhibited consistent low flow. One spike was present in the discharge record occurring in 2001. This spike was not significantly above the low flow margin. The event occurred in 2001 with a daily average discharge of 30 cfs.

March: Overall, the daily average discharge for March was low; however, a significant increase from the low flow margin to 150 cfs occurred at the end of the month in 2004. This increase stayed above the low flow margin throughout the end of the month. In addition to the 2004 event, another significant increase in discharge occurred mid month in 2003. This increase topped out at 125 cfs and gradually decreased through the remainder of the month until spiking again heading into April.

April: April exhibited a gradual increase in discharge throughout the month. For all four years of record analyzed, significant spikes were present in the middle of the month. These significant spikes ranged in size from 110 cfs in 2003 to 225 cfs in 2001. The amount of discharge recorded gradually declined towards the end of the month but still stayed above the low flow margin averaging between 50 cfs to 100 cfs.

May: May exhibited a large degree of variance in the daily average discharge record depending on the year. In 2001, the large spike occurring in April begins to decrease at the beginning of the month followed by a 225 cfs spike in discharge. By mid month the flow was back to below the low flow margin. With regard to 2002, 2003, and 2004, high flow rates, averaging between 50 cfs and 175 cfs, persisted throughout the month's entirety. Monthly correlations from different years are starting to show a higher degree of variance than the previous months.

June: June, like the previous two month has a sporadic daily average discharge record with regard to the year. Overall, there is one significant discharge event for each of the years analyzed. The event occurred early in the month for years 2001, 2002, and 2004. The event in 2001 peaked at 55 cfs while the event in 2002 peaked at 165 cfs. The 2004 event peaked at 85 cfs. The significant event in 2003 occurred during the middle of the month, peaking at 145 cfs. The overall trend for the month of June is one large discharge event usually occurring at the beginning of the month. Other than these spikes the average daily discharge remained around 25 cfs.

July: July exhibited sporadic discharges with regard to the year analyzed. Overall, the amount of water discharged hovers around the low flow margin for the years of 2001, 2002, and 2003. The record for 2004 indicated a significantly higher discharge average for the month, approximately twice the amount of the low flow threshold. 2004 also had a higher amount of spikes in the discharge, six, while the years of 2001, 2002, and 2003 only showed 1 to 2.

August: Overall, the daily average discharge for the month of August stayed below the low flow limit. 2001 and 2003 showed 1 small spike per month in the discharge record. The 2001 event occurred towards the end of the month. The 2003 event occurred in the beginning of the month. Discharge for 2002 stayed below the low flow limit. The record for 2004 indicated a significantly larger amount of discharge for the month. Two spiked were present on the record for 2004, both occurring above 75 cfs.

September: The discharge for the month of September was significantly higher than the previous month. 2001, 2002, and 2004 all had large discharge events ranging between 60 cfs and 160 cfs. The 2003 record stayed below the low flow limit.

October: The average daily discharge for the years 2000 and 2001 showed the discharge rate to be at, or just above the low flow limit. 2002 showed a spike in the discharge occurring mid month at 80 cfs. The 2003 record indicated several significant discharge events occurring consistently throughout the month ranging in severity from 55 cfs to 135 cfs.

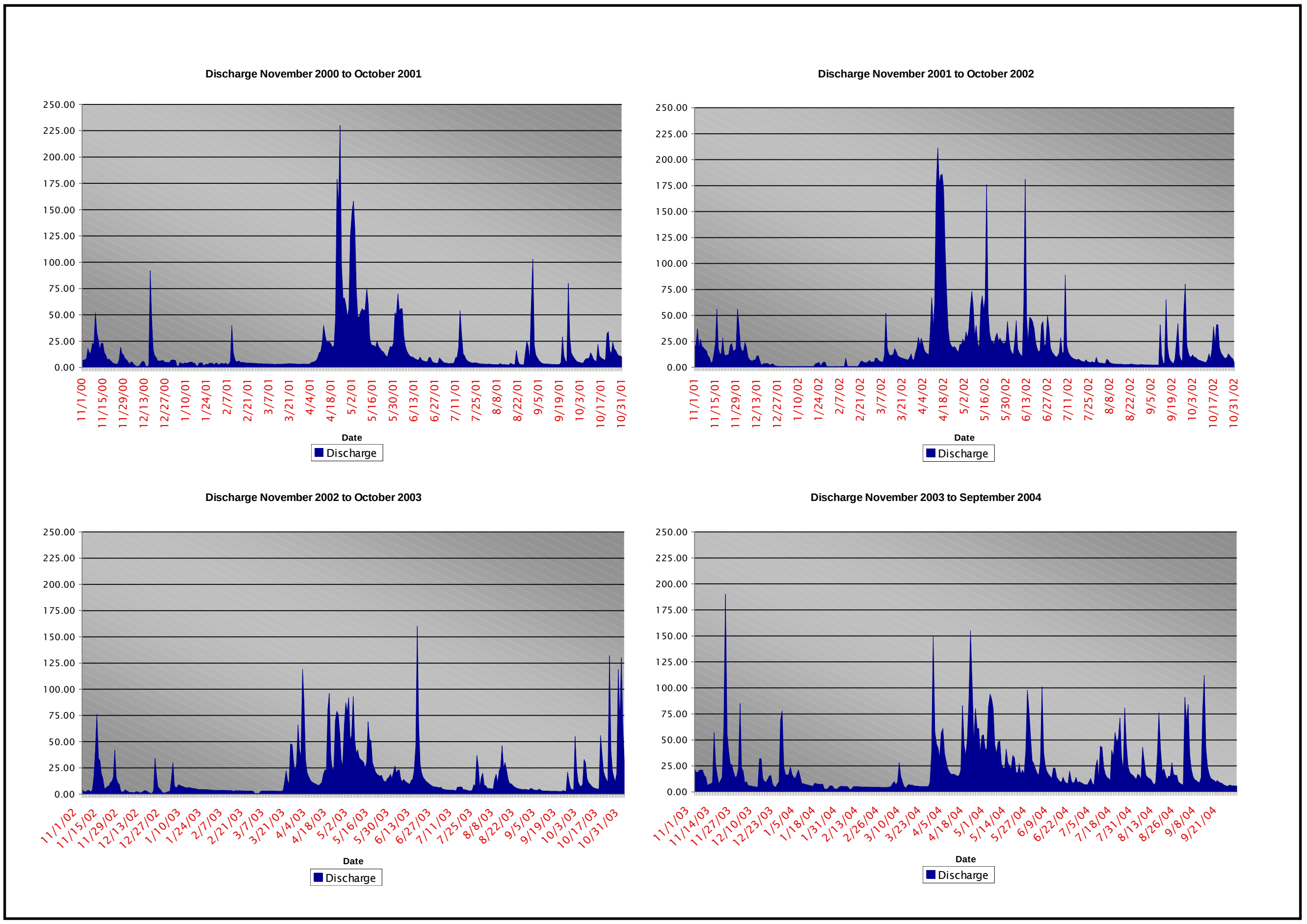
Evaluation: The graphical analysis of the monthly graphs revealed three distinct groups of discharge patterns. These patterns are best described as seasonal, dependant on the type of precipitation; snow or rain. The months that correlated from year to year were December through March. Based on the temperatures for this time of year in Vermont, the form of precipitation was most likely snow. For the months of December through March the daily average discharge was consistently below the low flow limit. Few spikes in discharge were present. When a spike was present during this time of year, the event was not significant, only rising just above the low flow limit of 25 cfs. The occurrence of a spike above this limit was not common for this time of year. These small spikes during this time period may be connected to a limited thaw. Further investigation as to the reason for these spikes is addressed in the following sections.

Each year of record examined revealed a significant spike occurring in the early spring. These spikes, while they varied in intensity were always present, starting as early as mid-March and sometimes occurring as late as mid-April. The spikes in discharge for this time frame were always significant; discharge rose from the low flow limit to ranging from 110 cfs to 225 cfs. These spikes are visible in Figure 7. This time of year, mid-March to mid-April was the time of year where the largest amounts of discharges were present for the years or record examined.

The daily average discharge for the months of May through November did not correlate with each other from year to year. Spikes in discharge were present and common for this time period; however, some years exhibited more or less spikes for concurrent months of different years. There is no identifiable pattern in discharge variance for this time period; discharge is best described as random. The significance of spikes relating to their intensity also varied greatly.

Overall, the analysis revealed low flow for the months of December through March. From mid-March to mid-April, significant increases in discharge were present. The months of May through November had no identifiable trends with regard to discharge. Figure 7 illustrates the conclusions described above; however, there may be some discrepancies in the noted identified trends. These discrepancies between the noted observations and the Figure 7 illustration are a result of the time scale being compressed for presentation purposes. Note that the observations were deducted from monthly graphs, which have a higher degree of clarity because of the uncompressed time span. The monthly graphs revealed a greater amount of detail than the yearly representations.

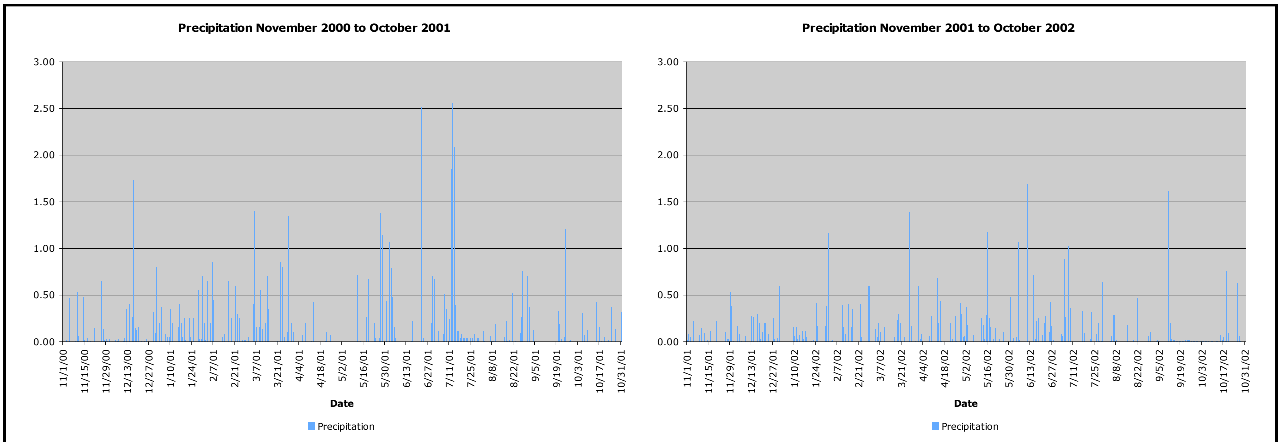
Figure 7. Discharge

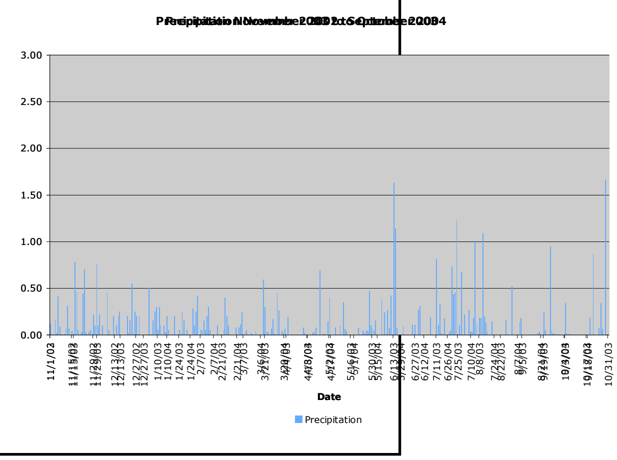


PRECIPITATION:

Precipitation within the study area varied with respect to the year in question. Precipitation for concurrent months of different years also varied. The overall amount of precipitation received within any particular year was highly dependant on the number and intensity of the storm systems that moved through the area. Factors such as the Jet Stream, tropical systems that have move up the east coast, and high and low pressure systems all influenced the size and number of storm systems that move through the area. Figure 8 illustrates the randomness of precipitation events.

Figure 8. Precipitation





With regard to the study area, June precipitation events occurred in a random pattern. Correlations between precipitation events of corresponding months of different years showed no identifiable pattern. This randomness of the occurrence of precipitation events and their varying intensities made it difficult to correlate the precipitation record to the other variables used in the study.

SNOW PACK:

The snow pack record began on January 1st 2001, thus, three months of data (October, November, and December of 2000) were not available for analysis at the beginning of the concurrent dates for the discharge record. Figure 9 illustrates the pattern of snow accumulation and snowmelt respectively. This data record also contained several holes in the period of record available. These holes ranged in length from one day to eleven days. The holes in the data record did not interfere with the overall analysis because the overall trends were still identifiable. The analyses for snow pack were conducted based on the years of the winter season.

2000/2001: The first three months for the 2000/2001 data record were not available, thus, the approximate time the snow pack began to build could not be identified. The data record started on January 1st 2001. The depth of the snow pack increased steadily peaking at the end of March at a depth of 132 inches. On the 1st of April the snow pack began to decline rapidly taking approximately one month to reach a depth of 0 inches.

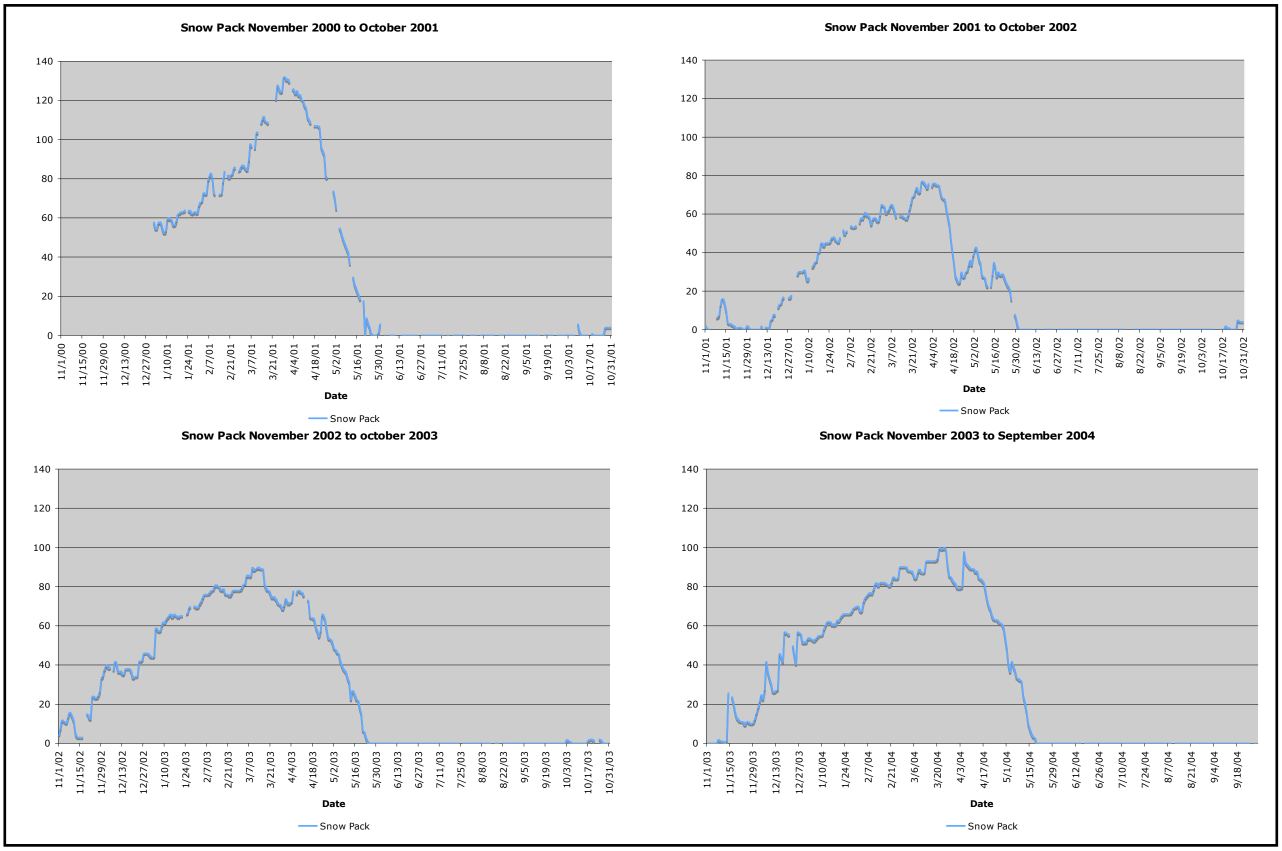
2001/2002: The snow pack for the 2001/2002 season began to build at the end of October. The snow pack reaches a depth of 16 inches and then declined back to 0. On January 1st the snow pack began to build and hold, climbing to a depth of 76 inches by the end of March. A slow decline to 24 inches was noted throughout the first half of April. Around mid-April the snow pack began to build again to a depth of 40 inches, declining to 22 inches by the beginning of May. Mid-May indicated another increase in the depth, bringing the total depth to 32 inches. After this final increase in the depth of the snow pack, a rapid decline to 0 inches occurred. The snow pack reached 0 by the end of May.

2002/2003: The snow pack for the 2002/2003 season began to build and hold at the end of October 2002. The depth continued to increase peaking at the end of March at a depth of 89 inches. A steady decline was present continuing until the end of May when the snow depth reached 0 inches. This decline was not rapid.

2003/2004: The snow pack for the 2003/2004 season began with a rapid increase in mid-November, rising to a depth of 26 inches. The snow depth declined to a depth of 9 inches by the end of the month, before continuing to rise steadily. The peak was reached towards the end of March, at a depth of 99 inches. A rapid decline was noted prior to the end of the month; this decline dropped the depth of the snow pack to a depth of 79 inches. The snow pack began to build again in the beginning of April, to a depth of 98 inches. After this increase a rapid decline was present. The snow pack reached a depth of 0 inches by mid-May.

Evaluation: The average time span for the snow pack to begin to build and hold its depth occurred in the months of November and December; however, the snow pack can begin to build as early as October or as late as January. The peak of the snow pack depth was reached in March. March was the time of greatest snow depth for all of the four years of record analyzed. The disappearance of the snow pack commonly occurred on, or by the end of May. A depth of 0 inches was reached as early as mid-May; however, this was not common. The rate of decline with regard to the snow depth varied from year to year. The maximum snow depth also varied from year to year; the maximum value occurring during the 2000/2001 season, the minimum occurring during the 2001/2002 season.

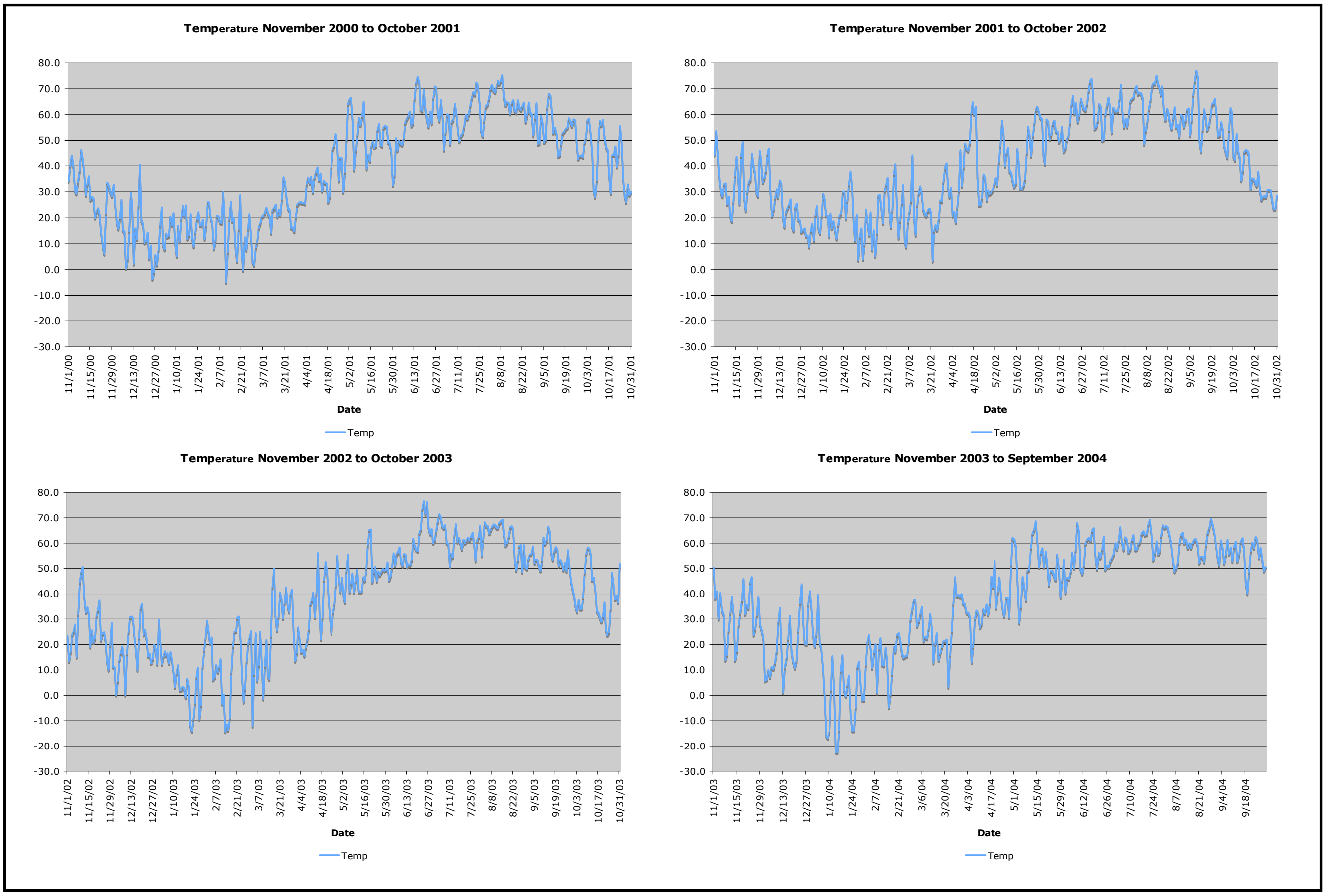
Figure 9. Snow Pack Depth



TEMPERATURE:

Temperature fluctuation within the study area was consistent with seasonal variation. Vermont is located in a temperate climate zone, experiencing a large variance in temperature with regard to the season. In 2005 the daily average temperatures ranged from -23 F° to 89 F° a range of 112 F°. The characteristics of this type of climate are consistent with the graphs generated. With regard to all four years of data analyzed, a general warming trend beginning during the month of February was identified. This trend continued until temperatures peaked around late July, early August. The onset and peak of this warming trend varied by a month, given the year being analyzed. A general decline in daily average temperature occurred after the peak in late July, early August. Daily average temperatures fluctuate, warming and cooling quite frequently in the short term; however, the overall trends were quite stable. A short lived increase in daily average temperature during the cooling trend previously discussed can be seen, lasting for approximately a week some time during January or February depending on the year. Daily average temperatures are represented in Figure 10.

Figure 10. Daily Average Temperature

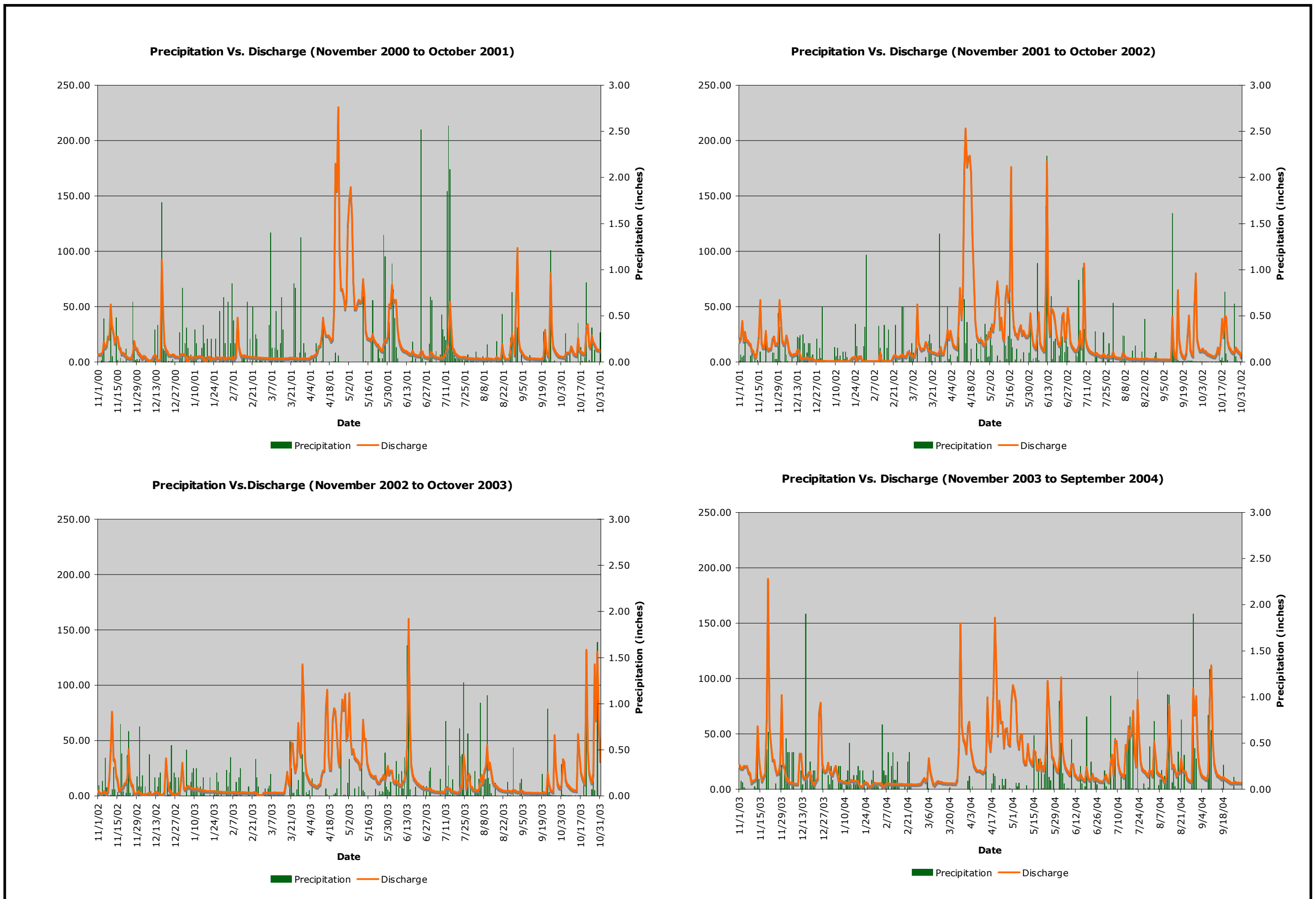


DISCHARGE AND PRECIPITATION CORRELATIONS:

Precipitation as it relates to discharge did not correlate consistently throughout the years of record analyzed. Vermont experiences a wide array of precipitation types. Depending on the type of precipitation, rain or snow, different lag times were present. During the winter months (October through February) the precipitation record did not correlate with the discharge record. This time period consisted of many precipitation events; however, there were no spikes in the discharge record to correlate the precipitation events to. This was due to the precipitation type, which was snow. Snow does not run-off like a rain event would; thus, it did not show up in the discharge record. To evaluate this discrepancy in the analysis of these two variables, precipitation during this time period was correlated with the snow pack record.

The precipitation and discharge records did not correlate with each other during the months of March through May either. During this time period significant increases in the discharge record were present when precipitation events were not. This discrepancy in the analyzed records was attributed to snow melt. To monitor this relationship, connections between the depth of the snow pack and discharge were investigated. Temperature was expected to be a significant controlling factor in this relationship.

Figure 11. Precipitation Vs. Discharge



As a result of precipitation falling in the form of snow, and large discrepancies in the correlating relationships between precipitation and discharge directly, the months of October through May were analyzed using the variables: temperature and snow pack, as they related to precipitation and discharge. This left the months of June through September from which to draw direct relationships between the variables of precipitation and discharge. Figure 11 depicts this relationship. With regard to the months of June through September, there was a direct relationship between these variables. When a precipitation event occurred there was also a spike in the discharge record. The extent of these two variables correlates as well in that, the greater the volume of the precipitation event the greater the volume of the discharge event. There were however, some discrepancies in the data during this time period; discharge events without precipitation events and vice versa. In addition, on occasion, such as June 23, 2001 the size of the precipitation event did not correlate with the size of the discharge event. These types of discrepancies in the data record as well as correlation discrepancies were identified and addressed in a separate section.

PRECIPITATION AND SNOW PACK CORRELATIONS:

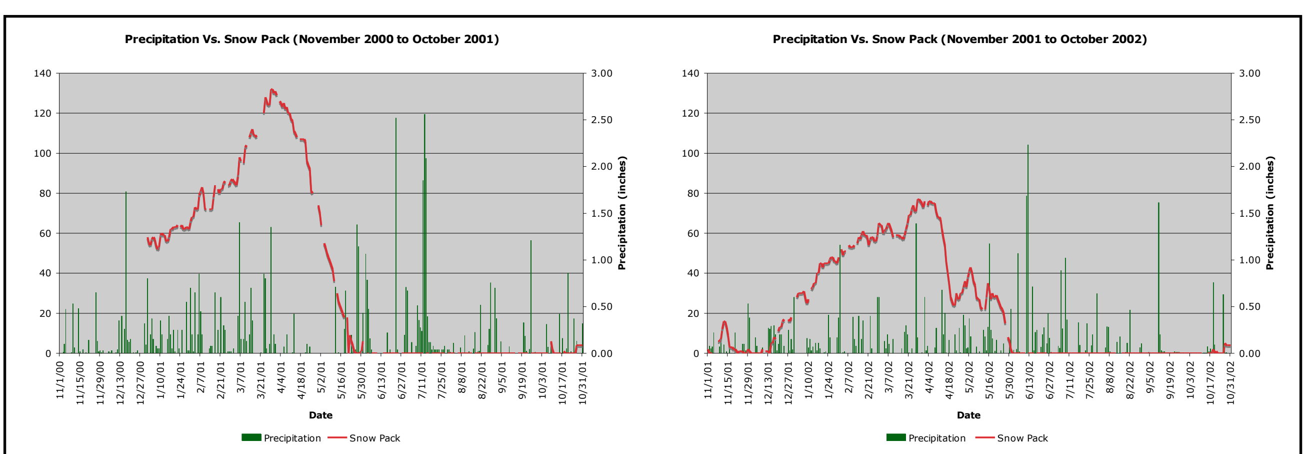
One of the discrepancies in correlating precipitation to discharge during the months of October though February was a result of the precipitation falling in the form of snow. Precipitation falling in the form of snow did not show up in the discharge record in as timely a manner as rain. To monitor the absence of this precipitation in the discharge record, correlations between precipitation and snow pack were conducted. The graphs depicting the number and amount of precipitation events as they related to the snow pack is depicted in figure 12.

This part of the hydrological history analysis covers the building of the snow pack, specifically the depth. As precipitation events occurred during the months of October through February, the depth of the snow pack increased overall. Declines in the snow pack were correlated to increases in the daily average temperature. The trend identified is simple; when a precipitation event occurred the depth of the snow pack increased. A direct relationship exists between these two variables. The greater the amount of precipitation falling during a specific event correlates to a greater increase in the depth of the snow pack. An example of this relationship appears in Figure 12. On September 15, 2003 a precipitation event producing 0.75 inches of water caused the depth of the snow pack to rise by 28 inches (a significant precipitation event correlates to a significant increase in the depth of the snow pack). In contrast, a precipitation event occurring on October 2, 2003 delivering 0.4 inches of water increased the depth of the snow pack by only 8 inches.

Temperature was a factor in the type of snow falling. Some precipitation events occurring in the form of snow can have the same snow-water equivalent but register a different increase in the depth of the snow pack. In other words, the snow-water equivalent is dependant on temperature. Precipitation events occurring over several days also had to be taken into account. Precipitation events occurring during the time of snowmelt were expected to be present in the discharge record; however, this deduction was also dependent upon temperature.

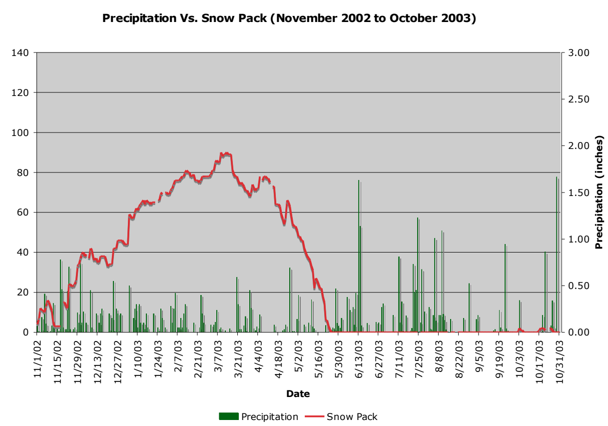
Overall, there was a correlation between precipitation and the increased depth of the snow pack. Larger precipitation events generated a larger increase in the depth of the snow pack. Smaller precipitation events produce smaller increases in the depth of the snow pack. Now that the form, extent and location of precipitation had been accounted for, correlations were made between snow pack and discharge. Temperature also had to be taken into consideration as a vital variable when making these connections.

Figure 12. Precipitation Vs. Snow Pack



SNOW PACK AND TEMPATURE CORRELATIONS:

Now that a relationship between precipitation and the depth of the snow pack had been revealed, the significance of the temperature variable was established. The time frame of analysis regarding how temperature correlated to the snow pack was limited to the duration of the presence of the snow pack. Temperature was an important factor in determining if the precipitation had fallen in the form of snow when the snow pack was building. When the depth of the snow pack was decreasing, temperature was again an important factor.



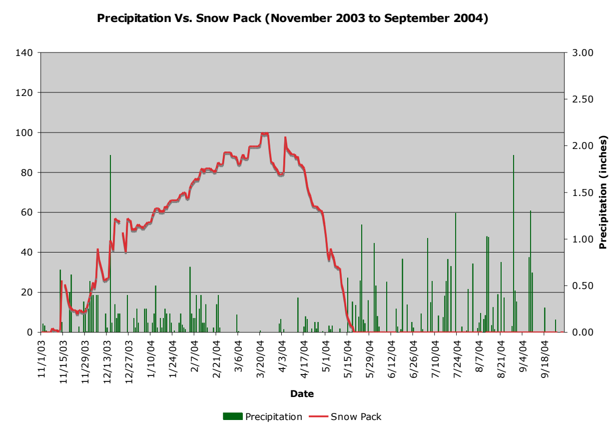
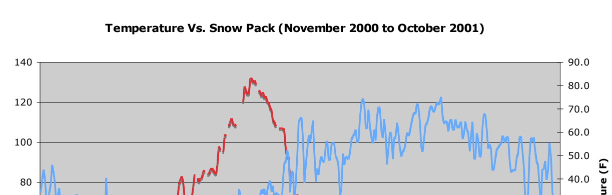


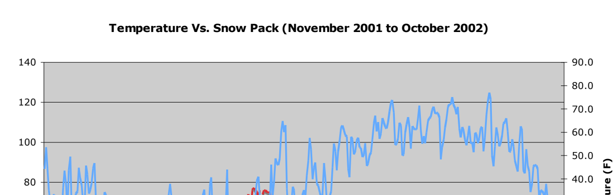
Figure 13 indicates the snow pack usually began to build during the month of October (as it did in 2002, 2003 and 2004). The snow pack was usually present until the end of May with regard to the four years of record analyzed.

With regard to the building of the snow pack, Figure 13 indicates the daily average temperature must be at or below freezing for the snow pack to build or hold its depth if no precipitation events were present. Any slight discrepancies were attributed to the nature of the graphs. The daily average temperature, which was the unit of time used, did not depict the range of temperatures experienced for any particular day, thus, if the daily average temperature was just below freezing, the afternoon hours may have been above the freezing point for part of the day in question. Figure 13 represents the daily average temperature. If the average daily temperature remains just below freezing, the high for that day may have been above the freezing point, which resulted in snowmelt or precipitation in the form of rain.

Temperature correlated directly with the building or decreasing of the snow pack. The specific point of interest was the freezing point. When the daily average temperature dropped below freezing the snow pack began to build, given precipitation events were present. This phenomena was present for all of the years of record analyzed.

Figure 13. Temperature Vs. Snow Pack





With regard to the decreasing of the snow pack, specifically spring snow melt, there was an inverse relationship with regard to daily average temperatures above freezing and the depth of the snow pack. A great example of this relationship is present in Figure13, specifically March 20, 2004 to May 1, 2004. Here, a sharp increase in temperature, rising above freezing, is present. As a result of this increase, the snow pack declined sharply. Later in the month the temperatures dropped below freezing again and the snow pack showed no decline. There is an increase in the snow pack indicating that there must have been a precipitation event. The daily average temperature at this time indicated that the most likely form of this precipitation was snow. Shortly after this increase in the snow pack the daily average temperatures begin to rise above freezing again and the depth of the snow pack declined accordingly. This relationship between temperature and the depth of the snow pack, similar to the example just described, was a consistent occurrence throughout the four years of record analyzed. The range of this relationship lasted from October through May. Specifically, during October through February the snow pack was building and from March through May the snow pack was declining.

SNOW PACK AND DISCHARGE CORRELATIONS:

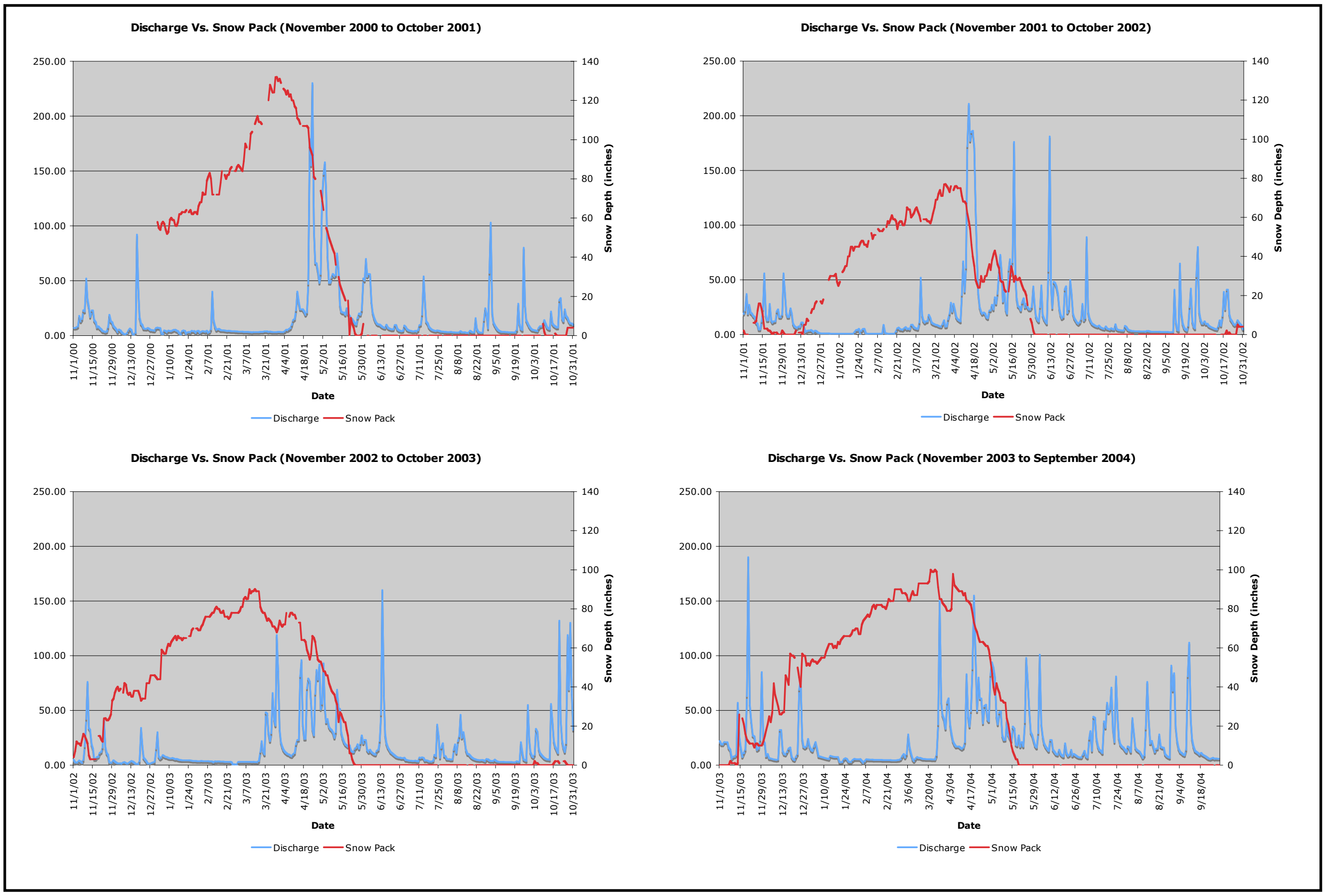
Now that a relationship has been established between temperature and the building or decline of the depth of the snow pack, a relationship between the snow pack and discharge was established. In Figure 14, a notable inverse relationship between these two variables was present. When the depth of the snow pack was building, the volume of discharge was significantly lowered, which was a result of the precipitation being held on the land surface because it was in the form of snow, which is a result of temperatures being below freezing. Conversely, when the depth of the snow pack was decreasing, a significant increase in the volume of discharge was present, even if there were no precipitation events occurring during this time. This increase in discharge was the direct result of the melting of the snow pack. For all four years of record analyzed, this phenomenon occurred during the months of March through May.

Furthermore, the amount of increase of discharge was directly proportional to the decline in the depth of the snow pack. Examples of the relationship described above are represented in Figure 14. Attention should be paid to two specific time spans. First, the building of the snow pack, occurring during the months of October through February. The second is the decline in the depth of the snow pack, occurring during the months of March through May. The building of the snow pack, as it related to discharge, revealed a continuous level of low flow. Occasional spikes in the discharge record during this time period were related to Figure 13, as the daily average temperature had risen above freezing, creating a short term period of snow melt. An example can be seen from Figure 14 on February 7, 2001. A spike in discharge from 5 cfs to 45 cfs was present. A decline in the depth of the snow pack was also present for this date. Referring to Figure 13, an increase in the daily average temperature to just below freezing is noticed. Even though the daily average temperature did not rise above freezing, the daily high (referring to the raw data used to create the master data sheet indicated afternoon temperatures) was in the forties. This type of relationship, regarding spikes for this time period consistently correlate with one another.

The second time span of interest was the March through May period, the period of snow melt. A direct connection was visible between the magnitude of the discharge event and the rate of decline in the depth of the snow pack. Using the same time period used to correlate temperature to the depth of the snow pack (March 20, 2004 to May 1, 2004), a connection between the snow pack and discharge was also present. Represented in Figure 14, a significant jump in the amount of discharge from 12 cfs to 150 cfs was present when the depth of the snow pack declined. Shortly after this event, the depth of the snow pack stabilized; as a result the amount of discharge decreased.

Overall, the building of the snow pack was dependent on two factors, precipitation and temperature. However, the decline of the snow pack was only dependent upon temperature. Discharge was dependent upon the depth of the snow pack as it relates to the daily average temperature. In other words the temperature had to be below freezing with the presence of precipitation events in order for it to build. The decline in the snow pack was strictly dependent upon temperature.

Figure 14. Discharge Vs. Snow Pack



HYDROLOGIC HISTORY CONCLUSIONS:

Three major patterns and/or trends were identified via the graphical analyses. The discharge record correlated with the precipitation record during the summer and early fall months, specifically June through September. During the late fall and early to mid-winter months, October through February, the precipitation record correlated with the building of the snow pack, this relationship was temperature dependant. The increased discharge during the late winter and early spring months, March through May, correlated with the decreasing depth of the snow pack, this relationship was also temperature dependent.

DISCREPANCY IN THE DATA RECORD

Throughout the course of compiling and organizing data within the master datasheet, as well as the process of generating graphs, several discrepancies within the dataset became apparent. These discrepancies ranged from missing data to the absence of correlations when one should have been present; for example, a discharge event with no significant precipitation event occurring during the summer months or the occurrence of a precipitation event without any increase in the depth of the snow pack during the winter months. A large precipitation event with only minimal discharge increase is defined within this report as a discrepancy.

The years of 2000, 2001, and 2002 showed a minimal number of incidents. During the years of 2003 and 2004 the occurrences increased dramatically. Several reasons for these discrepancies have been investigated. Data collection device malfunction was one of two major contributing factors believed to be the cause for the noted discrepancies. Battery loss was a common problem contributing to data loss. MMW fell over for a short period of time and the MME rain gauge was clogged with leaves for a short period of time. The development is believed to be the main reason for the large increase during the years of 2003 and 2004.

DEVELOPMENT INTERFEARENCE

An increase in the number of discrepancies in the data record was noted during the years of 2003 and 2004. Development began in 2003. The majority of the discrepancies during this time are most likely the result of the development. Table 3 indicates that 65 percent of the proposed development began during this time. Road and golf course construction are believed to be the biggest factors for explaining the large increase of discrepancies with in the data set for this time period.

AREAS FOR FURTHER RESEARCH

This evaluation of the Spruce Peak development only covered on aspect of a wide array of potential environmental impacts. The volume of discharge is a significant indicator as to the extent of change with regard to land use and land cover; however, even this investigation did not cover all of the factors relating to discharge volume. A soil analysis should be conducted to identify the percent of the area available for groundwater recharge and the percentage of this area that has been developed upon, as this will impact the area available for infiltration resulting in an increase of runoff. Investigations with regard to the four variables and methods used in this report should be conducted throughout the duration of construction and continue for a significant period of time after completion of the development. The longer the site is monitored the more detailed and accurate the results will become.

FUTURE USE OF THIS REPORT

The identified patterns and trends with regard to the relationships between the four variables are intended to be used as a basis for comparison when determining the impact of the spruce peak development both during and after the completion of construction. When future analyses are conducted, it is expected that the same patterns and trends will be present. If future analyses reveal different patterns or trends, the extent of the differences will reveal the significance of the developmental impact

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